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GEOLOGY AND COAL POTENTIAL OF THE TANEUM-MANASTASH AREA, KITTITAS COUNTY, WASHINGTON

by

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ABSTRACT

The Manastash Formation is a lower Eocene formation unconformably overlying a pre-Tertiary metamorphic complex. The formation has a minimum thickness of approximately 1000 meters. Sandstone is the dominant lithology, but also present are siltstones, mudstones, pebble conglomerates, and thin beds of coal. Definite compositional differences are seen in sandstones from different areas. Sandstones in the northern part of the study area are commonly finer-grained and more feldspar-rich than those in the southern area of study, which are more quartzose and lithic-rich.

The formation was deposited in a non-marine fluvial/lacustrine environment. Paleocurrent data from crossbeds indicate a southerly paleoslope.

Detrital grains in the sandstones were derived from a mixed provenance of granitic, gneissic, schistose, metasedimentary, sedimentary, and lesser volcanic rocks.

Major folds and faults have a northwest trend. Faulting appears generally to be high-angle dip-slip.

Fold axial planes are vertical with symmetrical and planar limbs. The folds are open and commonly plunge gently to the southeast. There is local plunge to the northwest.

The Manastash Formation is overlain unconformably by the Taneum Andesite. Dips taken on fold limbs readily demonstrate the greater degree of deformation of the Manastash Formation.

Thin beds of coal are locally abundant throughout the Manastash Formation, but are more common low in the section. Small scale mining of several of these coal seams took place intermittently throughout the first forty years of this century. One hundred thousand tons of coal are believed to have been mined from the Wilson mine on lower Taneum Creek

before 1914. Nonetheless, structural deformation and seam discontinuity, numerous igneous intrusions, and poor quality make these coals unattractive for mining. However, coal potential has never been fully tested in the main outcrop of Manastash Formation, and the coals may be a source of natural gas.

INTRODUCTION

Purpose and General Description

This study has been initiated in order to evaluate the coal potential of the Manastash Formation. Field work was conducted during parts of the summers of 1980, 1981, and 1982 in order to achieve this objective.

Tabor and others (1984) have renamed some of the units discussed in this report. The Taneum Andesite has been renamed Taneum Formation, Teanaway Basalt to Teanaway Formation, and Silver Pass Volcanics to Silver Pass Volcanic Member of the Swauk Formation. The authors recognize these changes, but will retain Taneum Andesite for this report.

The Manastash Formation crops out on the east slope of the south-central Cascade Mountains of Washington (fig. 1). Located in central Kittitas County, the area which contains the Manastash Formation is drained by the eastward flowing north and south Forks of Taneum and Manastash Creeks and their tributaries. The study area lies approximately five to ten miles south of Cle Elum, Washington.

Exposure of the Manastash Formation is within three distinct areas (fig. 1). These areas are referred to as the "lower Taneum," near the Taneum Guard Station in T. 19 N., R. 16 E.; "upper Tanuem," located between the two forks of Taneum Creek in T. 19 N., R. 15 E.; and "Manastash Creek," located along the creek for which it is named in T. 18 N., R. 15 E.

Rock outcrop is poor in many parts of the study area. The hills and valleys are generally covered by thick stands of forest and meadows. Road cuts and steep ridges provide the best exposures of rock. Overall, the vegetation varies from thick timber in the west to open forests of pine and range land to the east.

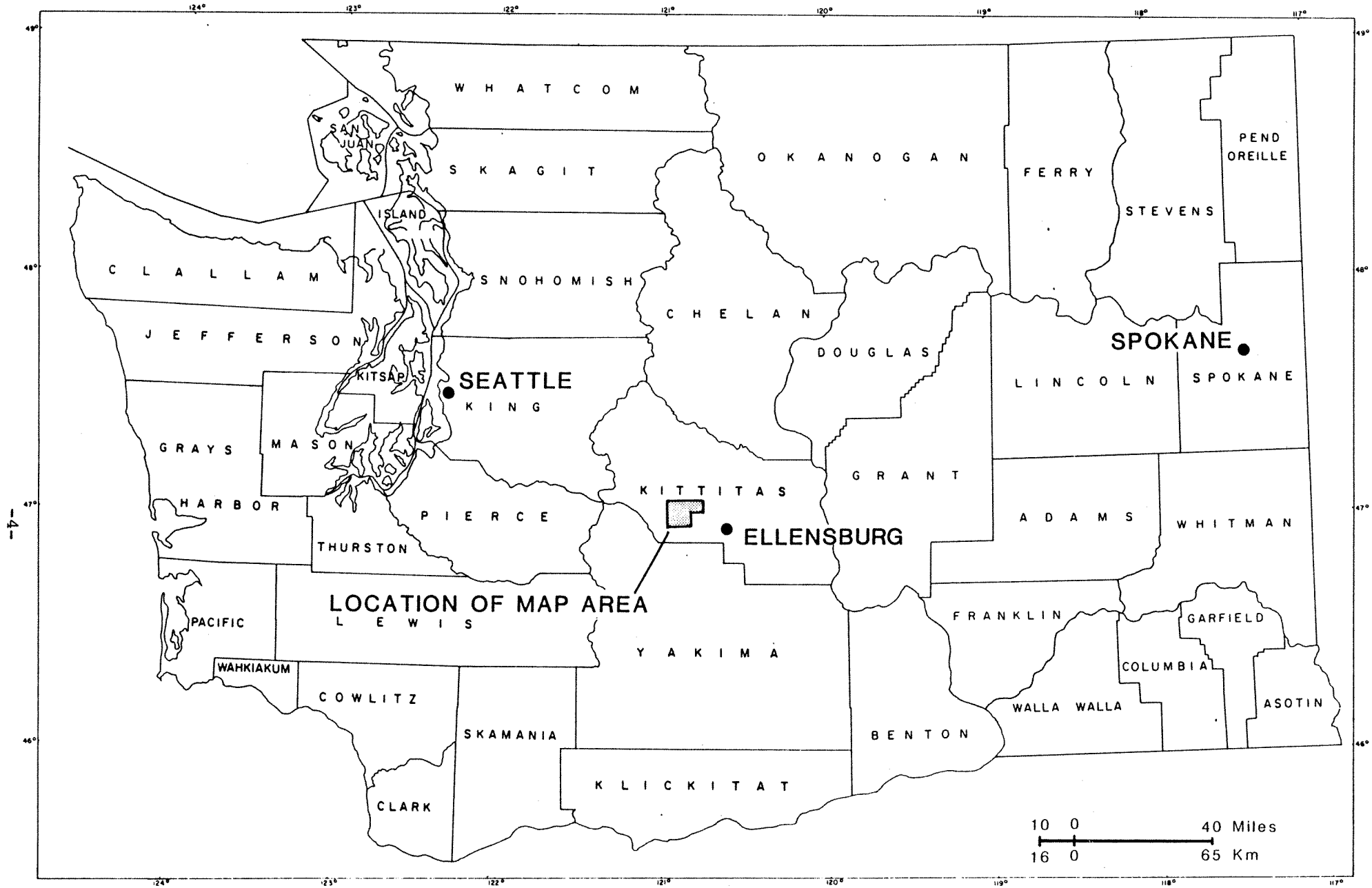

Figure 1. — Map of the State of Washington showing the location of the map area.

REGIONAL GEOLOGICAL SETTING

The study area lies on the boundary of the Cascade Mountains and the Columbia Plateau physiographic provinces. As such, an extremely diverse assemblage of rocks is located within the study area.

Basalt flows of the Yakima Basalt Subgroup are found in the southern and eastern parts of the study area. The basalt flows form a thick pile of volcanic rocks belived to have originated from feeder dikes located in northeastern Oregon and southeastern Washington. Interbedded in the basalt flows are volcaniclastic rocks of the Ellensburg Formation.

Extensive middle Tertiary volcanic rocks are located several kilometers to the west of the study area. These volcanic rocks make up the bulk of the southern Cascade Mountains of Washington. Formations such as the Naches, Ohanapecosh, Stevens Ridge, and Fifes Peak, to name a few, characterize the rock units of the south Cascades. Dominating the scene are the young composite volcanoes of the Cascade Mountains. Mt. Rainier, Glacier Peak, and Mt. Adams can be readily seen on a clear day from the higher localities in the study area.

PREVIOUS WORK

The first geological reconnaissance into the area was undertaken in the early 1890's by Russel (1893). His various journeys up the ridges leading toward the Cascade crest from Kittitas Valley skirted the center of the study area, and he did not see the Eocene section. In the early years of this century the first detailed geology was undertaken by Smith (1903, 1903a, 1904) and by Smith and Calkins (1906). At this time most of the rock units in the area were first described and named.

In 1914 Saunders published his exemplary study of the smaller coal fields of Kittitas County, which included the small mines and prospects

located along both Taneum and Manastash Creeks. A similar evaluation by Beikman and others (1961) of the coal fields of Washington again included a chapter on the Taneum/Manastash area.

In the 1950s and 1960s, Stout mapped the area and produced several papers (1957, 1959, 1961, 1964). Beginning in 1959, Stout abandoned Smith's formation nomenclature and included the Manastash Formation in the Naches Formation and the Taneum Andesite with the Keechelus Andesitic Series (1964, p. 329). This interpretation has not been adopted by subsequent workers.

More recent work has been done by Misch (1966), Goetsch (1978), Ashleman (1979), Frizzell (1979), Waitt (1979), Cushman (1980), Walker (1980), Lewellen (1983), Ort and others (1983), and Tabor and others 1982, 1984). Tabor and others in 1977 first described the Basalt of Frost Mountain as a separate rock unit. Engels and others (1976) have dated volcanics and Newman (1975, 1977) has done palynologic age dating in the Manastash and nearby Eocene sedimentary bodies. This work has demonstrated the correlation of the Manastash Formation with the nearby Swauk Formation. Aeromagnetic data from Weston Geophysical Research (1978) have been very useful in showing large structural features.

The Manastash Formation unconformably overlies the southern end of a discontinous belt of Pre-Tertiary metamorphic rocks that extend into Canada. Located in the North Cascades and Okanogan Highlands, these Pre-Tertiary rocks are lithologically very diverse and include a variety of igneous, metamorphic, and sedimentary rocks.

The Manastash Formation is part of a discontinous group of arkosic sandstone bodies, which extend northward to the Canadian border. Other arkosic units in the Cascade Mountains are the Chumstick, Roslyn, Swauk,

Wenatchee, and Chuckanut Formations, and parts of the Naches Formation. The units are Eocene to Oligocene in age and represent a period of continental clastic sedimentary deposition in the region.

LOCAL GEOLOGIC UNITS

Easton Schist

The oldest unit in the study area is the Easton Schist. It is composed of low grade metamorphic rocks and was first mapped and named by Smith (1903, p. 14). The Easton Schist as defined by Smith is composed of graphitic phyllite, greenschist, blue amphibole schist, and some gneiss and amphibolite on South Cle Elum Ridge. Stout (1964, p. 322) restricted the Easton Schist to the low grade metamorphic rocks.

The Easton Schist located in the study area occupies two belts, a northern belt located in the north-central part of the study area and a smaller belt in the south-central part of the study area. The southern belt of Easton Schist is poorly exposed and has been mapped primarily from float and a few outcrops of greenschist. The dominant rocks appear to be greenschist and phyllite. The phyllite was only seen as float. The exact nature of the contact between the Manastash Formation and the southern belt of the Easton Schist is uncertain.

The northern belt is composed of graphitic phyllite, micaceous schist, greenschist, minor glaucophane schist, and amphibolite. The amphibolite is a fine-grained rock located in parts of sections 18 and 19, T. 19 N., R. 15 E. and part of section 13, T. 19 N., R. 14 E. The amphibolite is located in a belt that borders a large outcrop of quartz diorite gneiss in sections 13 and 24, T. 19 N., R. 14 E. Intermixed with the amphibolite are lenses of epidote greenschist. The greenschist does not appear to be tectonically

implanted. Either retrograde metamorphism has locally affected the rocks or metamorphism to the amphibolite facies was incomplete. Overall, the phyllite and schist were probably derived from marine sediments and basalt.

The northern belt of the Easton Schist is in fault contact with the Manastash Formation and the Taneum Andesite on the eastern side of the Upper Taneum area. Other parts of the Manastash Formation in the Upper Taneum area appear to unconformably overlie the Easton Schist.

The age of the Easton Schist is uncertain, but a Pre-Tertiary age has usually been assigned to this unit (Smith, 1903). The Shuksan Greenschist and Darrington Phyllite have been correlated with the Easton Schist (Ashleman, 1979, p. 16). K-Ar and Rb-Sr dates from the Shuksan Greenschist and Darrington Phyllite range from 95-220 million years for the age of metamorphism. A tentative average age of 125 million years is given for the age of metamorphism (Ashleman, 1979, p. 17).

Amphibolite

Rocks of this unit are dark green and well foliated. The major mineral components are hornblende, plagioclase, epidote, and quartz. The amphibolite is located on the west side of the Taneum Lake Fault in the southwestern part of the study area. Possible intrusions of dioritic rocks, which have been subsequently sheared and recrystallized to diorite gneiss are also in the amphibolite unit.

These rocks were originally mapped as part of the Hawkins Formation by Smith and Calkins (1906). Stout (1959, p. 9-18) and Goetsch (1978, p. 7-18) have mapped these rocks as a separate unit of uncertain stratigraphic position. This unit is exposed west of the Taneum Lake Fault, thus its stratigraphic position relative to the Easton Schist is uncertain. If it

is part of the Hawkins Formation as originally mapped by Smith and Calkins (1906), it would be younger than the Easton Schist.

A nearby unit of quartz diorite from Quartz Mountain has a radiometric age of 157 million years, (Goetsch, 1978, p. 40). If the diorite gneiss located in the amphibolite is correlative with the quartz diorite that has been dated, a minimum Late Jurassic age for the amphibolite would be established.

Quartz Diorite Gneiss

The quartz diorite gneiss is located in the northwest corner of the study area, in parts of section 13 and 24, T. 19 N., R. 14 E. and part of section 19, T. 19 N., R. 15 E. It has also been located in float in the NW1/4, section 29, T. 19 N., R. 16 E. This unit was first mapped by Smith and Calkins (1906, p. 4) and later by Stout (1959, p. 33-36). The quartz diorite gneiss appears to have intruded the Easton Schist prior to metamorphism of the two units. Small dikes and xenoliths of amphibolite or greenschist in the gneiss can be identified near the contact between the two units. The effects of thermal metamorphism may in part account for the medium-grade amphibolite facies rocks along the contact between the Easton Schist and the quartz diorite gneiss. Smith and Calkins (1906, p. 4) concluded that the quartz diorite gneiss intruded the Easton Schist. Stout (1959, p. 39-40) was unsure of these conclusions and thought that synkinematic metamorphism may have caused the present texture and composition of the rocks. Nonetheless, if these interpretations are correct, the quartz diorite gneiss would be younger than the Easton Schist. The metamorphic character of the unit suggests a Pre-Tertiary age for the quartz diorite gneiss.

The Eocene Manastash Formation and the Taneum Andesite are mapped along the southern contact of this unit. Exposures along this contact are almost nonexistent, and the contact was not seen in outcrop.

Serpentinites

Serpentinites are mapped along the trace of the Taneum Lake Fault and along another fault in the SE1/4, section 18, T. 19 N., R. 15 E. The rocks are composed predominantly of antigorite and opaque minerals. Smith and Calkins (1906, p. 3) correlated these rocks with the ultramafic rocks of the Ingalls Tectonic Complex. The generally accepted age for the Ingalls Complex is Late Jurassic (Tabor and others, 1982, p. 5). This correlation is very tentative, but a Pre-Tertiary age for this unit does seem likely.

Tectonic Complex

A tectonic complex of diverse lithologic composition is mapped along most of the west side of the Taneum Lake Fault. Ultramafic and metamorphic rocks of diverse composition and grade have been tectonically juxtaposed in this area. Pre-Tertiary units, such as the Easton Schist, Lookout Mountain unit of Stout (1959), and nearby amphibolites have been postulated as being tectonic blocks in this unit by Stout (1959) and Goetsch (1978). Other tectonic blocks in this unit are of unknown parentage. Based upon the composition of this unit and its relationship to the Pre-Tertiary metamorphic rocks to the west, Stout (1959, p. 61) has suggested that this unit is a Pre-Tertiary tectonic-shear complex.

Manastash Formation

The Manastash Formation was originally named by Smith (1904, p. 7) for the sandstone and finer-grained sedimentary rocks, which are exposed in the

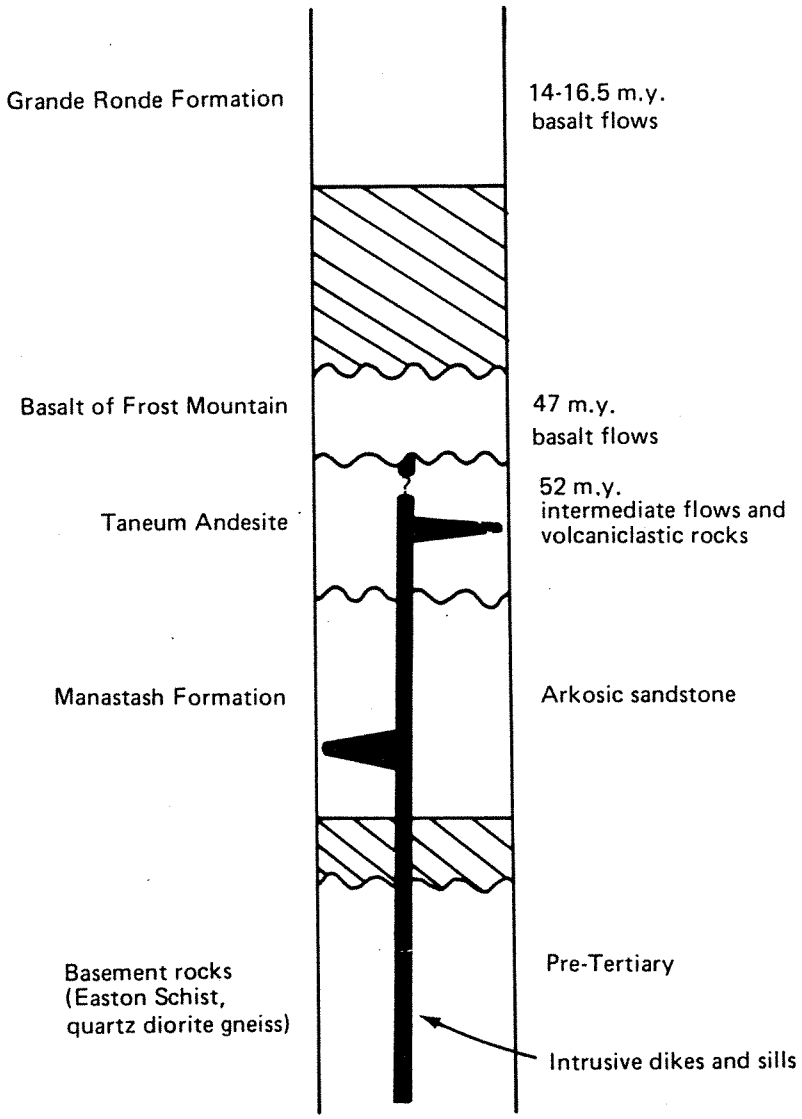

Figure 2. – Generalized stratigraphic column of the study area. The ages along the right side of the column are in millions of years (m.y.) before present.

headwaters of Manastash and Taneum Creeks. This unit is composed of arkosic sandstone, siltstone, mudstone, shale, conglomerate, and coal. The Manastash Formation, as calculated from the geologic map, is a minimum of 3,117 ft (950 meters) thick in the Upper Taneum area. The base of this section is in fault contact with the Easton Schist, while the top of the section is unconformably overlain by the Taneum Andesite. Other areas do not provide sufficient exposures to permit an accurate estimate of the formation's thickness.

The Manastash Formation is the lowest Tertiary unit in the area and nonconformably overlies the Easton Schist and quartz diorite gneiss (fig. 2). Fossil leaves collected from the Manastash Formation indicate an Eocene to early Oligocene age in studies by Knowlton (in Smith, 1904, p. 7). Studies by Chaney (in Stout, 1957, p. 39-42) of plant fossils collected from the Manastash Formation indicate the existence of subtropical, broadleafed, evergreen trees during deposition. This subtropical climate is thought to have existed in Washington during the Paleocene and Eocene Epochs. Newman (1977, p. 1113) suggests that palynomorph data collected from the Manastash Formation along Taneum Creek may be equivalent to the lower Eocene Swauk Formation. Newman included the Manastash Formation into the Naches Formation following Stout (1964). The original nomenclature (i.e. Manastash Formation) has subsequently been readopted.

Two fission-track dates of zircons from rhyolite ash-flow tuffs in the overlying Taneum Andesite have ages of 51.8 and 45.3 million years (Tabor and others, 1982, p. 10). These fission-track ages indicate an early Eocene age for the Manastash Formation.

Taneum Andesite

The Taneum Andesite was originally named by Smith (1904, p. 7) for a sequence of andesitic rocks exposed along the North and South Forks of Taneum Creek and in the Frost Mountain area. A recent proposal has been made to formally rename the Taneum Andesite the Taneum Formation (Tabor and others, 1984, p. 26).

This unit is composed mostly of volcaniclastic rocks interlayered with lava flow rocks. The flow rocks are basalt, andesite, and dacite. The coarse volcaniclastic rocks are generally composed of andesitic and dacitic clasts. Rhyolite tuffs, volcanic breccias, mudflows, and minor coal-bearing sedimentary units occur as well.

The Taneum Andesite is interpreted to be part of an eroded composite volcano. Volcanic breccias and mudflows denote a possible vent on Taneum Ridge in sections 29 and 30, T. 19 N., R. 15 E. The interlayered volcanic flows and volcaniclastic rocks and the variable rock compositions are characteristic of a composite volcano.

Basalt flows and minor sedimentary units characterize what has been mapped as the Taneum Andesite in the area south of Mole Mountain, west of Frost Mountain, and east of the Taneum Lake Fault. An outcrop of sedimentary rocks dipping about 75 degrees to the northwest, in the NW1/4, section 7, T. 18 N., R. 15 E. contains over 6 ft (two meters) of coal in two seams. Another sedimentary unit about 330 ft (100 meters) east of the top of hill 5827 in section 7, T. 18 N., R. 15 E. (see plate 2) is interbedded in basalt flows. This unit consists of claystone, carbonaceous shale, and siltstone, dipping 68 degrees to the southwest.

The bedding of the Taneum Andesite generally dips between 20 and 30 degrees, except near the Taneum Lake Fault, where measurements of bedding

attitudes are nearly vertical. Generally, the deformation of the Taneum Andesite appears to be considerably less than that of the Manastash Formation. The average dip of a fold limb in the Manastash Formation is approximately 40 degrees. An angular unconformity of 10 to 15 degrees between the Taneum Andesite and the Manastash Formation is clearly seen in the SW¼NW¼ section 33, T. 19 N., R. 15 E. and in section 15, T. 18 N., R. 15 E.

A fission-track age of 51.8 million years (Tabor and others, 1982) from ash-flow tuffs in the Taneum Andesite document an early Eocene age for this unit. Another fission-track age of 46.2 million years is probably too young for the Taneum Andesite according to Tabor and others (1982, table 1).

Basalt of Frost Mountain

Both Smith (1904) and Stout (1964, pl. 1) mapped this unit as Columbia River Basalt. The unit is composed of a series of basalt flows restricted to the Frost Mountain and the manner in which it outcrops appear identical to the nearby flows of the Columbia River Basalt Group. Compositionally, the basalt of Frost Mountain is similiar to the nearby basalt flows of the Columbia River Basalt Group except that olivine is present in many samples from the basalt of Frost Mountain. Olivine is rare in basalt samples from the nearby flows of the Columbia River Basalt Group (Stout, 1957, p. 91).

Recent whole-rock potassium-argon dates from the basalt of Frost Mountain range from 47 million years to 33.2 million years (Tabor and others, 1982, p. 11) with considerable possible error. Therefore, the basalt of Frost Mountain is an older unit than the Columbia River Basalt Group.

The contact between the Tanuem Andesite and the basalt of Frost Mountain is apparently an angular unconformity. This statement is based

upon the fact that bedding attitudes from the Taneum Andesite near Frost Mountain have dips ranging from 60 to 75 degrees, while the basalt flows on Frost Mountain are nearly horizontal.

Grande Ronde Formation and Interbeds

Waitt (1979, p. 1) concluded that the Columbia River Basalt flows located on the western periphery of Kittitas Valley are part of the Grande Ronde Formation, which is stratigraphically the lowest unit in the Yakima Basalt Subgroup. Several volcaniclastic beds of the Ellensburg Formation are interbedded in the Grande Ronde flows. Together these formations are the most widespread rocks in the study area.

The Grande Ronde and Ellensburg Formations unconformably overlie many of the major units in the study area, such as the Easton Schist, Manastash Formation, and the Tanuem Andesite. An erosional surface of moderate relief must have been covered by the basalt flows. The Lower Taneum area is a good example of this ancient erosional surface. Scattered outcrops of the Manastash Formation and the Easton Schist are unexpectedly found next to basalt and volcaniclastic rocks. An excellent example can be seen in the southern half of section 19, T. 19 N., R. 16 E.

The Grande Ronde Formation is dated as late early Miocene. Potassium-argon ages have been measured ranging from 16.5 to 14 million years by (Baksi and Watkins, 1973; Watkins and Baksi, 1974).

The volcaniclastic rocks of the Ellensburg Formation are generally composed of light colored, poorly indurated volcanic sandstone, siltstone, conglomerate, and minor diatomite. The clasts are composed of basaltic and andesitic to dacitic rocks, pumice, and tuffaeous material. The beds are generally four meters or less in thickness in the study area.

Structurally, they are nearly horizontal or dip gently to the east. The best exposures occur along South Cle Elum Ridge in the lower Taneum area.

Diabase and Basalt Intrusives

A number of northwest-trending dikes and sills of basalt composition have been mapped in the Manastash Formation and the Taneum Andesite. Only the larger intrusions are shown on the geologic map.

These intrusive may be in part related to the basalt of Frost Mountain. Both units follow the same regional trend and at least one of the intrusives is an olivine basalt (SE1/4 section 15, T. 18 N., R. 15 E.). Olivine-rich diabase has been mapped in the Mt. Clifty area to the west of the study area. According to Stout (1961, p. 348-349) two intrusions near Mt. Clifty can be traced almost continuously to basalt flows of the Naches Formation. This would make the diabase and basalt intrusives in the study area late Eocene to early Oligocene in age, if they are correlative with the Naches Formation.

It is improbable that any of these intrusive rocks represent feeder sources of the Grande Ronde Formation. Flow directions measured from foreset-bedded lava deltas of various basalt flows show a consistent west to northwest movement away from the vent source farther to the east or southeast of the study area (Tabor and others, 1982, p. 13). The best estimate is that these diabase and basalt intrusives were emplaced sometime during the late Eocene to earliest Miocene and may represent more than one intrusive event.

Correlation of the Tertiary Units in the Study Area to the Cle Elum-Roslyn Area

Correlation of the Tertiary units in the study area with other units in central Washington is based upon palynomorph assemblages, radiometric ages,

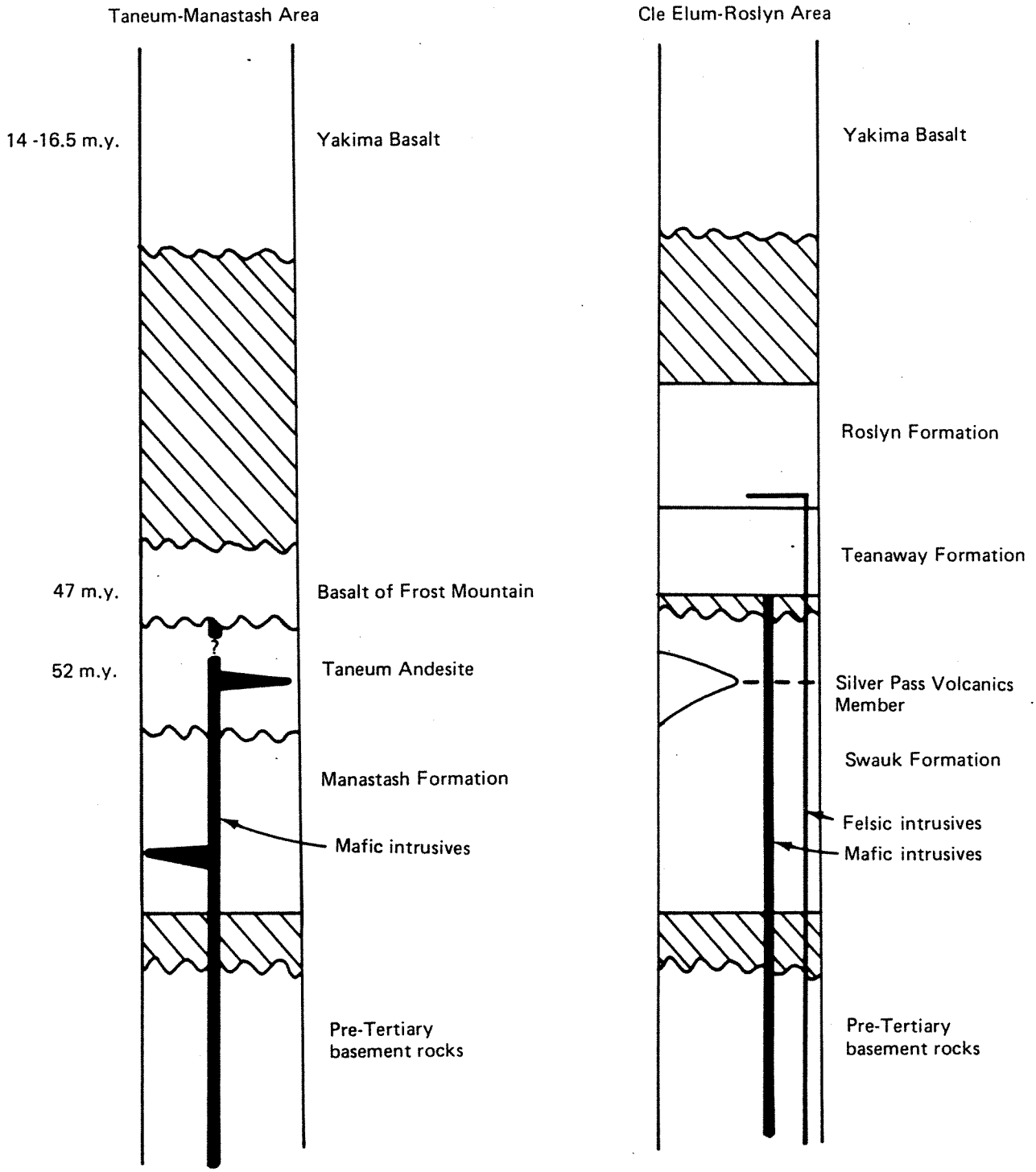

Figure 3. – Generalized correlation of stratigraphic units in the study area and the Cle Elum-Roslyn area (Walker, 1980) to the north.

and stratigraphic postion. Accordingly, the Manastash Formation, Taneum Andesite and Basalt of Frost Mountain are correlatives of the Swauk Formation, Silver Pass Volcanic member of the Swauk Formation, and Teanaway Formation sequence respectively (fig. 3).

The Manastash and Swauk Formations overlie the Pre-Tertiary basement complex in the region. Palynomorph assemblages from the Swauk are considered to be early to middle Eocene by Newman (1975, p. 158). Fission-track ages from tuffs interbedded in the Swauk have yielded ages of 50.4, 51, 49, and 44 million year before present (Frizzel, 1979, p. 28).

Fission-track ages and stratigraphic position are the bases for correlating the Tanuem Andesite and Silver Pass Volcanic member. The Silver Pass Volcanic member is interbedded in the middle to upper half of the Swauk Formation and has yielded fission-track ages of 51 and 53 million years (Frizzel, 1979, p. 28).

Whole-rock potassium-argon ages of around 47 million years are the basis for correlation of the basalt of Frost Mountain and the Teanaway Formation. Potassium-argon ages ranging from 39 to 47 million years have been measured in samples from the Teanaway Formation but 47 million years is believed to be the most correct age (Tabor and others, 1982, p. 9).

STRUCTURE OF THE MANASTASH FORMATION

General Statement

Exposures are generally poor in many parts of the Manastash Formation. Therefore, reliable structural data could not be gathered from many localities. It is generally unwise to interpret fold trends between geographically separate parts of the Manastash Formation. Faulting, multiple

episodes of erosion, igneous intrusions, poor exposures, and numerous minor folds can lead to spurious conclusions about the structure of the formation.

A good understanding of the structural characteristics of the Manastash Formation is not possible without realizing that at least three major erosional events are recorded in the formation. The first erosional episode occurred in the early Eocene. It is represented by the angular unconformity between the Manastash Formation and the overlying Taneum Andesite. A major unconformity between the Yakima Basalt (Grande Ronde Formation) and the underlying Tertiary and Pre-Tertiary rocks represents the second erosional episode. This second episode of erosion is best seen in the Lower Taneum area. The latest erosional episode is responsible for the present outcrop pattern. The present erosional surface is associated with uplift of the Cascade Mountains during the late Tertiary and Quaternary.

A northwesterly trend to the strike of most of the major structures in the Manastash Formation is common. This is also a regional trend observed in the Pre-Miocene units of this part of central Washington (see Stout, 1964, plate 1).

Folds

Folds in the Manastash Formation can generally be described as northwest-trending. The style of folding is upright, and the limbs are planar and symmetrical to each other. Interlimb angles generally indicate open folds. An overall subhorizontal plunge of ten degrees or less to the southeast best describes the orientation of the fold axes; however, northwest-plunging fold axes are also present in the Manastash Formation.

Only one outcrop was located that contains minor folds whose fold axes could be physically measured in the field using a Brunton compass. A coal outcrop in the NE1/4 section 22, T. 18 N., R. 15 E. contains many sheared, over-turned and tightly folded layers plunging S2°E-11° along their hinge lines. Minor folds in the NW1/4 section 16, T. 18 N., R. 15 E. indicate shallowly plunging fold axes to the southeast. A northwest-plunging anticline is located in parts of section 36, T. 19 N., R. 14 E. and section 31, T. 19 N., R. 15 E. The fold axis of the anticline plunges 10 to 20 degrees N50°W.

Unlike the Manastash Creek area, the Upper Taneum area has some excellent exposures of southwest-dipping strata in parts of sections 28, 33, and 34, T. 19 N., R. 15 E. Overall, the strata of the Upper Taneum area are dipping southwest except for a small northwest-trending syncline in the NE1/4 section 19, T. 19 N., R. 15 E. The limbs of this syncline dip between 20 and 40 degrees.

Exposures of the Manastash Formation are limited in the Lower Taneum area. However, coal mine information is available on the structure of the area from the old Wilson Mine located in the SW1/4NE1/4 section 33, T. 19 N., R. 16 E. According to Saunders (1914, p. 138), if the outcrops are in place, an anticline is indicated for the area.

The small outcrop of the Manastash Formation located near the center of section 18, T. 18 N., R. 15 E. is composed of conglomerate and coal-bearing sedimentary rocks. It is postulated that these rocks were tectonically emplaced by dip-slip movement along the Taneum Lake Fault.

Faults

The major faults in the study area have a northwesterly trend. A pair of faults with a northeast trend have been mapped in the southern part of

the Upper Taneum area. Exposures are such that it is not possible to further define the faults.

The parts of the Manastash Formation in the Upper Taneum and Manastash Creek areas appear to lie in a stream bounded by the Taneum Lake fault and another fault, which forms the contact between the Easton Schist and the Manastash Formation in the Upper Taneum area. This fault will hereafter be informally referred to as the Frost Creek Fault. The Taneum Lake Fault has been postulated to have Pre-Tertiary strike-slip movement and dip-slip reactivation during the Tertiary (Goetsch, 1978). Structural analyses by Goetsch (1978, p. 49-51) indicate possible left-lateral strike-slip movement during the Pre-Tertiary. The Taneum Lake Fault is a high angle feature whose Tertiary movement seems to be dip-slip (Goetsch, 1978, p. 73).

The Frost Creek Fault is more difficult to define than the Taneum Lake Fault, because of poor exposures. However, the Frost Creek Fault is visible wherever good exposures of rock occur along the mapped trend. Sulfide mineralization and alteration of the rock occur along much of the fault. Chalcopyrite, malachite, and pyrite have been observed in outcrop. Propylitic alteration was observed in greenschist in section 20, T. 19 N., R. 15 E. Serpentinite has been mapped along the fault in the SE1/4 section 18, T. 19 N., R. 15 E. The topographic expression of the Frost Creek Fault is sinuous and very subdued when compared to the 300 meter cliffs along the Taneum Lake Fault to the northwest of the mapped area. This may be due in part to greater weathering of the phyllites and sandstones relative to the medium-grade metamorphic rocks west of the Taneum Lake Fault.

Fault contacts between the Taneum Andesite and the Manastash Formation are mapped in section 24, T. 19 N., R. 14 E. and in sections 25 and 36, T.

19 N., R. 14 E. Another fault mapped in the Taneum Andesite trends into the Taneum Lake Fault. Pre-Tertiary metamorphic and ultramafic rocks, diabase, volcaniclastic rocks, and coarse-grained sandstone, thought to be from the Manastash Formation, occur in the fault zone in the SE1/4SW1/4 section 7, T. 18 N., R. 15 E. on the north side of the Quartz Mountain Road.

The small faults mapped in the Upper Taneum area are generally high-angle reverse faults or normal faults (see Appendix B, units 46 and 68). A small high-angle reverse fault trending to the northeast can be seen in a road cut in the NW1/4 section 33, T. 19 N., R. 15 E. A poorly exposed northeast-trending fault, offsetting the northwest-trending Frost Creek Fault, is mapped in the NW1/4 section 34, T. 19 N., R. 15 E. The strike-separation of the Frost Creek Fault is approximately 790 feet (240 meters) at this locality. Strike separation may have been caused by strike-slip movement, erosion of the rocks, or a combination of these factors.

PETROLOGY OF THE MANASTASH FORMATION

General Statement

The Manastash Formation is predominantly composed of arkosic sandstone of variable mineralogic composition. In order to better understand the variations in composition of this unit a petrographic study of the sandstone was undertaken. It was felt such a study might also allow differentiation of the Manastash Formation into members and/or facies.

Sandstones are classified according to Folk (1980, fig. 4). The modifications to Folk's (1980) classification are that chert is included in the quartz apex rather than the lithic apex, while granite and gneiss fragments are included in the lithic apex rather than the feldspar apex. The most

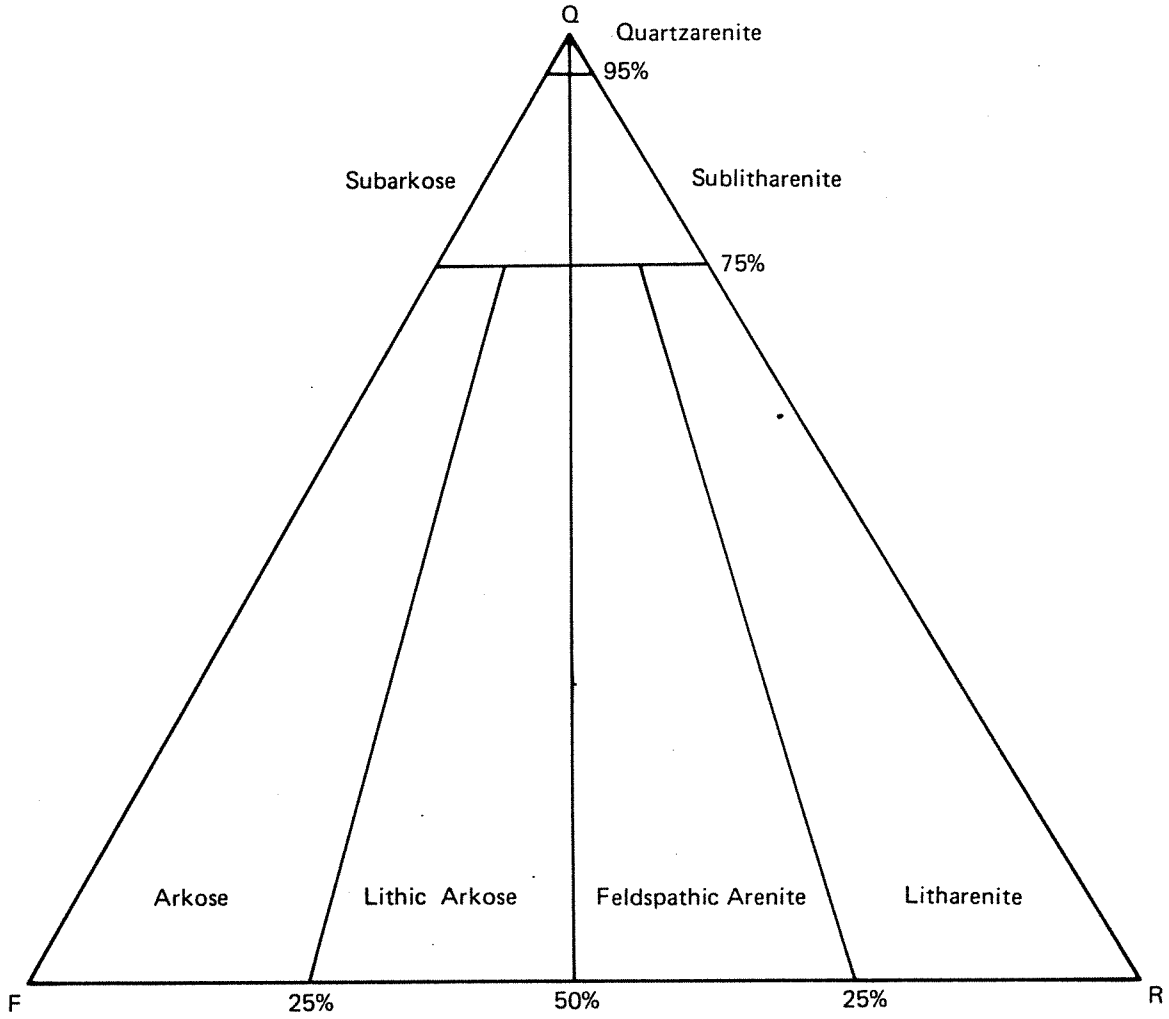

Figure 4. – Sandstone classification ternary diagram (from Folk, 1980).

important tenet of this classification system is that composition is kept separate from texture. Basically, sandstone is classified according to the quantity of detrital quartz, feldspar, and lithic fragments. These grain types are plotted on a QFL triangular diagram and the rock is named according to its position. The quartz (Q) apex represents the greatest stability and includes all catagories of quartz. Feldspars (F) are less stable grains and consist of single-crystal grains. The lithic (L) apex contains the most unstable grains in sandstone. Lithic fragments represent all polycrystalline grains except quartzite and chert.

Other components of sandstone, such as micas, clay matrix, components less than .03 mm, cements, and heavy minerals are ignored in this classification system. Heavy minerals and micas have been left out, since the concentration of these minerals in the rocks are largely determined by the hydrologic characteristics of the system. Matrix material (components less than .03 mm) is ignored in this system in order to avoid the ambiguity and confusion in attempting to distinguish detrital matrix and matrix formed by diagenesis of the rock. The various cements observed in sandstone are generally formed penecontemporaneously or after deposition of the sediments.

Sandstone Petrography

The sandstone of the Manastash Formation can be described as generally submature, subquartzose, and feldspathic. There are distinct compositional differences between the sandstone sampled in the Upper Taneum and the Manastash Creek areas. Comparison of the sandstone composition in Appendix A and rock descriptions in Appendix B and C clearly demonstrate a number of compositional and textural differences in the Manastash Formation. A brief description of each sample is listed in Appendix D.

The sedimentary rocks in the Upper Taneum area are composed of fine- to very-fine-grained arkosic sandstone, siltstone, mudstone, carbonaceous shale, and minor coal. Medium- to coarse-grained sandstone is exposed in only a few locations. Generally, the sandstone is composed of moderately sorted and subangular fragments.

Sedimentary rocks in the Manastash Creek area consist of arkose, subarkose, lithic arkose and other types of lithic-rich sandstone, pebble conglomerate, and minor coal and shale. The sandstone is generally medium- to coarse-grained, moderately sorted, and subangular. Pebble conglomerate and pebbles scattered throughout the sandstone are locally abundant.

Petrographic study of the major detrital grain types of the sandstone (quartz, feldspars, lithic fragments, micas, and heavy minerals) indicate a number of common characteristics. Quartz is clear and unaltered in all of the samples studied. Small inclusions are abundant in most quartz grains.

The alkali feldspars are relatively unaltered and appear fresh. A small amount of clay-like alteration is sometimes observed on the surface of some alkali feldspar grains. Orthoclase is the most abundant alkali feldspar. Microcline is rare to locally abundant.

Almost all of the detrital plagioclase observed is altered to some extent. Clay-like alteration, sericitic alteration, and patches of carbonate minerals in the plagioclase grains are the most commonly observed types of alteration.

The most abundant plagioclase mineral in the sandstone is oligoclase. A number of A-normal measurements of the oligoclase indicate a range of An 20 to An 29 and average An 23. Andesine is the second most abundant plagioclase mineral identified, ranging from An 32 to An 47 and averaging An 36. Calcium-rich plagioclase (An>65) is present in a few thin sections.

The Manastash Formation has a fairly consistent P/F (Plagioclase/Feldspar) ratio of .84 throughout the formation.

A large variety of lithic types occur in the sandstone of the Manastash Formation. However, recent work by Cushman (1984) indicates a greater variability in P/F ratios, notably in the lower Taneum Creek deposits. These include fragments of Easton Schist, with minor amounts of sedimentary and volcanic lithic fragments. As a general rule the lithic fragments are more rounded than the other detrital grain types. Lithic fragments are generally deformed between rigid quartz and feldspar grains.

Detrital biotite and muscovite are concentrated along bedding planes in a number of the Upper Taneum samples. In plane-polarized light biotite has a pale brown pleochroism, which may indicate that some iron has been leached from the biotite. Some of the detrital biotite has been altered to chlorite and other grains appear to be oxidized to a hematitic-appearing material and to clay-like minerals.

Heavy minerals are relatively rare in all of the samples studied and seldom constitute more than a trace amount in any sample. The most frequently identified heavy mineral is detrital epidote, while the less abundant heavy minerals are tourmaline, garnet, amphibole, pyroxene, and apatite. The heavy minerals are generally finer-grained than the more abundant detrital grain types.

Generally, sandstone samples collected from the entire study area are uncemented. A carbonate cement, which appears to be replacing plagioclase is observed in few samples. The best examples of well-cemented sandstone have been collected at locations M42 and M63 (see sample location map, plate 2).

A triangular diagram of the QFL (quartz, feldspar, lithic fragments) detrital modes of the Manastash Formation (fig. 5) clearly demonstrates the

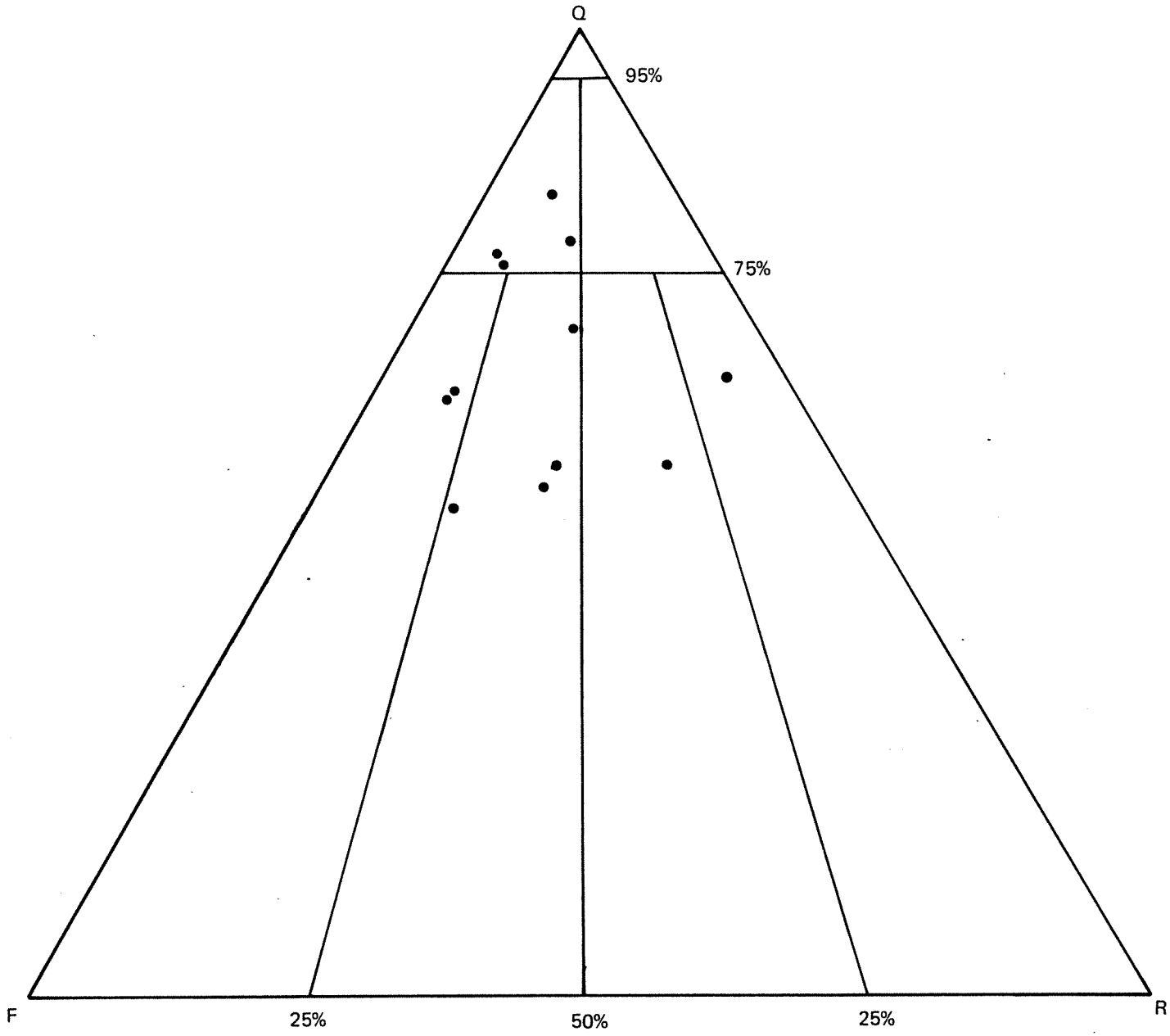

Figure 5 -- Triangular diagram for the QFR detrital modes of the Manastash Formation.

compositional differences between the Upper Taneum area and Manastash Creek area sandstones. As a general rule the sandstone from the Upper Taneum is much more micaceous and feldspar rich than the Manastash Creek area sandstone. Sandstone from the Manastash Creek area contains greater quantities of quartz and lithic fragments than the sandstone from the Upper Taneum area.

The variation in composition of the sandstone is further discussed in Cushman (1984). Briefly, the sandstones found in 19 N., 15 E. sections 18, 19, 20, 28, 29, 33, and 34 are significantly different than those found elsewhere in the area, being poor in quartz and richer in feldspar.

PETROGENESIS OF THE SANDSTONE

Sandstone Provenance

Sandstone composition is determined in part by the provenance of the detrital grains, means of transportation to the basin of deposition, and the nature of the basin. The determination of sandstone provenance is accomplished through careful study of the mineralogy and texture of the detrital components and paleocurrent indicators from the primary structures of the sedimentary rocks.

A table of paleocurrent data from crossbedded rocks indicates a possible south-directed stream flow. Paleocurrent directions, locations, and types of crossbeds measured are given in Table 1.

A south-dipping paleoslope can be inferred for the Manastash Formation. Unfortunately, not enough paleocurrent indicators could be measured to determine a more precise paleocurrent direction. This information is still consistent with paleocurrent studies conducted in the Eocene Roslyn

TABLE 1. - Paleocurrent data gathered from crossbedded rocks in the Manastash Formation

Location	Type of crossbed	Foreset attitude	Paleocurrent azimuth
M-5	tabular	N14E, 40SE	104
M-18	tabular	N82W, 32SW	192
M-21	trough	N22E, 30SE	112
M-22	trough	N79E, 32SE	169
M-24	trough	N12E, 66SE	102
M-25	trough	N14W, 48SW	256
M-34	trough	N7E, 58SW	97
NW1/4 sec. 33, T. 19N., R. 15E.	tabular	N16W, 54NE	254
M-40	uncertain	N59E, 18SE	149
NE1/4 sec. 16, T. 18N., R. 15E.	uncertain	N72E, 49NW	162
NE1/4 sec. 16, T. 18N., R. 15E.	uncertain	N33W, 70NE	237

Average paleocurrent azimuth of 167 degrees

Formation. Paleocurrent studies by Walker (1980) and Brent Barnett (1983, person. commun.) indicate a southwest paleocurrent direction for the Upper Roslyn. Another study in the Wenatchee Formation demonstrates a west to southwest paleocurrent direction for this unit (Gresens, 1983, p. 24).

Recent work by Barnett (personal communication, 1984) shows flow directions in the Eocene sedimentary formations in the Eastern Cascades are in a more westerly direction (with few exceptions).

Petrographic study of samples from the Manastash Formation indicate a mixed provenance. Volcanic, sedimentary, and metamorphic rock fragments have been identified. Fine-grained lithic fragments were classified as microgranular lithic fragments.

Dickinson (1970) and Dickinson and Suczek (1979) have carried this idea of provenances further by developing a system of provenance types and a series of triangular diagrams, which they believe can determine the provenance type. They state that sandstone composition is determined by the type of sedimentary provenance, nature of the sedimentary processes occurring in the basin, and the paths that link provenance to the basin of deposition. The controlling factor in the process between provenance and basin is plate tectonics.

Three basic provenance types have been developed by Dickinson (1970) and Dickinson and Suczek (1979). These are the continental block provenance, which consists of quartzose sand-sized grains from a craton interior and uplifted basement provenances of gneissic and plutonic rocks. Magmatic arc provenances are volcanic regions, which are further subdivided into undissected and dissected magmatic arc provenances. The undissected magmatic arc represents a region composed of uneroded volcanic units. The dissected magmatic arc consists of a volcanic region, which has been eroded down to its plutonic roots. Collision orogens, subduction complexes, and

foreland uplifts are the three types of recycled orogens. Subduction complexes are composed of deformed oceanic sediments and lavas, foreland uplifts are associated with foreland fold-thrust belts, while the collision orogens are formed along crustal sutures between once-separate continental blocks.

Plotting of framework modes from the Manastash Formation into four triangular diagrams (QFL, QmFLt, QpLvLs, and QmPK) as shown in Figure 6 denotes a mixed provenance. Detritus from a continental block and a recycled orogen are indicated. Framework modes denote the continental block as an uplifted continental basement complex of plagioclase-rich granitic plutons and gneiss. This composition could account for the high biotite content of the upper Taneum sandstone. It also accounts for the generally arkosic nature of the sandstone. An average P/F ratio of .84 for the Manastash Formation requires that the provenance be plagioclase rich relative to alkali feldspar.

The presence of chert, sedimentary, and metasedimentary lithic fragments indicates debris from a recycled orogen. Debris from a foreland uplift and/or a subduction complex provenance may be the source of these grains. In addition the metamorphic and sedimentary rocks may have partly covered or been adjacent to the uplifted continental basement rocks.

The source of the volcanic detritus may have been from the remnants of Mesozoic or lower Tertiary volcanic activity. Radiometric ages tend to denote extensive volcanic activity in the region during the early Eocene approximately 50 million years before present. The Taneum Andesite, Silver Pass Volcanics, and Sanpoil Volcanics yield radiometric ages of 50 million years before present.

One major source of detrital grains for the Manastash Formation is the Easton Schist. Conglomerates in the Manastash Formation, which contain

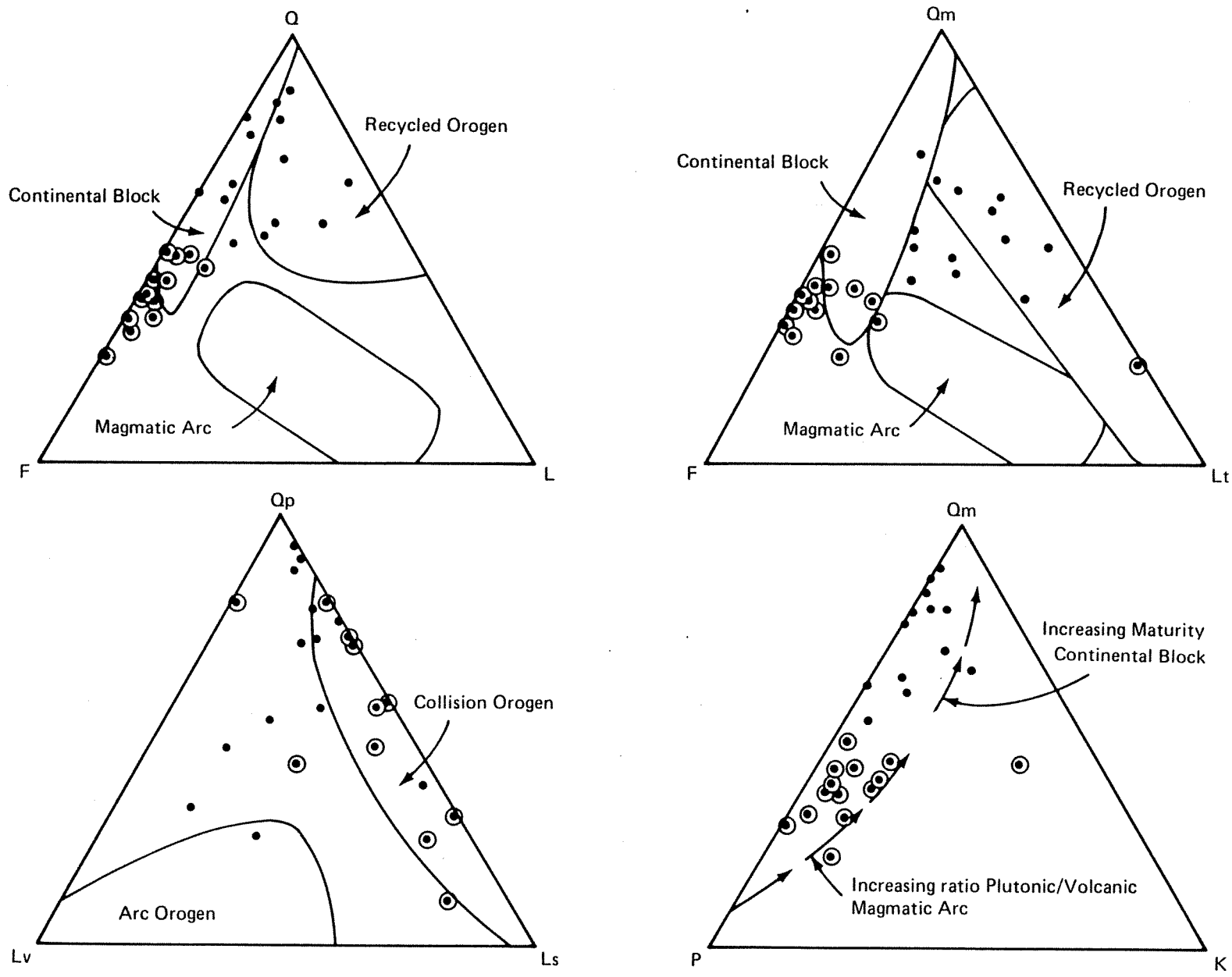

Figure 6. – Framework modes for the Manastash Formation. Circled points are from the upper Taneum area; uncircled points are from the Manastash Creek area.

phyllite and quartz grains believed to be from the Easton Schist, are located in section 18, T. 18 N., R. 15 E. Pebbles of graphitic phyllite and quartz were observed in a pebble conglomerate in the NW1/4 section 16, T. 18 N., R. 15 E. Well-rounded pebbles of quartz, jasper, volcanic rock fragments, hornfels, and one granitic lithic fragment were observed in this pebble conglomerate as well.

Other more distant sources of possible detrital grains include the Mt. Stuart region, North Cascade region, and the Okanogan Highlands. These regions to the north and northeast of the study area contain Pre-Tertiary granitic and tectonic rocks, which could shed detritus to accumulate as an arkosic unit under the proper environmental conditions. Furthermore, any south-directed paleoslope for the Manastash Formation would point towards these regions as possible provenances.

Depositional Environment

The Manastash Formation was deposited in a nonmarine fluvial/lacustrine environment. The fossil record denotes an environment, which supported broadleafed evergreen trees, of a subtropical environment (Stout, 1957, p. 40). Plant fossils of broadleafed trees, palm fronds, and ferns have been observed in the more carbonaceous rocks of the Manastash Formation. No marine fossils of any type have been collected from the Manastash Formation.

Analysis of coal samples from the Manastash Formation provide useful environmental evidence. Ultimate analyses (determination of major elements in a coal sample) in Appendix D of as received (analysis of a coal samples containing natural bed moisture) have sulfur concentrations of less than 1.5 percent. Overall disseminated sulfide minerals are extremely rare in

occurrence in all of the rocks of the Manastash Formation. Low sulfur concentrations in coal deposits and the lack of pyrite and other sulfides in organic-rich sediments connote fresh water environments and/or rapid sedimentation and burial rates of sediments. Apparently, salt water or brackish water bacteria generate H_2S, which combines with iron to form pyrite in a reducing environment rich in organic debris (Saxena, 1976, p. 64 and p. 70).

A vertical sequence of sandstone and finer-grained rocks exposed in the upper Taneum has a cyclic sedimentation pattern (see Appendix B). Alternating layers of mudstone/shale and sandstone/siltstone are located in approximately 1,020 feet (310 meters) of section. This section is composed of about 50 percent arkosic sandstone, 33 percent mudstone and shale, and 18 percent siltstone.

The Manastash type of cyclic sedimentation is strongly characteristic of fluvial sediments according to Miall (1981, p. 12). In order to statistically verify the observed cyclicity of the rocks, a single dependency, embedded Markov chain analysis of the lithofacies transitions was conducted. The statistical data are presented in Table 2 in a transition count matrix, independent trials matrix, transition probability matrix, and a difference matrix. Methodology for this statistical analysis is outlined by Miall (1973). The null hypothesis for the chi-square test is that the sequence is totally random.

The nature of the cyclic process can be followed in a flow diagram (fig. 7) derived from the positive values of the difference matrix. Analysis documents a cyclic process of fining upwards facies. The coarse-grained facies represents high energy channel and bar deposits, while the finer grained facies represents overbank, backswamp, and lacustrine deposits.

TABLE 2. Markov chain analysis of facies transitions probabilities for part of the Upper Taneum area, Manastash Formation.

A. Transition Count Matrix

		1	2	3	4	
sandstone (ss)	1	--	22	0	2	24
mudstone (ms)	2	18	--	5	0	23
siltstone (sl)	3	0	5	--	1	6
shale (sh)	4	1	0	3	--	4
		19	27	8	3	57

B. Independent Trials Matrix

		1	2	3	4
sandstone (ss)	1	--	.82	0	.09
mudstone (ms)	2	.56	--	.24	0
siltstone (sl)	3	0	.53	--	.06
shale (sh)	4	.36	0	.15	--

C. Transition Probability Matrix

		1	2	3	4
sandstone (ss)	1	--	.92	0	.08
mudstone (ms)	2	.78	--	.22	0
siltstone (sl)	3	0	.83	--	.17
shale (sh)	4	.25	0	.75	--

D. Difference Matrix

		1	2	3	4
sandstone (ss)	1	--	+.10	0	-.01
mudstone (ms)	2	+.22	--	-.02	0
siltstone (sl)	3	0	+.30	--	+.11
shale (sh)	4	-.11	0	+.60	--

$X^2=14.28$ d.o.f.=4

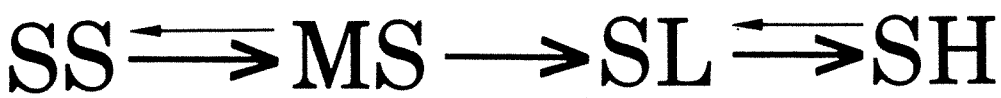

Figure 7. – Flow diagram showing the most likely facies transitions from the difference matrix. Transitions with positive values greater than +.21 are shown with a heavy arrow, while transitions greater than +.09, but less than +.22 are shown by thin arrows (SS = sandstone, MS = mudstone, SL = siltstone, and SH = shale).

An interesting aspect of this flow diagram is the cyclicity between sandstone and mudstone, siltstone and shale transitions, while mudstone acts as a unidirectional transition to the siltstone facies. Other transitions recorded, but not shown on the flow diagram may represent the occurrence of non-cyclic or random changes in the depositional environment. An example would be the five transitions recorded between the siltstone and mudstone facies.

PREVIOUS COAL MINING AND RELATED ACTIVITY

Manastash Creek Area

Prospecting for coal in the Manastash Formation began around 1871 or 1872 by Isiah Buchanan (Saunders, 1914, p. 119). Most of his prospecting was concentrated in sections 15, 16, 21, and 22 of T. 18 N., R. 15 E. In the northeast quarter of section 21 a number of short adits were opened on the hillside by Buchanan. Another outcrop of sheared and folded coal prospected by Buchanan is exposed in the northeast quarter of section 22 on the south side of the South Fork of Manastash Creek.

Two other significant prospects are located in sections 10 and 14 of T. 18 N., R. 15 E. These prospects were in operation sometime during the 1920's and 1930's. Mining operations in the NW1/4 section 14 consisted of at least three tunnels. The prospect in section 10 consisted of at least two tunnels. Both of these prospects appear to have ended after intercepting diabase intrusions. This appears to be the curse of the coal prospects in the Manastash Creek area, as many of the tailings piles located in the area are topped off by diabase.

Upper Taneum Area

The only significant prospect in the Upper Taneum area is located along the South Fork of Tanuem Creek in the NW1/4 section 34, T. 19 N., R. 15 E. According to Saunders (1914, p. 139), the Carothers brothers in 1899 prospected beds which crop out in this area along the south bank of the stream. One tunnel and a large tailings pile is still present in the area.

A few carbonaceous layers of shale and lenses of coal have been located along the south bank of the North Fork of Taneum Creek. Apparently, some prospecting was done in the area by a Mr. Hooper (Saunders, 1914, p. 143-144), but no evidence of tunnels or prospect pits was observed.

Lower Taneum Area

The only coal mine which produced any significant quantities of coal in the Manastash Formation was the Wilson Mine. Mr. Joseph Wilson discovered several coal seams on his homestead in the northeast quarter of section 33, T. 19 N., R. 16 E., on the steep slope along the south bank of Taneum Creek.

The Wilson Mine was located along the hinge line of a northwest-trending anticline. Mine operations were hindered by faulting and rolls of the coal beds. Coal quantity and quality was also variable. Nonetheless, we estimate that up to 100,000 tons of coal have been removed by various operators of the Wilson Mine. An excellent account of the Wilson Mine and other prospects in the Manastash Formation is given by Saunders (1914).

Coal data are presented in Appendix C. Samples (120) 32-80, (122) 34-80, (124) 36-80, and (132) 44-80 are considered unreliable because of high oxygen content due to oxidation and because of high ash content. Samples (121) 33-80 is high volatile A, and samples (123) 34-80 and (133) 45-80, while high is ash, rank as high volatile A based on vitrinite reflectance.

High ash sample (125) 37-80 is bituminous, while sample (131) 43-80, a moist oxidized sample, is ranked as high volatile A by vitrinite reflectance. Vitrinite reflectance rankings are based on techniques and specifications of ASTM and McCartny and Teichmuller (1972).

Samples taken by Saunders in 1911 and Lloyd in 1916 were analysed by the U.S. Bureau of Mines (Fieldner, Cooper, and Osgood, 1931). They were ranked as high volatile C and B. A high ash sample from upper Tanuem Creek analysed 12,932 BTU on a moist, mineral-matter-free basis (Fieldner, Cooper, and Osgood, 1931).

The coal is low in sulfur (commonly <.5 percent S). High ash content is unfortunately common, with many samples exceeding 25 percent ash on an as-received basis. Known thicknesses of coal seams range from 3 to 7.5 feet with bone common (Osgood, 1931). Continuity of any given seam is questionable. In the Wilson Mine on Taneum Creek the worked seam appears to be stratigraphically continuous but heavily faulted. No continuity of outcrop is known elsewhere in the area, and many of the seams appear to have been truncated (and possibly thermally upgraded [?]) by diabase intrusives.

It was not possible to make a determination of the coal reserves present in the Manastash Formation. None of the sections measured in the Manastash Formation could be correlated with other sections. A lack of detailed mine information and of drill hole data further hindered the chances of determining the coal reserves. Nonetheless, it is the belief of the authors that a reserve estimate of 41 million tons (31 million tons inferred, 10 million tons measured and indicated) determined by Beikman and others (1961, p. 33) is far too high. The coal seams lack the inferred

continuity. At the time these estimates were made detailed knowledge of the structure and the extent of igneous intrusions into the Manastash Formation were not available.

In addition, the rank of the coal appears to be upgraded in the presence of diabase intrusives, and may indeed be an aid to mapping of subcropping intrusives.

GEOLOGIC HISTORY

Deposition of the Manastash Formation sediments upon eroded pre-Tertiary metamorphic and igneous rocks took place during the lower Eocene. Deposition of more than 3,000 feet (915 meters) of arkosic sediments took place within a fault-bounded block. Block faulting in the region has been documented by Gresens (1983) and Tabor and others (1984). Topography at time of deposition was essentially subdued, with some variable, nearby relief present. Distance from the Eocene coast was probably on the order of 100 to 200 kilometers. Sometime prior to the eruption of the Taneum Andesite volcanics a pause in subsidence or possibly some uplift of the depositional basin permitted erosion of the upper parts of the Manastash Formation.

Evidence for folding of the Manastash Formation after deposition, but prior to the deposition of the Taneum Andesite, is indicated by the greater deformation of the Manastash Formation relative to the overlying Taneum Andesite. The pre-Tertiary Taneum Lake Fault was apparently reactivated sometime during the Eocene Epoch. Extensional forces activated northwest-trending high-angle faults, which down-faulted the upper Taneum and Manastash Creek areas, but did not visibly affect the lower Taneum area.

The net effect of these extensional forces was to produce a graben, which preserved a relatively thick sequence of lower Eocene arkosic and volcanic rocks. Extensive erosion of the Manastash Formation prior to extrusion of the Miocene flood basalt had left only small remnants of the Manastash Formation in the lower Taneum area. The southeast trend of the unit beneath the thick sequence of Miocene flood basalt indicates a possible continuance of the entire unit to the east or southeast.

It is likely the Manastash Formation and the Swauk Formation were deposited in the same tectonic environment during the Eocene. Petrographic differences between the two formations indicate separate fluvial systems and somewhat different provenances for the two formations (see Frizzell, 1979 and Cushman, 1984). Possibly a low drainage divide existed between the two stream systems.

No major structures separating the two formations during the time of deposition are known. The Easton Ridge Fault, located to the north of the mapped area (see Walker, 1980), appears, however, to have uplifted the Manastash Formation relative to the Swauk Formation. Small outcrops of the Manastash Formation are found immediately to the south of the Easton Ridge Fault, on the relative up side of the fault. The Teanaway Formation, which unconformably overlies the Swauk Formation, is restricted to the north side of the fault.

Recent work by Frizzell (1977), Lewellen (1983), Tabor and others (1984), and Cushman (1984) have pointed to a complex regional setting which possibly involves numerous juxtaposed blocks "splaying" off of the strike-slip Straight Creek Fault along faults more or less parallel to the Olympic-Wallowa Lineament. This multi-block picture, indicates that through the Eocene, depositional sources, direction of stream flow, basin

geometry, and erosional processes were highly variant, and possibly very restricted geographically. This complexity is revealed in the complex variations seen in the sandstones (Frizzell, 1977, Lewellen, 1983, and Cushman, 1984).

The source stream for the sediments possibly flowed to the south, although the flow structures used to determine this are from the Taneum Creek area, and these may not be representative of the Manastash Formation as a whole. The provenance for the sediments was an uplifted continental block of mixed lithologies. The large amounts of polygonal quartz appear to be derived from Easton-like rocks, but other granitic/gneissic source rocks provided sediments for the deposits, notably in the area of upper Taneum Creek. There are also lesser amounts of metasedimentary, sedimentary, volcanic, and other lithic clasts from an older, recycled orogen, derived, at least in part, from oceanic crust. There is also a possibility that some detrital material was derived from lower Tertiary volcanic units.

The generally altered condition of the plagioclase in the arkose indicates a humid climate in which the source rock underwent extensive chemical weathering. Relatively short transport distances are indicated by the arkosic composition and subangular form of the detrital grains.

The presence of coal deposits in the unit denotes a fluvial system stable enough to permit the development of peat in adjacent backswamp and lacustrine environments. Plant fossils of broadleafed evergreen trees show that broadleafed evergreen trees were present and would have provided an excellent source of peat.

Two hypotheses might explain the compositional differences between the sandstones of the upper Taneum and Manastash Creek areas. One is that the two areas are coeval and that differences in composition are caused by

facies changes in the rocks as they are observed laterally. The second hypothesis is that the upper Taneum and the Manastash Creek areas represent two separate members of the Manastash. A combination of the two is quite possible as well. Recent work (Cushman, 1984) indicates the variance from the norm of the sandstones in the upper Taneum Creek area from the overall Manastash/Taneum area is sufficiently great that the former may possibly be a sedimentary body distinct from the Manastash Formation.

The facies change hypothesis would account for variations in sandstone composition through changes in subenvironment. Essentially, the medium- to coarse-sandstone of the Manastash Creek area would represent a high energy environment, while the fine-grained arkosic rocks of the upper Taneum area would be a lower energy environment.

A number of explanations can be given for the variations in grain types seen in the sandstone using the facies-change hypothesis. Micas can be concentrated in certain parts of a unit due to the hydrologic characteristics of the system. Micas tend to be concentrated in the finer-grained portions of a sedimentary unit. This generally does apply to what is seen in the Manastash Formation. The fine-grained sediments of the upper Taneum area contain three to 20 percent micas, whereas the medium- to coarse-grained sandstone of the Manastash Creek area contains zero to seven percent micas.

Differences in the total quartz and feldspar contents in the Manastash Formation can be attributed to the chemical composition and crustal structures of the minerals forming the detrital grains and the energy of the system. Quartz is harder (H=7) and more chemically stable than feldspar (H=6) under surface environmental conditions. Most of the feldspars studied in the sandstone were altered. Feldspars have a well-developed

cleavage in two directions, while quartz has a conchoidal fracture. A relatively high energy environment would tend to break the physically softer and altered feldspars along cleavage planes more readily than the more resistant quartz grains. The effect of this would be to concentrate the feldspar in the finer sediments of the lower energy parts of the system. The harder and more chemically resistant quartz would be concentrated in the higher energy parts of the system.

The variations seen in the polycrystalline quartz content can be attributed to the differences in average grain size in the Manastash Creek area and the upper Taneum area. It is possible that due to mechanical weathering most of the polycrystalline quartz and lithic fragments have been reduced to their crystal constituents in the coarse silt and very fine- to fine-grained sand-sized detrital grains of the upper Taneum area. The polycrystalline quartz and lithic fragments would still tend to be in crystal aggregates in the medium- to coarse-grained sandstone of the Manastash Formation. Cushman (1984) proposes an Easton Schist source for much of the polygonal quartz, with possible source change accounting for the variation in amounts present.

A number of problems exist with the facies change hypothesis. It ignores the overall subhorizontal southeastward plunge of the unit, which would tend to expose the youngest rocks in the southern part of the study area (Manastash Creek area). It also ignores the obvious cyclicity of the high energy channel and bar deposits and the lower energy overbank, backswamp, and lacustrine deposits of the upper Taneum. Furthermore, the outcrop exposures of the upper Taneum and Manastash Creek areas are less than 6,560 feet (two kilometers) apart in places. No subarkosic or lithic rich sandstone channel or bar sands have been located in the upper Taneum

area. The medium- to coarse-grained sandstone that does occur in the upper Taneum is arkosic and is compositional similar to the fine-grained sandstone. Any channel sandstones cutting coals or fine-grained sedimentary rocks in the Manastash Creek area are medium- to coarse-grained quartz and lithic-rich sandstone.

The second hypothesis would require that the upper Taneum and the Manastash Creek occurrences represent two separate members. The upper Taneum area would likely be the stratigraphically lower member. It is uncertain as to where the lower Taneum area would fit into this stratigraphic sequence.

Separation of the upper Taneum and Manastash Creek areas into separate members readily explains the compositional differences of the sandstone. It would also imply that the Manastash Formation coarsens upward.

For a discussion of the relationship of the various sedimentary bodies, see Cushman (1984).

CONCLUSION

The Manastash Formation represents fluvial deposits from various sources deposited during the Eocene Epoch, a time of intensive regional tectonism. During a relatively short period of time thick deposits were laid down within an area most likely characterised by relative movement of several crustal blocks. Appropriate conditions existed in terms of local subsidence, reducing environment, infill of organic matter, and subsequent burial and coalification to yield the present-day coal occurrences. The strike continuity of the coals is unknown: some appear podiform, others are continuous but interrupted by small faults, and diabase intrusives

truncate yet others. The commonly high ash content discourages exploitation. It is to be noted, however, that most samples are from the margins of the sedimentary bodies; no known drilling has taken place well within the larger sedimentary deposits. A possible test for coals less affected by diabase and near-surface oxidation would be in section 9, T. 18 N., R. 15 E., in the largest of the sedimentary bodies forming the Manastash Formation.

Whereas many of the coals have proximate analyses discouraging to coal production per se, virtrinite reflectance showing high-volatile bituminous varieties indicate that Manastash Formation coals may not be unfavorable sources of natural gas according to T.J. Walsh of the Washington Division of Geology and Earth Resources who has been studying the thermal maturity of the coals of Washington State (personal communication, 1984). The sandstones are highly permeable and porous; gas may be found in potentially economical amounts, specifically where Manastash Formation sandstones are truncated by overlying Columbia River Basalts.

In a matter of more academic interest, this study and more recent work (Cushman, 1984) have noted differences between some of the sedimentary bodies in the area. As some conclusions concerning the Manastash Formation (notably palynologic age-dating) have been based on an assumption of homogeneity of the formation, it may be necessary to take these differences into account in order to refine further our understanding of the area.

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APPENDICES

APPENDIX A: Point-count data for the Manastash Formation.

Key to the composition of the Manastash Formation
in the Upper Taneum and Taneum Ridge areas
(from Lewellen, 1983). Due to rounding, not all
percentages equal 100%.

1. Location (see map #1) and sample number (No.)

2. Number of points counted (TC)

3. Monocrystalline quartz (Qm)

4. Polycrystalline quartz (Qp)

5. Plagioclase (P)

6. Alkali feldspar (K)

7. Sedimentary lithics (Ls)

8. Volcanic lithics (Lv)

9. Metamorphic lithics (Lm)

10. Microgranular lithics (fine-grained fragments indistiguishable from two or more grain types) (ML)

11. Matrix (clay, chlorite, and any other particles less than .03mm) (Mat)

12. Biotite and muscovite (Mic)

13. Miscellaneous (heavy minerals, opague grains, cements, and unknown grains) (Misc)

P/F = 5/(5+6)
C/Q = 4/(3+4) calculated after Dickinson (1970)
Lv/L = 8/(7+8+9+10)

QFL = 3+4, 5+6, 7+8+9+10
QmFLt = 3, 5+6, 4+7+8+9+10
QmPK = 3, 5, 6
QpLvLs = 4, 8, 7+9
QmQpL = 3, 4, 7+8+9+10

Q=3+4	Qm=3	K=6	Ls=7+9
F=5+6	Lt=4+7+8+9+10	Qp=4	
L=7+8+9+10	P=5	Lv=8	

1.	sample location and number	M-2 82-12D	M-4 82-14D	M-6 82-17D	M-8 82-19D	M-10 82-21D	M-13 82-24D	M-14 82-25D
2.	number of points counted	802	800	863	823	816	821	836
3.	monocrystalline quartz	39	34	25	19	28	38	40
4.	polycrystalline quartz	0	0	8	0	1	7	1
5.	plagioclase	39	50	57	54	52	34	49
6.	alkali feldspar	2	4	1	11	12	12	4
7.	sedimentary lithic	0	0	0	0	0	1	0
8.	volcanic lithic	0	0	0	0	0	0	0
9.	metamorphic lithic	1	1	6	0	0	2	0
10.	microgranular lithic	0	0	0	0	1	1	1
11.	matrix	2	2	0	1	2	1	0
12.	biotite and muscovite	16	7	2	15	3	5	5
13.	miscellaneous	0	2	1	0	0	1	0
14.	P/F	.95	.93	.98	.83	.82	.74	.92
15.	C/Q	.01	.00	.32	.00	.01	.15	.04
16.	Lv/L	.10	.13	.07	.00	.07	.00	.00
17.	Q, F, L[1]	49,50,1	39,60,1	33,60,6	23,77,0	31,67,2	48,49,4	43,56,1
18.	Qm, F, Lt	48,50,2	39,60,1	25,60,15	23,77,0	30,67,3	40,49,11	42,56,3
19.	Qm, P, K	49,48,2	39,56,5	30,69,1	23,64,13	31,57,13	45,41,14	43,53,5
20.	Qp, Lv, Ls	25,8,67	11,11,78	55,3,41	0,0,0	46,8,46	71,0,29	80,0,20
21.	Qm, Qp, L	98,0,2	97,0,3	64,20,16	100,0,0	92,2,6	79,14,7	94,3,2

[1] Items 17 through 21 are the normalized modes, in percent, for triangular diagrams of each sample for various grain types.

1.	M-16 82-27D	M-17 82-29D	M-23 82-35D	M-27 82-39D	M-29 82-41D	M-33 82-45D	M-34 82-46D	M-35 82-62D	M-36 82-63D	M-37 82-64D
2.	638	823	833	813	807	811	838	818	817	806
3.	28	31	28	31	33	32	32	59	59	41
4.	7	0	1	0	1	0	9	22	23	9
5.	31	39	41	58	38	48	28	8	10	25
6.	10	11	4	0	6	8	11	0	1	0
7.	0	0	0	0	0	0	1	2	2	7
8.	4	0	0	0	0	0	0	1	0	0
9.	4	0	0	0	2	0	3	1	0	8
10.	1	0	1	0	0	0	1	4	4	4
11.	10	5	4	14	1	1	6	4	1	3
12.	5	12	20	6	13	10	6	0	0	1
13.	2	2	1	0	6	0	3	0	0	1
14.	.76	.78	.92	.95	.87	.86	.72	.94	.93	1.00
15.	.20	.00	.04	.02	.03	.01	.21	.27	.28	.18
16.	.44	.00	.00	.00	.00	.20	.00	.12	.00	.03
17.	41,48,11	39,61,0	38,59,3	34,66,0	42,54,4	37,63,0	48,46,6	84,9,7	83,11,6	53,27,20
18.	33,48,19	39,61,0	37,59,4	33.67,1	41,54,5	36,63,1	38,46,16	61,9,30	59,11,30	43,27,30
19.	41,45,14	39,48,13	38,57,5	33,63,3	43,50,8	37,55,9	45,40,15	88,12,1	85,14,1	62,38,0
20.	44,26,30	50,0,50	71,0,29	100,0,0	30,0,70	75,25,0	72,0,28	87,3,9	92,0,8	38,2,60
21.	64,16,21	100,0,0	90,4,6	98,2,0	90,3,7	97,1,2	71,19,10	67,25,8	67,26,7	59,13,28

1.	M-38 82-67D	M-39 82-68D	M-40 82-69D	M-41 82-71D	M-42 82-72D	M-43 82-73D	M-44 82-74D	M-45 82-75D	M-46 82-80D	M-47 82-83D
2.	805	713	824	872	801	813	824	807	812	813
3.	62	36	52	49	38	49	70	37	60	50
4.	6	17	26	15	5	11	5	7	10	10
5.	9	9	10	5	8	23	19	28	18	22
6.	6	6	2	0	11	7	0	3	0	6
7.	2	3	1	4	1	1	1	1	0	1
8.	2	14	0	24	9	2	0	2	0	0
9.	1	3	8	3	5	2	1	3	1	2
10.	9	10	1	0	1	2	3	6	3	4
11.	1	2	0	0	0	3	0	6	6	5
12.	0	0	0	0	0	0	1	7	1	1
13.	0	0	0	0	20	0	0	0	1	0
14.	.61	.60	.80	.93	.41	.76	1.00	.90	1.00	.80
15.	.09	.32	.34	.24	.12	.18	.07	.21	.15	.16
16.	.20	.47	.04	.78	.53	.23	.09	.15	.03	.08
17.	69,16,15	55,15,30	78,12,10	64,5,31	55,25,20	62,31,7	76,19,5	51,36,13	77,19,4	63,30,7
18.	63,16,21	37,15,48	52,12,36	49,5,46	48,25,27	51,31,18	71,19,10	43,36,21	65,19,15	53,30,17
19.	80,12,8	71,17,12	81,15,4	90,9,1	66,14,20	62,29,9	79,21,0	55,41,5	77,23,0	64,29,7
20.	53,26,22	47,38,16	74,1,25	33,52,15	26,42,33	70,10,21	71,7,22	55,15,30	90,1,9	78,4,19
21.	75,7,18	44,21,36	59,30,11	52,16,32	64,9,27	74,16,10	87,6,7	67,12,21	81,14,5	75,15,10

APPENDIX B: Description of sedimentary section of the Manastash Formation, upper Taneum Creek.

Appendix B. A measured section of the Manastash Formation.

The top of the section begins at the base of the Taneum Andesite, the contact is an angular unconformity.

	Thickness meters	feet
85. Sandy siltstone, pale-yellowish-brown (10YR 6/2); course silt-sized grains and approximately 5% very fine sand intermingled, poorly sorted, subangular, convoluted bedding; composed of 30% quartz, 52% feldspars, 15% biotite, and 3% muscovite; numerous plant fossils, layers are about two millimeters to one centimeter thick; sample #82-11D, location M-1.	.6	1.8
84. Siltstone	.6	2.0
83. Covered section.	1.4	4.5
82. Arkose, light-olive-gray (5Y 6/1); very fine grained, well sorted, subangular, crossbedded; major components are 41% quartz, 41% feldspar, 1% lithics, 15% biotite, and 2% muscovite; sample #82-12D, M-2.	2.9	9.6
81. Silty shale, coal fragments scattered throughtout the unit.	.2	.8
80. Arkose, same as unit 82.	2.4	7.8
79. Mudstone, gray; friable.	1.6	5.2
78. Mudstone, very-pale-orange (10YR 8/2); convoluted bedding.	3.4	11.0
77. Basalt sill.	2.4	8.0
76. Arkose, light-gray (N-7); very fine grained, well sorted, angular, and crossbeds; major components are 33% quartz, 55% feldspar, 1% lithics, 5% biotite, 3% muscovite, and 1% matrix; sample #82-14D, location M-4.	2.4	7.9
75. Mudstone, carbonaceous.	.3	.9
74. Arkose; same as unit 76.	1.4	4.6
72. Arkose, medium-light-gray (N16); very fine grained, moderately sorted, angular, crossbedded; major components are 30% quartz, 56% feldspar, 1% lithics, 12% biotite, and 1% muscovite; a small dike of andesitic rock, pyrite occurs in the bake zone; sample #82-15D, location M-5.	3.6	11.8

	Thickness meters	feet
71. Arkose, yellowish-gray (5Y 7/2); fine grained, moderately sorted, subangular to angular; major components are 33% quartz, 59% feldspar, 6% lithics, and 2% mica; same dike as in unit 72 occurs; sample #82-17D, location M-6.	2.3	7.5
70. Mudstone and random coal layers <2 inches thick.	1.1	3.6
69. Muddy arkose, light-brownish-gray (5Y 6/1); fine grained and a clay-sized matrix, poorly sorted, subangular, crossbedded, sand sized fraction consists of 35% quartz, 60% feldspar, 3% biotite and 2% muscovite; sample #82-18D, location M-7.	2.2	7.1
68. Mudstone; small channel filled with sandstone in this unit, small high-angle reverse fault, six inches of displacement.	2.5	8.3
67. Arkose, light-gray (N7); very fine sand, well sorted, angular, crossbedded; major components are 20% quartz, 66% feldspar, 12% biotite, and 2% muscovite; sample #82-19D, location M-8.	4.2	13.6
66. Mudstone.	1.6	5.3
65. Siltstone, yellowish-gray (5Y 7/2); coarse silt, moderately sorted, subangular; major components are 31% quartz, 60% feldspars, 8% biotite, and 1% muscovite; unit forms a large channel; sample #82-20D, location M-9.	1.3	4.3
64. Mudstone, carbonaceous material at the top of the unit.	1.5	4.8
63. Arkose, very-pale-orange (10YR 8/2); fine grained, moderately sorted, crossbedded; major components are 31% quartz, 67% feldspars, 2% lithics, and 2% biotite, unit forms a large channel; sample #82-21D, location M-10.	4.9	16.0
62. Mudstone	1.2	4.0
61. Arkose, pinkish-gray (5YR 8/1); fine grained, well sorted, subangular, crossbedded; major components are 36% quartz, 57% feldspar, 3% lithics, and 4% biotite; unit contains coal fragments and forms a channel; sample #82-22D, location M-11.	1.5	4.9

	Thickness meters	Thickness feet
60. Covered section	39.2	128.6
59. Arkose, very-pale-orange (10YR 8/2); fine grained, poorly sorted, angular; major components are 30% quartz, 66% feldspar, 3% biotite, and 1% muscovite; unit contains small pods of mudstone; sample #82-23D, location M-12.	1.8	5.8
58. Arkose, very-pale-orange (10YR 8/2); coarse grained, moderately sorted, angular; major components are 45% quartz, 46% feldspar, 4% lithics, and 5% biotite; sample #82-34D, location M-13.	2.5	8.1
57. Arkose, pinkish-gray (5YR 8/1); fine to medium grained, poorly sorted, subangular, crossbedded; major components are 41% quartz, 54% feldspar, 15% lithics, and 5% biotite; sample #82-25D, location M-14.	2.0	6.4
56. Mudstone.	.2	.7
55. Arkose, same as unit 57.	3.0	9.7
54. Mudstone.	.2	.8
53. Arkose, same as unit 57.	1.3	4.3
52. Mudstone.	.1	.4
51. Arkose, very-pale-orange (10YR 8/2); fine to very fine grained, poorly sorted, angular, laminated; major components are 30% quartz, 61% feldspar, 3% lithics, 5% biotite, and 1% muscovite; sample #82-26D, location M-15.	2.0	6.7
50. Mudstone.	7.6	25.0
49. Lithic arkose, light-brownish-gray (5YR 6/1); fine grained, poorly sorted, angular, major components are 35% quartz, 41% feldspar, 9% lithics, 3% biotite, 2% muscovite, and 10% matrix; rare concretion up to four inches in diameter; sample #82-27D, location M-16.	6.1	20.0
48. Covered section.	1.5	5.0
47. Lithic arkose, same as unit 49.	3.1	10.0
46. Mudstone; unit contains a channel filled with sandstone; normal fault that has six feet of displacement.	3.1	10.0

	Thickness meters	feet
45. Arkose, grayish-orange-pink (5YR 7/2); very fine grained, well sorted, subangular; major components are 34% quartz, 54% feldspar, 9% biotite, and 3% muscovite; coal lenses occur in this unit; sample #82-29D, location M-17.	4.6	15.0
44. Carbonaceous shale.	.8	2.5
43. Siltstone, olive-gray (5Y 3/2); silt grains, moderately sorted, angular, crossbedded; major components are 35% quartz, 40% feldspar, 20% biotite, and 5% muscovite; mud chip conglomerate at the base of the unit; sample #82-30D, location M-18.	3.3	10.8
42. Covered section.	19.1	62.5
41. Carbonaceous shale.	.2	.5
40. Sandy siltstone, medium-light-gray (N6); coarse silt and very fine sand, poorly sorted, subangular, contorted bedding; major components are 35% quartz, 60% feldspar, 3% biotite, and 2% muscovite; very carbonaceous and numerous plant fossils; sample #82-31D, location M-19.	4.6	15.0
39. Covered section.	43.1	141.4
39. Siltstone, pale-yellowish-brown (10YR 6/2); coarse silt, poorly sorted, angular, thinly laminated; major components are 40% quartz, 48% feldspar, 10% biotite, and 2% muscovite; sample #82-32D, location M-20.	3.4	11.0
37. Shale.	.8	2.5
36. Siltstone, olive-gray (5Y 3/2); silt grains, poorly sorted, angular, crossbedded; major components are 35% quartz, 40% feldspar, 20% biotite, and 5% muscovite; sample #82-33D, location M-21.	3.4	11.2
35. Covered section.	21.0	69.0
34. Arkose, very-pale-orange (10YR 8/2); very fine grained, well sorted, angular, crossbedded; major components are 30% quartz, 61% feldspar, 8% biotite, and 1% muscovite; sample #82-34D, location M-22.	.8	2.5
33. Mudstone.	.3	1.0

	Thickness meters	feet
32. Covered section.	12.1	39.6
31. Arkose, yellowish-gray (5Y 5/2); very fine grained, moderately sorted, subangular, crossbedded; major components are 29% quartz, 45% feldspar, 2% lithics, 21% micas, and 3% matrix; sample #82-35D, location M-23.	.4	1.4
30. Mudstone; channels composed of sandstone are in this unit.	2.5	8.2
29. Covered section.	6.7	22.0
28. Mudstone.	1.1	3.6
27. Siltstone, pale-yellowish-brown (10YR 6/2); coarse silt, moderately sorted, angular, contorted bedding and crossbeds; major components are 40% quartz, 48% feldspar, 10% biotite, and 2% muscovite; unit contains small lenses of mudstone; sample #82-36D, location M-24.	4.1	13.5
26. Mudstone.	1.1	3.6
25. Arkose, very-pale-orange (10YR 8/2); very fine grained, moderately sorted, angular, crossbedded; major components are 31% quartz, 60% feldspar, 7% biotite, and 2% muscovite; sample #82-37D, location M-25.	2.0	6.0
24. Mudstone.	3.3	10.8
23. Siltstone, yellowish-gray (5Y 7/2); coarse silt grains and about 2% very fine sand, poorly sorted, subangular, crossbedded; major components are 35% quartz, 56% feldspar 8% biotite, and 1% muscovite; sample #82-38D, location M-26.	1.5	4.8
22. Mudstone.	1.0	3.2
21. Arkose, light-olive-gray (5Y 6/1); very fine grained, well sorted, subangular, thinly laminated, interlayered by sandy siltstone; major components are 32% quartz, 62% feldspar, 5% biotite, and 1% muscovite; sample #82-39D, location M-27.	.9	3.0
20. Mudstone.	1.4	4.5

	Thickness meters	feet
19. Sandy siltstone, paly-yellowish-brown (10YR 6/2); very fine sand and coarse silt, poorly sorted, subangular; major components are 35% quartz, 50% feldspar, 12% biotite, and 3% muscovite; sample #82-40D, location M-28.	.8	2.5
18. Mudstone; contact between unit 19 and 18 is gradational.	1.1	3.5
17. Covered section.	8.6	28.3
16. Arkose, light-gray (N-7); fine grained, well sorted, angular, carbonate cement; major components are 34% quartz, 44% feldspar, 3% lithics, 11% biotite, 2% muscovite, and 6% carbonate; sample #82-41D, location M-29.	.7	2.3
15. Mudstone.	.4	1.3
14. Arkose, pale-yellowish-brown (10YR 6/2); fine grained, moderately sorted, angular, laminated; major components are 27% quartz, 60% feldspar, 2% lithics, 8% biotite, and 3% muscovite; sample #82-42D, location M-30.	2.0	6.7
13. Mudstone.	1.0	3.4
12. Arkose, pinkish-gray (5YR 8/1); fine grained, well sorted subangular, crossbedded; major components are 33% quartz, 57% feldspar, and 9% biotite; sample #82-43D, location M-31.	1.7	5.6
11. Mudstone.	.2	.5
10. Arkose, same as unit 12.	.6	2.0
9. Mudstone.	.3	1.0
8. Sandy siltstone, pale-yellowish-brown (10YR 6/2); very fine sand and silt, poorly sorted, angular, major components are 30% quartz, 56% feldspar, 15% biotite, and 1% muscovite; sample #82-44D, location M-32D.	3.1	10.0
7. Mudstone.	1.3	4.3
6. Sandstone channel cutting through the mudstone.	.4	1.2
5. Mudstone.	.6	2.0
4. Covered section.	6.1	20.0

	Thickness meters	Thickness feet
3. Arkose, grayish-orange (10YR 7/4); very fine grained, moderately sorted, subangular; major components are 35% quartz, 53% feldspar, 2% lithics, 8% biotite, and 2% muscovite; sample #82-45D, location M-33.	4.6	15.0
2. Mudstone.	4.6	15.0
1. Arkose, pinkish-gray (5YR 8/1); medium grained, moderately sorted, angular, crossbedded; major components are 41% quartz, 40% feldspar, 5% lithics, 6% biotite, 3% carbonate, and 6% matrix; sample #82-46D, location M-34.	6.5	21.2
Total thickness of the section.	311.0	1020.3

The location of this measured section is on Plate 2.

APPENDIX C: Coal data.

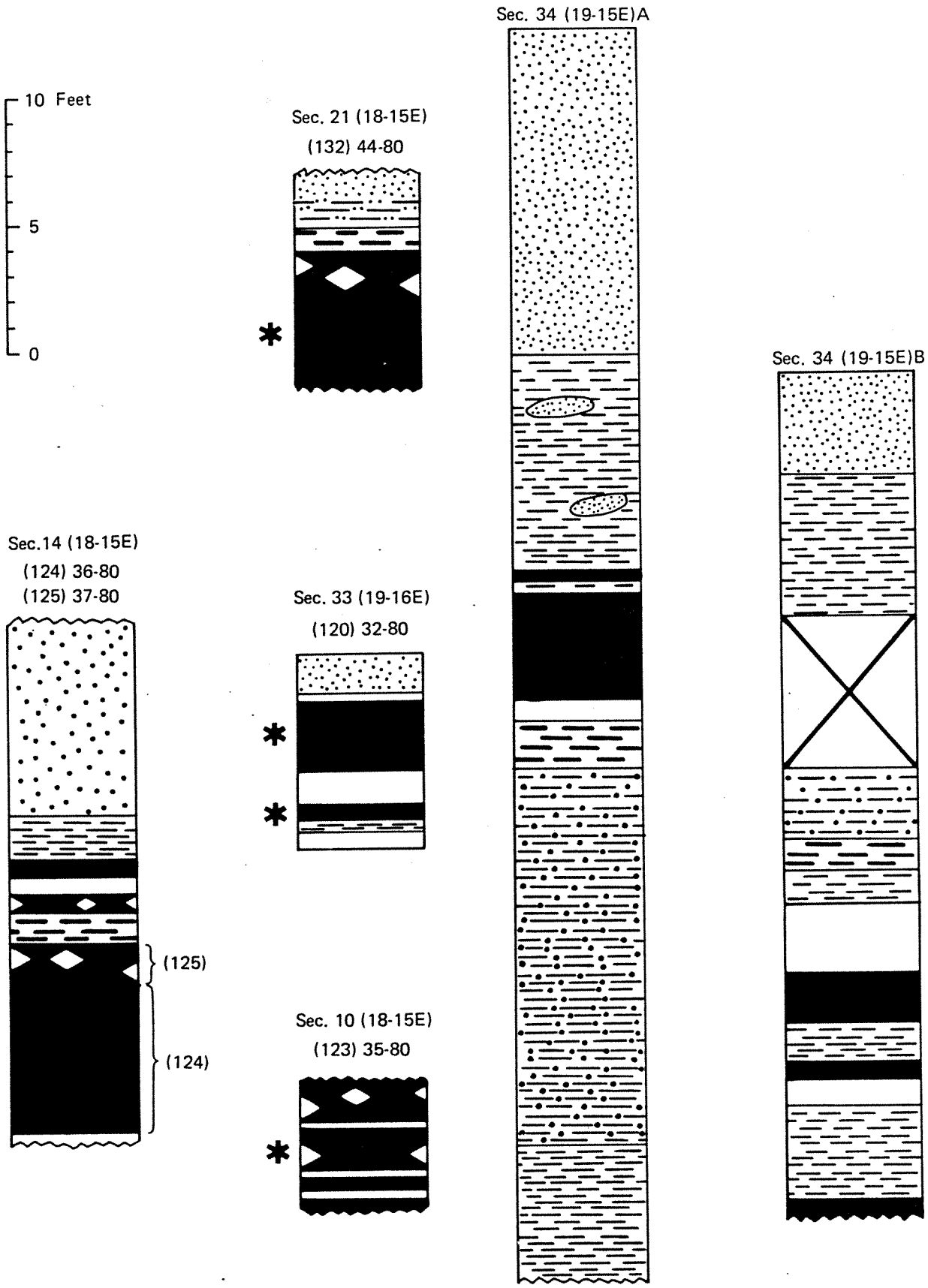

Figure 8. – Stratigraphic sections: Taneum-Manastash area. Sample analysis results follow. Refer to Sedimentary Body and Sample Location Map (Plate 2).

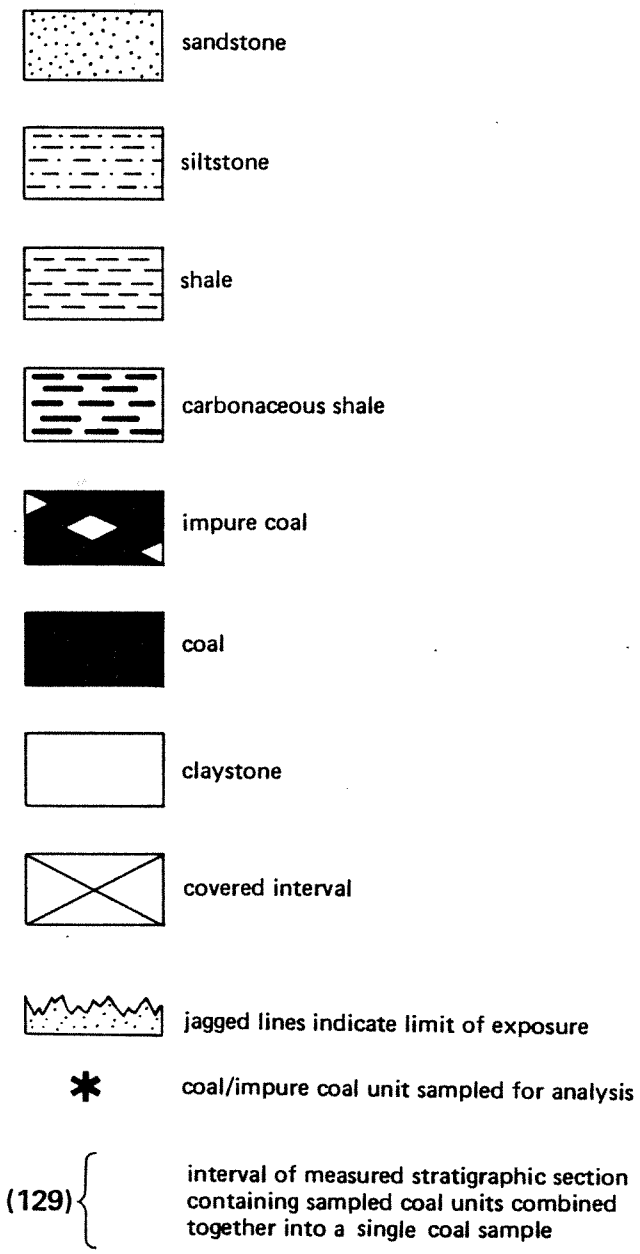

Figure 9. – Legend for Stratigraphic Sections (Figure 8).

County: Kittitas

Sample Number: (120) 32-80

Coal Name: Wilson Seam

Mine Name: Wilson
Coal Area: Taneum
Sample site elevation (ft): 2350

Quarter Section: N/A Section: 33
Township: 19N Range: 16E
Quadrangle: Cle Elum 15

Geologic Formation: Manastash
Age: Eocene

Strike: N55E Dip: 20SE
Major joints in coal: N/A

Exposure type: Portal
Sample type: Channel
Sample condition: Weathered

Total section measured (ft): 7.7
Coal thickness (ft): 3.4
Sample thickness (ft): 3.4

Overburden thickness (ft): 2
Sample collector: Walker (DGER)

Date of sampling: 06-03-80
Date of analysis: 09-23-80

Laboratory: Doe-Pittsburg

Lab. Number: L03825

Air dry loss: 16.0	Coal (AR)	Coal (MMMF)	Coal (DMMF)
Proximate analysis			
Moisture	26.0	41.1	N/A
Volatile matter	24.9	39.3	66.8
Fixed carbon	15.2	24.0	40.7
Ash	33.9	N/A	N/A
Ultimate analysis			
Hydrogen	4.9	5.3	5.3
Carbon	25.6	40.4	68.7
Nitrogen	0.7	1.0	1.8
Sulfur	0.3	N/A	N/A
Oxygen (IND)	34.6	54.7	30.7
Heating value (BTU/LB)	3996	6297	10695

Ash - Initial deformation	2260 F
Softening temp.	2360 F
Fluid temp.	2470 F

Sulfur forms	
Sulfate	N
Pyritic	N
Organic	N

Miscellaneous comments: Coal seam had 1.3 ft of shale parting. Coal sampled from 2.8 ft above and 0.6 ft below this parting. Samples were mixed together for analysis.

County: Kittitas

Sample Number: (121) 33-80

Coal Name: Unnamed

Mine Name: None
Coal Area: Manastash
Sample site elevation (ft): 4560

Quarter Section: N/A Section: 10
Township: 18N Range: 15E
Quadrangle: Cle Elum 15

Geologic Formation: Manastash
Age: Eocene

Strike: N/A Dip: N/A
Major joints in coal: N/A

Exposure type: Tailings
Sample type: Grab
Sample condition: Weathered

Total section measured (ft): N
Coal thickness (ft): N
Sample thickness (ft): N

Overburden thickness (ft): N
Sample collector: Walker (DGER)

Date of sampling: 06-17-80
Date of analysis: 09-23-80

Laboratory: Doe-Pittsburg

Lab. Number: L03826

Air dry loss: 1.0	Coal (AR)	Coal (MMMF)	Coal (DMMF)
Proximate analysis			
Moisture	4.2	5.7	N/A
Volatile matter	37.6	52.3	55.5
Fixed carbon	32.4	45.0	47.8
Ash	25.8	N/A	N/A
Ultimate analysis			
Hydrogen	4.0	5.1	5.1
Carbon	60.4	84.1	89.3
Nitrogen	1.5	1.9	2.0
Sulfur	0.8	N/A	N/A
Oxygen (IND)	7.6	10.4	5.6
Heating value (BTU/LB)	10267	14264	15152

Ash - Initial deformation	2490 F
Softening temp.	2600 F
Fluid temp.	2710 F

Sulfur forms	
Sulfate	N
Pyritic	N
Organic	N

Miscellaneous comments: Tailings from unnamed abandoned mine. High graded for this sample. Sample (122) 34-80 is random sample.

County: Kittitas

Sample Number: (122) 34-80

Coal Name: Unnamed

Mine Name: Unknown
Coal Area: Manastash
Sample site elevation (ft): 4560

Quarter Section: N/A Section: 10
Township: 18N Range: 15E
Quadrangle: Cle Elum 15

Geologic Formation: Manastash
Age: Eocene

Strike: N/A Dip: N/A
Major joints in coal: N/A

Exposure type: Tailings
Sample type: Grab
Sample condition: Weathered

Total section measured (ft): N
Coal thickness (ft): N
Sample thickness (ft): N

Overburden thickness (ft): 0
Sample collector: Walker (DGER)

Date of sampling: 06-04-80
Date of analysis: 09-23-80

Laboratory: Doe-Pittsburg

Lab. Number: L03827

Air dry loss: 3.0	Coal (AR)	Coal (MMMF)	Coal (DMMF)
Proximate analysis			
Moisture	6.6	29.7	N/A
Volatile matter	33.6	152	216
Fixed carbon	0.0	-0.1	-0.2
Ash	72.0	N/A	N/A
Ultimate analysis			
Hydrogen	2.3	9.9	9.9
Carbon	15.1	68.1	97.0
Nitrogen	0.5	2.1	3.0
Sulfur	0.2	N/A	N/A
Oxygen (IND)	9.8	44.1	25.1
Heating value (BTU/LB)	2229	10027	14288

Ash - Initial deformation	2440 F
Softening temp.	2520 F
Fluid temp.	2640 F

Sulfur forms	
Sulfate	N
Pyritic	N
Organic	N

Miscellaneous comments: Random sample of tailings from abandoned mine.

County: Kittitas

Sample Number: (123) 35-80

Coal Name: Unnamed

Mine Name: None
Coal Area: Manastash
Sample site elevation (ft): 4600

Quarter Section: N/A Section: 10
Township: 18N Range: 15E
Quadrangle: Cle Elum 15

Geologic Formation: Manastash
Age: Eocene

Strike: N90E Dip: 40S
Major joints in coal: N/A

Exposure type: Roadcut
Sample type: Channel
Sample condition: Fresh

Total section measured (ft): 4.4
Coal thickness (ft): 3.9
Sample thickness (ft): 3.9

Overburden thickness (ft): 6
Sample collector: Walker (DGER)

Date of sampling: 06-17-80
Date of analysis: 09-23-80

Laboratory: Doe-Pittsburg

Lab. Number: L03828

Air dry loss: 6.0	Coal (AR)	Coal (MMMF)	Coal (DMMF)
Proximate analysis			
Moisture	12.8	40.8	N/A
Volatile matter	14.0	44.6	75.5
Fixed carbon	9.7	30.9	52.2
Ash	63.5	N/A	N/A
Ultimate analysis			
Hydrogen	2.5	5.7	5.7
Carbon	15.7	50.0	84.7
Nitrogen	0.4	1.2	2.0
Sulfur	0.2	N/A	N/A
Oxygen (IND)	17.7	56.4	34.0
Heating value (BTU/LB)	2210	7027	11885

Ash - Initial deformation	2040 F
Softening temp.	2170 F
Fluid temp.	2290 F

Sulfur forms	
Sulfate	N
Pyritic	N
Organic	N

Miscellaneous comments: Coal from area of possible tectonic activity dip-strike unlike good measured section nearby. Bottom of coal zone not reached.

County: Kittitas

Sample Number: (124) 36-80

Coal Name: Unnamed

Mine Name: Unknown
Coal Area: Manastash
Sample site elevation (ft): 4480

Quarter Section: N/A Section: 14
Township: 18N Range: 15E
Quadrangle: Cle Elum 15

Geologic Formation: Manastash
Age: Eocene

Strike: N70W Dip: 46SW
Major joints in coal: N/A

Exposure type: Portal
Sample type: Channel
Sample condition: Weathered

Total section measured (ft): 20.7
Coal thickness (ft): 5.7
Sample thickness (ft): 5.7

Overburden thickness (ft): N
Sample collector: Walker (DGER)

Date of sampling: 06-18-80
Date of analysis: 09-23-80

Laboratory: Doe-Pittsburg

Lab. Number: L03829

Air dry loss: N	Coal (AR)	Coal (MMMF)	Coal (DMMF)
Proximate analysis			
Moisture	20.3	29.6	N/A
Volatile matter	24.0	35.6	49.8
Fixed carbon	26.6	38.8	55.2
Ash	29.1	N/A	N/A
Ultimate analysis			
Hydrogen	4.6	4.8	4.8
Carbon	35.7	52.1	74.1
Nitrogen	0.9	1.2	1.8
Sulfur	0.3	N/A	N/A
Oxygen (IND)	29.4	42.9	23.5
Heating value (BTU/LB)	5789	8441	12002

Ash - Initial deformation	2230 F
Softening temp.	2320 F
Fluid temp.	2390 F

Sulfur forms	
Sulfate	N
Pyritic	N
Organic	N

Miscellaneous comments: Sample from northernmost of three drifts in unnamed, abandoned coal field. Sample (125) 37-80 from impure coal immediately above this sample.

County: Kittitas

Sample Number: (125) 37-80

Coal Name: Unnamed

Mine Name: Unknown
Coal Area: Manastash
Sample site elevation (ft): 4480

Quarter Section: N/A Section: 14
Township: 18N Range: 15E
Quadrangle: Cle Elum 15

Geologic Formation: Manastash
Age: Eocene

Strike: N70W Dip: 46SW
Major joints in coal: N/A

Exposure type: Portal
Sample type: Channel
Sample condition: Weathered

Total section measured (ft): 20.7
Coal thickness (ft): 1.8
Sample thickness (ft): 1.8

Overburden thickness (ft): N
Sample collector: Walker (DGER)

Date of sampling: 06-18-80
Date of analysis: 09-24-80

Laboratory: Doe-Pittsburg

Lab. Number: L03830

Air dry loss: 5.0	Coal (AR)	Coal (MMMF)	Coal (DMMF)
Proximate analysis			
Moisture	8.9	63.6	N/A
Volatile matter	11.8	84.3	232
Fixed carbon	0.0	-0.1	-0.3
Ash	79.6	N/A	N/A
Ultimate analysis			
Hydrogen	2.0	19.6	19.6
Carbon	5.2	37.1	102
Nitrogen	0.3	2.0	5.6
Sulfur	0.1	N/A	N/A
Oxygen (IND)	12.8	91.5	96.0
Heating value (BTU/LB)	693	4922	13551
Ash - Initial deformation	2430 F		
Softening temp.	2520 F		
Fluid temp.	2620 F		
Sulfur forms			
Sulfate	N		
Pyritic	N		
Organic	N		

Miscellaneous comments: Impure coal exposed in northernmost of three drifts in unnamed abandoned coal field. Sample immediately above sample (124) 36-80.

County: Kittitas

Sample Number: (131) 43-80

Coal Name: Unnamed

Mine Name: None
Coal Area: Manastash
Sample site elevation (ft): N

Quarter Section: N/A Section: 17
Township: 18N Range: 15E
Quadrangle: Cle Elum 15

Geologic Formation: Manastash
Age: Eocene

Strike: Horz Dip: 0
Major joints in coal: N/A

Exposure type: Roadcut
Sample type: Grab
Sample condition: Weathered

Total section measured (ft): N
Coal thickness (ft): N
Sample thickness (ft): N

Overburden thickness (ft): 0
Sample collector: Cushman (DGER)

Date of sampling: 07-18-80
Date of analysis: 09-23-80

Laboratory: Doe-Pittsburg

Lab. Number: L03831

Air dry loss: 14.0	Coal (AR)	Coal (MMMF)	Coal (DMMF)
Proximate analysis			
Moisture	26.7	36.2	N/A
Volatile matter	25.2	34.2	53.6
Fixed carbon	23.8	32.3	50.7
Ash	24.3	N/A	N/A
Ultimate analysis			
Hydrogen	5.1	4.5	4.5
Carbon	33.5	45.5	71.3
Nitrogen	1.0	1.3	2.0
Sulfur	0.3	N/A	N/A
Oxygen (IND)	35.9	48.7	25.9
Heating value (BTU/LB)	5416	7339	11518
Ash - Initial deformation	2190 F		
Softening temp.	2270 F		
Fluid temp.	2360 F		
Sulfur forms			
Sulfate	N		
Pyritic	N		
Organic	N		

County: Kittitas

Sample Number: (132) 44-80

Coal Name: Unnamed

Mine Name: Unnamed
Coal Area: Manastash
Sample site elevation (ft): N

Quarter Section: NE Section: 21
Township: 18N Range: 15E
Quadrangle: Cle Elum 15

Geologic Formation: Manastash
Age: Eocene

Strike: N/A Dip: N/A
Major joints in coal: N/A

Exposure type: Prospect
Sample type: Grab
Sample condition: Weathered

Total section measured (ft): 8.5
Coal thickness (ft): 3.5
Sample thickness (ft): 3.5

Overburden thickness (ft): 0
Sample collector: Cushman (DGER)

Date of sampling: 07-18-80
Date of analysis: 09-23-80

Laboratory: Doe-Pittsburg

Lab. Number: L03832

Air dry loss: 9.0	Coal (AR)	Coal (MMMF)	Coal (DMMF)
Proximate analysis			
Moisture	12.7	78.1	N/A
Volatile matter	9.6	59.0	270
Fixed carbon	0.2	1.1	5.2
Ash	77.5	N/A	N/A
Ultimate analysis			
Hydrogen	2.4	27.5	27.5
Carbon	4.3	26.4	121
Nitrogen	0.1	0.5	2.4
Sulfur	0.1	N/A	N/A
Oxygen (IND)	15.7	96.6	124
Heating value (BTU/LB)	479	2918	13371
Ash - Initial deformation	2680 F		
Softening temp.	2760 F		
Fluid temp.	2800 F		
Sulfur forms			
Sulfate	N		
Pyritic	N		
Organic	N		

Miscellaneous comments: Because strike and dip of coal not known, sample was of "best" coal visible in seam. Complete coal section not exposed at prospect.

County: Kittitas

Sample Number: (133) 45-80

Coal Name: Unnamed

Mine Name: Unnamed
Coal Area: Manastash
Sample site elevation (ft): N

Quarter Section: NE Section: 21
Township: 18N Range: 15E
Quadrangle: Cle Elum 15

Geologic Formation: Manastash
Age: Eocene

Strike: N/A Dip: N/A
Major joints in coal: N/A

Exposure type: Tipple
Sample type: Grab
Sample condition: Weathered

Total section measured (ft): N
Coal thickness (ft): N
Sample thickness (ft): N

Overburden thickness (ft): 0
Sample collector: Cushman (DGER)

Date of sampling: 07-18-80
Date of analysis: 09-23-80

Laboratory: Doe-Pittsburg

Lab. Number: L03833

Air dry loss: 9.0	Coal (AR)	Coal (MMMF)	Coal (DMMF)
Proximate analysis			
Moisture	14.9	40.8	N/A
Volatile matter	13.1	35.9	60.7
Fixed carbon	13.2	36.2	61.2
Ash	58.8	N/A	N/A
Ultimate analysis			
Hydrogen	3.1	6.6	6.6
Carbon	18.3	50.2	84.9
Nitrogen	0.3	0.8	1.3
Sulfur	0.1	N/A	N/A
Oxygen (IND)	19.4	53.2	28.5
Heating value (BTU/LB)	2755	7546	12766

Ash - Initial deformation	2800 F
Softening temp.	2800 F
Fluid temp.	2800 F

Sulfur forms	
Sulfate	N
Pyritic	N
Organic	N

APPENDIX D: Sample descriptions.

Sample descriptions.

Sample 82-62D, location M-35; subarkose, grayish-pink (5YR 8/1); course sand, moderately sorted, angular; 81% quartz, 8% feldspar, 8% lithics, and 4% matrix.

Sample 82-63D, location M-36; subarkose, pinkish-gray (5YR 8/1); coarse sand, moderately sorted, angular; 82% quartz, 11% feldspar, 6% lithics, and 1% matrix.

Sample 82-64D, location M-37; lithic arkose, light-gray (N7); fine sand, moderately sorted, angular; 50% quartz, 25% feldspar, 19% lithics, 3% matrix, 1% micas, and 1% miscellaneous.

Sample 82-67D, location M-38; subarkose, grayish-pink (5R 8/2); coarse sand, well sorted, subangular; 68% quartz, 15% feldspar, 14% lithics, and 1% matrix.

Sample 82-68D, location M-39; feldspathic litharenite, light-gray (N7); medium sand, moderately sorted, subangular; 53% quartz, 15% feldspar, 30% lithics, and 2% matrix.

Sample 82-69D, location M-40; subarkose, pale-yellowish-brown (10YR 6/2); coarse sand, moderately sorted, angular; 78% quartz, 12% feldspar, and 10% lithics.

Sample 82-71D, location M-41; litharenite, pale-red (5R 6/2); coarse sand, moderately sorted, angular; 64% quartz, 5% feldspar, and 31% lithics.

Sample 82-72D, location M-42; lithic arkose, grayish-orange-pink (10R 8/2); coarse sand, moderately sorted, subangular, carbonate cement; 43% quartz, 19% feldspar, 16% lithics, and 20% miscellaneous.

Sample 82-73D, location M-43; arkose, pale-red (10R 6/2); medium to coarse sand, poorly sorted, angular; 60% quartz, 30% feldspar, 7% lithics and 3% matrix.

Sample 83-74D, location M-44; subarkose, grayish-orange (5YR 7/2); coarse sand, moderately sorted, angular; 75% quartz, 19% feldspar, 5% lithics, and 1% micas.

Sample 82-75D, location M-45; lithic arkose, pale-red (5R 7/2); fine to medium sand, moderately sorted, subangular, laminated bedding; 44% quartz, 31% feldspar, 12% lithics, 6% matrix, and 7% micas.

Sample 82-80D, location M-46; subarkose, grayish-orange-pink (5YR 7/2); medium to coarse sand, poorly sorted, angular; 70% quartz, 18% feldspar, 4% lithics, 6% matrix, 1% micas, and 1% miscellaneous.

Sample 82-83D, location M-47; arkose, grayish-pink-orange (5YR 7/2); coarse sand, moderately sorted, angular; 60% quartz, 28% feldspar, 7% lithics, 5% matrix, and 1% micas.

Sample 82-47D, location M-48; arkose, pale yellowish-brown (10YR 6/2); very fine sand, moderately sorted, angular, 40% quartz, 43% feldspar, and 17% micas.

Sample CC-2A, location M-49; litharenite; coarse sand, subangular to subrounded; 68% quartz, 4% feldspar, and 28% lithics.

Sample CC-2B, location M-50; sublitharenite; coarse sand, moderately sorted, subangular to subrounded; 79% quartz, 3% feldspar, and 18% lithics.

Sample CC-6, location M-49; litharenite; medium to coarse sand, moderately well sorted, subangular to subrounded; 73% quartz, 22% lithics, 4.5% feldspar, and .5% mica.

Sample CC-13(1), location M-51; litharenite; medium grained, poorly sorted, subangular to subrounded; 69% quartz, 7% feldspar, 23% lithics, 1% micas.

Sample CC-13(2), location M-51; litharenite; medium to coarse grained, poorly sorted, subangular to subrounded; 75% quartz, 7% feldspar, 18% lithics, and a trace of biotite.

Sample CC-16, location M-52; pebble conglomerate; sand sized matrix of moderately sorted, subangular to subrounded grains; 61% quartz, 3% feldspar, 36% lithics, and trace amounts of biotite and epidote.

Sample CC-24, location M-53; sublitharenite; medium grained, poorly sorted, subangular to subrounded; 79% quartz, 19% lithics, 2% micas and a trace of feldspar.

Sample CC-25, location M-54; sublitharenite; medium to fine-grained, poorly sorted, subangular to subrounded; 81% quartz, 1% feldspar, 16% lithics, and 2% biotite.

Sample CC-26, location M-54; pebble conglomerate; poorly sorted, subangular; 59% quartz, 39% lithics, 2% biotite, and traces of epidotie, muscovite and opaque minerals.

Sample CC-45, location M-55; sublitharenite; medium-grained, moderartely sorted, angular to subangular; 78% quartz, 7% feldspar, 15% lithics, and trace amounts of micas and epidote.

Sample CC-46, location M-56; pebble conglomerate; 54% quartz, 4% feldspar, 42% lithics, and traces of biotite.

Sample CC-50, location M-57; feldspathic litharenite; medium-grained, poorly sorted, subangular to subrounded; 62% quartz, 16% feldspar, 21% lithics, and 1% mica.

Sample CC-52, location M-58; feldspathic litharenite; medium-grained, moderately well sorted, subangular to subrounded; 71% quartz, 9% feldspar, 19% lithics, 1% biotite, and trace amounts of epidote.

Sample CC-53, location M-59; litharenite; medium to fine-grained, poorly sorted, subangular to subrounded; 69% quartz, 7% feldspar, 23% lithics, and 1% epidote and micas.

Sample CC-54, location M-60; litharenite fine-grained, poorly sorted, subangular; 68% quartz, 9% feldspar, 23% lithics, and trace amounts of mica, epidote and sphene.

Sample CC-55, location M-61; feldspathic litharenite; medium-grained, poorly sorted, subangular to subrounded; 62% quartz, 26% lithics, 11% feldspar, and 1% biotite and epidote.

Sample CC-57, location M-62; feldspathic litharenite; medium-grained, moderately sorted; 58% quartz, 12% feldspar, 30% lithics, and trace amounts of micas and epidote.

Sample CC-98, location M-63; lithic arkose; medium-grained, poorly sorted, subangular to subrounded; 55% quartz, 20% feldspar, 19% lithics, 1% biotite, and 5% carbonate cement.

Sample CC-16, location M-64; feldspathic litharenite; 67% quartz, 12% feldspar, 20% lithics, and 1% micas.

Sample CC-117, location M-65; feldspathic litharenite; coarse-grained, moderately sorted, subangular; 64% quartz, 9% feldspar, 26% lithics, and 1% micas.

Sample CC-22, location M-66; lithic arkose; very fine- to coarse-grained, poorly sorted, subangular; 54% quartz, 25% feldspar, 18% lithics, and 3% micas.