GEOLOGY OF THE SOUTHWESTERN PORTION OF THE MT. STUART QUADRANGLE, WASHINGTON

by

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A thesis submitted in partial fulfillment of the requirements

for the degree of

MASTER OF SCIENCE

UNIVERSITY OF WASHINGTON

1957

Approved by Howard A. Coombs

Department Geology

Date Sept. 26, 1957

Abstract

The Mt. Stuart quadrangle is approximately 74 airline miles southeast of Seattle and 39 airline miles northeast of Mt. Rainier, Washington. It is on the eastern flank of the Cascade Mountains of central Washington.

The oldest formation in the area is the Easton schist, a series of low grade metamorphic rocks. The principal lithologic types in the Easton are phyllites, graphitic phyllites and greenschists. Quartz exudation bands are common in all rocks of the Easton schist. All of these rocks have been extremely deformed. The age of the formation is unknown except that it is pre-Tertiary.

Unconformably overlying the Easton schist in the southern part of the area is the Manastash formation, a series of conglomerates, feldspathic sandstones and carbonaceous shales, along with seams of impure coal. These sediments have been deformed into gentle, northwesterly trending folds. The age of the Manastash formation as determined by fossil leaves is lower Tertiary.

In the northern part of the area, the Easton schist is unconformably overlain by arkosic sandstones which have been referred to as pre-Teanaway sediments in this thesis. Overlying these sediments is the Teanaway basalt—a thick unit of basaltic flows and pyroclastic rocks with interbedded sediments. The age of the Teanaway basalt is lower to middle Eocene.

Unconformably overlying the Manastash formation is the Taneum formation, comprised of porphyritic andesitic to basaltic flows, tuffs and volcanic conglomerates. The Taneum formation has not been subjected to the greater amount of deformation seen in the Manastash formation. The definite age of the formation is unknown, but is believed to be lower Miocene.

The next youngest unit is the upper Miocene to lower Pliocene Yakima basalt, which is not a single flow, but a number of basaltic flows that are part of the widespread Columbia Plateau basalts. Associated with the Yakima basalt are sedimentary interbeds and diabase dikes which may represent local feeders for some of the basalt.

A band of serpentinite in the southern part of the area is believed to have been intruded along a large, deep-seated fault. However, more study is needed before more definite conclusions can be reached regarding the fault.

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GEOLOGY OF THE SOUTHWESTERN PORTION OF THE MT. STUART QUADRANGLE, WASHINGTON

INTRODUCTION

Location and access

The area covered by this report is in the southwestern corner of the Mt. Stuart quadrangle, Washington, approximately 74 airline miles southeast of Seattle and 39 airline miles northeast of Mt. Rainier (figure 1). It is entirely within the boundaries of Kittitas County on the eastern slope of the Cascade Mountains.

U. S. Highway #10, the principal east-west highway in the state, traverses the area to the north and secondary paved and dirt roads leading from it provide access to the area. The main secondary access road to the area follows Taneum Creek to the Taneum guard station where it leaves the Taneum Valley and follows a southwesterly direction to Quartz Mountain where a U. S. Forest Service lookout is maintained.

Purpose

Heretofore, only reconnaissance geology has been undertaken in the area. The purpose of this report is to present a more detailed description of the geology of the southwestern portion of the Mt. Stuart quadrangle. Emphasis was placed on a study of the Manastash formation, a sedimentary unit designated by G. O. Smith (1904, p. 7) in the Mt. Stuart Folio.

Methods

The field work was done in the summer of 1956. The geology was mapped on aerial photographs with an approximate scale of 1:20,000, which were taken by the U. S. Department of Agriculture in 1954. Using proportional dividers, the geology was then transferred to a U. S. Forest Service planimetric map which

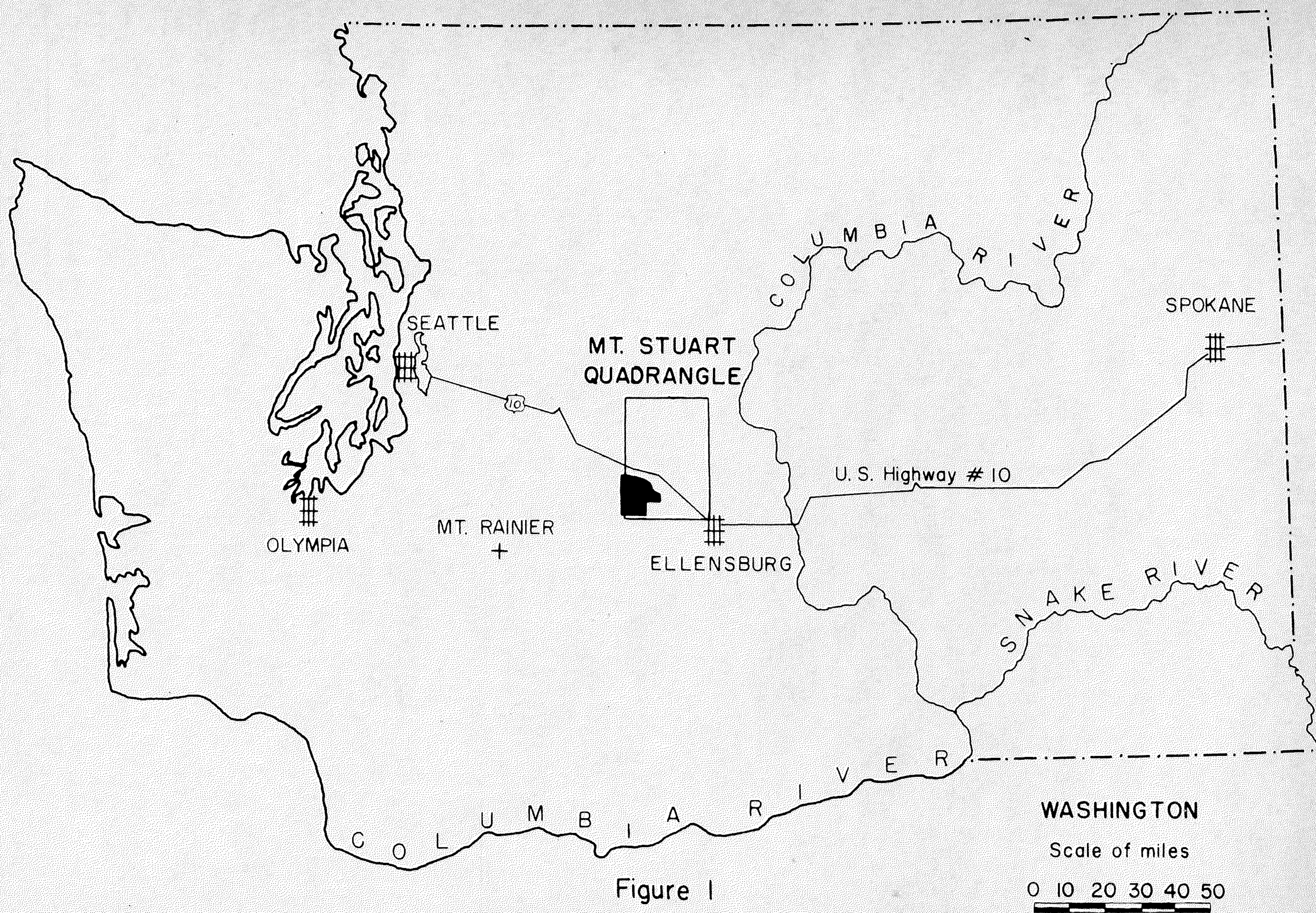

Figure I

INDEX MAP

was used as a base map. If possible, Brunton compass traverses were made in areas not readily located on the aerial photographs.

Petrographic study was done during the winter and spring quarters at the University of Washington.

Fossil leaves collected during the summer are deposited as Lot #36 in the Museum of Paleontology, Department of Geology, University of Washington.

Previous work

The first geological investigation was in 1892 when I. C. Russell made a circular traverse into the extreme northeastern portion of the area. He returned again in 1897, but again only mapped in this same restricted area.

A more comprehensive study by G. O. Smith (1903a,1904) was published as part of U. S. G. S. Professional Paper #19 and the Mt. Stuart Folio #106. This work produced the first complete map of the southwestern portion of the Mt. Stuart quadrangle. In 1906, Smith and F. C. Calkins completed their mapping of the Snoqualmie quadrangle which adjoins the Mt. Stuart quadrangle to the west.

Using the previous work of Russell and Smith, E. J. Saunders (1914) made a survey of the coal fields of Kittitas County. In mapping the coal outcrops south of the Yakima River, Saunders made detailed sketch maps of the coal mines and their immediate geological surroundings.

Acknowledgments

Appreciation is extended to Dr. Howard A. Coombs of the University of Washington Geology Department for his constructive criticism and counsel both in the preparation of the manuscript and in the field. The Land Department of the Northern Pacific Railroad permitted the writer to examine their aerial photographs of the area and obtain certain section corner locations from them. The Coal Department of Northern Pacific allowed the writer to examine their bore hole records made in the Cle Elum area. The Miller Brothers of Ellensburg, Washington, gave the writer subsurface information on the Yakima River Valley southeast of Cle Elum, Washington. Dr. Ralph W. Chaney of the Department of Paleontology, University of California, studied and identified the writer's collection of leaves from the Manastash formation. The writer's wife, Diane, proofread the final draft and also provided financial support during the winter and spring months.

TOPOGRAPHY AND RELIEF

The area consists of a series of westerly to northwesterly trending ridges and valleys, the valleys being drained by easterly or southeasterly flowing streams. The elevation of the ridges decreases in an easterly direction.

Separating the Yakima Valley to the north from Taneum Valley to the south is Cle Elum Ridge. The highest point on this ridge in the area is Taneum Point (elevation 4400 feet). South of Taneum Valley and at a slightly higher elevation than Cle Elum Ridge is a relatively flat upland surface in places reaching an elevation of 4900 feet. South of this surface are the North and South Forks of Manastash Creek, which are separated from each other by another northwesterly trending ridge. Elevations on this ridge do not generally exceed 5000 feet.

The most outstanding relief feature of the Yakima Valley is Cle Elum Point, a rugged mass of andesites on the south side of the valley immediately south of Cle Elum (figure 2). The relief of this point is the most extreme in the entire area—from the Yakima Valley which has an elevation around 2000 feet, Cle Elum Point rises to an elevation of 4000 feet in about a $\frac{1}{2}$ mile map distance.

The highest point in the area is Frost Mountain which has an elevation of 5750 feet. The lowest point is in the Yakima Valley. Total relief therefore, does not exceed 3800 feet.

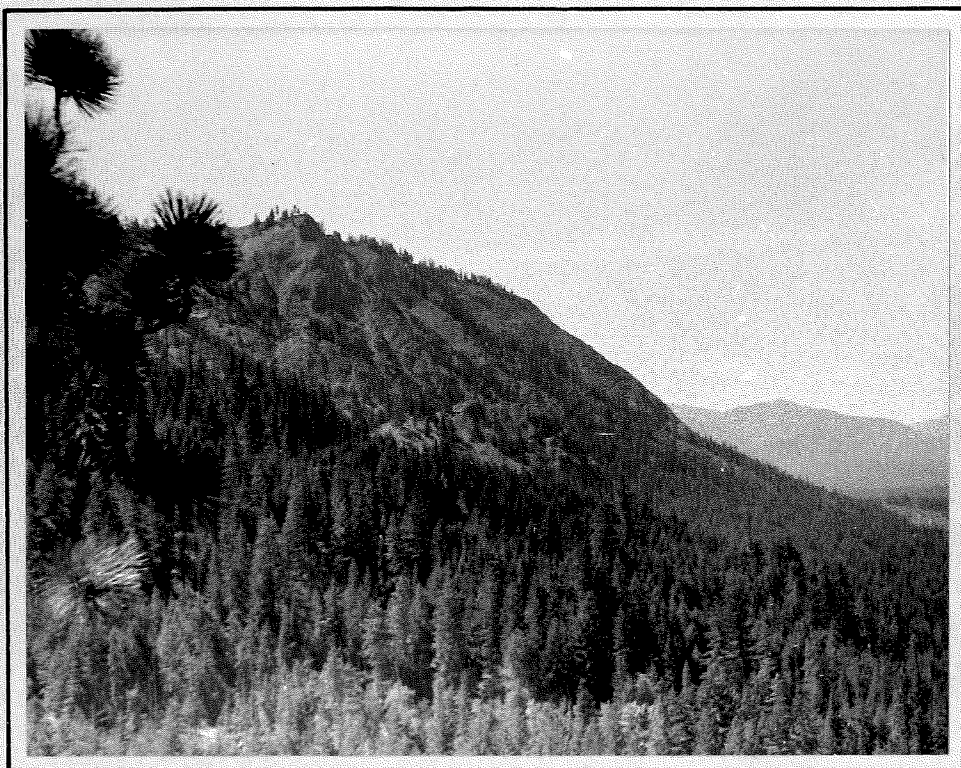

Figure 2

View showing Cle Elum Point from the east. It is composed of a series of andesitic flows and forms a rugged escarpment on the south side of the Yakima River Valley. The tree covered ridge in the foreground consists of Teanaway basalt.

GEOLOGIC SETTING

Geologically the area is in an interesting position. To the south and east are Miocene to Pliocene basalts of the Columbia Plateau; to the north and west are older crystalline and volcanic rocks and sediments of the Cascade Mountains. Immediately north and northwest of the area are a series of late Cretaceous (?) to early Tertiary sediments and Eocene volcanics. Pre-Tertiary metamorphic and igneous rocks underlie these units farther to the north and these older rocks are known to continue beyond the Canadian border. The late Cretaceous (?) to early Tertiary sediments may also extend northward beyond the Canadian border. Generally the trend of these units and/or structure in any of the rocks is northwest-southeast, cutting across the north-south topographic alignment of the Cascade Mountains.

In the southern part of the area mapped for this report, one of the pre-Tertiary metamorphic units crops out. To the writer's knowledge, this is the southernmost occurrence of pre-Tertiary schist in the state of Washington. It disappears to the south under the Miocene to Pliocene basalts.

DESCRIPTIVE GEOLOGY

Rock exposures

Outcrops in the area are definitely limited and anyone working with the geologic map accompanying the thesis must realize this. At only three localities were actual contacts seen--the other contacts were located on the basis of soil, float, topographic expression, vegetation or any combination of these.

Southwest of Frost Mountain, alpine meadows are common and exposures are more abundant. In most of the area, however, the northern slopes are more densely wooded than the southern ones and consequently, the location of contacts on the northern slopes is not as accurate as on the southern slopes. This is because of three reasons: (1) It is very difficult and sometimes impossible to get locations on aerial photographs when in the woods; (2) There are very few, if any, outcrops in the woods; (3) There is generally no float on the northern slopes and the soil is nothing but organic material.

Bulldozer cuts made for logging roads were invaluable. Two logging roads were constructed along the North Fork of Manastash Creek during the summer of 1956 and these uncovered many valuable exposures.

Easton schist

The oldest and only metamorphic formation in the area is the Easton schist. This formation was named by G. O. Smith (1904, p. 3) for the prominent exposures of amphibolites and phyllites around the town of Easton. Easton is approximately 14 airline miles northwest of Cle Elum on U. S. Highway #10. According to Smith, the Easton schist can be traced northwesterly from the southwestern part of the Mt. Stuart quadrangle to approximately the Cascade Crest. Recent work by graduate students at the University of Washington shows that Easton equivalents may extend farther north.

The Easton schist crops out over two large areas south of Cle Elum in the thesis area. Extending south from under the gravels of the Yakima Valley west of Cle Elum Point, the Easton schist forms most of Cle Elum Ridge southwest of Cle Elum Point except where it is capped by younger basalt flows. The metamorphic rocks on this ridge continue to the west beyond the area mapped. The southernmost boundary of this occurrence of Easton schist is approximately $1\frac{1}{2}$ miles south of where the two forks of Taneum Creek join. Here the Easton disappears under younger basalt flows. Immediately northwest of this locality, the Easton is covered to the south by younger sediments.

The other occurrence of Easton schist is in the extreme southern part of the area, about $1\frac{1}{2}$ miles south of Frost Mountain. The Easton occurs as a narrow band up to $\frac{1}{2}$ mile wide. The northern contact of this band, east of the South Fork of Manastash Creek, is in question because of the dense growth of vegetation in this area. The band represents the southernmost occurrence of schist in Washington known to the writer.

Generally the Easton schist is quite a distinctive unit to map. In the field, quartz pebbles from quartz stringers in the metamorphic rocks are readily seen in the soil cover and the presence of these is an indication that the underlying bedrock is Easton schist. On the north side of Taneum Valley, springs were common at or near the contact between the Easton schist and the overlying Yakima basalt. Another factor used in mapping the Easton schist where it is covered, was an abundance of sericite and other micaceous minerals in the soil giving the ground a peculiar shiny luster.

The Easton schist is regarded as the basement rock because it contains the only metamorphic rocks in the area. No definite sequence of lithologies could be determined in the Easton schist largely because of the limited number of outcrops and consequently, no attempt has been made to discuss the petrography in detail. More detailed petrography will probably be possible with a study of the Easton schist exposed west of the thesis area near the type locality of the formation.

Three predominant rock types were recognized in the Easton schist: (1) graphitic phyllite; (2) silvery-gray phyllite; (3) greenschist. The most widespread unit is the graphitic phyllite. In addition to these rocks, a blue amphibole schist was found and will be discussed briefly later. Quartzites have been described from the Easton near Cle Elum Point (Smith, 1904, p. 3).

All of the units contain numerous quartz exudation bands or pods. The bands commonly are parallel to the schistosity, which will be referred to as "s", but it is not rare to find them at right angles to the schistosity. Generally the bands are narrow, but they range up to nearly a foot in width at some places. In several places it is possible to trace s through the quartz exudation bands.

The graphitic phyllite is very common and exposed in many places. The most accessible of these are along the road from South Cle Elum to Cle Elum Point and on the north side of the South Fork of Taneum Creek along the road

Figure 3

Folded graphitic phyllites in the Easton schist in the valley of the South Fork of Taneum Creek. The wider, light colored bands are quartz exudation bands in the phyllite. Note hammer for scale.

to South Fork Meadows (figure 3).

The graphitic phyllite is intensely sheared and deformed and it is impossible in most places to determine attitudes of the foliation. Generally the graphitic phyllite contains a considerable quantity of water and when such is the case, slumping and sliding are very common. In several places, the road along the South Fork of Taneum Creek has to be relocated nearly every year because of the continual sliding of the Easton into the canyon during the winter months.

No thin sections were made of the graphitic phyllite as the rock is composed almost entirely of graphite with quartz exudation bands and is extremely friable. All of the phyllite has at least one direction of b lineation, formed by small folds on s, and commonly there are two b lineations intersecting each other at very small angles.

The silvery-gray phyllite can be best seen along the Taneum Creek road east and west of the intersection of the two forks of Taneum Creek (figure 4) or in certain places along the South Cle Elum-Cle Elum Point road. The phyllite is folded, sometimes isoclinally, and sheared so that attitudes are very difficult to determine.

In thin section, the phyllite consists predominantly of quartz and untwinned albite with minor amounts of actinolite, epidote, sericite and chlorite. A pronounced b lineation is rare, although s is generally very well developed and is extremely folded. Iron oxide stains follow many small shear zones.

Greenschist is not as common as the graphitic phyllite, but is still an important rock type in the Easton. The greenschist is fairly resistant to erosion and forms bold outcrops at many places (figure 5). Greenschist crops out on the north side of Cle Elum Ridge in section 10, T.19 N., R.15 E., along the North and South Forks of Taneum Creek and along the South Fork of

Figure 4

The dashed line indicates a small fault in the extremely deformed Easton schist. Here the Easton consists of silvery-gray phyllite with minor amounts of graphite. Quartz exudation bands are common. Exposure is along the Taneum Creek road. Note hammer for scale.

Figure 5

Outcrop of Easton greenschist along the South Fork of Taneum Creek. Copper and iron minerals are associated with the metamorphic rocks at this locality.

Manastash Creek in the southern part of the area.

In thin section the most common minerals are albite, quartz, epidote, actinolite and clinozoisite (figure 6). The albite is predominantly untwinned although twin lamellae were present in one thin section. In another specimen, epidote has replaced part of the plagioclase. Commonly calcite has replaced some of the quartz in the exudation bands.

Similar to the phyllites in the Easton, the greenschist is complexly folded and sheared. At some localities a well developed s exists and at others, there was no well developed foliation.

An unusually coarse grained actinolite schist was found in the southern exposure of Easton schist in the canyon of the South Fork of Manastash Creek. At first it was believed to be an amphibolite, but microscopic study showed it to be deficient in feldspar and rich in actinolite. Actinolite forms more than 90% of the rock with the remainder made up of clinozoisite, epidote, sphene and albite. The actinolite forms both small grains in the matrix and also occurs as porphyroblasts. The finer grained actinolite in the groundmass has been contorted around the porphyroblasts.

Immediately west of Cle Elum Point in section 10, T.19 N., R.15 E., the Easton schist contains a blue amphibole schist. This is the only place that blue amphibole schists were found in the area and the samples taken from this one outcrop were exceptionally high in blue amphiboles.

In the hand specimen, the rock is very distinctive with a bluish steel gray color. The schist has been complexly folded and accurate attitudes are difficult to obtain.

An attempt was made to determine the major type of blue amphibole in the rock. Optic axis figures indicate the sodic amphibole is very close to the uniaxial transition member of the glaucophane--crossite group (Peter

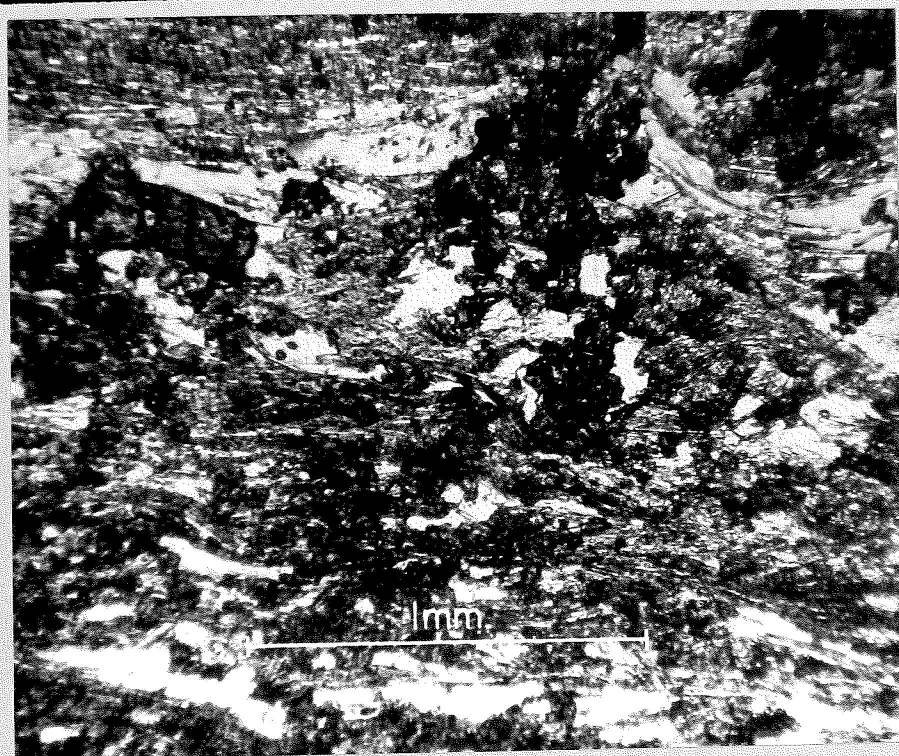

Figure 6

Photomicrograph of greenschist from the Easton schist just west of Cle Elum Point. The minerals are actinolite, untwinned albite, epidote, clinozoisite and quartz. Plane polarized light.

Misch, unpublished manuscript). With an off-centered optic axis figure, it was impossible to determine whether the interference figure was uniaxial or biaxial with a very small optic angle. Even with a centered optic axis figure, it was difficult to determine if the isogyres parted in the 45° position. Rotation of the stage with the gypsum plate inserted showed that the isogyres part a very small amount, so the mineral has a very small optic angle. The optic plane is normal to (010) so the blue amphibole is probably crossite, although it is very close to the uniaxial transition member.

Other properties of the blue amphibole are: (1) Pleochroism: X=greenish yellow, Y=light blue, Z=dark blue or purple; (2) The grains have a very low birefringence and are commonly zoned; (3) The extinction angle is generally very small (13° Y:c).

The blue amphibole forms about 75% to 85% of the rock with the remainder consisting of epidote, untwinned albite, actinolite and sphene. The actinolite and blue amphibole vary directly in percentage with each other. The actinolite may form as distinct bands in the rock or may be small irregular areas in the thin section. Small folds are numerous and many are isoclinal.

The metamorphic rocks of the Easton were probably derived from a series of argillaceous sediments and quartzose sandstones which had interbedded basic volcanics.

The variation in the foliation attitudes in the metamorphics caused by the folding has been pointed out. However, it was noted in the field that the foliations which strike in a northwesterly direction are generally the most consistent.

All other formations in stratigraphic contact with the Easton schist lie unconformably over it in the area mapped. Evidence for the unconformity is apparent in the degree of metamorphism and extreme deformation which has affected the Easton rocks, but not any of the younger rocks in contact with it.

The contact between the Easton schist and Manastash formation was seen at two localities immediately north of the South Fork of Taneum Creek. One exposure is behind an old storage building along the creek where the Easton apparently overlies the Manastash formation (figure 7), but this is because the contact is a small fault. The other exposure of the contact is in a mine about half way up the south slope of Taneum Ridge. The mine had been worked in the early summer and two adits expose the contact in several places. The portal of the mine is in massive arkosic sandstone making it impossible to get an attitude. The bearing of the main adit is N.27°E. About 50 feet from the portal along the main adit, thin-bedded sandstones and shales trend N.57°W. and dip 59° to the southwest. About 110 feet from the portal is the contact between the sediments and the metamorphics. Side adits branch off here on both sides of the main adit and the side adits expose the contact in several additional places. The sediments are badly sheared, but generally consist of sandstone. No basal conglomerate is exposed in the mine although it is known to occur at certain places along the contact on Taneum Ridge. The metamorphics are likewise crumpled and consist of sheared graphitic phyllite. The phyllite is more graphitic here than in any other exposure in the entire thesis area.

The contact is razor sharp in most places, but very irregular. In all places, the graphitic material shows a slickensided contact with the sandstone. Two general attitudes were taken on the contact at different places about 25 feet apart. Both show a strike of N.85°W., but one dips 79° N. and the other dips 45° S. In general, the small faults tend to parallel the strike of the contact. Several pods of the graphitic material appear to be surrounded by sandstone near the contact. Sheared zones generally show a gneissoid structure from the intermixing of quartz and graphite. Rocks in the sheared zone are very weak and saturated with water.

The main adit continues into the phyllite for approximately another 90 feet. The graphite near the contact shows no distinguishable quartz exudation bands, but does contain pods of sheared quartz. About 25 feet from the contact, white pods and stringers of quartz stand out against the black phyllite. The foliation here trends N.56°W. and dips 85° S. At the end of the main adit, approximately 200 feet from the portal, the s plane in the phyllite is remarkably flat giving the rock the appearance of a slate. The attitude of the flat s plane is N.73°W. 38° S. Pyrite porphyroblasts are very common in the graphitic phyllite that has not been sheared. Quartz stringers are abundant and as much as 8 inches thick.

The zone of shearing at and around the contact in the mine does not appear to be of the magnitude associated with large scale faulting. It is more likely the zone of sliding between the well-indurated sandstones and the weak phyllites during the period of post-Manastash deformation.

The contact between Easton schist and Yakima basalt (Miocene) was seen at one place. This was in the steep-sided gorge of the South Fork of Manastash Creek in section 20, T.18 N., R.15 E. The Easton shows about a three inch zone of alteration with secondary calcite at certain places in the altered zone. The contact parallels the foliation in the schist trending N.65°W. and dipping 64° S. The metamorphic rock adjacent to the contact consists of greenschist with quartz stringers. The Yakima basalt is a very dense and generally non-porphyritic basalt.

The other contacts between the Easton schist and adjacent rocks were covered with soil and no direct relationships could be mapped. However, several small areas in the Yakima Valley south of the river suggest the schist is not far below the surface although no outcrops were seen. One area is approximately 50 yards south of an exposure of pre-Teanaway sediments in the NE$\frac{1}{4}$SW$\frac{1}{4}$ of section 4, T.19 N., R.15 E. The sediments are discussed later. Easton schist occurs as float on the crest of a gentle ridge and consists of graphitic phyllite and quartz boulders. The quartz boulders are both rounded and angular. The writer believes the Easton underlies this small ridge because of (1) the abundance of the phyllite here, especially the graphite which would not be able to withstand much transportation or attrition because it is so easily broken along the foliation planes; (2) the absence of any of the other types of river gravels that cover most of the surrounding area; (3) the large amount of quartz from the Easton in the small gullies leading off the ridge. It is the only rock type in the gullies and the quartz pebbles commonly have graphitic bands through them. No basal conglomerate could be found in the small exposure of sediments to the north, but it has been stated earlier that a basal conglomerate is not always developed in sediments overlying the Easton schist. With 50 yards covered between the sedimentary beds and the metamorphic rocks, it is impossible to locate the contact exactly or to determine what type of contact it is.

Along the road leading southwest from South Cle Elum is another similar area where the graphitic phyllite is concentrated. This area is just south of where the road passes under the transmission lines in the southwest corner of section 4, T.19 N., R.15 E. The quartz pebbles are rounded to angular and the graphite does not occur as large boulders, but is more disseminated through the soil. This area is completely surrounded by a covering of various types of river gravels, but no gravels occur within the small area described.

In the southwestern corner of section 22, T.18 N., R.15 E., just south of an outcrop of Easton schist (attitude of foliation is given on geologic map), one outcrop of quartz diorite was found apparently in place. This outcrop is too small to indicate on the map and the area is covered with a thick soil cover and dense vegetation, so no relationships are known. Yakima basalt crops out to the south of the quartz diorite outcrop. The quartz diorite has a hypidiomorphic granular texture and consists of about 70% andesine (An_{36}-An_{46}) and 25% quartz. It is possible that this small mass of rock may be similar to the small granodiorite bodies mapped by Smith and Calkins (1906, p. 7) a few miles to the west in the southeastern part of the Snoqualmie quadrangle.

Neither the age of the original rocks or the age of metamorphism of the Easton is known. The only age that could be ascribed to the Easton schist from field relations in this area is pre-Tertiary. The extreme difference between the metamorphosed Easton schist and the younger Eocene rocks led Smith (1904, p. 2) to the conclusion that the unconformity between them represents a time interval that "was not only great but eventful". He theorized that the period of deformation and erosion could easily include all of Mesozoic time making the original rocks from which the Easton schist was formed Paleozoic in age.

Figure 8

View to the west from the south side of Cle Elum Ridge shows Taneum Ridge in the center of the picture. The east end of the ridge is composed of Easton schist. Rock in the foreground is Yakima basalt.

Manastash formation

Stratigraphic nomenclature and type locality

G. O. Smith (1904, p. 7) originally named the Manastash formation for the outcrops near the headwaters of Manastash Creek and the outcrops on Taneum Creek. He described the formation as a series of sandstones and shales, with seams of bone and impure coal associated with the shales. Smith also stated that wherever the Manastash rests on the Easton schist, it has a well developed basal conglomerate.

Smith did not specifically designate a type locality and to the present time, no type locality has been considered. The writer found only very limited exposures of the formation in the Manastash drainage basin despite the large areal extent of the formation there. In addition, the exposures are very widely scattered. Much better outcrops and more representative lithologies of the formation as a whole were found along the road up the South Fork of Taneum Creek and consequently, it is proposed that this area be regarded as the type locality of the Manastash formation. The designation of this area as the type locality of the formation is favored even more because of the large number of more representative exposures in a relatively small area. Unfortunately, the exposures are not continuous enough here to enable an accurate section to be made. The outcrops along the road are in sections 33 and 34, T.19 N., R.15 E., and are quite accessible.

Distribution

The largest occurrence of the Manastash formation is southeast of Frost Mountain. On the southeastern slope of Frost Mountain, the contact between the Manastash formation and the overlying Taneum formation has an irregular horseshoe shape with the open end to the northwest. This pattern is explained by the topography of Frost Mountain coupled with a broad synclinal structure in the Manastash. The Manastash in the northeastern arm of the horseshoe crops out as a thin band on the northeast side of Frost Mountain because of the high relief there. To the south, the closed end of the horseshoe is extremely wide because of the low relief of the surface.

North of this area is another band of sediments. Beginning near the junction of Frost Creek and the South Fork of Taneum Creek, this band trends northwesterly over Taneum Ridge, the ridge separating the forks of Taneum Creek, and extends at least to the North Fork of Taneum Creek.

Seemingly isolated from these major occurrences of the Manastash formation is a small area of arkosic sandstones and shales in the lower Taneum Valley, largely in sections 28 and 33, T.19 N., R.16 E. Reasons for believing these sediments belong to the Manastash formation are given later.

Description

To describe the sedimentary rocks in the area, the writer has used certain terms which may possibly be confusing if not defined specifically for this thesis. Arkose in this thesis is used to describe a detrital sedimentary rock in which the principal constituents are quartz and feldspar; the feldspar comprises at least 25% of the rock and generally there is only a small percentage of matrix. If the feldspar content of the rock is between 10% and 25%, the specimen is called a feldspathic sandstone. Quartzose sandstone refers to a detrital sedimentary rock which has an unusually high percentage of quartz, but is not extremely well indurated.

For describing the stratification of all the sedimentary units in this thesis, the writer has used the terminology of McKee and Wier (1953, p. 381-390), except the writer has used the term "massive" instead of "very thick-bedded" to describe beds greater than 4 feet in thickness.

The Manastash formation can be categorized into three principal rock types: (1) Conglomerates--the most notable of these is a basal conglomerate found near the Easton schist; (2) Coarse and medium clastic arkosic and feldspathic sandstones; (3) Carbonaceous and arenaceous shales. These rock types will be described in detail below.

The best basal conglomerate is in a very small area in the west central part of section 18, T.18 N., R.15 E. Although the contacts are very indefinite, the conglomerate appears to be limited to a very thin area along the contact between the Easton and the Manastash. East of this area where the trail to the South Fork of Manastash Creek crosses the Easton contact, large blocks of basal conglomerate were seen, but this occurrence is apparently limited to a very small area.

Basal conglomerates were also found as float on the north side of the South Fork of Taneum Creek below the Easton contact. However, the conglomerate does not occur everywhere the Manastash is in contact with the Easton schist.

In the hand specimen, the conglomerate consists of subrounded to angular pebbles of vein quartz and phyllite (figure 9). Some of the pebbles are a combination of both the quartz and the phyllite. Pebbles up to an inch in longest dimension were noted. The matrix consists predominantly of subangular quartz grains, although minor amounts of feldspar and sericite are present. The color of the rock is gray, but on weathered surfaces the conglomerate becomes more brownish and is quite conspicuous as the white quartz pebbles protrude from the weathered surface.

An accurate thickness could not be determined, but in the small area south of Frost Mountain, the basal conglomerate must be at least 25 feet thick.

In addition to the basal conglomerate with the high percentage of quartz derived from the Easton schist, other conglomerates were found higher in the

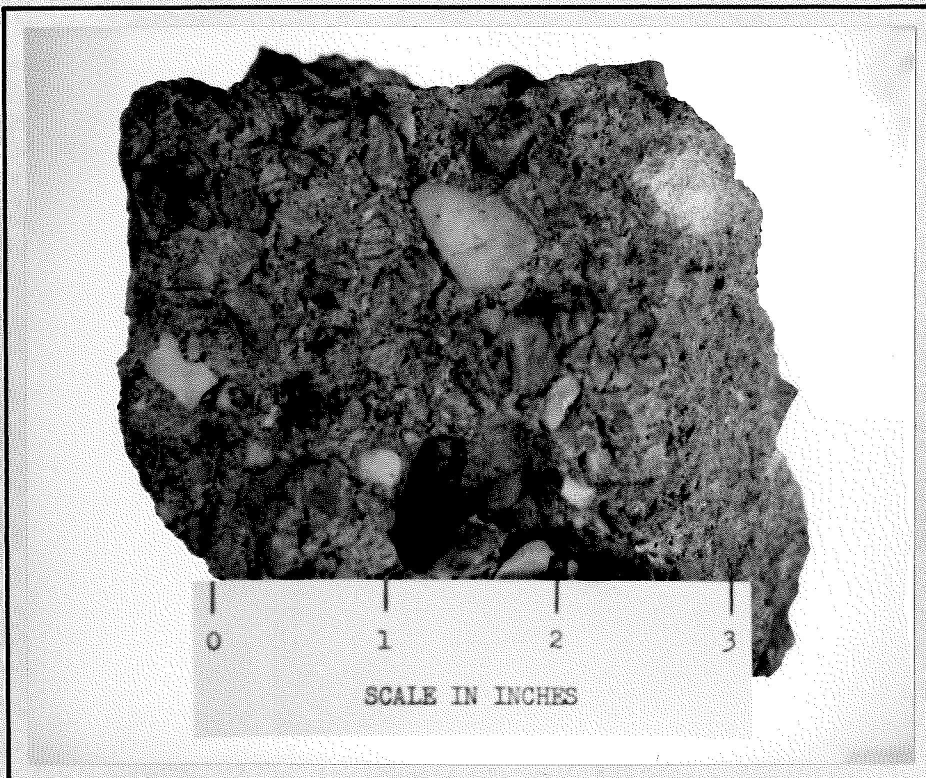

Figure 9

Specimen of basal conglomerate from the Manastash formation south of Frost Mountain near the Easton schist contact. The white pebbles are quartz and the gray foliated pebbles are phyllite. The matrix is composed almost entirely of sand size quartz grains, although sericite and feldspar are present in minor amounts.

section, but the average size of the pebbles was not as large as in the basal conglomerate. The average pebbles are about $\frac{1}{4}$ inch in longest dimension and consist of quartz, quartzite and dark aphanitic rock fragments. However, a quartzite cobble 3 inches in longest dimension was seen in a conglomerate unit on the south side of Frost Mountain, but this size was not common. In comparison to the basal conglomerate, these conglomerates generally have a much higher percentage of feldspar, although quartz is still the predominant mineral.

The predominant lithologic type in the Manastash formation is arkosic to feldspathic sandstone. In just about every outcrop of the formation, with the exception of the basal conglomerates, there are either thinly-bedded or massive, arkosic or feldspathic sandstones. The large area of the Manastash formation southeast of Frost Mountain is almost entirely medium to coarse grained sandstone with the feldspar content ranging from 15% to 35%. These rocks range in color from light shades of brown to buff to lighter shades of gray.

The most characteristic outcrop of the sandstones in the Manastash formation is a pile of rounded boulders forming a small knob (figure 10). In the area southeast of Frost Mountain, the outcrops are commonly in a group of trees surrounded by open meadows. Characteristically, the sandstone is massive and shows no distinct bedding planes. However, the attitudes shown on the geologic map were taken at localities where either the sandstone was thin-bedded or there were thin-bedded shales. In many outcrops, larger granules and pebbles are roughly aligned and, in some places, show cross-bedding. Cross-bedding can be seen in several exposures of sandstone as well. Cut and fill structures are not too common, but were seen at two different localities.

Microscopically, a typical specimen of the Manastash sandstone is medium

Figure 10

Typical outcrop of the Manastash formation in the area southeast of Frost Mountain. Bedding is hard to identify unless sandstones are thinly-bedded. Note hammer for scale.

clastic according to Krynine's classification of detrital sedimentary rocks (1948, p. 140). The grains are subangular to subrounded and consist of approximately 65-70% quartz and 20-25% plagioclase. The rest of the rock is composed of muscovite, calcite, biotite and quartzite (figure 11). Iron oxide and calcite are the main cementing constituents. The plagioclase ranges in composition between An_{32} and An_{52} and occurs both as fresh grains and grains which have been altered to sericite. Calcite has selectively replaced some of the plagioclase. The muscovite has been contorted between the quartz and feldspar grains by the stresses produced from compaction of the sandstone, although its general orientation is parallel to the bedding. The quartz grains in the quartzite fragments are of various sizes, but most of the grains show a preferred orientation suggesting the metamorphic derivation.

Some of the sandstones at various localities had other types of detrital material. Dark aphanitic rock fragments were seen in a few outcrops. Detrital garnet was noted in one thin section.

In the southeast corner of section 18, T.18 N., R.15 E., a quartzose sandstone was found with only a very small amount of feldspar. Subangular quartz or quartzite grains comprise 90% of the rock (figure 12). Only a few feet from this locality are exposures of the basal conglomerate.

A fairly common rock type, but areally much less important than the arkosic and feldspathic sandstones, is arenaceous and carbonaceous shale. The shales are generally fairly well-indurated, contain carbonaceous material as well as fossil leaves, and are very thinly-bedded. In thin section, a well-indurated shale contained about 95% of very fine grained material with the remainder of the rock consisting of larger subangular grains of quartz, muscovite and feldspar that average .08 mm. in size. Calcite is abundant in the fine grained matrix. The muscovite occurs as small flakes parallel

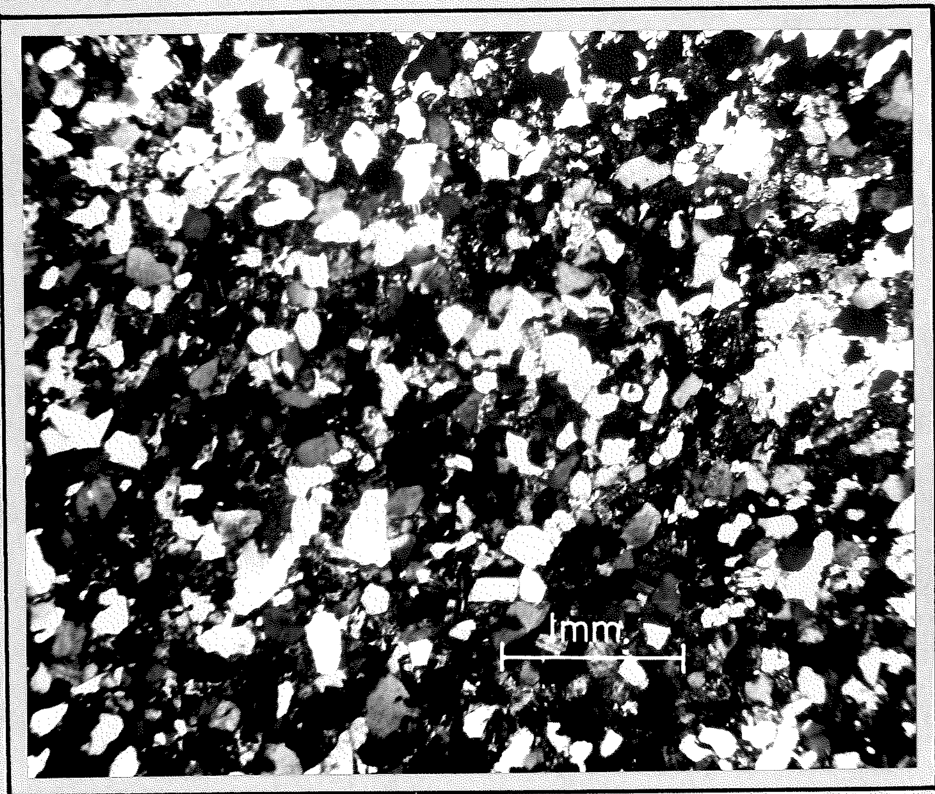

Figure 11

Photomicrograph showing a typical section of feldspathic sandstone from the Manastash formation. The section contains approximately 70% quartz and 20% plagioclase with minor amounts of muscovite, biotite, calcite and quartzite. Crossed nicols.

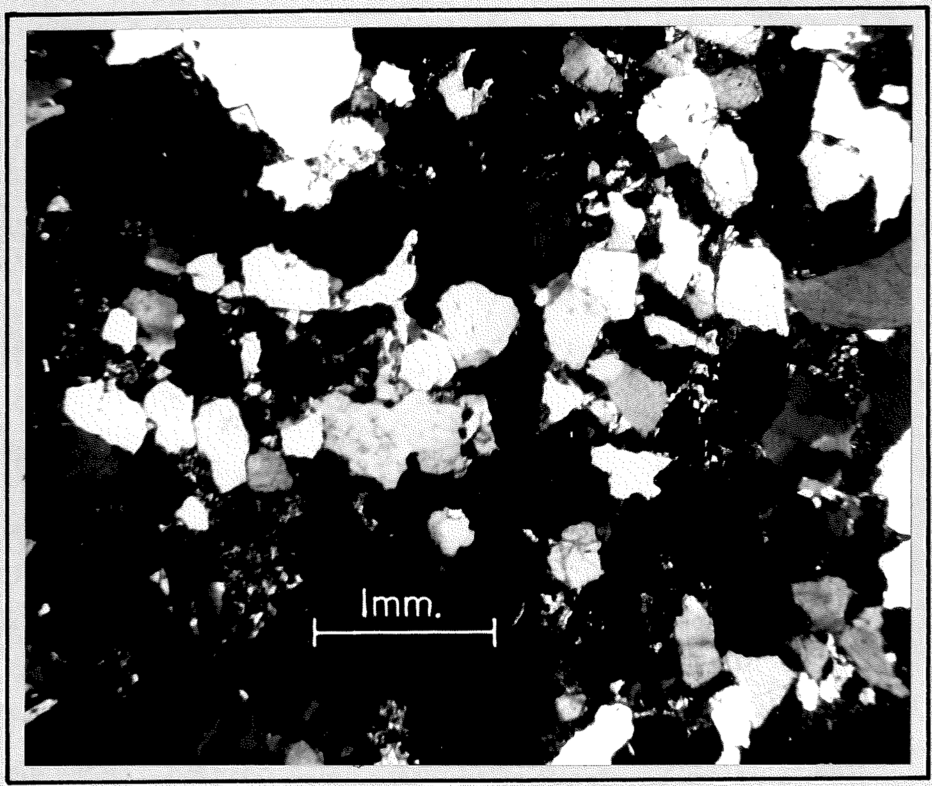

Figure 12

Photomicrograph showing quartzose sandstone from the Manastash formation south of Frost Mountain. At least 90% of the grains in the section are quartz or quartzite. Crossed nicols.

to the bedding.

Coal seams occur in the Manastash formation at many different localities (figure 13). The coal is not confined to any one lithologic assemblage, although it is more commonly associated with the shales than it is with the arkosic sandstones. The larger seams of coal exposed on the surface have been developed or mined. Old mines no longer in operation are at the following localities: Lower Taneum Valley—Wilson Coal Mine (section 33, T.19 N., R.16 E.); South Fork of Taneum Creek (section 34, T.19 N., R.15 E.); North Fork of Manastash Creek (sections 11 and 14, T.18 N., R.15 E.); South Fork of Manastash Creek (sections 21 and 22, T.18 N., R.15 E.); Frost Creek (section 10, T.18 N., R.15 E.). None of the coal seams could be correlated with each other because of the limited extent of the coal seams and inadequate exposures.

The absolute thickness of the Manastash formation could not be determined specifically, but it certainly is greater than the 200-300 feet estimated by C. E. Weaver (1937, p. 52). Saunders (1914, p. 133) stated that the Manastash must be at least 1000 feet thick as a result of a drill hole in the lower part of Taneum Valley in the NW$\frac{1}{4}$ of section 33, T.19 N., R.16 E. This hole ended in sandstone.

The good roadcuts and exposures in sections 33 and 34, T.19 N., R.15 E. show that the Manastash formation in these two sections is homoclinally dipping to the southwest. The strikes and dips are fairly uniform and, assuming there has been no repetition by faulting or folding, the sediments are at least 3000 feet thick and there is no way to determine how much of the formation has been removed by erosion before the overlying Taneum flows were extruded.

The sediments exposed in lower Taneum Valley deserve special attention because they have been broken down into two different sedimentary units in

Figure 13

View of caved-in adit showing coal seams overlain by massive feldspathic sandstones in the Manastash formation. Hammer is on coal seams. Note squeezing of coal into one of the fractures in the massive sandstone.

this thesis: the Manastash formation, and either an interbed of Yakima basalt (Miocene), or sediments of post-Yakima age. Heretofore, both units have always been mapped as Manastash formation. G. O. Smith (1904, p. 7) in the original work in this area commented, "Lower on Taneum Creek, about 200 feet of sandstone and shale are exposed beneath the Miocene basalt, and the position of this small area is believed to justify the correlation of the sedimentary rock with the Manastash formation".

Saunders (1914, p. 131) in describing the rocks around the Wilson Coal Mine on the south side of Taneum Creek in section 33, T.19 N., R.16 E. stated:

> "The formation in which the coal is found is called the Manastash formation because of its similarity and relation to the formation farther south along the Manastash Creek. It consists of coarse conglomeratic sandstones, arkosic sandstones and shales with abundant leaf remains, unlike those found in the Roslyn formation and similar to those found along Manastash Creek. Thin beds of a fine grained white shale containing volcanic glass fragments are interbedded with the other sediments as in the Manastash formation. It is therefore inferred that these beds were laid down in the same lake basin as those exposed on the upper Taneum and on Manastash Creek".

The coal mine is now entirely caved-in and no coal is seen in place, although the remains of large coal dumps from the mine are visible immediately south of Taneum Creek.

The eastern group of sediments are well exposed along the road and in the stream bank on the south side of Taneum Creek. The sediments consist of gently to steeply dipping arkosic conglomerates and sandstones, thin-bedded siltstones and leaf bearing shales. The leaves have been identified as Eocene in age and will be discussed later. The coal seams have already been mentioned.

The western group of sediments are not as well exposed as the eastern group being much more non-resistant to weathering compared with the eastern beds. The only exposures are in bulldozer cuts. The best exposure of the western sediments is in a roadcut along the road to Quartz Mountain where the road crosses the section line between sections 28 and 29, T.19 N., R.16 E. The cut exposes several types of flat lying strata. One type is a clay shale that is very distinctly bedded, compact and breaks with a pronounced conchoidal fracture. The other main type of sediment is a tuffaceous sandstone which contains larger fragments of volcanic material. Megascopically, the tuffaceous sandstone here is identical to sandstone exposed in two other localities in the area. The sediments at both of the other localities are distinctly either interbeds of Yakima basalt or post-Yakima sediments. These localities are discussed in detail in the description of the Yakima interbeds.

North of the Taneum guard station on the south side of Cle Elum Ridge, a short road was constructed in the early summer of 1956 to provide access to a spring site for the guard station. Cuts along the road show the rocks to be chiefly clay shales, fine grained sandstones and coarse grained sandstones and conglomerates consisting predominantly of volcanic fragments. The clay shales are markedly cross-bedded and in several places, the coarse grained sediments appear to have a faint cross-bedding shown by the alignment of the larger fragments. The stratification was not sufficiently developed to determine any attitudes.

In an old railroad cut just south of Taneum Creek in the NW$\frac{1}{4}$SW$\frac{1}{4}$ of section 28, T.19 N., R.16 E., a series of tuffaceous sandstones are exposed dipping about 4° east. The attitudes were variable, so this represents just a general figure.

Although the thickness could not be accurately determined, the interbeds must be at least 200 feet thick near the Taneum guard station because of the different elevations of several exposures of the unit in a relatively small area.

Laval (1948, p. 36) was the first person to suggest an apparent discrepancy in the identification of the sediments exposed in the roadcut in sections 28 and 29, T.19 N., R.16 E. Laval had been studying the Ellensburg formation (upper Miocene ?) with special emphasis on percentages and types of heavy minerals in the sediments. The nearest outcrops of the Ellensburg formation are exposed several miles to the east and southeast of the roadcut, but Laval sampled the roadcut when driving up the valley. He stated in his thesis:

> "An apparently horizontal bed of tuffaceous sandstone is exposed here. Basalt may be seen across the creek at a slightly higher elevation. The petrographical character of this sandstone is different than that of the Manastash sandstones as described by Smith (1903). The Manastash sandstone is described as arkosic and similar to that of the Eocene Swauk and Roslyn formations, which contain very little glass, unlike the Ellensburg. It is possible that the sandstone at locality 13 (the roadcut) represents an early phase of the volcanic activity which apparently culminated in Ellensburg time. Further evidence for this view is afforded by Beck who states that middle Miocene fossil leaves have been found in this vicinity, although not far below the guard station Eocene leaves have been collected from steeply dipping beds".

To summarize, only the easternmost sedimentary unit was mapped as Manastash in the lower Taneum Valley for the following reasons: (1) Presence of coal and Eocene fossil leaves in the eastern area and the absence of them in the western sediments; (2) Steeply dipping beds in the eastern area whereas the sediments in the western area are horizontal or very gently dipping; (3) Distinctly different lithologies—the sediments of the western area were not seen in any other exposures of the Manastash formation, but rather, in other areas, were seen only as interbeds in the Yakima basalt; (4) Laval's suggestion after studying the heavy minerals in samples of sediments from the roadcut.

Age

G. O. Smith (1904, p. 7) made a collection of fossil plants from a nondescript locality near the head of the North Fork of Manastash Creek. Of about 25 specimens examined, Knowlton was able to identify the following:

Quercus consimilis Newberry

Quercus drymeja Newberry
Castanea castaneaefolia (Unger) Knowlton
Laurus grandis Lesquereux
Laurus princeps Lesquereux
Laurus californica Lesquereux

Knowlton commented, "Not a single one of these species, or anything closely approaching them, has thus far been found in either the Roslyn or Swauk formations". Smith added to this, "The two species of Quercus occur also in the Clarno formation of the John Day basin, Quercus drymeja being found also in the Florissant beds of Colorado. The other species occur also at Corral Hollow, California. Upon these considerations the Manastash formation is believed to be of upper Eocene age".

Warren (1936, p. 244) suggested that the Manastash formation could be lower Miocene or upper Oligocene in age on the basis of leaves. He stated:

> "Of five species of plants recognized from the latter by Knowlton, three occur in the Corral Hollow beds of California; the other two occur in the upper Clarno beds of Oregon; and one of the latter occurs in the Florissant beds of Colorado. The Clarno beds and, apparently, the Corral Hollow beds, were considered at that time to be Eocene; and, on that basis, the Manastash was called upper Eocene by Smith. According to the more recent views of Chaney (Pub. Carnegie Inst. of Washington, No. 349, pp. 1-33, 1925), the Corral Hollow flora is Miocene, and the upper Clarno (Bridge Creek) flora is Oligocene. If the Manastash is lower Miocene, or upper Oligocene as seems indicated by the flora, the lower Miocene age of both the Taneum andesite (as postulated by Smith) and the upper part of the Keechelus series (as postulated here) seems probable. However, correlation based on so small a flora should not be stressed too strongly, and it may well be that the Manastash is more nearly of the age that Smith has indicated, thus leaving some leeway in the age assigned to the Taneum and the upper part of the Keechelus".

The writer found identifiable fossil leaves at five different localities in the Manastash formation. The exact localities are shown on the geologic map with a FL prefix (i.e. FL 8166.7). A detailed description of the fossil localities is given later.

The better specimens were taken to Dr. Ralph W. Chaney of the Department of Paleontology, University of California at Berkeley, who studied them and was able to identify the following:

LOCALITY	GENUS	SPECIES	CORRELATIVE
8266.5—8306.7	*Glyptostrobus*	*europaeus*	Clarno
8166.7	*Sabalites*	*powellii*	Swauk or Green River
8176.2	*Dryophyllum*	*tennesseensis*	Wilcox
8176.2	*Meliosma*	*goshenensis*	Goshen
936.3—8176.2	*Ficus*	*quisumbingi*	Goshen
8166.7—8176.2	*Tetracera*	*oregona*	Goshen
8306.7	*Magnolia*	*reticulata*	Goshen
8166.7	*Chaetoptelea*	*pseudo-fulva*	Chalk Bluffs
8166.7	*Phytocrene*	*sordida*	Chalk Bluffs
8166.7	*Platanus*	*aceroides*	Goshen

It must be emphasized in considering these determinations that all the species are subject to question as well as the last five genera.

Dr. Chaney noted that the family *Lauraceae* was probably represented, but could not be positively identified because of incomplete specimens. *Dryophyllum* might be the equivalent of Knowlton's *Quercus* and *Tetracera* might be the equivalent of *Castanea*.

All the leaves represent broad leafed evergreens typical of the early Tertiary in Washington. They indicate a sub-tropical climate during their time of growth. It is interesting to note that florally the late Cretaceous (?)-early Tertiary Swauk formation, the middle Eocene Roslyn formation, and the Manastash formation are so similar as now known that there is no basis for distinguishing them stratigraphically. Chaney believes that with larger collections they may be separated as readily as are other older Tertiary floras in western North America.

It has been stated by many writers that no single species of leaf has been duplicated in the Swauk, Roslyn or Manastash formations, although several genera are duplicated. With the present lists, two species are duplicated, at least by name, in the Swauk and Manastash formations. Landes (1901, p. 32) made a collection of leaves from the Swauk formation along Coal Creek near

Hamilton, Skagit County, Washington. Knowlton identified from this collection Glyptostrobus europaeus (Brongniart) Heer. According to La Motte (1952, p. 178), this species has been found in sediments ranging in age from Paleocene to Pliocene. However, Chaney would limit Glyptostrobus europaeus to the Paleocene and Eocene and would list Glyptostrobus oregonensis for the Miocene and Pliocene (personal communication).

C. A. Duror (see W. S. Smith, 1916, p. 572) collected leaves from the Swauk formation near Skykomish, King County, Washington. From these leaves she was able to identify, among other species, Sabal powelli (Newberry). La Motte states this species has been found in beds of Paleocene and Eocene age.

In addition to locality FL 8166.7 in the thesis area, Sabalities was found at localities FL 8176.2 and FL 936.3 and is one of the more abundant types at all of these localities.

Dr. Chaney pointed out that Knowlton's original collection needs to be entirely re-examined and identified again. The names used by Knowlton have since been synonymized or the names or time values have been changed so the original names have lost their chronological significance. This must be realized by anyone working with fossil leaf names from older literature because it is impossible to use the older names to obtain modern time determinations. For instance, Dr. Chaney said the Roslyn formation which is regarded as middle Eocene (Hesse, 1936; Wheeler, 1955) in age, would, on the basis of fossil leaves taken from it and identified by Knowlton in 1898, be in part the equivalent of the Latah formation in eastern Washington and Idaho. The Latah is considered to be middle to upper Miocene in age.

Dr. Chaney felt that a middle Eocene age was most probable for the assemblage of leaves studied, but he noted in a later letter that the sub-tropical trend represented by leaves in the Manastash places its age as older Tertiary. In this case, at the present time, the age cannot be pinpointed accurately between the base of the Paleocene and the top of the Eocene.

Fossil leaf localities

Fossil leaves were found at several localities besides those mentioned previously and described in detail below, but the specimens collected were not complete enough to be identified. One of these localities is about half a mile southeast of the Taneum guard station along the Taneum Creek road (figure 14). The leaves occur in thinly-bedded sandstones and arenaceous shales. Another locality is along the south bank of Manastash Creek on the section line between sections 22 and 23, T.18 N., R.15 E. Here the leaves are in carbonaceous shales. One leaf fossil was also found in massive feldspathic sandstone near the western contact of the Manastash formation in the western part of section 33, T.19 N., R.15 E.

FL 8166.7—Located approximately 50 yards south of an old coal loader and dump in a bulldozer cut near the North Fork of Manastash Creek in the NE$\frac{1}{4}$NW$\frac{1}{4}$ of section 14, T.18 N., R.15 E. (figure 15). The area has been logged off and the bulldozer cut formed as a result of the logging operations is an excellent place for collecting leaves. The leaves are in shales, arenaceous shales and sandstones, although the coarser sediments predominant. Most of the leaves, with the exception of Sabalites, are poorly preserved because of the friable coarse material. Six different palm fronds were encountered in digging as well as a 12 inch section of a palm stem. The sediments are principally thin-bedded and strike northwest with a southwesterly dip. All the palm fronds were oriented with the converging parts pointed up the dip which means that in reconstructing the depositional surface, all the stems would be pointed to the northeast. The stratigraphic distance from the base

Figure 14

Arkosic sandstones and arenaceous shales exposed in a roadcut $\frac{1}{2}$ mile southeast of the Taneum guard station. The sediments dip steeply to the north. Very poorly preserved Eocene leaves occur in thinly-bedded arenaceous shales at the base of the hammer.

of the formation to the sediments in this cut is not known.

FL 8176.2—Located along a new logging road which has been constructed along the north side of the North Fork of Manastash Creek in the SW$\frac{1}{4}$ of section 11, T.18 N., R.15 E. Leaves are not confined to one particular place, but occur in many of the exposed sediments for several hundred yards along the road. This locality can be reached by driving up the North Fork road. The road is close to the creek, but as the east side of section 11 is crossed (marked on tree on northeast side of road), the road begins to rise above the stream. Leaf bearing strata are along the road west of the section marker on the tree. The leaves are generally very well preserved in dark gray to black arenaceous or carbonaceous shales. Coal seams $\frac{1}{4}$ inch to 10 inches thick occur at various stratigraphic positions. Palms are very abundant. In one place, three different palms were in a piece of shale 1 inch thick. The base of the section was not exposed.

FL 8266.5—Located in a roadcut along the South Fork of Taneum Creek in the SW$\frac{1}{4}$NE$\frac{1}{4}$ of section 33, T.19 N., R.15 E. (figure 16). The road at this place winds down the south side of Taneum Ridge and is immediately adjacent to the creek. The roadcut is on the north side of the road about 15 feet from the stream. The leaves are well preserved in a dark gray, thinly-bedded carbonaceous shale and in a very well-indurated thin-bedded shale. A thin seam of coal is interbedded with the thinly-bedded shales. The sediments are approximately 2000 feet above the stratigraphic base of the formation which is exposed northeast of this locality.

FL 8306.7—Located on the southern bank of the North Fork of Taneum Creek in the SW$\frac{1}{4}$NW$\frac{1}{4}$ of section 20, T.19 N., R.15 E. The locality is accessible by trail only and is between the 4 and 5 mile markers on the U. S. Forest Service trail which follows the north side of Taneum Creek. As the locality

Figure 15

Fossil locality FL 8166.7 in the Manastash formation. The sediments are thinly-bedded sandstones and shales which dip to the southwest. An old coal loader and coal dump is in the background.

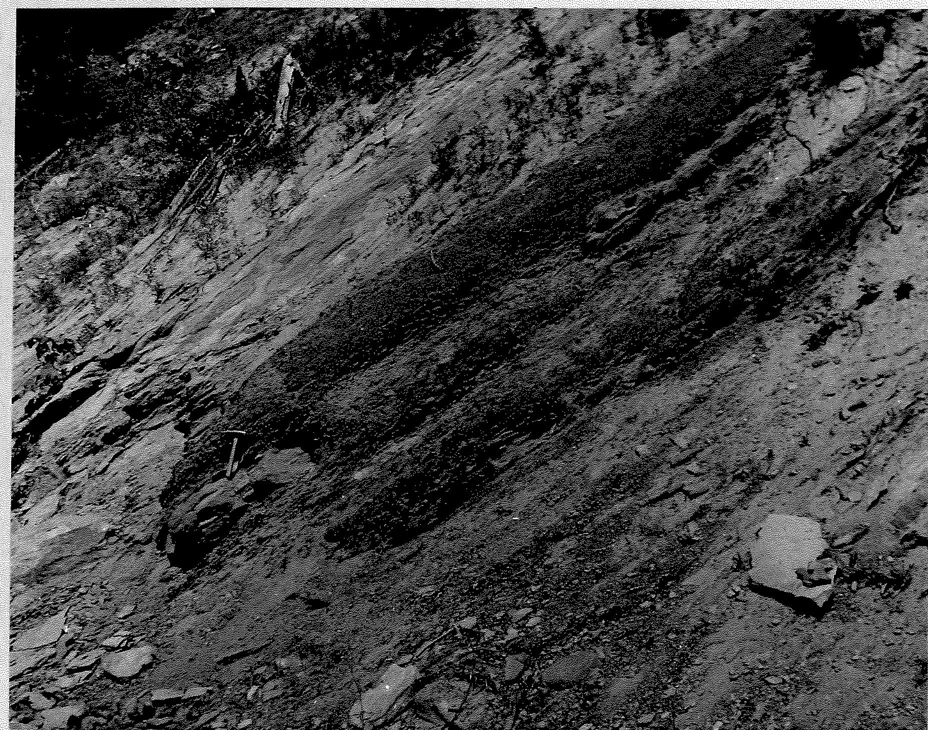

Figure 16

Darker sediments are thinly-bedded, leaf bearing shales of the Manastash formation exposed along the South Fork of Taneum Creek. Thin seams of coal are common in the shales. The shales are underlain and overlain by massive feldspathic sandstones. The sediments are dipping 40° to the southwest. This is fossil locality FL 8266.5. Note hammer for scale.

is approached from the east, a very prominent cliff of Easton greenschist can be seen on the south side of the stream. About 100 yards farther up the trail is a large clearing several hundred yards in length. The leaf locality is approximately 75 yards southwest of the western margin of this clearing and can be reached only by struggling through the underbrush along the stream. The leaves are in thinly-bedded, carbonaceous shales and are well preserved. Many fragments of carbonized material, apparently the remains of small twigs, are scattered through the shales. This locality is approximately 500 feet above the base of the formation.

FL 936.3—Located on the southern bank of Taneum Creek in the NE$\frac{1}{4}$NW$\frac{1}{4}$ of section 33, T.19 N., R.16 E. The locality can be reached by driving approximately $\frac{1}{2}$ mile southeast from the Taneum guard station where there is a rather sharp curve in the road. From this sharp curve, the locality is about 100 yards south across the river. Only one of several exposures of sediments was found to be leaf bearing. The leaves are in a brown, thinly-bedded, arenaceous shale. Seven palm fronds were seen at this exposure. The base of the formation was not exposed.

Conditions of deposition and source of sediments

In order to reconstruct the depositional environment of the Manastash formation as accurately as possible with existing information, the writer would like to review some of the criteria used for his conclusions. They are as follows:

1. Cross-bedding in some of the sandstones and similar structures shown by pebbles in some conglomerates and coarse grained sandstones.
2. Cut and fill structures and channels filled with massive indurated shale and sandstone in thinly bedded carbonaceous shale.
3. Absence of any fossils except leaves and these indicate a sub-tropical

climate at time of growth.

4. Predominance of red to brown arkosic sandstones and conglomerates in the formation, with almost no shales other than the dark carbonaceous shales bearing the leaves. The carbonaceous shales are generally grouped together with the coal seams in stratigraphic section.
5. Reddish-brown sandstones probably indicate deposition under oxidizing conditions.

G. O. Smith (1904, p. 2) and Saunders (1914, p. 28, 131) visualized a series of southward migrating basins to account for the deposition of the Swauk, Roslyn and Manastash formations. Although Smith did not state it as directly as Saunders did, he implied the sediments of the Manastash formation were deposited in a large lake occupying the basin. However, as Davis (1900, p. 596-604) pointed out, at this time it was an accepted rule that most sediments containing no marine fossils with good bedding were lacustrine deposits. Very little attention was given to field evidence which would separate fluvial from lake deposits.

Some of the individual criteria listed above do not definitely indicate any one type of environment, but considered collectively, they seem to indicate what the principal environment was. In view of the above criteria, it is believed the Manastash formation was deposited in a fluviatile type environment on the floodplain of a moderate sized river. This would be the valley flat environment according to Twenhofel (1950) and others. Sediments were not being deposited uniformily over the floodplain at any given time and swampy areas were common on the floodplain containing dense growths of vegetation. The distribution of the individual swampy areas determined the location of the present coal seams.

The occurrence of quartzose sandstone in the southern part of the area could be explained in several ways. If the Easton schist was supplying detrital material, quartz would be the principal resistant constituent. Otherwise, it might be the result of local reworking by streams or possibly formed as a result of selective transportation by streams. No evidence was found to indicate it represents a beach deposit.

There are many things which can explain the aggradation of a river. The question as to why the river was aggrading in this area or why the Manastash sediments were being deposited cannot be definitely answered, but the writer believes that it was, at least in part, due to deformation during deposition. Questionable evidence is given later in the structure chapter which suggests there was deformation contemporaneous with deposition. In addition to this evidence, the great thickness of fluvial sediments in the Manastash formation also suggests there could have been deformation occurring with the deposition. It is possible to get a considerable thickness of fluvial sediments without having any deformation, but in this case, it is hard to conceive of the large amount of material being deposited over a fairly large area without having any deformation.

Probably just as important a factor for causing deposition and possibly contemporaneous with any deformation would be a change in climatic conditions. Not enough is known about the paleobotany in Washington during the early Tertiary to determine local climatic trends, so this factor cannot be given full evaluation. It is known that most of Washington and Oregon probably went from a sub-tropical climate in the early Tertiary to a more temperate climate in the latter part of the Tertiary (Chaney, 1940).

Not enough information could be obtained to determine the source of most of the Manastash sediments. It is known that some of the formation was derived locally from positive areas of the Easton schist, but the high feldspar content in some of the sands cannot be accounted for in this respect as the Easton schist contains very little andesine or oligoclase. The provenance in this case must be one which is capable of supplying a large amount of feldspar and is probably one of granitic composition.

Correlation

The Manastash is not in contact with any other sedimentary unit in the Mt. Stuart quadrangle and this makes correlation on a purely stratigraphic basis very difficult. It also makes several alternative interpretations possible.

Before attempting a correlation, several factors must be considered and each one of these must be evaluated according to its own merit.

One of these factors, of course, is the middle to upper Eocene age of the Manastash formation suggested by the fossil leaf assemblage. However, the value of this age has been discussed and until more work is done on floras of this type, the age designation will have to remain tentative.

Another factor to be considered is the lithology of the Manastash. Although the Manastash consists predominantly of feldspathic or arkosic sandstones similar to most of the early Tertiary terrestrial sediments in this part of Washington, shales, both carbonaceous and leaf bearing, are not uncommon. Bressler (1951) describes very few shales in the Roslyn formation, and does not state that any of them are leaf bearing. However, Smith (1904, p. 5) described shale from the Swauk formation as "black and carbonaceous, and at several localities it contains well preserved fossil leaves". The coal is of no value as a factor in correlation as all the early Tertiary sedimentary units in Washington contain various quantities and grades of coal.

Probably the most important factor in correlation is the amount of deformation that has affected the Manastash formation. Dips in the Manastash are as high as 70°, with more common figures around 40°. At one locality on the North Fork of Manastash Creek, thin-bedded arkosic sandstones are overturned to the north, but this is just a local feature and probably directly related to a coal seam near the overturned sediments (figure 17).

High angle superficial dips are not known in the Roslyn formation. Bressler (1951) found no dips over 23°. The structure in the Roslyn formation is generally homoclinal to the south. No folding other than the homoclinal structure is recorded on the surface. Saunders (1914, p. 62) mentioned that dips in the Roslyn coal field varied from 10° to 30°, and some dips were higher around local sandstone rolls near the coal beds.

Approximately 15 miles northwest of Cle Elum, Foster (oral communication) has mapped places in the Swauk formation where the sediments are vertical or even overturned. However, high angle dips around 60° to 70° are more common in the Swauk formation in Foster's area.

In the Blewett Pass—Swauk area, approximately 20 miles northeast of Cle Elum, Alexander (1956, p. 16) divided the sediments of the area into two formations as Russell (1899, p. 118) had done earlier. The older formation is called the Swauk formation and the younger is the Camas formation. Alexander reported dips in the Swauk as high as 80° overturned, but the majority of them range between 50° and 70° in normal position. Dips in the Camas were not as extreme. The highest dip was 60° in undisturbed sediments with more common dips around 40°.

The relationship of the Eocene feldspathic to arkosic sandstones and conglomerates in lower Taneum Valley to the sandstone found in water wells and drill holes in the Yakima Valley is unknown. This sandstone will be referred to in the discussion of the Roslyn formation. The two places are

Figure 17

Local folding in the Manastash formation has produced overturned beds in this bull-dozer cut. Sediments are thinly-bedded feld-spathic sandstones. Arrows indicate direction of dip. Prevalent dip around this locality is to the south. View is to the east. Note hammer for scale.

approximately 5 miles apart; the area in between the two localities is covered by younger basalt flows. No attitudes could be taken on the sandstone in the well, but the sediments in lower Taneum Valley have a maximum dip of 62° north. Several possible relations could exist under the basalt flows of Cle Elum Ridge: (1) The two sedimentary units could be the same; (2) The sandstones in lower Taneum Valley could dip under the northern sandstones and consequently, be older—the units could be separated either by an unconformity or the Teanaway basalt or both; (3) The sandstones in lower Taneum Valley could overlie the sandstones to the north and thus be younger. As the units cannot be traced either continuously or by scattered outcrops, the relationship is entirely theoretical and no one hypothesis is more suggestive of being true than another.

As stated before, Smith believed the Manastash was later that the Roslyn on the basis of certain leaves. Weaver (1937, p. 53) stated, "It (the Manastash) may be entirely later than the Roslyn or may be equivalent to the upper Roslyn as well as very late Eocene and possibly early Oligocene", but he cautioned that a detailed study of the flora was needed for more positive evidence. Any conclusion made from the factors discussed above is only tentative as more critical information is needed. However, on the basis of structural deformation, the Manastash appears to be more closely correlated with the older sedimentary rocks in adjoining areas. This would indicate that the Manastash is not a correlative of the upper Roslyn nor is it younger than the Roslyn. If the Manastash is pre-Roslyn in age as seems to be suggested, then it is probably a correlative of the upper part of the Swauk formation.

Figure 18

Southeastern end of Frost Mountain from the southwest. Dashed lines represent the approximate contacts between the Manastash formation (M), Taneum formation (T), and the Yakima basalt (Y). Frost Mountain lookout is on the bare hill on the left. Cle Elum Ridge is in the right background.

Pre-Teanaway sediments

Southwest of Cle Elum, arkosic sandstones are exposed in a railroad cut and along the southern bank of the Yakima River. They crop out at the eastern end of the Chicago, Milwaukee, St. Paul and Pacific Railroad bridge across the Yakima River, just south of the intersection of the Cle Elum River with the Yakima River. The sediments have not been mapped before.

The sediments are very-thin bedded to massive arkosic sandstones and slabs of the thin-bedded sandstones are common along the bank of the river south of the railroad bridge. Shaly partings and carbonaceous partings separate the individual beds.

In the railroad cut, attitudes are extremely variable and true bedding planes are hard to distinguish. In one place the strike of apparent bedding ranges from N.80° E. to N.45° W. in about 25 feet. The dip varies only slightly, and is always to the north. However, west of the cut, near the railroad bridge and along the river south of the bridge, attitudes are very constant and bedding is well defined. The sediments here also dip to the north.

A small diabase dike has intruded the sandstone in the railroad cut about 100 yards east of the railroad bridge. Around the dike is a red colored alteration zone that ranges in width from less than a foot to 4 feet. Sheared zones are common in the sandstone around the dike and these crushed zones have enabled altering solutions from the intrusive material to penetrate beyond the immediate vicinity of the dike. Other small faults showing slickensided surfaces cut into the altered zone and adjacent sandstones. These faults are not of any great magnitude because most of them disappear in the massive sandstones on both sides of the dike. The sandstones adjacent to the faults are more indurated than the thin-bedded sandstones near the railroad bridge. The sheared and altered sandstones around the dike are very friable and it is quite difficult to collect indurated hand specimens, but some of the sandstones along the small faults are very indurated and consequently, it is easy to prepare thin sections from them.

The northerly dip of the sediments suggests they underlie a basalt unit which is exposed approximately 700 yards to the east on both sides of the Yakima River. The contact between the basalt and the sandstones is not exposed. Sandstone float could be found on the steep slope just south of the railroad approximately 400 yards east of the railroad bridge, 450 yards to the west of a railroad cut through the basalt.

Another small area in which these rocks are exposed is in the west central portion of section 4, T.19 N., R.15 E. Thin-bedded to massive arkosic sandstones and arenaceous siltstones are exposed in road cuts, stream banks, and along a siphon constructed to carry the water of an irrigation canal across the stream valley. In this area, the strike is more constant where the thin-bedded sediments are exposed and the dip is always to the north. No carbonaceous material was seen. Slabs of the sandstone cover the eastern slope of the stream canyon just south of where the canal crosses under the road.

The sediments exposed at both localities are very similar in lithology. The predominant rock type is an arkosic sandstone which forms individual beds ranging from thin-bedded to massive. The sandstone is buff or some shade of brown, largely because of the iron oxide in the matrix as cementing material. Most commonly, the rock is medium clastic with the average grain size around .12 mm. The grains are angular and consist of approximately 60% quartz and 35% plagioclase. The composition of the feldspar ranges between An_{26} and An_{44}. Only a few good sections normal to (010) could be found, so it could not be determined whether oligoclase or andesine was predominant. A large amount of the plagioclase is unaltered, but some of it has been altered to sericite or replaced by calcite. The calcite is confined to only the plagioclase grains. Minor amounts of calcite, muscovite, detrital garnet, biotite, microcline and quartzite form the rest of the rock (figures 19, 20). The muscovite is generally parallel to the bedding, although most of the muscovite grains have been contorted around the quartz and feldspar grains as a result of compaction. Another indication of the stresses that accompanied compaction is the bent twin lamellae of the plagioclase grains. Both bending with fracture and without fracture were noted, although neither was very common.

It was not possible to determine the thickness of the sediments as no definite base or top could be mapped.

Immediately north of the sediments in section 4, but separated from them by a cover of gravels, is an outcrop of basalt along the road. The distance from the sediments to the basalt is approximately 75 yards. No dip could be determined in the volcanic unit, but it is assumed that the sediments dip under the basalt.

Approximately 275 yards south of where the irrigation canal crosses under the road, there is a diabase dike cutting the sediments. The diabase, in a roadcut, is covered with considerable soil, so the actual contact zone could not be seen. However, sediments occur on both sides of and over the diabase in the roadcut.

At first glance, the small diabase dikes cutting the sediments at both localities are very difficult to recognize from the surrounding sediments because the color is very similar, especially on weathered surfaces. It was found that a good test to differentiate them is to strike the rock with

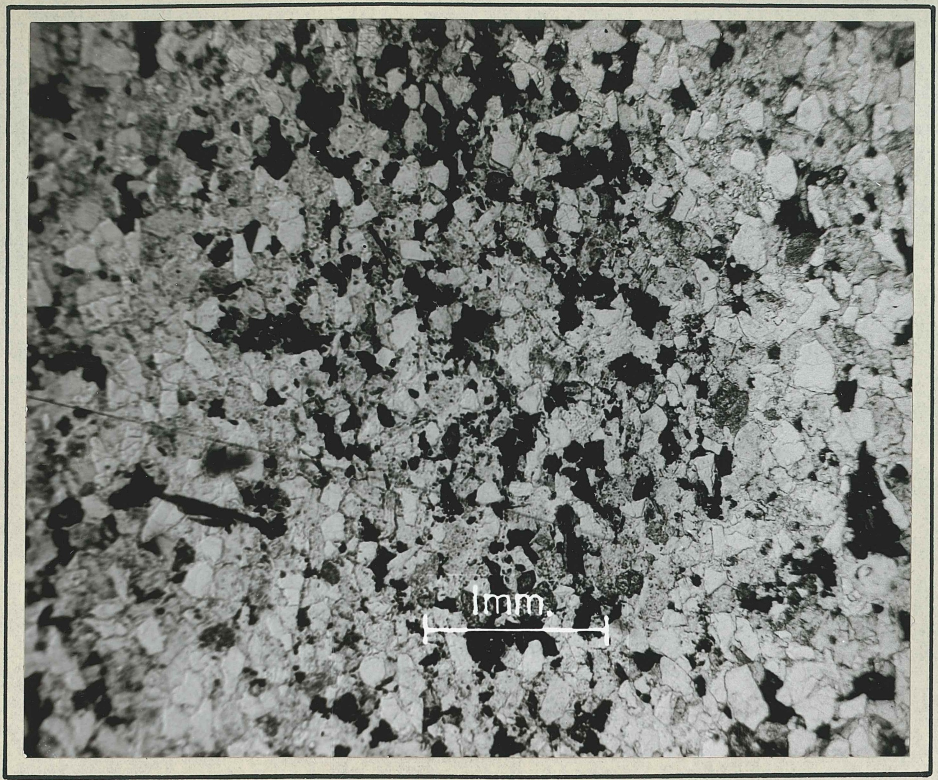

Figure 19--plane polarized light.

Figure 20--crossed nicols.

Figures 19, 20

Photomicrographs of an arkosic sandstone collected from the pre-Teanaway sediments adjoining the Yakima River. Detrital material is largely quartz and plagioclase with minor amounts of biotite, muscovite, calcite, microcline, garnet and quartzite. The bedding is vertical in the pictures and is shown by a concentration of the opaque iron oxides (figure 19).

a hammer. If the ring is sharp, the rock may be diabase. However, altered specimens of diabase are very weak and almost impossible to separate from the sediments without a thin section. Another thing which is misleading in identifying the diabase is that it is finer grained than other diabases encountered south of Cle Elum Ridge and the plagioclase does not stand out as "clay laths" on weathered surfaces as it does in the other diabases to the south.

The diabase was quite altered in all thin sections and mineral percentages were impossible to estimate. Plagioclase is the predominant mineral with pyroxene second in abundance. The plagioclase has been largely replaced by calcite and sericite. Remnants of albite twinning indicate the plagioclase is principally labradorite (An_{54}-An_{60}). The pyroxene has been entirely broken down into its component oxides and could not be identified. Magnetite is identifiable and is surprisingly fresh in appearance. Calcite seams are very common in the rock.

The similarity of lithologies, diabase dikes at both localities, and the proximity of these two small areas of sediments indicate they are the same unit, although they cannot be traced continuously because of a gravel covering.

The isolation of both of these outcrops of sediments from any other known sedimentary unit makes correlation somewhat questionable. It is believed that the sediments are older than the Teanaway basalt and the natural conclusion to make is that they represent an upper unit of the Swauk formation. The Swauk formation stratigraphically underlies the southerly dipping Teanaway basalt 12 miles north of Cle Elum. If the sediments are the correlative of the upper part of the Swauk, the lithology of the upper part of the formation is very similar to some of the rock types in the

Manastash formation.

In addition to the stratigraphic position of the sediments, the amount of deformation they have been subjected to also suggests they may be a correlative of the Manastash formation, at least in time.

Teanaway basalt

I. C. Russell (1899, p. 129, 130) in his early geological reconnaissance within the Mt. Stuart quadrangle, mapped a volcanic unit north of Cle Elum as Columbia lava, which at that time included basalts of Eocene through Pleistocene age. G. O. Smith (1904, p. 6) recognized that the volcanic unit was definitely of Eocene age because it lies between two Eocene sedimentary formations. Therefore, he applied the name Teanaway basalt to it for the exposures along the three forks of the Teanaway River north of Cle Elum. Smith considered the Teanaway basalt to be a series of basalt flows with interbedded basaltic pyroclastics including tuffs.

Southwest of Cle Elum in the southeast corner of section 32, T.20 N., R.15 E., on the north bank of the Yakima River, an old abandoned Northern Pacific Railroad cut exposes a volcanic unit. Smith (1904, p. 6) mapped this particular cut as Teanaway basalt. The writer also believes the volcanics belong to the Teanaway basalt for the following reasons: (1) Similar lithologies compared to the Teanaway basalt exposed to the north in the area defined by Smith as being representative of the formation; (2) Areal alignment of the exposure with known Teanaway basalt 2½ miles to the northwest; (3) Peculiar shiny stained appearance of the basalt when weathered and brittleness of the rock. In this last respect, it is very similar to the Teanaway basalt exposed along the Sunset Highway (U. S. Highway #97) northeast of Cle Elum in Swauk Canyon.

In addition, R. J. Foster, who is currently studying the Teanaway basalt as part of a doctoral dissertation at the University of Washington, informed the writer that the basal part of the Teanaway, in places, is an amygdaloidal basalt which has quite distinctive blue amygdules of secondary silica, probably chalcedony. Inclusions of amygdaloidal basalt with blue amygdules are in this railroad cut (figure 21). The inclusions are large and numerous. One of them is 4 feet in its longest dimension. The high angularity suggests the inclusions have not been carried far and the lack of weathering suggests they have not been exposed at the surface for any large amount of time. If this is true, the volcanics exposed in the railroad cut not only belong to the Teanaway basalt, but are very close to the base of the formation.

Tuff breccias, as well as basalts, are exposed in the railroad cut. Tuff breccias are quite common in the Teanaway basalt north of this area according to Foster (oral communication).

Although the attitude of the volcanics in the exposure could not be determined when examined at close range, it appears that the entire unit is dipping very gently to the northeast (10° to 20°) when viewed from a westerly direction across the river (figure 22).

Small faults are common in the cut and these generally have the same apparent dip as the flows. Calcite, quartz and chalcedony fill many of the brecciated zones. Other faults show freshly slickensided surfaces.

Individual flows could not be distinguished in this cut. No zones of weathering appear in the outcrop and no zones of higher vesicularity were found.

Immediately south of this exposure, on the south bank of the Yakima River, basalt and tuff breccias are exposed in a cut made along the Chicago, Milwaukee, St. Paul and Pacific Railroad. Most of the cut has been made in tuff breccias. This is apparently the same unit as the one on the northern bank because of the (1) proximity to each other, (2) similar lithologies, (3) rapids in the river between these two outcrops which indicate the river flows over a resistant unit, in this place the Teanaway basalt.

Faults of small magnitude are common. One fault in the cut is rather

Figure 21

The hammer is on a large inclusion of amygdaloidal basalt in Teanaway basalt exposed on the north side of the Yakima River near Cle Elum. The Teanaway basalt shows chilled margins next to the inclusion. The amygdules in the inclusion are quartz and blue chalcedony. The inclosing basalt contains amygdules of quartz, chalcedony, and calcite in some places. The white seams above the block are quartz and calcite fillings in fractures and small faults.

Figure 22

View to the northeast across the Yakima River shows an exposure of Teanaway basalt. The flows in the exposure appear to dip to the north. The light colored materials over the flows are Yakima River gravels. The gravels cover the entire area surrounding the exposure.

prominent. Its attitude is N.40° W., 25° SW. and the fault can be traced on each side of the railroad cut. Movement along the fault has apparently caused enough friction and heat to consolidate and weld about a four inch zone in the tuff breccias. This zone is very resistant and stands out in comparison to the tuff breccias.

No attitudes in the basalt or tuff breccias could be determined. With the exception of the outcrop of the northern side of the river, Yakima River gravels cover all the bedrock around the railroad cut.

Two other knobs of Teanaway basalt crop out on the Yakima Valley floor southwest of Cle Elum. One small outcrop is in the NE$\frac{1}{4}$NW$\frac{1}{4}$ of section 4, T.19 N., R.15 E., along an improved secondary road leading southwesterly from South Cle Elum. The only basalt exposed is in the roadcut and just above it. Gravels cover the area surrounding the outcrop. No individual flows could be seen nor any attitudes determined. Part of the basalt has been leached and weathered, but this zone of weathering is confined to a very small area, so it is doubtful if the leaching represents a period of weathering between flows. It is more likely the result of recent weathering along joints or other planes of weakness.

The basalt is very brittle and breaks into small angular pieces. Many randomly oriented joints cut the basalt and it is extremely difficult to get a specimen that will not break apart when cut with a diamond saw.

A larger exposure of Teanaway basalt is in the north central part of sections 3 and 4, T.19 N., R.15 E. The basalt forms a low rounded hill, which is quite distinctive compared to the relatively flat surface formed by the river gravels surrounding it. On the north side of this exposure, an irrigation canal has been contoured around the hill. The excavation made for the canal has produced good exposures of the basalt along the south side of the canal. The basalt is jointed and fractured, but it is still easy to cut a specimen for a thin section. Many of the fractures have been filled with secondary silica and several filled cavities in the basalt contain outer layers of chalcedony with centers of quartz crystals. The chalcedony in these fillings is blue-gray in color and is not similar to the distinctive blue amygdules referred to earlier. The largest of the fillings that was seen was about 4 inches in diameter. Smaller fillings are more common.

The attitude of the basalt unit could not be determined. No individual flows could be discerned.

The largest area of Teanaway basalt south of the Yakima River is $1\frac{1}{2}$ miles east of Cle Elum Point, largely in sections 12 and 13, T.19 N., R.15 E. Here, the Teanaway basalt forms a northwesterly trending ridge. The ridge is a very conspicuous feature from the Yakima Valley because the basalt weathers to form a dark red soil and there is very little vegetation on the crest or the northeastern slope. Jagged crags of basalt rise above the general level of the crest. On aerial photographs, the ridge appears to have a steeper slope on the southwestern side and this was found to be true on the ground. This relationship suggests the basalt unit dips to the northeast, but this could not be verified on the ground. The relationships found near the Yakima River indicate the basalt there is dipping north, so the Teanaway basalt on this ridge would be most likely dipping to the northeast.

In traversing the crest of the ridge, basalts, tuff breccias and leached basalts were encountered. This variation in lithology coupled with the difference in topographic expression along the crest of the ridge indicates there is more than one flow represented, but the exact number could not be ascertained.

Although the ridge of Teanaway basalt is aligned in a northwesterly direction, its extrapolation to the northwest fails to align the basalt with the small exposures of Teanaway basalt on the Yakima Valley floor or the hills of Teanaway basalt on the north side of Yakima Valley. Only theories can be given to explain this situation as the gravel cover prevented the writer from getting information from which to make more definite conclusions.

One explanation might be that the pre-basalt surface was very irregular and consequently, the flows and tuff breccias exposed along the crest of the ridge could be earlier flows that filled the low areas on this irregular surface.

Another explanation might be faulting. Assuming the basalt maintains a consistent dip, a strike-slip fault would have to displace the basalt approximately one mile. Of course, faulting would not necessarily be limited to pure strike-slip types, so other combinations would be possible.

Of the two explanations, the first one is probably the most logical one and also the simplest.

Specimens taken from the different localities at which the Teanaway basalt is exposed were very similar. In the hand specimen, the basalt is a black aphanitic rock on fresh surfaces and is red to brown on weathered surfaces. Commonly it is very brittle and is extremely fractured. In thin sections, the rocks from different localities are just as similar as they are in hand specimen. The texture is mainly intergranular and intersertal, but several specimens were trachitic. A typical thin section has the following average grain sizes for the minerals: plagioclase—.16 mm. in length; pigeonite—.08 mm.; magnetite—.06 mm. No specimens were porphyritic and no porphyritic flows were seen in the field. The basalt consists of about 60% plagioclase, 10-25% pyroxene and 5-15% magnetite. Chlorophaeite occurs in two thin sections. The plagioclase ranges in composition between An_{46} and An_{62}. Pigeonite was the only pyroxene that could be identified using optic axis figures. All optic axis figures on the pyroxene showed an optic angle of less than 40°. Fractures in the basalt are filled with calcite or chalcedony. Iron staining is common along many of the fractures. The iron stain has colored much of the pigeonite along the fractures. Some of the magnetite has broken down to hematite or limonite, but most of it is fresh. The magnetite is mostly euhedral, although anhedral grains occur as well.

Roslyn formation

The Roslyn formation, an Eocene sedimentary unit consisting principally of massive arkosic sandstones with coal seams near the top, does not crop out in the area. However, G. O. Smith (1904, p. 7) mapped approximately 2 square miles of the Roslyn formation south of the Yakima River about 3 miles east of Cle Elum Point. He noted about this occurrence, "....the presence of this formation might not be suspected, so few and obscure are the exposures". The writer could find no exposures whatsoever, and in addition, could find no sandstone float on the surface. There is no reason for the sandstone to crop out as the area is a plain, gently sloping to the north and covered by Yakima River gravels.

An attempt was made to obtain subsurface information to determine if a sandstone unit does lie below the gravels. An Ellensburg drilling firm, the Miller Brothers, have drilled for water on two ranches in this area. One well, on the Roseburg Ranch, in the SW$\frac{1}{4}$SE$\frac{1}{4}$SW$\frac{1}{4}$ of section 1, T.19 N., R.15 E., penetrated 167 feet of clay before encountering gravel. The well was finished in the gravels. One mile east of this well, a second well penetrated 130 feet of top formation (assumed to be clays and gravels) and then hit sandstone. This well was terminated in sandstone at an approximate depth of 438 feet.

During the early part of this century, the Northern Pacific Railroad made a series of bore holes around the Roslyn coal field in an attempt to determine the extent of the minable coal beds. One of these holes was drilled in the NW$\frac{1}{4}$NW$\frac{1}{4}$ of section 33, T.20 N., R.15 E. to a depth of 516 feet. The material encountered consisted of boulders, gravels, sands and clays, apparently all Yakima River deposits. The hole did not reach bedrock. Several holes were drilled immediately north and east of South Cle Elum. The deepest of the holes is in the SE$\frac{1}{4}$SE$\frac{1}{4}$ of section 27, T.20 N., R.15 E. and was drilled to 980 feet.

Clay, sand and gravels were found to a depth of 486 feet where shale was encountered. Below 486 feet, sandstones and shales were the principal rock types. At a depth of 732 feet, a very thin coal seam was found. The hole was ended in sandstone. Another hole drilled farther to the east in the northeastern corner of section 35 encountered the shale at 641 feet and a thin coal unit at 759 feet. This hole was ended at 764 feet. Beside the coal, sandstones and shales were the only rocks below 641 feet.

In the northeastern corner of section 4, T.19 N., R.15 E. are several old coal prospects. The workings are all caved-in or filled with water, but the dumps contain sandstone and shale as well as coal. No outcrops were seen around the dumps. The writer believes that in this area the Roslyn formation is very close to the surface because the volume of material in the dumps indicate very small adits and probably very little of the coal was ever hauled away or used because the coal is a fairly low grade variety.

It will be noted that this area is less than a quarter of a mile north of an exposure of Teanaway basalt. Although no attitudes in the sandstone near the coal prospects are known, there is a good possibility that the Roslyn is dipping to the north forming part of the southern limb of the Roslyn syncline.

Taneum formation

The term Taneum andesite was used by Smith (1904, p. 7) to describe the exposures of andesitic rock occuring along the South Fork of Taneum Creek and extending south to Frost Mountain. Smith described the Taneum andesite as a hypersthene andesite with a subordinate amount of plagioclase and pyroxene phenocrysts. He states that the Taneum andesite includes tuffs and tuff breccias as well as loose textured lavas.

The name Taneum formation will be used through this thesis as a synonyn for Smith's Taneum andesite. However, where the term Taneum andesite is used in this thesis, it refers strictly to andesite flows. As well be seen later, several rock types are present in Smith's original unit which are not andesitic in composition, but in order to avoid the introduction of new names for the non-andesitic rocks, the writer felt it was better to use the established nomenclature in this thesis. With more study, it will probably be possible to break the Taneum formation into several distinct and possibly mapable units.

The largest area in which the Taneum formation is exposed is in the north central part of T.18 N,, R.15 E. and the southern part of T.19 N., R.15 E. From the South Fork of Taneum Creek northward, the rocks are principally volcanic conglomerates[1] with thin andesite or basalt flows at certain intervals (figure 39). To the south, this large area appears to be cut off from its southern extension on the geologic map by a large diabase mass. However, andesite flows continue south for 2½ miles before they disappear under younger basalt flows.

The best exposures of the Taneum formation are along the South Fork of Taneum Creek (figure 23), on Taneum Ridge and in Frost Creek Canyon.

1. Using the classification of Wentworth and Williams (1932).

Figure 23

Cliffs and rugged outcrops of the Taneum formation on the south side of the South Fork of Taneum Creek. The Taneum in the picture is largely a volcanic conglomerate; matrix and boulders consist of porphyritic andesites. This area is the type locality for the Taneum formation.

Generally an outcrop of the Taneum formation can be found in areas free of trees or in roadcuts because of its resistance to weathering.

A smaller area of the Taneum formation is exposed on the mapped flanks of Frost Mountain. Although smaller in areal extent than the area mentioned above, it is relatively important as the relief on the east side of Frost Mountain is high enough to afford a view at part of the stratigraphic section of the formation. Here, the Taneum rests directly on the Manastash formation. The basal part of the Taneum formation consists of andesitic to basaltic flows, some of which are highly vesicular. Overlying the flows are a series of tuffs and volcanic conglomerates and breccias with fragments and boulders of volcanic material. Some of the tuff is composed of ash size fragments, although larger, angular volcanic fragments are more common. The uppermost unit consists of an amygdaloidal basalt. The amygdules are predominantly chalcedony and quartz, but a few calcite amygdules were seen. This exact section was not found duplicated at any other area, although in some places, similar rock types were found. The outcrops were not plentiful enough to provide a detailed section, so it is impossible to give thicknesses of the various types of rock.

The thickness of the formation on the east flank of Frost Mountain where the underlying and overlying rocks are exposed is approximately 400 feet. The thickness of the Taneum formation in the valley of the South Fork of Taneum Creek, where large cliffs of the formation are exposed, must be at least 700 feet on the basis of topographical expression. However, this figure is subject to error as the attitudes of different flows is not known.

Hand specimens from the Taneum formation are all volcanic, but vary greatly in color. Colors range from black to green with several rocks light brown. The more highly altered flows are very light gray or brown. Most of the Taneum is megaporphyritic and some specimens which appeared to be non-porphyritic in hand specimen were microporphyritic in thin section. The rocks vary in freshness; most of the flows appear to be fresh in hand specimen, although in a few local places, alteration has made the rocks extremely friable.

It is difficult to describe the thin sections of rocks from the Taneum formation in general because of the many different types of lithologies. In addition, no definite breakdown of the formation into mapable units could be made, so the flows cannot be described stratigraphically.

One characteristic applying to all of the Taneum rocks is that the microlitic plagioclase in the groundmass is generally altered (figure 24). In some cases, the albite twinning cannot even be recognized in the groundmass feldspar. Plagioclase phenocrysts are usually relatively fresh and generally are zoned. Plagioclase and pyroxene phenocrysts are commonly grouped together in a glomeroporphyritic texture. The most common texture is pilotaxitic with phenocrysts of plagioclase and/or pyroxene in a microlitic plagioclase and "cryptofelsitic" groundmass. The phenocrysts are very numerous in some rocks, but are never more than 35% of the total volume of the rock. Most of the zoning in the plagioclase phenocrysts is oscillatory, with overall composition ranging from a calcic center to a more sodic rim. Many of the plagioclase phenocrysts are corroded with inclusions of pyroxene and glass. The inclusions may be aligned in zones parallel to the compositional zoning. The phenocrysts range in composition between An_{42} and An_{66}, but those of labradorite composition are more predominant. The plagioclase in the groundmass ranges between An_{42} and An_{64}, but only three sections had plagioclase crystals large enough to identify. Calcite and sericite have locally replaced some of the plagioclase.

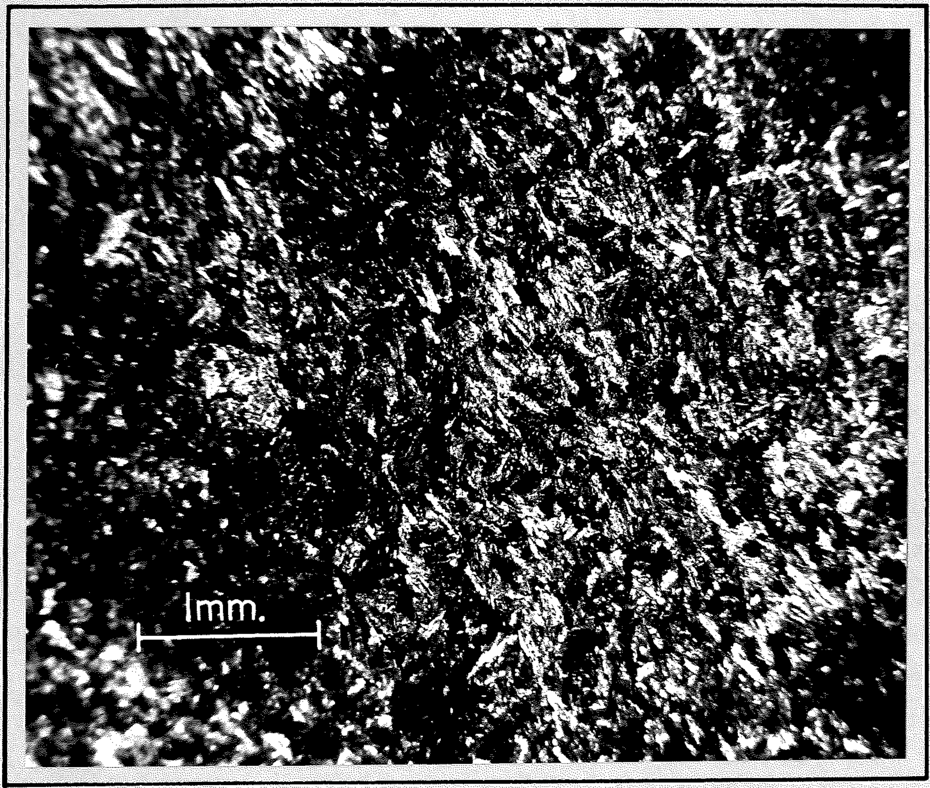

Figure 24

Photomicrograph showing typical altered appearance of the plagioclase in rocks of the Taneum formation. The plagioclase has been largely altered to sericite and calcite with the destruction of the albite twinning. Crossed nicols.

The pyroxene is generally hypersthene, although many sections with hypersthene have subordinate amounts of augite. One section contained only augite. In most of the sections, the pyroxene has been altered leaving only small amounts of fresh pyroxene. Calcite has replaced some of the pyroxene and serpentine and a zeolite occur in other slides and may have replaced the original pyroxene. Many of the pyroxene grains have rims of magnetite or some alteration mineral, possibly bowlingite.

Magnetite occurs in most sections, but never occupies more than 5 to 10% of the section.

The most common boulders in the volcanic conglomerate are porphyritic volcanics, many having the same general composition as the interstitial material. Some of the fragments are angular and in a strict sense should be referred to as volcanic breccias. Other types of clastic material in both the conglomerates and the breccias are diabase, quartzite and very altered volcanics (figure 25).

Even though the composition of the plagioclase phenocrysts is generally that of a basalt, it is not proposed that the volcanics of the Taneum formation be referred to as basalts. The plagioclase microlites may be sodic enough to warrant calling the volcanics andesites.

G. O. Smith (1904, p. 7) mapped the mass of andesites forming Cle Elum Point just south of Cle Elum as intrusive stating, "The relations indicate that the whole mass is intrusive in the schist, sandstone, and Teanaway basalt.... The Cle Elum Point occurrence may be regarded, then as an intrusive mass from the same magma as the effusive lavas of Taneum andesite. It is somewhat doubtful whether this represents the conduit by which the lava flows a few miles away reached the surface, since there is no trace of Taneum andesite in the intervening territory, where it might be expected to have

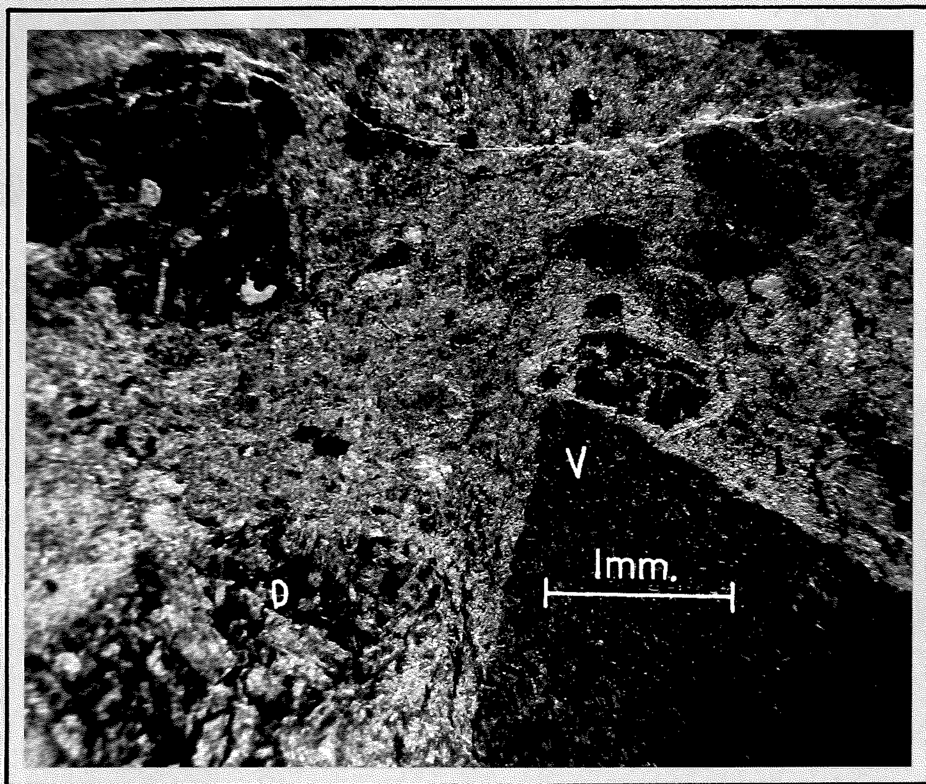

Figure 25

Photomicrograph showing a volcanic conglomerate of the Taneum formation from the area northeast of Frost Mountain. Diabase (D) and altered volcanic fragments (V) are common in a groundmass of altered plagioclase microlites or "cryptofelsitic" material. Plane polarized light.

been preserved beneath the Yakima basalt".

As Smith pointed out, the similarity between the rocks exposed at Cle Elum Point and those exposed farther south is striking. In hand specimen, the volcanics at Cle Elum Point vary in color from light brown to black and are always porphyritic with phenocrysts of plagioclase and commonly pyroxene. The groundmass is always dense or very fine grained. In thin section, the similarity to the southern flows is just as striking except the groundmass texture is coarser than in many of the southern flows. The phenocrysts are labradorite (An_{47}-An_{66}) and pyroxene. The labradorite generally has oscillatory zoning and is commonly corroded containing inclusions of glass, pyroxene and zircon (figures 26, 27). The zones of inclusions are parallel to the margins of the phenocrysts. The more calcic cores of the zoned phenocrysts may be replaced by calcite. The plagioclase in the groundmass is too fine grained to get accurate determinations of the composition. Hornblende, which was not found in the southern flows, occurs in the Cle Elum Point volcanics, and is always surrounded by a dark rim of magnetite and alteration minerals.

Pyroxene occurs in most of the sections and is generally hypersthene. The pyroxene phenocrysts show no alteration rims.

As Smith did not state the reasons or evidence he had for believing the mass of rock is intrusive into the surrounding rocks, it was impossible to check his evidence. The writer believes that a more simple explanation might explain the field relations better than the intrusive origin. No intrusive relations could be found near any of the contacts. The andesites are more altered near the Teanaway contact, but this alteration is characteristic of local areas in the Taneum formation south of Cle Elum Point. The rock always has an aphanitic groundmass. Columnar jointing is very common on the northern

Figures 26, 27

Photomicrographs of the Taneum formation showing porphyritic andesites which form Cle Elum Point. In figure 26, the corroded zones in the plagioclase are very pronounced. Inclusions in the phenocrysts are mainly pyroxene and glass. The dark areas in the groundmass (figure 26) are altered hornblende crystals.

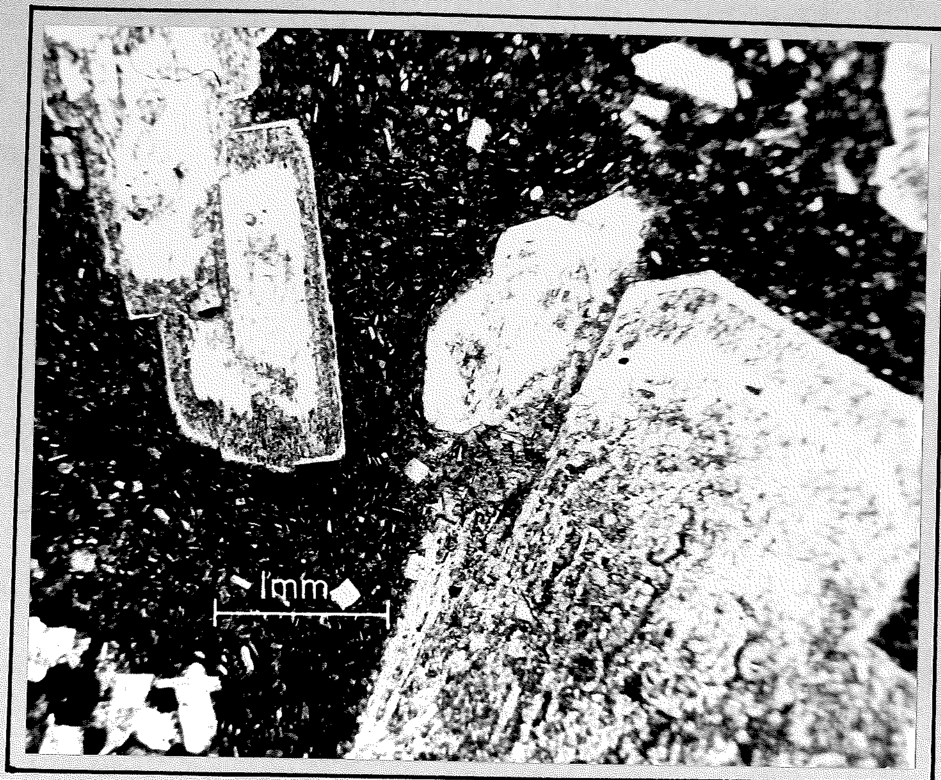

Figure 26—plane polarized light.

Figure 27—crossed nicols.

slope of Cle Elum Point (figure 28).

In discussing the blue amphibole schists near Cle Elum Point, Smith (1904, p. 3) states, "Their occurrence close to the intrusive rock of Cle Elum Point suggests a possible cause of the metamorphism". However, because the blue amphiboles have been found northwest of this occurrence (Foster, oral communication), there is reason to believe the blue amphibole schists are not localized around the Cle Elum Point andesite and there is no need to suggest a local cause for metamorphism.

The writer believes that this occurrence of andesite can be readily explained as a series of flows. No good flow contacts were seen, but even in the type area, none could be definitely recognized. Unless more definite evidence is found to prove an intrusive origin, the field relations, as they have been determined so far, favor the idea of flow origin.

The exact age of the formation is unknown as no fossils were found within it. The only age which can be assigned is that it is younger than the Manastash formation and older than the Yakima basalt. This gives it a range from early to late Eocene to somewhere in the Miocene. Whether the outpouring of the Taneum volcanics occupied a large percentage of that time or whether it was confined to one part of that time is subject to question. There apparently was very little time between flows as no soils or old weathered zones could be found nor were any sedimentary interbeds found. This, of course, does not mean that such things do not exist in the formation.

Several things suggest the age of the Taneum is nearer to the Miocene than to the Eocene. These are: (1) Some relatively fresh flows within the Taneum formation, although most of them have been altered; (2) Time must be allowed for the erosion which took place before the Taneum formation was extruded; (3) The Manastash formation has been involved in strong deformation

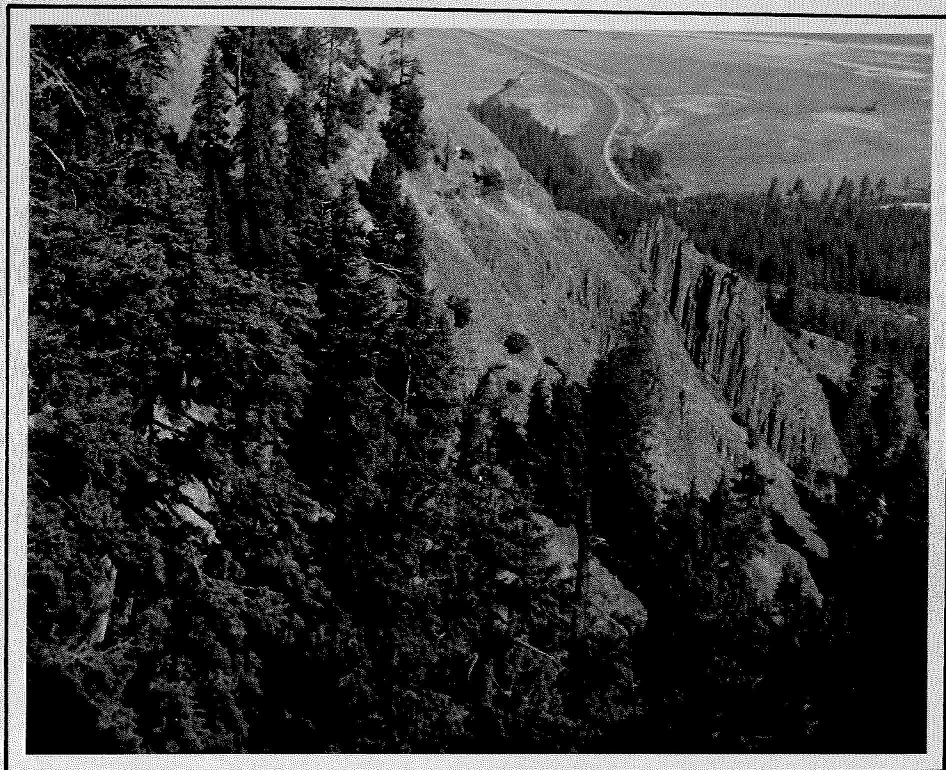

Figure 28

Almost vertical columnar jointing in the andesites at Cle Elum Point. The Yakima River Valley is in the background.

and the Taneum has not, so some time must be allowed for this deformation, although it was probably contemporaneous with the erosion.

With the present study, it is impossible to suggest a correlation of the Taneum formation to units north and west of the area. Mapping of the westward continuation of the Taneum will probably provide more information on this problem.

Warren (1936, p. 244) after working in the area southwest of the Mt. Stuart quadrangle states:

> "The upper part of the Keechelus extends into the northwestern corner of the Ellensburg quadrangle where it forms the prominent cliff known as the Devils slide. It was originally mapped as Quaternic (Tieton) andesite. However, its position subjacent to the Yakima seems to differentiate it from the type Tieton of the lower Naches valley. Five miles north of the Devils slide, in the Mount Stuart quadrangle, is the Taneum andesite which is also overlain by the Yakima basalt. From their petrologic character, as indicated by Smith, their relation to the Yakima, and their geologic proximity, close correlation, if not actual identity, of the Taneum and the upper part of the Keechelus is probable".

The writer believes that Warren's suggestion is at least in part correct. The andesite flows of the Taneum formation which disappear under the younger basalts in sections 13 and 14, T.18 N., R.15 E. may be the same rocks as those which Smith mapped as Tieton andesite in the northwestern part of the Ellensburg quadrangle. The Ellensburg quadrangle is immediately south of the Mt. Stuart quadrangle. The distance between these two exposures is about 4 miles; the area in between is covered by Yakima basalt.

The Tieton andesite was named for its occurrences along the Tieton River farther south in the Ellensburg quadrangle and at its type locality, the Tieton andesite consists of Pleistocene valley fillings. Smith (1903, p. 4) states that "The Tieton andesite, however, is plainly much younger than either the basalt (Yakima) or the Ellensburg formation, since it occupies canyons and valleys eroded in these.... Andesite tuff and conglomerate, red and purple in color, make up the conspicuous cliff known as Devil's Slide". Smith, in addition, mentions that the flows are very fresh.

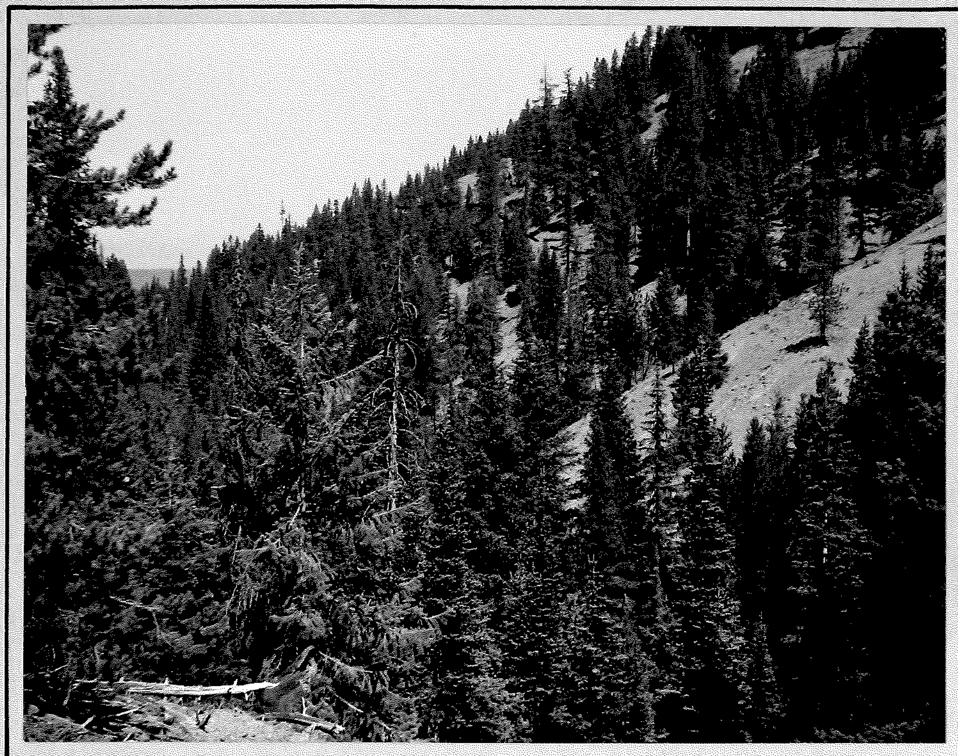

Figure 29

View to the north along Frost Creek Canyon showing approximate contact between the Taneum formation (below) and the Yakima basalt (above).

Yakima basalt and interbeds

The Yakima basalt and interbeds comprise the youngest rocks in the area. Originally the writer intended to map the older units up to the Yakima basalt and make the basal contact of the basalt the eastern and southern margins of the thesis area. However, during the summer, field investigations showed that a study of interbeds both within the Yakima and possibly post-Yakima in age was essential to correctly differentiate the rocks of different ages.

It has been pointed out in the description of the Manastash formation that some of the sediments in the lower Taneum Valley which were originally mapped as Eocene in age, are now believed to be of Yakima or post-Yakima age.

The Yakima basalt was named by Smith (1903, p. 3) after being called Columbia lava and Columbia River lava by Russell and others. No type locality was designated, but Smith described the rock as "a black rock, compact and heavy.... Petrographically, the Yakima basalt is a normal feldspar-basalt containing basic plagioclase, augite, and olivine, in crystals or rounded grains, with varying amounts of glassy base". More recently, detailed petrography of the Yakima basalt has been included in the theses of Abbott (1953, p. 114 ff.) and Laval (1956, p. 14 ff.)

The western and northern contacts of the Yakima basalt where it rests on older rocks represent the erosionally exposed contact of the basalts of the Columbia Plateau. Evidence for the fact that the Yakima basalt was once more continuous, probably covering most of the area, can be seen in the Taneum Valley, in sections 3 and 4, T.18 N., R.15 E. on the northeast flank of Frost Mountain, on Cle Elum Ridge southwest of Cle Elum Point, and on the top of Frost Mountain. At all these places, erosional remnants of Yakima basalt have been preserved resting on older rocks.

Figure 30

View of Frost Mountain from the north. On the ridges approximately parallel to the line of sight are exposures of the Taneum formation, diabase and Yakima basalt. The lookout is on the bare hill in the center of the picture (arrow).

The relief of the pre-Yakima erosion surface can only be given in general terms as the topographic map used for elevations was very inaccurate in places. The highest relief on the erosion surface is on the north side of Taneum Valley. The contact between Yakima basalt and Easton schist rises from Taneum Creek, where it is at an elevation of approximately 2700 feet, to the crest of Cle Elum Ridge, at an elevation of 4200 feet, making the total relief about 1500 feet. It must be remembered that the erosional interval represented here is not only the pre-Yakima—post-Taneum interval. It includes the long interval after the deformation of the Easton and before deposition of the Manastash and also the post-Manastash—pre-Taneum interval. The basalt flows exposed east of this contact are essentially horizontal indicating that there has been very little deformation in this area since the flows were extruded. The horizontal flows can be seen quite well from the south side of Taneum Valley (figure 31).

The difference in elevation between the small area of Yakima basalt northeast of Frost Mountain and the basalt on top of Frost Mountain is approximately 500 feet.

A typical specimen of Yakima basalt from Cle Elum Ridge in section 34, T.19 N., R.16 E. has an intersertal texture and consists of approximately 50% plagioclase, 40% glass and 10% pyroxene. Magnetite is a common accessory mineral and occurs in varying amounts. The plagioclase ranges in composition between An_{38} and An_{60}, but is predominantly labradorite. The only pyroxene that could be determined had a small optic angle, along with the other properties of pigeonite. Polysynthetic twinning is common in the pyroxene. The glass is probably tachylite as it is black and opaque and contains magnetite dust.

The writer found that this general description did not apply to every-

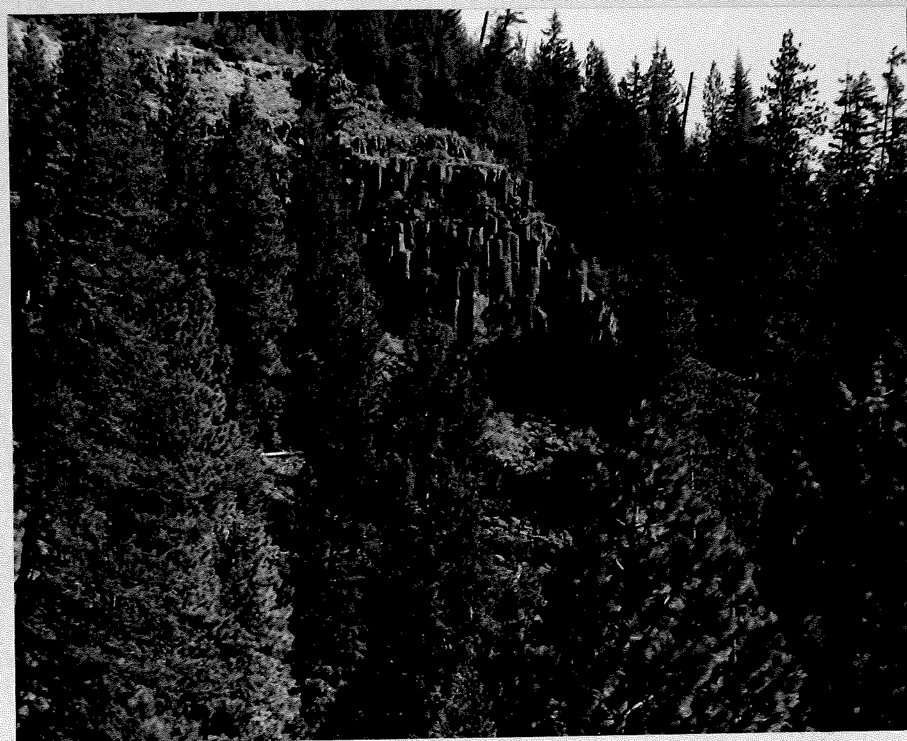

Figure 31

Vertical columnar joints in the Yakima basalt on the north side of Taneum Valley. All Yakima flows in this area are nearly horizontal.

thing that has been mapped as Yakima basalt in the area. The percentage of glass varies at different localities commonly being completely absent. The pyroxene content in others was as high as 40%.

In thin section, several microporphyritic basalts were noted. Generally the plagioclase phenocrysts contain inclusions of glass and pyroxene and the plagioclase has been largely altered to sericite.

The area of Yakima basalt showing the greatest divergence from the general texture and composition of the basalt in lower Taneum Valley is on the top of Frost Mountain. However, one sample collected near the northwestern end of Frost Mountain had an identical mineralogical composition to the basalt from the lower Taneum Valley (figure 32). This sample contains approximately the same percentage of glassy material, feldspar and pigeonite; the only difference is that it is finer grained.

The only olivine bearing basalts in the area were found on the top of Frost Mountain. The olivine commonly occurs as large euhedral phenocrysts which have been largely altered to iddingsite (figure 33). The pyroxene in the groundmass is predominantly pigeonite, although one thin section showed large euhedral augite phenocrysts. Calcite occurs locally and generally has replaced the plagioclase. Corroded phenocrysts of plagioclase (composition between An_{40} and An_{48}) containing inclusions of glass, magnetite and pyroxene were seen in another section. However, most of the plagioclase has a fresh appearance and very little zoning was noted in the phenocrysts. The fresh plagioclase phenocrysts and all the microlitic feldspar that could be identified using albite twinning methods was labradorite.

Detailed study of hand specimens and thin sections of the Teanaway basalt and the Yakima basalt showed that the two are very similar and the only possible definite way to separate them in the area is by field relations. Both

Figure 32

Horizontal columnar jointing in the Yakima basalt on the top of Frost Mountain just west of the lookout. The basalt in this exposure has a large percentage of glass in the groundmass. Note hammer for scale.

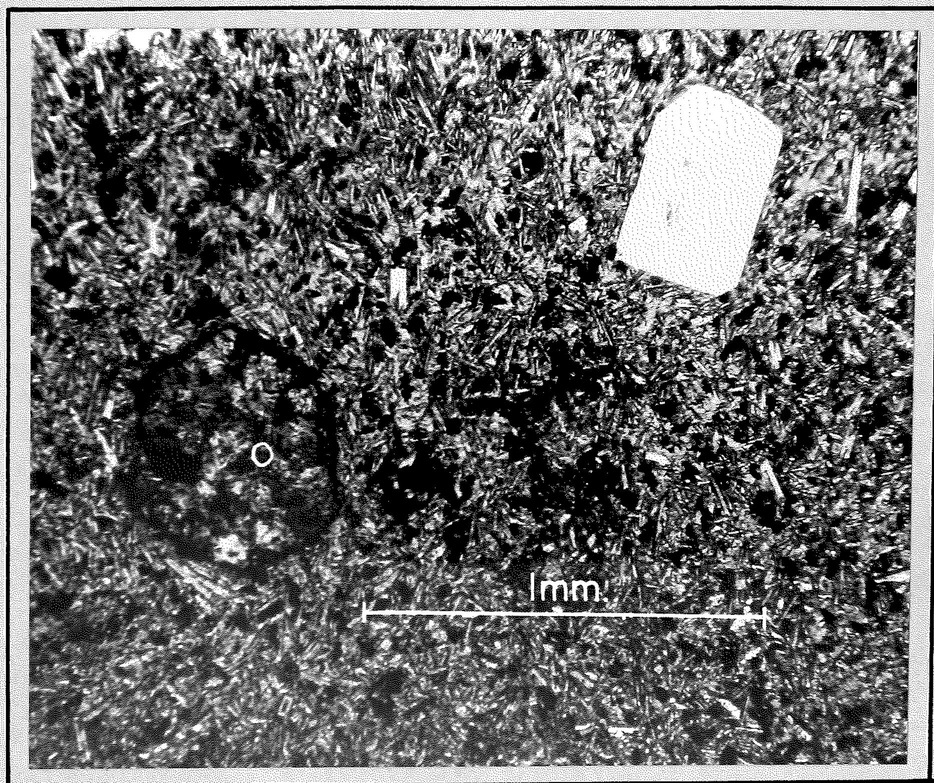

Figure 33

Photomicrograph of Yakima basalt from the crest of Frost Mountain. Note the euhedral olivine phenocryst which is largely altered to iddingsite. The white phenocryst is plagioclase. The groundmass consists of labradorite microlites, pyroxene, and magnetite. Plane polarized light.

basalts are remarkably similar in mineral composition: labradorite, pigeonite and magnetite. However, olivine and tachylite were found in the Yakima basalt, but not in the Teanaway basalt. Microporphyritic flows were common in the Yakima basalt and none were found in the Teanaway basalt.

In general, the volcanics of the Taneum formation can be recognized fairly easily from the Teanaway or Yakima basalts. The microlitic plagioclase in the Taneum volcanics is characteristically altered to sericite making the determination of the plagioclase very difficult. Most of the flows are porphyritic with zoned and corroded phenocrysts of plagioclase. Hypersthene is the most common pyroxene in the Taneum volcanics, although augite may be present.

Within the Yakima basalt, palagonite breccias were seen at several localities at the bases of different flows. One locality in particular was very outstanding from a distance and it was first believed to be horizontal beds of sandstone (figure 34). The locality is in the northwest corner of section 2, T.18 N., R.15 E. on the east side of Frost Creek near the top of the canyon. The outcrop of palagonite breccia can be seen from the lookout on Frost Mountain. Approximately 125 feet of palagonite breccia is exposed for 200 to 250 yards horizontally. Small, hollow, pillow shaped masses, 8 to 12 inches in longest dimension, are common (figure 35). Some of the hollows have a thin coating of calcite or quartz on the inside of them. The pillows are highly vesicular with no definite orientation in the vesicles. The stratification in the exposure appears to be horizontal. Larger pillows at the bottom of the exposure grade upward into smaller pillows and finally only palagonite fragments are present. Lithic tuff fragments are common with the palagonite.

It has already been mentioned that the sediments exposed west of the

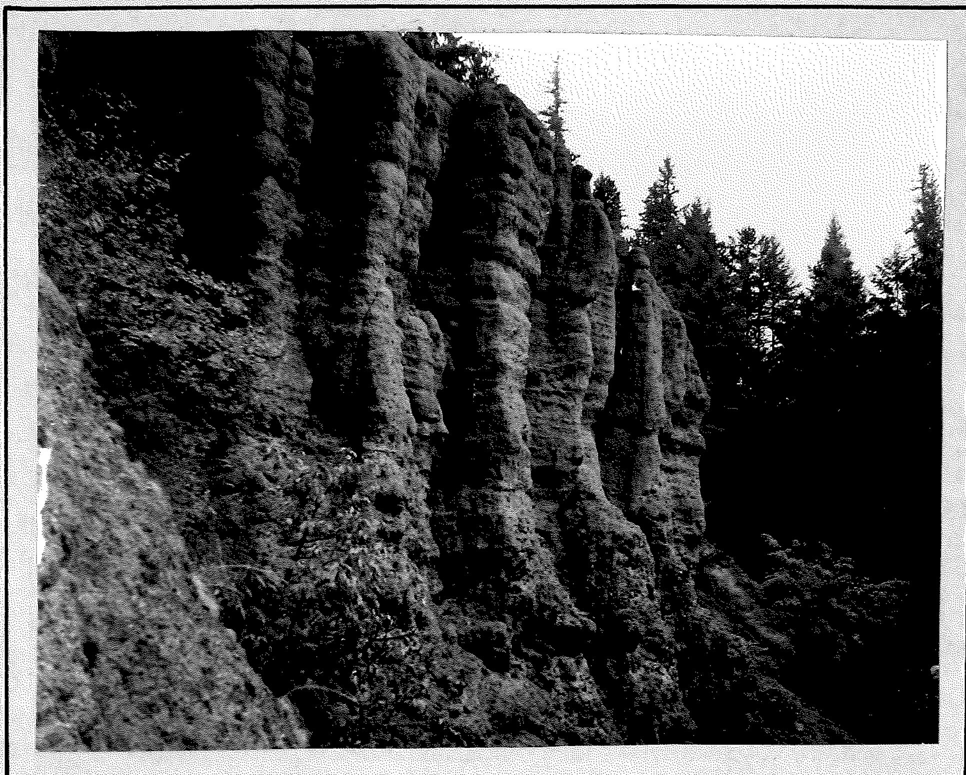

Figure 34

Exposure of palagonite breccia interbedded with flows of Yakima basalt on the east side of Frost Creek Canyon. Erosion has accentuated the horizontal stratification. At the bottom of the exposure are large pillow shaped masses. These grade upward into smaller "pillows" and palagonite fragments. The exposure in the picture is about 75 feet high.

Figure 35

Detail of the pillow shaped masses in the palagonite breccias on the east side of Frost Creek Canyon. Note the hollow interiors of the "pillows". The white material in the broken hollow in the lower right hand corner is the remnant of an original quartz coating on the inside of the hollow.

Taneum guard station are believed to be interbeds. The tuffaceous sandstone exposed in the roadcut between sections 28 and 29, T.19 N., R.16 E. is identical to one exposed south of Taneum Valley in the NW$\frac{1}{4}$SW$\frac{1}{4}$ of section 32, T.19 N., R.16 E. At this locality, the sediments are exposed in several roadcuts and are clearly underlain by basalt. No basalt directly overlies the sediments, although farther to the south and topographically higher, are cliffs of Yakima basalt. Basaltic dikes cut through the sediments in one roadcut, but it was impossible to determine whether it was a channel filling or actually a small, intrusive dike.

The other exposure of tuffaceous sandstone is southwest of Cle Elum Point in section 15, T.19 N., R.15 E. These sediments were studied because it is believed that Smith mapped them as part of the Manastash formation on the folio map. Smith (1904, p. 7) had a small area of Manastash sediments exposed just southwest of Cle Elum Point. He states about these:

> "Somewhat less certain however, is the determination of the horizon of some sandstone which is exposed immediately southwest of Cle Elum Point. These beds rest upon the schist and dip to the southeast. The presence of the intrusive rock at Cle Elum Point prevents any determination of the relation of the sandstone to the Teanaway basalt. The knowledge, gained farther west, that the Swauk sediments were not so thick in the southern part of the area as farther north makes it doubtful that this exposure belongs to the Swauk formation; more likely it is the northern extension of the sandstone exposed 2 miles southwest, on Taneum Creek".

The writer made a series of traverses from the Yakima Valley floor to the top of Cle Elum Ridge, but these interbeds were the only sediments found. Topographically, basalt can be found below and above the sediments, but the age relationships of the sediments to the basalt is unknown.

No accurate thickness can be given to the interbeds described above as the only exposures were in roadcuts. However, they would probably not be more than 50 feet thick as there would probably be some indication of a thicker unit in the topography.

The youngest sediments in the area were found in section 19, T.19 N., R.16 E. along the road on the crest of Cle Elum Ridge. The sediments consist of sandstones and conglomerates of volcanic material. The conglomerate unit is quite distinctive with light-gray, hornblende andesite cobbles up to 4 inches in longest dimension (figure 36). A few hundred yards south of this area and several hundred feet below it, are exposures of horizontal basalt flows of the Yakima basalt. It is believed that the sediments probably belong to the Ellensburg formation, an upper Miocene sedimentary unit consisting of sediments of volcanic material foreign to this area. The Ellensburg formation is principally exposed over large areas to the east of the thesis area. However, G. O. Smith and F. C. Calkins have mapped small areas of the Ellensburg formation much farther west in the Snoqualmie quadrangle. Elevations of these isolated patches are as high as 5400 feet. The elevation of this locality is about 3700 feet. There has been much discussion concerning the Ellensburg formation by Laval (1956) and others and because the problem involved deals with post-Yakima sediments, it will not be considered further here.

<u>Diabase</u>

Scattered throughout the area south of Taneum Creek are diabase intrusions. Diabase is used as a general term in this thesis to describe a basic igneous rock having the composition of basalt and generally intermediate between gabbro and basalt in grain size. Although some of the diabase masses are very large, they will be referred to as dikes for purposes of this discussion. The largest of the diabase dikes is northeast of Frost Mountain between Frost Mountain and the South Fork of Taneum Creek. Here two large dike-like bodies have cut through and are now surrounded by the Taneum formation.

In the thesis area, the diabase has definitely intruded rocks of the

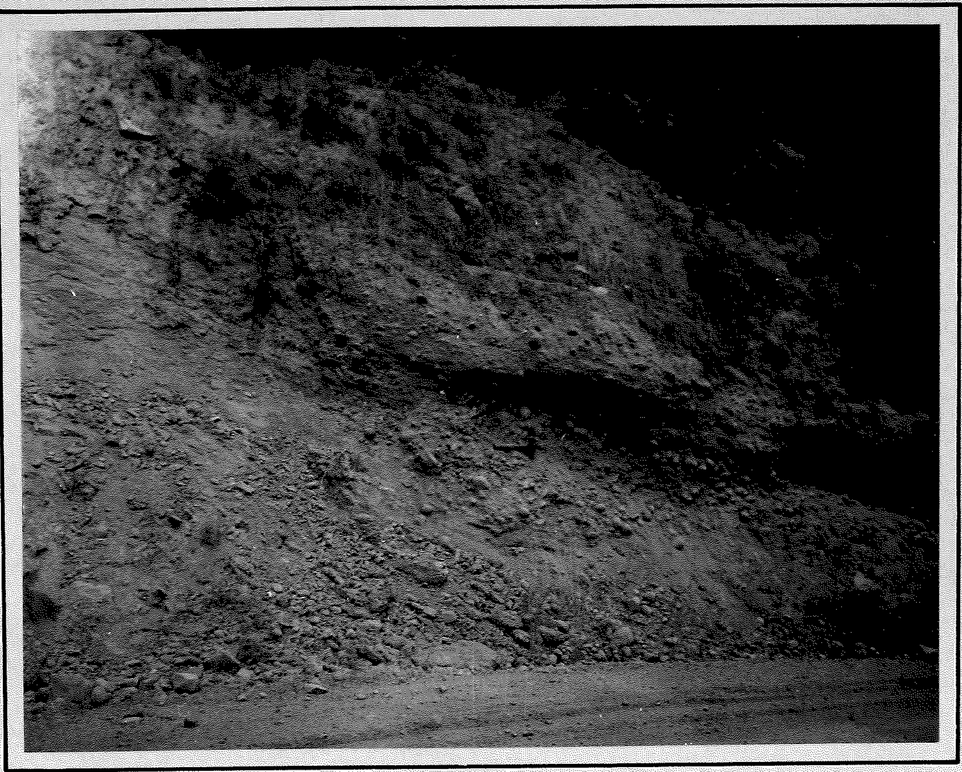

Figure 36

Conglomerate exposed in a roadcut on the crest of Cle Elum Ridge. This conglomerate is believed to be part of the Ellensburg formation. The sediments are dipping gently to the south. The cobbles are all hornblende andesite. Note hammer for scale.

Taneum and Manastash formations, and it is possible that the diabase has intruded the lower flows of the Yakima basalt.

A large number of dikes are in the area east and southeast of Frost Mountain. The diabase dikes generally form resistant ridges and are fairly easy to recognize because the Manastash is not characteristically a ridge former. In addition, the dikes can be recognized easily because they produce a reddish brown soil when weathered. Outcrops of the dike rocks are common in this area and these are mostly large piles of dark colored, rounded boulders.

Several good exposures of typical diabase can be seen where the road to Buck Meadows crosses a rather large dike in section 16, T.18 N., R.15 E. South of the road across the small stream, are rounded boulders of weathered diabase. About 25 yards north of the road, Manastash sandstone crops out and the diabase is 10 feet away. Although the contact is covered, the sandstone here has a very high content of iron in the cement and is more highly indurated than usual.

Most of the dikes have a strong northwesterly trend. This probably reflects control by the earlier structures in the area. The dikes do not appear to be controlled by folding in the Manastash as they are located on the flanks of the folds as well as on the crests and troughs.

G. O. Smith (1904, p. 8) related these diabase dikes to the Yakima basalt flows. He believed the dikes represented the conduits for some of the Yakima basalt. He mapped one dike on the west side of the North Fork of Manastash Creek that cut the lower sheets of Yakima basalt.

The contact between the Yakima basalt and the diabase on the east side of Frost Creek in section 3, T.18 N., R.15 E. was not sufficiently exposed to determine the exact relationship between the diabase and the Yakima basalt.

However, in Frost Canyon, the diabase is a distinctive coarse grained rock and this rock can be traced, by scattered outcrops, up the east side of the canyon. This area is covered with considerable soil and the diabase outcrops finally disappear. Several hundred feet above the last exposure of the diabase is the vesicular portion of a basalt flow. No diabase could be found in place or as float around the area where the basalt flow was exposed, so it is assumed that either the diabase had been eroded before the Yakima basalt covered the area or the diabase represents a feeder pipe for some basalt flows.

In the Ellensburg quadrangle, Smith (1903, p. 2) cited the Bald Mountain region as one of the centers of volcanic activity during Miocene time. Bald Mountain is 7 miles south of Frost Mountain. It is possible that the diabase dikes are part of this volcanic field. Exactly how much basalt the dikes would have been able to contribute to the Yakima basalt is unknown.

In the hand specimen, the diabase is generally very friable crumbling into its component grains when struck with a hammer. It varies in color from a reddish brown to various shades of gray. The only identifiable minerals in the hand specimen are pyroxene and plagioclase. The plagioclase can be easily recognized on a weathered surface because it forms white elongate laths of clay material.

In thin section, the diabases vary slightly in texture and composition from one locality to another, but generally they have an ophitic texture with several plagioclase crystals inclosed in one crystal of pyroxene. Grains of pyroxene over 5 mm. in diameter are not uncommon. The plagioclase is generally smaller in size. The diabase consists of approximately 60% plagioclase and 30% pyroxene with the remainder composed of varying amounts of magnetite, apatite, olivine and red and green alteration material. The plagioclase ranges in composition between An_{46} and An_{74} and has been altered, in part, to sericite, although one specimen showed no signs of any alteration. No oscillatory zoning was seen in any of the plagioclase. The pyroxene is predominantly pigeonite, although augite is present in several sections. One thin section contained pigeonite with such a small optic angle, it was considered to be uniaxial at first glance. However, the isogyres parted very slightly in the 45° position, so it is biaxial with $2V = < 5^{\circ}$. Augite was distinguished from pigeonite by its larger optic angle. Polysynthetic twinning was common in the pigeonite (figures 37, 38). Olivine is rare, but where it is present, it has been altered, in part, to iddingsite.

The diabase dikes in the pre-Teanaway sediments have already been described in that chapter. In comparison to the diabase dikes by the Yakima River, the feldspar in the diabases south of Cle Elum Ridge is much fresher in appearance. Although some or most of the feldspar has been altered to sericite in both places, the degree of alteration is more advanced in the dikes cutting the pre-Teanaway sediments. In addition, the dikes near the Yakima River are more fine grained, as a general rule, than the diabases to the south.

Figures 37, 38

Photomicrographs of diabase from the northeastern side of Frost Mountain. Plagioclase and pigeonite are the essential minerals. This specimen of diabase is unusually fresh in appearance. Generally the plagioclase has been altered in part to sericite. Note the polysynthetic twinning in the pigeonite grains under the scale in figure 38.

Figure 37—plane polarized light.

Figure 38—crossed nicols.

INTRUSIVE ROCKS

Serpentinite

The Easton schist is in contact with a band of serpentinite south of Frost Mountain in sections 17, 18 and 20, T.18 N., R.15 E. In the hand specimen, the serpentinite is extremely slickensided giving the rock a waxy appearance. The slickensided surfaces are light green in color and the non-slickensided material is dark blue to black. Examination under the microscope shows that the principal constituent in the rock is antigorite. For a more detailed discussion of similar serpentinite bodies which occur in the Snoqualmie quadrangle, the reader is referred to U. S. G. S. Folio #139, p. 3. The significance of the serpentinite in the area is discussed in the structure chapter.

STRUCTURE

The dominant structural features in the area are several southeasterly plunging synclines and anticlines in the Manastash formation. At the northernmost occurrence of the Manastash formation in Taneum Valley where the Manastash is in contact with the Easton schist, the sediments dip to the southwest off the schist. These sediments form the northern limb of a fairly large syncline. A small anticline about half way between Frost Mountain and the South Fork of Taneum Creek disrupts this synclinal structure to the southwest. Although most of the anticline is covered by the Taneum formation, exposures at the northwestern end of Frost Mountain along the South Fork of Taneum Creek, show high anticlinal dips. Southwest of this small anticline is the largest syncline in the area. Frost Mountain is directly on the synclinal axis and thus is a synclinal mountain, although the volcanics capping it have not taken part in the deformation which produced the syncline. The southern flank of this broad syncline probably extends south directly to the Easton schist in some places. However, just northwest of Buck Meadows, sufficient exposures and attitudes were available to determine that another small anticline occurs at this locality. As anticlinal attitudes could only be found in this one area, it is not known whether it is just a local fold in the Manastash. South of the small anticline in this area is another small syncline; the sediments on the south limb of the syncline dip to the north apparently off the Easton schist.

The axial traces of these structures are roughly parallel and trend approximately N.50° W. The folds all have open limbs (the limbs of an anticline diverge downward) and most of the axial planes are slightly inclined either to the northeast or to the southwest. All of the folds are asymmetrical as the axial plane is not a plane of symmetry.

In the lower portion of Taneum Valley near the Taneum guard station, attitudes in the Manastash formation indicate Taneum Creek is flowing over the crest of a small anticline. The structure is not exposed over a large enough area to describe it in detail.

It has been pointed out in discussing the pre-Teanaway sediments and the Teanaway basalt near the Yakima River that these units have a northerly dip. This would prove the existence of a syncline under Roslyn and Cle Elum. In discussing the geology of Washington, it has been common to refer to the Roslyn basin. However, it should be noted that the structure is not a basin as there is no evidence to indicate the structure has a southeastern limb, but rather it is a southeasterly plunging syncline. Until this time, the existence of the southern limb in the thesis area has never been definitely proven.

As it has been pointed out in the discussion of conditions of deposition for the Manastash formation, there is evidence indicating some deformation was contemporaneous with the deposition of the Manastash. In addition to the evidence furnished by the large thickness of sediments, there is the possibility that the small anticline on the northeast side of Frost Mountain displays supratenuous folding. North of Frost Mountain, along the South Fork of Taneum Creek, anticlinal dips in the Manastash are as high as 70° to the south and 64° to the north. East of Frost Mountain, the dips on the south flank of the northwesterly trending anticline are much smaller than those north of Frost Mountain; the more accurate dips average about 40° southwest. These dips are at approximately the same elevation as those northwest of Frost Mountain. Consequently, with a southeasterly plunge, older rocks are exposed in the axis of the anticline north of Frost Mountain. If this is the case, the older rocks are more deformed than the younger ones exposed to the southeast. This evidence is not infallible as there is no way to determine if the same stratigraphic unit or its equivalent is involved in the folding at the two localities.

The age of the major period of folding shown by the Manastash sediments is believed to be sometime after the deposition of most of the Manastash, but before extrusion of the Taneum flows. Field evidence for this statement can be found along the South Fork of Taneum Creek on the section line between sections 32 and 33, T.19 N., R.15 E. The exposures at this locality are very good and andesite flows containing rounded cobbles and andesitic material can be seen dipping gently to the north (figure 39), but less than a quarter of a mile to the east, Manastash sandstones are dipping 40° to the southwest. If the Taneum flows had been extruded directly after the Manastash sediments had been deposited, the Taneum flows would be dipping to the southwest as well.

Other evidence that indicates the major deformation did not involve the Taneum formation can only be gained by a study of the areal distribution of the Taneum formation on the geologic map. It will be noted that the Taneum in many places is transverse to the trend of the structures in the Manastash formation, although this in itself is not definite evidence that the Taneum has not participated in the major folding. The unconformity separating the two formations could also explain this pattern.

In another area, near the central part of the map, the distribution of the Taneum formation indicates the Taneum was not involved in the major folding. This area includes the tongue of Taneum andesite that extends south from the Frost Creek area to sections 13 and 14, T.18 N., R.15 E. where it is covered by the Yakima basalt. It is just about impossible to explain this distribution as a result of the unconformity following Manastash deposition. The Manastash formation underlies the Taneum along the tongue of andesite and

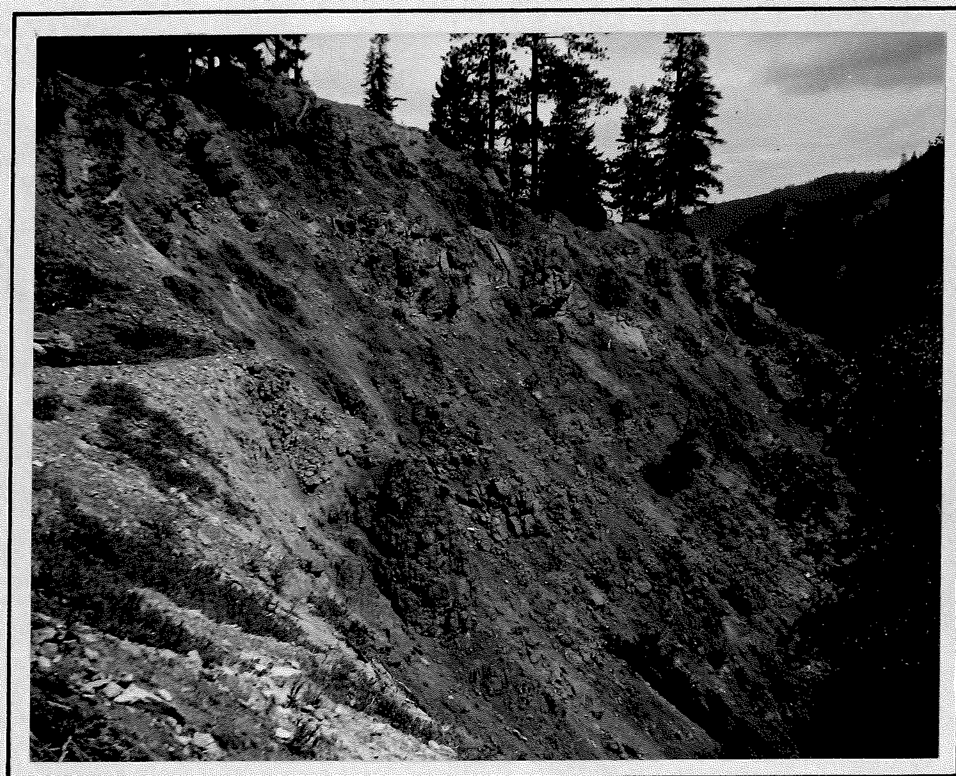

Figure 39

Alternating light and dark andesitic flows of the Taneum formation on the north side of the South Fork of Taneum Creek near South Fork Meadows. The flows are dipping very gently to the north and consist of volcanic conglomerates. View is to the east.

the sediments always dip to the southwest. If the Taneum had participated in the major deformation, erosion would either have completely destroyed or in some way disrupted this tongue of Taneum andesite on the homoclinal sediments.

It is possible that some of the early flows of the Taneum formation participated in minor periods of folding following the major deformation. The Taneum exposed on the flanks of Frost Mountain could be explained in this manner, although much more likely would be the possibility that strike ridges and valleys developed on the erosion surface of the Manastash and the earlier flows flowed into the strike valleys. This would account for the peculiar distribution of the Taneum formation on the northeast side of Frost Mountain. Of course, it must be remembered that the topography is the principal reason for the horseshoe shaped distribution of the formations around Frost Mountain.

It is believed that the serpentinite in the southern part of the area has intruded along a large, deep-seated fault. Any detailed information about the fault must be obtained by further field study of the area to the west as no direct evidence of faulting, other than the presence and alignment of the serpentinite and some suggestion of faulting in the topography, was found in the present area. The area east of the place where the serpentinite contact crosses the South Fork of Manastash Creek in section 20, T.18 N., R.15 E. is so heavily wooded that float as well as outcrops are very rare. The geologic relationships here are entirely theoretical. It is known that the Manastash sediments are dipping to the north a short distance from the inferred contact between the Manastash and the Easton. This suggests, but does not definitely indicate, that the contact between the two units is depositional; the sediments dipping north off the Easton schist. However, if a fault is in this area, it could easily be entirely within the Easton schist and covered by the Yakima basalt.

The presence of the well developed basal conglomerate along the fault to the west suggests that deposition could either have finished before movement along the fault or deposition was in part contemporaneous with movement on the fault—uplift on the southern side being great enough to supply Easton detrital material to the north.

Other than the above hypotheses, the writer does not feel that he is qualified at this time to make any further statements as to the type of faulting involved or the relative time of movement. Further study may answer these questions.

It is impossible to draw a detailed cross section because of poor topographic maps and limited accurate attitudes along the cross section line in the Manastash formation. The absence of a good marker bed further limits the accuracy of the cross section as the exact stratigraphic position of the Manastash rocks participating in each fold is unknown. However, for better understanding of the geologic relations involved, the writer has attempted to construct a generalized cross section at the end of this thesis.

MINERAL RESOURCES

Coal was the most important economic commodity produced in the area. All of the coal seams occur in the Manastash formation and most of the coal is a fairly low grade, bony variety. Seams of high grade coal have been mined, but these generally are small and limited in extent. Small coal mines operated in the early 1900's and have since been abandoned. Production in these mines never reached a high enough degree to warrant construction of railroads into the area.

Cinnabar and quicksilver have been mined from the Easton schist in sections 26, 27, 28 and 34, T.19 N., R.15 E. The ore occurs either in fractures and as coatings on fractures in the shear zone between the graphitic phyllite and the Manastash formation, or in some places, the quicksilver occurs in fractured areas entirely within the Easton phyllites. In addition to the cinnabar, some of the mines have attempted to produce graphite from the phyllites. A mill was set up to grind the graphite, but the graphite proved to be of non-commercial value.

Iron ore has been reported by Shedd and others (1922, p. 79-81) from a locality on the north side of Cle Elum Ridge in sections 9 and 10, T.19 N., R.15 E. The ore is chiefly hematite and is reported to occur in a glaucophane garnet schist. This deposit has never been of commercial importance as the ore is quite siliceous with a high percentage of phosphorus.

Malachite occurs as very thin coatings on fractured surfaces in a greenschist unit of the Easton schist in the NW$\frac{1}{4}$NE$\frac{1}{4}$ of section 34, T.19 N., R.15 E. At this same locality, altered cubes of pyrite in the greenschist are very common. Several shallow exploration pits have been dug, but no extensive work has been undertaken.

In the NW$\frac{1}{4}$NW$\frac{1}{4}$ of section 20, T.19 N., R.15 E., a "nickel ledge" rock, 100 to 150 feet wide, has been reported (Huntting, p. 277) in graphitic schist. Ores of nickel and chromium occur in a silica-carbonate gangue. No production has been recorded. This area is accessible by trail only.

The Yakima basalt was utilized early in the summer of 1956 when a construction firm moved into the area to set up a crushing plant in the SW$\frac{1}{4}$SW$\frac{1}{4}$ of section 32, T.19 N., R.16 E. The basalt was crushed and then trucked out of the area to be used as road ballast and asphalt aggregate. This operation lasted until mid-August.

A manganese occurrence has been reported from a deposit in the Easton schist in the northwestern part of T.19 N., R.15 E. This deposit was not found and it could not be more accurately located.

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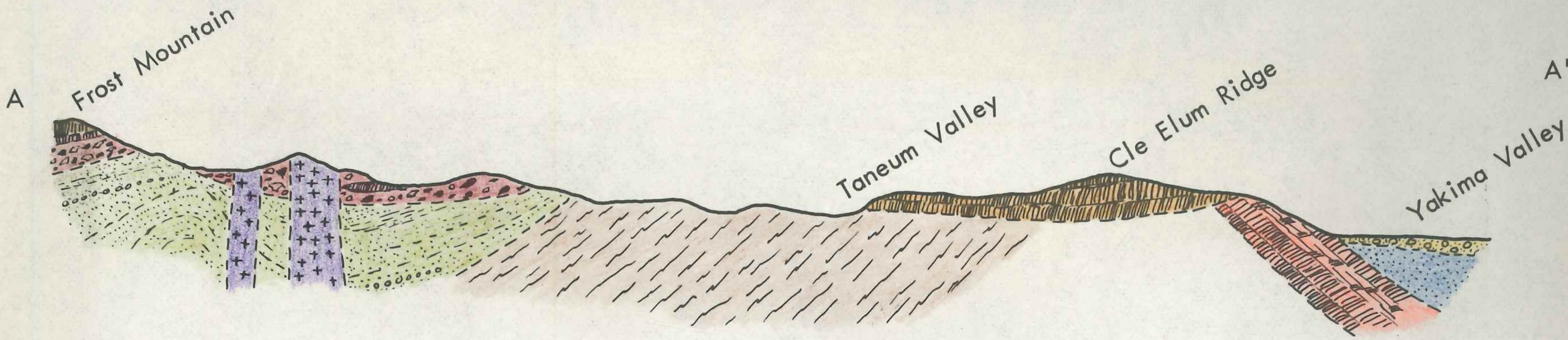
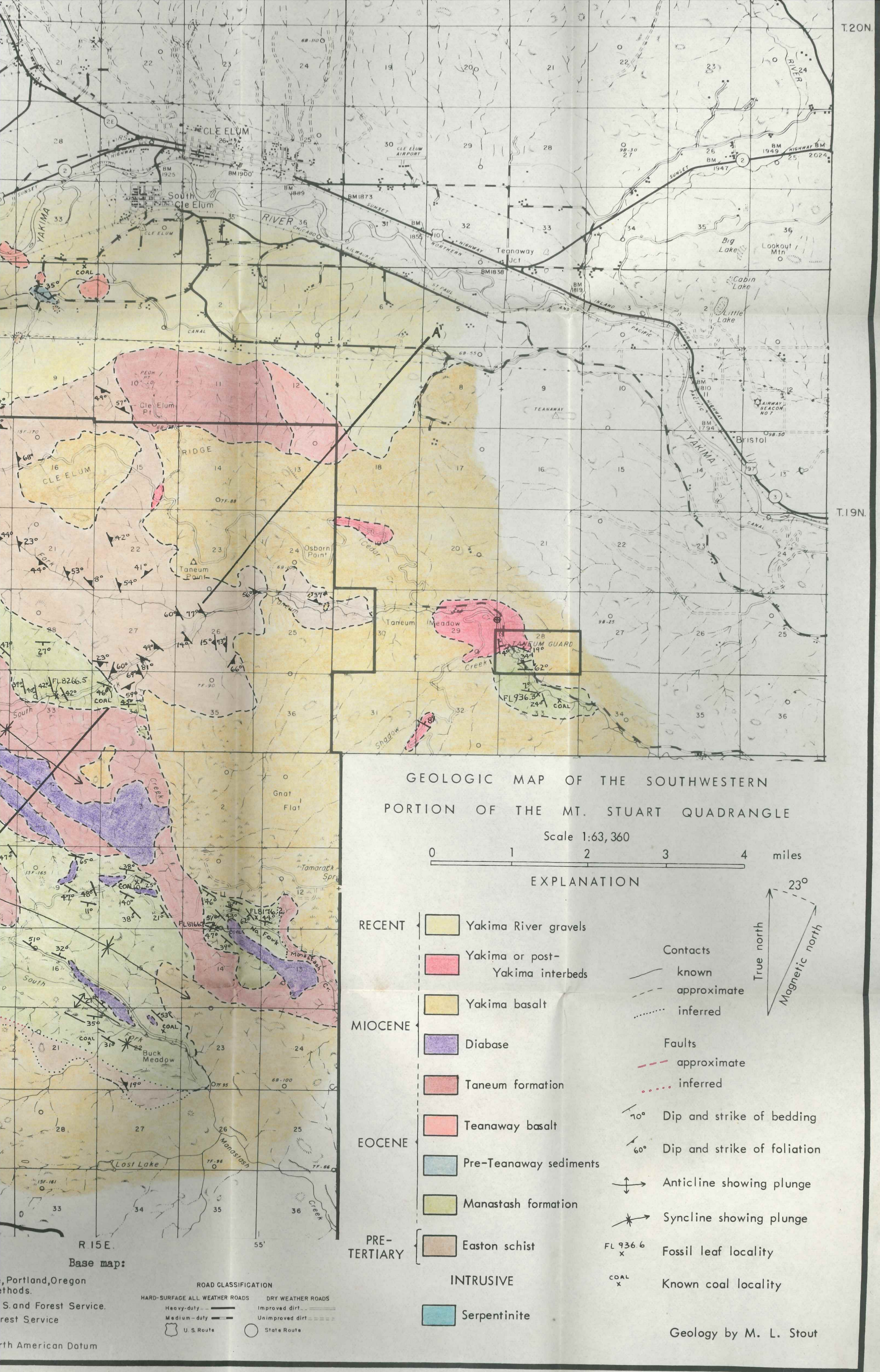


GENERALIZED GEOLOGIC CROSS SECTION ALONG LINE A - A'

Scale: vertical is equal to horizontal

0 1 2 3 4 miles

Roslyn formation	Yakima River gravels
Teanaway basalt	Diabase
Manastash formation	Yakima basalt
Easton schist	Taneum formation


GEOLOGIC MAP OF THE SOUTHWESTERN
PORTION OF THE MT. STUART QUADRANGLE
Scale 1:63,360
0 1 2 3 4 miles
EXPLANATION
RECENT
Yakima River gravels
Yakima or post-Yakima interbeds
MIOCENE
Yakima basalt
Diabase
EOCENE
Taneum formation
Teanaway basalt
Pre-Teanaway sediments
Manastash formation
PRE-TERTIARY
Easton schist
INTRUSIVE
Serpentinite
Contacts
known
approximate
inferred
Faults
approximate
inferred
Dip and strike of bedding
Dip and strike of foliation
Anticline showing plunge
Syncline showing plunge
FL 936.6
Fossil leaf locality
COAL
Known coal locality
True north
Magnetic north
23°
Geology by M. L. Stout
T.20N.
T.19N.
R 15 E.
55'
Base map:
,Portland,Oregon
ethods.
S. and Forest Service.
rest Service
rth American Datum
ROAD CLASSIFICATION
HARD-SURFACE ALL WEATHER ROADS
DRY WEATHER ROADS
Heavy-duty
Medium-duty
Improved dirt
Unimproved dirt
U. S. Route
State Route
CLE ELUM
South Cle Elum
YAKIMA RIVER
Teanaway Jct
Big Lake
Lookout Mtn
Cabin Lake
Little Lake
Bristol
Cle Elum Pt
RIDGE
CLE ELUM
Taneum Point
Osborn Point
Taneum Meadow
TANEUM GUARD
Gnat Flat
Tamarack Spr
Buck Meadow
Lost Lake
Manastash