THE TERTIARY GEOLOGY OF A PORTION OF THE

CENTRAL CASCADE MOUNTAINS, WASHINGTON

by

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abstract

The Central Cascade Mountains lie near the geographical
center of Washington. They are composed largely of Tertiary
continental and volcanic rocks, and are situated between older
metamorphic rocks to the north, and younger volcanic rocks to
the south and east. The area discussed in this study was
mapped in reconnaissance fashion around the turn of the century.
The inaccurate dating of that early mapping was used by the
later workers to date the Tertiary history of the Cascade
Mountains.

The main structure in the area mapped is a north-south
fault through Lake Kachess. This fault separates two different
Tertiary stratigraphic sections of the same general age.
Evidence north of the area mapped indicates that this is a
reverse fault and dips steeply to the east. The youngest rocks
cut by this fault are Eocene and it is older than the Snoqualmie
granodiorite.

East of the fault, the structures are mostly open and the
section consists of the well established eastern Cascade forma-
tions. The pre-Tertiary basement rocks are peridotite and
Easton schist, both of which are covered unconformably by the
Swauk arkose. The Swauk is folded along northwest trends that
become almost east-west in the area south of the uplifted pre-
Tertiary rocks of the Mt. Stuart block. This change in trend,
together with the local origin of some of the Swauk sediments,
suggests that the Mt. Stuart block was an important positive
element in Swauk time. Locally, the Swauk sediments are covered,
apparently unconformably, by an andesitic unit here named the

Silver Pass volcanics. Unconformably above these volcanic rocks
is the Teanaway basalt, which is followed concordantly by the
Roslyn arkose. The Teanaway and the Roslyn have been deformed
into a broad structural basin with a steep southwest limb. The
nearly flat-lying Yakima basalt lies unconformably on the
earlier rocks.

West of the Kachess fault, the structures are more complex,
and are in part obscured by the metamorphism that attended the
emplacement of the Snoqualmie granodiorite. In this area, most
of the mapped units have either been named or redefined by the
author. The oldest rocks are the marbles and limy hornfelses
of the Denny formation. These metamorphic rocks are overlain
unconformably by the sediments of the Guye formation as re-
stricted by the author. Unconformably above the Guye formation
is the Mt. Catherine rhyolite. This rhyolite is followed by
the intercalated sediments and basalts of the Naches formation.
The Naches formation is tightly folded. The Keechelus andesite
is mildly deformed and overlies the Naches unconformably. All
of the formations in this western stratigraphic column are
intruded by the Snoqualmie granodiorite.

Fossils are rare in these continental rocks. The only
reasonably well dated formation is the Roslyn which is probably
middle or upper Eocene on the basis of one fish, two turtles,
and fossil leaves. Fossil leaves indicate a Paleocene or Eocene
age for the Swauk and Guye formations and a probable Eocene age
for the Naches formation.
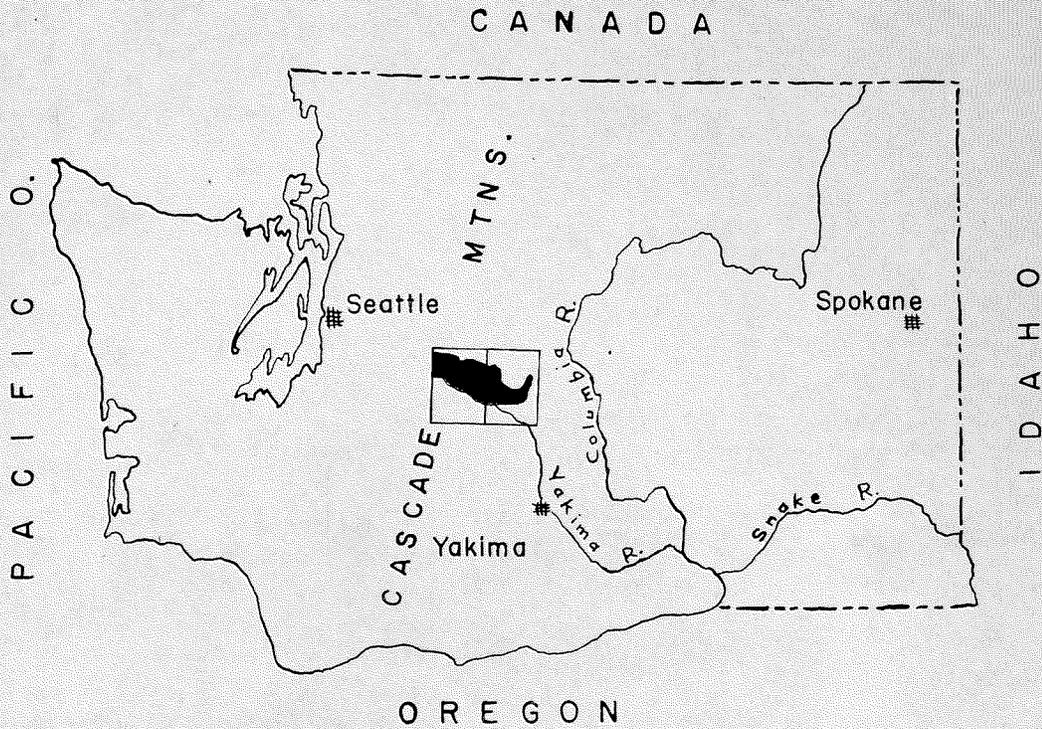
Fig. 1 Index map of Washington. Black indicates area mapped in this study. Outlined are the Snoqualmie quadrangle to the west and the Mt. Stuart quadrangle to the east.

THE TERTIARY GEOLOGY OF A PORTION OF THE
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INTRODUCTION

GEOLOGIC SETTING AND PURPOSE

The portion of the Cascade Mountains discussed in this study has been designated the Central Cascades to separate it from the Northern Cascades, which are composed of older metamorphic rocks, and from the younger volcanics which comprise the Southern Cascades. The Central Cascades were mapped around the turn of the century by such masters of reconnaissance geology as I. C. Russell, G. O. Smith, and Bailey Willis, and often their reports are the only descriptions of the area. They named many formations and described volcanic features that rival the classic Scottish areas. They described such features as the youngest granitic rocks in the United States, the Teanaway dike swarms, the huge basalt flows of the Columbia Plateau, the high volcanoes, such as Rainier, that cap the Cascade Range, and the antecedent Yakima River which has eroded its canyon through growing anticlinal ridges of basalt. Thus the area might have become a classic area of American geology had this reconnaissance been followed by detailed studies, but the difficult terrain, harsh climate, and thick vegetation, together with the lack of economic incentive, have discouraged detailed study.

The area discussed here is critical in understanding the Tertiary history of the Cascade Range for two reasons. First, it contains the type sections for many of the Tertiary rocks, and most subsequent workers in other areas have correlated their

sections with these rocks. Thus these rocks are used to date the Tertiary history of the Cascade Range. Secondly, this area contains one of the few good sections of lower Tertiary rocks in the Cascades. To the south and west, these lower Tertiary rocks are covered by the widespread Keechelus volcanics; to the east, they are overlapped by the Columbia River basalt; and to the north is the contact with the older metamorphic rocks.

Thus, the Tertiary stratigraphy of the Cascades was based almost entirely on reconnaissance mapping done fifty years ago. The need for restudy became apparent to the author during an earlier study (Foster, 1955). The purpose of this work is to restudy the type sections, and so to re-evaluate the stratigraphic and structural relations in order that the Tertiary history of the Cascades can be better understood. An integral problem in this study of the structure and stratigraphy is the origin and petrology of the low grade hydrothermally altered rocks associated with the Keechelus formation.

LOCATION

This area lies in the central part of the Cascade Mountains, near the geographical center of Washington, in King and Kittitas Counties. The area extends from the Cascade Crest at Snoqualmie Pass forty miles eastward to Table Mountain which forms the edge of the Columbia Plateau. The southern boundary is the Yakima River, and the area lies entirely within the northern parts of the Snoqualmie and Mt. Stuart folios of the Geologic Atlas of the United States.

Access to the area is via U. S. 10, the Sunset Highway, which crosses the Cascades at Snoqualmie Pass and follows the

Yakima River across the southern boundary of the area. U. S. Highway 97 goes north through the easternmost part of the area. Good roads are also found along the North Fork of the Teanaway River and the Cle Elum Valley, and there are many logging roads throughout the entire area. The higher country is accessable only by Forest Service trails.

As might be expected in an area that extends from the rainy crest of the Cascades to the edge of the semi-arid Columbia Plateau, there are great changes in climate, vegetation, topography, culture, and rock exposure. At Snoqualmie Pass on the west, the rainfall is approximately 100 inches per year, and at Ellensburg, 15 miles south of the eastern edge of the area, it is approximately 10 inches per year. The highest point in the area is Jolly Mountain, 6400 feet, and the lowest elevation is approximately 2000 feet in the Yakima Valley. The eastern portion of the area is the Roslyn Basin, a structural and topographic basin rimmed by 4000 to 5000 foot elevations. The western part of the area is composed of mountains 5000 to 6000 feet in elevation, that are broken by the valleys containing the three glacial lakes, Keechelus, Kachess, and Cle Elum. Lumbering is the principal industry of the area; some grazing is carried on in the Roslyn Basin, and there are a few farms in the extreme southeastern portion of the area. The towns of Roslyn and Cle Elum in the Roslyn Basin mark the largest coal field in the state. The rock exposures range from excellent on some of the high mountain ridges to poor in the heavy vegetation to the west and on low hills to the east. Because of these

contrasts, the character of the exposures is best discussed
under the individual formations.

METHODS

This study was begun in 1953, and was the subject of a
thesis presented in the spring of 1955 on a complex area center-
ing near Snoqualmie Pass. Because that thesis raised more
problems than it answered, it led the author to propose an
extension to the eastward as a PhD thesis problem. Mapping of
this larger area during eight weeks in 1955 and four months in
1956 gained the author a broader knowledge of the stratigraphy
and structure, which enabled him to remap, in part, the earlier
study. In 1955 and 1956, the author obtained aerial photographs
of the entire area which permitted more accurate mapping.

Petrographic study was continued from 1954 to 1957, and
this concurrent study greatly assisted the field work in the
latter years. Over four hundred thin sections were examined in
the course of this study. The feldspars were determined by
measuring extinction angles with the petrographic microscope
and using the standard low temperature curves. In the case of
the volcanic rocks, this may mean that the anorthite content is
several percent too high (Köhler, 1949).

The nomenclature of Wentworth & Williams (1932) is used in
describing the pyroclastic rocks.

ACKNOWLEDGEMENTS

It is a pleasure to thank the many people who advised and
assisted the author. This study is the outgrowth of an earlier
problem suggested by Howard A. Coombs, head of the Geology
Department, who has helped and encouraged the author in every

possible way throughout both studies. Financial assistance was
provided by the Geology Department through a teaching assistant-
ship from 1955 to 1957, and field expenses for the season of
1956 were paid by the Humble Oil and Refining Company. The
author's colleagues who were mapping surrounding areas, Ross C.
Ellis, Martin Stout, and Richard M. Pratt, placed at his dis-
posal the unpublished results of their work; and their discus-
sions and criticism, both at home and in the field, have
contributed much to the coherence of the present work.

Dr. J. A. Aurèle La Rocque of Ohio State University studied
the freshwater mollusks, and Dr. Roland W. Brown of the U. S.
National Museum identified the leaf collections. Professors
H. A. Coombs and G. E. Goodspeed loaned the author thin sections
and they, together with Professors Peter Misch and J. Hoover
Mackin, gave freely of their time and advice on a wide variety
of problems.

The author's wife, Joan Callin Foster, acted as field
assistant and did much of the drafting, typing, and editing.

STRATIGRAPHY

GENERAL STATEMENT

This area was mapped in reconnaissance manner around the turn of the century, and the present study is a reinterpretation as a result of remapping the area in a more detailed but still reconnaissance fashion. The necessity for this remapping should not be construed as a criticism of the early workers who, though working in a pioneer area, established many of the main relationships. In the next few paragraphs, the results of this restudy are summarized from the evidence which forms the bulk of this chapter. This summary differs from some of the published accounts, and these differences are discussed in this chapter.

The most significant conclusion of this work is the recognition of two distinct Tertiary stratigraphic sections separated by a major north-south fault through Kachess Lake.

East of this fault, the structures are open and the section consists of the well known eastern Cascade formations. The pre-Tertiary basement rocks are the peridotite and Easton schist, both of which are covered unconformably by the Swauk arkose. Locally the Swauk is covered, apparently unconformably, by an andesitic unit here named the Silver Pass volcanics. Unconformably above these volcanics is the Teanaway basalt, followed concordantly by the Roslyn arkose. The Yakima basalt is the youngest unit in this section and it lies unconformably on the earlier rocks.

West of the Kachess fault, the formations are less well known, and the structures are more complex and are in part obscured by the metamorphism that attended the emplacement of

the Snoqualmie granodiorite. In this area, most of the mapped units have either been named or redefined by the author. Here the oldest rocks are the marbles and limy hornfelses of the Denny formation. These rocks are unconformably followed by the sediments of the Guye formation as restricted by the author. Unconformably above the Guye formation is the Mt. Catherine rhyolite, which is followed by the Naches formation. The youngest unit is the Keechelus andesite which unconformably covers all of the younger rocks. This entire western section is intruded by the Snoqualmie granodiorite.

It is suggested that the Naches formation be correlated with the Puget group that crops out along the western front of the Cascade Mountains for many miles west and south of this area. Throughout the western Cascades, the Puget is usually the lowest formation exposed and it is usually followed by the Keechelus andesite. In this area, the Naches formation is in the same stratigraphic and structural position as the Puget is to the west.

Thus the fault through Kachess Lake separates the Tertiary rocks of the central Cascades into two distinct, widespread provinces. Because these two sections are in fault contact, it was not possible to find any direct evidence to show the relationship between these two sections. On the basis of a few fossil leaves, it is suggested that the Naches formation may correlate with the Roslyn or Teanaway formations, but until more detailed study is made of these units, no firm correlation can be made.

It should be noted that while the regional superposition of the formations discussed is well established here and in the

earlier literature, the stratigraphy of the individual formations
has not been deciphered except in a general way. This intra-unit
stratigraphy is probably the next step in the study of this
region. It could not be done in this work because there was not
enough time available to map in detail the rapid lithologic
changes in these volcanic and continental formations, especially
in view of the structural complexities and the difficult terrain.

EASTERN STRATIGRAPHIC SECTION

THE PRE-TERTIARY ROCKS

Although the pre-Tertiary rocks are not the subject of this
study, it is necessary to discuss them briefly in order to under-
stand the Tertiary history of the area. The pre-Tertiary base-
ment in this area is composed of two different rock units. West
of the Cle Elum Valley, the basement is the Easton schist. East
of that valley, the basement is composed of the peridotite and a
complex of older metamorphic rocks that form what we can call
the Mt. Stuart (or the Wenatchee Mountains) block. The relation-
ship between these two basement units is not known but, as will
be noted below and in the discussion of the Swauk structures,
there is a difference in deformation of the younger rocks over-
lying these different basement units. This difference in defor-
mation of the Tertiary rocks may be caused by the same forces
that brought into contact the different basement rocks, or it
may be a reflection of the difference in response of the two
very different basement lithologies.

Easton Schist

Previous Work

The Easton schist was named by G. O. Smith in 1903 (p. 14)
and his entire description follows.

> "This is probably the oldest rock to be found in
> central Washington. It is not shown upon either of
> the accompanying geologic maps, but occupies a few
> square miles in the southwestern part of the Mount
> Stuart quadrangle and extends westward into the
> Snoqualmie quadrangle. Here it forms in large part
> the southern wall of the Yakima Valley, and is es-
> pecially prominent southeast of the town of Easton.
> The Easton schist is typically a silver-gray or
> green rock, composed principally of quartz and micas.
> The schist is extremely crumpled and is gashed and

seamed with veins and stringers of quartz. Associated
with this quartz-mica rock are other schists, contain-
ing hornblende or epidote, while quartzite is also
found. The occurrence of this quartzite in close
association with the schists is believed to indicate
the sedimentary origin of the schists."

In 1904 Smith (p. 3) expanded his description somewhat repeating
what he had said before and adding only more precise localities.
At this same time, he first mentioned blue amphiboles in this
unit. Finally, in 1906 he published the Snoqualmie folio that
includes the town of Easton which he meant to be the type local-
ity. Smith in that publication (1906, p. 2) gave a much more ex-
tensive description of the occurrences and especially of the
several lithologies which he included in this formation, so that
probably this publication should be considered as defining the
formation.

This problem of type localities or type sections will come
up again and again in these pages, for the early workers never
designated types precisely but only stated what the unit was
named for, and several places where it is exposed. This has led
to much confusion, and in this study, where possible, the author
will designate type sections keeping as close as possible to the
intent of the namers.

Occurrence and Relations

In the area mapped in this study, the Easton schist is
exposed only in the cores of the two anticlines between Kachess
and Cle Elum Lakes. Erosion has stripped away the overlying
Swauk sandstone so that the ridge overlooking the Kachess Lakes
is composed entirely of Easton schist with the exception of two
tiny remnants of Swauk which were found just southeast of Thorp
Mountain. Throughout this section, the Easton is for the most

part a blue-amphibole schist with some apparently interbedded greenschists.

The details of the complex internal structure of the schists could not be determined in the limited time available. However, some lower grade metamorphic rocks were found, apparently in tectonic contact with the Easton. These lower grade rocks are shown on the map as the marble and volcanics west of Cle Elum Lake and, for the most part, are confined to the ridge south of French Cabin Creek and the ridge between Knox Creek and French Cabin Creek. The larger of these occurrences was described by G. O. Smith (1906, p. 2) as

> "... a small area of impure limestone and calcareous shale northwest of Clealum Lake, but as these rocks are not near any exposure of characteristic Peshastin slate, their reference to that formation is somewhat tentative..."
> "At the occurrence near Clealum Lake the calcareous rock overlies Easton schist but is separated from it by a layer of metamorphosed volcanic rocks. Here there is a distinct unconformity for the schist is vertical while the limestone and shale have a dip of 45°."
> (p. 3) "The small area of volcanic rock northwest of Clealum Lake has been mapped as belonging to the Hawkins formation, but, ... this reference is made with some doubt."
> "In the area near Clealum Lake, however the rocks appear to have been more acid in composition. (than typical Hawkins formation) Here there is a green, spotted schist, which might have been derived from a basic tuff or lava, but above this are some porphyritic rocks of andesitic composition and a purple flow breccia, with phenocrysts of quartz and feldspar, which is rhyolitic or dacitic. Locally this material is sheared to a purple, slaty rock that shows no igneous features."

In the present investigation Smith's observations were confirmed and somewhat extended arealy; however, his interpretation of the relations between these units is questioned. A sheared zone was always found between these lower grade rocks and the Easton schist which suggests that they are in tectonic contact.

Smith attempted to fit his observations into the geologic column of the area as he knew it. If the correlations he suggested above could be made with some certainty, then we would be a step closer to understanding the relationship between the two basement lithologies for the Hawkins and Peshastin formations are part of the Mount Stuart block and are intruded by the peridotite. Smith, however, was aware that his observations quoted above were contrary to the relations he had mapped in the Mt. Stuart block, and he concluded (1906, p. 3),

> "The relations at the occurrence near Clealum Lake, however, appear to be not in accord with the foregoing evidence. (from the Mt. Stuart area) Here the volcanic rock underlies the calcareous shale and the two rest unconformably upon the Easton schist. It has been mentioned above, however, that the lava and breccia here exposed is partly rhyolitic and unlike the typical Hawkins greenstone, so that these may be some earlier volcanic rocks which lie at the base of the Peshastin formation and are distinct from the later eruptives which overlie the sediments. In view of all the evidence this is perhaps the most satisfactory explanation of the occurrence, but provisionally these pre-Tertiary volcanic rocks are mapped as belonging to the Hawkins formation."

The Hawkins and Peshastin formations were both named by Smith in U.S.G.S. Professional Paper 19 (1903) and were further described in the Mt. Stuart Folio (1904). It is to these reports that the interested student should proceed for a more detailed account of the relationships of these two units.

The relationship between the two basement lithologies may be discovered by mapping north of this area. Misch and his students have mapped a greenschist and blue-amphibole schist unit, and have traced it as a discontinuous band from near the Canadian border to just north of the Snoqualmie quadrangle. In lithology, this unit is similar to the Easton schist which is

believed to be the southern continuation of this band (cf. Misch, 1952; Bryant, 1955; Galster, 1956). The rocks of the Mt. Stuart block have also been traced to the north (Oles, 1951, 1956). Mapping has not yet proceeded in enough detail to answer the questions raised here, but future work may provide the answers.

Age

From this study, nothing more can be said about the age of the Easton schist except that it is pre-Swauk. As noted above, the age will probably be determined by mapping north of this area. In most of his publications, G. O. Smith estimated these rocks to be Carboniferous (cf. 1906, p. 2), but his only criteria were degree of metamorphism and the known age of similar rocks in British Columbia and Oregon.

In 1915 and 1916, W. S. Smith reported Ordovician fossils in the Skykomish area north of the Snoqualmie quadrangle, and used these fossils to date the Easton schist as pre-Ordovician. Recent mapping, however, has failed to disclose Ordovician fossils, and W. S. Smith's lithologic correlations are in doubt. The original Ordovician collection has also been lost (Galster 1956, p. 14-33, and W. R. Danner, personal communication). Thus, all we know at the present time is that the Easton schist is pre-Swauk and thus pre-Tertiary.

Description

blue-amphibole schist

Most of the Easton schist in the area mapped is blue-amphibole schist. In hand specimen, these rocks are very fine grained, are blue or greenish blue in color and have a silky luster. Microscopic study shows that they are composed of

epidote, a moderate amount of blue amphibole, and minor quartz, albite and chlorite. The epidote comprises between 40 and 60 per cent of the rock and is in the form of small anhedral porphyroblasts. The most interesting minerals in these rocks are the blue amphiboles that make up between 10 and 35 per cent of these schists. Of five blue-amphibole schists studied, about half contain glaucophane and the other half contain crossite. Some of these amphiboles are zoned, with crossite or glaucophane cores and green, apparently sodic actinolite, rims. Quartz and albite form up to 20 per cent of the rock and occur both as tiny pods and veinlets, and as disseminated anhedral grains. Chlorite content ranges between 5 and 10 per cent.

greenschist

In the area mapped, greenschists appear to be less abundant than the blue-amphibole schist and are apparently intercalated with the blue-amphibole schist. These rocks are fine grained and quite similar in appearance to the blue-amphibole schists except for color. Their average composition is 20 per cent epidote, 35 per cent actinolite, 15 per cent chlorite, 25 per cent quartz, and 5 per cent albite.

phyllite

The phyllites associated with the Easton schist are fine grained, medium gray rocks in which quartz and graphite can be distinguished in hand specimen. They have a greasy sheen due to their graphite content, and the weathered surface is commonly stained with limonite. The schistosity is marked by thin layers of graphitic material between the layers of lighter colored minerals. Pods and veins of quartz are common. Under the

microscope, the light colored minerals are seen to be principally
quartz with minor untwinned albite, sericite, chlorite and, in
some sections, stilpnomelane.

Marble and Volcanics West of Cle Elum Lake

The occurrence and relations of these rocks were necessarily
discussed with the Easton schist and this section will include
only the petrographic descriptions of these rocks.

Description

marble

In hand specimen, the marble from the ridge south of French
Cabin Creek is a medium grained, somewhat foliated, rock of
medium gray color with brown bands marking the foliation. Micro-
scopic examination reveals that it is composed mostly of large
and small grains of somewhat sheared calcite, together with
isolated grains of quartz and altered plagioclase. The bound-
aries of these isolated grains are very irregular, and the quartz
has wavy extinction (See Fig. 2).

The rocks on the ridge between Knox Creek and French Cabin
Creek are calc-phyllites. It is not known whether these rocks
are part of the Easton schist unit or are related to the marbles
that crop out on the ridge south of French Cabin Creek. No
calcareous rocks have been reported in the Easton schist and
these calc-phyllites, as noted above, seem to be in tectonic
contact with the Easton greenschists. In hand specimen, they
are fine grained, light green, schistose rocks with calcite pods
and lenses. In thin section, they are seen to be composed of
chlorite, quartz, carbonate, and minor epidote.

Fig. 2   Photomicrograph of sheared marble from the ridge south of French Cabin Creek. Note the isolated quartz grains. Plane light, x 48.

Fig. 3   Photomicrograph of sheared rock between the Easton schist and the marble on the ridge south of French Cabin Creek. Plane light, x 48.

volcanics

The volcanic rocks on the ridge south of French Cabin Creek are statically altered tuffs and lapilli-tuffs. The matrix of these rocks is green or purple, and the angular fragments are different shades of these same colors. In thin section, only chlorite, quartz, altered plagioclase, magnetite, and hematite can be distinguished. Although the rock fragments in these tuffs are altered, several different lithologic types can be distinguished. Some of the fragments are of pilotaxitic lava with the feldspars still discernable, and others have quartz grains in a chloritic matrix. There are a few small late quartz veinlets in these rocks.

Peridotite and older rocks south of Mt. Stuart

East of the Cle Elum Valley, the northern contact of the Swauk sediments is with the peridotite, and locally, with older rocks intruded by the peridotite. In this district, the peridotite forms the pre-Tertiary basement and is the southern end of the uplifted Mt. Stuart block. This peridotite has never been formally named, but was first mentioned by Russell in 1899 (p. 109) and was further described by G. O. Smith in 1903, 1904, and 1906.

In this study of the Tertiary rocks, the peridotite contact was used as a map boundary. This contact was always apparent on the aerial photographs and in the field; for this ultra-basic rock supports only limited vegetation and so stands out in bare slopes.

Smith (1904, p. 4) described the many variations of this rock, and it is to this work that one should turn for the most

Fig. 4   Looking north toward Mt. Stuart from the
west ridge of Jolly Mountain. In the middle ground
the bare ridge is composed of peridotite intruded
by several dikes. The rocks in the foreground are
Swauk sediments intruded by the Teanaway dikes.

complete discussion of the peridotite. The name serpentinite would be more appropriate, for the peridotite is more or less completely serpentinized. Smith noted reddish brown and green as the principal colors in outcrop. He also mentioned erosive forms as diverse as steep slopes covered with huge talus boulders and low rounded hills. In handspecimen, this rock is usually mottled shades of green and has a waxy luster. Under the microscope, remnants of the original olivine are seen along with amphiboles, pyroxenes, and magnetite.

Little can be said about the age of the peridotite except that it is pre-Swauk for, as will be discussed below, the basal Swauk rocks are often composed of peridotite detritus. Further study of the Mt. Stuart block to the north may shed more light on the age of these rocks.

SWAUK FORMATION

Previous Work

The first mention of these rocks was by I. C. Russell in 1893 (p. 20) who referred them to the "Kittitas system". He described these rocks as,

> "... an important system of sandstones and shales, with interbedded coal seams, which forms the surface of the country near Wenache, (sic) and extend with increasing breadth southwestward through the western part of Kittitas county and probably also through the western part of Yakima county. The important coal mines at Roslyn are in this system. From the character of the fossil leaves occurring abundantly in the shale above the coal at Roslyn, it is known that the rocks are of early Tertiary age. ....(The Kittitas system) is limited below, at its junction with the upturned crystalline rock on which it rests, by a great unconformity, and is defined above by another unconformity at its contact with overlying basalt. Further study may show that this system should be subdivided..."

Thus, in his first paper on the area, Russell did not distinguish between what is now usually called Swauk formation and the Roslyn formation. However, six years later, he alluded to a possible subdivision within the Swauk formation which was named in that paper. He states (1899, p. 118),

> "... the author proposed the term "Kittitas system" for the formations here named the Roslyn and Swauk sandstones. It has been thought best to abandon the provisional name first used."

He continues,

> "The rocks included in this formation (Swauk) present two quite distinct phases, which led me to divide them into two systems, one termed the Camas sandstone and the other the Wenatche sandstone; subsequently, however, these terranes were studied, in part in considerable detail, by Messrs. Willis and Smith and were found by them to be deposits of a single Tertiary Lake or estuary; therefore, the name Swauk sandstone was given to the entire formation after the Swauk mining district where it occurs."

Since Russell's day, a large number of workers have carried the name Swauk all through the Cascades, and it will be sufficient to mention only those of significance to this study. In 1904, G. O. Smith published the results of the work which Russell referred to above and in that publication, and a later one in 1906, traced the Swauk formation through the area under discussion. Smith's more complete description of the Swauk is often considered as the definition of the formation. The Swauk formation was traced far to the north by Russell (1899) and G. O. Smith and Calkins (1906), and to the west by W. R. Smith (1916).

Thus the Swauk has become recognized as one of the most widespread formations in the Cascades and, though its age has been debated, its unity as a formation was not questioned until recently. In 1956, after remapping the northeast portion of the

Mt. Stuart Quadrangle, Alexander presented arguments favoring a reversion to Russell's subdivision of the Swauk into two formations. Alexander favored retaining the name Swauk but restricting it and using the name Camas for a second and higher unit. The validity of this subdivision remains to be proved by more extensive mapping. The fossil leaf localities in nearby areas apparently on strike with both of his subdivisions have the same flora (c. f. Waters 1930); however, these plants are known to have had long ranges. In 1936, Chappell (p. 93) mapped an unconformity in what he called Swauk in the Wenatchee Quadrangle east of Alexander's area. The meaning of this unconformity is unknown and it has been reported nowhere else. Because there is no evidence as to the age of the rocks above the unconformity, and they cover such a small area, they could be related to the similar appearing sediments found between flows of the Yakima basalt that crops out nearby. An inter-basalt lake or fluviatile environment may have extended in this area beyond the limit of the basalts so that the inter-basalt sediments were deposited on the Swauk. On the other hand, this unconformity may confirm Alexander's observations.

Litholgic differences in the Swauk within the area of the present study have been reported. Lupher (1944, pp. 7 - 8) noted that the Swauk formation near Swauk Creek was "not greatly lithified" and "composed of nearly equal parts of shale and sandstone", and to the west (apparently in the vicinity of Cle Elum River) the Swauk is "very well-lithified" sandstone and conglomerate. He concluded that these differences are best explained by assuming that the Swauk Creek rocks are the upper

beds of the formation. The differences in induration may be the
result of the intrusion of the Teanaway dike swarms and the
small intrusions of granodiorite and acid dikes mentioned by
Smith (1904, p. 6) and Smith and Calkins (1906, p. 6). (cf.
Coombs 1950 also) The importance of the changes in grain size
may be overstressed; for, as noted by Lamy and Hotz (1952, p. 32),
the Swauk lithologies change rapidly both horizontally and
vertically. This variability is to be expected in fluviatile
sediments, and numerous conglomerate lenses and filled channels
were noted in the field.

Smith was aware of these differences in the Swauk formation
but tended to minimize their importance. He stated (1904, p. 5),

> "The general character of the Swauk sandstone is
> that of an arkose. It is usually plainly bedded, and
> interstratified with shaly and conglomerate beds. In
> color the sandstone is gray, and light grains of feldspar
> and quartz and dark flakes of mica may be noticed. In
> the eastern part of the area, especially along Mission
> Creek and its tributaries, the Swauk formation shows a
> notable change in character. The shale and conglomerate
> become insignificant in amount, and the sandstone is
> lighter colored and plainly more purely quartzose. The
> phase of the sandstone is massive and less plainly
> bedded, and doubtless represents different conditions
> of sedimentation..."

In spite of this observation, Smith used the description of the
rocks along Swauk Creek in both the Mt. Stuart and the Snoqualmie
folios, even though the indurated rocks in the Snoqualmie quad-
rangle bear little resemblance to the non-indurated rocks to the
east.

The lack of distinctive fossils or mappable key beds in
these continental rocks makes it difficult to resolve the con-
fusion in the literature. The beds south of Mt. Stuart were
followed in this study to the area around Swauk Creek that

Alexander called Swauk formation, restricted. For this reason, the name Swauk was used in this study.

Occurrence and Relations

The Swauk formation is a thick series of light colored arkoses and dark shales with prominent conglomerate beds. The Swauk crops out in a broad band along the northern border of the map area. Throughout much of this area, the Swauk is intruded by the spectacular Teanaway dike swarms. These dikes have indurated the Swauk sediments and the resultant complex has been eroded to form rugged mountains and ridges. Smaller areas of Swauk sediments are also found between Kachess and Cle Elum Lakes just south of the main Swauk outcrop, and the structures shown on the geologic map indicate clearly that these small areas were once continuous with the main occurrence of the Swauk sediments. For the most part, the best exposures are found on the higher ridges. However, even on the ridges, because of the differences in vegetation caused by the differences in rainfall, the exposures vary from good on the high eastern ridges to poor on the more humid western ridges. The exposures in the valleys are usually poor for only the Teanaway dikes are resistant enough to crop out. In the eastern part of the area, a series of fill terraces extend far up the valleys covering the bed-rock.

The Swauk outcrops in the area of the dike swarms are remarkable for their sparseness. G. O. Smith (1906, p. 6) noted "... (the dikes) are almost incredibly numerous, and over considerable area actually occupy more of the surface than the sedimentary rock which they intrude." In the author's opinion this seemingly extreme view is an understatement. In the dike

swarms, the Swauk forms thin septa, many of which are only a few feet wide and pinch out in short distances. These septa are often widely separated and frequently they are less resistant than the dikes and so are covered with basalt talus. As a result, the dike swarms often make it difficult to find the contact between the Swauk sediments and the Teanaway basalt flows. This contact is difficult to find in such places as the ridge between the Cle Elum Valley and the West Fork of the Teanaway River where the Teanaway basalt is represented by aphanitic basalt flows quite similar to the dike rocks. The most remarkable feature of the Swauk septa is their general lack of internal deformation. The attitude of the beds in these septa is constant over wide areas and the folding of the Swauk was often mapped by study of these septa. On the aerial photographs, the strong grain of the dikes obscures the bedding of the Swauk sediments except in a few areas. In the local absence of dikes, the Swauk bedding shows clearly on the photographs. Another feature of the dikes that could puzzle one until a close inspection is made, is the strong induration of the Swauk for several inches up to a foot at the contact with a dike wall. This induration has caused the Swauk to be more resistant and so to simulate a stronger bed parallel to the dike.

The local origin of at least part of the basal Swauk is shown by abundant evidence. Smith (1904, p. 5) noted,

> "... the coarsest phases of the basal conglomerates
> are very local in their occurrence, and in their
> composition often bear a definite relation to the
> underlying formation."

and where forming the basal beds,
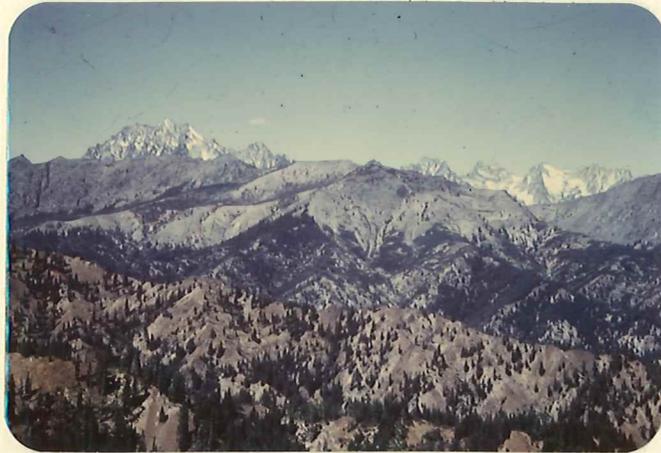
Fig. 5   Looking northwest toward Mt. Stuart. In
the foreground the Swauk sediments appear as thin
septa between the Teanaway dikes. The bare slopes
in the middle ground are composed of the peridotite
that supports almost no vegetation.

Fig. 6   Teanaway dikes on the southeast flank of
Jolly Mountain. The light colored areas are the
septa of Swauk sediments. The figure in the fore-
ground gives the scale.

"... sandstone and shale is composed of material plainly derived from the underlying rock, so that greenish-yellow sandstone containing fragments of serpentine may be seen resting on the serpentine."

The Swauk lies unconformably above two different basement rocks in this area. South of Mt. Stuart and the Wenatchee Mountains, it lies above a complex basement of peridotite and older metamorphic rocks. In the Snoqualmie quadrangle west of the Cle Elum Valley, the Swauk is unconformably above the Easton schist. The reason for this difference in basement rocks is not known. In this map area, the change occurs in the vicinity of the Cle Elum Valley with the Easton schist west of the Cle Elum and the peridotite to the east. The character of the Swauk folding changes somewhat at this boundary, but whether this change is due to the same causes which account for the two basement types or whether it is due to the different response of the dissimilar basement rocks to the same stresses is not known.

Inspection of the geologic map shows the different Swauk structures referred to above. To the west, the folds trend more northwesterly and the Easton schist is widely exposed on the eroded anticlines. South of the Wenatchee Mountains, the folds expose only Swauk sediments and the beds dip more steeply and trend more nearly east-west. In the North Fork Teanaway River - Stafford Creek drainage, the Swauk is nearly vertical but rapid changes of dip are common, especially near the peridotite contact. These features are described by Lupher (1944, pp. 26-27) and their cause is not known; however, they may be due to the emplacement of the dikes or to minor flexures superimposed on the larger folds. Locally, however, just east of the Cle Elum Valley on Sasse Ridge, the Swauk is thin bedded and dips only

10 to 15 degrees (see Fig. 8). In this area and to the south of Sasse Mountain, the fold axes could not be traced across the Cle Elum Valley. As noted above, these differences could be related to differences in the basement, the presence of the dike swarms east of the Cle Elum, the presence of the Mt. Stuart block around which the folds appear to be wrapped, or an unconformity within the Swauk such as Alexander suggested east of here.

The unconformity at the base of the Swauk in the area where the Swauk overlies the peridotite is of great interest because lateritic iron ores have formed on the serpentinized peridotite. Chemical and stratigraphic evidence, as well as the form of the ore bodies, point toward a local origin for these iron-rich sediments. These ores were first described in 1898, and in 1901 Smith and Willis presented a complete description. From that day to the present, there have been many attempts to exploit these deposits, but their small size and irregular form have prevented them from becoming commercial producers. During World War II, there was a renewed interest in these deposits, and so there is much recent literature.

In the case of a laterite, the problem arises whether to give the laterite formational rank; for, although a product of weathering, the laterite is a lithologic unit that was formed during part of the time interval of an unconformity. However, the same statement can be made about a soil developed on an unconformity. Hence it is not surprising that, while most authors have considered these laterites as the basal Swauk, Lupher (1944, p. 7) proposed Cle Elum formation for these deposits. The situation is further complicated by the fact
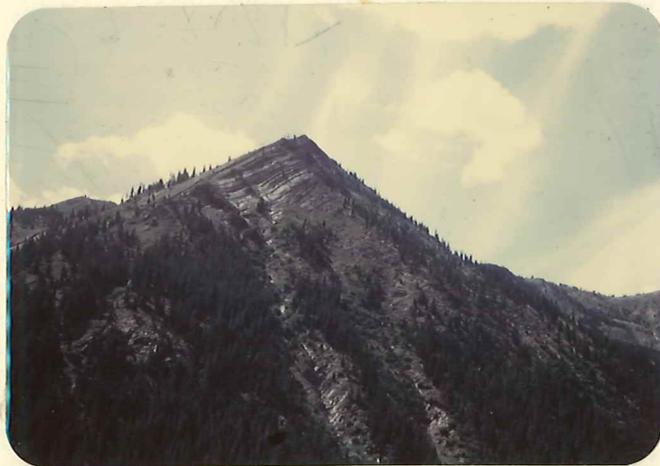
Fig. 7   South dipping Swauk sediments on the
southeast ridge of Jolly Mountain. Exposures of
Swauk sediments this large are not common in the
area south of Mt. Stuart.

Fig. 8   Almost flat lying Swauk sediments in-
truded by Teanaway dikes on the ridge north of
Sasse Mountain.

that the iron ores here show definite evidence of limited trans-
portation, although everyone recognizes the local source of the
weathered material. A complete resume and bibliography can be
found in Lupher (1944) and Lamey and Hotz (1952) whose excellent
discussions need not be repeated here.

The pre-Swauk relief is discussed by Lupher (1944, pp. 17-
18 and 26) who concluded that, in general, the relief was low
during formation of the iron ores in spite of G. O. Smith's
contention that conglomerates near the base of the Swauk indi-
cate considerable local relief. Southeast of Thorp Mountain,
two tiny outliers of Swauk sandstone were discovered during the
present study over a mile from the main occurrence of Swauk.
These two exposures are interpreted as remnants of a once con-
tinuous sheet of Swauk formation. Near these remnants, the
Easton schist is topographically several hundred feet higher
than the Swauk, indicating that here, at least that much relief
existed in pre-Swauk time.

In most of this area, the Swauk is overlain unconformably
by the Teanaway basalt and, very locally between Kachess and
Cle Elum Lakes, by the Silver Pass andesite. This unconformity
and folding of the Swauk described above have not always been
recognized by workers in this region, although they were men-
tioned over fifty years ago (G. O. Smith, 1904, p. 5). The
controversy was born in 1899 when Russell noted (p. 122),

> "The Swauk sandstone to the south of the Wenache
> Mountains has not been crumpled into folds, as in the
> case of the same formation to the northeast, but up-
> raised in at least two regions so as to have more or
> less quaquaversal dips. One of these regions has its
> center in the Wenache Mountains, and the rocks dip
> southward from the region about Mount Stuart as far
> as they have been traced..."

"The dip of the Swauk sandstone in the region adjacent to the southern border of the Wenache Mountains is southward at angles varying, in general, from thirty to forty degrees, but the prevailing dip decreases somewhat when followed southward, and becomes on an average fifteen to twenty degrees where the sandstone passes under the earlier sheet of Columbia lava (the Teanaway basalt)."

The quote shows two points. First, Russell noted that the Swauk was folded in other areas, and secondly, that he believed it dipped homoclinally southward in the area south of Mt. Stuart.

In 1903, G. O. Smith (p. 15) mentioned, "a slight unconformity" between the Swauk and the Teanaway basalt. However in 1904 (p. 5) he wrote,

"In a general way the structure of the Swauk formation may be described as simple, consisting of anticlines or arches and synclines or troughs, the axes of which trend northwest-southeast. These folds are rather narrow and six or eight folds may be traced in the area between Middle Fork of the Teanaway River and Mission Creek....and the syncline along Middle Fork of Teanaway River has a north-south axis, but the more common direction is that given above."

The last statement is apparently a misprint and he probably meant an east-west axis. He continued,

"The folding of the Swauk rocks was plainly begun soon after their deposition. An examination of the contact of this formation and the basalt directly overlying it shows that the sandstone and shales had been folded and somewhat eroded before the Teanaway basalt covered them."

In the Snoqualmie Folio two years later, he added more evidence in favor of his earlier opinion (1906, p. 6),

"The relations of the basalt to the rocks beneath show that its outpouring was immediately preceded by a period of general erosion.... In the Snoqualmie Quadrangle the unconformity at the base of the Teanaway may be most plainly observed at a point northwest of Clealum Lake, where the formation overlaps the beveled edge of the Kachess rhyolite (Silver Pass andesite of this report)..."

He further noted (p. 11) that the Easton schist exposed in central Snoqualmie quadrangle marks the cores of Swauk folds. Thus G. O. Smith corrected Russell's earlier misconceptions that were based on very limited field work. Smith clearly demonstrated that there is an unconformity between the Swauk and the Teanaway basalt, and that pre-Teanaway folding and erosion of the Swauk is well documented in the rocks. The point is stressed here because of the confusion regarding these relations in the recent literature (cf. Bressler 1951, pp. 41-43).

Minor faulting and brecciated zones near the base of the Swauk indicate that it has undergone more than one period of diastrophism. This was first noticed by Russell (1899, p. 120) and has since been described by many others. The most recent and most complete study of this zone was by Lupher, who (1944, pp. 27-8) reported 2000 feet of offset on one fault and less than 200 feet of offset on many others. The more conspicuous of these faults are shown on the folio maps.

Age and Correlation

The age of the Swauk sediments has been much debated. The first paleontological report was by F. H. Knowlton (in Smith 1904, p. 5). On the basis of about twenty-five new species of fossil leaves collected near Liberty, he reported,

> "a more or less close resemblance to certain Laramie, Denver, and Fort Union species, and on this rather insecure basis, it is assumed that the age should be regarded as Eocene."

In Knowlton's day, the term Paleocene had not yet come into use and it seems clear from his reference to what are now considered Cretaceous and Paleocene formations that he regarded the Swauk as being near the Cretaceous - Tertiary boundary, and not Eocene

as we use the term today. Many, however, have continued to call the Swauk Eocene on the basis of Knowlton's report.

The Swauk formation has been traced from its type locality in the Mt. Stuart quadrangle northward and westward so that it is now recognized as one of the most widespread formations in the Cascade Mountains. The Swauk has also been extended far to the northwest by correlating it with the Chuckanut formation near Bellingham. The Chuckanut has been considered the continental equivalent of the Upper Cretaceous Nanaimo formation (Mc Lellan 1927, p. 136). The extension of the Swauk has been the subject of many papers spread over a long time, so that it is no wonder that there are many conflicting hypotheses. The best summary of these is in Chappell, (1936, pp. 68-82) and the more recent work is summarized in C. L. Willis (1950, pp. 87-94) and Alexander (1956, pp. 41-43). In spite of disagreements in the literature, one fact remains constant; most of the leaf collections (and no other fossils have been found) are of Paleocene (Fort Union) age.

The Paleocene or Late Cretaceous age of the Swauk based on paleobotany is in accord with the stratigraphic relations. As noted earlier, the Swauk unconformably overlies a metamorphic basement of unknown age. Unconformably above the Swauk is the Teanaway basalt, and concordantly above the Teanaway is the Roslyn arkose that contains middle or upper Eocene fossils (Wheeler 1955, p. 1668). Thus the evidence at hand suggests a Paleocene - Late Cretaceous age for the Swauk, but more secure dating must await future fossil discoveries.

Conditions of Deposition

In almost all of the early geologic reports on the western
United States, the non-marine sediments were assumed to have
been deposited in large lakes. This dogma began in the Rocky
Mountain area and was carried into the Cascades by the early
workers such as Russell and G. O. Smith who envisioned the Ter-
tiary history of the Cascades as a series of lakes interrupted
by volcanic eruptions. This theory was first questioned at
approximately the same time that Smith was completing his field
work in Washington. At that time William Morris Davis (1900),
in a general paper, discussed the criteria for distinguishing
lake versus river deposits, and questioned the existence of
large Tertiary lakes in the western United States. However,
the lacustrine origin of the continental sediments in the
Cascades was not questioned until 1916 by W. S. Smith.

Although this section was written with the Swauk formation
in mind it applies equally well to the other continental sedi-
ments discussed in this paper. The descriptions of these rocks
by G. O. Smith and Russell are quite accurate, so that the care-
ful reader may become suspicious of their alleged lacustrine
origin. As an example of this, Russell (1899, p. 125) described
"thin bands of well-worn pebbles" in the Roslyn formation.
G. O. Smith (1904, p. 7) described the same rocks as,

> "With the sandstone occur shales, both fine-grained
> clay shales and the coarser arenaceous phase. As a
> rule, the stratification of these rocks is not strongly
> marked, and in some localities irregularities of
> bedding can be seen and local unconformities detected.
> Conglomeritic beds are not common, pebble bands in
> the sandstone being the coarsest material usually found
> in this formation."

These descriptions show that G. O. Smith and Russell observed
many of the criteria Davis had pointed out as indicative of
fluviatile origin, such as conglomerate and sandstone alternat-
ing with shale and mudstone, and local unconformities often with
cut and fill structure.

In the case of the Swauk formation, the meaning of these
ubiquitous fluviatile features was first pointed out by W. S.
Smith in 1916 (p. 565). Since then they have been very well
documented by Waters, Chappell, C. L. Willis, and others. In
the area under discussion, fluviatile features such as cross-
bedding, alternating coarse and fine grained layers, gravel
lenses, local unconformities often with cut and fill structure,
and terrestial (leaf) fossils are common.

Weaver (1945, pp. 1403-6) suggested that the Swauk was
deposited on a vast coastal plain or estuary environment. The
coarse detritus from the Mt. Stuart block found in the basal
Swauk, together with the almost complete lack of marine rocks
interfingered with the Swauk, both argue against this suggestion.

Alexander (1956, p. 38) interpreted some of the coarse
material in his Swauk as deposited by density currents in a
large lake. While this hypothesis may be true, he marshalls no
evidence in its favor except the existence of the conglomerates
themselves. He states that many of the Swauk rocks are well-
bedded shales and sandstones that resemble marine rocks and are
not cross-bedded; so he postulates density currents to emplace
the conglomerates and calls for periodic rising and falling of
the lake to account for the sharp contacts. Alexander did
recognize the fluviatile origin of the Camas sandstone of his

nomenclature that was called Swauk by Waters, Chappell, and
C. L. Willis and was mentioned above. In his discussion of
the Swauk, Alexander does not mention specific localities, and
it seems quite possible that he may have been describing true
lake sediments, for in any continental unit like the Swauk,
ephemeral lakes must have been common features. The question
really is whether a single lake existed long enough to accumu-
late the thick Swauk formation.

These fluviatile rocks may have had a depositional dip
that is now difficult to estimate. A high depositional dip
could have a large effect on the calculated thickness of these
rocks. However, the magnitude and effect of these initial dips
cannot be estimated from the present data.

Description

The Swauk formation is composed predominatly of arkose,
with shale much less abundant, and conglomerate in minor amounts.
The distribution of these lithologies is extremely irregular so
that it is impossible to describe a section applicable for more
than a small area. This lack of regularity is to be expected in
fluviatile sediments, and is further expressed in the bedding
that varies in thickness from a few inches to over one hundred
feet with abrupt changes in grain size both laterally and verti-
cally. Most of the Swauk is massive but crossbedding is not
uncommon.

The Swauk is at least four thousand feet thick in this area
and may be much thicker. The intrusion of the dike swarms and
the lack of key beds makes it impossible to estimate the thickness
any closer. Smith described a basal conglomerate in the Swauk

formation, but more detailed work has shown that in most places,
the basal Swauk is shale or siltstone that grades downward into
the iron rich laterite (Lamey and Hotz 1952, p. 32). Above these
basal rocks are the arkoses with some interbedded dark shales.
The conglomerates are scattered throughout the section, some
lying directly on the basement rocks. The recent investigation
of the iron deposits has resulted in several publications cited
above that describe the Swauk in this area. The most recent and
complete of these is Lamey and Hotz, 1952.

Arkose

The arkoses are light gray on the fresh surface and weather
to a brown or brown gray color. They are medium to coarse
grained and quartz, feldspar, and biotite can be identified in
hand specimen.

In thin section, the arkoses are seen to be composed of
angular equant grains that show pressure solution in some thin
sections. The principal minerals are quartz, 40 to 50 per cent;
feldspar, 20 to 40 per cent; and up to 10 per cent biotite, much
of which is altered to chlorite and magnetite. The feldspar is
mostly twinned plagioclase, much of which is turbid with appar-
ently kaolin and sericite. The plagioclase is primarily
oligoclase but ranges from albite to andesine. The minor constit-
uents are muscovite, orthoclase, garnet, magnetite, chlorite,
apatite, sphene, and in some specimens, rock fragments, es-
pecially chert or quartzite and volcanic rocks. These arkoses
are fairly well sorted and there is little matrix material. The
cement is silica in most sections, but calcite is not uncommon.
Near the dikes, the alteration of the feldspar and the biotite

Fig. 9   Photomicrograph of Swauk arkose composed
of angular grains of quartz and turbid plagioclase
with a few flakes of biotite. Plane light, x 48.

is most pronounced, and some of the quartz grains are sheared
and healed with quartz and calcite.

Shale

The shales are dark gray to black in color and weather to
medium brown. At some horizons, leaf fossils and carbonaceous
material are common. Many of these rocks should probably be
called fine-grained siltstones or mudstones for they are composed
of the same minerals as the sandstones. These beds vary from a
few inches to many feet in thickness, and are interbedded with
the sandstones. In most places the contact with the beds of
more coarse grained rocks is quite sharp, but thin laminations
of sand mark the bedding planes of some of these shales.

Conglomerate

The conglomerates are scattered through the section in
thick and thin beds. Many of these conglomerates are composed
of rounded cobbles ranging between two and six inches in
diameter. The matrix of these conglomerates is similar to the
arkose described above. In the present area, the cobbles are
predominantly quartzite, but light colored gneiss, vein quartz,
and granitic rock types are common. These conglomerates form
prominent outcrops, and are well exposed north of Paris Creek
on the Cle Elum River road and on the ridge south of French
Cabin Creek.

SILVER PASS VOLCANICS

Previous Work

G. O. Smith and Calkins (1906, p. 5) included these rocks
in their Kachess rhyolite, although they did comment on the
difference between these rocks and the Kachess rhyolite.
They observed,

> "A thicker bed of andesite constitutes the base of
> the formation west of the head of Clealum Lake and
> is poorly exposed on the eastern side of Kachess
> Lake. This rock is of light greenish-gray color
> and is not conspicuously different from the
> rhyolite."

The Kachess rhyolite was "named for Kachess Lake, on whose
northeast side it is well exposed." Thus, what is here called
Silver Pass volcanics, includes the type area for Smith and
Calkins' Kachess rhyolite; however, the mapping for the present
study has shown that rhyolites of many different ages were
included in the Kachess by Smith and Calkins, so that only con-
fusion can result if the name Kachess is retained. Smith and
Calkins seem to have been aware of the inconsistancies of their
Kachess rhyolite. They described its relations as peculiar,
noting that the Kachess was interbedded with the Swauk, Teanaway,
and Naches formations, and occurred between the Naches and
Teanaway formations as well as between the Swauk and Teanaway
formations. These relations seem to be impossible, for they re-
quire the extrusion of the Kachess to have begun in Swauk time
and to have extended across the major unconformity between Swauk
and Teanaway and then to have continued until post-Teanaway time.
The present study has shown that in the area mapped, the rocks
previously called Kachess by Smith and Calkins can be separated

Fig. 10   Looking north toward Silver Pass, the
type area for the formation of the same name. On
the right is French Cabin Mountain which is com-
posed of southwest dipping Silver Pass volcanics.
Several Teanaway dikes are intrusive into the
volcanics on the right.

Fig. 11   A closeup view of Silver Pass.   The
seriate ridge in the foreground is formed by
southwest dipping Silver Pass volcanics.

into two groups, presumably of different age. The first of these
two units is the Silver Pass volcanics of post-Swauk and pre-
Teanaway age, and the second is the rhyolites within the Naches
formation whose areal distribution is indicated on the geologic
map. It was thought best to abandon the name Kachess rhyolite
for several reasons, even though this area contains the type
section. First, rocks of several ages were included in the for-
mation. Secondly, the type section contains rocks mostly more
basic than rhyolite. Smith and Calkins mapped large areas of
their Kachess rhyolite south of the present region, and until
those rocks have been restudied, any effort to use the name
Kachess in a restricted sense in this paper can only result in
confusion in that area.

Occurrence and Relations

The name Silver Pass volcanics is proposed here for the
andesites and more acid volcanic rocks including flows, tuffs
and breccia, that are well exposed in the vicinity of Silver
Pass. Silver Pass, the type area, is a pass over 5100 feet in
elevation between Silver Creek and French Cabin Creek, both of
which drain the region between Kachess and Cle Elum Lakes. At
Silver Pass, the volcanics unconformably overlie Easton schist,
but southwest of here on the west ridge of French Cabin Mountain,
they overlie the Swauk formation. Near Silver Pass, these rocks
are intruded by basaltic dikes, presumably related to the Teana-
way dike swarms. Farther south on the ridge between Kachess Lake
and Silver Creek, the Teanaway basalt overlies the Silver Pass
rocks, apparently unconformably. Thus the Silver Pass volcanics
are younger than the Swauk and Easton and older than the Teanaway.

The Silver Pass volcanics are preserved near the north end of the southeast plunging syncline that forms the steep western margin of the Roslyn basin. This particular syncline, and the other folds to the north of it, were apparently formed at the time the Swauk was folded and subsequently, refolding of this syncline has steeply tilted the Roslyn strata, accounting for the asymmetry of the Roslyn basin. However, the presence of these volcanics documents one more chapter in the history of the area that is preserved only here. Because the Silver Pass volcanics unconformably overlie both the Swauk and the Easton schist, it probably records a period of folding and erosion in post-Swauk time before its extrusion. The Teanaway unconformably overlies both the Swauk and the Silver Pass, thus indicating another period of folding and erosion. Elsewhere in this region, the Teanaway directly overlies the Swauk; and the Silver Pass, if ever present, has been removed by erosion, obliterating a chapter in the development of the structure.

The Silver Pass volcanics form rugged pinnacles and spires in the French Cabin Mountain - Silver Pass area. Near timberline, the andesites weather to a whitish color and from a distance the red-brown weathering basalt dikes that intrude these rocks are strikingly displayed. The ridge from Silver Pass to French Cabin Mountain and continuing southeast from that point is formed by a hogback of southwest dipping Silver Pass volcanics. This ridge is continued to the south by a hogback of Teanaway basalt that has been aligned with the Silver Pass hogback, presumably by a fault, so that a contact is not suspected until it is crossed.

Fig. 12   Looking north at east dipping Silver Pass
volcanics on the east side of Kachess Lake.

On the ridge between Silver Creek and Kachess Lake, heavy timber obscures the Silver Pass volcanics, but they are well exposed at the north end of this ridge near Silver Pass. To the southeast along the base of this ridge, the Silver Pass volcanics can be followed into the area where they underlie the Teanaway basalt.

The Silver Pass volcanics have been identified only in the area described above and in an outlier east of Thomas Mountain. A small body of similar andesite crops out near the head of Cle Elum Lake, and has provisionally been included with the Silver Pass volcanics. On the slope above this latter area, an andesite dike was observed.

Smith and Calkins mapped a large area of andesite overlying Swauk formation on Goat Mountain, just north of the present map area. They correlated these andesites with the Keechelus formation. The Keechelus and Silver Pass andesites are quite similar, so that the possibility of the Goat Mountain rocks being Silver Pass formation should not be overlooked. The Goat Mountain rocks have yielded no fossils, and no basalt dikes are reported, so all that is known of their age is that they are post-Swauk.

Age and Correlation

These volcanic rocks have not yet yielded any organic remains so that their age can be determined only by a study of their relations to other rocks. The Silver Pass volcanics lie unconformably on the Swauk that, as we noted earlier, is perhaps of Late Cretaceous or Paleocene age. Unconformably above the Silver Pass volcanics is the Teanaway basalt, and concordantly

Fig. 13   Brecciated Silver Pass andesite exposed
near the bridge across the Cle Elum River on the
Roslyn road.

above the Teanaway is the Roslyn arkose of probable middle or
late Eocene age (Wheeler 1955, p. 1668). Therefore from our
present knowledge, the Silver Pass volcanics may be of Paleocene
to middle Eocene age, but due to the uncertainties involved in
arriving at this age determination, the discovery of any fossils
may alter this interpretation.

These rocks may correlate with the Taneum andesite which
Smith mapped nearby in southern Snoqualmie and Mt. Stuart quad-
rangles. Smith's description of the Taneum is similar to the
Silver Pass andesite. He mentioned a little rhyolitic material
in the Taneum and noted that the Taneum thickens toward the
north. The Taneum crops out more or less on strike with the
Silver Pass volcanics, overlies the Manastash formation and is
unconformably covered by the Yakima basalt. In this southern
area, the relations of the Taneum and the Manastash to the
Teanaway basalt cannot be determined; however, the Manastash
may be equivalent to the Swauk (Martin Stout personal communi-
cation). Stout, who has remapped this area, reports that the
Manastash is intruded by a few basalt dikes similar to the
Teanaway dikes which intrude the Swauk. The Manastash overlies
the metamorphic rocks in this area as the Swauk does to the
north. Thus if on this admittedly weak evidence, the Swauk can
be correlated with the Manastash, then the Silver Pass volcanics
may be correlated with the Taneum andesite. If this correlation
is assumed, little more can be said regarding the age of the
Silver Pass volcanics; for the Taneum is overlain by the Miocene
Yakima basalt and is underlain by the Manastash which bears a
flora that, while different, cannot be distinguished from the

Fig. 14   Silver Pass volcanic conglomerate
exposed on the west side of Kachess Lake. This
rock is similar to the matrix of the mud-flow
shown below.

Fig. 15   Probable mud-flow deposit in the
Silver Pass andesite on the west side of Kachess
Lake. The long slab in the photograph is one of
the larger fragments that compose this mud-flow.

flora of the other lower Tertiary formations (R. W. Chaney personal communication to Martin Stout).

Description

The Silver Pass volcanics form a thick unit composed of lava, pyroclastic rocks, and volcanic sediments. The formation as a whole is heterogeneous and is characterized by abrupt horizontal and vertical changes in lithology. These changes make it very difficult to estimate which rock types are the most prevalent; however, it appears that the fragmental rocks may be the most common.

Andesite

The majority of the lavas are of andesitic composition and most of the rock chips in the fragmental rocks are also of this composition. The thickness of the lava flows is quite variable but averages a few hundred feet. All of the rocks in the Silver Pass formation are altered to some degree. In hand specimen these rocks vary in color from light to dark green and some are dark purple or gray. The weathered outcrop is usually brown or light gray. In most specimens, white plagioclase phenocrysts, and in some rocks small white or green amygdules, are conspicuous in the aphanitic groundmass.

Under the microscope, the andesites have phenocrysts of plagioclase set in a pilotaxitic groundmass. Many of these rocks also have a few pyroxene phenocrysts. The plagioclase phenocrysts are euhedral to subhedral and have the composition of andesine, An 33. Many of these phenocrysts are zoned and have slightly more calcic cores. These feldspars are altered and are cloudy with inclusions of kaolin, sericite, and chlorite.

The scattered pyroxene phenocrysts are subhedral to anhedral.
These few pyroxenes are probably augite. They are remarkably
unaltered and have a 2V of about 35 degrees. Two pyroxenes may
have been present at one time, because in addition to the few
unaltered augite phenocrysts, there are scattered masses of
chloritic material or antigorite that appear to be pseudomorphs
after a ferromagnesian mineral. The groundmass is composed in
most cases of plagioclase microlites, chloritic material and
opaques. The microlites are oligoclase, An27. Sphene is pre-
sent in most of these rocks. It occurs as inclusions in the
plagioclase phenocrysts and small grains scattered in the
groundmass.

Rhyolite and dacite

The more acidic lavas are commonly light green or light
pink in color but some are light to medium brown. They weather
to a brown or red brown color. In a few of these rocks, tiny
phenocrysts of clear quartz are prominent.

In thin section, most of these rocks are seen to be altered.
They all have a microcrystalline groundmass. Some contain
rounded embayed quartz phenocrysts and all contain phenocrysts
of altered plagioclase. The plagioclase is cloudy with inclu-
sions of kaolin, sericite, and chlorite. It ranges in composi-
tion from sodic to calcic oligoclase. In some of these rocks
there are irregular radial concentrations of darker indeterminate
material scattered throughout the groundmass.

Fig. 16   Photomicrograph of Silver Pass andesite.
Altered plagioclase phenocryst in a pilotaxitic
matrix composed of plagioclase microlites and
chlorite. Plane light, x 48.

Volcanic sediments and pyroclastic rocks

These rocks comprise over half of the Silver Pass unit. The volcanic sediments are more numerous than the pyroclastics. Volcanic sediment is used here to include all those rocks that contain both normal sedimentary fragments and volcanic fragments. Some of these rocks are pyroclastics that mixed with sedimentary rocks, and others are the result of erosion of a volcanic terrain. They are a drab brownish green color and are thick bedded. They weather to a brown color.

The volcanic sediments are exposed on the eastern shore of Kachess Lake, see Fig. 12. The rocks here are composed mostly of volcanic fragments and in the field might be called tuffs and breccias. However, microscopic examination reveals that there is much intermixed sedimentary material in most of these rocks. The fragments in these rocks range in size from volcanic ash to blocks over ten feet in their greatest dimension, see Figs. 14 and 15. The finer grained rocks are very poorly sorted and consist of angular altered volcanic chips mixed with quartz and plagioclase clasts and are commonly cemented with calcite. These poorly sorted, fine-grained, volcanic sandstones occur as both thick and thin beds and form the matrix for the volcanic conglomerates. The volcanic conglomerates are poorly sorted and are composed predominently of andesitic fragments. Some beds have angular fragments, others have rounded fragments, and a few have both. These beds, where well exposed, average about twenty feet in thickness.

At a few localities, especially in the vicinity of Silver Pass, there are a few thin beds of indurated arkose. These rocks

are composed of quartz, plagioclase, pyroxene, chlorite, and a
few fragments of lava.

In addition to the volcanic sediments, some true pyro-
clastics were noted, especially east of Silver Creek. These
rocks are lithic lapilli-tuffs and are composed of fragments
of altered volcanic rocks, presumably andesite.

Some of the features of the Silver Pass volcanics suggest
that they may be local deposits. If this interpretation is
correct, it may also explain the limited areal extent of the
unit. The principal evidence for this view is the nature of
the volcanic sediments. The poor sorting, together with the
large size of some of the blocks and boulders, see fig. 15,
suggests that these rocks may be mudflow deposits. Mudflows
interbedded with pyroclastic rocks and lavas suggest nearness
to the volcano.

TEANAWAY BASALT

Previous Work

The Teanaway basalt was named by G. O. Smith in 1903
(p. 15). His complete description is only two paragraphs long
with no locality references, so no type area was designated.
However, he did state that this name was proposed for what
Russell had called the lowest or first sheet of Columbia lava.
In his reconnaissance work, Russell had used Columbia lava for
all of the Tertiary basalts in this part of Washington. To
avoid confusion, Smith separated Russell's Columbia lava into
several formations of different ages, two of which will be dis-
cussed in this study, the Yakima basalt and the Teanaway basalt.

Russell (1899, pp. 129-31) first mentioned these rocks in the literature and described them at some length, designating them the first sheet of Columbia lava. Although Russell also failed to designate a type area, he did describe these rocks at several localities and made a preliminary statement of their distribution.

In 1904 Smith (pp. 5-6) again failed to designate a type area and stated,

"... the name Teanaway has been applied to this formation, which includes only the basalt flows and interbedded basaltic pyroclastics of Eocene age and which constitutes a series that can be taken as a unit, since it represents the products of volcanic activity uninterrupted by any other important geologic process."

This is not a valid definition, especially in view of the fact that the meaning of Eocene has changed since the passage was written, and we still lack good evidence on the age of the Teanaway basalt.

Finally in 1906 Smith and Calkins (p. 5) said,

"The Teanaway basalt has been fully described in the Mount Stuart folio. It was named for the river in whose basin it is most extensively developed."

This is the only statement that could be considered a type area and it is quite broad. Thus, even though this formation has been long recognized as important in the geology of the area, it was never well defined.

Occurrence

The Teanaway basalt crops out in an arcuate band, up to four miles wide, that extends from just east of Kachess Lake to Table Mountain. It lies unconformably above the Swauk and

Fig. 17   Looking southeast across Silver Creek
valley toward Thomas Mountain. The two flatirons
are formed by southwest dipping Teanaway basalt.
The contact between the Teanaway basalt and the
Silver Pass volcanics occurs in the wooded gully
to the left of the flatirons in the center of the
photograph.

Fig. 18   Looking northwest from Teanaway Butte
Lookout. The foreground ridge is composed of
Teanaway basalt. The Swauk that makes up the
middle ground ridge can be seen as thin bands
between the dikes. In the background are the
older rocks of the Mt. Stuart block.

concordantly below the Roslyn. The arcuate outcrop pattern is
determined by relatively gentle folding that formed the Roslyn
basin. The present map area contains the main body of the
Teanaway basalt, however small exposures have been noted south
of Cle Elum on the south side of the Roslyn basin (Smith 1904)
and to the east of Table Mountain (Saunders, 1914, p. 152).

The Teanaway basalt is composed of basaltic lavas and
clastic rocks that include both sedimentary and pyroclastic
rocks. The general distribution of lithologies within the
Teanaway is shown on Fig. 23. This diagram shows the nature
of this unit and its difference from the Yakima basalt in which
individual flows can be traced tens of miles (Waters 1955a,
p. 708). The exposures of the Teanaway essentially represent
a cross section through a volcanic field. The clastic rocks
and the lavas are interbedded in a complex manner and the
attitudes shown on the map are probably influenced by initial
dip. Many of the attitudes show a marked discordance with the
outcrop pattern, and this is interpreted to mean that these
rocks were initially deposited on the slopes of volcanoes.
The present study was aimed toward understanding the regional
structure and stratigraphy so time was not available to study
the Teanaway in detail, but this reconnaissance has shown how
profitable detailed study of this formation would be. The ex-
posures of the Teanaway show a cross section through a volcanic
field and the life history of this volcanic field from its birth
to its burial is recorded here. In this area, however, such a
study would be hampered by the rugged terrain and the vegetation.

Sections through the Teanaway are afforded by the many
streams that cross the trend of this unit. Good exposures are

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Fig. 19   West dipping Teanaway basalt at Red Top
Lookout.

Fig. 20   Teanaway clastics exposed on the ridge
northwest of Yellow Hill.

found for the most part in these streams and on the tops of the ridges between them. The most accessible exposures are along the county road on the east side of Cle Elum Lake and along U. S. 97 south of Liberty, where the highway follows the course of Swauk Creek. The Teanaway basalt is also well displayed along the West Fork and the Middle Fork of the Teanaway River. As noted above, Smith intended that the type area be on the Teanaway River. For this reason, and because the rocks are thickest and well exposed along the Middle Fork of the Teanaway River, that area should be considered the type area. Recent logging operations in the vicinity of the Middle Fork have resulted in the construction of many logging roads that make these rocks more accessible. Although this is designated the type area, the earlier discussion of the complex intermingling of lavas and clastics, many with large initial dips, should make it clear that a section described and measured here would be of little value in characterizing the sequence at another place.

In the type area along the Middle Fork of the Teanaway River, the Teanaway basalt is over 5000 feet thick and is composed of basaltic lava, tuff, and lapilli-tuff. The lower part of the section exposed here is composed of lavas with some interbedded tuffs and lapilli-tuff. The typical Teanaway basalt is a dark aphanitic or fine-grained rock that at some places contains green or white amygdules. The clastic rocks are either green or yellowish brown in color with an earthy appearance. The upper part of the section is primarily clastic with tuffs and lapilli-tuffs predominating, although there is some columnar basalt. These rocks are very well exposed near the mouth of the canyon

where the Middle Fork flows in a narrow gorge. The rocks exposed on the Middle Fork can be traced both to the east and to the west. Moving east, these rocks can be followed up Way Creek and Malcolm Creek to the bare ridge top. To the east, the Teanaway rocks crop out on Yellow Hill and the bare ridge to the northwest of Yellow Hill where there are excellent exposures of clastic rocks, mostly tuffs.

The West Fork of the Teanaway River flows through a narrow canyon and affords very good exposures. Here the rocks are interbedded lavas and clastics. The ridges between here and Cle Elum Lake are composed almost entirely of greenish breccia and lapilli-tuff.

These clastic rocks are also exposed in the road cuts and along the east shore of Cle Elum Lake. Further north along the lake, east dipping micaceous sandstone crops out. This sandstone is very thin bedded and is interbedded with green tuffs. Above these rocks are conglomerates with a sandy matrix and pebbles of both quartzite and basalt. This sequence of rocks is interpreted as the base of the Teanaway; however, these rocks have apparently been jostled by the faulting that trends nearly parallel to the Lake, so the exact relation of these rocks is not known.

The Teanaway rocks on the opposite sides of Lake Cle Elum are of different lithologies and are offset. These features are interpreted as further indications of the faulting just mentioned. On the west side of the lake, the Teanaway is an aphanitic basalt that has been folded into a tight syncline. The reason for the change in lithology from predominantly

Fig. 21   Southwest dipping Teanaway lapilli-tuff on the ridge south of Hex Creek.

Fig. 22   Dip slope of southwest dipping Teanaway lapilli-tuff on First Creek.

clastic on the east to lava on the west is not known. There
are several possible explanations and perhaps a combination may
be the correct answer. This difference may be due to a change
in the Teanaway from clastics to lava, the fault may bring into
contact the different lithologies, or the folding to the west
may have squeezed out the less competent clastics.

In the eastern part of the area, there are also good ex-
posures of Teanaway. An especially good section is exposed in
the road cuts along U. S. Highway 97, south of Liberty. Here
the lower part of the Teanaway is mostly a dark aphanitic to
glassy basalt. In some exposures, the glassy lava has a
definite ellipsoidal aspect and in some places these lavas are
associated with clastics. Some of these features are shown in
Fig. 24. The upper part of the section here is predominantly
clastic with green or yellow-green tuff and lapilli-tuff as
the most common rock type. East of Swauk Creek and U. S. 97,
the clastic rocks are exposed on dip slopes north of First
Creek. On the west face of Table Mountain there are good ex-
posures of interbedded clastics and lavas.

Relations

Russell (1899, p. 131) made the first statement about the
relations of the Teanaway when he stated,

> "The earlier sheet of the Columbia lava rests conformably
> on the Swauk sandstone, and is overlain conformably,
> so far as can be judged, by the Roslyn sandstone.
> Each of these junctions is obscure, however..."

Earlier in the present paper, it has been pointed out that the
Teanaway basalt lies unconformably above the Swauk formation
and, locally, above the Silver Pass volcanics. The Teanaway is
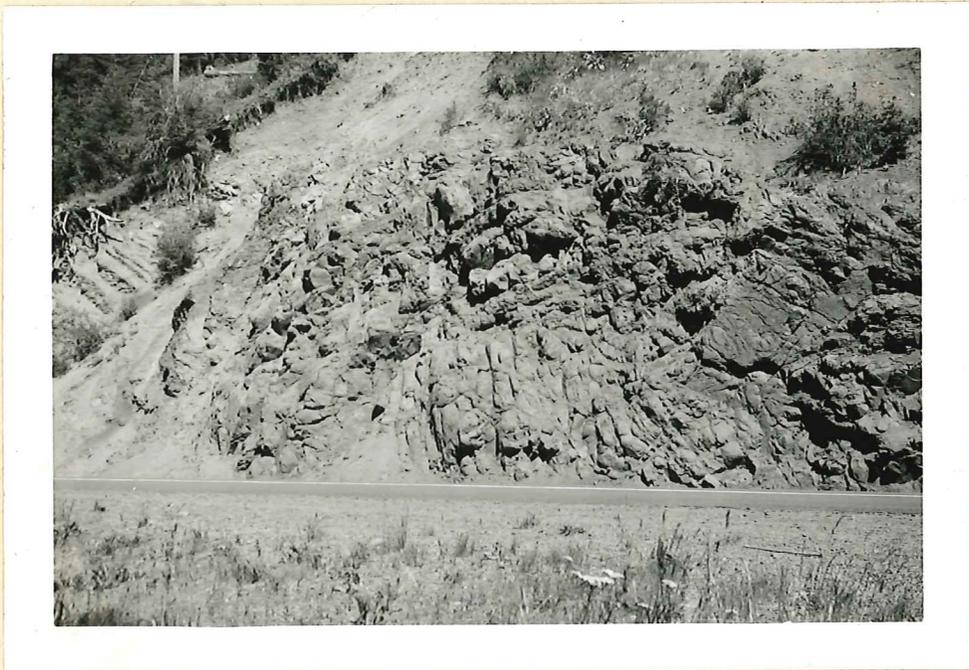
Fig. 24   Ellipsoidal Teanaway basalt exposed in
a road cut on U. S. Highway 97 south of Liberty.

overlain by three units, the Roslyn arkose, the Yakima basalt
and what is called here post-Roslyn rhyolite. The oldest of
these three formations is the Roslyn which concordantly overlays
the Teanaway; the other two are younger and are discordant on
the Teanaway.

All the previous workers agree that the Roslyn concordantly
overlies the Teanaway; however, there is some disagreement as to
the exact nature of the contact. Russell (1899, p. 123) des-
cribed the contact as completely gradational so that, "no two
observers would draw the boundary in precisely the same place."
In a footnote on the same page, he notes that Willis "states
that the base of the Roslyn on the Teanaway is precisely deter-
mined by a conglomerate containing pebbles of basalt." G. O.
Smith was the next to publish on this contact and the changes
in his interpretation as his field work progressed are interest-
ing. In his first mention of this contact (Smith, 1903, p. 16),
he noted the Roslyn,

> "overlies the basalt without any apparent structural
> break, but also without any evidence of transitional
> sedimentation of interbedded sands and tuffs. A few
> pebbles of basalt in the basal beds show that locally
> there may have been erosion of the lava before the
> sedimentary beds began to be deposited."

By 1904, Smith (p. 7) observed,

> "At the base of the (Roslyn) on Middle Fork of the
> Teanaway River occurs a small amount of conglomerate
> containing pebbles of the pre-Eocene rocks, with an
> occassional pebble of basalt. The Roslyn formation
> appears here to overlie conformably the Teanaway
> basalt, but with basal sediments that are distinct
> from the basaltic tuffs."

In 1906, Smith and Calkins (p. 6) stated,

> "It (the Roslyn) overlies the basalt without observed
> angular unconformity or distinct evidence of an
> erosion interval."

and,

> "... there is no evidence of a long interval between
> the Teanaway and the overlying Roslyn sandstone."

The most recent study of this contact was by Bressler in
1951, who worked in more detail than the earlier workers. He
confirmed many of the earlier observations, citing locations
where they are true; however, he was unable to find the con-
glomerate reported by B. Willis. His major contribution was
the observation of a "bonafide" red-bed about 200 feet thick
on the contact between the Teanaway and the Roslyn (p. 28).
He interpreted this red-bed, and a possible discordance he
observed at the mouth of the canyon of the Middle Fork of the
Teanaway River (p. 36), to mean that the Roslyn is disconformable
on the Teanaway.

Age and Correlation

The Teanaway contains no fossils that are useful in deter-
mining its age. None of the previous workers reported any
fossils. During the present study, several types of fossils
were found, but none of them were well enough preserved to date
the enclosing rocks.

A few fragments of _Viviparus_, too poorly preserved for
specific identification, were found in beds exposed at very low
water on the east shore of Cle Elum Lake, just south of Morgan
Creek. This locality is approximately on the border line be-
tween section 16 and 17, T 21 N, R 14 E. The rocks here are
mostly thin-bedded micaceous and tuffaceous sands and shales,

with a few conglomerate beds composed of rounded shale fragments up to ten inches in diameter. In a single shale fragment from this conglomerate, all of the _Viviparus_ fragments were found. In spite of diligent search in the surrounding rocks no other fossils were discovered. These mollusks were studied by Dr. J. A. Aurèle La Rocque, who was unable to speciate them due to their poor preservation. The genus _Viviparus_ ranges from at least Cretaceous to Recent, so exact dating must await the discovery of more useful fossils.

At the same locality, in a fine-grained, thinly bedded, cross-bedded sandstone, possible worm borings were discovered. These borings have a circular or slightly elliptical cross section about 5/32 of an inch in diameter and are at least an inch long. The matrix contains some dark material, principally carbon, and the borings are filled with only light-colored fragments making them conspicuous.

What may also be worm borings were found by the shore of the lake, approximately a quarter mile south of the mollusk locality. This second locality is probably northeast of the west quarter corner of section 16, T 21 N, R 14 E. These supposed worm borings occur in a green, fine-grained, tuffaceous sandstone and consist of curved cylinders about 3/16 of an inch in diameter and about an inch long, composed of the same material as the matrix.

The only other organic material noted in these rocks consisted of a few macerated leaves and stem material. These were found on the west bank of the Middle Fork of the Teanaway River in the northeast quarter of section 21, T 21 N, R 15 E, a few

hundred feet northwest of where the Middle Fork road joins the Spring Creek road. Weathering has etched out the leaves in relief on the surface of a tuff bed. Because of the massive nature of this tuff bed, it was impossible to collect any leaves suitable for identification.

In view of the fossils found, the best way to date the Teanaway basalt is to consider its relations with other formations. The Teanaway basalt unconformably overlies two older formations, the Silver Pass volcanics, and the Swauk formation. As noted earlier, both of these formations have been indirectly and loosely dated. The Swauk is estimated to be late Cretaceous or Paleocene, and the Silver Pass to be Paleocene to middle Eocene; however, this dating should be considered as only tentative until useful fossils are discovered. The Teanaway basalt is overlain concordantly by the Roslyn arkose, which contains fossils considered to be of probably middle or late Eocene age (Wheeler 1955, p. 1668). From these relations it appears that the Teanaway basalt is probably of Eocene age and may belong to the early or middle Eocene. This dating should only be considered as tentative.

The lack of good dating of the Cascade rocks makes the correlation of a unit such as the Teanaway difficult. In 1936, Warren (p. 246) suggested correlating the Teanaway with the Keechelus; however, work since Warren's paper (Grant, 1941) has shown that the Keechelus is younger than the Teanaway. Weaver (1945, p. 1401) suggested correlating the Teanaway with the Metchosin basalts of the Olympic Mountains. The Metchosin basalts contain submarine volcanics that bear a lower Eocene

fauna. These two formations may be of the same general age, but there is no evidence that they were ever connected in space. It is a striking coincidence, however, that two thick basaltic units in relatively close areas seem to belong to the same general time interval. Waters (1955 b, p. 705) noted that western Washington and Oregon were the site of vast basaltic accumulations throughout all of Eocene and early Oligocene time.

Description

As described above, the Teanaway basalt is a very irregular unit ranging in thickness from about a thousand feet to over five thousand feet, and composed of interbedded lava and clastic rocks. This general hererogeneity gives the Teanaway a distinctive aspect when the formation is viewed as a whole, but such lithologic differences often make it difficult to recognize isolated outcrops, especially if they consist of basalt alone. Two features were found useful in identifying this unit in the field. First was the presence of the distinctive green lapilli-tuff described below, and second was the presence of blue or less commonly, greenish-yellow chalcedony filled amygdules. These, together with structural and stratigraphic evidence, were used to identify the Teanaway basalt in the field.

The Teanaway rocks all contain iron, and so frequently weather to a yellow brown, or more commonly, to a red color. The soil that usually develops on the Teanaway rocks is red in color. This distinctive red soil is well developed on the east-west extension of the south end of Teanaway Ridge, and forms a striking display when viewed from Swauk Prairie.

Basalt

The thickness and lateral extent of the individual Teanaway basalt flows is not known. Lack of exposures and heterogeneity prevented tracing individual flows in the time available. The thickness of the individual flows could not be determined because in the few places where there are fairly continuous exposures, none of the usual criteria that mark flow tops, such as vesicular zones, could be found. The general distribution of the basalt and the clastics is shown diagrammatically in Fig. 23.

Most of the basalt flows in the Teanaway are remarkably fresh, unaltered rocks. Amygdules are megascopically visible in only a few of these rocks, but under the microscope, amygdules were noted in most. Glassy material is usually present even in the coarser grained rocks, although only some of the aphanitic rocks have the silky sheen in hand specimen that is usually associated with glassy basalt.

In hand specimen, these lavas are all dark gray in color on fresh fracture, and some have a greenish hue. The grain size ranges from aphanitic to fine-grained. Amygdules are visible in many rocks. They are commonly filled with chlorophaeite, a dark brown, soft, pitchlike mineraloid, and calcite. The greenish rocks are commonly amygdaloidal, and in these rocks the amygdules are filled with green chlorite and white quartz, commonly in concentric layers.

In thin section, most of these rocks have an intersertal texture. A typical basalt is composed of about 20 per cent plagioclase, 15 per cent augite (2V of 35 to 40 degrees) 5 per
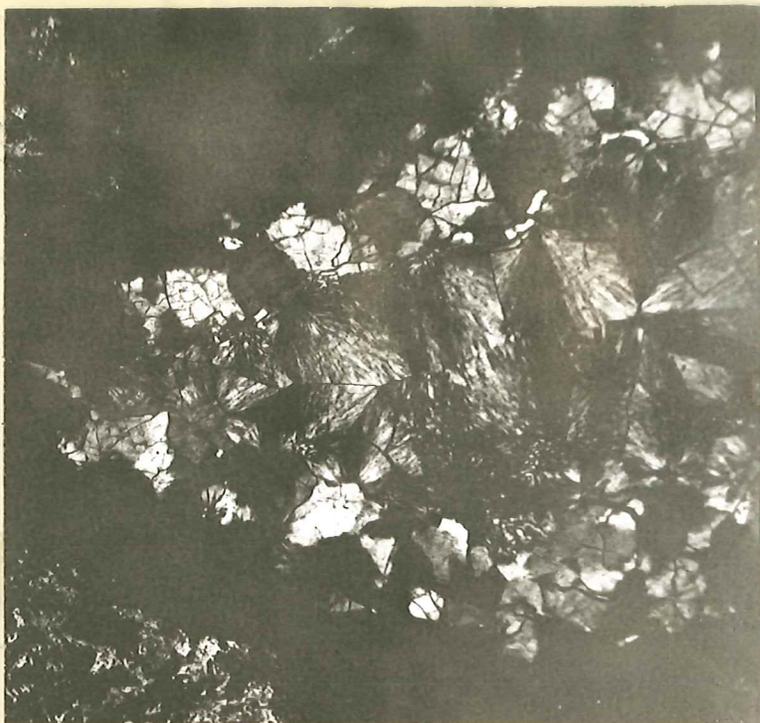
Fig. 25   Photomicrograph of an amygdule in the
Teanaway basalt near Red Top. The rim is quartz and
the center is blue chalcedony. This is the Ellens-
burg blue agate of the rock collectors. Crossed
nicols, x 48.

Fig. 26   Photomicrograph of Teanaway basalt. Lab-
radorite laths and pyroxene grains in a matrix of
glass and chloritic material. Plane light, x 48.

cent opaque grains, 45 per cent glassy material and 15 per cent
amygdules. The plagioclase is gradationally zoned from cores
of labradorite (An 52) to rims of oligoclase (An 26), and is in
the form of long subhedral laths. The augite occurs as shape-
less grains or clots. The opaques are probably magnetite and/or
illmenite. They are in the form of shapeless grains, some of
which are inclusions in the augite, and others appear to be
interstitial. These opaque grains have very irregular shapes
and many of them are long ragged rods. The glassy material is
light brown in color and is best described as hypocrystalline.
Between crossed nicols, much of this material shows a dark gray
color and tiny microlites of what is apparently plagioclase are
visible. This glassy material is full of opaque dust, probably
magnetite. In addition to this magnetite dust, needles of
apparently the same mineral are common, and many of these
needles are aligned sub-parallel to each other.

The amygdules commonly occur in the glassy material in
these rocks. These amygdules are composed predominantly of
chlorophaeite, a yellow-brown isotropic mineraloid, but many of
them have cores of calcite. They range in size from microscopic
to over an inch in diameter. The shape also varies with very
irregular amoeba-like cavities the most common. The chloro-
phaeite is almost universally arranged in concentric layers of
slightly different colors, commonly with thin bands of opaque
material between the layers. Most of this chlorophaeite is
isotropic, but some of the layers are weakly birefringent and
in these layers, the chlorophaeite can be seen to have grown
radially. The chlorophaeite in these rocks seems to fit the

descriptions of Peacock and Fuller (1928, p. 369), who suggested
this name be used for all the pitch-like mineraloids common in
basalts. The material from these rocks differs from their des-
cription in two respects. First, the color change from green to
brown upon exposure was not noted, but perhaps only indicates
that this material is already oxidized. Secondly, the index of
refraction was in the range 1.400 to 1.440, or somewhat lower
than their measurements. In spite of these differences, the
material in these rocks seems to resemble chlorophaeite more
closely than any other mineral or mineraloid, with the possible
exception of hisingerite which also shows a large variation in
index of refraction.

There are all gradations between the rocks just described
and the more aphanitic rocks. These aphanitic rocks all have a
silky luster in hand specimen and range in color from dark gray
to a distinctly green-gray. In thin section, they have a few
microlites of plagioclase set in an extremely fine-grained
groundmass. The groundmass is composed of many tiny opaque
grains, apparently of magnetite, and tiny microlites of plagio-
clase. This groundmass viewed in plane light has a salt and
pepper aspect of gray and black, and between crossed nicols is
a very dark gray. Some specimens have some green, faintly
birefringent, material in the groundmass. The larger micro-
lites, as close as could be determined, seem to lie near the
labradorite-bytownite boundary. In some sections, there was a
banding of alternate layers richer and poorer in opaques.

The Teanaway basalt flows are petrographically very similar
to the dike swarms. In thin section, a typical flow rock and

many of the dike rocks are virtually indistinguishable. Both have an intersertal texture, essentially the same mineral composition, the same type zoning of the plagioclase and, in many cases, the same degree of alteration. This similarity, together with the field relations, have been interpreted as indicating a genetic relationship that is discussed in the next few pages.

The Teanaway basalt is much different petrographically from the Naches basalt. These differences are discussed under the description of the Naches basalts.

Clastics

The most common clastic rock in the Teanaway is a green lapilli-tuff. In hand specimen, this rock is a dull green color and is composed of very angular, poorly sorted, lithic fragments up to three quarters of an inch in diameter. The lithic fragments are, for the most part, different shades of green but purple, red and brown fragments are not uncommon. These fragments are set in a green groundmass. This rock weathers to a brown or red-brown color and, as shown in the photographs (Figs. 21 and 22), is commonly well bedded.

Under the microscope, the overall aspect of these rocks is alteration. The fragments seem to be composed predominantly of green chlorite, much opaque material and some finely divided quartz. Much of the groundmass is composed of the same constituents; but in many specimens, the groundmass is extremely fine grained, green-gray in color, and is a dark gray between crossed nicols. This material, and probably part of what is called chlorite both in the groundmass and in the fragments, may be nontronite. Nontronite is a clay mineral common in

altered basalts, believed to form from the alteration of
palagonite, and is difficult to identify by optical methods
(Allen and Scheid 1946, p. 294-312). A few of the fragments
contain plagioclase microlites. These microlites are usually
somewhat altered and are sodic andesine. Amygdules of calcite,
quartz and chlorite are ubiquitous. These amygdules appear to
be late features and are probably associated with the altera-
tion of these rocks. In most specimens, the groundmass is a
plexus of extremely irregular amygdules and some of the amyg-
dules seem to pass into the fragments. Many of the fragments
are also crowded with amygdules. Associated with the amygdules
are branching calcite veinlets in both the groundmass and some
of the fragments. These features are best seen in the accom-
panying photomicrograph.

The amygdules are very irregularly shaped. They are com-
posed of calcite or radial chlorite with an opaque rim. In
some rocks the calcite amygdules have discontinuous quartz
rims. Chalcedony as well as intergrowths of quartz and chlo-
rite were also observed.

The finer-grained clastic rocks contain the same minerals
as the lapilli-tuffs, except that in some of the sections
studied a scaly mineral having the properties of iddingsite
was noted. These tuffs contain only a few amygdules. One of
these rocks when examined petrographically, was composed of a
few chlorite-filled amygdules and the rest of the rock was made
up of a very finely divided apparently opaque substance that
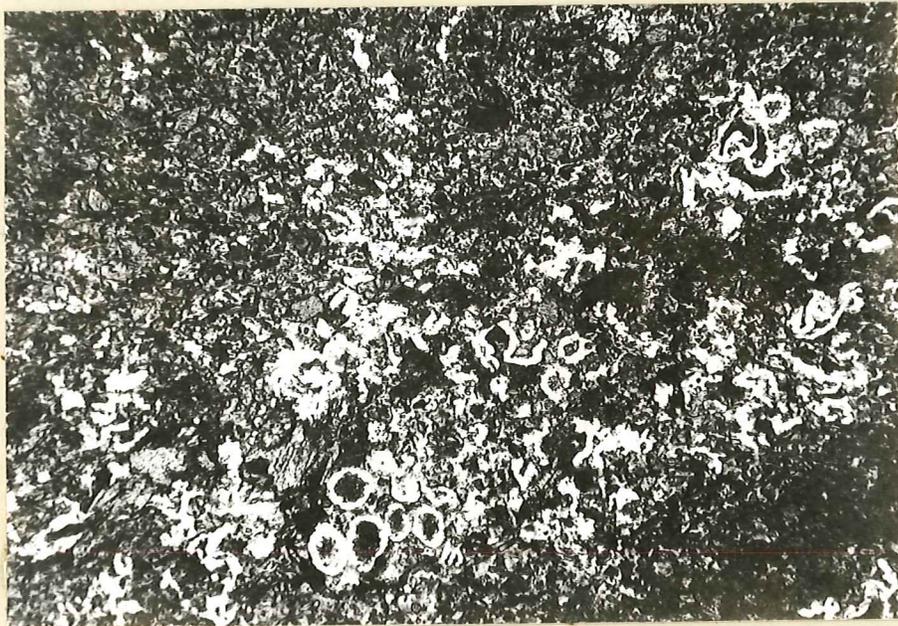was gray in reflected light.

Fig. 27   Photomicrograph of Teanaway pyroclastic
rock. This rock is a plexus of amygdules filled
with quartz, chlorite and calcite. Plane light,
x 48.

Here and there in the Teanaway basalt, sedimentary rocks were found. They are not common and are of limited extent. Typical of these rocks is the sharpstone conglomerate that out-crops along the shore of Cle Elum Lake near the base of the Teanaway basalt. It is composed of angular and sub-rounded fragments of quartz, argillite, and basalt up to three inches in diameter, in a sand size groundmass of poorly sorted fragments of the same material.

DIKES AND DIABASE INTRUSIVES ASSOCIATED WITH THE TEANAWAY BASALT

Occurrence and Relations

The dike swarm briefly mentioned above is one of the most spectacular features in this area. The dikes are most abundant in the area south of Mt. Stuart, and have a total east-west extent of over 30 miles. They were first mentioned by Russell in 1893 (pp. 67-8), who described the relations near the west face of Table Mountain as,

> "The strata are penetrated by an extensive system
> of dikes of hard basaltic rock, which accounts for
> many of the features in the relief of the land.
> These are of special interest because they seem to
> have been the source of the great sheet of basalt
> which once covered this portion of the Kittitas
> system. (Swauk) In places beneath the escarpment
> formed by the western edge of the Columbia lava
> there are large dikes which lead up to the basalt
> and merge with it. Their immediate junction with
> the lava crowning the cliffs was not closely examined,
> but the dikes in the slope below have every appear-
> ance of being connected with it, and lend support
> to the hypothesis of fissure eruption to account
> for the great flood of basalt covering such a large
> part of the northwestern states."

This quote shows how difficult it is to interpret the contact relations between these dikes and an overlying basalt, for we now believe that the Yakima basalt that forms Table Mountain is much younger than the dike swarms.

The relations of these dikes were next discussed by Smith

(1903, p. 16), whose total comment on the dikes was,

> "The most striking feature of the Teanaway basalt is
> the occurrence of hundreds of dikes which cut through
> the underlying Swauk formation and connect with this
> surface flow. The opportunity is afforded for ob-
> serving almost diagrammatically the evidence that
> these basalt flows were erupted through fissures,
> and for the most part the eruption appeared to be
> unaccompanied by any disturbance of the underlying
> rocks."

In 1904 (p. 6), he repeated,

> "In exceptionally favorable exposures the vertical
> dike can be traced, as it cuts the sandstone, to a
> point where the narrow dike abruptly widens out and
> becomes a part of the horizontal or gently inclined
> flow. The evidence is conclusive that the Teanaway
> basalt was erupted through many fissures rather than
> from a large volcanic center."

It is interesting that Turner and Verhoogen (1951, p. 176),

in discussing dike swarms all over the world, note the,

> "absence of authentic instances of transition be-
> tween individual flows and individual dikes remains
> an unexplained anomaly."

This is another indication of the difficulties involved in

studying these dikes.

These dikes have also been suggested as the feeders of the

Columbia River basalts as well as the Teanaway basalts. Chappell

(1936, p. 156) interpreted multiple dikes in the Teanaway dike

swarm in Wenatchee quadrangle as possibly meaning that these

conduits also fed the Columbia River lavas in that area. Most

of the recent workers believe that the Columbia River basalt had

its source to the southeast, so that even if these dikes were

active in Miocene time, they were probably not very important

(Waters, 1955b, p. 708).

The individual dikes that make up the Teanaway dike swarms were described by Russell (1899, p. 121). He observed them to range in width from a few inches to over 160 feet, with many between 15 and 60 feet across, and their trend seldom varies more than a few degrees from N 15° E. Many are nearly vertical but most dip westerly from 75 to 85 degrees. He further noted that frequently these dikes, especially in their central portion, have columns at right angles to their walls. Lupher (1944, pp. 30-31) separated the dikes into two kinds. His first type is composed of solid basaltic material and is fairly constant in width, strike, and dip where in the Swauk, but becomes more variable where intruding the peridotite. These dikes are commonly 30 to 40 feet wide but extend up to 100 feet in width. The second type consists of irregular complex intrusions, some of which are ovoid or wedge-shaped or even amoeba-like. These intrusions are composed of brecciated and highly vesicular material as well as a soft, brown, massive basalt type that resembles a weathered basalt.

The number of the dikes has been mentioned before, but the true magnitude of the dike swarm cannot be appreciated until a few examples are considered. Russell (1899, p. 121) said,

> "Practically they (the dikes) are countless. In one section near the head of Stafford Creek, about five miles southeast of Mount Stuart, fifty dikes, ranging in thickness from 15 to 60 feet, were observed in an area 3,500 feet broad, measured at right angles to their trend."

Lupher (1944, p. 29) observed that most of the dikes are in the Swauk formation and in the area he studied, are most commonly about 500 feet above the base of the Swauk. He further noted that the dikes became fewer between 2000 and 4000 feet south of

the peridotite contact and that there is a zone 20 to 200 feet wide at the base of the Swauk where there are very few dikes. At the horizon 500 feet above the base of the Swauk, he estimated the ratio of intrusive to sedimentary rock to average one to four, and,

> "From the east side of Miller Peak west to the west side of Iron Peak, a distance of more than eight miles, the intrusions are so numerous as to reduce the Swauk to a series of thin sandstone slabs lying between large complex dike masses. The ridge between Standup and Bean Creeks is probably more than 90 per cent basic dike material and the Swauk sandstones are preserved as occasional thin layers or lenses a few feet or a few tens of feet thick."

As all the earlier workers have noted, one of the most interesting features of the dike swarm is that their emplacement was apparently quiet so that even the thin slivers of Swauk between the dikes were not noticeably disturbed. As noted above, the Swauk folds were mapped by studying these tiny Swauk slivers. This feature shows that the Swauk was folded before the intrusion of the dike swarms and suggests that the dikes were not all emplaced at the same time. The Swauk, however, has been subjected to orogenic forces since its initial folding as evidenced by the overlying younger folded rocks and the crushed and faulted zones in the Swauk which were mentioned earlier. The individual dikes can be traced in some instances for several miles in the Swauk sediments, but on entering the peridotite the dikes become quite discontinuous. This feature has been interpreted in different ways. Russell (1899, p. 122) suggested that the dikes had been faulted off and G. O. Smith (1904, p. 6) believed that the difference in jointing between the sandstone and the sheared serpentinized peridotite more likely was the cause. Smith's

hypothesis seems more likely if Lupher's observations are in-
terpreted as meaning that the Swauk acted as a preferred zone
for dike injection, probably because of its regular jointing.
Russell's observation of faulted and rotated dikes is probably
also true in view of the known faulting at this contact, but in
view of Lupher's observations, does not seem adequate.

The dike swarms are shown diagrammatically in Figure 23.
From the foregoing description it should be clear that it is
impossible to adequately show the thousands of dikes on this
scale. In this diagram the most dikes are shown on the ridge-
tops for there they are best exposed while on the hillsides and
in the valleys they are obscured by vegetation and talus.

A diabase intrusive body near Dry Creek was studied. It
is shown on the map, however, its limits could not be clearly
determined because of the difficulty in distinguishing the dikes
from the diabase intrusive, and because of the paucity of Swauk
exposures. This intrusive is well exposed in road cuts and al-
most horizontal columns are conspicuous. Because of the lithic
similarity between this diabase and the Teanaway dikes, they are
believed to be related. Smith and Calkins (1906, p. 6) reported
other diabase intrusives too small to be shown on their map, and
suggested that they were related to the Teanaway dikes.

Age

The dike swarms are intrusive only into the basement rocks,
the Swauk formation and the Silver Pass volcanics. Thus their
distribution indicates they may be of pre-Teanaway or Teanaway
age. The fact that the dikes terminate near the base of the
Teanaway basalt, best seen on Fig. 23, is suggestive of a genetic

relationship between the dikes and the Teanaway basalt. The evidence for this relationship has been reviewed above and while many of the details are in doubt, the general proposition that the dike swarms were the source of the Teanaway basalt seems quite secure.

Chappell (1936, p. 156) reported that some of these dikes may have also been the source of the Yakima basalt. However he described multiple dikes and suggested that a long time interval existed between the different parts of the dikes.

Description

In hand specimen these diabases and dike rocks are all dark gray or green-gray, and vary from aphanitic to fine grained.

A medium-grained diabase from the intrusion near Dry Creek just east of Cle Elum Lake may be taken as typical of the holo-crystalline rocks. This rock has an intergranular texture and is composed of approximately 59 per cent plagioclase, 25 per cent augite, 10 per cent pigeonite, 5 per cent opaques and 1 per cent chlorite. The plagioclase laths are zoned with labradorite cores (An 58) and andesine rims (An 30). This zoning is grada-tional and distinct layers were not noted in any thin sections. The augite is light green and is identified by a 2V in the range 30 to 50 degrees. It is in the form of large anhedral grains and contains an occasional apatite crystal. In some slices, it can be distinguished from the pigeonite by its lower apparent relief and finer, closer spaced, cleavage. The pigeonite is in the form of small rounded grains and has a faint green color. It is distinguished by its small optic angle which is less than 15 degrees. The magnetite is in the form of large partly

Fig. 28   Photomicrograph of diabase near Dry Creek.
Note the large magnetite grain at the edge of the
field. Plane light, x 48.

Fig. 29   Photomicrograph of a coarse phase of the
diabase near Dry Creek. Anhedral augite and labra-
dorite with some chlorite. Plane light, x 48.

resorbed grains and the chlorite is interstitial. Smith and
Calkins reported in addition to the above, hypersthene, olivine,
micropegmatite and hornblende, but none of these were identified
in over a hundred thin sections that were studied. Interstitial
quartz, perhaps due to contamination, was noted in several dike
rocks. Late interstitial or amygdaloidal calcite is present in
a few thin sections.

The texture, composition, alteration and contamination of
these diabasic and basaltic rocks varies from place to place but
the most important factor controlling these variables appears to
be distance from the wall rocks.

Almost all of these rocks show some degree of alteration,
apparently deuteric. Many of the feldspars in the rock des-
cribed above are cloudy, with inclusions of what is apparently
chlorite and sericite. In the porphyritic rocks described be-
low, the glass in the groundmass, in almost every case, has
been altered to mineraloids or to chloritic material.

Some of the variations in the Dry Creek diabase described
above can be seen in the accompanying photomicrographs. In
this large intrusion, as noted earlier, it was not possible to
map the contacts accurately so the relationship between the
different phases is not well known.

The dike rocks are very similar in mineralogy and texture
to the diabase but are, in general, less crystalline. The
coarser grained, more crystalline of these rocks have an inter-
sertal texture and are composed on the average of 50 per cent
plagioclase, 30 per cent pyroxene, 15 per cent glass, mineraloids
or chloritic material, and 5 per cent magnetite. The plagioclase

occurs as elongate laths and its composition changes gradually
from cores as calcic as An 68 to rims of An 33. The pyroxene
is in the form of anhedral to subhedral grains. Some of these
grains have a 2V of near zero degrees and others have a 2V of
about 40 degrees. Hence both pigeonite and augite are present.
The magnetite is in several forms. Some of it occurs as small
disseminated grains, some as large, partly resorbed, grains,
and some as elongate ragged rods.

The interstitial groundmass material in these rocks is
composed of several minerals or mineraloids. The identity of
these materials cannot be clearly determined optically. It
appears that this material was originally glassy and has been
altered, probably deuterically. In some of these rocks, this
material is green in color, some is pleochroic, and between
crossed nicols, is seen to be composed of a felty mass of weakly
birefringent crystals. This material is believed to be chlorite
and is sometimes intermixed with tiny opaque grains. In some
rocks, this material appears to form by the alteration of the
pyroxenes. Another, perhaps more common, mineral or mineraloid
in these rocks is yellow or yellow-brown, non-pleochroic, weakly
birefringent, and grows in radial aggregates. In some rocks
the pyroxenes, as well as the glassy interstitial material,
appear to alter to this substance. This material is considered
to be chlorophaeite although it does not have all the optical
properties of this mineral. The reader is referred to the dis-
cussion of this mineraloid earlier in the description of the
Teanaway basalt. A third mineral was noted in these rocks; but
in very limited quantity. This material is tentatively identified

as iddingsite. It is yellowish brown, non-pleochroic, has a
radial extinction, and has a birefringence notably higher than
the other materials described above. It, too, appears to be an
alteration product of both pyroxene and interstitial material.

Study of an individual dike will illustrate the variations
in these rocks. Near the edge of a dike, the rocks are fine-
grained and somewhat altered. A specimen six inches from the
edge of a thirty foot dike is composed of 40 per cent plagioclase,
30 per cent chloritic material, 10 per cent very altered pyroxene,
10 per cent magnetite, 8 per cent quartz, and 2 per cent calcite.
The plagioclase is oligoclase. It is cloudy with tiny inclusions
and much of it has altered to chlorite. The pyroxene has mostly
altered to chlorite and magnetite, and the few remaining shreds
could not be determined any closer. Most of the chlorite is
interstitial and probably replaces glass. The calcite and some
of the chlorite appear to fill vesicules. The quartz is appar-
ently contamination from the Swauk that forms the wall rocks and
some of it contains rutile needles. In short, the whole aspect
of this rock is alteration.

A specimen ten feet from the edge of the same thirty foot
dike is much less altered and is coarser grained. It contains
40 per cent plagioclase, 30 per cent pyroxene, 15 per cent
opaques, and 5 per cent each, chlorite, quartz, and glass or
mineraloids. The plagioclase is fresh and is gradationally
zoned from labradorite cores to oligoclase rims. Both pigeonite
(2V near zero degrees) and augite (2V about 40 degrees) are
present as subhedral grains.
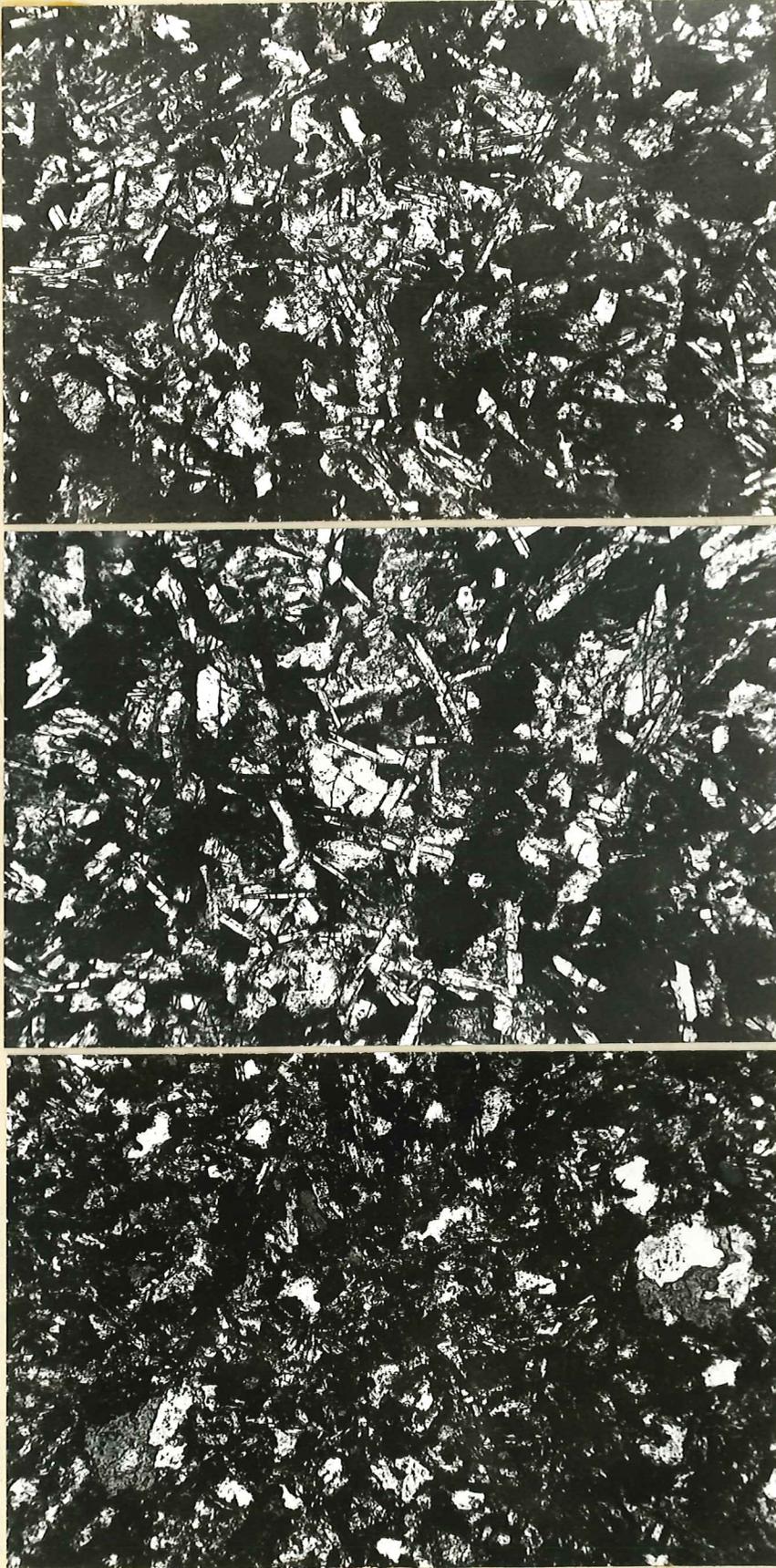
Six inches   Ten feet   Fifteen feet

Fig. 30 Photomicrographs showing the change in texture in a single thirty foot wide dike. Plane light, x 48.

At the center of this dike, the rock is much like the last specimen described and is not notably coarser grained. It is composed of 60 per cent zoned plagioclase, 20 per cent pyroxene (including both pigeonite and augite), 10 per cent chlorite, 5 per cent magnetite and 5 per cent quartz. Photomicrographs of these three rocks are shown in Fig. 30.

These dikes are apparently genetically related to the Teanaway basalt. The field evidence was described above and although there are still many unanswered questions about the details of these relations and the nature of the Teanaway vulcanism, the genetic relationship is apparently well established. Petrographically, the dike rocks are very similar to the Teanaway lavas. Many of these dike rocks have the same composition, texture, alteration, and plagioclase zoning as the lavas. This petrographic similarity strengthens and augments the field evidence that these dikes are the source of the Teanaway basalt.

ROSLYN FORMATION

The Roslyn formation was named by Russell in 1899. The passage in which he named it was quoted in total earlier in these pages. A type section was not designated either there or in G. O. Smith's later publications.

The Roslyn was not studied in any detail in the present work because it was the subject of a detailed study by Bressler in 1951. Bressler's work was focused on the petrology of the formation; however, he also failed to designate a type section. The description and subdivisions of the Roslyn are abstracted from Bressler's work. They are included here only for completeness, and the interested student should consult Bressler's paper

for details.

The Roslyn formation occurs in what can be called the Roslyn
Basin, a structural and topographic basin drained by the Yakima
and Teanaway Rivers. Structurally, the Roslyn basin is quite
asymmetrical with the steep limb on the southwest side. The
minor folds shown on the map near the main synclinal axis were
mapped from data from drillholes and the mine workings (Saunders,
1914). There is faulting on the steep southwest side of the
basin where the underlying Teanaway basalt is deformed into a
tight syncline. In this area, just southwest of Cle Elum Lake,
a basalt outcrop, apparently faulted into place, was discovered
in the Roslyn sediments, but the thick vegetation obscured the
relations. For the most part the Roslyn is poorly exposed on
the low wooded hills and ridges of the basin but it is well ex-
posed on the forks of the Teanaway River.

Near Ryepatch, erosion has exposed the Teanaway basalt on
what was apparently a topographically high place on the pre-
Roslyn surface. The relations are not clear at this place due
to the soil and vegetative cover. Bressler considered this to
be a gentle fold. It is possible that this outcrop could be
due to the forceful emplacement of the nearby rhyolite but ex-
posures are too poor to decide.

Bressler (1951, p. 29) divided the Roslyn into three units.
The lower unit lies apparently concordantly on the Teanaway
basalt. The differing opinions on the exact nature of this con-
tact were summarized earlier. The basal beds of the Roslyn con-
sist of 200 feet or less of red clastics that grade upward into
nearly white clastics. Above the basal beds are 2300 feet of

largely massive, yellowish-gray arkosic conglomerates, pebbly,
and medium sands. The middle unit is composed of 2500 feet of
yellowish-gray arkosic medium-grained sand with darker inter-
bedded fine sand and silt. The upper unit is 1500 feet thick,
and contains the coal measures. This unit is composed of eight
major coal beds interbedded with medium to very fine sands and
silts. Saunders (1914, p. 28) reported interbedded lava sheets
and tuff beds in the Roslyn. He gives no locations and none of
the other workers have reported these volcanics.

The Roslyn in the area studied is in contact with two
younger rocks, the post-Roslyn rhyolite and the Yakima basalt.
The relations with the rhyolite will be considered later. The
Yakima basalt overlies the Roslyn with an angular unconformity.
This unconformity is quite clear from the map pattern and the
actual unconformity can be seen at the west face of Table Moun-
tain. At this location the almost flat lying Yakima basalt can
be seen overlying gently east dipping Roslyn and Teanaway.
Fig. 31.

The age of the Roslyn has been repeatedly referred to be-
fore because it is the only reasonably well dated formation in
the column. It is considered as middle and/or upper Eocene on
the basis of one fossil fish and two turtle carapaces which to-
gether with leaves are the only fossils yet found in these rocks
(Wheeler, 1955, p. 1668). The original leaf collection was
studied by Knowlton who reported (in Smith 1904, p. 7) an Eocene
age younger than the Swauk, noting that not a single species was
common to the Swauk. The fish was studied by Hesse (1936) who
considered it probably middle Eocene.

POST - ROSLYN RHYOLITE

The rocks discussed under this heading are a loosely associated group of altered acid volcanic rocks. They are scattered in an area a few miles wide bordering the outcrop of the Teanaway basalt. For the most part, they are poorly exposed in this wooded country. They were first mentioned by Russell in 1899 (p. 130), who wrote,

"In intimate association with these (the Teanaway basalt) in the region embraced between the North and Middle Forks of the Teanaway River, there are peaks composed of nearly white rhyolite. The relation of the rhyolite to the Columbia basalt (Teanaway basalt) is not well known, but it seems to be a dike exposed by erosion and much shattered and altered in color by weathering."

In 1903 (p. 18), Smith interpreted these rocks as,

"... on the middle fork of the Teanaway River, where rhyolitic rock is seen to rest upon the eroded surface of the older rocks. The age of this lava is somewhat problematical, but evidently it is considerably younger than the Eocene rocks with which it is in contact."

A year later in the Mt. Stuart folio, Smith (p. 8) gave a more complete description of both the rocks and their relations. He described the large rhyolite occurrence a few miles west of Ryepatch as a post-Teanaway flow. Elsewhere, however, he noted that the rhyolite overlay both the Roslyn and the Teanaway, and suggested Pliocene as the age. No name has ever been suggested for these rocks and because their relations are still somewhat obscure, it seems best to refer to them simply as post-Roslyn rhyolites until they are better understood.

The most profitable means of studying these rocks is under the microscope, especially in view of the fact that the relations between the rhyolite and its surrounding rocks are usually not

exposed. Each of these scattered occurrences must be studied as
a separate unit for in view of Smith's observations, it appears
that rocks of more than one age may be grouped together in this
instance.

Most of these scattered occurrences have a common feature
in their alteration, in addition to all being light colored
volcanic rocks. It is this ubiquitous alteration that often
makes these rocks weather easily and so obscures the relations
to the surrounding rocks. It is frequently difficult to obtain
a solid specimen because the alteration has produced a rock that
crumbles under the hammer. This alteration is apparently hydro-
thermal and seems to be related to the rhyolite itself, although
in some areas, such as the roadcut near the mouth of the Middle
Fork of the Teanaway River canyon, it appears that what has been
mapped as rhyolite is simply hydrothermally altered country rock.
Smith noticed similar features (1904, p. 8), for he observed that
some of the rhyolite looked like altered shale in the field.

Further north along the Middle Fork of the Teanaway River,
another rhyolite body was found but here, the rhyolite seemed
to be interbedded with the Teanaway basalt.

Near Redtop Lookout, a small dike of this altered rhyolite
intruding the Teanaway basalt is exposed. Here the rhyolite is
at least in part intrusive and it may be that the intrusion of
the rhyolite is responsible for the local coloration and resist-
ance of the Teanaway basalt.

Description

From the discussion above it seems clear that rocks of
several ages and different origins are included in this unit.

All of these rocks do have a common feature in their alteration.
Proper study of this unit would entail detailed investigation of
each of the occurrences; however, the degree of alteration and
the very poor exposures would make such a study difficult if not
impossible. Therefore, the petrographic descriptions that follow
are offered only in an effort to show the rock types and the
difficulties involved in their study while genetic interpreta-
tions must await more detailed study.

In hand specimen, these rocks are all light in color. The
color varies from a creamy white to a very light brown. Commonly
these rocks have an earthy luster and are partly stained by
limonite. The clastic texture of some of these rocks is shown
by color differences between the fragments and the groundmass.
In a few other rocks, small spherulitic growths can be seen with
a hand lens.

In thin section, the extreme variability of this group of
rocks becomes apparent. A few are welded tuffs. The two tiny
occurrences on First Creek are both welded tuff. The groundmass
in these rocks is altered and somewhat devitrified. The out-
lines of flattened glass shards are emphasized by concentrations
of limonitic material. In addition, these rocks contain a few
quartz phenocrysts and some altered feldspar phenocrysts.

At other localities, the rocks are more altered so that
little can be said about their origin but judging from the field
relations, both intrusions and flows are present. The alteration
takes many forms. In some of these rocks, spherulitic growths
obscure the earlier textures. Other rocks consist of a plexus
of amygdules filled with some form of silica or calcite. In

others, the alteration to clay minerals, sericite, limonite, and alunite has proceeded to a point where the original textures can not be determined. In a few of these rocks, very altered feldspar phenocrysts, that now consist largely of clay minerals, were noted.

The alteration was not confined to the rhyolite itself but it also affected the surrounding rocks. On the hill between Indian and Middle Creeks, apparent gradations between Roslyn arkose and these altered rhyolitic rocks were observed in the scattered outcrops.

The field evidence and these descriptions suggest that both intrusive and extrusive rocks are grouped together in this unit. The types of alteration of both the rhyolites and the country rock further suggest that the alteration is probably the result of hydrothermal solutions that may have accompanied the emplacement of the rhyolites. Much more study would be required to understand the details of these scattered occurrences or to show that this interpretation is correct.

YAKIMA BASALT

The Yakima basalt contact was used as a limiting boundary in this study. The older Tertiary rocks were followed until they were unconformably overlapped by the Yakima. This contact extends from Table Mountain to Lookout Mountain and forms the east and southeast border of the area.

The Yakima basalt was named by G. O. Smith in 1901 (p. 15). It is one of the formations into which Smith split Russell's Columbia lava. Smith defined the Yakima as the basalt of the Miocene period (sic.) and designated no type section. Yakima
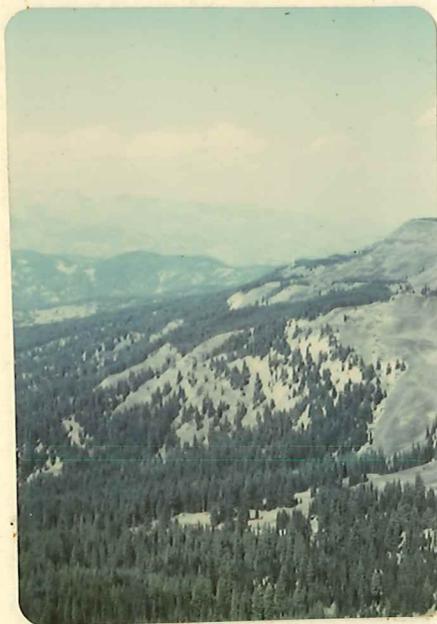
Fig. 31   Looking north along the west face of Table
Mountain.   The flat lying Yakima basalt on the right
unconformably overlies the east dipping Teanaway
basalt and Roslyn arkose in the middle ground.

basalt is used in this study as Smith used the term in practice, that is, for the pre-Ellensburg formation basalts.

The Yakima basalt is composed of a large number of flows, some of which can be traced for many miles. The typical rock is an aphanitic to fine-grained black or dark gray basalt with a few phenocrysts of feldspar. The most recent study of the petrography, stratigraphy, and structure of this unit is by Laval (1956).

The age of this formation is now considered to be near the Miocene-Pliocene border (Waters, 1955a, p. 664). It is reasonably well dated by leaves, freshwater mollusks, and vertebrates found in the sediments between the Yakima basalt flows and especially in the Ellensburg formation. This age is in accord with the relations observed in this study. That is, the Yakima basalt can be seen unconformably overlying the Eocene rocks along the west face of Table Mountain.

The Yakima basalt is a relatively competent unit and where it overlies the Swauk and Roslyn sediments large landslides have developed as a result of erosion of the weaker underlying sediments. The resulting landslide topography is striking, even to a casual observer, along the face of Table Mountain and Lookout Mountain. Some of these landslides are quite old for the Yakima River has cut terraces on them (Smith, 1900, p. 583).

HOWSON ANDESITE

The Howson andesite occurs only in two small outcrops on Sasse Mountain north and northeast of Howson Creek. It was named and described by Smith and Calkins (1906, p. 10) and much of the following material was abstracted from that source. It is a

light gray andesite with prominent elongate hornblende pheno-
crysts and smaller feldspar phenocrysts. At these two local-
ities, it overlies Swauk formation that has been intruded by
Teanaway dikes. The Howson andesite has well developed columnar
structure which gives rise to extensive talus slopes that ob-
scure the contact with the older rocks.

The Howson andesite differs from the other andesites in
the area because of its lack of alteration. It is very similar
to the hornblende andesite boulders in the Ellensburg formation
and Smith and Calkins have suggested that it may be the source
of the Ellensburg detritus. These Howson outcrops, however, are
some distance from the nearest Ellensburg and the lithic simi-
larity may only indicate that these two formations are contem-
poraneous. This may put an upper limit on the age of the Howson,
for the Ellensburg detritus seems to have come from contemporary
vulcanism. As noted in the last section, the Ellensburg forma-
tion lies near the Miocene-Pliocene border (Waters 1955a, p.
664).

Under the microscope, Smith and Calkins report zoned plagio-
clase, hypersthene in some specimens, and hornblende of several
varieties with differing optical properties, in a groundmass of
glass, iron oxide, quartz, and orthoclase.

The Howson andesite, although it occupies only a small area,
is significant in that it is apparently the youngest formation in
the area, and there is no similar unaltered andesite any place
nearby.

Fig. 32   Typical view of Howson andesite on the
ridge west of Sasse Mountain showing columnar joint-
ing and talus slopes.

Kendall Pk.

Red Mtn.

Lundin Pk.

Guye Pk.

Snoqualmie Mtn.

Denny Mtn.

The Tooth Mtn.

Chair Pk.

Kaleetan Pk.

Low Mtn.

Fig. 33 Looking north toward Snoqualmie Pass from Mt. Catherine. The low rounded hill in the middle ground is composed of Guye formation sediments.

WESTERN STRATIGRAPHIC SECTION

Repeated mention has been made of the Kachess fault that separates two totally different stratigraphic columns. To the east of this fault, we have seen that the structures are open and the column is composed of well-known formations. We now turn to the area west of the fault where the structures are complex and the rocks not well known.

A part of this western area was studied earlier by the author. In this more recent study of a much larger area, he became more familiar with some of the units and was able to trace them into that original area. In this paper then, the opportunity is taken to correct some earlier misconceptions and to review the earlier study and place it in its regional setting.

DENNY FORMATION

Previous Work

These pre-Tertiary rocks were originally called Guye formation by Smith and Calkins and were later called Sunset by the author (1955, p. 11). The Sunset was named for the exposures on the Sunset Highway west of Snoqualmie Pass; however, detailed mapping has shown that the rocks cropping out on the highway are really younger than the Guye formation. The purpose of that earlier paper was to study the Guye formation and to separate the units of different ages that had been included in Smith and Calkins' Guye formation. This purpose was accomplished, but the relations of the rocks separated from the Guye formation were confused because the stratigraphic column was imperfectly known at the time.

Occurrence and Relations

The present mapping has shown that the older rocks that are here called Denny formation are confined to two small areas on Denny and Snoqualmie Mountains. The total areal extent of the Denny formation is less than two square miles. Coarse-grained marble is the most typical rock in the Denny formation and there is also interbedded hornfels. These older rocks are apparently separated from the hornfelsed basalts and sediments of the Naches formation outcropping on the highway by a fault north of the Snoqualmie River. Exposed in the river are somewhat hornfelsed clastic sediments. North of here, the next outcrops encountered are the marbles exposed on the side of Denny Mountain. The contact between these different rock types is concealed by the heavy vegetation in this area and a fault appears to be the most logical relation. This change in rock type was of course known during the earlier study, but during the recent field mapping, a distinctive conglomerate bed was traced from Cold Creek to northeast of Silver Peak. This, together with the map pattern of the rhyolite that also turns at that point, is now interpreted as indicating that the rocks along the Sunset Highway are the same formation that occurs in Cold Creek, that is, the Naches formation. According to this interpretation, the structure south of Snoqualmie Pass is an eroded anticline, in the core of which the east-dipping Guye formation is exposed unconformably below the rhyolite. This structure will be discussed in more detail presently.

The Denny formation is well exposed both on the south flank of Denny Mountain and especially in the saddle between Guye Peak

and Snoqualmie Mountain. The latter location, because of its better exposures, should be considered as the type area. At this locality, the rocks are medium to coarsely crystalline marbles interbedded with fine grained hornfels. They are intruded by the Snoqualmie granodiorite, which is responsible at least in part for the metamorphism. The marble lenses dip steeply to the south but this may not be true bedding for plastic flowage has probably occurred. No estimate can be made of the thickness of the rocks because the intense deformation and metamorphism that accompanied the emplacement of the Snoqualmie granodiorite has obscured the structure. In this relatively flat saddle, a small scale Karst type topography has developed and many sinkholes, some quite deep, were observed. The contact with the Mt. Catherine rhyolite is not exposed due to the vegetation, but the abrupt termination of the rhyolite indicates that the contact is probably a fault.

On the south flank of Denny Mountain, the marbles and hornfels of the Denny formation are not well exposed because of the vegetation. As at the other locality, these rocks have been deformed and hornfelsed by the Snoqualmie granodiorite. The contact between the granodiorite and the marble, especially on the southwest side of Denny Mountain, is the site of small but spectacular mineralization.

Age and Correlation

These rocks were originally considered as Miocene with some reservation by Smith and Calkins who included them in their Guye formation. The field relations show that they are pre-Snoqualmie granodiorite and in fault contact with the other rocks. These

rocks are believed to be pre-Tertiary because there has never
been any limestone found in the Tertiary rocks of the Cascades
except for a few, thin, limited beds of freshwater limestone in
the Puget formation.

The nearest outcrops of limestone occur in the Mt. Index
region northwest of here, where there is a small body of Permian
limestone. For this reason a Permian age is suggested for these
rocks. To the north, there are limestones of probable Mesozoic
as well as Paleozoic age and the Denny may correlate with one of
them.

The Denny formation may be the southernmost portion of a
group of metamorphic rocks reported by Bethel (1951, pp. 78-81),
who mapped an area just northwest of here. Bethel called these
rocks the Lake Wildcat metamorphics and described them as
amphibolites, mylonitic schists, and greenstones. On Chair
Peak, about midway between the Wildcat metamorphics and the
Denny formation, Smith and Calkins (1906, p. 7) reported a thick
chert mass. This occurrence is shown on the map as Denny forma-
tion. It is questionable whether the Denny can be correlated
with the Wildcat in view of the latter's reported more intense
dynamic metamorphism, but they are both pre-Tertiary. The Wild-
cat metamorphics were thought by Bethel to be either older than,
or the metamorphosed equivalent of, his Calligan formation which
is a thick series of graywackes, argillites, and tuffaceous sedi-
ments. Recently Danner, working further to the north, found
Jura-Cretaceous fossils in rocks similar to the Calligan forma-
tion (W. R. Danner, 1955 p. 454).

Description

The metamorphism of these rocks seems to be due mostly to the emplacement of the Snoqualmie granodiorite for two reasons. First, the metamorphism is static with the hornfelsic type of texture predominant. Secondly, the grade of the metamorphism increases as the contact with the granodiorite is approached. The Denny rocks do not occur at any great distance from the granodiorite so the contact metamorphism due to this intrusion may obscure earlier metamorphism of these rocks.

In hand specimen, the marbles are medium to coarse grained and are a mottled light and medium gray. They weather to a medium gray color. In thin section, these marbles show a mosaic of anhedral calcite crystals. In some thin sections, clusters of small diopside crystalloblasts were observed.

The composition of the hornfels is more variable than that of the marbles. In hand specimen most of the hornfelses are medium to dark gray or greenish gray aphanitic rocks that weather to a medium or light gray color. They are very fine-grained except in the immediate vicinity of the granodiorite. The hornfelses at some distance from the intrusion are very fine grained, and the minerals are commonly turbid with tiny inclusions. As a consequence, these low grade rocks are very difficult to study. The fine-grained rocks are composed of quartz, a little oligoclase, epidote, opaques, and in some specimens, actinolite, chlorite, or hornblende. The higher grade rocks are more coarsely crystalline and are characterized by diopside and calcic andesine, commonly with sphene and apatite as abundant accessories.

Fig. 34   Photomicrograph of marble from Denny
Mountain.   Plane light, x 48.

Fig. 35   Photomicrograph of diopside-plagioclase
(An 45) hornfels. Plane light, x 48.

The contact between the marble and the Snoqualmie granodiorite is the site of small but spectacular mineralization. This mineralization was first described by Smith and Calkins (1906, p. 13) but has been mentioned in many earlier and later publications. Because this mineralization is spectacular it has attracted the attention of many prospectors but it consists for the most part of small pods of magnetite in the marble. Associated with the magnetite are massive garnet bands, garnet crystals, pyrite, specular hematite, actinolite, quartz crystals, and epidote. Thus these deposits seem to be metasomatic skarns formed by the intrusion of the Snoqualmie granodiorite into the Denny marble. These occurrences are described in Shedd et al (1922).

GUYE FORMATION (RESTRICTED)

Previous Work

The name Guye formation was applied by Smith and Calkins (1906, p. 7) to a heterogeneous group of sedimentary and volcanic rocks whose structure was not at all clear. As a result, rocks of several ages were included in the formation. The age of this composite unit was erroneously determined as Miocene from a small collection of fossil leaves, but Smith and Calkins and most of the later workers realized that the lithology and structure resembled the lower Tertiary rocks more closely than the Miocene rocks. The Guye formation was one of the few dated units in the region so its age was used to date more widespread formations and this created much confusion. Thus the Guye formation became an enigma and while every paper on Cascade Tertiary rocks discussed the problem, no one studied the rocks themselves.

In an earlier work, the author (1955, p. 21) restudied the Guye formation and separated the rocks of different ages from Smith and Calkins' Guye formation and defined a restricted Guye formation. Prior to this there was no type section. Because the present work revises in part some of the rocks split from Smith and Calkins' Guye formation, the author's earlier work will be repeated here so that all the available information about these rocks will be in one place.

The rocks included by Smith and Calkins in their Guye formation have been separated into four formations. They are the Denny formation, the Guye formation, restricted, the Mt. Catherine rhyolite, and the Naches formation. In the 1955 study, these rocks were called Sunset, Guye, Mt. Catherine, Keechelus, and Kendall member of Keechelus. The only difference between the 1955 study and the present paper is that what were called the Kendall, Keechelus, and part of what was called Sunset are here shown to be Naches formation. These new correlations are the result of a better knowledge of the stratigraphy and structure of the region as a whole. In this thesis, unless otherwise noted, all reference to the Guye formation will refer to the restricted Guye formation, which as we shall see is composed of fluviatile shale, sandstone, and conglomerate of lower Tertiary age.

Occurrence and Relations

The Guye formation occurs in the region around Snoqualmie Pass where it crops out in only two areas, one northwest and the other south of the Pass. The larger of these areas is the ridge that extends south from Snoqualmie Pass. This exposure is bounded

on three sides by the Mt. Catherine rhyolite, which dips away from
the Guye on all sides, and apparently unconformably overlies the
Guye. Throughout this area, the Guye strikes approximately N
30° E and dips to the southeast from 45 to 70 degrees. Rare
crossbedding shows top is to the southeast. The exposures are
generally poor in this area of heavy vegetation, but outcrops
can be found in the creeks, scattered along the ridge crest and
in road cuts. It is this area that should be considered the
type area for the Guye formation, restricted. As there are no
large continuous areas of outcrop where a large vertical section
of Guye can be seen, probably the most accessible place to desig-
nate a type section is the exposures in Coal Creek, and its tri-
butaries, on the east side of Snoqualmie Pass. These exposures
display the distinctive Guye lithology composed of black leaf
bearing shales, some quite carbonaceous, interbedded with dark
coarse and fine sandstone, which rapidly interfingers with con-
glomerates made of subangular fragments of black and gray chert.
This type section runs almost parallel with the strike of the
Guye, so that its main disadvantage is the limited vertical ex-
posure. However, these are the most extensive exposures avail-
able.

At this area south of Snoqualmie Pass, the main structure
seems to be a breached anticline with its axis oriented approxi-
mately north-south. This structure is indicated by the map
pattern showing the Mt. Catherine rhyolite surrounding the Guye
formation and dipping away from the Guye sediments on all sides.
The rhyolite appears to overlie the Guye unconformably and is
overlain, apparently concordantly, by the Naches formation.

These rocks have been folded into an anticline and erosion has
exposed the core of steeply southeast dipping Guye sediments.

The second area of Guye formation is on Denny and Snoqualmie
Mountains, northwest of Snoqualmie Pass. In this area, the Guye
is fairly well exposed on the high ridges carved from the in-
durated Guye sediments that dip southeastward at about 50 degrees.
On Denny Mountain the Guye is overlain, apparently unconformably,
by the Keechelus andesite breccias that form the summit ridge.
The rest of this area is in intrusive contact with the Snoqualmie
granodiorite except for a short distance on Chair Mountain where
the Guye may overlie chert beds that have been referred to the
Denny formation.

Age and Correlation

The age of these rocks has been determined from the abun-
dant fossil leaves found in the finer grained, more carbonaceous
sediments. The first report on these leaves was by Knowlton
(in Smith and Calkins, 1906, p. 7) who reported,

> "Platanus dissecta Lesq.
> Acer aequidentatum Lesq.
> Ficus n. sp., cf. F. artocarpoides Lesq.
> Cinnamomum n. sp.
>
> The first two species are without question Miocene.
> The Ficus approaches quite clearly F. artocarpoides,
> which is from the Fort Union group (Eocene) (sic) of
> Montana. The specimen is not perfect and cannot there-
> fore be positively determined. If it differs at all
> from the Fort Union species the difference must be
> very slight. Yet the species may prove to be new.
> The Cinnamomum is undoubtedly new and is a fine
> characteristic species. It does not approach any
> described species very closely, yet appears to be of
> a Tertiary type.
> The two species that can be determined are Miocene,
> and the other two are of Tertiary, probably Miocene
> facies."

Smith and Calkins commented on the determination saying,

> "... the stratigraphic relations to the overlying rocks, added to the lithologic resemblance of the Guye formation... to the Eocene formations, would have led to its reference to the Eocene were it not for the paleobotanic evidence just cited."

The next comment on this problem came from Beck in 1934 (p. 3), who presented the results of his paleobotanical studies in abstract form. He correlated the Guye with the Naches formation, and suggested that both the Naches and Swauk may be of Cretaceous age. In a letter to H. A. Coombs (November 6, 1954), he elaborated on his much earlier work as follows,

> "My viewpoint about the age of the Guye is based upon a key fossil leaf (Quercus banksiaefolia Newberry) first located in the Bellingham area in the Discovery mine. I have found it at Easton (at the N. P. - Milw. crossover), at Snoqualmie Pass, in South Cle Elum etc."

In 1941 R. W. Brown restudied the original Knowlton collection (in W. C. Warren, pp. 810-11). He thought the two Miocene forms were probably "leaf variations of a single species, probably ancestral to Platanus dissecta Lx", and the "Ficus too fragmentary to identify satisfactorily". He considered "the excellent specimens of Cinnamomum are very similar to, if not identical with, C. dilleri Kn."

Dr. Brown very kindly studied a leaf collection made by the author from the southwestern bank of Coal Creek, a few hundred feet below the mouth of Hyak Creek. He identified the following:

> "Allantodiopsis erosa (Lesquereux) Knowlton
> Asplenium magnum Knowlton
> Glyptostrobus dakotensis Brown
> Ocotea eocernua Chaney and Sanborn
>
> Comment: This is an Eocene assemblage, and probably from the later half of the Eocene. Most of the specimens in the collection represent the one species of Ocotea."

This information is best summarized in chart form. In the following chart the ranges are from La Motte 1952.

	Paleocene	Eocene	Oligocene
Allantodiopsis erosa (Lesquereux) Knowlton	X	X	
Asplenium magnum Knowlton	X		
Cinnamomum dilleri Knowlton		X	
Ficus artocarpoides Lesq.	X	X	
Glyptostrobus dakotensis Brown	X	X	
Ocotea eocernua Chaney and Sanborn		X	X
Quercus banksiaefolia Newberry	X	X	

Of these leaves only three are reported from nearby localities. Beck has found the Quercus quite widespread in the lowest Tertiary formations. The Allantodiopsis and the Cinnamomum were identified by Brown in the McIntosh formation (in Snavely et al 1951) that was dated as mid-Eocene by microfossils.

It is difficult to decide on an absolute age for the Guye formation from these data. The ranges of the leaves indicate Paleocene or Eocene as the probable age, and perhaps suggest an age near the border between Paleocene and Eocene.

The relations of the Guye with the other formations also suggest this age. The Guye is unconformably overlain by the Mt. Catherine rhyolite which is overlain, apparently concordantly, by the Naches formation. The Naches formation west of Kachess Lake was called Teanaway basalt by Smith and Calkins who collected fossil leaves at Gale Creek (1906, pp. 5-6). Knowlton studied those leaves and reported that they were quite similar to the flora of the Puget formation (in Smith and Calkins 1906, p. 6).

The Puget formation is usually considered to be of Eocene age. Thus the Guye formation is unconformably below rocks that may be of Eocene age, indicating an Eocene or Paleocene age for the Guye.

If we accept the age of the Guye indicated by the leaves as near the Paleocene - Eocene boundary, then the Guye may be of the same general age as the Swauk formation. However, the two are lithologically much different and must have had different source areas, and probably somewhat different ages.

Description

The Guye formation is a thick sequence of shale, sandstone, and conglomerate. Its fluviatile origin is shown by the many lenses of conglomerate that are interbedded with the leaf-bearing finer lithologies. The structure is homoclinal and the thickness is difficult to estimate, but appears to be at least five thousand feet. This great apparent thickness may be due to either folding or faulting. The top data seems to preclude folding, but repetition by faulting is possible and cannot be ascertained because of the sparseness of outcrops.

Lithologically, the Guye is a very distinctive formation. The sandstones are usually of light gray to bluish gray color, and the shales vary from deep black to blue-gray in color depending on the amount of carbon. Limonitic stain is common in outcrops and occasionally pyrite is seen in the black shales. The conglomerate usually weathers to a medium gray color; the sandstone to various shades of gray and brown; and the shale to a light or medium gray.

These three lithologies are typically mixed in all proportions in an outcrop, but in other places, the beds may be thick

so that only one lithology is seen for several hundred feet.
Commonly the beds or lenses are only a few inches to a few feet
thick and the grain size is seen to change rapidly. In sedimen-
tation such as this, no key bed or horizon can be traced for a
long distance.

Conglomerate

The conglomerate, percentagewise, is the least important
lithology of the Guye formation but it is the most distinctive
of the formation. Megascopically, the conglomerate is seen to
consist of angular to subangular fragments up to two or three
inches in diameter. The fragments are composed of medium or
dark gray to black chert, and milky white quartz. These frag-
ments are set in a matrix of coarse to fine sandstone similar
to that described below.

Under the microscope, the fragments of chert are seen to
be veined with tiny quartz veins, and the milky quartz appears
to be vein quartz. The sandstone matrix will be described below.

Sandstone

The sandstone varies in color from medium gray to a dark
greenish gray on fresh surfaces depending, in part, on the amount
of carbon. The grain size varies from fine to very coarse.
Fragments of quartz and feldspar can be identified with the hand
lens, and carbonaceous layers or fragments mark the bedding in
some outcrops. These rocks are well cemented, but near the
granodiorite intrusive their aspect changes, and they become
silicified and very indurated. This alteration is discussed
below.

In thin section, these sandstones are seen to contain about 50 per cent quartz or chert, 20 to 40 per cent feldspar, a few to 30 per cent chlorite, up to ten per cent each biotite and opaques, and up to five per cent muscovite. The feldspar is mostly plagioclase, much of which is twinned, and about one quarter of the feldspar is orthoclase. Most of the feldspar is cloudy but about a quarter of it is clear and fresh. Grains of chlorite are present, but most of the chlorite is partially replacing biotite that is altering to chlorite and magnetite. The opaques appear to be mostly composed of iron oxides and carbon. Scattered grains of other minerals are present, and Wilson et al (1942, p. 57) report augite, rutile, hornblende, garnet, and glauconite. The reported glauconite is interesting, for its presence is usually interpreted as meaning a marine origin, but the present author noted none in his thin sections.

The grains in these sandstones are angular to subangular. They are poorly sorted and most show some matrix which is commonly chloritic material. Some of the grains in a few of these sandstones have sutured boundaries, apparently indicative of pressure solution.

Shale

The Guye shales are all black or very dark gray, and are usually carbonaceous. Fossil leaves are crowded on bedding planes at many horizons. In many areas, these shales are quite coaly and have much carbonized wood, but no coal beds of any extent have been found. These shales often have very fine sand mixed with them, and sandy partings on bedding planes are not uncommon. At a few localities, pebbles or granules of quartz
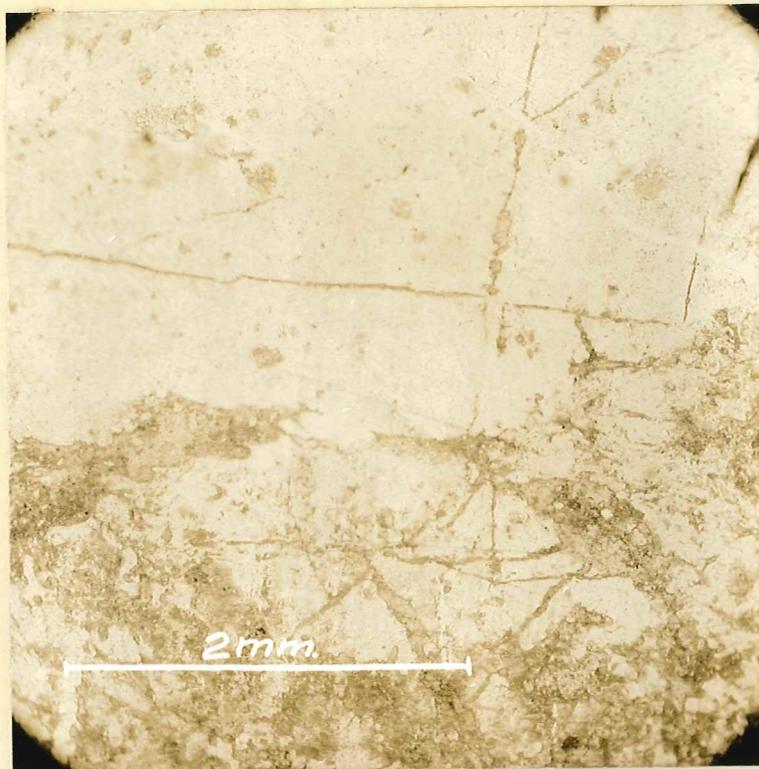
Fig. 36   Photomicrograph of Guye conglomerate.
Chert fragments with tiny quartz veins in a finer
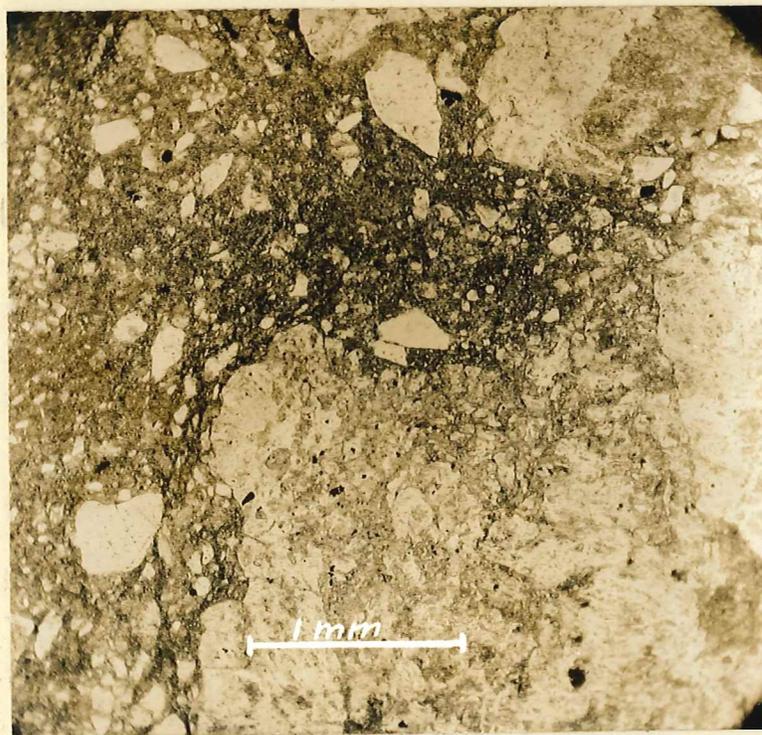grained matrix. Plane light.

Fig. 37   Photomicrograph of a contact between Guye
conglomerate and sandy silt. Plane light.

or chert floating in the shale are common.

Alteration of the Guye Sediments

All of the Guye rocks are altered to a greater or lesser
extent. Apparently this alteration was caused by the intrusion
of the Snoqualmie granodiorite, for it is most marked near the
contact with the granodiorite. Near this contact, the sediments
are commonly indurated and silicified. In the quartz rich sedi-
ments, especially the chert pebble conglomerates, even near the
granodiorite, the alteration consists only of silification and
recrystallization. The fine grained cement or matrix of the
sandstones and conglomerates is most affected and becomes quartz,
chlorite, sericite, and opaques presumably graphite and iron
oxides. (c.f. Goodspeed, 1947, p. 65) Tourmaline porphyroblasts
are not uncommon near the granodiorite, and garnet porphyroblasts
were noted in the quartz and chloritic matrix in several thin
sections. The origin of the garnets is apparently similar to
the garnet-quartz-diopside veinlets described by Goodspeed and
Coombs (1932, p. 554). A few of these sandstones are more com-
pletely altered to a hornfels in which the original clastic tex-
ture is replaced by a granoblastic texture of quartz, muscovite,
and biotite.

MT. CATHERINE RHYOLITE

Previous Work

A part of what is called Mt. Catherine rhyolite was recog-
nized by Smith and Calkins in 1906 and mapped as rhyolite in the
Guye formation. They made only two references to this rock in
their text and only vaguely described it. The extent of this
rhyolite was first mapped by the author in 1955 when the name

Mt. Catherine was proposed for its development on the ridge of
that name. The Mt. Catherine is composed of light purple rhyo-
lite flows, tuffs, and breccias most of which contain small
clear quartz phenocrysts.

Occurrence and Relations

On their map, Smith and Calkins showed only the southern
part of the outcrop of this rhyolite. More detailed mapping has
shown that the outcrop pattern of the Mt. Catherine rhyolite is
a crude oval shape, open to the northwest. For the most part
the exposures of this rhyolite are poor, but its full extent is
easily verified from the scattered outcrops. The northwestern
part of the arc begins near Lodge Lake, and traveling south from
here, occasional glimpses of rhyolite outcrops are seen in the
heavily wooded, steep hillside. The rhyolite is well exposed on
the power line cuts near Rockdale Creek. From these power line
cuts, it can be traced to the hill immediately to the south, and
from there, to Mt. Catherine that forms the southern part of the
arc. Traveling northeast from Mt. Catherine, excellent exposures
are found in Mill Creek, on the hill to the northeast of Mill
Creek, and along the railroad cuts that parallel the shore of the
Lake. The northeast side of the arc is exposed in road cuts on
U. S. 10 near Gold Creek, and on the creek draining Kendall Peak,
as well as on the two ridges of Kendall Peak. The northern end
of this side of the arc is Guye Peak.

The best exposures are on the southeast side of the arc from
Gold Creek to Mt. Catherine. A nearly complete section can be
seen in the steep-walled canyon of Mill Creek, the small creek
running southeasterly just northeast of Mt. Catherine. The rocks

field, it is difficult to ascertain whether this rhyolite is intrusive or extrusive by studying the rhyolite alone. Its extrusive origin was determined from its clastic nature apparent in some hand specimen and more commonly in thin sections from some areas, and from the structural and stratigraphic relations that indicate its anticlinal structure. This interpretation seems quite simple on the map, but in the field, these relations are obscured by the sparseness of outcrops, and the alteration of the overlying rocks to the west by the intrusion of the Snoqualmie granodiorite. In the preceding section, the strati-graphic and structural relations were described, and in this section, the petrography of the Mt. Catherine will be described.

In hand specimen the Mt. Catherine has many aspects, but in general, it is a distinctive, easily recognized rock. Most hand specimens are some shade of purple and have many small clear phenocrysts of quartz. The color does vary however, and some of the lighter phases are a light orange or a light blue-gray color, and the phenocrysts are not present in all speci-mens. The color of the rock is apparently due to hematite, and, because of this iron content, the weathered outcrops are com-monly limonite stained. For this reason, the weathered rock is buff in color and is more or less limonite stained. At some localities, flow banding swirls in intricate patterns and at other places, the clastic nature of the rock is obvious. Each of the types will be described below.

The clastic textured rocks seem to be most common, at least in the places where alteration has not obscured the original texture. There are two types of clastic lavas. The first is

well exposed on U. S. 10 just north of Gold Creek. In hand specimen, this rock is purple and has many small clear quartz phenocrysts. It is composed of angular fragments of the purple porphyry set in a matrix of the same rock. This texture can be seen in outcrops where the matrix contains more hematite than the fragments, and so outlines the fragments. Under the microscope, these fragments are seen to be composed of devitrified glass and are set in a matrix of devitrified glass. Embayed quartz occurs in both the fragments and the matrix. The fragments are angular, and range in size from about half an millimeter to over one centimeter. There are also a few phenocrysts of altered plagioclase, probably albite, orthoclase altered to sericite, and unrecognizable ferromagnesian minerals. See figures 38 and 39.

The other common clastic textured rock in the Mt. Catherine rhyolite is a well bedded tuffaceous rock that commonly occurs near the base of this unit. On a weathered surface, it is seen to be composed of angular fragments in a matrix of what appears to be streaked-out glass. In thin section, this rock is seen to be composed almost entirely of devitrified glass with a few rock fragments, mostly of a trachytic lava. The devitrification of this rock masks its texture in thin section, so that little more can be said about the origin of the rock. In a few thin sections, what seem to be glass shards were noted. This basal tuff is sheared in the area where Coal Creek crosses the rhyolite. These rocks were exposed in the foundation excavations for the bridge built in 1956.
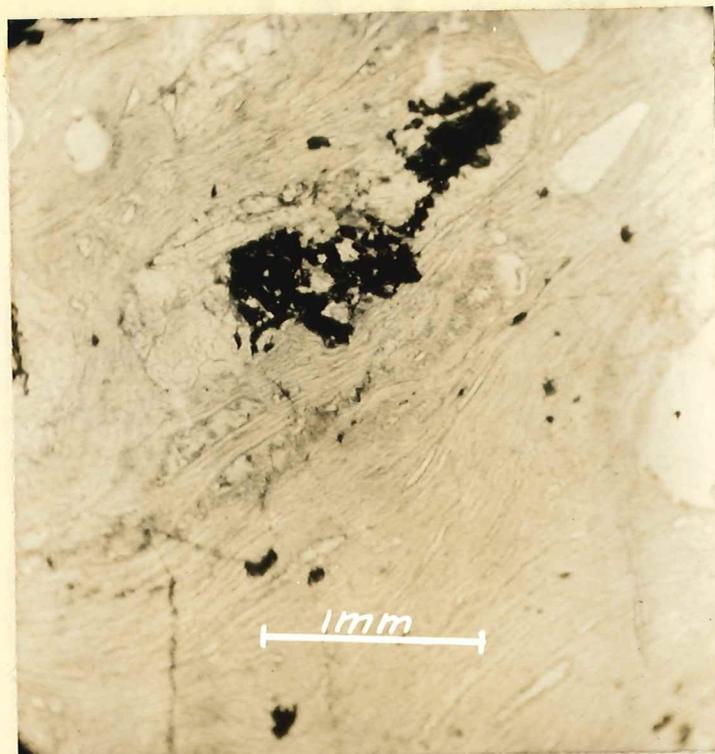
Fig. 38   Photomicrograph of Mt. Catherine rhyolite.
Rounded quartz phenocrysts and opaques in a matrix of
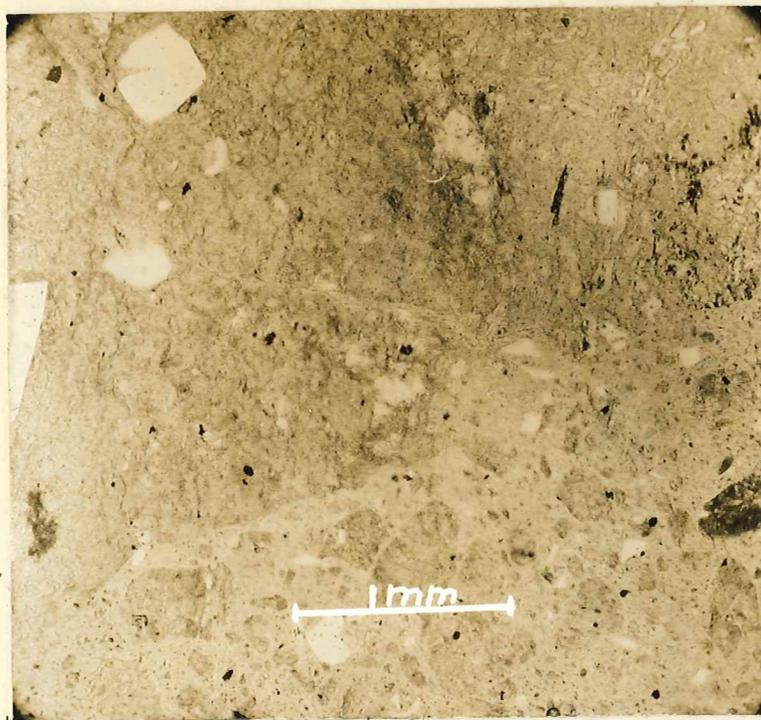devitrified flow banded glass.   Plane light.

Fig. 39   Photomicrograph of Mt. Catherine rhyolite.
Embayed quartz and devitrified glass fragments in a
matrix of devitrified glass.   Plane light.

The flow banded rhyolites have about the same composition as the rocks described above. They are devitrified and contain embayed quartz phenocrysts and a few feldspar crystals altered to sericite. At a few localities, these lavas contain amygdules of calcite.

A related rock was noted in the railroad cut west of the head of Keechelus Lake. This rock is a drab green color, and in thin section, is seen to have a clastic texture, and is altered to chlorite and opaques with a few sericitized, barely recognizable crystals of plagioclase, apparently oligoclase, and some calcite. This alteration seems to be deuteric, and has not affected the rhyolites nearby.

At many localities, especially to the south and west, the original texture of the Mt. Catherine rhyolite is obscured by the development of later spherulites. These spherulites all show a dark cross when the nicols are crossed, and no structure can be seen in plane light except concentric zones of tiny inclusions. The fine-grained matrix between the sperulites is composed apparently of quartz and chlorite. Perlitic cracks occur with the spherulites in some rocks.

The preceding descriptions, especially of the clastic textured rocks, indicate that much of the Mt. Catherine rhyolite is probably extrusive. This is in agreement with the structural and stratigraphic evidence. However, the devitrification and the later alteration of this unit has obscured the original textures so that little more can be said about the origin of this rhyolite.

Occurrence and Relations

In the western part of the area of this study, there is a thick, widespread unit of interbedded sediments and basalts with a few rhyolitic rocks, that is correlated with the Naches formation of Smith and Calkins. The Naches of this study is in stratigraphic contact with only one formation in most of the area, that being the Keechelus andesite which overlies it unconformably. Locally near Snoqualmie Pass, it is underlain, apparently concordantly, by the Mt. Catherine rhyolite. The Naches formation of this study is correlated with the Naches formation of Smith and Calkins for three reasons. The first reason is the lithic similarity of the two units. Secondly, they are both folded and overlain unconformably by the Keechelus. Lastly, they are both thick widespread units that lie almost in contact on opposite sides of the Yakima Valley.

The rocks that are here called Naches were mapped as several other formations by Smith and Calkins. They called this unit in the area immediately west of Kachess and Little Kachess Lakes Teanaway basalt, and further west, in the Kendall Peak area, they referred some of these rocks to the Guye formation and to the Keechelus formation.

Smith and Calkins called the rocks west of the Kachess Lakes Teanaway basalt, probably because basalt is the most common natural outcrop in this area, but they did observe the intercalated sediments. The importance of the sediments is quickly noted today because the roads built for the current logging operations have exposed the usually non-resistant sediments. In this area, shale, coarse and fine commonly arkosic sandstone,

NACHES FORMATION

Previous Work

The Naches formation, which is a widespread unit in south-
western Snoqualmie quadrangle, was named by Smith and Calkins
(1906, p. 4-5), who stated,

> "The Naches formation is composed of interbedded sand-
> stone and basalt, the sedimentary rock predominating
> in the lower, and the volcanic in the upper portion.
> The formation is named for the river in whose basin
> it is most extensively developed."

Smith and Calkins believed that the Swauk and the Naches
were of the same age on the basis of two fossil leaves found in
the Naches formation. They thought that they were laid down in
separate contemporaneous lakes. This theory does not seem cor-
rect for two reasons. First, as noted earlier, there is abundant
evidence that these rocks are fluviatile, not lacustrine, and
secondly, in spite of the fossil leaves, the complete lack of
contemporaneous volcanics in the Swauk suggests that they are
of different ages. These two formations are not in stratigraphic
contact. Smith and Calkins did show that both Swauk and Naches
have the same relation at least to the basement rocks, for both
overlie Easton schist with an unconformity. They also showed
that in southern Snoqualmie quadrangle, the Keechelus volcanics
overlie the Naches formation apparently unconformably. They
further noted that their Kachess rhyolite had a peculiar rela-
tion to the Naches, being in part interbedded with the Naches,
and in part overlying it.

In the present area, the rocks that are correlated with
Smith and Calkins' Naches formation were called by them Teanaway
basalt, Guye formation, and Keechelus formation.

Fig. 40   Looking northeast toward Box Ridge which
is composed of resistant basalt in the Naches forma-
tion. Mt. Stuart in the background.

and conglomerate comprise about fifty per cent of the Naches.
In contrast to this, the Teanaway basalt at its type area con-
tains only a very few sedimentary, usually tuffaceous, beds.
Smith and Calkins thought that the sediments were quite limited
for they stated (1906, p. 6),

> "The section along (Gale)[1] Creek contains several beds
> of leaf-bearing shale and sandstone. This carbonaceous
> rock has been prospected for coal, but these beds rep-
> resent simply lenses of sandy mud, of very limited ex-
> tent, that were deposited in depressions in lava sheets
> and covered by the later flows."

In this area west of the Kachess Lakes, the Naches rocks
are folded into a series of tightly compressed northwest strik-
ing anticlines and synclines. The dip of the Naches rocks is
steep, and the northwest striking basalt ridges stand out boldly
on the aerial photographs. The fold axes shown on the geologic
map are only diagrammatic, because it was not possible to deter-
mine the stratigraphy of the formation. On their map, Smith and
Calkins showed an up-faulted block of Swauk formation and Kachess
rhyolite in this area. The present study has shown that the
Swauk and Kachess lithologies (arkose and rhyolite) are part of
the normal Naches sequence, and faulting is not necessary to ex-
plain the presence of these lithologies.

To the east, the fold axes are terminated at Little Kachess
Lake by the Easton schist that crops out on the east side of the
lake. This trucation of the structure is interpreted as indicat-
ing the presence of a large fault that is here named the Kachess
fault. This fault has been mapped nearly ten miles north of
Little Kachess Lake by R. C. Ellis (personal communication) who
reports that on the Cascade crest between Chimney Peak and Summit
Chief Mountain, the fault plane is exposed. Here the fault dips

[1] Guye Creek is used in the original, apparently a misprint.

Fig. 41   Southwest dipping Naches sediments along
Cold Creek, southwest of Mt. Catherine.

Fig. 42   Conglomerate composed of fragments of very
fine grained carbonaceous sandstone in a matrix of
medium grained arkose exposed along Rocky Run Creek.

about 60 degrees to the east. This is a major structure, for it brings into contact two different stratigraphic sections, and will be discussed later. To the west of Little Kachess Lake, the Naches formation is unconformably overlain by the west dipping Keechelus andesites. The contact can be seen on Gale and Box Creeks and on the various ridges.

(To the south on Amabilis Mountain, the rocks are not well exposed so that the fold axes shown on the map are quite tentative. Heavy timber obscures the rocks except for a few scattered outcrops on the hillsides. Exposed along the lakeshore on the east side of Amabilis Mountain, are arkose to the south and rhyolite to the north.) The road cuts along U. S. 10 on the south and west sides of Amabilis Mountain expose sandstones and a variety of igneous rocks. Basalt dikes intruding these rocks are visible in the road cuts, and blue chalcedony similar to that in the Teanaway basalt is present in the basalts. Thus if the rocks on Amabilis Mountain were better exposed, the relationship between those rocks and the Teanaway basalt could probably be determined there.

To the north, these areas of Naches formation are in intrusive contact with the Snoqualmie granodiorite. North of Mineral Creek, on both sides of Rocky Run Creek, and north of Kendall Peak, the Naches rocks are intruded by the granodiorite. In the Mineral Creek region, this contact is the site of copper mineralization.

The Naches in the vicinity of Snoqualmie Pass, has, for the most part, been hornfelsed by the emplacement of the Snoqualmie granodiorite. The rocks exposed along U. S. 10 on the west side

of Snoqualmie Pass are mostly hornfelsed basalts, in a few of
which the original igneous textures are still visible. On the
east side of the Pass, the indurated Naches forms the rugged
ridges and peaks of Kendall Peak. Smith and Calkins were con-
fused by these rocks that they included in their Guye formation,
for they described several puzzling rocks such as (1906, p. 7),

> "A very peculiar apparently rhyolitic rock is
> found on the southwest shoulder of Kendall Peak.
> It consists mainly of a rather hard, aphanitic
> groundmass, dull coal black in color, which con-
> tains abundant small angular grains and crystals
> of quartz. Its texture and composition studied
> microscopically, indicate that it is tuffaceous.
> Its black color is due partly to an abundance of
> finely divided scaly material resembling green
> biotite and numerous black opaque particles of
> undetermined character.
> "The basalt near Kendall Peak is mostly a
> greenish black, compact aphanitic rock, not very
> readily distinguished from the indurated black
> shale. Its true character was first recognized
> by the finding of amygdaloidal phases, with
> cavities full of quartz, hornblende and other
> secondary minerals. A little indurated tuff was
> also found."

The Naches exposed on the southern side of Kendall, on Rocky Run
Creek, and across the lake on Cold Creek, are far enough removed
from the granodiorite so that they are not hornfelsed.

Age and Correlation

The age of the Naches formation can only be found by compar-
ing its small flora with better dated rocks that bear the same
flora. The only described fossils in this formation are the
leaves in the carbonaceous shales on Gale Creek. Most of the
sedimentary rocks in the Naches formation contain coaly wood
fragments. Poorly preserved leaf fragments were observed in
several localities, but none were suitable for identification.
A collection from the carbonaceous shale near the mouth of Cold

Creek was examined by Dr. R. W. Brown of the National Museum,
who reported only undiagnostic leaf fragments and waterlily root
scars. The Gale Creek flora was examined by Knowlton who re-
ported (in Smith and Calkins, 1906, p. 6),

> "This is a collection consisting of a dozen or
> more pieces of matrix showing numerous impressions.
> I note the following genera: Populus sp, Ficus sp.,
> Pterospermites sp., Ulmus (?) sp.
> I do not recognize any of the species in this
> collection. The genera are sufficiently clear, but
> the species are new and are unlike any heretofore ob-
> tained. The forms are not similar to those found in
> either the Roslyn or the Swauk, but appear to find
> their greatest affinity with material from the west
> side of the Cascades, at Carbonado and vicinity. For
> example, no Eocene species of Populus has heretofore
> been found east of the Cascades, while several forms
> have been found about Carbonado, South Prairie Creek,
> and Franklin. The species of Ulmus is similar to elm
> leaves from vein 12 at Franklin, but I am not certain
> that it is absolutely identical."

This correlation of these rocks on the east side of the Cascades
with the Puget formation at Carbonado and vicinity on the west
side of the Cascades is somewhat strengthened by the relations
of the rocks on both sides of the Cascades. In the area of this
study, the Naches formation is unconformably covered by the
Keechelus volcanic series, and to the west only Keechelus rocks
are exposed until the western front of the range is reached where
the Keechelus rocks give way to the underlying Puget formation.
Lithologically, the Puget is similar to the Naches, but contains
more carbonaceous sediments and fewer volcanics. The nature of
this western contact is in doubt. It has been reported as almost
concordant (Warren et al, 1945), and as interbedded by Fisher
(1954, p. 1340) on the basis of doubtful correlations. The dis-
tance between the two leaf localities is about 38 miles and the
shortest distance between the Puget and Naches formations is about

18 miles. Abbott (1953) also reported Puget rocks in the Mt. Aix quadrangle south of the Snoqualmie quadrangle. Thus the evidence for this correlation is weak, but at least some idea of the relative age of the Naches can be gained from this comparison, for the Puget is considered to be middle or upper Eocene.

A summary of the paleobotanical data of all these formations will show the state of our knowledge. Knowlton thought that the Naches correlated with the Swauk (Smith and Calkins, 1906, p. 5) and that some of the rocks here called Naches formation (along Gale Creek) correlated with the Puget (Smith and Calkins, 1906, p. 6). Beck, in a letter quoted earlier, reported the same leaf in beds here considered Naches and Swauk. The only conclusion that can be reached from these data is that until more study is made of the fossil leaves, the physical relations are the safest way to date these rocks.

The Naches formation is concordantly underlain by the Mt. Catherine rhyolite that unconformably overlies the Guye formation of probably Paleocene or early Eocene age. The Naches formation is unconformably overlain by the Keechelus andesite that yielded an Oligocene mammal in the Mt. Aix quadrangle to the south. Thus the Naches lies unconformably between rocks of Paleocene or Eocene age and Oligocene age, which suggests an Eocene date for the Naches, and so favors correlation with the Puget formation. This dating and correlation should be considered tentative, however, until diagnostic fossils are discovered.

Description

    The Naches formation is approximately 5000 feet thick and is
composed of interbedded basalts, sediments, and rhyolite. In
detail the stratigraphy varies markedly from place to place so
that it is not possible to describe a general section, although
in general, in the area studied the basalts are probably more
prevalent in the lower part of the formation.

Basalt

    The Naches basalt is usually a resistant unit and commonly
outcrops as prominent ridges. Except in a few places it is not
possible to trace the Naches beds any considerable distance. In
the area west of Little Kachess Lake however, apparently con-
tinuous basalt flows can be followed on the ground or on aerial
photographs for several miles. Along the west shore of Little
Kachess Lake, there are almost continuous exposures of both sedi-
mentary and volcanic rocks. At this place the basalt flows are
up to 400 feet thick.

    The Naches basalt is not uniform, and several types of ba-
salt can be distinguished both in the field and under the micro-
scope. Three quarters of these basalts are amygdaloidal or
porphyritic or both. In hand specimen, most are green-gray or
gray, have an aphanitic groundmass, and have prominent milky
white plagioclase phenocrysts and/or white or green amygdules.
These basalts commonly weather to a brown or red brown color,
apparently due to their iron content.

    The porphyritic amygdaloidal rocks are the most common.
Under the microscope, this group of basalts can be further sub-
divided on the basis of texture which apparently depends on the

relative amount of pyroxene and the degree of alteration. The
porphyritic, amygdaloidal basalts with an intergranular ground-
mass will be considered first. These rocks are all distinctly
green in color and have conspicuous dark green and/or white amyg-
dules. The porphyritic nature of most of the rocks is apparent
in hand specimen. In thin section, they are seen to be composed
on the average of 55 per cent labradorite, 20 per cent augite,
20 per cent chlorite, and 5 per cent opaques. The plagioclase
is in the form of microlites and much larger lath shaped pheno-
crysts many of which are fractured. Both types of plagioclase
have about the same composition, An60. The augite has a faint
violet color and occurs as tiny grains. The opaques are for the
most part interstitial, and the chlorite is in part intersti-
tial, and in part fills amygdules. Many of these rocks are
somewhat altered, probably deuterically, and in these rocks much,
if not all, of the pyroxene is altered to chlorite and opaques.
In a few of these altered basalts the plagioclase phenocrysts
are glomeroporphyritic and the individual phenocrysts are com-
monly divergent so that they form what may be termed asterated
basalt. In these altered rocks, there are many amygdules filled
with epidote, calcite, chlorite, and quartz. A few of these
rocks contain the typical basalt alteration minerals such as
iddingsite, but in most cases chlorite is the alteration product.

Not all of the prophyritic, amygdaloidal basalts have an
intergranular texture. In one thin section examined, the pyroxene
is in the form of very small rounded grains that crystalized
earlier than the labradorite. These small pyroxene grains are
included in both the porphyritic and the groundmass plagioclase.

Other sections show an ophitic or a subophitic groundmass texture. The plagioclase appears to have been originally only slightly in excess over the augite; however, these rocks are now composed of about one third chlorite. In some of the ophitic rocks, the groundmass and the porphyritic plagioclase is labradorite, and in others, the phenocrysts are as sodic as oligoclase.

The non-amygdaloidal porphyritic rocks are of two types. The first has a subophitic texture and is similar to the ophitic rocks described above except they are less altered and have no amygdules. The second kind is best described as porphyritic basalt with a pilotaxitic groundmass. These rocks are composed predominantly of plagioclase with some interstitial augite, chlorite, and opaques. Both the groundmass plagioclase and the phenocrysts are calcic labradorite. The augite is generally altered to chlorite.

The non-porphyritic rocks are, in general, quite similar to the porphyritic rocks described above but are less common. They are composed of the same minerals, labradorite, violet augite, chlorite, and opaques. In general, the amygdaloidal rocks are more altered and contain more chlorite and other alteration products. These non-porphyritic rocks can also be subdivided on the basis of texture. Some of these rocks have an ophitic texture and are similar to the rocks described above. These basalts grade into trachytic texture with labradorite laths sub-parallel, and pilotaxitic texture with the plagioclase laths in random orientation. The pyroxene in these rocks is in the form of small interstitial grains. Intermediate between the ophitic basalts and the trachytic basalts, are sub-ophitic rocks

in which the augite crystals are intermediate in size. The al-
teration of these non-porphyritic rocks is similar to the por-
phyritic rocks described above. In general, the amygdaloidal
rocks are more altered. Chlorite is the usual alteration product
and calcite, hematite, and what was tentatively identified as
iddingsite were noted.

The Naches basalts exposed on the Sunset Highway west of
Snoqualmie Pass have been hornfelsed by the Snoqualmie granodio-
rite. In hand specimen, these rocks are porphyritic with a black
to dark gray aphanitic groundmass and large plagioclase laths
that tend to be glomeroporphyritic. The plagioclase laths have
all orientations and are quite large, averaging three-quarters
by three-sixteenths of an inch. Many small inclusions in the
laths are apparent, even to the naked eye. Vesicles about one-
quarter of an inch in diameter and filled with quartz are present
at some localities. In thin section, these rocks are seen to be
composed of fractured labradorite laths altered in part to
sericite, chlorite, epidote, and opaques, in a groundmass of
smaller labradorite laths, chlorite, and actinolite. The actino-
lite is in the form of radiating crystals and veinlets that cut
across the other minerals. In some sections, epidote, calcite,
stilpnomelane, clinozoisite, zoisite, apatite, and garnet are
present in addition to the minerals mentioned above. These rocks
are traversed by the garnet-diopside-quartz veinlets described
by Goodspeed and Coombs (1932, p. 554).

The Naches basalts are much different petrographically from
the Teanaway basalts described earlier. In general, the Naches
basalts are more diverse, are usually porphyritic and/or

Fig. 43   Photomicrograph of Naches basalt. Ophitic texture;
labradorite, white; augite, gray; and chlorite, black.
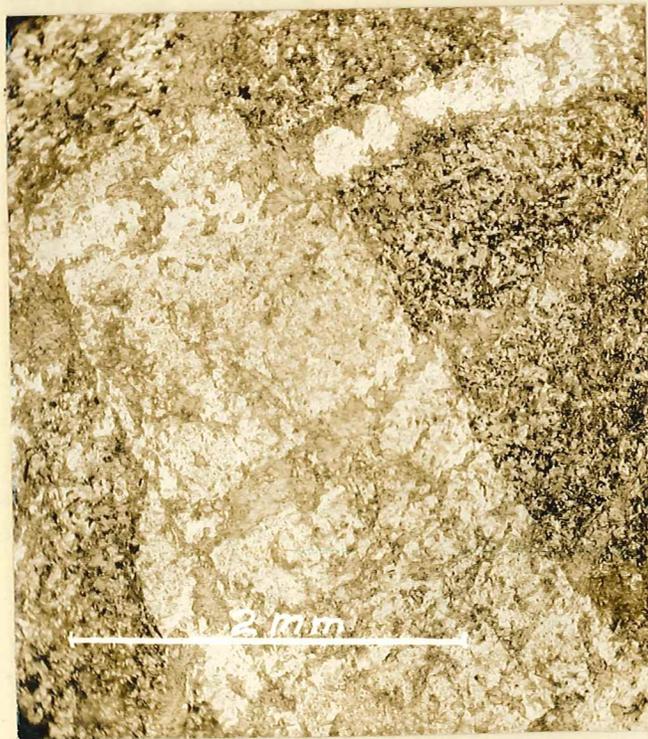Plane light, x 48.

Fig. 44   Photomicrograph of altered Naches basalt exposed on
the Sunset Highway west of Snoqualmie Pass. Labradorite laths
in a matrix of labradorite microlites, actinolite, chlorite,
epidote minerals and opaques. Veinlets are quartz, actinolite,
and epidote minerals.

amygdaloidal, and are more altered than the Teanaway basalts.

In detail, the differences can be summarized under several head-
ings. The texture is one of the more striking differences be-
tween these basalts. The Teanaway usually has an intergranular
or an intersertal texture, and Naches is holocrystalline and is
commonly porphyritic, with either an ophitic or an intergranular
groundmass. Mineralogically, these basalts are also different.
The Teanaway basalt contains both pigeonite and augite, and
either or both may occur in a given rock. The Naches, however,
contains only violet colored augite. The degree of alteration
is also different. The most common alteration product in the
Naches basalts is chlorite. In contrast, the Teanaway basalts
commonly contain mineraloids such as chlorophaeite. In short,
the basalts of these two formations are much different and can
usually be distinguished either in the field or under the
microscope.

Rhyolite

The rhyolites are apparently scattered throughout the Naches
section, and some may be intrusive into the Naches. The contact
relations were visible at only a very few localities so the
amount of intrusive rhyolite included with these rocks must re-
main an open question.

There is a great deal of variation in these rocks. In hand
specimen they are typically aphanitic and light in color, usually
some shade of yellow or buff, however gray, blue-gray or green
colors are not uncommon. The textures are also very diverse.
At many outcrops these rocks are massive, but at other outcrops,
their clastic texture is clearly shown by color differences between

the fragments and the groundmass. At other places this rhyolite is flow-banded. This flow-banding commonly swirls in complex patterns with many abrupt changes of attitude so that little can be learned from study of these features.

In thin section, these rocks show the same diversity, but in many, the original structures are obliterated by later alteration. The fresh rocks contain resorbed quartz phenocrysts and oligoclase phenocrysts that are partially altered to sericite and kaolin. These phenocrysts are in what is apparently a devitrified groundmass. This groundmass is flowbanded, with the banding shown by slight differences in crystal size, slight color changes, and localization of sericite and chlorite. The groundmass is very fine grained and is a dark gray in all orientations between crossed nicols. The outlines of what may have been glass shards occur scattered through this apparently devitrified groundmass. These rocks also contain a few opaque grains and some masses of chlorite and opaques that may be the alteration products of ferromagnesian minerals.

The fragmental textured rhyolites are generally in the lapilli size range, and are composed of lithic fragments, commonly of rhyolite, in a groundmass similar to that just described.

The altered rhyolites are more common. In hand specimen, the more altered of these rocks are commonly chalky. Often tiny spherulites are megascopically visible. In thin section, many of these rocks show simply a plexus of spherulites that cut across and destroy the original textures. These spherulites seem to be formed of radially intergrown quartz and orthoclase, and form a dark cross between crossed nicols. In some rocks,
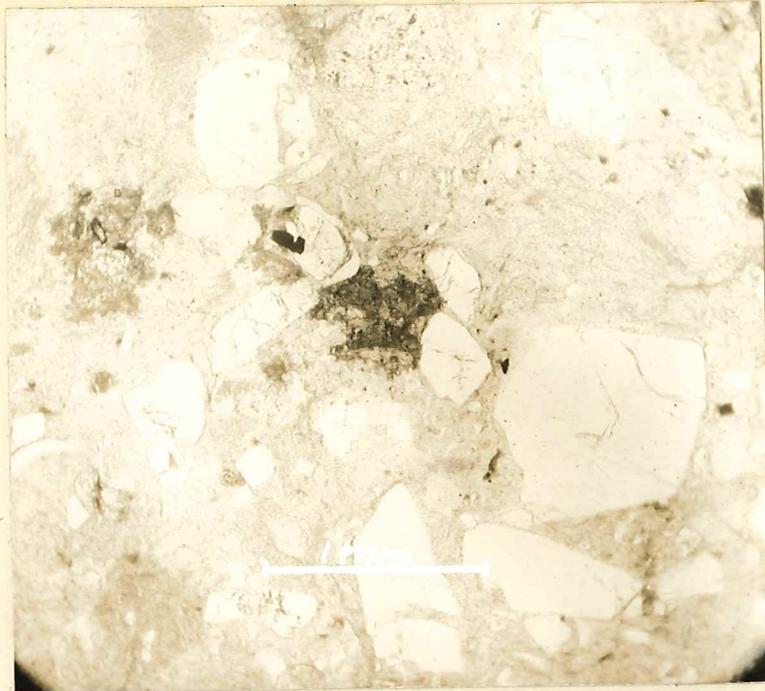
Fig. 45   Photomicrograph of Naches rhyolite from
Kendall Peak. Partially resorbed quartz, clear
oligoclase and altered mafic minerals in a devitri-
fied matrix. Plane light.

Fig. 46   Photomicrograph of Naches arkose. Quartz,
plagioclase, biotite and opaque grains. Plane light,
x 48.

perlitic cracks are also superposed on either the spherulites or the less altered portions of the rock.

These Naches rhyolites are very similar to the Mt. Catherine rhyolite described earlier, but in general, the Naches rhyolite is somewhat more altered than the Mt. Catherine. However, this slight difference is not enough to enable one to distinguish these two rhyolites petrographically.

A few rocks of intermediate composition also occur in the Naches formation. Some of these rocks are similar to the rhyolites, but contain only plagioclase phenocrysts and no quartz phenocrysts. These rocks should probably be classed as dacites, but in this paper they are mapped with the rhyolites. In addition to these rocks, a few andesites were noted. The andesites are for the most part porphyritic and are light green or buff in color. In thin section the composition of the phenocrysts is seen to be sodic andesine. In general, the groundmass of these rocks is somewhat altered. The groundmass of some consists of a felt of andesine microlites together with some chloritic material, and in others, the groundmass is mostly chloritic material.

Pyroclastic Rocks

The Naches formation contains pyroclastic rocks and volcanic derived sediments, as well as lava and normal sedimentary rocks. The poor exposures and the alteration make it very difficult to separate the pyroclastic rocks from the mixed rocks. For these reasons, the criteria used to distinguish between these rock types was presence or absence of clasts of chert, quartz, and other common sedimentary materials, and, where possible, the

degree of bedding. Such distinctions were not always possible in the field, hence, most of these rocks were distinguished in thin section.

The pyroclastic rocks are not very common and are apparently scattered throughout the Naches formation. They are probably of local origin for they are never extensive units, and most occurrences are different lithologically. On the basis of fragment size, the pyroclastic rocks are tuffs and lapilli-tuffs. All of these rocks are composed of lithic fragments.

Some of the tuffs are buff or brown in color and others are dark greenish gray. Most of these rocks are brown or tan in the weathered outcrop. In most, the clastic texture is obvious, especially on the exposed surfaces where weathering has etched out the differences in resistance of the different fragments. In thin section, these tuffs are seen to be made of lithic fragments. Most of these fragments are altered and now consist principally of chlorite, but there are also many fragments of pilotaxitic lava. The groundmass is very fine grained and composed mostly of chloritic material.

The lapilli-tuffs differ from the tuffs just described only in size. However, the larger size of the fragments, up to one and one half inches, makes the different lithologies of the fragments obvious in handspecimen. These larger fragments are dark maroon, dark green, and various shades of dark gray, and are set in a finer grained matrix. There are apparently all gradations between these rocks and the tuffs described above.

Sedimentary Rocks

The sedimentary rocks in the Naches formation are, for the most part, of sandstone size, although both coarser and finer grained rocks are also present. These sandstones, almost without exception, contain a considerable amount of feldspar, and hence fall into the classification of arkose or feldspathic sandstone.

The arkoses are commonly light gray in color, but many contain a considerable amount of carbonaceous material. They usually weather to a medium or dark brown color. Commonly they are massive, thick bedded units, so that facing cannot usually be determined. This fact, together with the heterogeneity of the formation as a whole, made location of the fold axes difficult.

In thin section, these rocks are seen to be composed of twenty to fifty per cent quartz (including a little quartzite and chert), ten to twenty-five per cent plagioclase, about five per cent orthoclase, ten to twenty-five per cent chlorite and biotite altered to chlorite and opaques, up to ten per cent muscovite, five to ten per cent opaques (including iron ores and carbon) and up to five per cent epidote, and a few per cent of any of the following, apatite, calcite, garnet, rutile, sphene, microcline, and granophyre. Much of the plagioclase is albite but some of it is as calcic as andesine. The fragments are equant and angular, and the micas are wrapped around these fragments showing that these rocks have been tightly compressed. Many of these arkoses contain carbonaceous material. In some areas, there are large fragments of woody material now largely

in the form of coal. In other areas, the carbon lies on the bedding planes as a thin film between the sand grains. These rocks grade into the carbonaceous shales described below.

The arkoses grade into the conglomerates as the grain size increases. The conglomerates are granule and pebble conglomerates and commonly have an arkosic groundmass. The larger fragments in these rocks in the order of their importance are quartz, basalt, schist, quartzite, and phyllite. The assemblage in these conglomerates suggests that there was more than one source area. The basalt fragments appear to be of local origin, perhaps from the Naches basalt. The arkosic matrix and the quartz probably came from a granitic or metamorphic terrain. The schist and phyllite fragments may have come from the Easton schist, which underlies the Naches formation south of the present area. The albite that forms a large part of the plagioclase content may also have come from this greenschist.

One special type of conglomerate is shown in Figure 42. This rock is composed of an arkose matrix with fragments up to cobble size of fine grained carbonaceous sandstone.

Another type of conglomerate was noted about three-quarters of a mile from the mouth of Thetis Creek. It is composed of boulders of serpentine in a matrix of the same material.

With decreasing grain size, the arkoses grade into siltstone and mudstone. Commonly as the grain size decreases, the amount of carbonaceous material increases. Hence most of these rocks are dark gray or black. At many places, especially on Gale and Thetis Creeks, there are extensive exposures of these shales, some of which contain the leaf fossils mentioned above. The very fine

sandstones are characterized by a dark gray color due to the high
carbon content, and commonly the bedding planes of the thin
bedded rocks are marked by abundant detrital mica.

The Naches sediments are in many respects similar to the
Swauk and the Roslyn formations; however, they are different in
some ways. The Naches arkoses can usually be identified by their
relatively large amounts of heavy minerals such as the epidote
that is ubiquitous. The Naches arkoses are not so well sorted
as the Swauk and Roslyn, and contain a higher percentage of matrix
material such as chlorite. The larger quantity of lithic frag-
ments in these rocks also shows that, in general, the Naches
sediments are less mature than the Swauk and the Roslyn.

Volcanic Sediments

The volcanic derived sediments consist of a mixture of the
sedimentary rocks just described with fragments of volcanic
rocks. Some of the rocks here called volcanic sediments proba-
bly were the result of pyroclastic debris mixing and interfering
with normal sedimentary processes, and others are simply the
result of normal sedimentary processes acting on a volcanic
terrain. It was not possible to differentiate between these two
types of rocks so they are necessarily grouped together.

The volcanic sediments are a varied group of rocks. They
constitute only a relatively small part of the Naches formation.
These rocks are commonly fine grained, and their color varies
from greenish brown to medium greenish gray. They are typically
exposed along the west side of Little Kachess Lake. The greenish
brown rocks are in the silt and shale size range, and the darker
colored rocks are commonly in the medium or fine sandstone size

range. Some of these rocks are well bedded, but more commonly they are massive. Under the microscope, they are seen to be composed primarily of fragments of basalt mixed with angular fragments of quartz and plagioclase in a chloritic matrix. Commonly these rocks are very poorly sorted and many of them are traversed by small calcite veinlets. The volcanic fragments are usually altered, at least in part, to chlorite.

The Naches formation is composed of a variety of rock types, but this variety itself gives the Naches a distinctive aspect. It is not possible to describe a general section of this unit; however, the rocks described above show the general nature of the Naches formation.

KEECHELUS ANDESITE

Previous Work

The Keechelus formation was named by Smith and Calkins (1906, p. 8). They designated no type section but most of the later workers, although usually unstated, have considered the east shore of Lake Keechelus as the type (c.f. Goodspeed and Coombs, 1957, p. 12). The Keechelus is a thick, very widespread unit composed of andesitic flows, tuffs, and breccias that is known to extend for at least 50 miles south of this area. It has an extremely variable lithology, is commonly altered, and contains no fossils; hence it is no wonder that study of this complex unit by several people working in different areas has resulted in divergent opinions regarding its origin and unity. The problem was first noted by Smith and Calkins (1906, p. 8) who suggested the possibility of an unconformity in this formation saying,

"The lower part of the series, comprising by far its greater portion, consists of a succession of volcanic rocks that show considerable alteration. The Keechelus rocks of the northern part of the quadrangle and most of those exposed in the southern part are of this character. In the basins of Greenwater and Naches rivers, however, there are some fresh lavas and tuffs, which are lithologically distinct from the more widely distributed decomposed rocks. ...

"The discrimination of the younger lavas, based primarily on lithologic grounds, is supported also by structural and topographic data and one bit of doubtful stratigraphic evidence. ...

"Lithologically, some of the lava in the Naches and Greenwater basins appears as fresh as any that might be collected from the slopes of the recently extinct volcanoes of the Cascade Range, and in the vicinity of Arch Rock there are great volumes of yellow fresh-looking tuff. The difference in alteration between the older and the younger lavas is made still more evident by microscopic study.

"As regards structure, the older portion has been somewhat tilted and gently folded, ... while the younger rocks display only such gentle dips as might be considered the initial slope of the lava flows.

"The topographic evidence is clear in the area about Naches Pass and ... may also be made out by inspection of the map. The summit of the ridge here is broad and flat, in contrast with the rugged topography to the north, and has every appearance of being near the original surface of the flow and but slightly modified by erosion. The lava forming this ridge appears to have been poured out after the extensive erosion which the Cascade Mountains suffered in Pliocene time. At other localities, however, lava showing a plateau-like upper surface is believed for other reasons to belong to the older portion of the series. The only stratigraphic evidence available is afforded by a locality on the ridge north of Crow Creek, where a little andesite apparently overlies the Ellensberg sandstone, but the contact is not well enough exposed to prove this relation."

From this they concluded,

"The conditions above described convinced the authors that the area mapped as Keechelus comprises lavas of two distinct ages."

and,

"In short, the criteria, while sufficient to establish the presence of two distinct groups of these volcanics, fail, except locally, to serve as a basis for the determination of boundaries between them."

and in some,

> "... areas certain phases of the two are so similar
> that they cannot be discriminated with certainty, and
> the endeavor to map them separately was therefore
> abandoned."

Careful reading of these passages indicates that Smith and
Calkins recognized that they were including locally in the
Greenwater and Naches River basins, some apparently younger an-
desites with their Keechelus. Younger andesites are common in
the Cascades and Smith and Calkins suggested that this was the
case, saying,

> "Lower in the Naches Valley, in the Ellensberg
> quadrangle, late andesitic lavas occur and have been
> mapped, since there they are in contact with basalt
> rather than with lava of similar composition."

Since Smith and Calkins dated the Keechelus as Miocene, it was
not unreasonable that this minimized to them the error of group-
ing the several andesites in one unit. They noted,

> "... there was little interruption of volcanic activity,
> so that the necessary grouping together of the late
> Miocene and subsequent lavas is not wholly unnatural."

From this admission of having included some apparently later
andesites in the Keechelus, a large volume of literature and the
concept of an upper and a lower Keechelus has grown. The problem
is complex, however, for we shall see that there are andesites of
many ages both pre and post the Keechelus (of Smith and Calkins)
that are difficult to distinguish from the Keechelus, especially
in view of the lithic similarity and the lack of marker beds and
fossils.

After Smith and Calkins' work, the name Keechelus was carried
north by W. S. Smith (1915), west by Fuller (1925, p. 56), and
south by Coombs (1934, p. 336). These extensions were made for

the most part on lithic similarity. The next discussion of age
of rocks called Keechelus was by Coombs (1936, pp. 165-6). He
described relations near Mt. Rainier similar to those described
earlier by Smith and Calkins, adding (p. 150) the observation
that near the intrusion of Snoqualmie granodiorite, the Keeche-
lus changes from extreme variability to homogeneity, and sug-
gested (pp. 166-7) that the age of these rocks was still an open
question.

The same year W. C. Warren (1936, pp. 242-7), working in
the Mt. Aix quadrangle, suggested an upper and a lower Keechelus.
In 1941, Warren, after further field work, separated the two,
naming the upper Keechelus the Fifes Peak andesite. He also
corrected Smith and Calkins' misinterpretation of the relation
of the Keechelus (and Fifes Peak) to the Yakima basalt, showing
that both are unconformably below the Yakima (pp. 799-804).

Abbott in 1953 (p. 44), remapped part of Warren's area in
the Mt. Aix quadrangle, reiterating Warren's breakdown, but
changing the location of the contact between the (lower) Keeche-
lus and the Fifes Peak. The next contribution to the problem
came from Laval in 1955 (pp. 118-120), who questioned the exis-
tence of the Fifes Peak andesite. Laval compared the petrogra-
phic character of the Yakima basalt in the central Columbia
Basin with the rocks described by Abbott, and suggested that the
Fifes Peak might be part of the Yakima basalt.

A similar series of studies along the west side of the
Cascades showed other inconsistancies. Coombs (1934, p. 336)
reported the Keechelus to be unconformable over the Puget forma-
tion near Mt. Rainier. In 1945, Warren reported a concordant

contact between these two units in an area north of Mt. Rainier. Fisher in 1954 (p. 1340), working south of Mt. Rainier, observed andesites he called Keechelus to be intercalated with the Puget sediments.

The dating of the Keechelus has changed several times as a result of this work, and a summary is in order. Smith and Calkins thought it was Miocene because they believed it to be between Guye and Yakima, both of which they dated as Miocene. Warren showed that the Keechelus is pre-Yakima. The Guye is now believed to be Eocene (see above). In 1941, Grant (p. 590) reported an oreodont in the Keechelus in the Mt. Aix quadrangle, thus suggesting an Oligocene age for the Keechelus. The age of the lower limit, however, has been opened by Fisher's reported interbedding of Keechelus and Puget, and similar reports of interbedded Swauk in areas in the Cascades by Galster (1955, p. 54) and Pratt (1954, p. 42). Recent mapping in this part of the Cascades, however, has failed to substantiate this reported interbedding (Ross Ellis, personal communication).

In addition to the stratigraphic studies summarized above, petrographic studies of the Keechelus were also conducted. The alteration of these rocks has been repeatedly referred to, and has attracted much attention. The true nature of some of the rocks mapped as Keechelus was first pointed out by Goodspeed and Coombs in 1937 who reported (p. 12),

> "A detailed study of new exposures of these breccias
> at the 'type locality' along the eastern shore of Lake
> Keechelus has led the writers to question the validity
> of the original explanation of pyroclastic origin.
> They offer instead the interpretation of recrystalliza-
> tion replacement to be applied to certain of these
> breccias. By this mechanism it is believed that a

> sandy shale has been gradually changed into an igneous-
> appearing rock as a process of additive hydrothermal
> metamorphism."

In 1941, Goodspeed, Fuller, and Coombs presented another more

spectacular example of this process. (p. 190)

> "At a number of localities in western Washington
> dacitic and rhyolitic rocks show gradational contacts
> with sedimentary rocks and are associated with replace-
> ment breccias."

and (p. 191),

> "Later work has added to our knowledge of the
> Keechelus andesitic series in the Snoqualmie region.
> It is known that it covers thousands of square miles
> in the Cascades of Washington... Recent petrologic
> work in limited areas of the lower Keechelus warrants,
> in the opinion of the writers, the suggestions that
> some of the breccias, seemingly igneous, have resulted
> from the metamorphism of sedimentary rock. Numerous
> feldspar crystals in the sedimentary rock are definitely
> porphyroblasts. The concentrated development of these
> crystals along fractures and in scattered patches pro-
> duced a rock which has been termed a replacement
> breccia."

Thus we see that the Keechelus is a many sided problem.

One of the problems is how to distinguish the andesites of

several ages that are doubtlessly included in the Keechelus in

some places. One phase of this problem is to decide if the sub-

division of (Lower) Keechelus and Fifes Peak is valid; another,

suggested by Smith and Calkins is whether younger andesites are

locally included; and the third possibility is that pre (Lower)

Keechelus andesites, such as the Silver Pass, may be included in

the unit. If we admit Fisher's correlation showing Keechelus

interbedded with Puget formation, then another series of ques-

tions is raised including the age of the lower beds in the forma-

tion. Finally, the petrographic studies indicate that much of

what is called Keechelus may be altered country rock.

It seems likely that the volcanic rocks in a unit such as the Keechelus probably had more than one source, especially in view of the large area covered by this formation. If this is true, then it is probable that when the lavas from one center of eruption came in contact with the lavas from another source, their initial dips would be much different. If this occurred, then these relations could be mistaken for an unconformity. Discordant relations, apparently of this sort, have been described by Rouse (1937, p. 1259) in the Absaroka andesites that are lithologically quite similar to the Keechelus. Thus, some of the reported unconformities in the Keechelus may only be places where lavas from different centers of eruption met. Much detailed mapping over a broad area will be necessary before this hypothesis can be evaluated.

The literature has been reviewed only to place the present study in proper context. The area mapped in this study is usually considered the type area, and the relation of the rocks in this area to some of the rocks discussed by the other workers is not known and is not likely to be known for some years; however, some suggestions will be made in the hope of clarifying some of the problems.

Occurrence and Relations

The Keechelus andesites, as used by the writer, occur in three places in the western part of the area mapped. The largest of these areas is Rampart Ridge, which is between Gold Creek and Little Kachess Lake, and the others are in the vicinity of Silver Peak and a small area on the summit ridge of Denny Mountain. At all of these localities, the Keechelus lies with a pronounced unconformity on the older rocks, and the only younger rock in

Fig. 47   Looking north at east dipping Keechelus
rocks at the west end of Box Ridge.

contact with it is the intrusive Snoqualmie granodiorite. The
Denny Mountain occurrence is correlated with the larger area on
the basis of lithic similarity and unconformable relation with
the older rocks, and this correlation is open to the same doubt
as the correlations discussed in the <u>Previous Work</u>. The Silver
Peak occurrence has the same relation to the older rocks as the
Rampart Ridge area and is essentially continuous with it.

The largest area of Keechelus is the most interesting, as
it seems to contain rocks of different origins. In the area
from Rampart Ridge eastward, the Keechelus andesites are distinctly
bedded and their open synclinal structure was mapped. The rocks
are somewhat altered here, and the bedding is much more distinct
on the west face of Rampart Ridge than near the eastern contact.
The stratification of the rocks on Rampart Ridge is easily seen
from U. S. 10. The Keechelus here unconformably overlies the
Naches formation, and the contact can be observed on Box Creek,
the ridges between Box Creek and Gale Creek, and on Box Ridge.
The rocks shown as Keechelus on the east shore of Lake Keechelus
are much different. These rocks show no bedding and are homo-
geneous over large areas. It was at this locality that Good-
speed and Coombs (1937, pp. 21-3) discovered the replacement
breccias mentioned earlier. These rocks then are probably hydro-
thermally altered sediments, perhaps the Naches formation which
seems to be the country rock here. The petrography of these
rocks will be discussed on a later page.

At the Denny Mountain locality, the Keechelus is an andesite
breccia with fragments up to several inches in diameter. This
breccia is massive and it is difficult to measure an attitude,

but the andesite appears to overlie Guye sediments unconformably. The contact between these two formations is covered by talus from the cliffs of Keechelus andesite which form the sides of the summit ridge. On the south and west, the Snoqualmie granodiorite is in intrusive contact with the Keechelus.

The Keechelus rocks near Silver Peak are quite similar to those on Rampart Ridge. Tinkham Peak viewed from the north looks much like the west face of Rampart Ridge. The Keechelus rocks here dip gently to the south and unconformably overlie the Naches formation.

Type Area

The necessity for a new type area may be questioned, because, although most workers since Smith and Calkins considered Lake Keechelus as the type area, it is not clear whether Smith and Calkins meant this to be the type. They described the Keechelus at many localities and at one place stated (1906, p. 8),

> "The two divisions in their typical development, the younger as illustrated by the tuffs of Arch Rock and the lavas just south of Naches Pass, and the older as illustrated by the lava of Pyramid Peak and the tuffs along the ridge to the north could hardly be confused."

This last statement could be considered as designating a type area, but since the area is remote and no one has used it as a type, it is probably best to define a new type more in keeping with the present usage of the name.

The first step in the solution of the Keechelus problem is the designation of a type area. This should be followed by finding the relationship of the Keechelus of the various workers to this type area. As noted above, what is usually considered the type area for the Keechelus, along the east shore of Lake

Fig. 48   The west face of Rampart Ridge viewed from
Gold Creek valley.   The escarpment is formed by east
dipping Keechelus rocks.   These exposures are part of
the type area proposed here for the Keechelus.

Fig. 49   Looking north along Rampart Ridge.   Alta
Mountain is the middle ground on the right.   The ex-
posures near the lakes in the foreground are part of
the type area proposed here for the Keechelus.

Fig. 50   A low angle fault exposed in a road cut
on the east short of Lake Keechelus. This locality
is near the contact between the replacement breccias
and the Naches formation.

Keechelus, is metamorphosed. Therefore, it is proposed that the type area be moved from the shore of Lake Keechelus to Rampart Ridge, where the Keechelus formation consists of a thick sequence of bedded andesites.

The type area proposed here is on the west face of Rampart Ridge at the latitude of Rachel Lake which drains into the south branch of Box Creek. In this area, a minimum of 3500 feet of section is well exposed, both on the west facing cliffs, and on the top of the ridge that is here above the timberline. These rocks are bedded, and their structure can be mapped, but no general section can be described because the alteration of these rocks is such that their aspect changes markedly along the strike of a given bed. These rocks will be described in more detail below. As noted above, these rocks overlie the Naches formation unconformably and are intruded by the Snoqualmie granodiorite both north and south of this type area. The rocks of this new type section can probably be correlated with the similar rocks far to the south. The rocks of the old type at Lake Keechelus could not be traced any great distance.

Age

In the area mapped, the Keechelus is unconformably above the Guye formation of probable Paleocene or Eocene age and the Naches formation of probable Eocene age. Thus in this area, its base may be of Eocene age, but the accuracy of dating the Guye and Naches formations is, as noted above, questionable. No younger rocks are in stratigraphic contact with the Keechelus here, but it is intruded by the Snoqualmie granodiorite. The Keechelus, however, is the youngest rock intruded by the

Snoqualmie, so it cannot be used to date the Keechelus.

Leaving the present area, we can gain more insight into the age of the Keechelus, but as noted repeatedly, the relation of other rocks called Keechelus to the Keechelus of this study is not known. The age of the Keechelus was necessarily discussed under previous work and will only be summarized here. On the basis of the oreodont found by Grant in the Mt. Aix quadrangle, the age of the Keechelus is usually considered to be Oligocene. This age is in accord with the findings of the present study. Pratt (1955, p. 42) reported the Keechelus interbedded with the Swauk formation of probable Paleocene age, and Fisher (1954, p. 1340) reported it intercalated with the Puget formation of Eocene age. These relations do not agree with the present study, and their work was discussed above. In the Mt. Aix quadrangle, Warren and Abbott report the Keechelus unconformably below both the Fifes Peak and the Yakima basalt. The Yakima is Mio-Pliocene in age (Waters, 1955a, p. 664), which is also in accord with an Oligocene age for the Keechelus. In a recent paper, Waters (1955b, p. 710) summarized the relations of the volcanic rocks of the Cascades. Although he included all the andesitic rocks in his Keechelus formation so that it overlaps in time the Eocene and the Miocene, his observations indicate an Oligocene age for the Keechelus. In dating the Keechelus rocks he says,

> "A little andesitic debris appears in the Cowlitz formation (Upper Eocene); the marine Oligocene and Miocene formations of western Washington and Oregon are flooded with it."

However, lumping all the andesites as Keechelus, in spite of un-conformities, as Waters has done, will not help us to understand the structural and stratigraphic problems. Thus, all the evidence

presently at hand indicates Oligocene as the probable age of the Keechelus formation.

Description

The petrographic descriptions of the Keechelus rocks will be discussed in two parts. The first group of rocks is composed of about equal amounts of lava and pyroclastic rocks, and the second group is the replacement breccias of metasomatic origin that crop out along the eastern shore of Lake Keechelus.

Lavas

The lavas, for the most part, are from Rampart Ridge and the area east of there. These rocks are all somewhat altered and so far as they can be determined, consist of basalt and andesite with a few rhyolitic rocks. The distinction between basalt and andesite is very difficult in these rocks. Most of these rocks are distinctly lighter in color than most basalts. In the absence of chemical analyses on which to base the classification, average, modal plagioclase composition is the only usable criterion. However, even this is difficult to determine in practice, because of the differences in composition between the microlites and the phenocrysts, and because zoning is common in all the plagioclase crystals. Also, the plagioclase phenocrysts in andesites are commonly more calcic than the phenocrysts in a basalt. Apparently, many of these rocks lie on the border between basalt and andesite and could be called either or basaltic andesite. Such arbitrary classification is not warranted, especially in view of the fact that the plagioclases were determined with low temperature curves, and in many of these rocks, the feldspars are altered so that their original composition could

not be ascertained. For these reasons, these rocks will be con-
sidered as a single group and will be called andesites for
convenience.

In hand specimen, these andesites range in color from light
to dark green although a few are dark gray. Most of these rocks
have milky white plagioclase phenocrysts and many have in addi-
tion dark green chlorite-filled amygdules or more rarely white
amygdules. Most of these rocks weather to a medium brown or red-
brown color but a few of them above timberline have a thin light
green to almost white weathering rind. As shown in Fig. 48, they
are thick bedded to massive rocks. Individual beds or flows can-
not be followed for any great distance because of changes in
lithology and degree of alteration.

In thin section the alteration of these rocks is very evi-
dent. The texture is porphyritic, commonly amygdaloidal, with a
pilotaxitic groundmass. In general, these rocks are composed of
plagioclase phenocrysts; augite phenocrysts; pseudomorphs of
chlorite, epidote, antigorite; and other alteration products
after ferromagnesian minerals. These crystals are set in a
groundmass of plagioclase microlites, opaque grains, pyroxene
grains in a few rocks, the alteration products mentioned above,
and glass or cryptocrystalline material.

The plagioclase phenocrysts have a composition ranging from
oligoclase An 24 to bytownite An 73; however, in most of these
rocks, the composition is either labradorite or sodic andesine.
The more sodic plagioclases tend to be commoner in the more al-
tered rocks. Many of these plagioclase phenocrysts show mild
gradational zoning that is usually progressive, but oscillatory

The groundmass of these rocks has a trachytic or more commonly a pilotaxitic texture. The plagioclase microlites in most of these rocks are oligoclase, but some are as calcic as labradorite. They are commonly cloudy with tiny inclusions of kaolin, sericite and chlorite. The only other minerals that can be distinguished in the groundmass are the iron ores, chlorite and, in a few rocks, pyroxene, epidote and irregular patches of calcite. In some rocks, there is a little cryptocrystalline material that is commonly altered to chlorite or indeterminate mineraloids.

The amygdules in most cases are filled with chlorite, often pennine with radial extinction. Others are filled with quartz and more rarely with chalcedony.

The rhyolites are much less common than the andesites and occur as thin flows throughout the Keechelus. They range in color from almost white to a very light purple. They commonly weather to a red-brown color. These acidic rocks in most cases are aphanitic and some are flow-banded. On Rampart Ridge south of Alta Mountain, there are exposures of an almost white aphanitic rhyolite that contains tiny disseminated grains of pyrite. The ridge between the north fork of Gale Creek and Box Creek (just south of the second E of Wenatchee) is partly composed of flow-banded rhyolite. The flow-banding is emphasized by fine grained light purple layers. In thin section, this rock is cryptocrystalline and is apparently devitrified. The only minerals that can be determined are turbid plagioclase, apparently oligoclase, and orthoclase.

Smith and Calkins described pyroxene diorite in the Keechelus volcanics. They mapped several occurrences of these rocks and
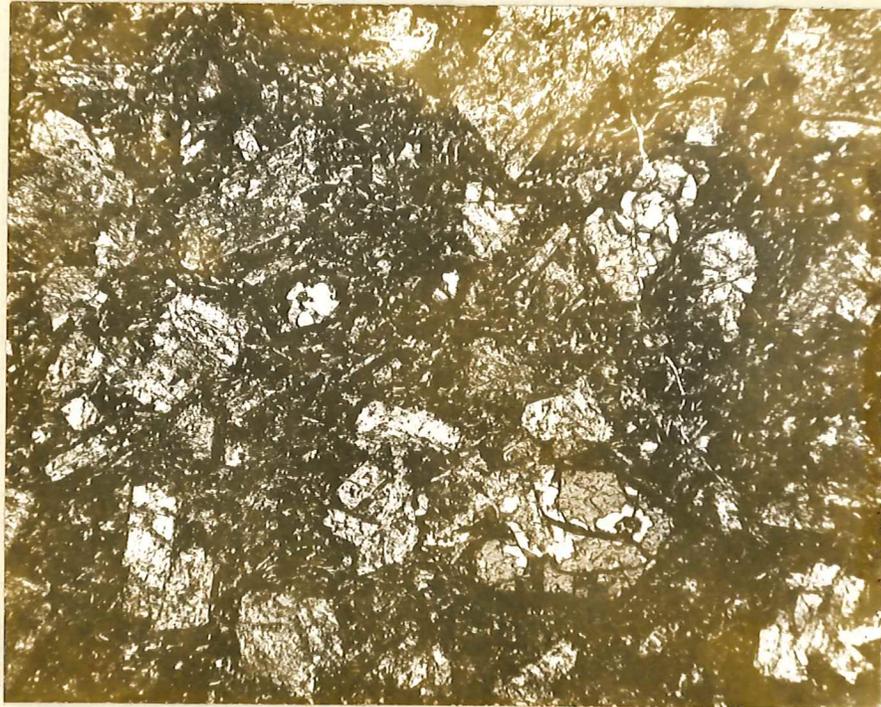
Fig. 51   Photomicrograph of Keechelus andesite.
The plagioclase phenocrysts are altered and in the
lower left hand part of the field there is a sub-
hedral pseudomorph of antigorite and chlorophaeite
after olivine. The groundmass is pilotaxitic.
Plane light x 48.

suggested on inconclusive field and petrographic evidence that
these occurrences represent the roots of the Keechelus volcanoes.
One of these occurrences is Silver Peak, which is in the area of
the present study. At Silver Peak the relations are not clear,
but if it is an old Keechelus volcano one might expect the Keeche-
lus volcanics to dip away from it. No relations of this sort
were observed in the field, but the intrusion of the nearby grano-
diorite and later folding may mask the original relations.

The rock on Silver Peak is a drab green, medium grained
phanerite in which only plagioclase and a green prismatic mineral
can be seen with the handlens. In thin section this rock is seen
to be considerably altered. It is composed of turbid oligoclase,
a little quartz, biotite in part altered to chlorite and iron
ores, with hornblende, epidote and chlorite as alteration pro-
ducts after the original pyroxene.

Pyroclastic Rocks

The pyroclastic rocks are about equal in quantity to the
lavas and are interbedded with them. In general, the alteration
of these pyroclastics is more intense than in the lavas. Without
exception, these rocks are tightly cemented to form compact, dense
rocks. They are light in color, commonly some shade of green and
a few are light purple or blue-gray. Most are lithic tuffs or
lapilli-tuffs and there are a few breccias. They commonly weather
to some shade of green or less commonly to brown or red-brown.
The texture of these rocks is well displayed in many outcrops
where weathering has etched out the differences in resistance be-
tween the fragments and the groundmass.

In thin section, these pyroclastics are seen to be composed of fragments of altered volcanic rocks in a groundmass composed principally of quartz and chloritic material that is commonly too finegrained to determine any closer. The lithic fragments in general are similar to the lavas described above, but are more altered. The plagioclase laths in the fragments are commonly turbid with inclusions of sericite, kaolin, and chlorite, and in some cases are not determinable. The rest of these fragments are composed of chlorite, epidote, and iron ores. Amygdules or amygdule-like structures are common in these pyroclastic rocks and are usually filled with radial growths of chlorite.

Because of the alteration of these rocks, it is not easy to distinguish between pyroclastic rocks and volcanic sediments. In a few of these clastic rocks, some fragments of quartz and feldspar were noted. These rocks may be volcanic sediments and it seems likely that a volcanic assemblage like the Keechelus would contain such rocks. Thin graded bedding is present in a few of the tuffaceous rocks and may represent sorting by water.

Replacement Breccias

The Keechelus replacement breccias crop out along the eastern shore of Lake Keechelus where U. S. 10 was built by blasting a notch in the bedrock. These roadcuts are virtually the only exposures in the vicinity so it was not possible to find the relationship between the replacement breccias and the Keechelus volcanics or the Naches formation which are the only other rocks in the vicinity. It may be possible to learn more about these relations because at the time of writing, preparations are underway to carve a four lane highway through these rocks. In the

timbered western part of the area, road cuts provide most of the exposures, and during the four year duration of the present study, many new road cuts and logging roads were made that provided much needed information. It appears that future construction will provide exposures that will solve many more of the puzzling details.

The replacement breccias are exposed from just southeast of Wolfe Creek to nearly the end of the lake. At Wolfe Creek, the Naches formation is exposed. This is the best exposed contact of the replacement breccias, but even here the relations are obscure and, unless the new road cuts provide more information, the nature of this contact will remain unknown. The contact could be gradational or it could be a fault. Faulting seems to be the most likely explanation at this place, because a small fault is exposed in the road cuts near here, see Fig. 50.

These replacement breccias have been described by Goodspeed and Coombs and only need to be discussed in a general way here. Several megascopically different rocks are present but all show the same microscopic features. Most of these rocks have a groundmass of some shade of green and contain fragments usually darker green in color. The most common rock has a gray-green matrix with many small milky white crystals of plagioclase and contains irregular dark purple-gray fragments. In favorable exposures, the relationship between the matrix and the fragments is seen to be very irregular and best described as lacy. This is the rock described by Goodspeed and Coombs. At other places, these rocks are light gray or light greenish-gray and are quartz bearing. A few of these rocks are altered so that the feldspars are somewhat chalky, and these rocks are stained with limonite.

The metasomatic, rather than pyroclastic, nature of these
rocks was first recognized by Goodspeed and Coombs in 1937. They
observed that the plagioclase crystals in the matrix, some of which
resemble microlites, contain many inclusions of the matrix material
and are porphyroblasts. Further there is a gradation between the
dacite-like matrix and the "fragments" that are clearly sedimen-
tary rock. The petrographic features, together with the irregu-
lar lacy contacts between matrix and the fragments with no trace
of a chilled border, suggested that these rocks were formed by a
process of recrystalization replacement and they called the rocks
replacement breccias. Chemical analyses showed that in the
matrix, silica and potash were added, and iron, magnesium and
calcium all decreased.

Thus, there are two kinds of rock that have been called
Keechelus in this area. One of these is the true Keechelus, a
volcanic formation composed of lavas and pyroclastics that have
been somewhat altered. The second is a replacement breccia
formed by the metamorphism of a sedimentary rock. Stratigraphi-
cally, these two lithologies are unrelated. They may be related
in that the metamorphism of these two lithologies may have had
the same source.

Why many of the rocks in the western part of the Central
Cascades have undergone this low temperature, apparently hydro-
thermal, alteration is not known. These altered rocks are, how-
ever, common throughout the western part of the Central Cascades.
Goodspeed, Fuller and Coombs (1941) described a dacite formed
by metasomatism of a sediment southeast of Mt. Rainier, and
there are alunite deposits and hydrothermally altered rhyolites

along the western front of the Central Cascades (Warren et al, 1945). Goodspeed and Coombs suggested that the Snoqualmie granodiorite may have been the source of the emanations that made the replacement breccias at Lake Keechelus; however, in other parts of the Central Cascades, these effects occur near as well as some distance away from the outcrops of the granodiorite. Coombs (1936) described the metamorphic effects of the Snoqualmie intrusion on the Keechelus volcanics near Mt. Rainier. These effects consisted, in part at least, of a homogenization of the rocks not unlike the changes that took place at Lake Keechelus. Detailed study of the Keechelus volcanics on a regional scale will probably be necessary before the cause of this low temperature hydrothermal metamorphism is ascertained.

Summary

The use of the term Keechelus as a stratigraphic unit has been one of the most discussed problems in the Tertiary geology of the Central Cascades. The situation is as follows:

1. Smith and Calkins noted that locally in the vicinity of Naches Pass they were forced to include some other andesites in their Keechelus series.

2. Warren, and later Abbott, working in the Mt. Aix quadrangle, developed the concept of an upper and a lower Keechelus. Warren named the upper unit the Fifes Peak andesite and both agreed that it is unconformably below the Yakima basalt. This unconformity however is of the order of a few degrees and Laval has questioned its existence.

3. The present author has also found two units in the
    Keechelus formation but his subdivision is much dif-
    ferent from those in 1 and 2. The two Keechelus units
    in this study are the Keechelus proper, a stratigraphic
    unit composed of lavas and pyroclastics, and a meta-
    morphic, pseudo-volcanic unit first recognized by
    Goodspeed and Coombs.

The principal point to be made is that these three break-
downs of the Keechelus are much different and each must be
evaluated separately. Smith and Calkins stated their case very
carefully and suggested that the rocks near Naches Pass which
they included in the Keechelus might be Tieton andesite, a late
valley fill andesite that occurs several miles down the Naches
valley, or some similar late volcanic. In the absence of more
recent mapping, the present author can only agree that their
explanation may be correct, and to further suggest that the
seeming unconformity mapped by Smith and Calkins near Naches
Pass may be due to different initial dips as a result of the
meeting of lavas from different source areas.

The subdivision into (lower) Keechelus and Fifes Peak is a
totally different matter. Its validity may be questioned for
two reasons that can only be evaluated by further mapping. The
first of these reasons is the difference in where Warren and
Abbott, the two advocates of this subdivision, place the contact
between the Keechelus and the Fifes Peak. The reader is invited
to examine their papers and to evaluate their evidence for the
contact and the resulting discrepancy. Second is Laval's sugges-
tion, based on structural and petrographic grounds, that the

Fifes Peak may be the lower flows of the Yakima basalt and there-
fore in no way related to the Keechelus.

In the present study two units called Keechelus were mapped
at the so-called type area. A new type area has been suggested
in this paper for the volcanic Keechelus in the hope that further
mapping tied into this type may eventually bring about a solution
to the Keechelus problem.

SNOQUALMIE GRANODIORITE

Previous Work

The Snoqualmie granodiorite was first described by Smith
and Mendenhall in 1900 who recognized its Tertiary age. It was
named by Smith and Calkins in 1906 (p. 9) who wrote,

> "Some genetically related masses of granular igneous
> rocks belonging for the most part to the granodiorite
> type, but including more acid as well as more basic
> modifications, are exposed in the northern part of
> the quadrangle, mostly about the headwaters of Sno-
> qualmie River, whose name is therefore adopted for
> the formation."

Similar Tertiary granitic rocks occupying several hundred square
miles have been described by other workers to the north and west
of this area. The reader is referred to Galster (1956, pp. 75-6)
for references. To the south, there are several disconnected
areas of Tertiary granitic rocks in the Rainier and Mt. Aix
quadrangles. These rocks have been called Snoqualmie by Coombs
(1956, p. 167), Warren (1941, p. 797) and Abbott (1953, p. 185).

Occurrence and Relations

In the present area, the Snoqualmie granodiorite occurs,
for the most part, in the region around Snoqualmie Pass, although
a small outcrop of a somewhat similar rock was mapped just south
of Howson Creek. In this study of the Tertiary stratigraphy, the

contact with the granodiorite was used as a map limit. The
Snoqualmie granodiorite is intrusive into the Sunset, Guye,
Naches and Keechelus formations. In general, the Snoqualmie
granodiorite is a resistant rock, and it is carved into high
peaks and ridges such as Granite Mountain, Denny Mountain, and
Snoqualmie Mountain.

The contact between the Snoqualmie granodiorite and the
country rock is exposed in several places. Along U. S. 10 and
in the Snoqualmie River just west of Snoqualmie Pass, the grano-
diorite can be seen intruding the Naches formation that has been
hornfelsed, apparently by the granodiorite. The hornfels zone
is apparently only a local effect of the intrusion, for it dis-
appears a few hundred feet away from the contact. On the west
side of Denny Mountain, similar relations are exposed, but here
the granodiorite intrudes the limestones of the Sunset formation.
At this locality, the intrusion has marmorized the limestone and
is apparently the cause of small but spectacular mineralization
in the form of magnetite pods, massive garnet lenses, and specu-
lar hematite. This mineralization is repeated on the west side
of Snoqualmie Mountain. In the area between Red Mountain and
Gold Creek, excellent exposures of the contact can be seen, es-
pecially north of Kendall Peak where a small stream has cut
deeply into the main ridge.

Age

The Snoqualmie granodiorite intrudes the Sunset, Guye,
Naches and Keechelus formations in this area. The Guye is pro-
bably Paleocene or Eocene in age; the Naches formation is proba-
bly Eocene; and the Keechelus appears to be Oligocene. Thus all

that can be said is that the Snoqualmie may be Oligocene or younger, but it should be recalled that the dating of the sedimentary rocks is not secure. The discovery of better fossils may alter this dating. In the present area, the Snoqualmie is not in contact with any younger rocks so no upper limit can be placed on its age.

Farther south, Warren (1941, p. 797) and Abbott (1953, p. 185) report granitic rocks, that they called Snoqualmie, intrusive into the Keechelus but not into the Fifes Peak andesite or the Yakima basalt. They considered the younger rocks to be Miocene in age and so dated the Snoqualmie granodiorite as Oligocene on this basis and because of the oreodont found nearby in the Keechelus. The relation of the Keechelus and Snoqualmie there to the rocks in the area of this study is not known, so the value of this observation to the present study is doubtful.

Larsen et al (1952, p. 1050) determined the age of the Snoqualmie granodiorite using the zircon method. In their paper they reported 65 million years as the age of "granite from Snoqualmie Mountains, Washington". Because they were not satisfied with this measurement, they collected a second specimen from White River, north of Goat Island Mountain near Mt. Rainier. This specimen was run by Howard Jaffe, who obtained a good measurement of 60 million years (Larsen, written communication, February 29, 1956). Sixty million years is usually considered as Paleocene or Eocene. The reason for the discrepancy between this measurement and the stratigraphic evidence is not known, and much more work will be necessary before the age of the Snoqualmie granodiorite is accurately determined.
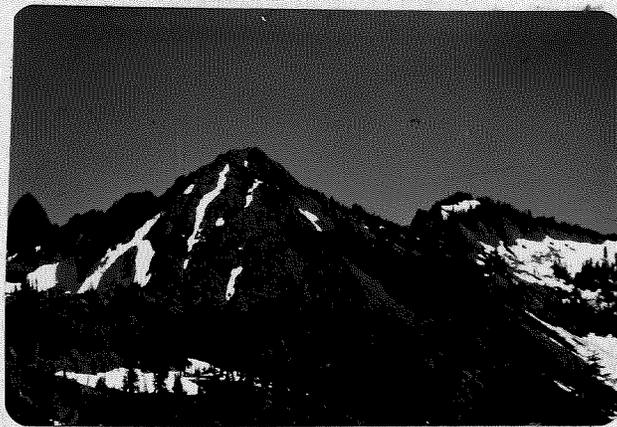
Fig. 52   Red Mountain composed of Naches formation
that has been hornfelsed and mineralized by the in-
trusion of the Snoqualmie granodiorite. The gray
ridge on the right is Snoqualmie granodiorite.

Description

For the most part, this intrusive unit is composed of granodiorite but it locally includes both more basic and more acidic rocks. The Snoqualmie granodiorite, together with its local variations and its associated dikes, were well described by G. O. Smith and his associates around the turn of the century. He noted (Smith and Mendenhall, 1900, p. 224), "There are more basic phases of the Snoqualmie granodiorite intermingled in such a way as to make their separation as futile as it would be unnatural." and (Smith and Calkins, 1906, p. 9) that Snoqualmie Mountain is composed of more acidic rocks. He further described the prophyritic dike and contact rocks that he traced into the granitoid rock.

In hand specimen, the granodiorite is a medium to fine grained light colored rock composed of white feldspars, clear quartz and prominent hornblende and biotite.

The rocks examined microscopically ranged in composition from granite to quartz diorite. All of these rocks had two features in common. The plagioclase was zoned generally with andesine cores and oligoclase rims and many individuals show several oscillitory cycles superposed on their normal progression. The second ubiquitous feature is the general alteration of these rocks. The feldspars are universally cloudy with sericite and kaolin and the mafic minerals are altered to chlorite and epidote.

Smith and Calkins (1906, p. 9) accurately described the principal rock type as granodiorite composed of well formed plagioclase, interstitial orthoclase, quartz anhedra, hornblende and biotite with apatite, zircon, magnetite, titanite, and

Fig. 53   Photomicrograph of Snoqualmie granodiorite.
Zoned subhedral plagioclase crystals surrounded by an
optically continuous anhedral quartz crystal. Crossed
nicols, x 48.

allanite as accessories. The small intrusive body near the head
of Gold Creek and the other small intrusions east of Gold Creek
contain only limited amounts of orthoclase and so are quartz
diorites. These quartz diorites contain on the average 70 per
cent zoned anhedral plagioclase, 15 per cent quartz, less than
5 per cent orthoclase, 5 per cent chlorite, 5 per cent biotite,
up to 5 per cent epidote (replacing the hornblende) and a few
per cent green hornblende and opaques. In the vicinity of
Snoqualmie Mountain, these rocks become more acidic and the
typical rock here is a nearly white granite composed of quartz,
altered feldspar predominantly orthoclase and a little biotite.
Near their contacts, many of these rocks become porphyries, many
with large quartz phenocrysts set in a fine grained, commonly
altered, matrix.

STRUCTURE

In this section, the structural geology of the Central Cascades in general, and the present area in particular, will be summarized. Much of the information that follows has been presented above, but this summary will bring to light many features of geologic interest.

To understand the structure, the stratigraphic relationships must first be understood. The accompanying chart shows the suggested correlation between the eastern and western stratigraphic columns of the present area. As repeatedly noted above, the ages and correlations of these rocks are tentative due to the lack of distinctive fossils.

This chart shows that, while there is an overall similarity between the two columns, the many local units indicate that this area was in a region of general crustal unrest during Tertiary time. Several times of folding and many degrees of folding are recorded in the many unconformities. The existence of the two different columns in juxtaposition also indicates large scale orogeny.

North of the present area, the Paleozoic and Mesozoic rocks have a northwesterly trend. This trend is apparently very old and the Tertiary rocks of the present area follow it, probably posthumously.

The structure of the pre-Tertiary rocks was not determined in this study because of the small area of pre-Tertiary rocks mapped. A few structural details of these rocks were described earlier. The structure and kind of pre-Tertiary rocks had a marked influence on the deformation of the Swauk which is the initial Tertiary formation.

AGE	WESTERN COLUMN	EASTERN COLUMN	LITHOLOGIES
Pliocene		Yakima	Basalt
Miocene			
Oligocene	Keechelus		Andesite
Eocene	Naches	Roslyn	Arkose and Basalt
	Mt. Catherine	Teanaway	Rhyolite
		Silver Pass	Andesite
Paleocene	Guye	Swauk	Sediments
Cretaceous			

Fig. 54 Diagrammatic tentative correlation chart of the eastern
and western stratigraphic columns in this area. Age assignments
are discussed in the text under each formation. Not to scale.

The first Tertiary deformation in the area is recorded by
the Swauk and Guye formations. The Swauk is a thick arkose unit
with prominent conglomerates and appears to have been deposited
under conditions that favored rapid erosion and quick burial.
The Guye formation may be of the same general age as the Swauk
for two reasons. First, both are of post-metamorphic and pre-
volcanic age, and secondly, although in overall aspect they are
different lithologically, the sandstones in both are somewhat
similar, with the Guye, in general, more mature. The Swauk was
folded along the old northwest trends, in part quite tightly.
As discussed earlier, the details of this deformation vary from
place to place. The Swauk is more intensely deformed where the
basement is peridotite than where the basement is Easton schist.
The reason for this difference in deformation is not known, but
it seems probable that the differences in folding are due to the
differences in response of the dissimilar basement rocks to the
orogenic forces. Just south of the uplifted pre-Tertiary rocks
that form the Mt. Stuart block, the northwest trends of the Swauk
folds become more east-west, perhaps indicating that the Mt.
Stuart block was an important positive structural element prior
to, and at the time of, Swauk folding. This hypothesis is
strengthened by the evidence discussed earlier, showing that
part, at least, of the Swauk sediments came from the Mt. Stuart
block.

To the west, presumably at the time of Swauk folding, the
Guye sediments were folded. The Guye beds have a steep east dip-
ping homoclinal structure with trends varying from north-south to
north-east. The reason for this local departure from the

regional north west trends in this area is not known. It could
be due to the local influence of the basement or, possibly, to
folding associated with the intrusion of the Snoqualmie granodio-
rite. The situation here is quite complicated, because immediately
to the east, and stratigraphically above the Guye formation, lies
the Naches formation which, although less steeply deformed,
follows the regional northwest trend.

Following this first folding, there was a time of erosion
and then the extrusion of the Silver Pass andesite. It appears
that this andesite was a very local phenomenon, because it is
found at only one locality. It is possible that the Silver Pass
volcanics may correlate with the Mt. Catherine rhyolite. Such a
correlation may be possible because they are both acidic volcanic
rocks and, as indicated on the chart, they may be of the same
general age. This correlation would only require the post-
Silver Pass unconformity to become a disconformity to the west.
The Silver Pass volcanics were folded along the earlier trends
and then were subjected to erosion.

The next sequence consists principally of arkose and basalt.
In the western part of the area, these two lithologies are inter-
bedded to form the Naches formation and to the east, they are
separated into the Teanaway basalt and the overlying Roslyn ar-
kose. The validity of this correlation may be open to some ques-
tion because neither the Roslyn nor the Teanaway shows any ten-
dency toward mixing sedimentary and volcanic rock. The struc-
tures of the two areas bring out more differences between the
Naches and the Teanaway - Roslyn. The Naches has been deformed
into a series of moderately tight folds that follow the northwest

trends. In contrast, the Teanaway-Roslyn has for the most part been only slightly deformed into a large basin. Although the Teanaway and Roslyn rocks have very gentle attitudes throughout most of this basin, the basin is asymmetrical and on the southwest side it is quite steep and bordered on the west by a tight fold mentioned earlier. These structural differences between the Naches and the Teanaway-Roslyn can be interpreted as indicating a different history and so, probably, a different age for these two sequences; or they may be interpreted as an example of sporadic folding. All of these rocks are interrupted by numerous faults but these faults are not well dated.

The folding of the Naches and the Teanaway-Roslyn was followed by an interval of erosion and then the Keechelus andesite was extruded. The Keechelus is preserved only in the western part of the area, but may have covered all of the older rocks, especially if the andesites on Goat Mountain are Keechelus as Smith and Calkins considered them. In the western part of the present area, the Keechelus is mildly deformed into a syncline.

In the western part of the area, the Snoqualmie granodiorite was intruded sometime after the Keechelus.

In the eastern part of the area, the youngest rocks comprise the Yakima basalt, which overlies the Eocene rocks unconformably. In this area, the Yakima is almost horizontal, but to the southeast in the Yakima Canyon it is steeply folded. There was no Cascade Range as we know it today until probably Pliocene time, when the range was uplifted on a more or less north-south axis. It was at this time that the Yakima basalt was folded. The nature of this uplift is not known, but it appears to have been in part

compressive (Laval 1956, p. 143). The effects in the present
area of this deformation which resulted in the uplift of the
range, are difficult to evaluate because there are no young rocks,
and erosion surfaces are also difficult to interpret because of
the glaciation and small scale of the topographic maps.

THE KACHESS FAULT

The major structure in the area is the Kachess fault which
brings into contact two very different stratigraphic columns of
the same general age. This fault has a north-south trend and
has been traced fifteen miles from the crest of the Cascade Range
to Kachess Lake, and it may extend at least to the Yakima Valley,
another five miles. At its northern end, high on the Cascade
crest, the fault plane is exposed. Here the fault plane dips
sixty degrees to the east, and the Easton schist on the east side
is brought into contact with Eocene rocks on the west side show-
ing that it is a reverse fault (R. C. Ellis, personal communica-
tion). In the area of this study, the fault plane itself is con-
cealed by the Kachess Lakes, but the effects of the fault are
quite apparent. To the east of Little Kachess Lake, the valley
sides rise 3300 feet and are composed of Easton schist. To the
west, the valley sides are 2000 feet high and are composed of the
Naches formation of Eocene age. This abrupt lithic change, to-
gether with the truncation of structure on both sides of the lake,
are indicative of faulting.

The amount of movement on this fault is difficult to esti-
mate because the same beds do not appear on both sides of the
fault. This very fact is probably an indication that the movement
has been large. If we assume that the Naches formation is

underlain by either the Guye or the Swauk formation, then the
fact that the Swauk has been eroded from the east side of the
fault indicates that the vertical movement must be at least
equal to the combined thicknesses of these two formations or
about 10,000 feet. The possibility of horizontal movement on
this fault must be considered but it is impossible to estimate
the possible magnitude of horizontal movement.

It is difficult to date this fault, for in the present
area, Eocene rocks are the youngest cut by it. It can, however,
be traced to the north as far as the crest of the Cascade range.
Here it is apparently terminated by the intrusive Snoqualmie
granodiorite and so is older than the Snoqualmie (R. C. Ellis,
personal communication). Recent movements may have occurred on
the Kachess fault. Dr. Frank Neumann (personal communication)
has computed the location of an epicenter for an earthquake that
occurred on May 15, 1955 as lying on the Cascade Crest near the
north end of the Kachess fault. This is a very interesting
coincidence, and may show recent movement at depth on this fault.
There is no topographic evidence in that area for recent move-
ment on the fault.

Near the north end of Kachess Lake, another fault trending
southwest seems to branch from it. This fault, which follows the
broad glaciated valley of Lodge Creek, is probably of much smaller
magnitude for Naches rocks are exposed on both sides of the fault.
The evidence for this fault is the apparent truncation of the
structure and the very broad valley that lines up strikingly with
another creek on the south side of the Yakima River.

There are many other faults in the area and, for the most part, their age is not known. The age of the fault near Snoqualmie Pass is not known but appears to be post Naches and pre-Snoqualmie granodiorite. The magnitude of the fault is probably several thousand feet for the pre-Tertiary rocks are brought into contact with the Naches formation. East of the Pass, a post-Keechelus fault follows Gold Creek. It is parallel to the Snoqualmie Pass fault. The Gold Creek fault is probably not a large magnitude fault, for less than 2000 feet of vertical movement would allow the projection of the Keechelus strata to pass above Kendall Peak.

This study has shown that the history of this part of the Central Cascades has been one of intermittent diastrophism throughout Tertiary time. The most important structure in this area is the Kachess fault which separates two very different stratigraphic sections of the same general age. The presence of these two thick sections indicates that two Tertiary basins with different environments are now in contact. The age of the fault is not known, but the geologic evidence shows that the last big movement was in middle or late Tertiary time and recent earthquakes suggest that it may still be active. This fault may have been active during the early Tertiary and could account for the two basins. However, the thickness of the two sections and the fact that none of the units tend to thin near the fault suggests that these two sections were brought together by later movements, perhaps of large magnitude. This second hypothesis is more in accord with the large movement that can be demonstrated for this fault.

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VITA

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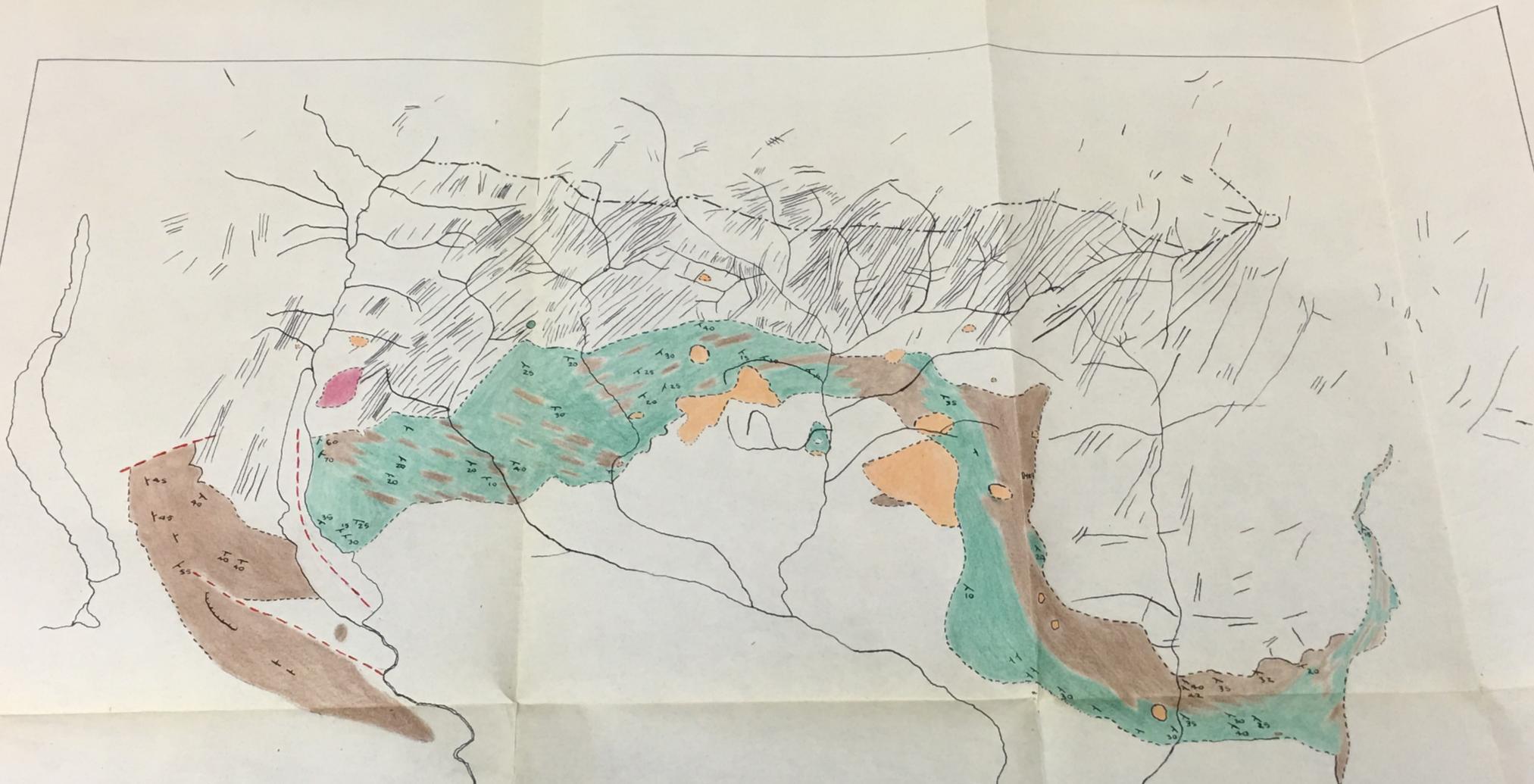
SKETCH MAP

SAME SCALE AS GEOLOGIC MAP

SHOWING

TEANAWAY DIKE SWARMS

AND

GENERAL DISTRIBUTION OF

ROCK TYPES IN THE TEANAWAY BASALT

Post Roslyn rhyolite

Diabase intrusive

Basaltic lavas

Clastic rocks
(includes sedimentary and pyroclastic rocks)

Dikes shown diagrammatically
(from USGS folios 106 and 139)

Swauk - peridotite contact

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WASHINGTON
SNOQUALMIE QUADRANGLE

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WASHINGTON
MOUNT STUART QUADRANGLE

GEOLOGIC MAP AND CROSS - SECTIONS

Geology by R. J. Foster 1956
Northern margin of Swauk
sections from USGS Folios 106 & 139
Attitudes in Roslyn from C. T. Bressler 1951
Fold axes in Roslyn from E. J. Saunders 1914
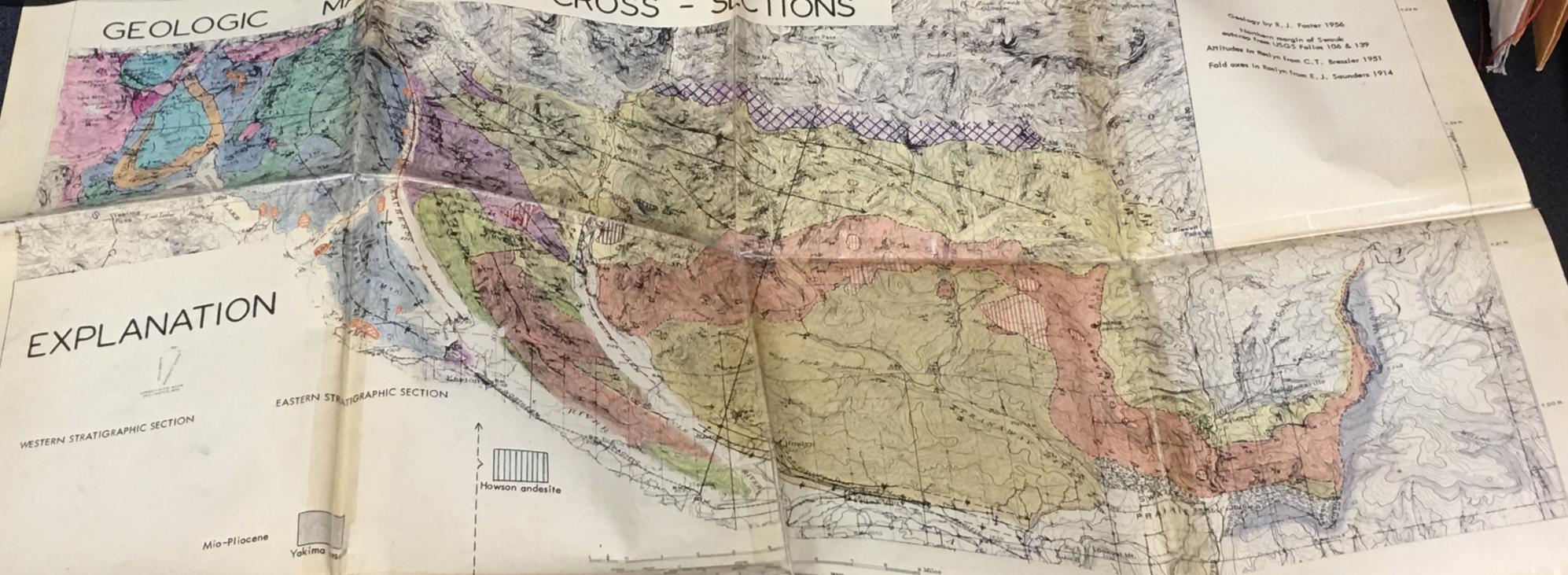
EXPLANATION

WESTERN STRATIGRAPHIC SECTION

EASTERN STRATIGRAPHIC SECTION

Howson andesite

Mio-Pliocene — Yakima

Snoqualmie granodiorite

Oligocene? — Keechelus andesite

Eocene — Post Roslyn rhyolite (may locally include older rhyolite)

Roslyn gneiss

Naches fm. (with included rhyolites)

Teanaway basalt — Diabase

Eocene? — Mt. Catherine rhyolite

Silver Pass volcanics

Guye fm. — Paleocene? — Swauk arkose

Pre-Tertiary — Denny fm.

Pre-Tertiary — Easton schist

Peridotite and older rocks south of Mt. Stuart

Marble (minor occurrences west of Cle Elum lake)

Volcanics

CONTACTS
located
inferred

FAULT

LANDSLIDES

INFERRED FOLD AXES
syncline (showing pitch)
anticline

STRIKE and DIP of BEDS

LOCATION of CROSS-SECTION

CROSS-SECTION A—A'

CROSS-SECTION B—B'