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GEOLOGY OF THE WENATCHEE AND MONITOR QUADRANGLES, CHELAN AND DOUGLAS COUNTIES, WASHINGTON

By

Randall L. Gresens

BULLETIN 75

1983

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FOREWORD

The first mining claims were staked for gold in the Wenatchee area in 1885. Prospectors flocked into the region and, as a result, the City of Wenatchee was incorporated in 1892. The lure of gold has again attracted the attention of the public and exploration companies. A staking and leasing rush of major proportions is taking place during 1983.

The Geology and Earth Resources Division of the Department of Natural Resources is fortunate to be able to publish this timely report by the late Randall L. Gresens, a professor at the University of Washington. The author was employed by the division to complete the geologic mapping of the Wenatchee and Monitor quadrangles, in the summers of 1975-1982, and to write a bulletin to accompany the maps. The division was in possession of his manuscript, completed field maps, and cross sections at the time of his tragic accident in the summer of 1982.

Randy's report presents new hypotheses regarding the age and origin of hydrothermal alteration, as well as associated ore minerals at the L-D gold mine (also known as the Lovitt, Gold King, and Golden King). The report expands and elaborates on the geologic units, especially sedimentary formations of the Wenatchee area. His attention to detail and lucid style of writing make this report extremely useful to present and future workers in the area.

The staff of the division will miss Randy both as a friend and as an esteemed colleague. We are proud to present this document to the geologic community and the public as a working monument to Randy's ability as a geologist.

Because the published report and maps could not receive the author's final scrutiny, the division accepts responsibility for any errors that may have been introduced as a result of the editing process. Special thanks go to Professor E. S. Cheney, of the University of Washington, for his assistance in reading the manuscript and locating the figures needed for this volume.

Raymond Lasmanis
Washington State Geologist

ERRATA

Bulletin 75, Geology of the Wenatchee and Monitor quadrangles, Chelan and Douglas Counties, Washington, by Randall L. Gresens

Under "Description of Units" on Plates 1, 2, and 3, the description of the Swauk(?) Formation reads

"Swauk(?) Formation of late Eocene Age."

It should read "Swauk(?) Formation of early Eocene age."

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GEOLOGY OF THE WENATCHEE AND MONITOR QUADRANGLES, CHELAN AND DOUGLAS COUNTIES, WASHINGTON

By

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INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

The major objective of this report is to describe the Cenozoic sedimentary and igneous rocks of the Wenatchee and Monitor quadrangles and selected adjoining areas and to discuss their significance to the depositional, igneous, and tectonic history of central Washington. The Cenozoic sedimentary units previously were grouped under a single designation--the Swauk Formation of Paleocene-Eocene age. Most of the rocks of the Wenatchee and Monitor quadrangles are now known to be younger. The relationship between the newly defined units, as well as their relation to igneous and tectonic events that have affected the area, leads to a detailed interpretation of the geologic history of the region from Paleocene to Miocene time.

A secondary objective is to describe occurrences of various Quaternary deposits in the Wenatchee and Monitor quadrangles. These descriptions will supplement a more extensive regional report and interpretation of Quaternary geologic history that is under preparation by the U.S. Geological Survey (R. D. Waitt, personal communication).

This investigation is primarily a field study supplemented with minor laboratory work and by petrographic descriptions reported by previous investigators. The author's interest in the area began while he was conducting a University of Washington field course in September of 1973. Geologic relationships based on a compilation of student maps provided the impetus for further study. A total of about 6 months was spent in mapping the area during the summers from 1975 to 1981.

A large part of the area, which included the most complex geology, was mapped on a scale of 1:12,000. The base map was a photographic enlargement of portions of the Wenatchee, Wenatchee Heights, and Monitor 7 1/2-minute quadrangles. This area covered a northwest-trending belt west of the city of Wenatchee, about 5 miles wide and 8 miles long, extending from Wenatchee Heights on the southeast to the Wenatchee River on the northwest. This map is available as a Washington Division of Geology and Earth Resources open-file report (Gresens, 1975). An area east of the Columbia River in the Wenatchee quadrangle was mapped on enlarged air photos at a scale of 1:12,000. The remainder of the Wenatchee and Monitor quadrangles was mapped using standard U.S. Geological Survey 1:24,000 topographic maps. All the geology was finally compiled at a 1:24,000 scale (plates 1 and 2).

REGIONAL GEOLOGIC SETTING

The geology of central Washington is dominated by the Chiwaukum graben (Willis, 1953). The two quadrangles reported here lie mainly within the southern part of the graben (fig. 1). Fig. 2 shows the regional stratigraphy.

East of Wenatchee, units of early to middle Tertiary age are covered by the Columbia River Basalt Group of Miocene age; to the west, parts of the Tertiary units have been removed by ero-

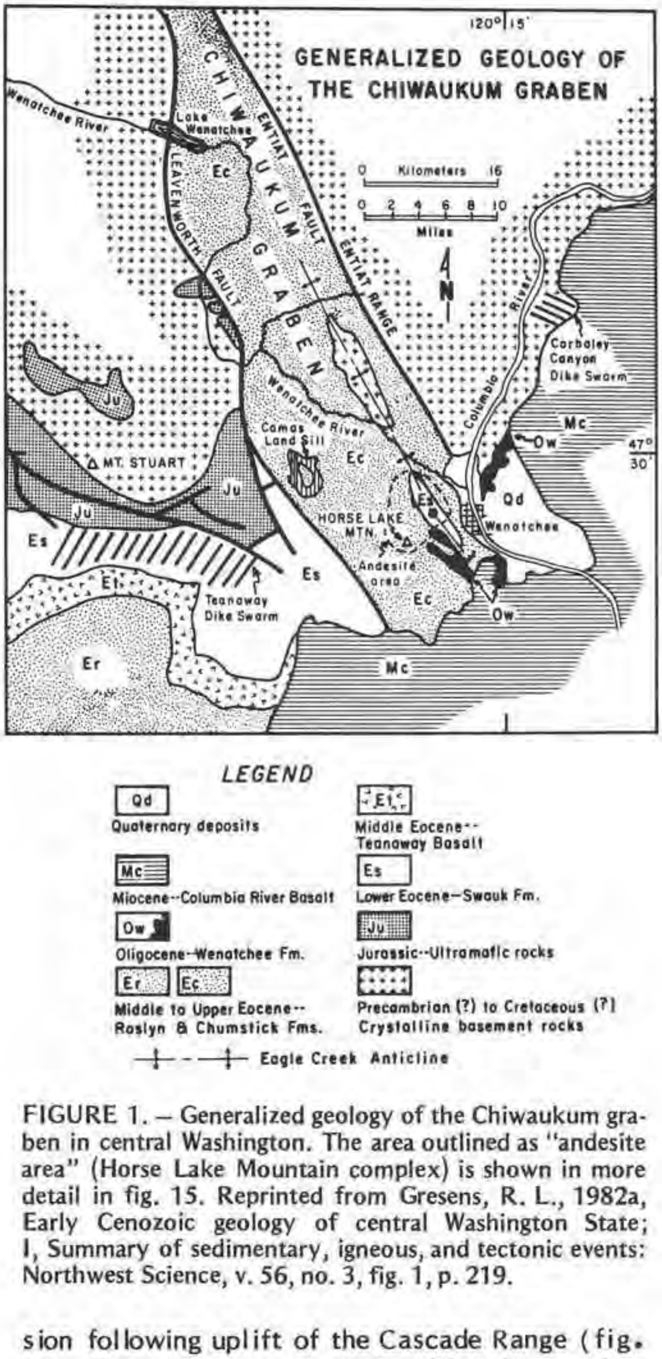

FIGURE 1. – Generalized geology of the Chiwaukum graben in central Washington. The area outlined as "andesite area" (Horse Lake Mountain complex) is shown in more detail in fig. 15. Reprinted from Gresens, R. L., 1982a, Early Cenozoic geology of central Washington State; I, Summary of sedimentary, igneous, and tectonic events: Northwest Science, v. 56, no. 3, fig. 1, p. 219.

sion following uplift of the Cascade Range (fig. 3). The southern part of the Chiwaukum graben on the east flank of the Cascade Range has retained a sufficiently detailed early to middle Tertiary stratigraphic record to establish an accurate early Tertiary history.

PRE-LATE CRETACEOUS METAMORPHIC ROCKS – SWAKANE BIOTITE GNEISS

Waters (1932) named an extensive terrane of metamorphic rocks, extending more than 100 km northwest from Wenatchee, as the Swakane gneiss. Crowder and others (1966) renamed the terrane that includes the type locality at Swakane Creek as the Swakane Biotite Gneiss. The new name is restricted to relatively homogeneous and uniform quartz-feldspar-biotite gneiss; heterogeneous schist and gneiss included under Waters' original definition are excluded from the new name. Chappell (1936) and Page (1939) described the Swakane in several areas. The original general field and petrographic description of the homogeneous rocks by Waters (1932, p. 615) is reproduced here.

> The rock is exceedingly well foliated and of fine grain. Indeed some of the finer-grained varieties may be classified either as coarse schist or fine-grained gneiss. Megascopically, biotite is one of the most prominent minerals, but its conspicuousness is due largely to the fact that its flat flakes cover a large percentage of the cleaved surfaces of the rock. The biotite shows the deep reddish-brown pleochroism regarded by Becke as characteristic of the mica in metamorphic rocks of the deepest zone. Quartz and feldspar are always present, and colorless mica and garnet can be found in varying quantities in practically all specimens. At some localities muscovite exceeds biotite in amount. In thin section quartz and feldspar are found to be present in about equal proportions. Both feldspars are present, but a plagioclase (commonly a calcic oligoclase) usually predominates. In addition to muscovite and garnet, titanite, zircon, apatite, and magnetite are usually present in small amounts.
>
> In all specimens of the biotite gneiss the texture of the rock has been controlled wholly by recrystallization. The minerals are fresh and clear, and they show the allotriomorphic and mutually interpenetrating boundaries of a typical crystalloblastic rock.
>
> A representative specimen of the biotite gneiss from the east wall of the Columbia gorge opposite the mouth of Swakane Creek was measured by the Rosiwal method with the following results:

Mineral	Volume percentage
Quartz	43.9
Feldspar	41.8
Biotite	13.3
Muscovite	0.7
Accessories	0.3

Computed specific gravity	2.7
Determined specific gravity	2.67

> The feldspar in this rock is largely plagioclase (An_{29}). The specimen shows a greater preponderance of biotite over muscovite than is commonly the case.

Waters (1932) described a number of minor metamorphic rock types locally intercalated

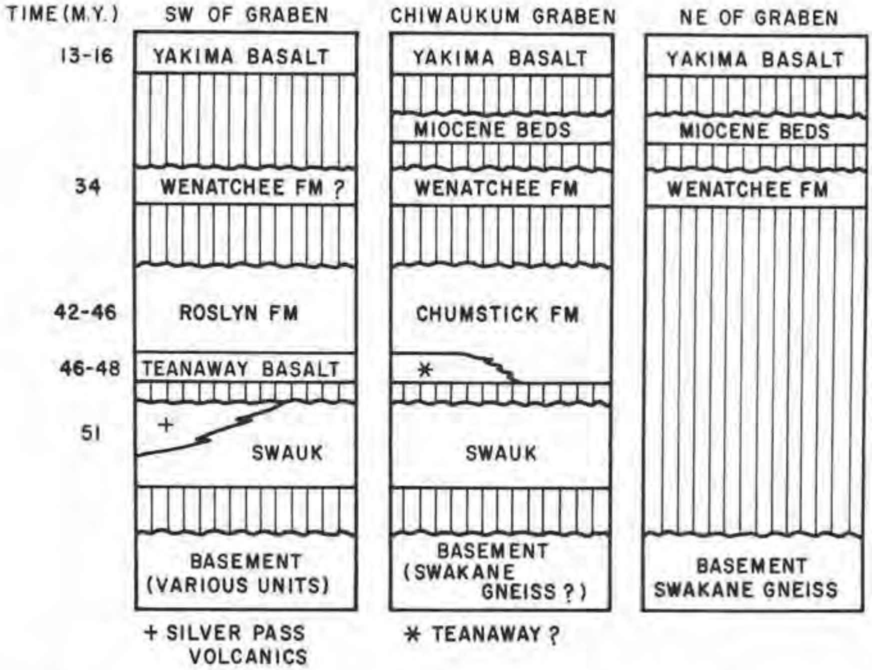

FIGURE 2. – Stratigraphic columns for terranes within, and on either side of, the Chiwaukum graben. Reprinted from Gresens, R. L., 1982a, Early Cenozoic geology of central Washington State; I, Summary of sedimentary, igneous, and tectonic events: Northwest Science, v. 56, no. 3, fig. 2, p. 220.

with the predominant biotite gneiss. These include marble, calc-silicate rocks, and amphibolite.

Quartzofeldspathic pegmatites and quartz veins are locally abundant in Swakane Biotite Gneiss. Waters (1932) described the pegmatites as sill-like; that is, concordant to metamorphic foliation. The most abundant mineral is white feldspar (microperthite or orthoclase), sometimes intergrown with quartz to form graphic granite. Biotite and muscovite occur as large hexagonal plates, with biotite predominant. Garnet occurs locally. Some pegmatites have aplitic borders and quartz-enriched cores; some show multiple zoning patterns.

SWAKANE BIOTITE GNEISS IN THE WENATCHEE QUADRANGLE

Swakane Biotite Gneiss occupies an area in the northeast part of the Wenatchee quadrangle, including the terrain on both sides of the Columbia River. The metamorphic rocks were not a specific target of this investigation, and the

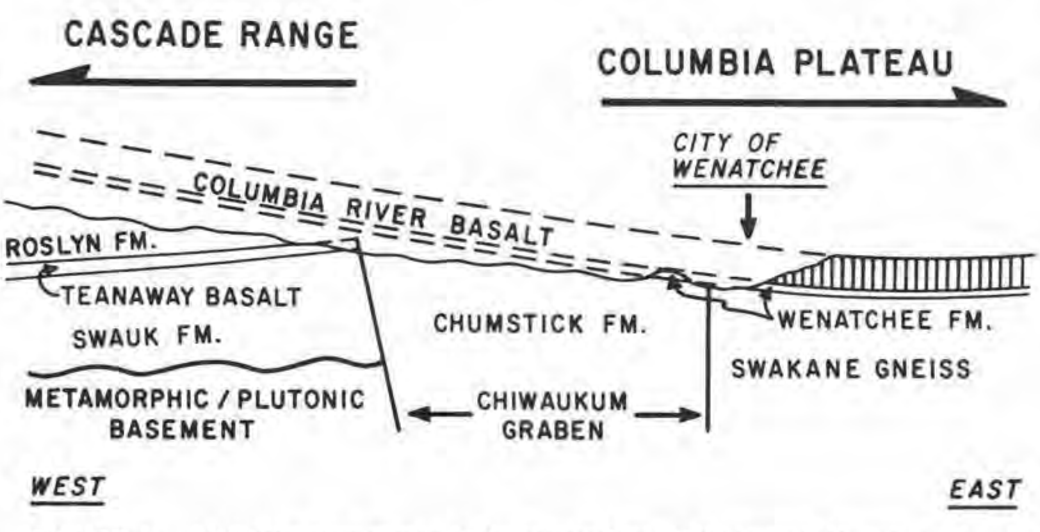

FIGURE 3. – Schematic cross section of the eastern flank of the Cascade Mountains, showing maximal preservation of Wenatchee Formation and Columbia River basalt near Wenatchee, and the effects of Cascade uplift and subsequent erosion.

summary reported here is primarily a condensation from Chappell (1936).

Chappell (1936, p. 31) estimated that at least 99 percent of the unit in the Wenatchee quadrangle is homogeneous biotite gneiss as described by Waters. The only important exception is an occurrence of marble and amphibolite at SW 1/4 sec. 10, T. 23 N., R. 20 E., a few hundred feet west of the mouth of a small ravine at the immediate north border of the Wenatchee quadrangle. Chappell (1936, p. 34) reported a white calcite marble that occurs as a main lenticular body measuring about 100 ft in length and 25 ft in maximum thickness, as well as several smaller layers averaging 6 ft in thickness. Associated with the marble are green calc-silicate bands and intercalated thin layers of amphibolite schist. Calc-silicates are composed of epidote group minerals, diopside, labradorite and calcite; amphibolite schist is composed of black hornblende.

A larger mass of amphibolite in the same vicinity as the marble occurrence consists of pleochroic green hornblende, oligoclase, quartz, and porphyroblastic garnet. Hornblende is idioblastic; quartz and plagioclase are unevenly distributed, giving the rock a mottled appearance. Titanite is an abundant accessory mineral.

Chappell (1936, p. 41-44) described a few pegmatite occurrences near the north border of the Wenatchee quadrangle that represent the southern fringe of a large pegmatite province described to the north by Waters (1932). Chappell noted cross-cutting apophyses that connect pegmatite sills. He described a pegmatite having an aplitic core and pegmatitic borders, which is the reverse of the generalized zoning reported by Waters. Chappell presented petrographic evidence that pegmatite borders are gradational on the microscopic level, even though they appear sharp in outcrop.

FOLIATION IN THE SWAKANE BIOTITE GNEISS

The general structure of gneissic foliation is a broad northwest-trending anticline whose axis coincides with the crest of the Entiat Range (the terrain just east of the Entiat fault) (Waters, 1932). The Swakane Biotite Gneiss within the Wenatchee quadrangle conforms to this structure except for local disruption along the Entiat fault zone or along subhorizontal cataclastic zones that locally cut the unit (Chappell, 1936).

CATACLASIS IN THE SWAKANE BIOTITE GNEISS

Waters (1932) described cataclastic mylonite zones that cut the Swakane Biotite Gneiss as essentially horizontal layers, which he referred to as thrust faults. Apparently they are not very obvious in the field, appearing as a sugary-textured variety of metamorphic rock or resembling an altered rhyolite; but the cataclastic texture is striking in thin section (Waters, 1932). They lack post-cataclastic recrystallization but may contain calcite and retrograde chlorite.

Chappell (1936) felt that cataclastic deformation is not as well represented within the Wenatchee quadrangle. However, he reported an occurrence of a cataclastic breccia of Swakane Biotite Gneiss exposed for a length of about 300 ft in a small ravine at the eastern part of sec. 6, T. 23 N., R. 20 E. Within the zone there are disoriented angular fragments of gneiss averaging 6 to 10 inches across. Chappell believed that the zone may be a continuation of a large thrust mapped by Waters. A peculiar fragmental rock noted during the present investigation at the junction of two drainages at SE 1/4 sec. 14, T. 23 N., R. 20 E. may be another example of cataclastically deformed gneiss in the Wenatchee quadrangle.

ORIGIN AND AGE OF THE SWAKANE BIOTITE GNEISS

The protolith of the Swakane Biotite Gneiss is a matter of some debate. Waters (1932) believed that its overall composition and the occurrence of obvious sedimentary protoliths such as marble support a sedimentary origin. C. A. Hopson, as quoted in Mattinson (1972, p. 3771), suggested that biotite gneiss is derived from rhyodacitic volcanic or volcaniclastic rocks. Chappell (1936) favored a sedimentary origin for biotite gneiss of the Wenatchee quadrangle, based in part on the occurrence of marble and an outcrop of what he considered to be relict sedimentary boulders as large as 3 1/2 feet in longest dimension. The boulder occurrence in gneiss is described as being 1 mile west of the Columbia River at the northern border of the Wenatchee quadrangle, in sec. 9, T. 23 N., R. 20 E., located in the scoured rocks of a creek bed above a small waterfall.

The age of the Swakane Biotite Gneiss is not well known. Based on comparative metamorphism of rocks within the region, Waters (1932, p. 608) considered it to be pre-Ordovician. Mattinson (1972) displayed an unusual pattern of three data points on a U-Pb concordia plot for zircon samples from Swakane Biotite Gneiss. He favored a highly interpretive explanation of crystallization of the zircons at a time greater than 1,650 m.y.b.p., followed by metamorphism at 415 m.y.b.p. I follow Tabor and others (1980) in simply considering Swakane Biotite Gneiss as pre-Late Cretaceous.

There is no hard evidence for the timing of cataclastic deformation in the biotite gneiss. In roadcuts at lower Corbaley Canyon just east of the town of Orondo (secs. 27 and 28, T. 25 N., R. 21 E., in the Entiat 7 1/2-minute quadrangle), felsic dikes dated at 47.5 m.y.b.p. (Gresens, 1982b) are cataclastically mixed with Swakane Biotite Gneiss. The orientation of the cataclastic zone is not known, and it does not rule out the possibility that older cataclastic deformation could have occurred prior to intrusion of felsic dikes. However, thrust faults are known to be associated with post-34 m.y.b.p. deformation (see section on structural geology of Cenozoic rocks), which would support the interpretation that mylonitic and brecciated zones within biotite gneiss could be middle to late Cenozoic structures.

SEDIMENTARY AND EXTRUSIVE IGNEOUS ROCKS OF CENOZOIC AGE

SWAUK FORMATION

The Swauk Formation was named by Russell (1900, p. 118-119) for sedimentary rocks along Swauk Creek in the Mount Stuart 15-minute quadrangle; Smith (1904) and Smith and Calkins (1906) extended the definition to include rocks to the south and west. Numerous investigations, reviewed by Gresens (1977) and Tabor and Frizzell (1977), used the name Swauk to include rocks of the Chiwaukum graben. Most of the rocks of the graben are now termed Chumstick Formation (Gresens and others, 1981). In this restricted sense, the Swauk Formation is defined as the rocks of the original type section and similar rocks to the west that unconformably underlie the Teanaway volcanic rocks. The most recent work on the Swauk by Tabor and Frizzell (1977) is the basis for the general description that follows.

GENERAL DESCRIPTION

Most of the Swauk is dark-colored lithic to arkosic sandstone. At the type section, thin to thick sandstone beds are interbedded with dark carbonaceous siltstone and shale. Sandstone is commonly crossbedded, and pebbly sandstone and conglomerate are typically present. The unit is moderately indurated. A fluvial depositional environment is inferred. Conglomerates, with clasts ranging from boulder to pebble size, locally compose up to 50 percent of the section. Some are interpreted as fanglomerate (alluvial fan deposition). Granitic and metamorphic clasts dominate in some rocks, whereas others are composed mostly of clasts of felsic volcanic rocks. Serpentine-bearing fanglomerate associated with lateritic ironstone is present where the Swauk rests unconformably on ultramafic rocks. A shaly facies, which consists of thinly and evenly bedded alternating shale and sandstone with only rare conglomerate, indicates lacustrine deposition. The youngest part of the section contains interbeds of lighter-colored, more thickly bedded, and more quartzose feldspathic sandstone that resembles sandstone of the Chumstick Formation.

SWAUK(?) ROCKS IN THE WENATCHEE AND MONITOR QUADRANGLES

A sedimentary unit, which the author considers to be significantly older than the Chumstick Formation, is present in the southern part of the erosionally breached core of the Eagle Creek anticline (fig. 1). Although they are labeled as Swauk in fig. 1, the assignment of these rocks to the Swauk Formation is in dispute. They are shown on the U.S. Geological Survey map of the Wenatchee 1:100,000 quadrangle as Chumstick Formation (Tabor and others, 1982), which the author believes is an incorrect designation. The unit is described here, and the significant differences between it and the Chumstick Formation are summarized in the section following the description of the Chumstick.

The rocks considered as possibly belonging to the Swauk Formation occur in a northwest-trending belt about 6 miles long and 1 1/2 miles in greatest width, extending from sec. 25, T. 23 N., R. 19 E., to sec. 22, T. 22 N., R. 20 E. The unit does not crop out well. The best natural exposures are on the north side of Number One Canyon just south of the center of sec. 6, on the north side of Number Two Canyon along the western border of sec. 8, and at a small exposure on the south side of Number Two Canyon in the NE 1/4 sec. 17 (T. 22 N., R. 20 E.). Some of the best artificial exposures are at a roadcut in NW 1/4 sec. 16, immediately southeast of Hill 1946, a roadcut on the east side of the mouth of Dry Gulch in northern sec. 21, several roadcuts in the terrain west of Rooster Comb in NW 1/4 sec. 22, and a small prospect cut on the north side of Squilchuck Canyon, west of the silicified mine rock, in SW 1/4 sec. 22 (T. 22 N., R. 20 E.).

The rocks are dominantly well-bedded and thin-bedded arkosic sandstone with abundant pebble, cobble, and boulder conglomerate and with thinner shale and siltstone interbeds. Color ranges from light gray to dark gray to nearly black, with darker colors associated with finer-grained units. The rocks are cemented with carbonate, and fresh exposures, such as below Chopper Hill on the north side of Number Two Canyon, are strongly indurated, even in the shaly units. A hammer rebounds when the rock is struck, and fractures cut across clasts of crystalline rocks that are firmly cemented in an arkosic matrix.

Bedding thickness varies from one locality to another, but generally the sandstone occurs in beds 1 to 6 ft thick, rarely exceeding 8 ft. Conglomerate beds or conglomeratic portions of sandstone beds are somewhat thinner, rarely exceeding 5 ft in thickness. Siltstone and shale beds have thicknesses typically measured in inches and seldom exceed 1 foot.

Most of the sandstone is poorly sorted, medium- to coarse-grained, and may grade into pebbly conglomerate. Some beds are graded from a conglomeratic base to a thicker sandstone portion to a thin siltstone top. Cross-bedding is typically absent to only faintly visible in most sandstone, but siltstone tops of beds frequently show fine cross-laminations. Some arkose seems to have a higher proportion of clay-sized matrix, giving it a darker color. At exposures in NE 1/4 sec. 17, T. 22 N., R. 20 E., there are repeated alternations of beds of the more typical arkose and beds of clay-rich arkose. In many of the exposures, a bed very rich in clay contains angular grains and lithic fragments up to 1/2-inch diameter in a mudstone matrix. Because of limited stratigraphic thickness at any one exposure, it is not known whether this is a single distinctive bed or a repetition of the lithology at several stratigraphic horizons. The thickness of this bed varies somewhat, but it is typically 3 to 4 ft thick.

Conglomerate clasts are dominantly plutonic and gneissic varieties of granodiorite. Clasts of quartz and a minor amount of fine-grained dark metamorphic rocks are represented; no clasts of volcanic origin were noted. The mineralogy of the sandstone reflects the same source terrane as the conglomerate; it is rich in plagioclase feldspar, quartz, and biotite.

Sandstone grains are angular to subangular. Conglomerate clasts are rounded to subrounded. The coarser conglomerates typically have clasts ranging from 1/2 to 1 foot in diameter, but some exceptionally coarse material, with clasts up to 2 1/2 ft in diameter are present in a small outcropping just north of Chopper Hill in the NE cor. sec. 7, T. 22 N., R. 20 E.

Fossil plant material is rare and poorly preserved. Some unidentified leaves of deciduous trees were noted in exposures south of Chopper Hill in sec. 8, T. 22 N., R. 20 E. At this locality, sedimentary structures that appear to be filled holes of small burrowing organisms are perpendicular to bedding planes in siltstone and sandstone. The exposure in NE 1/4 sec. 17, T. 22 N., R. 20 E., has fragments that appear to be derived from palmetto fronds, which are common in the type section of the Swauk.

Thick veins of coarsely crystalline calcite are typical of this belt of rocks. Veins are commonly 1/2 to 1 inch thick, and some are over 2 inches thick.

Because of the high clay content and carbonate cement of some sandstones, the rock weathers readily, and much of the Swauk(?) terrane consists of grassy slopes. Nonetheless, the unit may be identified by the abundance of residual conglomerate clasts and their composition (plutonic and gneissic granodiorite, and no volcanics), fragments of veins of coarsely crystalline calcite, and a carbonate-rich soil that reacts with acid.

The depositional environment represented by these rocks is enigmatic. The thinness and evenness of the beds and the lack of pronounced cross-bedding, cut-and-fill structure, or rip-up clasts suggest a lacustrine rather than fluvial environment, but lacustrine rocks are usually characterized by fine grain size rather than the coarse lithologies represented here. Perhaps the rocks were mudflows from a nearby highland source that moved into a shallow lake.

CHUMSTICK FORMATION

Earlier investigators suggested that two arkosic units are present in the area (Russell, 1900; Alexander, 1956); however, the definitive investigation included radiometric dating of tuffs recognized by Whetten in the younger unit (Gresens and others, 1981). The younger arkosic unit is now formally separated from the Swauk Formation and redesignated the Chumstick Formation (Gresens and others, 1981). The Chumstick was deposited within the Chiwaukum graben contemporaneously with its subsidence (fig. 4), and most of the rocks now occupying the area of the Chiwaukum graben are Chumstick Formation (fig. 1). The following general description is based on Whetten's (in Gresens and others, 1981) definition of the unit at the type and reference sections.

GENERAL DESCRIPTION

The Chumstick Formation is a thick section of interbedded sandstone, shale, and conglomerate that was deposited in environments that range from fluvial to lacustrine. The most common lithologies are sandstone, pebbly sandstone, and conglomerate, which occur together in massive beds. Shale is less abundant except in the Nahahum Canyon Member, which is designated as a separate facies. Clasts in the conglomeratic and pebbly beds include foliated metamorphic rocks, felsic volcanic rocks, and vein quartz in various proportions. The sandstones are feldspathic, biotite-rich, and reflect the same generally gneissic source terrane as the conglomerates. The sandstone is locally zeolitized with laumontite and, less commonly, clinoptilolite. Sedimentary structures of fluvial origin include imbrication in conglomerates, graded, cross-bedded, and channeled sandstone, rare ripple marks and flute casts, and organic remains such as leaves, branches, and logs. Minor coal seams and lenses occur locally.

Tuffs interbedded within the lower Chumstick rocks have proven to be extremely useful marker beds that delineate the stratigraphy and structure of the unit. They include both ash flow and ash fall tuffs, and some show local evidence of sedimentary reworking. The average thickness is about 20 ft, but a thickness of 35 ft is noted at one locality. They range in color from shades of gray to green, but tend to weather white. Zeolitization ranges from minor to extensive. Some are sufficiently distinctive and continuous in outcrop that they have been assigned names and serve as the most useful marker beds.

The Nahahum Canyon Member is an upper lacustrine facies that presumably reflects the final filling of the Chiwaukum graben. It is composed mostly of shale and shaly sandstone, but includes some sandy turbidites. It does not crop out well, and the unit is prone to

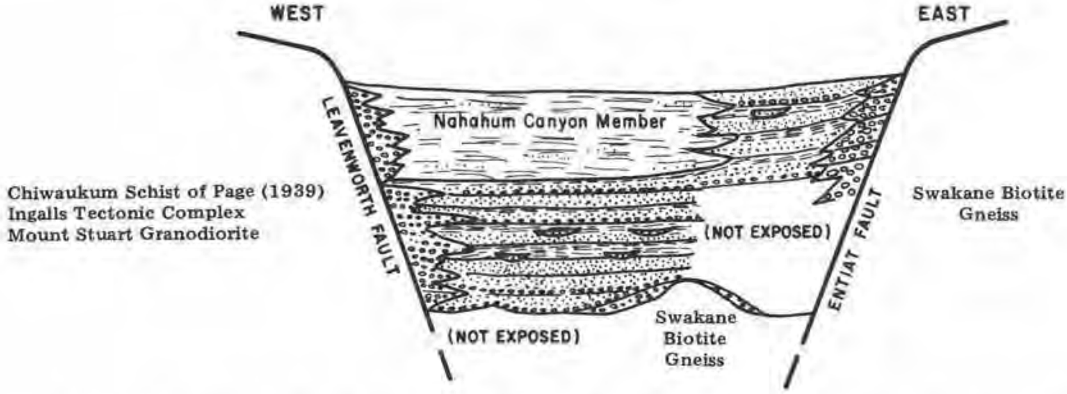

FIGURE 4. — Generalized cross section through the Chumstick Formation in the northern part of the Chiwaukum graben prior to folding [not drawn to scale]. From Gresens and others (1981, fig. 4, p. 848).

landsliding. The Nahahum facies is largely restricted to the eastern side of the Chiwaukum graben where it is in fault contact with the gneissic core of the Eagle Creek anticline, but it has been mapped conformably on lower Chumstick farther north in the graben.

Near major fault zones, including the bounding faults of the Chiwaukum graben, very coarse conglomerates interfinger with the more typical Chumstick rocks. They tend to reflect the lithologies of nearby crystalline terranes, and are interpreted as remnants of alluvial fans (fanglomerates) shed into the subsiding graben from adjacent crystalline fault blocks. Parts of these resemble typical conglomerate of lower Chumstick, and some of them interfinger with lacustrine facies (Nahahum Canyon Member).

CHUMSTICK ROCKS IN THE WENATCHEE AND MONITOR QUADRANGLES

LOWER CHUMSTICK ROCKS

As in the type area, rocks on the west flank of the Eagle Creek anticline (fig. 5) are lower Chumstick Formation. Though broken by one major fault zone and though having minor variations in strike, they essentially form a monotonous homoclinal sequence of feldspathic sandstone and interbedded shale dipping west to southwest from the Eagle Creek anticline to the western border of the Chiwaukum graben. The total stratigraphic thickness across this expanse is estimated as 18,000 to 20,000 feet. The stratigraphically lowest rocks are closest to the Eagle Creek anticline, but they cannot be observed resting unconformably on Swauk(?) rocks. At the type locality, Whetten (in Gresens and others, 1981) noted that a distinctive red bed fanglomerate marks the base of Chumstick Formation resting depositionally on Swakane Biotite Gneiss. Failure to observe an analogous distinctive basal unit in the Wenatchee-Monitor area is due to one or more causes. The red bed fanglomerate in the type area must represent weathered Swakane Biotite Gneiss; weathered Swauk(?) Formation would not produce a similar unit. The probability of exposure of a depositional contact is not high because both Swauk(?) and Chumstick arkoses weather readily and crop out poorly. The unconformity between Swauk(?) and Chumstick was at least locally involved in later tectonic movements and has been disrupted and silicified. The latter relationship is best displayed on the

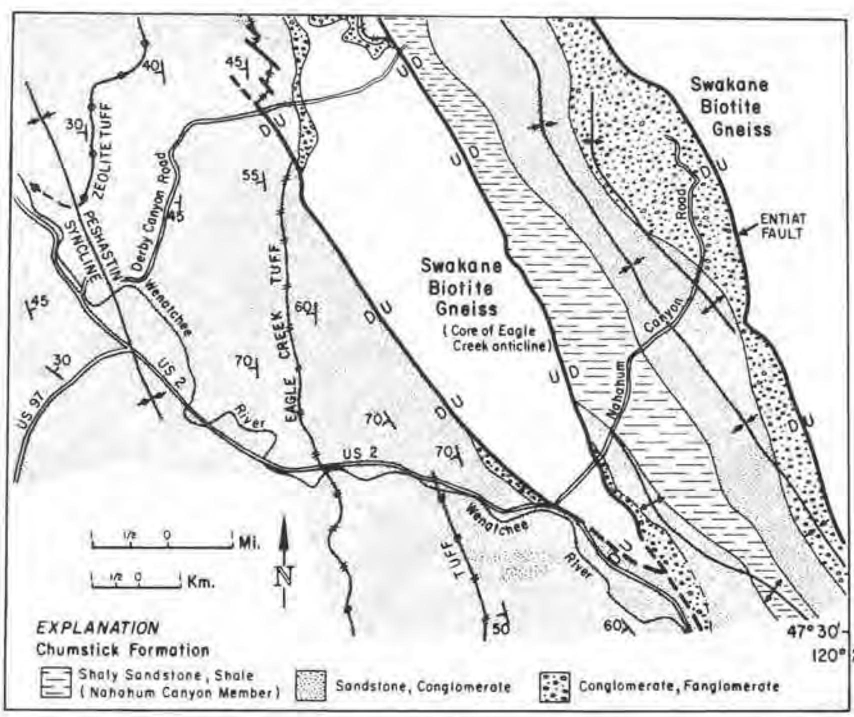

FIGURE 5. — Geologic sketch map showing lithologies of the Chumstick Formation in the central part of the Chiwaukum graben near the northern end of the Eagle Creek anticline. From Gresens and others (1981, fig. 3, p. 847).

north side of Number Two Canyon in SW 1/4 sec. 7, T. 22 N., R. 20 E., and SE 1/4 sec. 12, T. 22 N., R. 19 E. Here, the nearest exposures of Swauk(?) and Chumstick, about 1,500 ft apart, are structurally discordant and are separated by a tabular body of brecciated and silicified rock that parallels bedding in the Chumstick. The silicified zone is interpreted as a sheared and silicified unconformity, and the Chumstick rocks are considered to be essentially basal Chumstick Formation.

Lower Chumstick rocks that most closely resemble those in the type area, in terms of a relatively high proportion of conglomerate, are exposed just west of the Eagle Creek anticline in the Wenatchee Heights quadrangle on the northwest side of Stemilt Canyon in S 1/2 sec, 25, T. 22 N., R. 20 E. Here the Chumstick sandstones lying below the Wenatchee Formation are rich in coarse conglomerates with abundant clasts of felsic volcanic rocks. In contrast, most of the lower Chumstick between the Eagle Creek anticline and the Leavenworth fault is relatively poor in conglomerate, with clasts that are typically pebble-sized rather than cobble-sized or larger. A few beds of coarse conglomerate, with clasts up to 4 inches in diameter, occur in the lowermost part of the section, for example in the upper reaches of Number One Canyon in secs. 1 and 2, T. 22 N., R. 19 E.

Pebbly conglomerates have highly variable clast composition. Some are completely lacking the felsic volcanics that are generally abundant in coarser conglomerates. Various proportions of gneissic and plutonic granitic clasts, dark chert, and vein quartz are usually represented, as well as a major to minor proportion of felsic volcanics.

Massive sandstone beds are identical in lithology and sedimentary characteristics to those of the type area. Sandstone is often carbonate-bearing, and calcite occurs both as minor fracture fillings and in concretions. Shales and siltstones are only poorly represented in beds ranging from a few inches to several feet thick. Most are poorly indurated and range from light gray to dark brown in color. In a few localities, black shales, some with well-preserved leaf fossils, are present, such as along the road to Horse Lake Mountain in sec. 10, T. 22 N., R. 19 E., and along a logging road at the northern border of sec. 3, T. 22 N., R. 19 E.

The Leavenworth fault zone apparently does not cross the Monitor quadrangle. The homoclinal sequence of lower Chumstick rocks has been noted in the far southwest corner of the quadrangle, at the SE cor. sec. 19, T. 22 N., R. 19 E., and this occurrence is probably northeast of the Leavenworth fault zone by no more than a few hundred feet. The Devil's Gulch Trail, in sec. 19, T. 22 N., R. 19 E., in the adjacent Liberty 15-minute quadrangle, is a good location to observe the transition into the Leavenworth fault zone. The homoclinally dipping Chumstick beds, which at this point are stratigraphically high in the section, end abruptly. The next good exposures, on the north slopes in the northern half of sec. 19, are composed of Chumstick sandstone with interbeds of coarse conglomerate, and they have variable strike and dip that is discordant to the homoclinal sequence. The conglomerate occurs in massive beds up to 10 ft thick and the aggregate conglomerate thickness must exceed 80 ft. The clasts are mostly well rounded, but sorting is poor. The average size of the larger clasts is about 3 to 4 inches in diameter, but clasts up to 7 inches and ranging down to pea size are present. Clast composition is dominantly of volcanic varieties, although some thin-banded, fine-grained, low-grade siliceous metamorphic rocks are present. Some conglomerate beds are composed almost entirely of basaltic clasts in a dark-green colored matrix. Other beds contain abundant andesitic to rhyolitic clasts in addition to basalt. In massive sandstone underlying the thick conglomerates, there are thinner, 1- to 2-foot beds, of conglomerate composed entirely of clasts of felsic volcanic rocks, including some porphyritic varieties. These conglomeratic rocks are believed to be a tectonic slice of lower Chumstick rocks along the Leavenworth fault zone. The most probable source for the basaltic clasts is Teanaway Basalt, and the basaltic conglomerates are interpreted as monolithologic fanglomerate of Teanaway Basalt analogous to serpentine and granodiorite fanglomerates that interfinger with Chumstick sandstones farther north along the Leavenworth fault zone (Cashman and Whetten, 1976).

Another exposure of basaltic material occurs just east of the center of sec. 19, on the slopes below the Mission Ridge Trail. It is a chaotic mixture of angular basalt blocks that range in size from a few inches to several feet.

Some blocks are vesicular. The material is highly altered and zeolitized, and many of the vesicles are filled with secondary minerals. The basaltic unit is interbedded with Chumstick sandstone. Tabor and Frizzell (1977) interpreted these rocks as a distal tongue of volcanic breccia of Teanaway Basalt, with the inference that Teanaway volcanism overlapped Chumstick deposition. Although this interpretation may be correct, the presence of the nearby basaltic fanglomerate suggests that an alternate interpretation is at least possible. The rocks could be mass wasting debris derived from Teanaway Basalt and could be more-or-less coeval with fanglomerate deposition. In this case, the breccia could significantly postdate the actual time of Teanaway volcanism.

TUFF UNITS IN LOWER CHUMSTICK ROCKS

At least six distinct tuff beds, and perhaps seven or more, occur in the lower Chumstick in the Monitor quadrangle. Only two, those in the far northwest corner of the quadrangle, are continuations of units of Whetten and Waitt (1978) that were traced to the southern border of the adjacent Cashmere quadrangle. At least four others are stratigraphically lower than any of the tuffs mapped by Whetten and Waitt. In contrast to the thick tuff beds in the northern part of the Chiwaukum graben, those in the Monitor quadrangle tend to range from 1 to 4 ft in thickness, and the maximum observed thickness is only 7 ft. Because the tuffs are important as key marker beds, they are described below in detail. In general, individual beds may vary considerably along strike due to local variations in the fluvial and lacustrine depositional environments and in post-depositional alteration. Tuffs locally grade into tuffaceous sandstone along strike, and some are overlain by flaggy, resistant, apparently tuffaceous, sandstone.

There is some minor confusion in the designation of tuff units on previous maps. Whetten and Laravie (1976) mapped two major tuff units in the type Chumstick area and designated them Tt_1 and Tt_3; these were later given special names, the Eagle Creek tuff and Zeolite tuff, respectively (see Gresens and others, 1981). A less prominent tuff, Tt_2, occurs stratigraphically between them. Whetten and Waitt (1978) designated two tuff units in the Cashmere 7 1/2-minute quadrangle as Tt_1 and Tt_2. They continue into the Monitor quadrangle but are stratigraphically lower than units with the same designations in the Eagle Creek area. On the Chiwaukum 4 SE quadrangle, Whetten (1980) designated the continuation of Tt_1 from the Cashmere quadrangle as Tte. The scheme adopted in this report is to designate all tuffs "Tct" for "Tertiary Chumstick tuff," but also to add geographical letter codes to signify the tuffs of Mission Creek (Tctm), Yaxon Canyon (Tcty), Fairview Canyon (Tctf), Horse Lake Mountain area (Tcth). Minor tuff occurrences are located in the Wenatchee Heights and Mission Peak quadrangles. Within each group, numerical subscripts are added as necessary.

MISSION CREEK TUFFS

A pair of tuffs, separated by about 800 to 1,000 feet of stratigraphic thickness are present in the Mission Creek drainage; one of them crosses the valley floor. $Tctm_2$, the westernmost, stratigraphically highest bed, is the same as Tt_2 on the Cashmere quadrangle (Whetten and Waitt, 1978). $Tctm_1$ is their Tt_1. Tuff $Tctm_1$ was traced about 2.5 miles along its length in the Monitor quadrangle and has a total length of about 6.3 miles when the Cashmere (Whetten and Waitt, 1978) and Chiwaukum 4 SE (Whetten 1980) quadrangles are taken into account. Tuff $Tctm_2$ was traced 1.4 miles in the Monitor quadrangle and has nearly 2 miles total length when the Cashmere quadrangle is included; unlike $Tctm_1$, it was not found north of the Wenatchee River.

Tuff $Tctm_2$ is highly variable, both across and along bedding. It is 4 ft thick at an excellent exposure on the north side of Woodring Canyon in sec. 8, T. 23 N., R. 19 E. The basal 6 inches are mottled due to whiter fragments (mm to cm size) in a generally light-gray, fine-grained rock. These are presumed to be pumiceous clasts. The basal portion also contains abundant wood charcoal chips and other plant material. The remainder is more fine grained and uniform in appearance, with local fine bedding indicating that it has been partially water-worked. The bedding is defined by mm-size layers of slightly darker-gray color; biotite flakes, indicative of detrital admixture, occur on bedding planes. The upper foot or so of the bed is particularly rich in detrital admixture. The bed has been fractured, and a pink zeolite lines and fills the resulting cavities with crystals several mm in length. As the bed is traced downslope into Woodring Canyon, it changes along strike into a flaggy sandstone in which the pink zeolite continues to be abundant.

At the next good exposure, in Tripp Canyon just south of Hill 1841, the tuff bed is 6 ft thick. There is much fine banding and detrital admixture (as indicated by biotite flakes). The mottled portion is absent, as are the pink zeolites. It is overlain by 10 ft of flaggy sandstone. At the bottom of Tripp Canyon, the mottled facies with abundant plant and charcoal fragments reappears, and pink zeolite is pervasive. At the southernmost point that tuff $Tctm_2$ is mapped, just south of Slawson Canyon, no actual tuff is present, but a flaggy sandstone here contains abundant pink zeolites. This tuff unit clearly represents ash fall, in part pumiceous, that was deposited in a fluvial environment, was partly reworked and contaminated with detrital sediment, and locally was completely obliterated by stream action.

Tuff $Tctm_1$ is more uniform than $Tctm_2$ over most of its length in the Monitor quadrangle. It is about 6 ft thick at an excellent exposure on the north side of Woodring Canyon. It is uniformly fine grained, brittle, and highly fractured. The color is a medium gray, darker than tuff $Tctm_2$, and has a faint greenish cast. Some very faint banding and a few small flakes of detrital biotite are present. At the mouth of Tripp Canyon, the thickness remains about 5 to 6 ft, the rock remains uniformly fine grained, but the color is light gray. On the east side of Mission Creek, in sec. 20, T. 23 N., R. 19 E., the light-gray tuff is exposed on a dip slope, and thickness cannot be determined. There is evidence of significant water-working, including fine bedding, abundant detrital admixture, and plant fragments. At the center of sec. 20, tuff $Tctm_1$ is less than a foot thick.

YAXON CANYON TUFFS

A pair of prominent tuffs, $Tcty_1$ and $Tcty_2$, separated by 500 to 900(?) feet of stratigraphic thickness, are present in Yaxon Canyon in secs. 9, 16, 21, 28, and 33, T. 23 N., R. 19 E. A third tuff, $Tcty_3$, occurs discontinuously to the east, separated from $Tcty_2$ by about 400 to 600 ft of stratigraphic thickness. $Tcty_1$, the most westerly of the Yaxon Canyon tuffs, is separated from $Tctm_1$, the most easterly of the Mission Creek tuffs, by about 2,000 ft of stratigraphic thickness. $Tcty_1$ and $Tcty_2$ were each traced about 3 miles. Short segments of $Tcty_3$ define a maximum length of 2.5 miles from the northern to the southern extremity, but about 2 miles of tuff are missing or not exposed between the extreme occurrences.

Tuff $Tcty_1$ is generally thin, typically about 2 ft thick. Maximum observed thickness is 3 ft in the northernmost exposures; it is less than a foot thick where last observed to the south. Most tuffs in the Monitor quadrangle are sufficiently fine grained that they have mudstone texture and a waxy to lustrous fracture surface when wetted. Tuff $Tcty_1$ differs in having a more silty texture, and freshly fractured surfaces have a dull, somewhat porous appearance. Over most of its length, the tuff varies in color from very white with scattered flecks of yellowish brown (limonitic blebs) to a light-yellowish tan when limonite is more widely dispersed. Natural fracture surfaces are typically limonite stained. Minor detrital admixture is typically indicated by scattered biotite flakes, but plant remains are rare. The thicker northerly exposures are more grayish-colored, less limonitic, and have a greater abundance of detrital admixture and plant remains. This tuff lacks the fine internal laminations indicative of water-working in many other tuffs.

Tuff $Tcty_2$ is generally thin, varying from 3 to 4 ft thick at the most northerly exposures to about 2 ft thick at the southern end. Typically it is very fine grained and uniformly textured, with no evidence of significant detrital admixture or water-working. The best and freshest exposure is at a roadcut through a dip slope on the east side of Yaxon Canyon, just above valley floor, north of the center of sec. 16. The color here varies from a creamy light brownish-gray to olive drab. Pink zeolite locally coats fracture surfaces. In most other exposures the rock is weathered to various shades of tan and yellowish brown. Along a flat, north-trending ridge north of Hill 2451 in sec. 28, a 1 1/2-foot-thick bed of typical tuff grades upward into 3 to 3 1/2 ft of fissile, apparently tuffaceous, gray siltstone. This is overlain by an unusual dark-gray biotitic sandstone, which is in turn overlain by about 1 foot of fine-grained and finely laminated tuff. Rather than two closely spaced eruptive events, this is interpreted as local washing of tuff-laden sediment and redeposition of tuff onto the original ash fall.

Tuff $Tcty_3$ is poorly exposed and apparently never more than about a foot thick. At the best exposures in the NE 1/4 of sec. 16, it is a uniformly fine-grained, light-gray brittle rock. At the poorer, southerly exposure in the NE 1/4 of sec. 28, it includes some tuff of greenish-gray color, and it has abundant fracture fillings of pink zeolite.

FAIRVIEW CANYON TUFF

The Fairview Canyon tuff, Tctf, which occurs in secs. 22, 23, and 26, T. 23 N., R. 19 E., is the stratigraphically lowest tuff unit. It is separated from $Tcty_3$, the easternmost Yaxon Canyon tuff, by 4,200 to 4,400 ft of stratigraphic thickness. It has been traced a total length of about 1 1/2 miles. The tuff is poorly exposed, ranges from about a foot to somewhat less than 3 ft in thickness, and is variable in color, bedding, and detrital content. The thickest and best exposure just north of a minor drainage at the eastern border of sec. 22 is pure white, uniformly fine-grained tuff having a porcelainlike appearance. Elsewhere, light-gray tuff has fine bedding and medium-gray tuff has abundant biotite flakes and some plant remains.

HORSE LAKE MOUNTAIN TUFFS

Several small, isolated tuff exposures of uncertain stratigraphic position are present in the Horse Lake Mountain area in secs. 3, 10, and 14, T. 22 N., R. 19 E. None have been traced more than 0.4 mile.

A new logging road (summer, 1979), which does not appear on the U.S. Geological Survey 7 1/2 minute Monitor quadrangle (1966), makes a sharp bend around a prominent north-northwest-trending ridge at the extreme north border of sec. 3. Tuff $Tcth_1$, which is repeated by a small fault, is exposed in roadcuts about 150 ft southeast of the sharp bend and about 1,000 ft south of the bend where the road turns abruptly to the west. It is 4 1/2 ft thick at the first locality and 7 ft thick at the second locality. The unit cannot be traced beyond the roadcuts.

Even slight variability or uncertainty in structural measurements make projections of the marker beds dubious over any but short distances. Assuming no complication by faulting, and using the most favorable strike and dip, tuff $Tcth_1$ might be correlative with tuff $Tcty_3$. This is tenuous at best, and it is possible that $Tcth_1$ is stratigraphically between $Tcty_3$ and Tctf.

Tuff $Tcth_1$ is interbedded with dark, organic-rich shales and is uniformly fine-grained, brittle rock with no evidence of water-working. The color is generally light gray, with a faint greenish cast. At the first locality, the top grades upward through a darker gray into a very dark brittle tuffaceous mudstone about 6 inches thick. This is overlain by shale that has been slightly sheared. At the second locality, the top 3 inches are darker colored and overlain with organic-rich dark shale. This is the only locality within the Monitor quadrangle with good evidence for deposition in a lake or swamp environment. The lack of any internal bedding laminations and the nature of the enclosing rocks suggest this interpretation. The dark top of the tuff is interpreted as contamination with low-density organic gel (gyttja) that commonly is found at bottoms of stagnant organic-rich lakes. Gyttja would be displaced into the water column by the initial influx of volcanic ash and later would settle out and intimately intermix with the finest suspended ash fraction.

A thin, fine-grained, light-gray tuff, $Tcth_2$, is exposed in a roadcut at the center of sec. 10, and it crosses a flat-topped ridge in the northeast quarter of the section. In the roadcut it is 3 to 4 ft thick, and it is cut by an andesite dike and partly silicified. This is an area that is structurally complicated by faulting and numerous intrusions, and no correlation with tuff units to the north is possible.

A thin, fine-grained, light-gray tuff, $Tcth_3$, is poorly exposed along the west border of sec. 14. It lies adjacent to an andesite sill that cuts across the tuff. It contains leaf fossils at its southernmost extremity. It is more than a mile from tuff $Tcth_2$, but is more-or-less on strike. Given the structural complexity, it could be the same tuff unit.

MISCELLANEOUS TUFFS OF UNCERTAIN CORRELATION

A number of scattered tuff occurrences have been noted in terrain of generally poor exposure in the Wenatchee Heights and Mission Peak quadrangles to the south of the Wenatchee and Monitor quadrangles. They are in sec. 25, T. 22 N., R. 19 E., and secs. 30 and 31, T. 22 N., R. 20 E. An exposure of tuff can be followed for 800 ft just east of the center of sec. 25.

Thickness cannot be directly determined, but it must be thin, probably less than 2 ft thick. It is fine grained, light gray, and contains plant fragments. It is locally silicified along fractures. Less than a mile east, in the SE 1/4 sec. 30, another very poor exposure of fine-grained, light-brown (weathered) tuff is tentatively correlated with the tuff located just east of the center of sec. 25.

At the eastern border of sec. 31, a tuff can be followed for about 1,000 ft. It is thin, uniformly fine grained, and has a light yellowish-gray color. To the immediate west, across the valley at the center of sec. 31, there is a layer of brittle silty biotite-bearing rock that is probably tuff with detrital admixture.

A major fault zone projects through this area, as evidenced by the variation of strikes and dips. It is possible that all tuffs of this group are the same unit, but it is impossible to prove, and it is impossible to correlate them with the more continuous tuff exposures in the northern half of the Monitor quadrangle.

NAHAHUM CANYON MEMBER OF THE CHUMSTICK FORMATION

The belt of rocks between the gneissic core of the Eagle Creek anticline and the Entiat fault, consisting mainly of the Nahahum Canyon Member of the Chumstick Formation, can be traced southeastward into the Wenatchee and Monitor quadrangles. Whetten (in Gresens and others, 1981) has designated the Easy Street reference section for the Nahahum Canyon Member in NE 1/4 sec. 19, T. 23 N., R. 20 E. The rocks are described as thinly bedded lacustrine sandstones and shales and thickly bedded sandstones with ripple marks and flute casts. Some sandstone interbedded with lacustrine shale is believed to be turbidite, and thicker sandstones are believed to be deltaic.

The belt of Nahahum rocks apparently projects southeast to the southern border of the Wenatchee quadrangle in secs. 22 and 23, T. 22 N., R. 20 E. A large central portion of the belt is covered by Quaternary deposits, but must underlie much of the city of Wenatchee. Northwest of the city, exposure is poor in much of secs. 29, 30, 31, and 32, T. 23 N., R. 20 E., and only the sandstones crop out. Many of the feldspathic sandstones are relatively quartz rich, and may be difficult to distinguish from sandstones of the younger Wenatchee Formation. The presence of biotite flakes and occasional pebbles of felsic volcanic rocks are diagnostic of Chumstick sandstone. A good section of this terrane is exposed along roadcuts along Horse Lake Road, which trends E-W across secs. 29 and 30. Shale and siltstone make up most of the unit. Shales are dark-brown, buff-weathering, and poorly indurated. Beds range from 1 to 10 ft thick and are usually well-laminated with 1- to 3-inch-thick lamellae. Sandstones are medium grained, feldspathic, and micaceous. Muscovite, the predominant mica, is distributed on bedding planes in flakes as large as one-quarter inch in diameter; biotite is less common. Minor fluviatile cross-bedding is common in sandstone, and rare ripple marks have been noted. Poorly preserved plant material is common, and some moderately well-preserved leaf imprints are found locally in carbonate concretions within the shales. Large and well-preserved leaf fossils were taken from prospect pits in the vicinity of Hill 1049, sec. 29, according to a local resident.

Another excellent exposure of this terrane is along Sleepy Hollow Road at the northern border of sec. 24, T. 23 N., R. 19 E. In a small quarry, lacustrine facies are suggested by fine-grained sandstone beds 1 to 3 ft thick alternating with fissile shales about 1 foot thick. A channel sandstone cuts into underlying beds, truncating the bedding. It is ellipsoidal in cross section, about 15 ft wide and 8 ft thick. It is coarser grained than the bedded sandstones and has quartz-rich gravel layers, clasts of shale, and fluviatile cross-bedding. It is relatively quartz rich and biotite poor, and thus bears a resemblance to sandstone of the younger Wenatchee Formation. Much of the sandstone that crops out poorly in the terrane to the south is thought to be of similar origin.

As defined by Whetten, the Nahahum Canyon Member is a lacustrine facies of the Chumstick Formation. Where alluvial fans interfinger with the lacustrine rocks, the unit may resemble typical conglomeratic sandstone of the Chumstick, and it is mapped as such. A transitional facies appears to be present in the most southerly extension of the belt of Nahahum rocks in secs. 22 and 23, T. 22 N., R. 20 E. The rocks exposed on either side of Squilchuck Canyon in sec. 22 resemble typical Nahahum rocks in the general evenness of the bedding and the relatively high proportion of siltstone and shale. The even bedding is readily apparent on the southeast slopes, despite the poor outcrop of the unit. However, the rocks differ from Nahahum rocks farther north in the greater thickness of sandstone interbeds (up to 40 ft thick) and in the high proportion of pebbly conglomerate in sandstones. Pebbly layers are typically poorly sorted, with clasts typically ranging from one-eighth to 2 inches in diameter. Clasts include many volcanic varieties ranging from andesitic to rhyolitic, but generally felsic. Some white, soft clasts are possibly pumiceous, and some rhyolite is flow banded. Dark-gray, fine-grained clasts having a chertlike appearance may be silicified volcanics. Vein quartz is abundant, and clasts with pegmatitic texture are occasionally present. Gneissic and plutonic clasts of granitic composition are common, but generally are more weathered and lack the cohesiveness of the other clast types. Rare light-gray mudstone clasts are present. Individual conglomerate beds vary greatly in the proportions of clast types, and beds composed almost entirely of either clasts of vein quartz or of volcanics have been noted. It is thought that this unit represents Nahahum rocks interbedded with the distal portion of a fanglomerate.

To the immediate northeast, these transitional Nahahum rocks are in fault contact with more conglomerate-rich rocks near the center of sec. 23, and excellent exposures occur in roadcuts along the Malaga Road in the NE 1/4 of the section. They are mapped as Chumstick rather than Nahahum rocks, but they may represent coarse alluvial/fluvial facies from streams draining highlands east of the Entiat fault; they may be essentially coeval with the transitional Nahahum rocks. This would agree with similar depositional conditions described by Whetten in the type area of the Nahahum Canyon Member.

A mappable belt of coarse fanglomerate intervenes between the Nahahum Canyon Member and the Entiat fault in the type area (fig. 5). A hypothetical projection of the Entiat fault into the Wenatchee quadrangle suggests that any extension of the fanglomerate facies into the quadrangle would be masked by Quaternary deposits but may be present under much of the East Wenatchee area. The only possible expression of the fanglomerate facies is the occurrence described in the preceding paragraph.

In the type area, the Nahahum Canyon Member is in fault contact with the gneissic core of the Eagle Creek anticline (fig. 5). The anticlinal structure projects into the Wenatchee area but is cored by Swauk(?) Formation. Whetten was of the opinion that the gneissic core was a horstlike structure during subsidence and deposition within the graben and that material was shed both eastward and westward off a highland source. This interpretation is based in part on gneissic conglomerate that appears to interfinger eastward into Nahahum rocks. Analogous fanglomerates containing clasts of Swauk(?) would not be produced even if the Swauk(?) had occupied an analogous horst, because these rocks weather readily to a gruslike sand and would not form durable clasts. Lovitt and Skerl (1958), having the advantage of underground mine exposures, concluded that "Young Sandstone" (Chumstick in this report) was deposited on an "island chain" of "Old Sandstone" (Swauk? in this report). Their account could be an observation of a horst block of Swauk(?) in the subsiding graben. However, there is evidence that suggests that a fault contact exists between the belt of Swauk(?) rocks and the belt of Nahahum rocks to the east.

A distinctive coarse conglomerate is well exposed in the lower mining cuts on the north side of Squilchuck Canyon in sec. 22, T. 22 N., R. 20 E. It contains clasts up to 8 inches in diameter that are mostly felsic volcanic rocks but which also consist of plutonic rock types and vein quartz. The beds stand nearly vertically and are apparently in fault contact with silicified mine rocks to the west and overturned beds of the transitional Nahahum rocks to the east (Lovitt and Skerl, 1958; Patton and Cheney, 1971). Both Lovitt and Skerl and Patton and Cheney traced the unit to the north and northwest; although there is no outcrop, it is easily followed by the distinctive float of large clasts, including boulders up to a foot in diameter. This investigation has traced the unit farther northwest. It forms a low, northwest-trending ridge at the mouth of Number Two Canyon immediately southeast of the intersection of Cherry Street and Western Avenue in sec. 9, T. 22 N., R. 20 E. The most northerly outcrop of the unit is just south of the center of sec. 31, T. 23 N., R. 20 E. on a northwest-trending ridge. Here 90 percent of the clasts are of felsic volcanic types, with lesser amounts of vein quartz, quartzite, pegmatite, and plutonic and gneissic varieties of granite. This locality has a number of unique features. A clast of porphyritic rhyodacite is identical in color and texture to a rhyodacite dike cutting Swakane Biotite Gneiss in Corbaley Canyon some 16 miles to the northeast (see fig. 1). A limestone bed occurs at this locality. It is 4 to 6 inches thick, and only about 3 ft of it is exposed. It is interbedded with conglomerates. It is possibly a lithified caliche horizon. Some conglomerate clasts have been fractured, offset, and recemented within these beds, which suggests that they are involved in faulting.

The distinctive conglomerate can be traced nearly 5 miles northwest from the exposure at the mine workings. In every instance, the nearest exposure of sedimentary rocks to the west of it is Swauk(?) rocks, although silicified rocks occur between the two units in the vicinity of the mines. It is inferred that this represents a fault zone, and that the conglomerate is a tectonic sliver of lower Chumstick rocks.

The apparent fault contact is elsewhere represented by a zone of alteration that may be either hydrothermal alteration along the zone or deep penetration of ancient weathering solutions into the fault zone. The most northerly exposure is in the SW cor. sec. 30, T. 23 N., R. 20 E. Natural erosion has exposed a cut through rocks completely altered to a clay-rich residue. The colors range from yellowish tan to light gray. The material crumbles in the hand and becomes a greasy clay when wetted. Relict bedding suggests that it is concordant with Chumstick bedding to the east, but the original lithology cannot be ascertained. This occurrence should not be confused with whitish, partially slid material directly uphill to the west, which is apparently derived from a paleosol beneath the Wenatchee Formation (discussed in later section). The extension of the altered zone to the southeast can be recognized by patches of yellowish soil, such as in the northwest corner of the adjacent sec. 31. An extensive patch of similar altered rock is exposed just south of the mouth of Number One Canyon at the base of the slopes north of Castle Rock in sec. 5, T. 22 N., R. 20 E. This occurrence is on the fault zone defined by the distinctive conglomerate bed. Relict partially altered beds are present, but it is virtually impossible to identify them as Swauk(?) or Chumstick. Much of the material is a light-gray to light-brown silty material, powdery when dry, with scattered pebbly material within it. Any original carbonate has been completely leached. Although most of it was derived from sedimentary rocks, some minor hematite-red varieties may have been derived from mafic igneous rock.

CHUMSTICK FORMATION EAST OF THE ENTIAT FAULT

Occurrences of Chumstick Formation east of the projection of the Entiat fault are rare in the terrain east of the Columbia River. They are mostly confined to small outcrops at the bottoms of some of the major drainages that have cut through overlying mass wasting deposits. Two of the best examples are at the drainage that trends E-W near the center of sec. 26, T. 23 N., R. 20 E., and the drainage trending E-W near the border with sec. 19 in SE 1/4 sec. 24, T. 23 N., R. 20 E. Good outcrops of Chumstick Formation were found at relatively high elevation in NE 1/4 sec. 25, T. 23 N., R. 20 E., and nearby in NW 1/4 sec. 30, T. 23 N., R. 21 E. None of the outcrops are sufficiently extensive to definitively assign them to lower Chumstick Formation or the Nahahum Canyon Member. Identification as Chumstick Formation is based on the lithology of the sandstone (biotite-rich feldspathic sandstone) and lithologies of conglomerate clasts (abundant felsic volcanics), plus minor features typical of Chumstick such as fluvial cross-bedding, occurrence of soft brown shales, poorly preserved leaf fossils, and moderate degree of induration. Conglomerate beds occur in most of the exposures, although some lack them and have a high shale to sandstone ratio typical of the Nahahum Canyon Member. No interbedded tuffs were noted in these exposures.

SIGNIFICANT DIFFERENCES BETWEEN THE SWAUK(?) AND CHUMSTICK FORMATIONS

During the first summer of fieldwork, recognition of significant differences in

TABLE 1. — *Criteria for distinguishing Swauk from Chumstick*

		This study	
		Wenatchee 7½-minute quadrangle	
		Swauk(?)	Chumstick
Field criteria	Bedding	Generally evenly bedded. Arkose typically in 2- to 6-ft beds; shale/siltstone typically in 1/2- to 1 ft beds. Poorly sorted coarse conglomerate is in 1- to 4-foot lensoidal interbeds. Some arkose is graded, with siltstone tops having small-scale crossbeds; in a few graded beds there is a conglomeratic base	Sandstone is in massive beds 20 to 40 ft thick, and which may reach thicknesses of about 100 ft. Large-scale fluvial cross-bedding is common, and other features such as cut-and-fill structure and rip-rap clasts of shale are occasionally seen. More evenly bedded lacustrine facies are mostly shale and siltstone, but are locally incised and filled with channel sandstone
	Color	Light to dark gray on fresh exposures. Weathers to tan or brown. Isolated weathered outcrops of arkose are difficult to distinguish from Chumstick arkose	Generally lighter colored than Swauk(?). Has tan to light gray color even on fresh rock
	Lithification	Very well lithified in fresh exposures, to the extent that hammer blows bounce off the rock as they would a crystalline rock. In conglomerates, fractures cut across both clasts and matrix due to firm cementation of the clasts	Less well lithified than Swauk(?) to the extent that even fresh exposures of arkose are slightly friable. Fractures in conglomerates are around, rather than through, the clasts
	Veining	Fractures filled with coarse calcite are common in the belt of Swauk(?) rocks. Veins several cm in width are typical	Minor calcite veins are thin and infrequent
	Source, including clast lithologies	Arkose derived from crystalline terrane. Conglomerate clasts are mainly plutonic and gneissic rocks of granodioritic composition. Minor amounts of other metamorphic rocks. No clasts of volcanic origin have been noted. Some very large clasts (0.5 m in diameter are present)	Bulk of arkose is similar to Swauk(?) arkose, although locally becomes a more quartzose sandstone. Clast types found in Swauk(?) are all present in Chumstick conglomerate, but abundant volcanic clasts also present, making up 90 percent of total clasts in some rocks. A variety of felsic volcanic rocks are represented, including some distinctive porphyries. Large clasts of vein quartz occur in some conglomerates
	Structural and stratigraphic relations	There is always a structural discordance between rocks from the belt of Swauk(?) and the nearest Chumstick outcrops, although the contact is nowhere exposed	
	Tectonic history	Local evidence of multiple deformation (refolded folds). High degree of fracturing and veining	Apart from later minor thrust faulting of Oligocene age, deformation is a single folding event with gentle, open folds
Laboratory criteria	Thin section	Biotite is completely chloritized. No cross-hatched twins of microcline	Biotite is fresh or only partly chloritized. Cross-hatched twinning of microcline usually present
	Staining of rock slabs	Potassium feldspar not detected in specimens from the belt of Swauk(?)	Potassium feldspar noted in all specimens of Chumstick sandstone

TABLE 1. — *Criteria for distinguishing Swauk from Chumstick — Continued*

		Alexander (1956) Liberty 15-minute quadrangle — Swauk (type area)	Alexander (1956) Liberty 15-minute quadrangle — Camas sandstone (Chumstick)
Field criteria	Bedding	Generally well bedded in massive to thinly bedded layers thought to be mainly lacustrine origin. Arkose mostly in 1- to 20-ft-thick layers and some massive beds, but only occasionally in cross-bedded deposits. Shale about one-half in thinly bedded deposits; rest in beds up to 20 ft thick. Conglomerate mainly in massive wedge-shaped deposits	Arkosic sandstone is in cross-laminated massive beds up to 100 ft thick, thought to be primarily of fluvial origin. Inclined foresets and cut-and-fill structures are common. Conglomerates are in thin beds that commonly grade laterally into single-pebble-layer conglomerates appearing as "beads on a string"
	Color	Field appearance of unit is generally light brown. Fresh arkose is gray, but weathers to light- or dark-brown exterior. Fresh shale (siltstone) is dark gray, but weathers to light gray or brown	Field appearance is white sandstone. Fresh arkose is white to pale gray
	Lithification	Both arkose and shale (siltstone) are described as well lithified or well indurated	Typical arkose is described as poorly or loosely indurated
	Veining	Local joints and fractures commonly have calcite or zeolite fillings	
	Source, including clast lithologies	Formation contains granitic detritus from silt to boulder size. The poorly sorted conglomerates are mainly granitoid, but contain granodiorite, serpentine, gneiss, schist, slate, and aphanitic igneous rocks	The typical fine- to medium-grained sandstone ranges from arkose to feldspathic sandstone. Clasts in conglomerates are granodiorite, quartz diorite, granite, milky white quartz, aphanitic igneous rocks, porphyritic igneous rocks, gneisses, schists, and metasediments
	Structural and stratigraphic relations	Rocks separated by Leavenworth fault. No primary relationship is preserved	
	Tectonic history	The unit is in part tightly folded and complexly faulted. Intruded by Teanaway	Unit is relatively gently folded. Less faulting than the Swauk. Not intruded by Teanaway dikes
Laboratory criteria	Thin section	Predominantly angular to subangular quartz and feldspar. Orthoclase/plagioclase ranges 1:3 to 1:1. Most common plagioclase is oligoclase. Feldspars typically altered to kaoline and sericite. Other constituents are biotite, chlorite, muscovite, and rock fragments	Either quartz or feldspar may predominate. Some vein quartz present. Orthoclase/plagioclase ranges from 1:3 to 1:1, same as Swauk. Most common plagioclase is oligoclase. Reddish-brown biotite typically present; chlorite minor. In general, plagioclase not as decomposed as in Swauk and less chlorite in Camas
	Staining of rock slabs		

TABLE 1. — *Criteria for distinguishing Swauk from Chumstick — Continued*

		Lovitt and Skerl (1958)	
		Wenatchee 7½-minute quadrangle (L-D gold mine)	
		Old Sandstone (Swauk?)	Young Sandstone (Chumstick; Wenatchee)
Field criteria	Bedding		
	Color		
	Lithification	Described as better indurated than Young Sandstone	Described as more poorly indurated than Old Sandstone
	Veining		
	Source, including clast lithologies		
	Structural and stratigraphic relations	Old Sandstone had been tilted on end prior to deposition of Young Sandstone	Young Sandstone deposited over tilted Old Sandstone
	Tectonic history	Highly fractured	Little fractured
Laboratory criteria	Thin section		
	Staining of rock slabs		

bedding style, degree of lithification and veining, color, and composition of conglomerate clasts, coupled with inferred structural discontinuities, led to the field designation of feldspathic sandstone units as "old arkose" and "young arkose." A subsequent literature review indicated that earlier investigators (Alexander, 1956; Lovitt and Skerl, 1958, p. 964) recognized many of these same criteria (table 1). Because Alexander's criteria for distinguishing Swauk Formation from "Camas Formation" (now Chumstick Formation) were nearly identical to the criteria established during initial mapping in the Wenatchee area, the "old arkose" was tentatively assigned to Swauk(?) Formation. Lovitt and Skerl recognized an "Old Sandstone" and a "Young Sandstone" in the area of the L-D gold mine (Gold King or Golden King) in sec. 22, T. 22 N., R. 20 E. They recognized that the older rocks are more highly fractured and lithified and that the younger rocks were deposited on the steeply dipping older unit.

Petrographic criteria for distinguishing Swauk(?) from Chumstick are based on the degree of chloritization of biotite and the presence or absence of potassium feldspar. Biotite from Chumstick sandstone is either fresh or only partly chloritized; biotite from Swauk(?) sandstone is more completely chloritized. Potassium feldspar is present in all Chumstick rocks stained using the method of Bailey and Stevens (1960), and the typical cross-hatched twinning is obvious in thin section. Stained specimens of Swauk(?) rocks show no evidence of K-feldspar.

The cross-sections (plate 3) show the structural discordance between the belt of Swauk(?) rocks and adjacent Chumstick beds. The interpretation of the belt as an exposure of older rocks in the erosionally breached core of the Eagle Creek anticline agrees with the projection of the axis of the Eagle Creek anticline from its type area to the north (fig. 1).

In the area to the south of Mount Stuart (fig. 1) the contact between Swauk(?) Formation and older rocks strikes generally east-west. This contact, in general, projects toward the contact between Swauk(?) Formation and older metamorphic rocks exposed in the core of the Eagle Creek anticline, suggesting that this contact extends to the west from the Eagle Creek anticline beneath the younger Chumstick rocks of the Chiwaukum graben.

Multiple folding of Swauk(?) is observed in an exposure on the south side of Number Two Canyon in NE 1/4 sec. 17, T. 22 N., R. 20 E. (see later section on structural geology). There is no evidence of multiple folding of the Chumstick.

The Swauk(?) is thus distinguished from the Chumstick by (1) field criteria, many of which were recognized by previous investigators, (2) laboratory data, (3) climatic differences during deposition, as suggested by leaf fossils, and (4) structural discordance and tectonic history. The Swauk(?) clearly is an older unit, based on structural position, greater degree of lithification, more extensive diagenetic alteration (chloritization, loss of K-feldspar), more extensive fracturing and veining, and evidence for multiple deformation. Although some of the same criteria were used by Alexander (1956) farther west in the type Swauk area, the author does not imply that the differences that serve to distinguish Swauk(?) from Chumstick within the Wenatchee quadrangle are broadly applicable. For example, volcanic clasts and K-feldspar are reported elsewhere within the Swauk (Pongsapich, 1970).

The older unit does not contain diagnostic fossils nor material suitable for radiometric dating. Pollen was unsuccessfully sought. The unit cannot be proven to be Swauk Formation, but it seems the most likely possibility. If it is not Swauk, then it must be an even older formation. The nearest older unmetamorphosed sedimentary rocks are Cretaceous units in the Methow graben 50 km to the north (Barksdale, 1975). The only reasonable alternative correlation is with the Late Cretaceous Winthrop Sandstone, which is a continental arkose. Early Cretaceous units are of marine origin. Older units of Jurassic or Triassic age are weakly metamorphosed in the Cascade Range.

WENATCHEE FORMATION

The Wenatchee Formation was named by Gresens and others (1981) for exposures in the vicinity of the city of Wenatchee. The type section and three of the reference sections are within the Wenatchee and Monitor 7 1/2-minute quadrangles. A fourth reference section is in the Wenatchee Heights quadrangle. The locations of the type and reference sections are as follows (Gresens and others, 1981, p. 857):

> The type section is located on the northwest flank of Squilchuck Canyon at SE¼ sec. 21, SW¼ sec. 22, NW¼ sec. 27, and NE¼ sec. 28, T. 22 N., R. 20 E., where the formation is folded to form the Pitcher syncline (Patton and Cheney, 1971). . . . Four reference sections are here designated: (1) the silica quarry in Dry Gulch at center sec. 21, T. 22 N., R. 20 E., considered the principal reference section; (2) Chopper Hill, located at the boundary between secs. 7 and 8, T. 22 N., R. 20 E.; (3) the west-facing bluffs overlooking the Columbia River in the NW¼ sec. 23, T. 23 N., R. 20 E., from Blue Grade Road at the center of sec. 23 to the north border of sec. 23; and (4) the sandstone bluffs on the northwest side of Stemilt Canyon in SW¼ sec. 25 and NW¼ sec. 36, T. 22 N., R. 20 E. These will be referred to as the Dry Gulch, Chopper Hill, Blue Grade, and Stemilt Canyon reference sections . . . .

The formal description of the type and reference sections by Gresens and others (1981) serves as a general description of the formation, and it is reprinted below. Sections located west of the Entiat fault are repeated first, followed by additional data on occurrences in this terrain. The description of the Blue Grade reference section and additional data for occurrences east of the Entiat fault is then undertaken.

OCCURRENCES WEST OF THE ENTIAT FAULT

The type section at Squilchuck Canyon and the Dry Gulch, Stemilt Canyon, and Chopper Hill reference sections are all within this terrain. The following descriptions are from Gresens and others (1981, p. 857-866).

TYPE SECTION

At the type section, the formation is divided into two members, a sandstone and shale member and an overlying conglomerate member.

SANDSTONE AND SHALE MEMBER

The sandstone and shale member apparently does not include a basal sandstone at the type section, as it does not crop out on the flanks of the Pitcher syncline. . . . Because the basal shale and underlying feldspathic sandstone and shale of the Swauk(?) or Chumstick Formations do not crop out well on the grassy slopes, the basal contact of the Wenatchee is not exposed. Structural relations indicate that the base lies a few meters below the valley floor at the hinge of the syncline. . . . The sandstone and shale member is subdivided into three subunits or beds, in ascending order: (a) shale-dominated fluvial beds, (b) sandstone-dominated fluvial beds, and (c) shale and sandstone beds of lacustrine origin. These subunits will be referred to as the shale bed, the sandstone bed, and the lake beds.

The shale bed has an exposed thickness of about 145 m. It consists of thick beds of distinctive grayish-blue tuffaceous shale to siltstone, with thinner 0.5- to 3-m thick interbeds of buff, commonly limonitic, fine- to medium-grained, friable, cross-bedded and channeled quartz sandstone. Muscovite flakes to 1 cm in diameter occur throughout the section in both shale and sandstone. Minor amounts of dark lithic fragments and/or carbonaceous fragments typically are present, but calcite, biotite, and feldspar are conspicuously absent. Intraformational grayish-blue siltstone clasts to 4 cm in diameter occur locally in sandstone, and thin layers of angular quartz conglomerate are present locally. At some places, thin coal lenses occur in the shale. Red oxidized zones, presumably caused by subaerial weathering, occur in the upper part of the shale bed; partially oxidized rocks demonstrate a transition to grayish-blue shale. A prominent oxidized zone, about 1 m thick, marks the top of the bed.

The middle sandstone bed, about 70 m thick, is composed mostly of 5- to 15-m-thick beds of cross-bedded medium- to coarse-grained sandstone with thinner interbeds of grayish-blue shale and siltstone similar to beds in the underlying shale bed. Conglomeratic interbeds with quartz clasts to 2.5 cm in diameter are common within the sandstone. Quartz grains are angular to subangular, and the rock is poorly sorted, friable, and porous. Lithic fragments and muscovite flakes typically are present in small amounts (less than 1 percent).

The lake beds are about 25 m thick. They consist of poorly exposed brown fissile shale that grades upward into siltstone and sandstone. In contrast to the grayish-blue lower shale, the brown shale of the lake beds lacks mesoscopic muscovite flakes. Siltstone and sandstone are light gray to almost white, but they weather to light yellowish brown. Sandstone ranges from fine- to medium-grained and is lithologically similar to sandstones of the shale and sandstone beds, except that muscovite is not common. It is better sorted and better cemented than the friable sandstone of the underlying units; locally it is calcite cemented. Siltstone and sandstone typically are thinly and evenly laminated and locally cross-bedded; laminations are commonly accentuated by thin (less than 1 mm) layers rich in organic material. Leaf fossils are common throughout the unit. Dark reddish-brown iron-oxide concretions and irregular banding are common.

CONGLOMERATE MEMBER

About 15 m of the conglomerate member crops out at the type section. The contact with the underlying lake beds is sharp and appears slightly discordant (estimated as $\leq 5^{o}$), particularly when viewed from a distance. The conglomerate member is overlain by post-Miocene diamictite, composed mostly of basaltic material, that apparently is mass-wasting debris of the Yakima Basalt Subgroup (R. W. Tabor, 1977, personal communication). Holocene slide rock derived from the diamictite obscures its contact with the underlying conglomerate member.

The member contains both conglomerate and sandstone. The conglomerate is very poorly sorted with rounded to subrounded clasts as much as 20 cm in length. Clasts are mainly felsic volcanic rocks. Varieties of rhyolite (porphyritic, fine-grained nonporphyritic, and flow-banded) are the most common, but composition includes dacite. Altered volcanic rocks and irregular masses of white pumice occur locally. The second most common clast lithology is white vein quartz. Dark fine-grained clasts of silicified volcanic rock are present in minor amount. Conglomerate is common, and clast size is larger at the bottom of the unit, but conglomerate may occur anywhere within the member. The sandstone, which includes the matrix of the conglomerate, consists of coarse-grained poorly sorted quartz and dark cherty lithic fragments in a matrix of powdery white clay. The sandstone is very friable and appears to have been a feldspathic sandstone in which the feldspar has altered to clay. Where it crops out, the conglomerate member is strikingly white, the color of dry bone, owing to the clay matrix. Limonitic to hematitic bands and concretions occur within the unit.

GEOMORPHIC EXPRESSION

The shale bed forms subdued, featureless slopes. The sandstone bed forms prominent but irregular sandstone bluffs. The sandstone part of the overlying lake beds is a distinctive cliff-former. The conglomerate member forms white cliffs.

REFERENCE SECTION

Reference sections are designated to point up the lateral variability within the Wenatchee Formation and to demonstrate the relation of the Wenatchee Formation to underlying and, where possible, overlying rocks.

DRY GULCH REFERENCE SECTION

The Dry Gulch reference section, less than 1 km northwest of the type section, demonstrates that the lithologic subdivision of the shale and sandstone member at the type section does not persist over long distances. As at the type section, the base of the Wenatchee lies a few meters below the valley floor. The uppermost red oxidized zone is presumed to correlate with the prominent red zone that separates the shale bed from the overlying sandstone bed at the type section, and the thickness of shale bed below this marker horizon is approximately the same at both the type and this reference section. Rather than being dominated by shale, however, the shale bed at the Dry Gulch reference section is composed almost entirely of medium- to coarse-grained, friable quartz sandstone. Between the marker horizon and the base of the lake beds is a section dominated by sandstone lithologically similar to the sandstone bed of the type section, but only about 17 m thick (compared with 70 m at the type section).

On the northwest slope of Dry Gulch, across the valley from the quarry, the entire section between the base of the formation to the lake beds is dominated by shale, whereas the equivalent section at the quarry is dominated by sandstone. Clearly individual sandstone interbeds of the fluvial units have the geometry of large lenses that do not correlate over even relatively short distances. A prospect cut at the eastern mouth of Dry Gulch exposes a sand lens that ranges from zero to 4 m thick over a horizontal distance of 30 m, thickening southward in the direction of the quarry. A white porcelain-like, fine-grained tuff that cropped out in the lower quarry face in a cut, and that has since been destroyed by further mining, provided a fission-track age of 33.4±1.4 m.y. . . .

CHOPPER HILL REFERENCE SECTION

The Chopper Hill reference section displays the angular unconformity between the Wenatchee Formation and a unit that is probably the Swauk Formation (Gresens, 1976b, 1977). The generally flat-lying Wenatchee Formation overlies vertical to near-vertical beds of arkose and shale. A 12- to 15-m-thick weathering profile is present at the top of the underlying unit; it ranges from arkose with numerous limonite-stained fractures to a powdery white paleosol.

A 6-m-thick slightly feldspathic sandstone, which locally contains clasts of underlying Swauk(?) at its base, lies at the base of the section. Sandstone interbedded with grayish-blue tuffaceous shale and siltstone becomes thinner and less frequent upward, and the section correlates with the shale bed of the type section. It contains a few sills of reddish-brown andesite related to a nearby intrusion.

STEMILT CANYON REFERENCE SECTION

An angular unconformity between the Wenatchee Formation and the underlying Chumstick Formation is well exposed in the Stemilt Canyon reference section. The nearly flat-lying Wenatchee overlies the Chumstick, that dips as much as 45°. In contrast to the Blue Grade and Chopper Hill reference sections, there is no deeply weathered zone at the top of the underlying formation. This unconformity was noted earlier by Chappell (1936) and Patton and Cheney (1971).

At Stemilt Canyon, the basal unit of the Wenatchee Formation is a thick sandstone (≥30 m thick), whereas at the type section and other localities, the sandstone is either thin or absent. Lithologically, the basal sandstone is typical fluvial quartz sandstone of the type section.

ADDITIONAL OCCURRENCES OF THE UNIT

The shale and siltstone of the Wenatchee Formation is prone to landsliding, and much of the terrain of poor outcrop in upper Squilchuck Canyon and in Pitcher Canyon (secs. 28, 29, 32, and 33, T. 22 N., R. 20 E., and secs. 4 and 5, T. 21 N., R. 20 E.) in the Wenatchee Heights quadrangle is of this nature. However, some significant localities of in-place outcrop can be pointed out. The westernmost exposures of Wenatchee Formation are in fault contact with Chumstick Formation, and this fault is well-exposed (1) in a roadcut on the west side of Squilchuck Creek Road, 0.4 km north of its junction with the Wenatchee Heights Road and (2) on Halvorson Loop Road, both in the NW 1/4 sec. 4, T. 21 N., R. 20 E. Vertical beds of Wenatchee sandstone are prominent just east of the fault zone. Wenatchee Formation is exposed along a cut on a side road below the horseshoe loop in the Wenatchee Heights Road in SW 1/4 sec, 34, T. 22 N., R. 20 E. Here some beds show fine lamination typical of lacustrine facies, but others have deltaic cross-bedding, and the beds may represent a juncture between stream and lake environments. On the opposite side of Squilchuck Canyon, in the northern part of sec. 33, T. 22 N., R. 20 E., the unconformity between Chumstick and Wenatchee is exposed. To the immediate west, in the NW 1/4 sec. 33, there is a good exposure illustrating the variegated colors produced by oxidation of siltstone and shale, including some lavender hues that are not common elsewhere.

Beginning on the north side of Pitcher Canyon in sec. 29, T. 22 N., R. 20 E., and extending northwestward into sec. 19, T. 22 N., R. 20 E., there is a belt of Wenatchee Formation in a small graben bounded by Chumstick Formation. The exposures are not good in most of the belt, but Wenatchee Formation is readily recognized from disoriented sandstone blocks scattered about the surface. Extensive fracturing of the formation between the two faults, coupled with landsliding, accounts for the paucity of in-place outcrop.

North of Number One Canyon, at the border between sec. 1, T. 22 N., R. 19 E., and sec. 6, T. 22 N., R. 20 E., a wheat field is probably underlain by Wenatchee Formation. Well-exposed beds to the east are dipping toward the field, and apparently they flatten and underlie the field. Blocks of Wenatchee sandstone are found along the edges of the field, and a large, relatively intact block has slid off the south side into Number One Canyon.

There is an excellent exposure of an angular unconformity between the Wenatchee and Chumstick Formations on the southeast side of an unnamed canyon in southern sec. 35, T. 23 N., R. 19 E. A short distance to the west there is a small patch of the formation to the northeast of Hill 3790, where a low hill contains blocks of Wenatchee sandstone; it is not known whether this represents the most westerly occurrence of the formation or the remains of an ancient landslide. [Editor's note: This occurrence is labeled as a landslide deposit composed of debris from the Wenatchee Formation on plate 1.]

The most northerly exposure of the formation in the terrain west of the Entiat fault is on the north side of a northwest-trending ridge that extends to the mouth of Fairview Canyon in NE 1/4 sec. 23, T. 23 N., R. 19 E. Relatively flat-lying Wenatchee is in angular unconformity with Chumstick.

The basal sandstone of the Wenatchee varies considerably in thickness and in degree of contamination from underlying units. Apparently it is absent on the west flank of the Pitcher syncline at the type section. Near the mouth of Dry Gulch, in NW 1/4 sec. 21, T. 22 N., R. 20 E., the basal sandstone is 5 to 6 ft thick; it contains angular quartz pebbles and carbonate cement. The carbonate most likely was derived from underlying Swauk(?) Formation. As the contact is followed to the northwest, exposures southwest of Squaw Saddle show a basal sandstone about 20 ft thick, with local carbonate cement. Although pebble conglomerate clasts in the bed are about 95 percent quartz, clasts of felsic volcanics, undoubtedly derived from underlying Chumstick, are present. Another occurrence of basal sandstone with volcanics and carbonate cement occurs on the south side of Pitcher Canyon, in NE 1/4 sec. 32, T.22 N., R. 20 E. At the Chopper Hill reference section, the basal sandstone also is about 20 feet thick, and clasts of Swauk(?) Formation are found at the base. In upper Dry Gulch, separated from the reference section by a thrust fault, the formation has a basal sandstone at least 80 ft thick. At the Stemilt Canyon reference section, the basal sandstone is about 100 ft thick, and about the lower 1 to 2 ft contain felsic volcanic clasts derived from the underlying Chumstick.

The descriptions of the type section and the Dry Gulch reference section noted the apparent low angular unconformity between the upper and lower members of the Wenatchee Formation, and the lesser amount of section between a marker bed in the lower member and the base of the upper member at the Dry Gulch section. This suggests a thinning of the lower member before the deposition of the upper member, with greater thinning to the northwest. This is reinforced by float of felsic volcanics, often associated with a white matrix, that is widespread in the terrain to the north of Number One Canyon. The material appears to be derived from the upper member of the Wenatchee, but its postion would not allow much stratigraphic thickness between the upper member and the base of the Wenatchee. Localities where this material may be seen are in the NW 1/4 sec. 6, T. 22 N., R. 20 E., and along a ranch road in NW 1/4 sec. 25, T. 23 N., R. 19 E.

Scattered Wenatchee exposures in the vicinity of the large andesitic intrusion extending north from Number Two Canyon have the field appearance of "floating" on andesite. One can be seen just west of the Chopper Hill reference section near center sec. 7, T. 22 N., R 20 E. Several occur along the west side of the intrusion in northern sec. 1, T. 22 N., R. 19 E. and SW 1/4 sec. 36, T. 23 N., R. 19 E. In the upper reaches of Fairview Canyon, in SE 1/4 sec. 26, T. 23 N., R. 19 E., a prominent ledge of Wenatchee sandstone overlies an andesitic sill. As will be discussed in more detail in the section dealing with intrusions, this feature strongly suggests that the large intrusion is a sill emplaced along the basal unconformity of the Wenatchee.

OCCURRENCES EAST OF THE ENTIAT FAULT

REFERENCE SECTION

The formal description of the Blue Grade reference section from Gresens and others (1981, p. 864-865) is reproduced here.

BLUE GRADE REFERENCE SECTION

The Blue Grade reference section best exposes the unconformity between the Wenatchee Formation and the crystalline basement rocks (Swakane Biotite Gneiss). This contact was interpreted by Glover (1941) as the contact between metamorphic rocks and basal beds of the Swauk Formation. The Swakane is metasedimentary plagioclase-quartz-biotite schist and gneiss weathered to a depth of at least 15 to 20 m, producing a paleosol below the unconformity.

The reference section is mostly of fluvial origin, in lithology identical to rocks of the type section except that angular feldspar grains to 6 mm long occur in sandstones near the base. Thin beds of white tuff are common; one of these tuffs was dated at 34.5 ± 1.2 m.y. . . .

Beds of brown shale, 0.5 to 1 m thick, containing abundant leaf fossils can be seen on the north side of Blue Grade Road some 120 m east of a small quarry at the center of sec. 23, T. 23 N., R. 20 E. Similar, but thicker (3 m) beds occur in a side canyon 400 m south. These beds resemble and possibly correlate with the shaly part of the lake beds of the type section but, in contrast, are overlain by additional fluvial sandstone and shale.

ADDITIONAL OCCURRENCES OF THE UNIT

A prospect cut is present on the hillside south of the small quarry at the center of sec. 23, T. 23 N., R. 20 E. Much of the shale and siltstone at the quarry and in the prospect cut is a creamy grayish blue, suggestive of a relatively high tuffaceous component. Flecks of amber are present locally at exposures in the prospect cut.

Amber is also present in coaly shale at a pit in northern sec. 26, T. 23 N., R. 20 E. The pit is cut in Quaternary gravels, but the lower part exposes Wenatchee Formation. Dumps in the vicinity indicate that the rocks are rich in coal, in addition to showing the more typical grayish-blue shale with red oxidized horizons.

Wenatchee Formation is exposed in a stream bottom where the Quaternary gravels are erosionally breached in eastern sec. 26, T. 23 N., R. 20 E. At the exposures farthest upstream, the lithology is typical grayish-blue siltstone of the fluvial part of the section, containing abundant muscovite flakes and organic material. A volcanic ash layer, 1/2 to 1 inch thick, is present. Downstream through a broad anticline, are 6 ft of interbedded brown fissile shale and laminated siltstone of apparent lacustrine origin. Still farther downstream, highly sheared lacustrine beds dip vertically in apparent fault contact with Chumstick rocks that occur a short distance farther downstream.

A small patch of Wenatchee Formation rests unconformably on Swakane Biotite Gneiss in the Entiat Range along the Burch Mountain Road at the center of sec. 32, T. 24 N., R. 20 E. (fig. 6). Quartz-rich conglomerate, heavily cemented with iron oxide, occurs at the base of the unit. Near the lower part of the outcrop, where a spring emerges, a conglomerate in a silty, white clay matrix contains quartz clasts to 4 inches long. They are angular to subrounded and probably represent vein material weathered out of the Swakane and lying as lag material on the pre-Wenatchee erosion surface. The remainder of the section is typical fluvial Wenatchee Formation. A thin white volcanic ash layer is present.

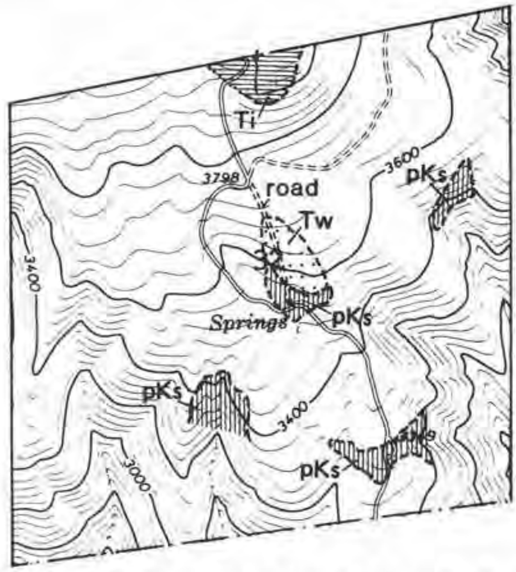

FIGURE 6. – Geologic map of sec. 32, T. 24 N., R. 20 E., showing Wenatchee Formation (Tw) unconformably overlying Swakane Biotite Gneiss (pKs) on the Burch Mountain Road, Rocky Reach Dam 7½-minute quadrangle. Ti is hornblende andesite.

DEPOSITIONAL ENVIRONMENT OF THE WENATCHEE FORMATION

The lower member of the Wenatchee Formation was probably deposited on a surface of low relief. Buried weathering profiles on all underlying units have been noted at the reference sections and elsewhere. Streams flowed across the surface and account for the lenslike form of the fluvial sandstones; a braided stream complex will account for the features observed at the Dry Gulch reference section (Tor Nilsen, personal communication, 1977). The grayish-blue shale and siltstone are considered to be overbank and floodplain deposits, and the red oxidation must have been produced by subaerial exposure and(or) an oxidizing ground-water table. Marshy areas in this environment accumulated enough organic material to form small coal beds, and local ponding created the environment for interbedded lacustrine deposits.

The tuffaceous component of shale and siltstone presumably resulted from widespread erosion and reworking of volcanic ash similar to the components of the preserved tuff beds. The fine grain size and thinness of the tuffs suggest that the ash came from a distant volcanic source. Mixing of ash with fine detrital sediment is indicated by muscovite flakes that are common in tuffaceous shale and siltstone but are not present in pure ash layers. The larger muscovite flakes are pegmatitic and suggest a crystalline source terrane.

Buza (1977, 1979) demonstrated that sediment transport directions in the Wenatchee are west to southwest. The pre-Wenatchee Swakane Biotite Gneiss terrane to the east must have been deeply weathered on a surface of low relief, and chemical weathering dominated over mechanical weathering. Under these conditions, feldspar and mafic minerals such as biotite are completely destroyed, leaving a residue of quartz, clay, and muscovite. The sweeping of this residue from subdued topographic highlands, particularly during times of flood, would provide the material for the clean quartz sands of the Wenatchee Formation as the clays are winnowed into the overbank and floodplain deposits. Most of the quartz sand of the Wenatchee is angular to subangular, suggesting that it was not transported very far from its eastern source terrane.

The upper member of the formation represents a sharp change in terms of environment of deposition and sediment source. Tectonic uplift is necesssary to bring about the thinning of the lower member that created the slight angular discordance between the members. Similarly, tectonic uplift or nearby volcanism is nessary to bring about a change from a surface of low relief to conditions that could supply the coarse volcanic detritus of the upper member. The areal extent of the upper member is very limited, and nothing is known about sediment transport direction or possible source rocks.

SEDIMENTARY ROCKS OF MIOCENE AGE

An unnamed sedimentary unit positioned stratigraphically beneath the Columbia River Basalt Group crops out in place in southern sec. 31, T. 22 N., R. 21 E., and northern sec. 6, T. 21 N., R. 21 E. The unit also occurs as a rotated landslide block near river level in SW 1/4 sec. 28, T. 22 N., R. 21 E., near the town of Malaga.

Less than 200 ft of section is exposed. The dominant lithology is shale in beds of variable thickness but attaining 30 ft. Sandstone beds are typically 6 to 10 ft thick. The color is variegated and includes red, maroon, light buff (almost white), light gray, yellowish brown, and black.

The shales contain swelling clays. The surface of a shale outcrop has a puffed texture and it is necessary to dig to obtain fresh rock. In contrast to red layers in the Wenatchee Formation, which are derived by oxidation of preexisting grayish-blue shale and siltstone, the red shales in the unnamed unit appear to have been deposited as red beds. Black shales, which are typically less than a foot thick, are organic-rich, but not coaly. Some of them contain flecks of amber.

Sandstone is very poorly consolidated and friable. It is felspathic and contains abundant biotite flakes. Pebbly layers in sandstone have clast lithologies dominated by quartz and black "cherty" rocks, but volcanic clasts, ranging from andesitic to felsic varieties, also are abundant. Pebbly layers typically are poorly sorted, and clasts are rounded to subrounded. Details of sedimentary structures are obscured by slumping of the puffed shales over sandstone beds.

The depositional environment of the unnamed unit is uncertain. The thin black organic-rich shales could be fossil humus horizons.

Preliminary palynology of specimens from the landslide block yields a tentative age of Miocene (Estella Leopold, personal communication). The pollen indicates either early or late Miocene age, but not middle Miocene. The position of the unit stratigraphically beneath the Columbia River Basalt Group makes early Miocene the preferred choice.

COLUMBIA RIVER BASALT GROUP

Previous investigators (Chappell, 1936; Patton and Cheney, 1971) mapped presumably in-place lava flows of the Columbia River Basalt Group in the Wenatchee and Monitor 7 1/2-minute quadrangles. The position adopted here is that of the U.S. Geological Survey (R. W. Tabor and R. D. Waitt, personal communication, 1978) that all the basaltic material that caps mesas and flat-topped divides is mass wasting debris, rather than remnants of undisturbed flows. (This is discussed under the section on landslides.) The only exception is some possible lower flows east of the Columbia River in the Wenatchee quadrangle, but even these were probably involved in at least minor sliding.

In-place basalt flows are present just outside the Wenatchee and Monitor quadrangles as the prominent bluffs on the skyline east of the city of Wenatchee and at Jumpoff Ridge that extends across the northern part of the Malaga and Wenatchee Heights 7 1/2-minute quadrangles. Chappell (1936) and Patton and Cheney (1971) followed Smith (1901) in using the name Yakima Basalt for flows in the Wenatchee area. The U.S. Geological Survey considers these flows to be the Grande Ronde Formation of the Columbia River Basalt Group, Yakima Basalt Subgroup (Swanson and others, 1979); the reader is referred to their report for a general description of the Columbia River Basalt Group.

INTERFLOW SEDIMENTS

A distinctive interflow sedimentary unit is recognizable at several localities, mainly along stream bottoms, in the terrain east of the Columbia River that is occupied mostly by landslide debris. The dominant lithology is a medium-grained, well-sorted, poorly consolidated, friable, yellow (limonite-stained) sandstone with fluvial cross-bedding. The sandstone is felspathic, but unlike Chumstick Formation, does not contain abundant biotite. Interbedded with it is a distinctive white to light-gray shale (mudstone). The shale has been observed in beds as thick as 3 ft, but more typically it is in thinner beds. Rip-up clasts of the white mudstone are common in the sandstone, sometimes as 1- to 2-inch-thick beds of rip-up clasts. Some of the beds in the shale clasts appear to be thin shale layers that were only slightly disrupted. Finely laminated siltstone with muscovite flakes on parting planes is found occasionally.

The unit is exposed to the southeast of the Badger Mountain Road in a northwest-trending gully in northern sec. 6, T. 22 N., R. 21 E. and SW 1/4 sec. 31, T. 23 N., R. 21 E. Along much of its exposure it is relatively flat lying, but locally it is cut by small faults that place it in contact with basalt, and the bedding may be steeply upturned. In one exposure in the gully, the sedimentary unit can be observed resting depositionally on basalt. About 2 to 3 ft of siltstone overlies columnar basalt and grades upward into sandstone. The depositional contact is well exposed in a southerly side canyon at the section line between sec. 1, T. 22 N., R. 20 E., and sec. 36, T. 23 N., R. 20 E. Here the basalt is overlain by about a 20-foot thickness of sandstone, which is in turn overlain by landslide debris. The contact between basalt and sandstone is slightly disrupted, but clearly depositional. Basalt columns with vesicular tops are normal to the contact. Across the main drainage to the north of this locality, massive basalt is clearly overlain by interflow sediment in cuts along an abandoned road.

In the northern part of sec. 13, T. 23 N., R. 20 E., a drainage can be followed eastward from Rainey Spring to a point where it crosses under power lines. Here a large mass of intact basalt with columnar structure is exposed in the stream and the northern hillside. It is nearly flat-lying, dipping only about 10° E. A short distance upstream, poor exposures of gently dipping interflow sediments suggest that it overlies the basalt depositionally. At the northern border of sec. 13, northwest of the stream locality, the apparent continuation of the sedimentary bed crops out poorly on the hillside. The surface exposure is "puffed" from swelling clays of the shale, but there is a general white color, and digging yields chips of light-gray shale and some iron oxide concretions. The continuation of the unit still farther to the northwest is evident from excellent exposure in a roadcut along a farm road at the border between secs. 12 and 13, T. 23 N., R. 20 E. The unit here is mostly typical interflow sediment as described above, but it also contains iron-concreted layers and some thin (3-inch) interbeds of dark shale. The contact between sediment and basalt is disrupted by small faults. The canyon just west of the roadcut is in massive basalt, and some poorly exposed interflow sediment is present above massive basalt across the canyon from the roadcut. The general impression is of a nearly intact sequence of massive basalt overlain by interflow sediment that is continuous for more than one-half mile along a northwest-trending belt.

Interflow sediments highly disrupted by landsliding are present in the middle reaches of a stream that drains westward across the center of sec. 26, T. 23 N., R. 20 E. Exposures of interflow sediment begin near the border between secs. 25 and 26, and are well displayed in a drainage that forks to the north. Some of the exposures up the north fork include a pure white, blocky, low-density sediment that may be diatomaceous. (Similar material was observed in back-hoe prospect pits in the NE 1/4 sec. 23, T. 23 N., R. 20 E. that have since been filled.) At one locality there is a clear example of basalt intrusive into interflow sediment. The basalt occurs as irregular masses only a few feet in diameter, having glassy margins.

Similar interflow sediment is exposed in roadcuts in the Wenatchee Heights 7 1/2-minute quadrangle. One exposure is in a roadcut where the boundaries between Rs. 20 and 21 E. and between Tps. 21 and 22 N. cross. Here basalt is intrusive into interflow sediment that consists entirely of light-colored, nearly white, shale. The shale contains well-preserved fossils of deciduous leaves and conifer needles. Farther down the same road, in the northern part of sec. 1, T. 21 N., R. 20 E., there is a similar occurrence. At this locality, fossils are rare, but a pumiceous layer is present.

ROCKS OF UNCERTAIN AGE

In the terrane east of the Wenatchee River, which is largely basaltic landslide debris that has been mantled with Quaternary flood deposits (sands and gravels) along the lower elevations, there is a unit that belongs to neither of these, but cannot be correlated with other units. Little of this unit is exposed, but the best occurrences are at a gravel pit in the NE 1/4 sec. 26, T. 23 N., R. 20 E. It is present on the north side of the pit, lying below unconsolidated sand of Quaternary age and above Wenatchee Formation that is exposed in the bottom of the pit. It also occurs in a smaller excavation north of the main pit. The thickness is only about 4 to 5 ft. The unit consists of well-cemented conglomerate that has a distinct bimodal grain size distribution between the general clast size and the sandy matrix. Clasts typically range from 2 to 4 inches long, but boulders up to 2 ft in diameter are present. Much of the clast material is gneissic, but other varieties of metamorphic rocks are present, including greenstone. Basalt clasts similar in apppearance to Columbia River basalt are included, as well as other types of volcanic rocks ranging from rhyolite to porphyritic andesite. All clasts are well rounded. Directly south of the pit, the unit is exposed on the south wall of a small canyon that drains to the west near the center of sec. 26. At this locality there is more sandstone, and conglomerate occurs as a 2-foot-thick bed within it. The sandstone, which is cemented with calcite, is best described as a lithic arkose.

Caliche zones are common in the terrain east of the Columbia River, and it is tempting to consider the unit to be calichified flood gravels of Quaternary age. However, the flood gravels (described in a later section) are typically poorly sorted and contain abundant angular clasts. Although Chumstick Formation also occurs in the drainage where the conglomerate crops out, and although Chumstick conglomerates typically contain clasts of gneiss and felsic volcanics, the unit is not believed to be Chumstick Formation because (1) it contains clasts of basalt that resemble Columbia River basalt and (2) it appears to stratigraphically overlie Wenatchee Formation at the gravel pit. If the unit is post-Miocene (post-Columbia River basalt) but pre-Quaternary, then it is difficult to ascribe a source to the clasts of metamorphic rocks other than by transport down the Columbia River valley. It is possible that this unit represents river gravels from an early stage in the development of the Columbia drainage.

Another unit of unknown age is present in the NE 1/4 sec. 14, T. 23 N., R. 20 E. The best exposures are along an east-west-trending belt on the slope facing south into the main drainage at an elevation of about 1,500 ft; another exposure is farther north around the hill at an elevation of about 1,600 ft. The unit probably forms a continuous loop between the two exposures. It is estimated that there is less than 100 ft of stratigraphic thickness. On the south-facing slope, the lower part of the unit is best exposed in a prominent pinnacle. The base of the pinnacle appears to be cemented alluvium. It rests on reddish rock that appears to be weathered gneiss. It is unstratified and contains angular clasts up to 1 foot in diameter composed of volcanic rocks and gneiss. The volcanics are varied in lithology, but the predominant type is a gray porphyritic andesite. Rare basaltic clasts occur, but they are of coarse-grained, almost diabasic texture, a texture that is not typical of Columbia River basalt in the Wenatchee area. The matrix is finer grained and moderately well cemented; calcite in the cement is only present locally. The cap of the pinnacle, which is depositionally on the basalt unit, is a 6-foot-thick section of volcanic rock. It has a reddish-brown color with abundant plagioclase phenocrysts, and it is probably an andesite. It is uniformly porous with a low density and may be a welded tuff. The volcanic unit can be followed across the slope to the west in poor exposures. About 60 to 70 ft upslope from the pinnacle, there is a well-exposed conglomerate unit with rounded clasts. The lithologies are the same as in the basal unit of the pinnacle. It is poorly sorted, with clasts up to 3 ft in diameter. The matrix is poorly sorted, including clay- to gravel-sized material, with angular pebbles. The unit is overlain by landslide debris of Columbia River basalt, although the contact is not exposed, and basalt talus from the overlying unit litters or covers parts of the conglomerate unit.

The conglomerate unit described above was noted by Chappell (1936, p. 64; fig. 20, p. 66), who apparently considered it to be a basal conglomerate of the Swauk Formation. It is not correlative with any of the formal units (Swauk, Chumstick, or Wenatchee) in terms of either lithology or mode of deposition. Nor is it considered to be correlative with the conglomerate at the gravel pit in sec. 26, because of differences in depositional environment, the presence versus absence of interbedded tuff, the role of calcite cement, and presence versus absence of clasts of Columbia River basalt. It is possible that the unit in sec. 14 is a Miocene unit that pre-dates Columbia River basalt, but definitive radiometric dating will be necessary because of the ambiguity of the stratigraphic position.

INTRUSIVE IGNEOUS ROCKS OF CENOZOIC AGE

Igneous rocks of the Wenatchee area were noted briefly by Smith and Calkins (1904), but the most detailed previous work is by Chappell (1936) and Bayley (1965). Chappell (p. 97) called the intrusive rocks "the most extraordinary of all the geologic features of the map area." He considered all to be of Eocene age, but he divided them, for convenience, into two groups. His first and largest group, which is referred to as the Horse Lake Mountain intrusive complex in this report, includes the several large andesitic intrusions and many associated dikes and sills that occur over a broad area, including Fairview and Yaxon Canyons, Bear Gulch, Horse Lake Mountain, Number One Canyon, Number Two Canyon, Dry Gulch, and Pitcher Canyon. Chappell's second group is the line of pluglike intrusions that occur along the foothills west of the city of Wenatchee; they are referred to as the Wentachee Pinnacles in this report. There is an age difference between the two groups. The Wenatchee Pinnacles are at least partly of Eocene age, whereas the Horse Lake Mountain intrusive complex is of Oligocene age.

Bayley (1965) limited his investigation to rocks of the Horse Lake Mountain intrusive complex. Both he and Chappell noted a gabbro, which they considered to be a phase of the andesitic rocks of the Horse Lake Mountain complex. It is now known to be older, of Eocene age.

This report will describe the younger, more extensive Horse Lake Mountain intrusive complex first, followed by the Wenatchee Pinnacles and the intrusive gabbro.

HORSE LAKE MOUNTAIN INTRUSIVE COMPLEX

The younger intrusive rocks of the area were investigated by both Chappell (1936) and Bayley (1965), and each used specific terminology and (or) assigned informal names to specific large intrusive bodies. None of the names have been formalized by publication. A revised nomenclature that retains much of the contribution of the previous investigators is presented in table 2.

Bayley (1965) used the name "Twin Peaks" as the general name of the intrusive complex. The general name "Horse Lake Mountain" is given here for several reasons. (1) Bayley's definition of the intrusive complex included rocks that are now known to be of Eocene age; the definition presented here includes only rocks that are demonstrably of late Oligocene age. (2) Bayley also used the name "Twin Peaks" for a specific local intrusive body; it is here retained in that sense. (3) The name "Twin Peaks" is used by local residents for two prominences located in northern sec. 10, T. 22 N., R. 19 E., visible on the skyline to the west of the city of Wenatchee. However, the name does not appear on either the Wenatchee 15-minute quadrangle nor the Monitor 7 1/2-minute quadrangle, whereas on the Monitor quadrangle the name Horse Lake Mountain is assigned to the greater prominence.

The names "Bear Gulch" and "Fairview Canyon" appear on both the Wenatchee 15-minute and Monitor 7 1/2-minute quadrangles, and they are retained for specific intrusive bodies. Chappell and Bayley both used the name "Martin" for a specific intrusion. It is here revised to "Martin's Ranch" which is the name that appears on the Wenatchee 15-minute quadrangle; the name is not given on the Monitor quadrangle. The name "Canyon Number One" is used on the Wenatchee

TABLE 2. —*Horse Lake Mountain intrusive complex, terminology*

Terminology and location in this report	Terminology of Chappell (1936)	Terminology of Bayley (1965)
General name:		
Horse Lake Mountain intrusive complex	Eocene intrusions (laccoliths)	Intrusive complex of the Twin Peaks area
Specific large intrusions:		
Bear Gulch composite sill; southern sec. 4, T. 22 N., R. 19 E.	Bear Gulch laccolith (p. 100)	Bear Gulch stock (p. 25,27)
Twin Peaks intrusive breccia and associated sill-dike complex; NE1/4 sec. 10, T. 22 N., R. 19 E.	None	Twin Peaks stock (p. 28)
Martin's Ranch sill; northern sec. 23, T. 22 N., R. 19 E.	Martin laccolith (p. 100)	Martin stock (p. 26,27)
Canyon Number One composite sill and stock; extends from SE1/4 sec. 23, SW1/4 sec. 6, T. 22 N., T. 23 N., R. 19 E. to southern sec. 7, T. 22 N., R. 20 E., reaching greatest width at eastern sec. 35 and most of sec. 36, T. 23 N., R. 19 E.	None	Canyon Number One stock (p. 28) (restricted to SW1/4 sec. 6, T. 22 N., R. 20 E.)
Fairview Canyon sill; extends from SE1/4 sec. 22 to center sec. 34, T. 23 N., R. 19 E.	Laccolith of Fairview Canyon (p. 104)	Group of sills of Fairview Canyon (p. 15-17)

Included in Horse Lake Mountain intrusive complex: Numerous scattered and(or) isolated dikes and sills having compositions ranging from andesite to basaltic andesite and characterized by hornblende phenocrysts.

Excluded from the Horse Lake Mountain intrusive complex: (1) An older gabbro dike or sill that occurs at several localities and that was noted by Chappell (1936, pp.111, 126, 144) and described by Bayley (1965) as diabase of his Canyon Number One stock (p.31) and the gabbroic sill of Pitcher Canyon (p.22) (2) The northwest-trending belt of pluglike intrusions in the foothills west of Wenatchee that range in composition from andesite to rhyodacite and are named, from north to south, Castle Rock, Old Butte, Squaw Saddle (Saddlerock), Wenatchee Dome, and Rooster Comb.

15-minute quadrangle, whereas the name "Number One Canyon" is used on the Monitor and Wenatchee 7 1/2-minute quadrangles. The former, previously applied to a specific intrusion by Bayley, is retained.

ROCK TYPES

Chappell (1936) concluded that the majority of the intrusive rocks (dikes, sills, and laccoliths) are similar in composition and range from basalt to andesite porphyry with phenocrysts of black hornblende, hypersthene or augite, and white plagioclase in a greenish-gray aphanitic groundmass. He was not able to classify them accurately in the field and mapped all as "andesite." Petrographically, Chappell noted that classification continues to be difficult if a plagioclase composition of An_{50} is used as the division between basalt and andesite clans. Chappell determined that a range of An_{40} to An_{60} is typical of the rocks. He found that the porphyritic texture is less noticeable and hypersthene or augite become minor constituents as the rocks become more basaltic. In rocks that contain labradorite, Chappell observed that mafic phenocrysts may be hypersthene or hornblende, but that pyroxene never achieves the large size of amphibole. He noted that augite occurs in many andesite porphyries and becomes the dominant mafic mineral of the more mafic rocks.

Bayley (1965) classified sills into two varieties. The first type is described as fine grained, light brown to gray, with occasional phenocrysts of hornblende. The phenocrysts range to 3 mm long and are needle shaped. The second type is described as medium grained, light gray to brown (more grayish than type one), and more highly porphyritic. Euhedral hornblende phenocrysts range to 7 mm long and plagioclase grains are up to 3 mm long. Bayley considered that the color and mineralogy of both types defines them as andesite porphyry.

Petrography described by Bayley is apparently on altered rocks, as he reported up to 20 percent "clay minerals" and 10 percent calcite in estimated modes of the two sill types. For type-one sills, he reported normally zoned plagioclase ranging in composition from An_{55} to An_{70}; where hornblende is present, plagioclase cores have a composition of An_{60}. Preserved plagioclase may show Carlsbad or albite twinning, and the grains are euhedral to subhedral. For type-two sills, Bayley reported euhedral to subhedral zoned plagioclase phenocrysts to 3mm long with compositions of about An_{70} for cores and An_{60} for the rims. Oscillatory zoning and synneusis twinning also were noted. For type-one sills, Bayley reported that cumulophyric segregations of hypersthene and augite may occur in the groundmass, but are not common. For type-two sills, he noted the common occurrence of euhedral hornblende phenocrysts to 4mm long that may exhibit either twinning or zoning. Pyroxenes were noted in the groundmass of some specimens, with hypersthene the most common in isolated phenocrysts to 0.5 mm long or as cumulophyric masses. Bayley found that type-one sills have a well-developed pilotaxitic texture due to alignment of plagioclase laths and microlites around phenocrysts, whereas type-two sills show a randomly oriented texture. He concluded that the plagioclase composition of most sills (both types) is in the labradorite field and that the rocks should be classified petrographically as basalt or basalt porphyry. However, the color index of 30-40 is in the andesitic range. Bayley therefore called the sills calcic andesite porphyry.

Bayley's (1965) hand specimen and petrographic descriptions of stocks and dikes are generally similar to his description of type-two sills, except that the reported plagioclase compositions are more sodic (andesine), ranging from An_{33} to An_{48}, and locally as high as An_{60}. Among all the intrusive rocks, primary igneous accessory minerals reported by Chappell (1936) and Bayley (1965) include quartz, magnetite, and apatite.

I agree with Chappell concerning the difficulty of field classification of the intrusive rocks, particularly in view of the high degree of alteration (described below) that has affected most of them. Some rocks that appear to lack mafic minerals can be shown to be altered varieties of typical hornblende andesite. Color also is sensitive to various kinds of alteration. Bayley (1965) failed to note the large hornblende phenocrysts that occur locally throughout the intrusive complex. Chappell (1936) had observed that "hornblende phenocrysts are usually sparsely distributed but often of abnormally large size." I noted two common varieties of igneous rock. The first has uniformly small, needle-shaped hornblende phenocrysts; the second has larger, stubbier phenocrysts. It is in the latter that abnormally large hornblende phenocrysts may occur. This variety also may contain hornblende phenocrysts of variable habit and with either a range of phenocryst sizes or with a distinctly bimodal distribution of the sizes of hornblende crystals. The variety with uniformly sized, acicular hornblende is typically light gray in an unaltered rock, such as in the Martin's Ranch sill. The variety with stubby hornblende crystals is typically darker and often has a greenish cast that may be due to chloritic alteration. Both varieties would be considered as type-two; that is, medium-grained porphyries in Bayley's classification. Occasional unusual compositions, including some that are sulfide-bearing, are discussed in a section below on isolated sill and dike occurrences.

CANYON NUMBER ONE COMPOSITE SILL AND STOCK

Bayley (1965) noted a prominent cliff of columnar jointed andesite on the south side of Number One Canyon at the border between sec. 7, T. 22 N., R. 20 E., and sec. 12, T. 22 N., R. 19 E., and used this occurrence to define the "Canyon Number

One" intrusion as a semiconcordant stock. Included in his definition is "diabase" occurring below the andesite and which is now known to be an older gabbro (discussed below). The jointed andesite noted by Bayley is part of the largest continuous mass of intrusive andesite in the map area, covering an area of about 9.5 km^2 (about 3.6 mi^2), and it is here defined as the Canyon Number One composite sill. The older gabbro is excluded from the new definition.

The great areal extent of the body was not recognized previously because generally it is not well exposed. This is due to several factors, including the altered and(or) weathered condition of much of the rock and the low topographic relief of much of the terrain in which the unit occurs. Such terrain is typically grassy, with only scattered poor outcrops of weathered andesite at ground level. Between exposures there may be a rubbly surface deposit of granular decomposed andesite. This may grade into dark-red to brown soils that are distinct from the lighter, grayer soils developed on the sedimentary units. Such criteria were used, for example, in mapping the eastern contact of the unit north of Number One Canyon, and verification was provided by occasional larger or fresher outcrops. Hill 2689 in the SW cor. sec. 31, T. 23 N., R. 20 E., is an example of an outcrop of altered andesite in which hornblende phenocrysts are destroyed, and an example of relatively "fresh" andesite with preserved hornblende is located at NE 1/4 sec. 36, T. 23 N., R. 19 E. The eastern contact is located between the center and western border of sec. 25, T. 23 N., R. 19 E. Here a farm road passes through a notch in a ridge of altered (zeolitized) andesite. To the immediate east of the notch, pebbly float of the upper member of the Wenatchee Formation is abundant. Much of the terrain in the vicinity of Horse Lake is under cultivation, but evidence that it is underlain by andesite is found in the abundant float of igneous rock around Horse Lake and in piles of andesitic rock gleaned from fields west of Horse Lake.

Over much of its extent, the Canyon Number One body apparently is a sill that was intruded at shallow depth into the unconformity between the Wenatchee and Chumstick Formations. Although of large areal extent, it is difficult to imagine that it continues at depth as a large discordant stock, because the porphyritic texture is not consistent with the coarser-grained texture expected from cooling of a large igneous mass. It is clear from the map and cross-sections that it occurs in a terrain of relatively flat topography, particularly in the vicinity of Horse Lake. This is interpreted as the stripped, partly eroded, and perhaps originally irregular upper surface of the sill. Wenatchee Formation occurs frequently around the edges of the intrusion, and patches of Wenatchee appear to "float" on the intrusion at several localities. Examples of "floating" Wenatchee Formation are (1) on the ridge between Number One and Number Two Canyons at the border between the Wenatchee and Monitor quadrangles in sec. 7, T. 22 N., R. 20 E., (2) on the north slope of Number One Canyon at the border between sec. 6, T. 22 N., R. 20 E., and sec. 1, T. 22 N., R. 19 E., (3) at SW 1/4 sec. 36, T. 23 N., R. 19 E., and (4) at SE 1/4 sec. 26, T. 23 N., R. 19 E. The large sill apparently was fed by smaller sills moving upward along inclined Chumstick and(or) Swauk bedding planes. The magma was channeled into the weak plane of the unconformity and was capable of hydraulically lifting flat-lying Wenatchee Formation, which was probably little more than 1,000 ft thick and not overlain with any significant thickness of younger formations.

At the southern end of the main mass of the intrusive body, in Number Two Canyon at sec. 7, T. 22 N., R. 20 E., it is thick and clearly discordant to Swauk(?) Formation that underlies the Swauk-Wenatchee unconformity as projected from the immediate east. Although exposures near the valley floor are poor, an 800-foot-thick, apparently uninterrupted, mass of andesite appears to extend from Hill 2410 to the 1,400-foot contour at the valley floor on the north side of the canyon. To the west of this point of greatest thickness, a patch of Swauk rocks illustrates thinning of the intrusive body and the discordance of its contact with the Swauk. On the grassy and partly landslide-affected south side of the canyon, scattered exposures at northern secs. 17 and 18, T. 22 N., R. 20 E. undoubtedly are tongues of the main intrusion, and it is conceivable, but not demonstrable, that small intrusive bodies in northern section 20 and in upper Dry Gulch could be distal parts of the intrusive unit.

In the eastern half of sec. 7, T. 22 N., R. 20 E., on the north side of Number Two Canyon, two belts of Wenatchee Formation are displaced downward and rotated relative to adjacent flat-lying Wenatchee that caps Chopper Hill. The westernmost belt contains a preserved segment of the Swauk-Wenatchee unconformity at its lower end. Tongues of andesite occur between the belts, and the small patch of Swauk(?) Formation below the preserved unconformity has bleached contacts against andesite. The general N-S orientation of the belts is subparallel to the strike of vertical Swauk beds below the Swauk-Wenatchee unconformity at Chopper Hill to the east. The belts are interpreted as slabs that foundered and sank into the liquid andesite. A few small sills of andesite are emplaced into flat-lying Wenatchee Formation on Chopper Hill.

At the massive exposure on the north side of Number Two Canyon below and west of Chopper Hill, there are two major rock types. The central and western portions of the exposure are composed of altered andesite having a light- to medium-gray color, sometimes with preserved or only partly altered acicular hornblende. Hornblende is gone from much of the rock and is replaced by calcite, which also locally replaces cores of plagioclase. On weathered surfaces the calcite has dissolved and left molds of euhedral mafic minerals that superficially resemble vesicularity. Patchy white zeolite may be developed in the rock. The second rock type occupies most of the western side of the large exposure. It is composed of fine-grained, somewhat flinty brownish-pink rock, in which only ghosts of mafic minerals occur as wispy brown iron oxides. It apparently is a more highly altered and oxidized variety of andesite. Postive response to HCl indicates minor calcite, but not as much as in the gray-colored rock type. Patchy white zeolite also may be present in the pink rock. These two rock types also are found on the south side of Number Two Canyon, for example at a large exposure in the NW cor. sec. 17, T. 22 N., R. 20 E. Here the gray variety has a lining of reddish iron oxide around calcite that has replaced mafic minerals. The pink variety also has been noted farther north at the west border of the intrusion near center sec. 1, T. 22 N., R. 19 E.

The prominent cliff of andesite on the south side of Number One Canyon in sec. 7, T. 22 N., R. 20 E., and sec. 12, T. 22 N., R. 19 E., for which Bayley named the Canyon Number One intrusion, is the type of hornblende andesite that contains relatively small, needlelike hornblende phenocrysts. Much of it is chloritized, but fresh rock can be found. Elsewhere, to the north, andesite of this intrusion is composed of hornblende andesite with generally larger, stubby hornblende crystals and phenocrysts of variable size and habit. For example, rocks of this type apparently underlie much of the terrain around Horse Lake. However, andesite with acicular hornblende occurs at least as far north as the exposure at NE 1/4 sec. 36, T. 23 N., R. 19 E. Because these two rock types are known to occur in the area as distinct sills or dikes of exclusively one hornblende type, the Canyon Number One body is believed to consist of at least two separate intrusions and is thus termed a "composite sill and stock."

TWIN PEAKS INTRUSIVE BRECCIA AND ASSOCIATED SILL-DIKE COMPLEX

Bayley (1965) defined the "Twin Peaks stock" as a northeast-trending, 2-mile-long, elliptical body forming the main summit of the Twin Peaks area (Horse Lake Mountain, sec. 10, T. 22 N., R. 19 E.). Actually, most of the igneous rock within the area of the "stock" is in the form of sills with some dikes. The only cross-cutting irregular igneous mass is a small intrusive breccia. Hence the terminology used here is the Twin Peaks intrusive breccia and associated sill-dike complex. Under this definition, the limits of the complex are not well defined. It includes all the area defined by Bayley plus sills and dikes that he mapped as emanating from the stock. It certainly includes all the intrusions associated with the intrusive breccia in the eastern half of sec. 10 and western half of sec. 11, T. 22 N., R. 19 E., which constitutes the main intrusive center. It probably should include, and is here considered to include, sills and dikes: (1) south of the main intrusive center in secs. 14 and 15, (2) north of the main intrusive center in E 1/2 sec. 3, and (3) west of the main intrusive center in sec. 9 and southern sec. 4 (all T. 22 N., R. 19 E.).

The intrusive breccia is most easily reached at the center of NE 1/4 sec. 10, T. 22 N., R. 19 E., where it forms a knob at the tip of a prominent flat-topped south-trending ridge. From that point it extends southeast down a steep ridge into a deep valley. It is a pipelike body and in map view appears as a northwest-trending cigar-shaped mass with sills emanating from it. The matrix rock type is dark-gray porphyritic andesite having a knobby weathering surface. Hornblende phenocrysts are abundant and vary widely in size and habit. They weather out of the rock intact and are found in float and talus as euhedral doubly terminated hornblende crystals. They generally have a stubby (as opposed to acicular) habit, but range from prisms somewhat elongated along the c-axis to tabular crystals greatly shortened along the c-axis. Locally hornblende crystals occur in clusters ("cumulophyric aggregates" of Bayley, 1965). Large masses of hornblende that are single crystals rather than aggregates occur locally; the largest observed is over 20 cm (8 inches) in length. This massive hornblende typically contains numerous inclusions.

Two types of xenoliths occur in intrusive breccia. The first type (described by Bayley, 1965, as gneissic basement and pictured in his fig. 11) is probably a cognate inclusion. The rocks are light gray, distinctly lighter colored than the main mass of intrusive breccia, and consist of hornblende phenocrysts in a light-gray, nearly white groundmass. The phenocrysts vary in size, but attain lengths as great as 3/4 inch (2 cm). In contrast to phenocrysts of the main breccia, those in the xenoliths are acicular; as in the breccia, they occur locally as aggregates of hornblende crystals.

The second type of xenolith is sandstone. These are undoubtedly pieces of Chumstick Formation, which the breccia intrudes. Both types of xenoliths are angular and the main igneous rock of the breccia is in sharp contact against them. Sandstone xenoliths as large as 2 ft in diameter are present; cognate igneous xenoliths typically are smaller, with the largest observed having a diameter of less than 1 foot.

The intrusive breccia is assumed to be an intrusive center. The density of sills and dikes is greatest in the vicinity of the breccia and it is estimated that within much of the area of sec. 10, T. 22 N., R. 19 E., the sills constitute perhaps 50 percent of the stratigraphic section. This is the impression gained, for example, in traversing the well-exposed section in the steep, east-facing canyon wall in NE 1/4 sec. 10. Because of the profusion of sills and the steep topography, the sills are only shown schematically on this portion of the map.

The thickness of sills varies from a few feet to at least 40 ft. Bayley (1965, p. 18-20) described how he traced a group of four sills from a point in southern sec. 14, T. 22 N., R. 19 E., to the north-northwest into the intrusive center. He reported that the sills increased in thickness northward toward the intrusive center from only about 4 to 10 ft thick to a maximum of about 40 ft thick.

In areas of rugged topography, the mechanically resistant sills frequently form dip slopes and thus show on the map as large irregular patches. A number of good examples are in secs. 9 and 15, T. 22 N., R. 19 E.

The sills included in the Twin Peaks complex are the type that are of dark-gray, often slightly greenish, color having large stubby hornblende phenocrysts. The habit of hornblende phenocrysts in the sills is thus consistent with the habit of hornblende phenocrysts in the matrix of the intrusive breccia.

A significant feature of the sill complex is the lack of disturbance of sedimentary bedding. Even where sills constitute perhaps 50 percent of a stratigraphic section, screens of sedimentary rocks sometimes less than a foot thick lie concordantly between sills with no evidence of internal disruption of bedding. This suggests two things: (1) the sills were probably emplaced passively, rather than forcefully and (2) sills were probably emplaced one-at-a-time, rather than in a single massive intrusion.

Dikes are much less abundant than sills, but several good examples of north-striking vertical to near-vertical dikes are exposed on canyon walls in the eastern half of sec. 10, T. 22 N., R. 19 E. Throughout the area of the Twin Peaks intrusive complex, there are occasional examples of sills that terminate abruptly by becoming cross-cutting dikes.

BEAR GULCH COMPOSITE SILL

The Bear Gulch composite sill, composed of several varieties of hornblende andesite, is located in sec. 4, T. 22 N., R. 19 E. Along its northern border, it forms a prominent north- to northeast-facing escarpment at least 200 ft high, with an extensive talus slope below it. A less prominent escarpment occurs along the southern border where the body extends slightly into sec. 9. Dips ranging from 25° to 35° SW. were measured on exposed surfaces of the sill, and dips ranging from 30° to 40° W. to SW. were measured in nearby Chumstick Formation; thus the igneous mass is essentially conformable with the sedimentary section.

Chappell (1936, p. 100) termed the Bear Gulch intrusion a laccolith; Bayley (1965, p. 25-26) termed it a semidiscordant stock because he could not see evidence for upward bulging and the floor is not exposed. Each estimated a minimum thickness of 200 ft based on the thickness of the northeast-facing escarpment. Cross sections drawn across the body from mapping in this report suggest that the total thickness is on the order of 600 to 800 ft.

A significant feature of the Bear Gulch intrusion is that it is composed of a large number of smaller sills. This is especially apparent in excellent exposures at the southwest end of the mass. Many separate sills can be traced from the sedimentary section into the Bear Gulch composite sill where they are either directly juxtaposed or have only a small amount of sedimentary section between them. Throughout the body, there are many examples of conformable screens of sedimentary rock between igneous rocks. This occurs on all scales, from screens only about a foot thick to sections of sedimentary rock that are probably measured in tens of feet. Irregular patches of sediment, having cross-cutting relations between bedding planes and igneous rock, also occur. The sedimentary rock, particularly the finer-grained sediments, often is baked to a white brittle rock that superficially resembles tuff.

The Bear Gulch composite sill lies in a structural transition zone between rocks to the southwest having the northwest strike that is typical of the dominant structural grain of the Chiwaukum graben and rocks to the north and northeast having strikes that are rotated to a north to slightly northeast strike. The large size of this intrusion is probably related to its position in this presumed fault zone.

MARTIN'S RANCH SILL

The Martin's Ranch sill is located in northern sec. 23, T. 22 N., R. 19 E. Like the Bear Gulch composite sill, the Martin's Ranch sill was termed a laccolith by Chappell (1936) and a discordant stock by Bayley (1965). The scanty structural data available in this terrain suggest that it is a concordant sill dipping 25° to 30° SW.

The best exposures are along a northeast-facing escarpment that makes a cliff several hundred feet high with striking columnar jointing. A large talus pile at the base of the cliff obscures the lower contact with the Chumstick Formation. The road west out of Number Two Canyon passes below the cliffs, intersecting the talus pile and the extreme northwest tip of the sill.

The thickness of the sill is estimated as 600 to 700 ft, similar to the thickness of the Bear Gulch composite sill. Unlike the Bear Gulch intrusion, the Martin's Ranch sill is not composite, but appears to be a single large intrusion. There is no evidence, in a traverse across the strike of the sill, of any screens of sedimentary rock that would suggest a composite origin.

The hornblende andesite composing this sill is the type that is light gray in color with relatively small acicular hornblende phenocrysts. Plagioclase phenocrysts also are abundant. Most of the rock from the Martin's Ranch sill is relatively fresh, in contrast to the alteration that is prevalent in most of the smaller sills of the area.

Bayley (1965, p. 27) noted that the Bear Gulch and Martin's Ranch intrusions lie along a line that strikes northwest, suggesting a common structural control. Structurally, the Martin's Ranch sill lies along the belt of Chumstick rocks with normal regional northwest strike, but just south of (and thus near to) the fault that separates it from a region of rotated or disturbed strikes.

FAIRVIEW CANYON SILL

The Fairview Canyon sill may be traced for about 2 miles in a northerly direction from the center of sec. 34 through sec. 27 to a point just southeast of the center of sec. 22 (T. 23 N., R. 19 E). Throughout its length in sec. 27, it forms a prominent cliff along the ridge on the west side of Fairview Canyon. The west side of the ridge is in part a dip slope of the sill. Along much of its exposure in sec. 34, the sill also forms a large dip slope. The sill was termed a laccolith by Chappell (1936), and Bayley (1965) grouped it as one of a series of sills in the vicinity of Fairview Canyon. There are indeed many smaller sills in the vicinity, but the maximum thickness of the Fairview Canyon sill is estimated at about 300 ft, which is an order of magnitude greater than the minor sill occurrences.

Bayley noted correctly that the sill thins southward. At its northern end, it thins rather abruptly from its area of maximum thickness in the cliff over Fairview Canyon, and can be seen to pinch out completely on the north wall of a ravine in SE 1/4 sec. 22, T. 23 N., R. 19 E. The point where the pinchout occurs is at a hinge line along which the beds to the south of the line, which strike nearly due north, are rotated to a northwest strike in the terrane north of the line.

Bayley (1965) noted that the area on the east side of Fairview Canyon, opposite the above-described sill, is also capped by a large sill. He stated that they are not correlative, but have a stratigraphic separation of several hundred feet. Bayley's second sill is actually the northern end of the Canyon Number One composite sill. In contrast to the Fairview Canyon sill, which is located between southwest-dipping Chumstick bedding planes, the Canyon Number One composite sill is relatively flat lying along the unconformity between the Chumstick and Wenatchee Formations. A fault that strikes northerly between the two sills occupies Fairview Canyon and has a west-side-up displacement. It thus seems reasonable to assume that the "stratigraphic separation" noted by Bayley is actually a fault separation and to postulate that the Fairview Canyon sill was a feeder into the larger Canyon Number One composite sill.

Much of the Fairview Canyon sill is altered. Occasional fresh exposures indicate that it is the type of hornblende andesite having a light-gray color with acicular hornblende phenocrysts.

MISCELLANEOUS SILLS AND DIKES

Many isolated intrusives or groups of intrusive rocks, mainly sills, are scattered over a much larger area than is indicated by the specific intrusions or regions of more highly concentrated intrusive activity defined above. Because all represent essentially the same igneous event, it is merely semantics to attempt to associate each occurrence with a major intrusive body, and it is not done here. In general, the sills and dikes consist of hornblende andesite of either the light-gray variety with acicular hornblende phenocrysts or the darker rock with stubby hornblende phenocrysts. There is no apparent systematic pattern of occurrence of the two varieties.

Parts of the map area, including much of the higher altitudes of the Monitor quadrangle in the vicinity of Horse Lake Mountain, are covered with forest and forest soil. These show as "bare spots" on the map amid terranes having abundant sills. They are undoubtedly also underlain by abundant intrusive rocks. Often the ridges in forested terrain are held up by igneous rock, which crops out intermittently along the ridge crest. These show as lines on the map, but there is often no way of knowing whether they represent dikes or sills. No attempt was made on the map to show sills and dikes with separate symbols. Most sill groups are obvious because they have map patterns that indicate conformity with bedding. Chappell (1936, p. 98-100) reported that most sills are in the range of 6 to 20 ft thick, which agrees with my observations. Bayley (1965, p. 12-13) reported several localities where numerous thin sills less than a foot thick occur.

The best easily accessible example of a series of dikes is along a new (1979) logging road across northern sec. 3, T. 22 N., R. 19 E. The road bends sharply around a northwest-trending ridge at the northern border of the section. Along the stretch of road southeast of the bend, dikes ranging in thickness from about 10 to 60 ft are exposed. They strike N. 20° W. and dip 75° NE.; this is nearly parallel to the direction of the road, so the dikes appear as slabs in the roadcut. At places the screen of sediment between two dikes is only a few feet thick. They display a variety of colors and textures. One is composed of hornblende andesite (the variety having large stubby hornblende phenocrysts). Several have a uniform fine-grained texture and have a greenish hue, perhaps indicating extensive chloritization. Several are fine grained, dark gray (almost black), with white spots that are probably altered plagioclase; one of these contains sulfide minerals. To the south of the hairpin bend in the road, a branch of the road trends nearly north-south with a slight westward bulge. Near the bulge, a dike striking N. 20° W. cuts a fault zone that pre-dates the intrusive activity. The slope above the road here is the dip-slope of a sill. The dike can be traced uphill from the roadcut, clearly cross-cutting the sill. The sill is extensively altered, but is a variety of typical hornblende andesite; the dike is a uniformly fine-grained, dark-gray rock.

CONTACT EFFECTS OF THE HORSE LAKE MOUNTAIN INTRUSIVE COMPLEX

Contact effects of sills and dikes of the Horse Lake complex are minimal. Thin chilled contacts are found locally, but generally are absent. Bayley (1965, p. 26 and fig. 9) described a 3-cm chill zone with oriented plagioclase laths at the upper contact of the Martin's Ranch sill.

Chappell (1936, p. 98) noted that except for slight induration of sedimentary rocks, sills and dikes typically have clean-cut sharp contacts with no contact metamorphism. As noted above for the Bear Gulch composite sill, I observed fine-grained sedimentary rock that is baked to a hard, brittle, white rock that superficially resembles tuff. Similar material was noted elsewhere, but occurrences are rare. Occasionally there are examples of arkose that are more brittle and indurated at the contact with an intrusive rock. A thin section of one of these showed that biotite, normally brown in plain light, had been converted to a nearly opaque black color by mild contact metamorphism.

XENOLITHS IN HORSE LAKE MOUNTAIN ROCKS

With the exception of the abundant xenoliths of Chumstick Formation and cognate inclusions described in the Twin Peaks intrusive breccia, occurrences of xenoliths are extremely rare in rocks of the Horse Lake Mountain complex. Chappell (1936, p. 120 and 122) described and pictured a small xenolith of biotite gneiss in a sill. During the present investigation, xenoliths were noted at only one locality. The new (1979) logging road, mentioned in the section on miscellaneous sills and dikes, diverges from a jeep trail shown on the 1966 Monitor 7 1/2-minute quadrangle at the border between sec. 34, T. 23 N., R. 19 E., and sec. 3, T. 22 N., R. 19 E. One-tenth of a mile south of this point along the new road, an altered sill of hornblende andesite contains several small (2- to 3-inch) xenoliths of what appear to be schistose or gneissic metamorphic rocks. They probably represent fragments of basement rocks related to the Swakane Biotite Gneiss.

ALTERATION OF ROCKS OF THE HORSE LAKE MOUNTAIN INTRUSIVE COMPLEX

Most of the rocks of the Horse Lake Mountain intrusive complex have undergone mild to severe post-emplacement alteration. Bayley (1965) described alteration to "clay minerals" and reported an average mode of 20 percent clay minerals for fine-grained porphyritic rocks. This clay mineral content is doubtful unless the samples were from weathered outcrops. Alteration that is exclusive of weathering is of three main types—chloritization, growth of zeolite minerals, and replacement by calcite.

Chloritization takes several forms. Sometimes the entire rock is extensively chloritized, giving an overall greenish cast and typically producing a fine-grained texture. In some rocks the hornblende phenocrysts are obviously chloritized but there is little evidence of chloritization of the bulk of the rock. Chappell (1936, p. 123) noted that magnetite may also be produced in association with chloritization of hornblende. At a number of localities, including some of the better exposures around Horse Lake Mountain, the chloritization is confined to the borders of sills and the interiors contain fresh rock.

Zeolites occur in various forms. Most typically they occur as small irregular white patches or blebs scattered through the rock, probably localized at sites of previous plagioclase phenocrysts. Larger patches several cms in diameter may occur, and sometimes these contain euhedral crystals, often in radiating aggregates. Occasional examples of zeolite growth in fractures were observed; some of these have cockscomb structure with relatively large well-developed crystals. No attempt was made to identify the varieties of zeolites. Bayley (1965, p. 18) reported cavities up to 6 inches in diameter lined with stilbite crystals; elsewhere (p. 39) he tentatively identified stilbite or heulandite. Chappell (1936, p. 114) reported laumontite and analcite in thin section and described and pictured (p. 120-121) 6-inch radiating clusters of heulandite.

Calcite may occur as replacements of individual silicate minerals, bulk replacements of silicate rock, or fillings in cavities and fractures. Both Chappell (1936) and Bayley (1965) noted that calcite replaces calcic cores of zoned plagioclase as seen in thin section. Calcite as a partial replacement of hornblende phenocrysts is obvious at numerous localities even in hand specimens; this phenomenon seems to be especially typical of rocks that are partially chloritized. Calcite replacement of silicate material often is as small irregular white patches or blebs scattered throughout the rock, similar to the distribution of zeolites; both zeolite and calcite blebs may occur together in the same rock. Larger irregular replacement patches may contain sparry calcite. A particularly good example of fracture-filling calcite occurs down the east side of the prominent flat-topped south-trending ridge in sec. 10, T. 22 N., R. 19 E. It attains a thickness of nearly 1 foot and is lined with dogtooth calcite crystals. Chappell (1936, p. 120) described cavities filled with both calcite and zeolite minerals.

Although one type of alteration may be more obvious or pronounced in an individual specimen, all three types of alteration may, and commonly do, occur together in the same rock. The texture of the intrusive rocks suggests that they are hypabyssal rocks emplaced at relatively shallow depth. The Chumstick Formation that they intrude has good porosity and permeability. During emplacement of the Horse Lake Mountain complex, the formation probably contained ground waters saturated with calcium carbonate. Heating of the ground waters by the igneous rocks, even after solidification, must have established long-lived thermal convective systems that caused the extensive alteration of the rocks soon after their emplacement.

AGE AND EMPLACEMENT OF THE HORSE LAKE MOUNTAIN INTRUSIVE COMPLEX

The age of the Horse Lake Mountain intrusive complex is based on five K-Ar dates of hornblende from various parts of the complex and by different investigators (table 3). The average age is about 29 m.y. or late Oligocene.

Chappell (1936, p. 137-147) apparently was impressed with the passive mode of emplacement inferred from the field relations. He postulated an "akmolithic" mechanism of emplacement whereby the sedimentary rocks were deformed independently of the crystalline basement, creating void spaces (such as in the axial portions of folds) that were filled passively by magma contemporaneously with deformation. Bayley (1965, p. 43) only com-

TABLE 3. — *Potassium-argon ages of hornblende from the Horse Lake Mountain intrusive complex — All ages from hornblende andesites*

Occurrence and locality	Age (m.y.)
Sill at Horse Lake Mountain, sec. 10, T. 22 N., R. 19 E.	29.4 ± 2.1
Shallow stock, Martin's Ranch, sec. 23, T. 22 N., R. 19 E.	28.2 ± 3.2
Shallow stock, Number One Canyon, sec. 7, T. 22 N., R. 20 E.	34.2 ± 3.2
Sill at Horse Lake Mountain, sec. 10, T. 22 N., R. 19 E.	24.9 ± 0.4*
Breccia dike at Horse Lake Mountain, sec. 10, T. 22 N., R. 19 E.	29.8 ± 6.6*
Average of ages from Horse Lake Mountain intrusive complex	29.3

* Courtesy of R. W. Tabor, personal communication.

mented briefly on the mechanism of emplacement; he considered intrusion of the complex to be post-deformational and controlled by a regional fracture system.

I agree with Chappell that the passive intrusion of the Horse Lake Mountain intrusive complex is synchronous with deformation, but I disagree with the 'akmolithic' concept. The evidence from the new detailed mapping suggests that a major right-lateral shear couple deformed the already southwest-dipping Chumstick beds, causing rotation of the beds and opening of bedding planes as in a giant kink band. The evidence for this is discussed in detail in the section on structural geology.

WENATCHEE PINNACLES

The Wenatchee Pinnacles consist of intrusions forming prominent spires along the foothills immediately west of the city of Wenatchee. They are aligned and trend northwest for approximately 3 miles from NW 1/4 sec. 22 to NW 1/4 sec. 8, T. 22 N., R. 20 E. Several of the more resistant and topographically prominent pinnacles are named. From northwest to southeast they are Castle Rock, Old Butte, Squaw Saddle, Wenatchee Dome, and Rooster Comb. With the exception of Wenatchee Dome, the names appear on the Wenatchee 7 1/2-minute quadrangle. Wenatchee Dome is a name used by Patton and Cheney (1971) for a prominent knob rising above the valley floor at the southern terminus of Miller Street in the SW cor. sec. 15, T. 22 N., R. 20 E. The igneous rocks that compose the pinnacles may be grouped into mafic and felsic varieties. Castle Rock, Old Butte, and Squaw Saddle are part of the mafic group; Wenatchee Dome and Rooster Comb compose the felsic group.

The mafic rocks apparently form a continuous belt with a pinch-and-swell structure; this is determined by mapping the less prominent mafic exposures and tracing zones of reddish soil (developed on the mafic rocks) between the prominent pinnacles. The belt of mafic rocks passes about 0.3 mile southwest of the felsic rocks and lies entirely within a northwest-trending belt of Swauk(?) Formation.

Patton and Cheney (1971) also mapped the belt of mafic rocks west of the felsic rocks and Chappell (1936, p. 126) noted that a dike west of the felsic rocks is similar in composition to a border phase of Squaw Saddle.

The felsic rocks are two isolated exposures that lie along the northwest-trending fault that separates the Swauk(?) and Chumstick Formations; there is no evidence of a connection between the two exposures. Rhyolite and perlite were reported to occur at depth at a site on the western border of sec. 26, T. 22 N., R. 20 E.; this is southwest of, and on line with, Wenatchee Dome and Rooster Comb. In a test hole drilled on Wenatchee Heights at an elevation of 2,500 ft, the igneous rock was encountered at depths of 678 to 940 and 1,060 to 1,360 ft (Patton and Cheney, 1971).

FELSIC ROCKS OF THE WENATCHEE PINNACLES

The composition of Wenatchee Dome and Rooster Comb has been described variously as soda-rhyolite (Smith and Calkins, 1904, p. 55-56), rhyolite (Lovitt and Skerl, 1958), and biotite-dacite porphyry or porphyritic biotitic dacite (Chappell, 1936, p. 125; Patton and Cheney, 1971). Chappell (1936, p. 126) estimated the silica content of a glassy phase of the intrusion as 72 wt. percent based on a measured refractive index of 1.495. No geochemical data are available, and the rock is here termed biotitic rhyodacite porphyry.

The outcrop appearance of rhyodacite, particularly Wenatchee Dome, is characterized by a distinct platy structure. Chappell (1936, p. 106) commented that it has a fairly consistent alignment with the periphery of the body, and Patton and Cheney (1971) referred to it as exfoliation sheets with flow banding parallel to jointing. Although slabs of the rock fall away as sheets parallel to the outcrop in many places, it should be emphasized that the platy structure is not a weathering exfoliation but is due to a pronounced flow banding. Locally, along the west side of Wenatchee Dome the flow banding and platy structure are clearly oblique to the outcrop surface. As one traverses up the west side of Wenatchee Dome, the flow banding flattens and roughly parallels the external domical form of the outcrop. But the flattened flow banding at the top terminates abruptly on the eastern side and does not bend back down the eastern side as would be expected of a weathering exfoliation. Rather, the truncated foliation gives the impression that an eastern part of the igneous body is missing.

The rhyodacite is light gray, nearly white. Quartz, mm-size, and plagioclase phenocrysts are in an aphanitic to glassy groundmass. Quartz phenocrysts sometimes show euhedral forms, but more typically are rounded and(or) embayed. Locally the rock has a brecciated texture on a submacroscopic level, evidenced by lighter-colored angular patches of aphanitic rock surrounded by slightly grayer, more glassy material. The pronounced flow banding is due to alternating layers of aphanitic and glassy material. The mafic mineral content is low and crystals are small; but typically biotite and, to a lesser extent, hornblende are recognizable under a hand lens.

A glassy phase of the intrusion, which has been termed "perlite" (Chappell, 1936, p. 106; Huntting, 1949) occurs at the borders of both Wenatchee Dome and Rooster Comb. It extends outward at least 50 feet west of Wenatchee Dome (Chappell, 1936) and the best exposures occur there. The material is intensely fractured and breaks down to a friable sand, making it impossible to obtain a coherent hand sample. It is light-gray colored with whitish to yellowish specks that apparently represent an alteration product. Biotite flakes occur in the glass matrix. The perlite appears to be restricted to the western side of Wenatchee Dome and the eastern side of Rooster Comb.

Petrographically, Chappell (1936, p. 125) reported that phenocrysts of plagioclase and quartz in the porphyry typically have irregular outlines and occasionally are broken. Plagioclase (andesine to oligoclase) is either zoned or consists of a compound aggregate of optical units; it commonly contains glass inclusions. The glassy groundmass has numerous microlites of quartz and plagioclase and local patches of microspherulites or swarms of rodlike longulites. Scattered biotite and occasional euhedral hornblende phenocrysts occur. The petrography of perlite is reported by Chappell as primarily glass with less than 10 percent total phenocrysts of quartz and plagioclase (An_{27}) with glass inclusions. The glass is described as having numerous aligned longulites, a few globulites, and characteristic perlitic cracks.

The apparent truncation of flow foliation on the east side of Wenatchee Dome and the distribution of the perlite border phases of the two bodies suggest the possibility that Wenatchee Dome and Rooster Comb were once part of a single intrusion and have been separated by faulting. The small amount of right-lateral displacement required is consistent with postulated right-lateral movement of the nearby Entiat fault during Eocene time.

Radiometric dates for Wenatchee Dome include K-Ar ages of 43.2 ± 0.4 m.y. and 43.5 ± 1.6 m.y. for biotite from, respectively, rhyodacite and perlite (table 4) and fission-track ages for zircon of 51.4 ± 2.8 m.y. (by Charles W. Naeser) and 47.0 ± 2.7 m.y. (by Joseph A. Vance) (J.A. Vance, personal communication, 1981). If the younger K-Ar ages are correct, they suggest that emplacement of rhyodacite was controlled by the fault zone between Swauk(?) and Chumstick Formations. If the older fission-track ages are correct, then the rhyodacite is older than the Chumstick

TABLE 4. —*Potassium-argon ages of Eocene shallow intrusions into the Chumstick and Swauk Formations*

Rock type and locality	Mineral	Age (m.y.)
Fine-grained gabbro dike/sill south of Number One Canyon in sec. 12, T. 22 N., R. 19 E.	Whole-rock	48.3 ± 2.8
Holocrystalline core of rhyodacite dome in sec. 15, T. 22 N., R. 20 E.	Biotite	43.2 ± 0.4*
Glassy margin of rhyodacite dome in sec. 15, T. 22 N., R. 20 E.	Biotite	41.4 ± 1.6
Dike of hornblende gabbro in quarry at Walker Canyon, sec. 20, T. 25 N., R. 18 E.	Hornblende	41.5 ± 2.6*

* Courtesy of R. W. Tabor, personal communication.

Formation; it would be an intrusion into the Swauk(?) that fortuitously occurs along the later fault between Swauk(?) and Chumstick.

MAFIC ROCKS OF THE WENATCHEE PINNACLES

The mafic rocks of the Wenatchee Pinnacles clearly differ in composition from the felsic rocks (rhyodacite), but a precise identification of the rock type is difficult because of extensive alteration at most exposures. Most of the alteration is probably coeval with silicification of nearby rocks in brecciated zones. Alteration commonly gives a lighter overall color to the rocks, making them appear superficially less mafic than their original composition (for example, most of Castle Rock).

Most of the mafic rocks contain either fresh hornblende phenocrysts, partly altered (but recognizable) hornblende phenocrysts, or indistinct, needlelike "ghosts" that appear to mark the sites of former hornblende phenocrysts. Thus most of the mafic rocks were probably hornblende andesite or a rock very close to this in composition. Smith and Calkins (1904) described a border phase of the Squaw Saddle body as hornblende-pyroxene andesite having phenocrysts of sodic labradorite, hornblende, hypersthene, and augite with microlites of hypersthene, plagioclase (An_{50}), and magnetite in a glassy groundmass. Chappell (1936, p. 123) stated that "the central portion of the Squaw Saddle intrusive body appears to be hypersthene-basalt porphyry." He pictured (p. 124, fig. 46) a hornblende andesite porphyry from Squaw Saddle and concluded that the main rock type is andesite porphyry with a lesser extent of dacite porphyry.

During my field examination of the rocks, I noted what appeared to be quartz phenocrysts under a hand lens; such rocks were noted as possibly "dacite" in field notes. Laboratory examination under higher magnification indicated that clear plagioclase phenocrysts resemble the glassy look of quartz if cleavage planes or twinning are not obvious. Although some of the rocks contain cloudy plagioclase phenocrysts, a common feature in these rocks is the occurrence of clear plagioclase. Some altered rocks have irregular blebs of quartz that apparently are due to a silicification process, but which also may be mistaken for quartz phenocrysts in the field.

Chappell (1936, p. 108) noted the near-vertical foliation in the mafic rocks, particularly at Old Butte. On a slabbed and wetted surface of a specimen from Old Butte, there is a faint banding due to zones having a slightly more yellowish color than the normal gray and having many internal fine fractures; this apparently is the source of the macroscopic platy structure.

Locally the altered varieties of mafic rocks are cut by fine veinlets of silica. At Old Butte there are larger silica veins (as thick as 3 cm) along the border. The veins show evidence of multiple fracturing and silica deposition. White and(or) green cherty silica forms laminations parallel to the walls of the vein. The interior of a vein may be filled with a clearer, more agatelike silica. In one specimen, an earlier band of white chert is broken into fragments and surrounded by later, more greenish silica. Just northwest of Old Butte there is a poorly exposed small intrusion that is totally oxidized to a reddish-brown color; abundant zeolites appear to be vesicle-fillings in the rock.

A small intrusion occurs just below the base of the Wenatchee Formation east of Chopper (a triangulation point, elevation 2319, in NW 1/4 sec. 8, T. 22 N., R. 20 E.). Although it is near sills of reddish-brown andesite that intrude the Wenatchee Formation, it appears more similar to rocks of the Wenatchee Pinnacles. Like some of the rocks near Castle Rock, it is a light-gray rock that superficially resembles dacite, but lacks quartz phenocrysts and is probably altered andesite. It contains local calcite veins and abundant cubes of pyrite that measure about a half mm across.

The age of the mafic rocks of the Wenatchee Pinnacles is uncertain. No radiometric ages have been determined, and it is not clear whether the rocks are correlative with the Horse Lake Mountain intrusive complex (29 m.y. age) or the felsic rocks of the Wenatchee Pinnacles (43-49 m.y. age). On the one hand, the mafic rocks are mostly similar in composition to hornblende andesite of the Horse Lake Mountain intrusive complex prior to alteration. On the other hand, they occur in proximity to the felsic rocks with similar alignment (similar structural control), and they may contain minor amounts of dacite (that is, compositionally more akin to rhyodacite).

EOCENE GABBRO

A distinctive gabbro occurs at several places along a regional northwest trend. The southernmost exposures are two northwest-striking dikes on the north side of Pitcher Canyon. The easternmost dike lies within the Wenatchee 7 1/2-minute quadrangle at NW 1/4 sec. 28, T. 22 N., R. 20 E.; its extension to the northwest is well exposed at canyon bottom in upper Dry Gulch at SE 1/4 sec. 20, T. 22 N., R. 20 E. To the east, a second dike is at NE 1/4 sec. 27, T. 22 N., R. 20 E., in the Wenatchee Heights 7 1/2-minute quadrangle. The dike is in fault contact with an andesite sill of the Horse Lake Mountain complex. A northwest-trending fault drops Wenatchee Formation down on the west side relative to Chumstick Formation; the andesite sill, which intrudes along the Wenatchee/Chumstick unconformity west of the fault, is brought into contact with the gabbro dike that intrudes Chumstick east of the fault. Bayley (1965, p. 22) noted the occurrence of this gabbro dike, but mapped the gabbro and andesite together as a single large intrusion.

In the vicinity of Number One Canyon the gabbro may be mapped continuously for a distance of more than 1 mile from the NE 1/4 sec. 12, T. 22 N., R. 19 E., northward to NW 1/4 sec. 1, T. 22 N., R. 19 E. The best exposures of the gabbro along this belt are at several prospect pits near its southern end on the slopes east of Hill 2521, at canyon bottom in the places where it crosses the north and south forks of Number One Canyon, and near its northern terminus. At its southern end, it is cut off obliquely by a thrust fault; at its northern end it is overlain by the Canyon Number One composite sill. It is a sill at its southern end and over much of the distance that it is traced northward, but becomes a cross-cutting dike just before its northern terminus. This gabbro sill(dike) has an estimated maximum thickness of about 250 ft.

Although good exposures of this body occur only sporadically, it is easily traced both in the field and on aerial photographs by a distinctive dark reddish-brown soil that develops on it. Both Chappell (1936, p. 145) and Bayley (1965, p. 31) observed the intrusion at Number One Canyon, and both described it as an irregular stocklike body. Chappell considered it to be a deeper-seated mafic phase of the Horse Lake Mountain complex; Bayley noted that it was structurally below the Canyon Number One andesitic intrusion but drew no conclusions concerning relative ages or correlation. Bayley correctly noted a similarity to the occurrences in Pitcher Canyon.

In hand specimen the gabbro is a dark-gray to black, medium-grained, nonporphyritic rock with laths of plagioclase and pyroxene visible under hand lens magnification and frequently to the naked eye. Sulfide minerals, apparently of primary origin, were noted in specimens from Pitcher Canyon and from prospect pits near Number One Canyon. Orientation of crystals is random. The mafic rock weathers readily and shows spheroidal weathering; excellent examples are at the occurrences in Pitcher Canyon and at the prospect pits at the southern terminus of the longer belt to the south of Number One Canyon.

The rock has been described petrographically by Bayley (1965, p. 38, 41) from two localities, both apparently on partially altered rocks. A specimen from Pitcher Canyon is reported as bearing plagioclase ranging in composition from An_{65} to An_{75}, normally zoned and synneusisly twinned; augite is poikilitically enclosed by plagioclase. He described a specimen from Number One Canyon as having 60 percent plagioclase of composition An_{30} to An_{60}, 15 percent pigeonite, 10 percent hypersthene, and 15 percent accessories and alteration products; plagioclase is normally zoned, and ophitic to subophitic textures are common.

The gabbro commonly displays alteration, especially near fault zones. The westernmost dike in Pitcher Canyon, in fault contact with andesite, is barely recognizable as gabbro in the field. It has calcite veinlets and is extensively zeolitized. Bayley (1965, p. 39) identified the zeolite minerals as stilbite or heulandite. The greatest amount of alteration is observed at the southern end of the longer belt of gabbro where it is cut obliquely by a thrust fault. There is a transitional interfingering contact between the silicified thrust fault and the gabbro sill at a locality just east of the center of sec. 12, T. 22 N., R. 19 E. Here there is extensive shearing, brecciation, silicification, and calcite veining. Just south of this locality, on the slopes northwest of Hill 2508 at the SE 1/4 of sec. 12, there is a good exposure of the silicified thrust fault. Although most of the silicified rock there is of sedimentary origin, a specimen collected at this locality has the igneous texture of gabbro, but is completely silicified. At the north end of the longer belt of gabbro, north of where it crosses the north fork of Number One Canyon at NW 1/4 sec. 1, T. 22 N., R. 19 E., alteration is pervasive, although not as extensive as at the southern end. Locally the gabbro is sheared and slickensided. At one locality the material that fills a 1/2-inch-thick vein changes along strike from cherty silica to calcite. At another locality a 3-inch-thick vein of calcite has a layered structure, indicating repeated periods of calcite deposition. At a third locality, a massive calcite vein at least a foot thick cuts the gabbro and contains numerous gabbro breccia fragments.

There are two localities that expose rocks that are of questionable correlation with the gabbro. Four small intrusions occur near the unconformable contact between Wenatchee and Chumstick Formations north of the mouth of Dry Gulch at SW 1/4 sec. 16, T. 22 N., R. 20 E. They are extensively altered and veined with calcite but appear to have been gabbro originally. Although shown on the map with the same symbol as the main gabbro, it is not clear that they are actually correlative or whether the four small intrusions may be related to the mafic rocks of the Wenatchee Pinnacles. In the Wenatchee Heights 7 1/2-minute quadrangle, just southwest of where the Squilchuck Creek Road meets the Halvorson Loop Road at northern sec. 8, T. 21 N., R. 20 E., a 3-foot-thick basalt sill in Chumstick Formation is exposed in a cut on the northwest side of the highway. It is clearly finer-grained than the gabbro observed elsewhere, but must be of similar composition, and a direct correlation remains uncertain.

A whole-rock K-Ar age of 48.3 ± 2.8 m.y. was obtained for a specimen from the main belt of gabbro (table 4). This suggests that it was emplaced during the early stages of development of the Chiwaukum graben, probably no more than a few million years after onset of deposition of the Chumstick Formation and certainly before deposition of the Chumstick was complete.

The gabbro possibly is correlative with the Camas Land diabase, which lies about 8 miles west-northwest of the main gabbro belt of Number One Canyon. The Camas Land diabase is a major mafic intrusion of presumed Eocene age, and it contains gabbroic phases (Southwick, 1966).

LAMPROPHYRE OF UNCERTAIN AGE

Chappell (1936) reported the occurrence of two lamprophyre sills emplaced into foliation planes of Swakane Biotite Gneiss at a roadcut described as located 1 1/4 miles south of the northern boundary of the Wenatchee quadrangle on the east side of the Columbia Valley, which would place it within southern sec. 14, T. 23 N., R. 20 E. The rocks are of interest because of Chappell's report of a mineral he thought might be nepheline. His petrographic description (p. 46) reported the following minerals in order of decreasing abundance: "augite, basaltic hornblende, nephelite(?), light blue chlorite, calcite, apatite, pyrite and chalcopyrite, kaolinic and iron oxide alteration products." Hornblende is dominant in the borders and augite in the centers of the sills. The largest phenocrysts are 5 mm in length.

As described by Chappell, the lamprophyre sills clearly post-date pegmatite emplacement, but beyond that the age is uncertain. As noted by Chappell, similar compositions are not known from dikes cutting Swakane Biotite Gneiss in nearby Corbaley Canyon, which are now known to have an age of about 48 m.y. (Gresens, 1982a, p. 222). As described, they are dissimilar to rocks of the Horse Lake Mountain complex, the Wenatchee Pinnacles, and Eocene gabbro.

HYDROTHERMALLY ALTERED ROCKS

Hydrothermally altered rocks, primarily silicified brecciated rock, occur at three localities. The first is a major northwest-trending belt of altered rocks that extends about 2.5 miles from a point near the northern border of NW 1/4 sec. 27 to a point south of Old Butte and west of the northern end of Squaw Saddle at NW 1/4 sec. 16 (T. 22 N., R. 20 E.). The southernmost point is a small prominence ("Compton's Knob" of Patton and Cheney,

1971) in a terrane of landslide debris. Because similar rock across the valley to the north (the L-D mine area) forms prominent spires, Compton's Knob is probably a bedrock exposure projecting through the landslide. A test hole south of Compton's Knob on Wenatchee Heights that encountered rhyodacite and perlite (see section on Wenatchee Pinnacles) also encountered silicified rocks between a depth of 715 and 815 feet (Patton and Cheney, 1971). The second occurrence of altered rocks is a northwest-trending silicified portion of a thrust fault that extends about 1.5 miles from a point just north of center sec. 18, T. 22 N., R. 20 E., to a point just east of center sec. 12, T. 22 N., R. 19 E. It makes a prominent "V" as it crosses Number Two Canyon. The third occurrence is at an abandoned mine at the extreme SE cor. sec. 3, T. 22 N., R. 19 E.; minor expressions of alteration occur in the vicinity of the mine.

SILICIFIED ZONE OF THE L-D MINE AREA

Considerable previous attention has been given to the major belt of hydrothermal alteration because of its economic (gold) potential. Following Patton and Cheney (1971) the name "L-D mine" is used here, although it appears on the Wenatchee 7 1/2-minute topographic quadrangle as the "Golden King mine." It has been described by Chappell (1936), Lovitt and McDowall (1954), and Patton and Cheney (1971); prominent outcrops of silcified rock are referred to as "reefs." Most of the altered rock is light colored, nearly white. Rusty weathering of sulfide minerals has stained the rock to limonitic colors on fracture surfaces. Silicification may occur as a pervasive cementation of the bulk rock, as veins and veinlets of cloudy to cherty silica, and as clear coxcomb quartz lining open fractures or vuggy cavities. According to Guilbert (1963, unpublished report) as quoted by Patton and Cheney (1971), these three modes of silicification are a chronologic sequence of three episodes of mineralization from (1) early pervasive silicification to (2) milky fine-grained quartz veins to (3) late coarse-grained clear coxcomb quartz. The silicification is concentrated in zones of brecciation; following Patton and Cheney (1971), these are considered to be silicified thrust faults and are so indicated on the map. Angular fragments on various scales are obvious at nearly every exposure. At G reef south of Old Butte, it is clear that earlier vein quartz has been fragmented and recemented, indicating that brecciation overlapped mineralization.

As reported by all previous investigators, the most prevalent relict texture suggests silicification of arkosic sedimentary rocks. Chappell (1936, p. 132) presented an excellent photomicrograph showing rounded clastic grains surrounded by halos of microscopic coxcomb quartz overgrowths in thin section. Chappell (p. 129) described shaly interbeds within silicified rock that contain recognizable plant fossils. Because this major zone of silicification lies within the belt of Swauk(?) Formation, most of these silicified sedimentary rocks are probably from that unit, but positive identification is not possible. Although similarly impressed with the abundance of relict sedimentary textures, I noted several localities (for example, at A reef near Squaw Saddle) where there are silicified breccia fragments that appear to have relict porphyritic texture. The section on the Wenatchee Pinnacles describes siliceous veins in altered igneous rocks, and Patton and Cheney (1971) described an occurrence of veins of clear coxcomb quartz cutting andesitic intrusions. Clearly, solid igneous rock was involved in shearing, brecciation, and silicification. Coombs (1950) described stages of alteration of sedimentary rocks near the L-D gold mine in which clear albite forms rims around plagioclase in association with the silicification process.

South of Squaw Saddle, near the center of SW 1/4 sec. 16, T. 22 N., R. 20 E., sheared and argillically altered Swauk Formation is exposed in a prospect cut. Crystals of selenite (gypsum) several cm long are scattered in a clay matrix; a photograph of these is given in Chappell (1936, p. 135). They are probably not of hydrothermal origin, but are more likely to be formed by reaction of weathering solutions from pyritic ore zones (which would carry sulfuric acid) with connate or meteoric water in the Swauk Formation (which would be saturated with calcium carbonate).

The reader is referred to publications by Lovitt and McDowall (1954), Lovitt and Skerl (1958), and Patton and Cheney (1971) for details of the mineralogy of the mine area and relationships between episodes of mineralization and faulting.

SILICIFIED ZONE OF NUMBER TWO CANYON

The second major belt of silcified rocks crosses Number Two Canyon and is apparently a branch of the thrust fault that offsets the Wenatchee Formation in upper Dry Gulch. The extensive silicification here is attributed to proximity to the thick stocklike portion of the Canyon Number One composite sill and stock. Relict textures suggest that most of the altered rock was originally sedimentary. However, excellent examples of relict porphyritic texture indicate that some altered rocks were hornblende andesites; some of these occur at roadcuts on the north side of Number Two Canyon. The thrust fault is along the former Chumstick-Swauk(?) unconformity where the silicified zone crosses Number Two Canyon, but farther north silicification continues along a portion of the fault that cuts entirely into the Chumstick Formation. Silicified sedimentary rocks within the zone probably include both formations.

Whereas the silicified rocks of the L-D mine area are typically lightly coated with yellowish limonitic alteration, the silicified zone of Number Two Canyon is heavily impregnated with iron oxides, typically of dark-brown to reddish hues. Chappell (1936, p. 134) used the term "cindery" for the iron oxide crusts, and this is a good descriptive term. As noted by Chappell, the crusts are sometimes interconnecting fracture fillings but also occur as botryoidal masses in open cavities.

Where the silicified zone crosses the divide between Number One and Number Two Canyons, near Hill 2508, cross-cutting relationships between the fault zone and the Canyon Number One stock are ambiguous. On the one hand, a tongue of the intrusion seems to cut across the fault zone. On the other hand, fragments of the andesite, which here are heavily coated with reddish-brown iron oxide, locally have small cavities lined with quartz crystals.

An interesting outcrop of the silicified zone is exposed on the ridge downhill to the west and northwest of Hill 2508 in sec. 12, T. 22 N., R. 19 E. There are good examples of silicified gabbro (described in the section on Eocene gabbro), as well as silicified sedimentary rocks. In one specimen of silicified breccia, an angular fragment of silicified sediment is enclosed in white cherty silica, but both are part of a larger angular fragment in a light-brown siliceous cement. This outcrop also provides examples of botryoidal coatings of brown iron oxide as thick as 2 cm, having a layered internal structure.

Rocks of the silicified zone of Number Two Canyon evidently were subjected to repeated brecciation and silicification, and the ambiguous cross-cutting relationships between hornblende andesite and the silicified fault zone may be evidence of contemporaneous thrust faulting and igneous intrusion.

The deposition of iron oxide crusts appears to postdate silicification but does not postdate all faulting. Chappell (1936, p. 134-137) pointed out that iron oxide occurs as outer layers in sharp contact with cores, but outcrops commonly have a blocky structure with abundant slickensided surfaces of iron oxide. The heavily iron-oxide-stained rocks are near the Canyon Number One stock. To the east, the stock is against the Chopper Hill reference section of the Wenatchee Formation. Although concretionary iron oxide material occurs locally at other localities, the amount of concretionary iron oxide in the Wenatchee Formation is more pronounced at Chopper Hill than anywhere else. This suggests that thermal convection of ground water in the vicinity of the stock may have played a role in iron transport and deposition. By this interpretation, silica replacement and deposition within the thrust fault is an early consequence of emplacement of the Canyon Number One stock, and iron-oxide deposition, although a later phenomenon, is still the result of igneous activity. The alternate possibility is that iron oxide crusts of the silicified zone are gossanlike features caused by late supergene alteration of the hydrothermally altered rocks. However, they are coatings rather than remnants of former sulfide masses, and there is no evidence that extensive sulfide deposition was part of the hydrothermal alteration of these rocks.

HYDROTHERMALLY ALTERED ROCKS NEAR HORSE LAKE MOUNTAIN

Specimens of relatively fresh rock from mine tailings at the hydrothermally altered area near Horse Lake Mountain are white to light gray on fresh surfaces with yellow to brown limonitic staining on fracture surfaces. The rock is so highly altered that relict textures and breccia structure are apparent only in a few specimens. Occasional clastic quartz grains that survived the alteration process suggest that most of the rock is silicified Chumstick Formation, which is the major host rock. Pyrite is abundant in the rock. It occurs pervasively in the matrix as individual crystals ranging to a few mm in diameter and in irregular masses ranging to nearly a cm in diameter. Numerous small cavities, typically less than a cm across, are lined with quartz crystals overgrown by pyrite crystals having dodecahedral habit.

Altered hornblende andesite also occurs at this locality. The porphyritic texture is well preserved. These rocks do not appear to be pervasively silicified, but the color of the rock is somewhat lighter than typical nearby intrusive rocks. Sulfide mineralization occurs as disseminated pyrite; it is not as extensively developed as pyrite in the lighter-colored rocks.

Although the rocks from the abandoned mine exhibit obvious hydrothermal alteration, rocks from scattered nearby localities have less clearly defined characteristics. There are examples of unusually well-cemented, brittle Chumstick sandstones having a white color and rusty weathering stains. Unlike the mine rocks, the sedimentary texture is well preserved and there are no quartz-lined cavities or obvious sulfide mineralization. Thus, it is difficult to decide whether these represent silicified rocks or simply the effect of baking by the numerous nearby intrusions. Slightly altered andesitic rocks with minor sulfide content sometimes occur near the indurated sediments. Rocks with these characteristics are found along a ridge extending downhill southeast of the mine in sec. 11 T. 22 N., R. 19 E., and as float rock at Hill 4474 less than a quarter mile northwest of the mine. Altered andesite with minor sulfide mineralization was noted a short distance down the ridge east of Hill 4474.

The abandoned mine is located only one quarter of a mile from the Twin Peaks intrusive breccia. Hydrothermal mineralization is thus assumed to be associated with this major center of intrusive activity. According to a local resident (Mr. Earl Burts, Monitor, Washington, personal communication, 1979) the abandoned mine was once worked for gold.

AGE OF HYDROTHERMAL ACTIVITY

The obvious association of hydrothermal activity with intrusive igneous activity was noted by all previous investigators. Moreover, there is at least an implied association between rhyodacite intrusions and the occurrence of gold in silicified rocks of the L-D mine area. Prior to radiometric dating of igneous rocks, this impression was strengthened by the fact that the silicified zone in Number Two Canyon is adjacent to andesitic rocks (the Canyon Number One stock) and appears to be barren of gold mineralization. A reasonable petrogenetic interpretation was that rhyodacite is a more highly differentiated phase of the andesitic intrusions in which trace metals had become more highly concentrated. The Wenatchee Pinnacles could be viewed as a suite of genetically related rocks that become progressively more felsic to the south.

Before radiometric dates were obtained for the rocks of the Wenatchee Pinnacles, ages of post-34 m.y.b.p. were expected. This is because the age of the Wenatchee Formation was known, and thrust faults (presumed to be responsible for brecciation that preceded or coincided with silicification) cut the Wenatchee. The roughly 40 to 50 m.y.b.p. dates for rhyodacite thus pose a fundamental problem.

Clearly some silicification is associated with emplacement of the Horse Lake Mountain complex. This must be the case for the silicified thrust fault cutting Number Two Canyon and for the mineralized area near the Twin Peaks intrusive breccia. There are two possibilities for the silicified rocks of the L-D mine area. The first possibility is that all silicification is post-Wenatchee age, about 30 m.y.b.p., and none of the mineralization is related to rhyodacite. The older rhyodacites simply occur fortuitously near the mineralized area. The second possibility is that there are two periods of brecciation and hydrothermal alteration. The first period related to intrusion of the rhyodacite of the Wenatchee Pinnacles, produced silicified rocks with gold mineralization. The second period, related to the Horse Lake Mountain complex, produced mainly barren silicified rocks, except for the Twin Peaks area.

The mafic rocks of the Wenatchee Pinnacles are not dated. They could be either part of the Horse Lake Mountain complex or they could be a more mafic phase of older intrusive activity. Because they lie within a belt of Swauk(?) rocks, the only restriction based on the age of intruded rocks is that their age must be post 51 m.y.b.p. If they are found to be of the same age as the Horse Lake Mountain complex, this would support a single period of hydrothermal activity. If they are found to be of the same age as rhyodacite, this would support two episodes of hydrothermal activity.

Lacking radiometric dates for the mafic rocks of the Wenatchee Pinnacles, I favor a single post-Wenatchee period of hydrothermal activity for the following reasons: (1) Other gold mineralization of this age occurs at the Twin Peaks area. Two periods of gold mineralization are possible, but the simplest explanation is that there is only one (Ockham's razor).* (2) Mafic rocks of the Wenatchee Pinnacles are themselves affected by silicification, whereas rhyodacite is not, even though silicified rocks occur near rhyodacite. Thus the mafic rocks, which are compositionally similar to rocks of the Horse Lake Mountain complex, may have been the agent of silicification, rather than rhyodacite.

DEPOSITS OF QUATERNARY AGE

A detailed study of the Quaternary history of the Wenatchee area was not a purpose of this investigation, and a report of a comprehensive investigation of the Quaternary geology by the U.S. Geological Survey is in preparation (R. D. Waitt, personal communication, 1980). This section will not attempt to duplicate the Survey report, nor is it intended to present a comprehensive description of all Quaternary deposits of the Wenatchee and Monitor quadrangles. Rather, it presents observations of surficial deposits noted during mapping of bedrock units. Some data were gathered in remote areas, and documentation of these will be of use to those investigating the Quaternary history of the region.

MASS WASTING AND FLUVIAL DEPOSITS COMPOSED PRIMARILY OF BASALTIC MATERIAL

As discussed under the section on the Columbia River Basalt Group, previous investigators mapped basaltic material west of the Columbia River in the Wenatchee and Monitor 7 1/2-minute quadrangles as undisturbed lava flows. It is now believed that the material represents mass wasting deposits, largely debris flows (R. W. Tabor and R. D. Waitt, personal communication). This section presents evidence in support of Tabor and Waitt's views, as well as evidence for stream-worked basaltic material and inverted topography.

Mesas and flat-topped divides in the southern part of the Wenatchee quadrangle and the northern part of the adjoining Wenatchee Heights quadrangle are clearly capped by basaltic material, and similar deposits often cap small hills in the area. Yet nowhere are, in place, upright columns of basalt observed, and typically the surfaces of such mesas are littered with rubbly basalt debris. Rare sandstone clasts occur locally, mixed with basaltic material. Where columnar structure is observed, it is in large blocks of basalt that clearly are rotated, to the extent that the columns are horizontal; such as on the ridge in the extreme NW cor. sec. 33, T. 22 N., R. 20 E. Blocky basalt rubble with a mud matrix is sometimes observed, as in NW 1/4 sec. 26, T. 22 N., R. 19 E., along the southwestern edge of a mesa. These features are consistent with a debris flow origin, but other exposures suggest other origins.

Locally the basaltic debris consists entirely of angular interlocking blocks of basalt with no matrix in the pore spaces. The individual clasts appear to be largely the debris expected from simple mechanical disintegration of highly jointed basalt. (In fact, similar looking material is found around blocks of columnar basalt currently exposed to weathering and erosion, as along Jumpoff Ridge in the Malaga quadrangle.) These deposits may be up to 40 ft thick. They are able to sustain steep, nearly vertical, cliff faces, despite the fact that there appears to be no cement. Apparently the interlocking angular clasts provide mechanical stability. Rather than of debris flow origin, these deposits resemble ancient talus piles. Good exposures are: (1) Below the drill hole (Norco No. 1 oil and gas test well, drilled in 1933, and shown on the Wenatchee Heights USGS 7 1/2-minute quadrangle map of 1966) at the west border of sec. 26, and in the SW 1/4 sec. 27, (T. 22 N., R. 20 E.), on the east side of Squilchuck Canyon; (2) at the edge of the mesa in sec. 28, T. 22 N., R. 20 E., on the west side of Squilchuck Canyon; and (3) above the east flank of the Pitcher syncline, overlying the upper member of the Wenatchee Formation at the eastern border of sec. 21, T. 22 N.,

*Ockham's razor - the philosophic rule that entities should not be multiplied unnecessarily.

R. 20 E. The latter locality was pictured by Chappell (1936, fig. 62, p. 166), who described it as basalt breccia.

Rare occurrences of stream-rounded basalt are known. The best example is at the common corner of secs. 23, 24, 25, and 26, T. 22 N., R. 20 E., just below Wenatchee Heights on the bluff overlooking the Columbia River. Outcrop in a ravine exposes a 20-foot-thick unit consisting entirely of rounded basalt cobbles. Exposures above the unit are poor, but it is clearly overlain by deposits containing the more typical angular basaltic rubble. Rounded basalt cobbles litter the ground along a ridge in a saddle that extends northeast from Hill 2647 in NE 1/4 sec. 32, T. 22 N., R. 20 E. Chappell (1936, p. 200) also noted the occurrence at Wenatchee Heights. He interpreted it as a deposit formed when basalt lava flowed into rapidly moving streams, and he considered it to be overlain by in-place lava flows. The interpretation presented here is that these are fluvial deposits formed during normal erosion of the lava flows, and they subsequently have been covered by debris flows derived from the eroding mass.

The features preserved in the Wenatchee quadrangle suggest that disintegration of the basalt flows and movement of basaltic debris over an unstable surface underlain by sandstone and shale began after the lavas were breached by erosion. Spreading of basaltic debris by various mass wasting and fluvial processes had the effect of armoring the surface so as to protect the less durable sedimentary rocks from mechanical erosion. The initial armored surface was developed nearly at the level of the original unconformity between the lava flows and underlying rocks. At many places where basalt debris caps small hills or mesas, it is possible to take a level sighting to the south; that is, parallel to the trend of the Cascade Range, toward cliffs of in-place basalt flows that rise gently from the Columbia River valley along Jumpoff Ridge into the Cascade Range. The level sighting invariably is at the base of, or slightly below, the cliffs of basalt. The remnants of the original basaltic armor now cap mesas and are classic examples of inverted topography whereby the areas of deposition are now preserved as topographic highs.

Other examples of inverted topography are linear ridges of basalt at elevations below the level of the original armored surface and commonly extending downward from a basalt-capped plateau. These are believed to be basaltic debris that accumulated in side drainages during a second stage of development when the armored surface was itself breached by erosion. Further degradation has caused them to invert to erosion-resistant ridges. The best example is in southern sec. 23 and northern sec. 26, T. 22 N., R. 19 E. On the map this occurrence has the form of a hand with three fingers pointed north. The "palm" of the hand is a relatively flat area that is interpreted as a remnant of the original armored surface, here consisting of a debris flow deposit. The "fingers" are ridges that extend downslope from the general plateau level. The westernmost "finger" is a narrow ridge covered with basalt rubble. At Hill 3705, the tip of the finger, there are large disoriented blocks with intact columnar structure. A huge block, measuring about 25 ft high and 30 ft in diameter, is found 75 ft southwest of the crest of Hill 3705. Along the ridge that forms the central "finger," basalt blocks 5 to 6 ft in diameter are common. At one point on the ridge a pile contains blocks to 20 ft in diameter with intact columnar structure. The easternmost "finger" is a ridge extending from the plateau to Hill 3457, along which blocks 2 to 2 1/2 ft in diameter are common and a maximum of 4 ft in diameter was noted. Below Hill 3457, where the finger bends to the northwest, there is a block the size of an automobile.

At the intersection of secs. 19, 20, 29, and 30, T. 22 N., R. 20 E., a sinuous low ridge of basalt rubble has blocks up to 2 ft in diameter in a terrain otherwise devoid of basalt float. It is another possible example of an inverted drainage.

Much of the terrain east of the Columbia River in the Wenatchee 7 1/2-minute quadrangle is underlain by landslide deposits. Most of the material is basaltic, derived from prominent cliffs of the Columbia River basalt to the east. The underlying rocks (Chumstick and Wenatchee Formations) are exposed locally in stream valleys that cut deeply through the landslide deposits. Although some of these are believed to be in-place outcrop, the incompetent sedimentary rocks and especially the landslide-prone Wenatchee Formation are often involved in, and probably facilitate, landsliding. A good example of a landslide deposit of Wenatchee Formation is at the NW 1/4 sec. 13, T. 23 N., R. 20 E., west of Rainey Spring. Bedding is disrupted, and shales locally are weathered or altered to greenish hues not typical of the Wenatchee Formation. Similar material was observed in back-hoe prospect pits (now filled) at NE 1/4 sec. 23, T. 23 N., R. 20 E. In one pit a landslide deposit of Wenatchee Formation was positioned above a landslide deposit composed of Columbia River basalt. Landsliding is also promoted by poorly consolidated interflow sediments; chaotic mixing of interflow sediment with basaltic debris is well exposed along drainages near the border between secs. 25 and 26, T. 23 N., R. 20 E.

Most of the minor drainages between wheat fields in the terrain east of the Columbia River have grassy sides that only occasionally expose the landslide deposits. Typically the material consists of angular basalt fragments with size controlled by the original jointing. Occasional larger disoriented blocks with intact columns form bolder outcrops. Some blocks are the size of automobiles or small houses, and they are more common closer to the basalt cliffs to the east. Good examples are in the extreme northeast corner of the Wenatchee quadrangle at sec. 7, T. 23 N., R. 21 E.

Internal shearing within basalt blocks and small faults, both believed to be related to landsliding, are obvious where outcrop is sufficiently good. A good example of internal shearing is at the hill that forms the backstop to a shooting range at NE 1/4 SW 1/4 sec. 25, T. 23 N., R. 20 E., where a cut exposes basalt that is severely fractured and cut by several wide shear zones. An example of small vertical faults is at SE 1/4 sec. 36, T. 23 N., R. 20 E. East of the bend in the Badger Mountain Road, at stream level in the canyon, a fault between basalt and interflow sediment is exposed. A fault of basalt against Chumstick Formation is more poorly exposed in a roadcut across the canyon north of the last locality and farther upstream.

As suggested in the section that describes interflow sediments, there is evidence that segments of relatively flat-lying massive basalt having upright intact columnar structure overlain by interflow sediment are more-or-less cohesive. Where this relationship is observed, Chumstick or Wenatchee Formations are typically found in the nearest exposures downstream. This suggests that a basal flow has moved only slightly over the unconformity with older sedimentary rocks and that much of the landsliding was initiated on and above the interflow sediment. Evidence that the slab has moved to some degree is clear from an exposure where a side drainage joins the main canyon from the north to the southwest of the bend of the Badger Mountain Road in SE 1/4 sec. 36, T. 23 N., R. 20 E. Massive basalt with intact columnar structure forms the upper part of a large basalt exposure, and farther upstream it is overlain by interflow sediment. The lower part of the exposure consists of irregular basalt rubble. At the contact, the columns of the upper mass are tectonically truncated. It appears that the massive basalt, carrying interflow sediment upon it, slid over rubbly basalt that may have been its own erosional debris.

Extensive mass wasting of mechanically disintegrated basalt must have begun when erosion breached the flows and exposed the underlying unstable sedimentary rocks. R. D. Waitt (personal communication) believes the process may have begun in Pliocene time. It is clearly a continuing process. For example, the landslide deposits were mantled with sands and gravels of Pleistocene age during the time of glacial flooding. This is clearly seen in the gravel pit in northern sec. 26, T. 23 N., R. 20 E. On the eastern side of the pit, Quaternary sands overlie basaltic landslide debris. Yet basaltic landslide debris can also be seen overlying Quaternary sands in a small drainage near the border between SE 1/4 sec. 14 and SW 1/4 sec. 13, T. 23 N., R. 20 E. Fresh landslide scars, cut in older landslide deposits, can be observed frequently in the Wenatchee quadrangle.

DEPOSITS RELATED TO GLACIATION

The Wenatchee area apparently was not directly covered by ice during Pleistocene glaciation. Nevertheless, the area has an abundance of deposits and landforms formed during glaciation that are critical to an understanding of the geologic history during Pleistocene time.

FLOOD DEPOSITS

The best overall summary of catastrophic flooding of the Columbia Plateau is by Baker (1981); an older, but very lucid, summary is by Bretz (1959). An ancient lake (glacial Lake Missoula) was formed as a Pleistocene continental glacier dammed an area of western Montana. The volume of water impounded was comparable to some of the present Great Lakes. The dam was periodically breached, sending catastrophic floods across the Columbia Plateau and forming the coulees of the channeled scablands. Some floods came down the Columbia River through the Wenatchee area.

Although once controversial, the hypothesis of catastrophic flooding is now well documented by factual data and has gained general acceptance. Current debate centers on the number of floods and the interpretation of deposits similar to the Touchet Beds. The Touchet Beds (Bretz, 1929; Allison, 1933) have characteristics that suggest deposition of a relatively large influx of sediment into quiet water. They are interpreted as due to ponding of flood water (slackwater deposits). Where repeated alternations of such beds occur, a major question is whether they represent surges of the same flood (Baker, 1973) or whether each bed represents a discrete flood event (Waitt, 1980).

Terrace deposits of flood origin are present in a canyon that trends approximately east-west across northern sec. 29, T. 23 N., R. 20 E., and in a side ravine that extends south from the main canyon into the southeast quarter of the section. The deposit apparently once completely filled these canyons to an elevation of 940 to 990 ft. Stream action subsequently has removed the central portions of the valley fill. Flat-topped remnants of the terrace remain along the sides of the canyons.

The best exposures are on the south side of the road 1,000 feet west of the mouth of the canyon. From this point, a new jeep trail (summer, 1981) trends southwest and provides a nearly complete roadcut to the top of the terrace. Because the unconsolidated terrace deposit deteriorates rapidly in outcrop, a measured section was made along the new jeep trail several months after it was completed.*

Between the jeep trail and the mouth of the canyon, the terrace deposits are in depositional contact with underlying material that consists of weakly stratified and poorly sorted unconsolidated sediments that contain angular blocks a foot or more in length. The larger blocks are Chumstick sandstone. This material could be a basal surge deposit of a flood event (R. D. Waitt, personal communication, 1977) or normal bottom debris in the pre-flood valley.

The terrace deposit may be divided into two parts having distinctive depositional characteristics. The lower part, which is just over two-thirds of the measured section, is predominantly evenly bedded and thinly laminated fine sand, silt, and clay of lacustrine origin. The upper part consists of a sequence of graded beds similar to Touchet Beds, and they probably are slackwater deposits.

Individual beds in the lower lacustrine part are typically 1/2 to 2 inches thick. Fine cross-bedding is present within some thin laminae, but in much of the section the laminations are smooth and flat, with mica flakes in the bedding planes. Such beds typically consist of silty clay or silt. Ripple laminations occur at several places throughout the lower part. Calcite concretions are common in silty clay layers; in some of the older roadcuts in the canyon they weather out in disclike shapes. At meter 33.8 of the measured section, there are trails of organisms preserved on bedding planes. Just above them at meter 34.0-34.5, there are varves. All of these characteristics are consistent with deposition in a lake environment.

There are local indications of fluvial deposition within the lower part of the terrace deposit. Above meter 10 of the measured section, there is a transition from evenly laminated beds to overlying ripple-laminated beds. Grain size increases as rippling increases, and above meter 11 there is cross-bedding and occurrences of pea-sized gravel. Between meters 12.0 and 13.5 there is abundant current cross-bedding, cut-and-fill structure, and occurrences of rip-up clasts. From meter 13.5 to 14.5 there is a transition through ripple-laminated beds back to evenly laminated beds of silty clay. Because the measured section is located where the terrace deposit is near the valley wall, the fluvial beds are interpreted as encroachment of deposits of side streams onto the lake deposit. A similar encroachment may be represented by the occurrence of a sand stringer in laminated beds at meter 34.8.

The first appearance of a graded bed is at meter 35.7 of the measured section, where a single bed about 0.3 m thick occurs. This is followed upward by 2.0 m of evenly laminated silty clay and about 0.5 m of thinly bedded silt to fine sand with undulatory bedding planes. The top of these beds is

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*Editor's note: The author prepared or intended to prepare a figure illustrating this measured section, but we have been unable to locate it among his papers.

considered the upper limit of the lower lacustrine facies. The remaining (upper) part of the section consists essentially of graded beds. Typically a graded bed is 0.5 to 1.0 m thick and has a thin layer of coarse sand or sand/gravel at the base with either a faint bedding or current cross-bedding. Often these coarser layers are heavily stained with iron-oxide coatings, probably because subsequent ground-water flow followed coarser beds that overlie impermeable clay. The graded bed that begins at meter 41.5 has a much thicker basal sand/gravel, whereas some graded beds (at meters 46.4, 46.9, and 47.4) begin with massive medium-grained sand. Most graded beds have a thick central portion of massive to weakly and irregularly bedded fine sand to silt. This material is highly unconsolidated, powdery, and tends to disintegrate readily in outcrop. Most graded beds have a thin clay layer at the top. The only atypical parts of the upper terrace deposits are at meter 39.2-39.8, where some evenly bedded silts and clays occur, and at meters 40.4-41.5, where there is abundant current cross-bedding and cut-and-fill structure.

Within the upper part of the terrace deposit there are 12 clearly defined graded beds. Two others are probable. There is loss of good exposure at the top of the terrace, but an estimate of five to seven additional graded beds is based on the average graded bed thickness in the measured section. Thus as many as 19 to 21 discrete graded beds may constitute the upper portion of the terrace deposit.

Occasional exposures of the uppermost terrace deposits occur in the canyon. An example is in an erosional gully on the south side of the largest flat terrace remnant at NW 1/4 sec. 29, T. 23 N., R. 20 E. Pebbles composed of plutonic and metamorphic rocks that are not known in the area and that are not typical of Chumstick clasts are common in the unstratified top of the terrace deposit, particularly along the edges of the terrace. Good examples are below Hill 1049 at NE 1/4 sec. 29 and in the upper reaches of the tributary ravine at the southeast quarter of the section. At the latter locality, the pebbly material is almost till-like. Erratics also occur along the edges of the terrace. Basalt blocks to 5 ft in diameter occur about 50 ft southeast of Hill 1049, and a granitic boulder is near the fork of the main canyon near the far western border of the section.

At the mouth of the canyon, there is an elongate hill bordered by the road on the north and by a drainage on the south. The far eastern end of the hill, at the canyon entrance, is composed of unconsolidated well-rounded pebbles and cobbles of crystalline rocks. The top of the hill is composed of the same material. Similar material also forms the small flat promontory to the main spur on the northern side of the canyon entrance. The top of the hill and the top of the promontory are at the same elevation as a terrace across the Wenatchee River to the north and east, which is composed of similar gravel. Thus it appears that the rounded gravels at the mouth of the canyon are a remnant of an older and depositionally different terrace. The lacustrine deposits of the terrace within the valley appear to have been deposited against a remnant of the older terrace. For example, on the southwest end of the hill, the gravels occur at the base of the hill as well as on the upper slopes, but a patch of laminated beds is perched on the hill slope at an intermediate elevation.

The lower lacustrine beds of the terrace deposit suggest that an arm of a lake may have been present in the canyon for as long as 1,000 to 2,000 years. Erratics and pebbly material that occur around the edges of the terrace are considered to be ice-rafted debris deposited by melting of ice grounded against the shoreline. The presence of a lake in the Columbia River valley in the Wenatchee area may be explained by either of two hypotheses for damming of the Columbia River: (1) The wedge of basaltic gravel shed from Moses Coulee during a catastrophic flood effectively dammed the river (Waitt, 1977); (2) a large landslide that is visible below Jumpoff Ridge near the hamlet of Malaga occurred during Pleistocene time and had sufficient mass to dam the river (Larry Hanson, personal communication, 1978).

Whatever the cause, the dam blocking the Columbia River below Wenatchee eventually was breached by subsequent floods down the Columbia Valley (Waitt, 1977). The relationships shown in the measured section of terrace deposits suggest that the lake first acted as a buffer that prevented breaching of the dam. This is indicated by the appearance of a first graded bed (representing a flood that caused a surge of sediment into the arm of the lake) that is covered by two additional meters of lacustrine beds. Thus the lake survived at least one flood event.

A terrace remnant at the mouth of Squilchuck Creek at NW 1/4 sec. 23, T. 22 N., R. 20 E., possibly formed while the lake existed. It is at nearly the same elevation (900 ft) as the previously described terrace deposit. At the mouth of Number One Canyon in NW 1/4 sec. 5, T. 23 N., R. 20 E., unconsolidated bedded deposits were noted in a very poor roadcut exposure in a residential subdivision, at an elevation of just under 1,000 ft.

A prominent topographic effect of flooding was the formation of terraces on the east side of the Columbia River. In contrast to the terrace described above, these terraces were formed by flowing water. Floodwaters swept around the bend in the valley in northern sec. 23, T. 23 N., R. 20 E., causing erosion of the outcrops of Wenatchee Formation. To the southeast, in the lee of the bend, deposition of suspended material formed streamlined terrace deposits. This includes the terrace that underlies Fancher Field at about 1,400 ft elevation in secs. 25, 26, 35, and 36, T. 23 N., R. 20 E., and the terrace farther southeast in sec. 1, T. 22 N., R. 20 E.

Most of the terrace material was deposited on preexisting basaltic mass wasting deposits, and the thickness varies from a thin veneer to deposits more than 100 ft thick, depending on the underlying topography. For example, deposits of sand and gravel at the southern end of the Fancher Field bar, near the Badger Mountain Road, are quite thick, presumably because a preexisting drainage was filled. In contrast, the southern terrace in sec. 1, T. 22 N., R. 20 E., has a thin veneer of sand and gravel over mass wasting debris in its central portion (exposed in small ravines along its western edge), but has no flood deposits at its southern end. Apparently the geomorphic form is in part depositional but includes erosional streamlining of mass wasting deposits at the southern extremity.

The unconsolidated terrace deposits generally do not form good outcrops. Specific localities for viewing them are here documented. The finest exposures are in the gravel pit in SW 1/4 sec. 36, T. 23 N., R. 20 E., where the Fancher Field bar is being actively mined. At this exposure a thick caliche horizon is developed near the top of the bar.

A good exposure occurs at the top of a new prospect cut on the southwest side of a ravine, south of the center of sec. 23, T. 23 N., R. 20 E. Wenatchee Formation is overlain by colluvium of basaltic mass wasting debris. Adjacent to these along an irregular near-vertical contact are bedded sands and gravels of flood origin. The colluvium includes angular clasts of basalt up to 1 foot in length, and one clast projects across the contact from colluvium into sand and gravel. The steep face of Wenatchee Formation and colluvium was apparently produced by the initial erosive action of the flood, and this was followed shortly by deposition of suspended material against the face.

Exposure is deteriorating in an old gravel pit in northern sec. 26, T. 23 N., R. 20 E., but about 40 feet of flood deposits are present, overlying Wenatchee Formation and mass wasting debris. A better exposure is a short distance down the road from the gravel pit at a water tank in the northwest quarter of the same section. The lower contact of the terrace deposits is not exposed. There are two depositional units within the terrace deposits--a finer-grained unit at the base and a coarser-grained unit above. Both units are poorly sorted sand and gravel. Both are bedded, but bedding is better developed in the lower unit. The base of the upper unit truncates bedding in the lower unit. The lower 20 ft of the outcrop is made of the finer-grained unit, in which the maximum clast size is generally about 1 inch in diameter, although a few scattered larger clasts are present. The general maximum clast size in the upper unit is about 1 foot in diameter, but some large boulders (up to 3 ft in diameter) were noted. Clast lithology is the same in both units; most are gneissic and well rounded. Clasts of basalt and Wenatchee sandstone are more likely to be angular to subangular. A 3-foot block of

Wenatchee sandstone is embedded in the upper unit. Apparently the gneissic material was transported a long distance by floodwaters, but some basalt and probably most Wenatchee sandstone has been transported only a short distance. It is not possible to ascertain whether the two depositional units represent two separate floods or two surges of a single flood.

A natural exposure of a thick section of flood deposits is on the sides of a deep northwest-trending ravine that enters a larger southwest-trending drainage at SE 1/4 sec. 14, T. 23 N., R. 20 E. Flood deposits overlie Wenatchee Formation at the mouth of the ravine but overlie basaltic mass wasting debris upstream to the southeast. The clasts in these deposits are almost entirely composed of gneiss and schist. No basalt clasts and only a few chips of Wenatchee sandstone were noted. There is a crude graded bedding here with coarser clasts near the bottom of the deposit. There is also a grading of the deposit from the mouth of the ravine to its upstream extent. Maximum clast size at the base of the deposit, as represented by flattened clasts of schist, is about 6 inches in diameter near the mouth, but decreases to 2 to 3 inches a short distance up the ravine. The finest material, consisting of interbedded pea-sized gravel, sand, silt, and clay, is in exposures farthest upstream.

Glacial erratics deposited by catastrophic floods are well known in parts of the Wenatchee area and have been discussed and illustrated by Chappell (1936, figs. 76, 77, and 80). These include the spectacular boulder field of gneissic rocks near the bridge over the Columbia River in sec. 11, T. 22 N., R. 20 E. A number of isolated erratics were noted during this investigation, often along the upper margin of terrace deposits or associated with isolated sand deposits.

UNCONSOLIDATED SAND OF FLOOD OR EOLIAN ORIGIN

Poorly exposed small patches of sands that resemble sands of the terraces on the east side of the Columbia River are found in the terrain farther east, but at elevations to 1,800 feet, well above the elevation of the flat-topped Fancher Field bar. Locations of isolated sand patches are shown as Qgs on the Wenatchee quadrangle. As suggested by Waitt (R. D. Waitt, personal communication, 1979), these may be sand of eolian origin, a feature common along the Columbia Valley. Although this may be the case for some, particularly those of highest elevation, others appear to be of flood origin.

A prominent drainage trends roughly east-west across the southern part of sec. 24, T. 23 N., R. 20 E. On the upper south side, at an elevation of about 1,600 ft, a belt of unconsolidated sand is present. In a small exposure at the western end, it can be seen to rest on caliche-cemented soil and mass wasting debris. The sand is carbonate-cemented, presumably from calcite derived from underlying caliche. Across the drainage to the north, but toward the east where the drainage bends to the north in the southeast quarter of the section, there are exposures of sand that are presumably part of the same sand unit. These sands also are carbonate-cemented and sometimes occur as 3- to 4-foot-thick, crudely bedded blocks that superficially resemble Chumstick sandstone. True Chumstick sandstone does crop out at stream bottom at the bend in the drainage, but the calcite-cemented sands have a more open porosity. At one locality the sand rests on a 5-foot-thick unit of blocky basalt clasts up to 6 inches in length that are cemented in a sand matrix. Minor gneissic clasts occur locally. This unit overlies basaltic mass wasting deposits that are cemented by caliche. Because there is no source for gneissic clasts through the local drainage pattern, the sand is interpreted as flood sediment deposited by currents capable of moving 6-inch-diameter basalt boulders in the bed load.

Unconsolidated sand occurs at an elevation of 1,500 ft in the vicinity of the intersection of the boundaries between Tps. 22 and 23 N. and Rs. 20 and 21 E. Just northwest of Hill 1551 in NE 1/4 sec. 1, T. 22 N., R. 20 E., 1- to 2-foot erratics of quartzite and argillite occur. A short distance to the west, on the northeast side of a gully just below 1,500 ft elevation, a patch of sand occurs with a 3-foot granitic erratic. These sands also are interpreted as flood deposits.

LOESS DEPOSITS

The terrain east of the Columbia River is extensively mantled with loess, which typically is not well exposed. Deposits up to 6 ft thick have been noted. Almost all of the numerous wheat fields of this region are underlain by loess that has been disturbed by plowing. Typical undisturbed loess is powdery light-brown material having variable degrees of intermixing with underlying material. For example, at the excavation by the water tank at NW 1/4 sec. 26, T. 23 N., R. 20 E., there is a transition upward from Quaternary flood gravel into loess. At the transition zone there are abundant weathered gneissic clasts. The overlying loess is dotted with small pebbles of more resistant rocks. In contrast, loess rests with sharp contact on unweathered basalt in a roadcut where a ranch road dips into a ravine south of Hill 1615 at NW 1/4 sec. 25, T. 23 N., R. 20 E. Near the northern border of the same section, a ranch road at the edge of a field exposes loess that overlies a patch of unconsolidated sand. Caliche is well developed in the loess in layers up to 3 feet thick. There are several generations of caliche development, including some near the present surface. Broken caliche fragments within loess suggest that some near-surface caliche layers were fragmented, transported, and mixed with loess at some stage in its history.

CONGLOMERATE OF UNKNOWN ORIGIN

An unconsolidated conglomerate of unknown origin occurs in the Mission Creek drainage in the Monitor quadrangle. A southwest-trending ridge that includes Hill 2530 is at SW 1/4 sec. 20, T. 22 N., R. 19 E. The conglomerate occurs just above the sandstone bluff where this ridge meets the road in the East Fork of Mission Creek. Exposure is poor, but abundant clasts litter the area. Clasts are rounded to subrounded, poorly sorted, and range up to 2 feet in diameter. Lithologies include pyroxene-bearing granitic clasts and ultramafic rocks bearing sulfide minerals. Bedrock of this type is not known in the area, and these lithologies are not known from Chumstick conglomerates. The conglomerate is not shown on the geologic map of the Monitor quadrangle.

VOLCANIC ASH

Powdery white volcanic ash, presumably the Mazama Ash, is present in the area. The best exposure is along a new (1979) logging road in secs. 3 and 4, T. 22 N., R. 19 E. A 3-foot-thick accumulation is exposed where the road crosses a north-trending ravine at SE 1/4 sec. 4. Ash mixed with alluvium is exposed in a roadcut on the south side of the mouth of Tripp Canyon near center of sec. 17, T. 23 N., R. 19 E. Ash encountered during excavation near valley floor on the west side of Yaxon Canyon near center of SW 1/4 sec. 16, T. 23 N., R. 19 E., was reported by a local resident.

STRUCTURAL GEOLOGY

The major structural feature that dominates the region is the Chiwaukum graben, bounded by the Leavenworth and Entiat faults (fig. 1). The Entiat fault, although largely hidden, must project beneath the city of Wenatchee, and the Leavenworth fault zone passes within a few hundred feet of the southwest corner of the Monitor quadrangle. Thus a nearly complete transect across the southern part of the graben is represented by these quadrangles. In general, the northwest-trending structural grain of the graben tends to control the orientation of post-graben structural features. A major exception is the north-south axis of the modern Cascade Range that tilts the area gently upward to the west.

The Chiwaukum graben came into existence about 45 to 46 million years ago, and by about 40 million years ago it was an inactive structure, at least in its original sense (Gresens, 1982b). I have suggested (Gresens, 1982b) two possibilities for origin of the Chiwaukum graben that involve major strike-slip movement on the Entiat fault. The first possibility is that the graben is the result of wedgelike opening as the terrane west of the Leavenworth fault simultaneously translated northward and rotated clockwise (fig. 7). This is compatible with clockwise rotation of units of equivalent age farther west (Globerman, 1979; Beck and Burr, 1979) and is a variation of the "ball-bearing" model proposed by Beck (1976). A second possibility is that a rhombochasm (Carey, 1958), also referred to as a "pull-apart structure" (Crowell, 1974), formed by strike-slip motion on a fault that had an original offset (fig. 7). A similar origin has been proposed for Tertiary basins of California (Crowell, 1974). The present author is inclined to favor the second possibility, although proof of this hypothesis will require a more complete regional structural and stratigraphic study.

Given this regional structural framework, the remainder of this section will describe

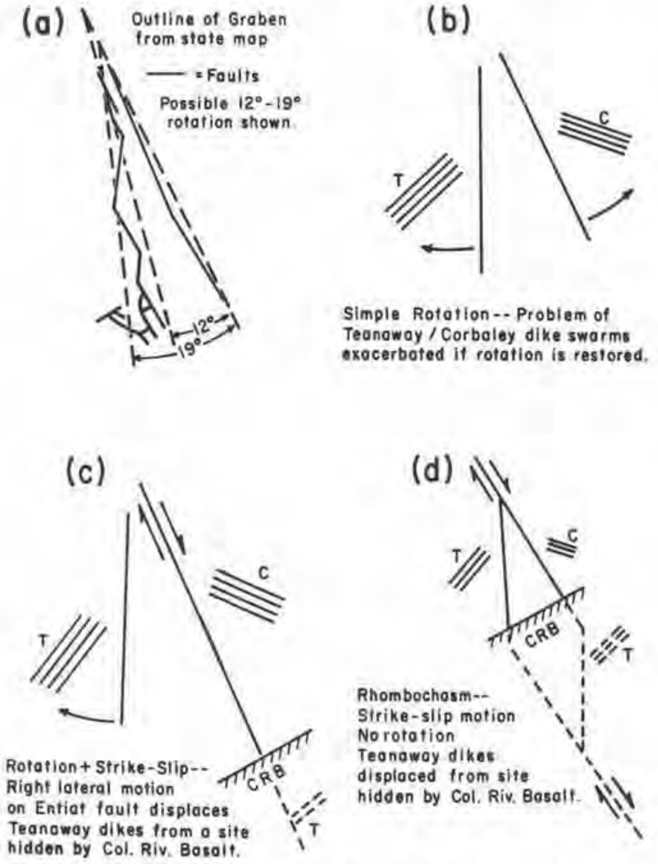

FIGURE 7. — Possible origins for the Chiwaukum graben. "T" and "C" on the diagrams indicate the dike swarms of Teanaway and Corbaley Canyon, respectively. "CRB" refers to the Columbia River Basalt Group, which covers the southern projection of the Chiwaukum graben. See text for additional explanation. Reprinted from Gresens, R. L., 1982b, Early Cenozoic geology of central Washington State; II, Implications for plate tectonics and alternatives for the origin of the Chiwaukum graben: Northwest Science, v. 56, no. 4, fig. 1, p. 262.

details of the structural geology within the Wenatchee and Monitor quadrangles. The structural geology of the Swakane Biotite Gneiss, which was reported by Waters (1932) and Chappell (1936) and reviewed in the section on pre-Late Cretaceous rocks, will not be considered.

POST-SWAUK, PRE-CHUMSTICK DEFORMATION

At the type area south of Mount Stuart the Swauk was folded about east-west fold axes prior to deposition of Teanaway Basalt (Tabor and Frizzell, 1977). In contrast, presumed Swauk rocks of the elongate northwest-trending belt in the Wenatchee and Monitor quadrangles strike generally northwest with occasional more northerly attitudes. Dip is variable, but typically near-vertical, and there are overturned beds. Because of the poor exposure, it is not possible to work out structural details within this belt. However, some exposures show evidence for multiple deformation. At NE 1/4 sec. 17, T. 22 N., R. 20 E., Swauk bedding can be traced through a gentle fold from an attitude of N. 55° W., 70° NE. to N. 85° W., overturned 85° S. This broad folding is clearly superimposed on the predominant structural grain. Overturned bedding, deduced from inverted graded bedding, can be seen at the roadcut near Hill 1946 at NW 1/4 sec. 16, T. 22 N., R. 20 E.

An isoclinal fold in arkose is present immediately below bluffs of sandstone marking the base of the Wenatchee Formation northeast of the center of sec. 20, T. 22 N., R. 20 E. This is near where the edge of the belt of Swauk would project from the north, but outcrop is so weathered that distinction between Swauk and Chumstick is not clear. The folded layer is coarse arkose, 1 to 1 1/2 feet thick, surrounded by finer-grained beds. There is no break at the sharp fold hinge. The upper limb has an attitude of N. 30° W., 20° NE.; the lower an attitude of N. 10° W., 45° SE.

The Swauk rocks are presumed to have been folded about east-west axes prior to deposition of Chumstick Formation, in concert with those of the type locality. The present geometry and evidence for multiple deformation suggest that they were rotated to their present structural grain of rough alignment with the trend of the Entiat fault. This is compatible with the possibility of strike-slip movement on the Entiat fault during development of the Chiwaukum graben.

Sheared Swauk Formation is well exposed in a prospect cut on the east side of the mouth of Dry Gulch at northern sec. 21, T. 22 N., R. 20 E. Possibly the shearing is of pre-Chumstick age, but it is considered more probable that it is the result of post-Wenatchee thrust faulting.

EAGLE CREEK ANTICLINE AND ASSOCIATED FOLDS AND FAULTS

The Eagle Creek anticline was defined by relationships in the northern part of the Chiwaukum graben (Willis, 1953), and the geology of the Wenatchee and Monitor quadrangles documents its continuation into the southern part of the graben. It is thus the single largest structural feature within the graben, extending along the entire length parallel to the Entiat fault. The southernmost expression of the anticline is near the center of sec. 25, T. 22 N., R. 20 E., at the Stemilt Canyon reference section of the Wenatchee Formation. The axis of the anticline is obscured by a landslide, but Patton and Cheney (1971) noted that beds on opposite sides of the fold do not match. There is no core of older rocks here, but this appears to be the continuation of the Eagle Creek structure, with lower Chumstick faulted up to the west at the anticlinal axis.

The term anticline is retained because beds of Chumstick Formation dip opposite ways on each of its flanks over its entire length. But it is clear that it is faulted along nearly its entire length. Beds on the west flank are lower Chumstick Formation, whereas beds on the east flank are the Nahahum Canyon Member. Because the crystalline core of the anticline to the north was a subsidiary horst within the graben during deposition of the Chumstick (see section on the Nahahum Canyon Member of the Chumstick Formation) there is a strong possibility that it is not a compressional structure but rather a faulted drape fold over a bedrock high that was present during extension and filling of the graben.

A synclinal axis parallel to the Eagle Creek anticline extends through secs. 19, 29, 30, and 32, T. 23 N., R. 20 E., within the belt of Nahahum Canyon rocks between the Eagle Creek anticline and the Entiat fault. It also is faulted, as is clear from exposures along the road across northern sec. 30 at the boundary between the Wenatchee and Monitor quadrangles. Other minor synclinal and anticlinal axes in the belt of Nahahum rocks were mapped by Whetten and Laravie (1976) farther north. Although these minor folds could have formed contemporaneously with the major Eagle Creek anticline during graben subsidence, it also is possible that they are related to later compressional deformation that affected the Wenatchee Formation.

Over most of the Wenatchee and Monitor quadrangles, the Chumstick beds dip continuously to the west or southwest from the west flank of the Eagle Creek anticline to the Leavenworth fault zone. Chappell (1936, p. 91) noted that if this were a homoclinal sequence, it would require a stratigraphic thickness of more than 30,000 feet, which he considered to be incomprehensible. Therefore he concluded that it is a section of isoclinal folds, produced by thrusting from the southwest. However, there are no overturned beds in the section, and the tuff stratigraphy indicates a continuous section broken only by minor faults. The conclusion of this report is that it is indeed a thick homoclinal sequence of Chumstick Formation.

The Eagle Creek anticline and associated fault zone are the only structures that are demonstrably of post-Chumstick, pre-Wenatchee age. Other faults of this age almost certainly exist. A later section describes minor faults of uncertain age that involve the Chumstick Formation.

POST-WENATCHEE, PRE-COLUMBIA RIVER BASALT DEFORMATION

Deformation that involves the Wenatchee Formation but does not affect the Columbia River Basalt Group includes both thrust faulting (with associated folding) and high-angle faulting, as described by Gresens (1980). The account is repeated here with additional details.

PITCHER SYNCLINE AND STRUCTURE AT DRY GULCH

At its type section the Wenatchee Formation is folded to form the Pitcher syncline. The syncline has continuous curvature. At Dry Gulch the syncline has a broad, flat-lying central area with sharply upturned edges at the eastern and western borders. This structure persists and widens northwest of Dry Gulch. Thus, as the axis of the Pitcher syncline is followed to the northwest, it may be described alternatively as (1) developing a broad, flat bottom or (2) splitting into two monoclinal structures.

In upper Dry Gulch, near the east border of sec. 20, T. 22 N., R. 20 E., Wenatchee beds are cut by two closely spaced branches of a thrust fault, with a sandstone bed rotated to a nearly vertical attitude between the fault planes (fig. 8). Excellent outcrops of the vertical sandstone bed are exposed high on both valley walls.

A small body of hornblende andesite of Horse Lake Mountain intrusive complex intrudes a plane of the thrust fault on the north side of upper Dry Gulch. It is presumed to postdate the episode of thrust faulting, as it shows no evidence of having been sheared. Thus thrust faulting

FIGURE 8. – Evidence for two thrust faults on the western limb of the Pitcher syncline. The two strands are defined by a block of vertically dipping upper Wenatchee sandstone, shown here in the right center of the photograph. Gently dipping beds on the right and left margins of the photograph are in the lower part of the Wenatchee Formation. The view is to the northwest across Dry Gulch.

observed in Dry Gulch occurred relatively soon after deposition of the Wenatchee Formation and is narrowly bracketed between 34 m.y. (the age of the Wenatchee Formation) and 29 m.y. (the average age of Horse Lake Mountain hornblende andesite).

INTERPRETATION OF THE PITCHER SYNCLINE AND DRY GULCH STRUCTURE

Two previous interpretations of the Pitcher syncline are reviewed here. An interpretation by Lovitt and Skerl (1958) is reproduced as fig. 9. They correctly identified an unconformity between "older sandstone" and "younger sandstone." However, the younger sandstone ("YS(W)" in fig. 9) is Wenatchee Formation in the syncline, but Chumstick Formation on either side. The two anticlines formed by connecting Wenatchee Formation to Chumstick Formation do not exist. A similar error was made by Chappell (1936). It is significant that Lovitt and Skerl recognized a unit older than Chumstick, which is the unit here mapped as Swauk(?).

An interpretation of the structural relations by Patton and Cheney (1971) is shown in fig. 9. They recognized that the beds of Wenatchee Formation are distinctive and do not extend beyond the syncline, and they observed west-dipping thrust faults underground at the nearby L-D gold mine. Their interpretation bounds the syncline with contemporaneous thrust faults on either flank. This is essentially correct, except that the geometry and development of the thrust faults is more complicated than is implied by fig. 9.

The structural problems posed by the Pitcher syncline and Dry Gulch localities are twofold: (1) Although the faults on the west side of Dry Gulch and the underground evidence at the L-D gold mine (Patton and Cheney, 1971) constitute strong evidence that the syncline is bounded by west-dipping thrust faults, it is difficult to

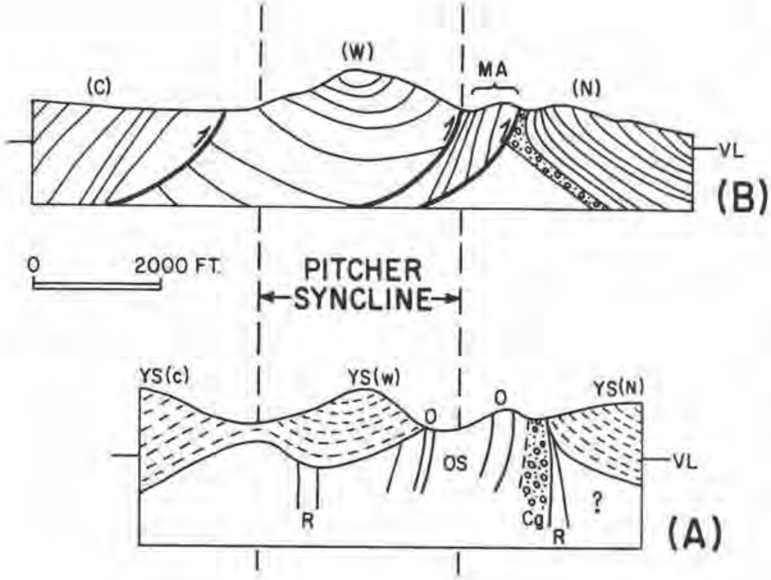

FIGURE 9. — Two published interpretations of structural relations at the Pitcher syncline. VL is valley level on both diagrams. Cross section A is the interpretation of Lovitt and Skerl (1958), where Cg is conglomerate, Os is Old Sandstone, Ys is Young Sandstone, R is rhyolite, and O is ore zone. Cg and Os are both listed as Swauk(?) and Ys as Swauk. As interpreted by the present author, Os is probably Swauk Formation as defined at the type locality (Smith, 1904); Ys is partly Wenatchee Formation [the part identified as Ys(w)], partly lower Chumstick Formation [YS(c)], and partly the Nahahum Canyon Member of the Chumstick Formation [Ys(n)]. Cg is a Chumstick conglomerate, and it may represent a fault slice of lower Chumstick along an extension of the Eagle Creek fault system that separates the Nahahum Canyon Member from the Swauk Formation at this locality (see figs. 11 and 12). Cross section B is the interpretation of Patton and Cheney (1971). The structural interpretation is accepted with minor revision (see figs. 11 and 12). They referred to all sedimentary units as Swauk Formation, but the units shown here — C, W, and N — are, respectively, lower Chumstick, Wenatchee, and Nahahum Canyon Member. MA refers to "Mine area." From Gresens (1980, fig. 8, p. 134).

imagine how these faults alone could produce the geometry of a syncline. The problem is illustrated in fig. 10. (2) The change in geometry of the structure between the two localities must be explained.

A proposed structural mechanism is based on consideration of the probable structure of rocks underlying the Wenatchee Formation prior to deformation. The profound unconformity of Wenatchee Formation on all older units (as documented at the Blue Grade, Chopper Hill, and Stemilt Canyon reference sections) and the occurrence of paleosols below the unit strongly suggest that the Wenatchee was deposited on an erosion surface of low relief. The geometry of older units on the erosion surface is shown in fig. 11, including the projection of the Eagle Creek anticline and the belt of Nahahum Canyon rocks into the southern part of the graben. The faulted anticline must have closed to the south

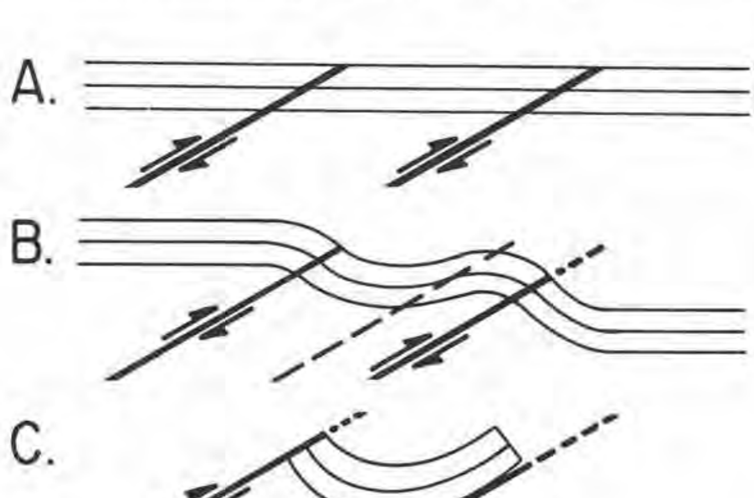

FIGURE 10. — Schematic diagram showing the improbability of generating the Pitcher syncline solely by movement along two west-dipping thrust faults, as implied in fig. 9B. Cross section A shows two parallel thrust faults beginning to deform the Wenatchee Formation. Cross Section B shows folding due to drag along the two faults. A subsequent fault would have to appear in the position of the dashed line to produce the geometry of fig. 9B. There is no field evidence for this relationship. It seems unlikely that a bed could be dragged in a "normal" sense along a western fault (left side of cross section C) but be broken off and forced upward with opposite (anti-drag) curvature on an eastern fault (right side of cross section C). Although such structural mechanism might be imagined on large complex fault systems, it seems unlikely for these faults with horizontal displacements on the order of only 0.5 to 1.5 km. From Gresens (1980, fig. 9, p. 136).

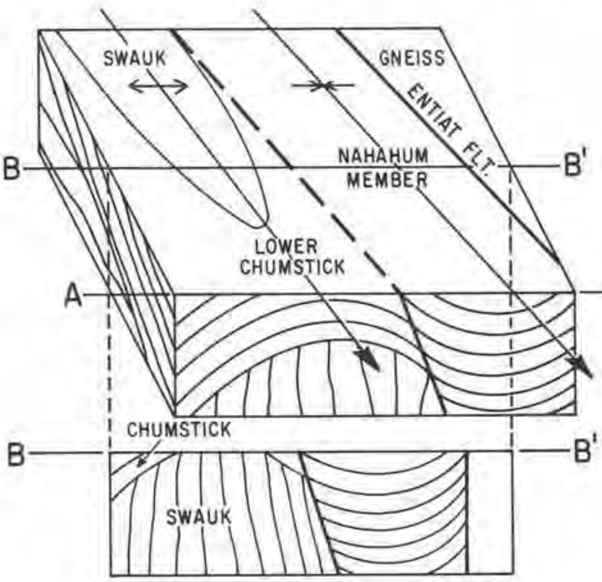

FIGURE 11. – Block diagram showing the inferred geologic relations on and below an erosion surface that existed prior to deposition of the Wenatchee Formation. Anticlinal and synclinal axes are defined by folds in the Chumstick Formation. The Eagle Creek anticline is shown as faulted, in accord with the structural interpretation of Whetten (1977a), and the fault brings upper Chumstick (Nahahum Canyon Member) into contact with lower Chumstick and the Swauk Formation. Geologic relations suggest that the erosionally breached anticline closed to the southeast on the pre-Wenatchee surface. The position of section A-A' corresponds approximately to the Stemilt Canyon area, and the position of section B-B' corresponds to the area just north of the Pitcher syncline. From Gresens (1980, fig. 10, p. 137).

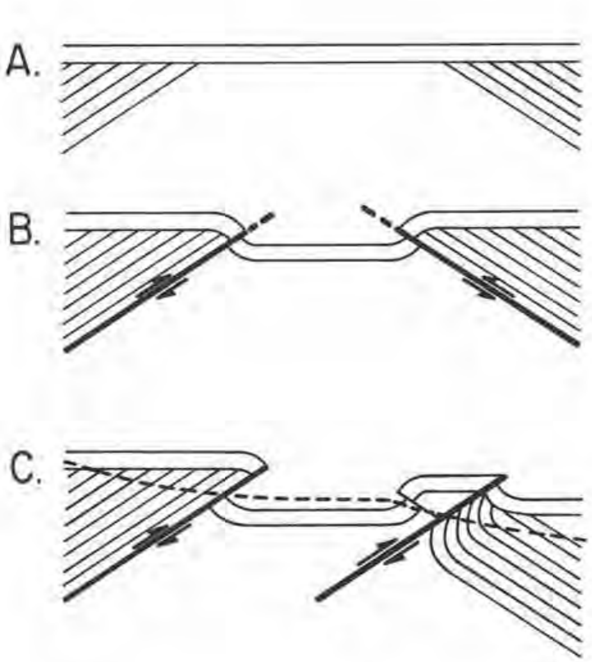

FIGURE 12. – Proposed antithetical thrust faulting and reversal of thrust motion to explain the structural relations at the Pitcher syncline. Section A corresponds to a portion of section B-B' on fig. 11. A thin sheet of Wenatchee Formation, perhaps 300 m thick, overlies the erosion surface with little or no additional sedimentary cover. In section B, an initial compression is assumed to initiate antithetical thrust motion along favorable oriented bedding planes that are controlled by the anticlinal structure in the underlying rocks. Edges of the Wenatchee Formation that are overridden by the faults are dragged upward, but a broad expanse remains in a horizontal attitude. In section C, continued compression is assumed to thrust the sedimentary units out of the graben and across the trace of the Entiat fault on west-dipping fault planes. The crystalline block to the east (see fig. 13) is presumed to act as a rigid buttress. To the west (left side of diagram), the initial motion continues to develop into a greater thrust displacement because of favorable orientation. To the east (right side of diagram), a west-dipping thrust fault cuts across the initial antithetical motion on east-dipping bedding planes and causes overturning of overridden beds. The dashed line in section C corresponds to the geology observed along the present erosion level at the Pitcher syncline, except that the upturned edges of Wenatchee Formation between the fault planes join in continuous curvature, with no horizontal beds present. Horizontal Wenatchee Formation, displaced 275 m vertically, is found up-canyon from the Pitcher syncline, as shown on the far left side of the diagram. Overturned beds of Chumstick Formation are found just east of the syncline, as shown at the right side of the diagram. Compare section C with figure 9B. From Gresens (1980, fig. 11, p. 139).

on the erosion surface, because no older core rocks (Swakane Biotite Gneiss) underlie Wenatchee Formation at the Stemilt Canyon reference section (the Wenatchee is underlain by Chumstick Formation).

The Wenatchee Formation was deposited as a sheet on the erosion surface. It should be noted that the Wenatchee Formation now has a maximum thickness of only 275 m (900 ft) and that it probably was never much thicker. Because deformation followed soon after deposition (between 29 and 34 m.y.b.p.), there was probably little or no additional sedimentary cover overlying the Wenatchee Formation during subsequent folding and faulting.

The anticlinal portion of cross-section B-B' of fig. 11 is shown in fig. 12. It is suggested that during the next period of deformation, which had at least a component of northeast-southwest compression, an initial response was to thrust the Chumstick Formation up along its unconformity with the Swauk(?) Formation and(or) along favorably oriented bedding planes on either side of the anticlinal structure (fig. 12). The edges of the Wenatchee Formation were dragged up on the sides of the structure, but in opposite directions. Where a broad expanse of Swauk(?) was exposed in the interior of the breached anticline, the overlying Wenatchee Formation remained undisturbed in its original horizontal attitude. Following the anticlinal structure southeastward toward its closure, the upturned edges of the formation are brought closer together until they join to form the continuous curvature of the Pitcher syncline. Farther southeast, in Stemilt Canyon, the Wenatchee Formation rests directly on an anticlinal structure in the Chumstick Formation, and no Swauk(?) Formation is present. By this interpretation, the axis of the Pitcher syncline in the Wenatchee Formation is coincident with the anticlinal axis in the Chumstick Formation (as viewed on a map), but it overlies the anticlinal axis in the third (vertical) dimension.

Although an initial doubly directed minor thrusting explains the geometry of structures at the Pitcher syncline and Dry Gulch, it does not account for west-dipping thrust faults observed underground by Patton and Cheney (1971) to the immediate east of the Pitcher syncline. The inclination of these faults is opposite to the proposed initial motion along an east-dipping unconformity or bedding plane (fig. 12). Patton and Cheney pointed out that steepening of the sedimentary unit (Chumstick) just east of the L-D mine is further evidence for eastward overthrusting. It is suggested that continuing deformation must have reversed the sense of motion along the east side of the Pitcher syncline to produce the observed relations (fig. 12). The block of crystalline rocks east of the Entiat fault must have acted as a rigid buttress, and the sedimentary rocks were thrust out of the graben and over the crystalline block to the east (fig. 13).

NORTHERN CONTINUATION OF THRUST FAULTS AT DRY GULCH

The closely spaced thrust faults that enclose a vertical bed of Wenatchee sandstone at Dry Gulch (fig. 8) become progressively more widely separated as followed to the northwest. The approximate continuation of the western branch is delineated by the westernmost exposures of Wenatchee Formation with upturned edges. A good example is at SE 1/4 sec. 18, T. 22 N., R. 20 E., where a broad exposure of Wenatchee has relatively gentle dip on the east, but has dips as high as 65° NE. on the west. The next outcrop farther west is Chumstick Formation, and the fault must lie between the two formations. Beyond this point to the northwest, the fault passes entirely into Chumstick Formation in an area of poor exposure and cannot be traced farther.

The eastern branch of the Dry Gulch thrust fault disappears below mass wasting debris to the immediate north, but is marked by vertical

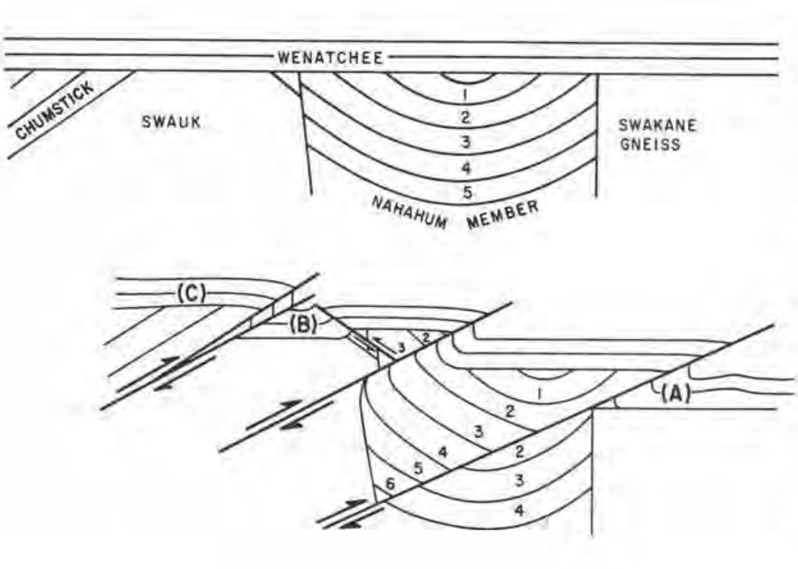

FIGURE 13. – Diagrammatic sections showing inferred structural development of the eastern border of the Chiwaukum graben between 19 and 34 m.y. ago. The upper section shows the Wenatchee Formation overlying an erosion surface. The lower section summarizes post-Wenatchee deformation. Included are antithetical initial thrust faulting and reversal of thrust motion due to structural control by an underlying anticline, imbrication of the westernmost thrust fault at Dry Gulch, and thrusting of sediments out of the graben across the trace of the Entiat fault. Numbering of beds of the Nahahum Canyon Member has no significance except as a guide to the structural relations. Letters A, B, and C refer to positions of profiles shown in fig. 14. From Gresens (1980, fig. 13, p. 144).

beds of Wenatchee Formation along a ridge at the south border of sec. 17, T. 22 N., R. 20 E., nearly directly south of the center of the section. The fault is again hidden farther northwest, but is on strike with the silicified rocks in NW 1/4 sec. 18 and SW 1/4 sec. 7, T. 22 N., R. 20 E. The silicified rock has the geometry of a sheet parallel to bedding in Chumstick Formation to the immediate west, dipping southwest to make a "V" in Number Two Canyon. The rock was brecciated prior to silicification. Swauk Formation occurs to the immediate east of the silicified zone. The zone is interpreted as the continuation of the eastern branch of the thrust fault. Here it has developed along the unconformity between the Swauk and Chumstick Formations. The zone can be followed over the north side of Number Two Canyon and is exposed on the southern hillside in the next ravine, just southeast of center of sec. 12, T. 22 N., R. 19 E. At this point it has cut away from the Swauk-Chumstick unconformity and passed into the Chumstick section. As followed into and across the next ravine, just east of the center of sec. 12, it truncates the gabbro intrusion in Chumstick that is striking into the fault zone from the north. At the truncation there are good exposures of sheared and silicified gabbro. It is not possible to trace the fault farther northwest in terrane of poorly exposed Chumstick Formation.

THRUSTING ACROSS THE ENTIAT FAULT

Scattered exposures of the Wenatchee and Chumstick Formations in low hills east of the city of Wenatchee, east of the projection of the Entiat Fault, confirm thrusting of rocks out of the graben and over the crystalline block. In exposures farthest northeast of the Entiat Fault, at central and northern sec. 23, T. 23 N., R. 20 E., the Wenatchee Formation dips gently southeast. In exposures closer to the projected trace of the fault, strikes are rotated subparallel to the strike of the Entiat fault, and the formation dips gently to steeply northeast, as at SW 1/4 sec. 23 and sec. 26, T. 23 N., R. 20 E. This change in orientation presumably reflects overriding of autochthonous Wenatchee Formation by an upper plate thrust out of the graben along a northeast-directed thrust fault.

At least some Chumstick Formation that occurs east of the projection of the Entiat fault is presumed to have been emplaced by thrust faulting of the rocks out of the graben. The structural relations are particularly clear along the base of a drainage that cuts through overlying Quaternary deposits between the center and east border of sec. 26, T. 23 N., R. 20 E. The position of the thrust plane is bracketed in the narrow gap between outcrops of Wenatchee and Chumstick Formations. Chumstick Formation is extensively fractured and cut by numerous low-angle shear planes that dip to the southwest at an exposure near the north border of sec. 1, T. 22 N., R. 20 E., south of benchmark 1236 on the Badger Mountain Road. This could be an allochthonous block emplaced by thrust faulting, but its position amid mass wasting deposits causes some uncertainty. A generalized summary of the control of structures in the Wenatchee Formation by preexisting structures is shown in fig. 13.

DISPLACEMENT ON THRUST FAULTS

Some of the thrust faults shown on the map at secs. 16, 21, and 22, T. 22 N., R. 20 E., are admittedly imaginary, in the sense that there are few hard data from surface exposures. Patton and Cheney (1971) had underground evidence that the main brecciated, silicified ore body at the L-D gold mine occupies a west-dipping thrust fault. Following Patton and Cheney, similar small brecciated and silicified zones northwest of the mine are presumed to occur along thrust faults, but they do not necessarily have to be connected as shown on the map.

The most precise geologic control of the orientation and displacement on thrust faulting is in upper Dry Gulch. The base of the Wenatchee Formation in the upper plate is raised nearly to the elevation of the top of the formation in the lower plate, which requires a vertical displacement of 250 to 275 m (800 to 900 ft). In Squilchuck Canyon, the difference in elevation from the projected base of the Wenatchee Formation at the Pitcher syncline to an exposure of the base of the formation up-canyon at SE 1/4 sec. 28, T. 22 N., R. 20 E., is also about 275 m (900 ft). In upper Dry Gulch, the eastern branch of the thrust fault is well exposed on the south side of the canyon, where it dips 40° to 45° SW. To the northwest, where the same branch makes a "V" in Number Two Canyon, it has a dip of 35° SW. The calculated horizontal displacement along the thrust fault thus is on the order of 250 to 400 m (800 to

1,300 ft).

A minimum horizontal displacement for thrusting of sedimentary rocks across the trace of the Entiat fault is estimated from exposures of Chumstick Formation east of the fault. The only demonstrably allocthonous Chumstick Formation is the exposure just east of center sec. 26 T. 23 N., R. 20 E., where it is in fault contact with Wenatchee Formation. This outcrop is 1.7 km (1.1 mi) normal to, and northeast of, the estimated projection of the Entiat fault. The base of the Wenatchee Formation just west of the Entiat fault is 275 m (900 ft) higher than the base just east of the fault, along a direction normal to the projected fault. The differential elevation and the minimum horizontal displacement suggest that the sedimentary rocks were thrust across the trace of the Entiat fault on a plane that dips no greater than about 10° to the southwest (unless there has been subsequent renewed uplift of the crystalline block east of the Entiat fault).

A greater minimum horizontal displacement is possible if it could be assumed that Chumstick rocks at SE 1/4 sec. 24 and NE 1/4 sec. 25, T. 23 N., R. 20 E., are allochthonous and had been deposited in the graben west of the Entiat fault. They are presently about 3.2 km (2.0 mi) northeast of the fault. There is no firm basis for this assumption at the present time.

Three northwest-southeast profiles of the base of the Wenatchee Formation, parallel to the Entiat fault, are shown in fig. 14. (The slope of the profiles is discussed in a later section on regional tilting.) Profile A is the base of the formation unconformably on Swakane Biotite Gneiss east of the Entiat fault. Profile B is the unconformity on the sedimentary rocks from a belt of Wenatchee Formation between the Entiat fault and the thrust fault that passes through upper Dry Gulch. Profile C is the unconformity displaced upward by the western thrust fault, that is, in the upper plate west of the fault. The consistent relative displacement of about 200 to 300 m (700 to 1,000 ft) between the southeast ends of profiles B and C leads to the conclusion that the Stemilt Canyon reference point (the most southerly point on profile C) must be in the upper plate of the thrust fault, whereas the Pitcher syncline reference point must be in the lower plate (profile B). Additional evidence is that upper plate Wenatchee Formation lies flat high on the west wall of Squilchuck Canyon at SE 1/4 sec. 28, T. 22 N., R. 20 E., but is folded down to the southwest and V's in the canyon in NE 1/4 sec. 33, T. 22 N., R. 20 E. A similar geometry is present in Stemilt Canyon, where nearly flat-lying Wenatchee at the Stemilt Canyon reference section folds gently down to the southwest at NW 1/4 sec. 36, T. 22 N., R. 20 E. This suggests that the Stemilt Canyon rocks are a continuation of the upper plate rocks of Squilchuck Canyon.

Assuming that the anticlinal axis in Chumstick Formation at Stemilt Canyon is the same anticlinal axis that occurs beneath the Pitcher syncline, then displacement along the thrust fault can be evaluated by offset of the anticlinal axis, which must be in the upper plate at Stemilt Canyon but in the lower plate at the Pitcher syncline. If it is assumed that thrusting was normal to the Entiat fault, that is, to N. 35° E. to N. 40° E., then the anticlinal axis is offset about 2.0 km (1.2 mi) to the

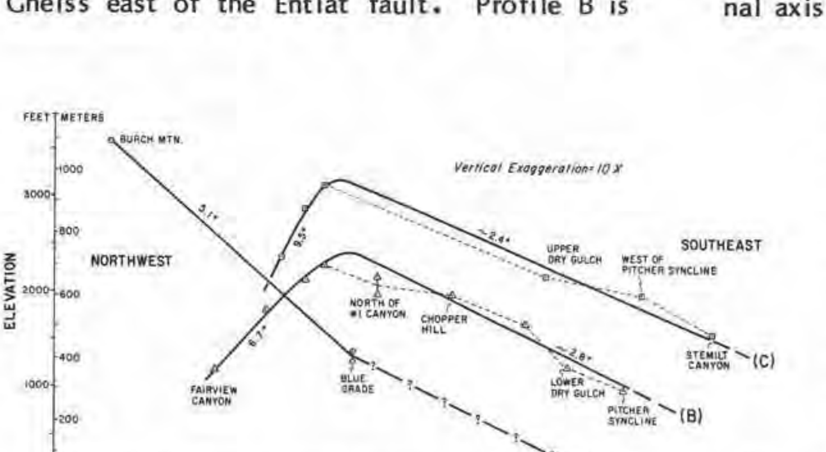

FIGURE 14. – Profiles on the base of the Wenatchee Formation. The profiles are projected onto NW-SE lines, following the general structural trend at the eastern border of the Chiwaukum graben, and each is within a strip of Wenatchee Formation bounded by thrust faults. See fig. 13 for a schematic representation, in cross section, of the positions of profiles relative to faults, and compare place names on this figure with plates 1 and 2 for actual data points. The location of the Burch Mountain point (profile A) is given in fig. 6. The dashed lines show direct connections between data; solid lines are smoothed profiles. The angle of inclination along segments of smoothed profiles is given. From Gresens (1980, fig. 14, p. 146).

northeast by the upper plate. The sense of displacement is consistent with the structural relations discussed above, but the offset is greater than the estimated 0.25 to 0.40 km of horizontal displacement at Dry Gulch and Number Two Canyon. A possible resolution of this inconsistency is to assume that thrusting was not normal to the Entiat fault. For example, if the direction of thrusting is N. 70° E., about 30° oblique to the Entiat fault, then horizontal displacement of the anticlinal axis would be about 0.4 km. Another possible interpretation is that the thrust fault flattens to the southeast of Dry Gulch.

The calculations suggest that crustal shortening was relatively small during the compressional event. The sum of horizontal displacements on all thrust faults is estimated at 2.5 to 3.0 km. When averaged over a 5.0 m.y. interval (29 to 34 m.y.), the average strain rate is only 5.0 to 6.0 X 10^{-2} cm/yr.

HIGH-ANGLE FAULTING

South of the Wenatchee River, from the vicinity of Fairview Canyon to Number One Canyon, the unconformity between Wenatchee and Chumstick Formations is exposed locally on the east side of valleys, but Wenatchee Formation is not present on the west side at elevations above a hypothetical projection of the unconformity. Moreover, no Wenatchee Formation has been noted in the higher elevations farther west, which are underlain entirely by Chumstick Formation. A good example is at the southern border of sec. 35, T. 23 N., R. 19 E., where the nearly flat unconformity of Wenatchee over Chumstick is at an elevation of about 3,000 ft. Across the valley to the southwest, less than a mile away at NE 1/4 sec. 3, T. 22 N., R. 19 E., cliffs with excellent exposure rise to over 4,000 ft elevation, and no Wenatchee Formation is present. A post-Wenatchee fault of significant vertical displacement is inferred, bringing Chumstick up on the western side. The fault is considered to follow Fairview Canyon. Sheared Chumstick rocks occur in the canyon in the cut of a ranch road immediately southeast of Hill 1570 at NW 1/4 sec. 26, T. 23 N., R. 19 E., and at cuts on the northeast side of Highway 2-97 north of the town of Monitor at NE 1/4 sec. 14, T. 23 N., R. 19 E. Both are considered to lie in the fault zone. The fault could be an extension of the Eagle Creek fault system, which strikes toward the Fairview Canyon area (Whetten and Waitt, 1978). The dip of the fault cannot be observed directly, but a high angle is inferred from its linearity. An upper time limit is not established for the fault, but it is clearly post-Wenatchee. This relationship suggests that the Eagle Creek fault system may have a long and complicated history of movement from pre- to post-Wenatchee time. This agrees with Whetten's (1977a, 1977b) conclusion that the Eagle Creek fault system had a long history of activity both during deposition of the Chumstick Formation and post-depositionally.

Another high-angle fault that cuts the Wenatchee Formation is well exposed in Squilchuck Canyon at the turnoff of the road leading to Wenatchee Heights and in the Halvorson Loop Road, both at NW 1/4 sec. 4, T. 21 N., R. 20 E. Sheared Wenatchee Formation is dragged upward to a nearly vertical attitude just east of the fault, and no Wenatchee has been noted to the west in the Chumstick terrane. The fault can be traced to the northwest, where it becomes parallel to a fault of small displacement that is offset in an opposite sense. The parallel faults strike northwest across most of sec. 19, T. 22 N., R. 20 E., but with too great a westerly component to be considered as extensions of the Eagle Creek fault system. The significance of this fault is discussed in a later section.

COMPLICATED STRUCTURE AT UPPER SQUILCHUCK CANYON

Flat-lying Wenatchee Formation resting on Chumstick Formation is exposed just below mass wasting deposits that cap the mesa on the west side of Squilchuck Canyon near the southern border of sec. 28, T. 22 N., R. 20 E., at an elevation of about 2,000 ft. One-fourth of a mile south, at northern sec. 33, the Wenatchee Formation is folded down to the southwest so that the Wenatchee-Chumstick unconformity drops in elevation toward the valley floor. Outcrop is then lost on the west side of the canyon, but the contact apparently V's in the valley, as it is exposed at valley level on the east side of the canyon between the center and the east border of sec. 33. From that point it is easily traced back to the northeast on the east side of the canyon for about one-fourth of a mile. These relationships are consistent with the occurrence of good outcrops of Wenatchee Formation at valley floor in the SW 1/4 sec. 33, near a major high-angle fault (described above).

Between these exposures, most of the central portion of sec. 33 is involved in landsliding and exposure is poor.

A structural difficulty is posed by the occurrence of Wenatchee Formation across the NW 1/4 sec. 33 near the top of the divide. At one point near the northern border of sec. 33, there is an outcrop having nearly flat-lying Wenatchee unconformable on steeply dipping Chumstick rocks, but this is at an elevation of nearly 2,200 ft, above the dipping Chumstick-Wenatchee contact described in the preceding paragraph, which is exposed directly downslope. Clearly a fault is required, but the implied sense of drag on the fault is in opposition to conventional experience. The poor exposure and landsliding make it impossible to fully reconstruct the structure. But the few key outcrops suggest that it is complicated. It is probably related to the high-angle faults described in the preceding section. This area is at the southeast end of a major northwest-trending, right-lateral strike-slip fault zone that cut across the southern Chiwaukum graben in post-Wenatchee time, as discussed in the following section.

DEFORMATION COEVAL WITH EMPLACEMENT OF THE HORSE LAKE MOUNTAIN INTRUSIVE COMPLEX

A broad northwest-trending structure that cuts across a large portion of the Monitor quadrangle is believed to have controlled emplacement of the Horse Lake Mountain intrusive complex. Fig. 15 consolidates the relevant structural data and outlines the structure.

The parallel faults in sec. 19, T. 22 N., R. 20 E., discussed above, can be traced because Wenatchee Formation is faulted against Chumstick Formation. They cannot be directly followed farther northwest because Chumstick is faulted against Chumstick in a terrain of poor exposure. However, a broad zone of disturbed Chumstick bedding is on strike to the northwest. Southwest of the zone, bedding strikes northwest, parallel to the regional structural grain, and dips typically 35° to 40° SW. North of the disturbed zone, bedding is uniformly north-striking and dips about 30° to 40° W. Still farther north, bedding swings back to the more typical northwest strike, but with a steeper dip

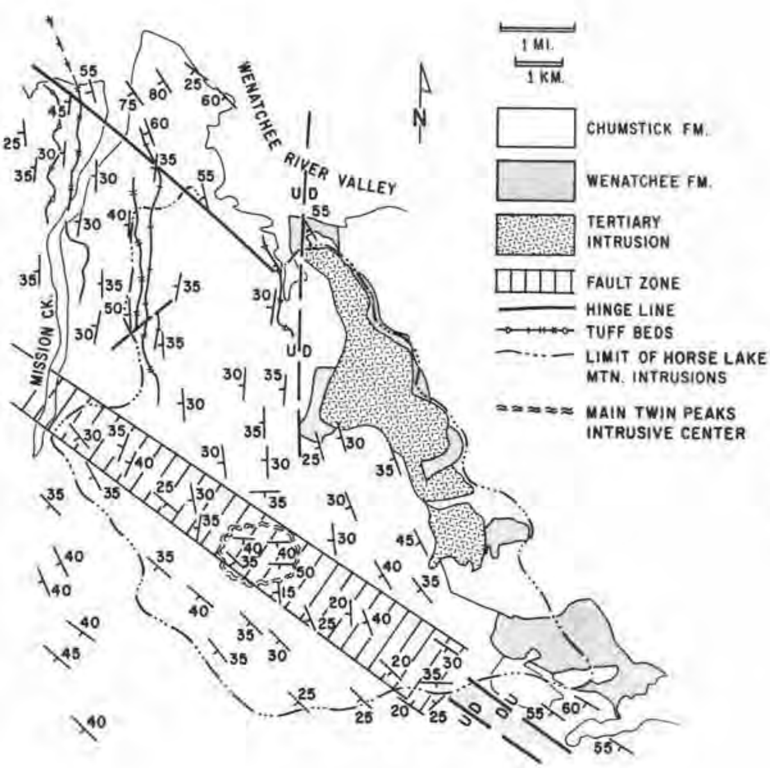

FIGURE 15. – Structural details of the post-Wenatchee northwesterly trending zone that control the Horse Lake Mountain intrusive complex. Modified from Gresens, R. L., 1982a, Early Cenozoic geology of central Washington State; I, Summary of sedimentary, igneous, and tectonic events: Northwest Science, v. 56, no. 3 fig. 5, p. 226.

(55° to 60° SW.) than bedding south of the disturbed zone. In contrast to the disturbed zone, which is clearly a fault zone, the northern change in bedding direction takes place about a hinge zone. The hinge zone strikes northwest, parallel to the disturbed zone, from about the mouth of Fairview Canyon to the mouth of Mission Creek. At four places along the hinge zone, tuff units pass through the hinge zone without offset.

Fig. 15 also outlines the known limit of occurrences of sills and dikes of the Horse Lake Mountain intrusive complex. Clearly there is a correlation between the occurrence of the intrusive rocks and the region of north-striking bedding. The main center of intrusive activity (the Twin Peaks intrusive breccia and sill-dike complex) occurs within the fault zone, at a point where bedding shows the most pronounced reorientation to east-west strike and southerly dip. Two of the large sills of the Horse Lake Mountain intrusive complex (the Bear Gulch composite sill and the Martin's Ranch sill) occur near the fault zone. South of the fault zone, sill and dike occurrences extend a short distance into the region of typical northwest-striking bedding. At the northern boundary, the limit of sill and dike occurrences conforms fairly precisely to the position of the hinge zone. A most striking example is well exposed at SE 1/4 sec. 22, T. 23 N., R. 19 E., where the northerly extension of the large sill that forms the ridge on the west side of Fairview Canyon pinches out at the hinge line.

These relationships suggest that Chumstick bedding, which had already been tilted to a homoclinal southwest-dipping structure in pre-Wenatchee time, was later subjected to stress by a right-lateral shear couple. Bedding between the shear couple was rotated clockwise to a northerly strike. The beds were disrupted along a fault zone to the south, but only rotated about a hinge line to the north. The beds between the zones have the structure of a giant kink band. During active shearing, the "bands," which are the Chumstick beds, were tensionally opened within the "kink," allowing passive emplacement of the many sills in this region, even though the main intrusive center was a structural weak zone within the major fault zone. By this interpretation, the deformation of the area by right-lateral shearing is dated at about 29 m.y.b.p., the average age of the andesites.

Minor faulting associated with emplacement of the Number One Canyon intrusion of the Horse Lake Mountain complex can be demonstrated on the north side of Number Two Canyon, southwest of the Chopper Hill reference section of the Wenatchee Formation, at SE 1/4 sec. 7, T. 22 N., R. 20 E. Along the margin of the intrusive contact, two elongate prongs of Wenatchee extend to the south. They are at an elevation lower than flat-lying Wenatchee beds that cap Chopper Hill, and bedding in them is rotated down to a southwest dip. At the southern tip of the western prong, an exposure of steeply dipping Swauk Formation marks the position of the Swauk-Wenatchee unconformity, displaced downward about 450 ft. Andesite occurs between the two prongs, and bleached sedimentary rocks occur locally at the contact. The prongs are interpreted as large slivers of country rock that foundered and rotated at the margins of the intrusion. Their northerly trend probably is controlled by the steeply dipping, north-striking bedding of underlying Swauk Formation.

MISCELLANEOUS STRUCTURES OF UNCERTAIN AGE

The Chumstick Formation clearly has been affected by pre-Wenatchee folding and faulting as well as post-Wenatchee thrust faulting and high-angle faulting. However, where structures involving Chumstick Formation are not constrained by relationships with other units, it is not possible to associate them with any specific period of deformation.

MINOR FAULTS

Faults involving only the Chumstick Formation are particularly difficult to detect, except where key tuff units are faulted. A good example is at NW 1/4 sec. 28, T. 23 N., R. 19 E., where a pair of the Yaxon Canyon tuffs are offset. Coincidentally, the stratigraphically higher tuff south of the fault is brought into alignment with the stratigraphically lower tuff north of it. During initial mapping these were mapped as a single tuff unit, until recognition of two tuffs and their distinctive characteristics indicated the presence of the fault. Nowhere can the fault be directly observed.

A fault cutting tuff at NW 1/4 sec. 3, T. 22 N., R. 19 E. is of interest because it demonstrably pre-dates emplacement of sills and dikes of the Horse Lake Mountain complex. A sharp north-northwest trending ridge extends from sec. 3 into SW 1/4 sec. 34, T. 23 N., R. 19 E. At the north border of sec. 3, there is a sharp (135°) bend of a new logging road around the ridge. There is a northwest-trending segment of road east of the 135° bend and a north-trending road segment south of it. The latter road segment makes a 90° bend at a ravine, and a west-trending road segment extends to the next ridge to the west. The road here roughly follows the contour between 3,560 and 3,600 ft elevation and may be easily visualized on the 1966 topographic map of the Monitor 7 1/2-minute quadrangle. The tuff bed occurs in roadcuts about 100 feet from the 135° bend and about the same distance from the 90° bend. The attitude of bedding requires about 110 feet of stratigraphic offset of the tuff. The fault is poorly exposed just west of the 90° bend, where it is partially obscured by mass wasting material in the ravine, but truncated Chumstick bedding is visible. The central portion of the north-trending road segment bulges slightly to the west, and a fault breccia is well-exposed in the roadcut at the bulge. The two points on the fault define a north-striking fault, nearly coincident with the road. Apparently it is a high-angle fault. Many andesitic sills and dikes of the Horse Lake Mountain complex are present, and the hill slope above the exposure of the fault breccia is the dip slope of a sill. Where the sill is exposed in the upper roadcut, it butts against a block of tuff in the fault zone. The fault breccia contains angular blocks of tuff and Chumstick sandstone, but no fragments of andesite. A dike that is darker and finer-grained than the sill cuts both the fault zone and the sill. It can be followed upslope cutting the sill east of the fault zone, and it is present in scattered outcrops downslope west of the fault zone. Clearly the fault pre-dates the igneous activity, but cannot be assigned definitively to pre- or post-Wenatchee tectonism.

A clear example of a fault that cuts a sill of the Horse Lake Mountain complex is along a north-trending ridge at the border between SE 1/4 sec. 13, T. 22 N., R. 19 E., and SW 1/4 sec. 18, T. 22 N., R. 20 E. Where the fault crosses the ridge the softer Chumstick rocks have peeled away from the more resistant sill, leaving the fault plane exposed. The fault strikes N. 70° W. and dips 80° N. It lies within the northwest-trending belt of disturbed Chumstick bedding that has been interpreted as a major right-lateral strike-slip fault zone across the graben (see previous section). The movement in this zone continued after at least some of the igneous activity, but there is no constraint on the minimum age of faulting.

Chumstick bedding is disrupted in exposures along the bottom of a ravine that trends northeast-southwest in SE 1/4 sec. 30, T. 23 N., R. 20 E. The outcrops are within the Wenatchee quadrangle, near the boundary with the Monitor quadrangle. Approximately 2,000 ft downstream from this border, near the adit of a coal prospect on the northwest side of the ravine, bedding attitudes are sharply discordant to the general trend within the area and from outcrop to outcrop. At one point measurements made on outcrops about 100 ft apart yield strikes at right angles. [This fault is not shown on the geologic map, but the disrupted bedding attitudes are.] A fault cannot be traced beyond the base of the ravine due to lack of outcrop, and it is not known whether the disruption is due to proximity to the high-angle fault separating the belts of Swauk and Nahahum Canyon rocks or due to post-Wenatchee thrust faulting.

Large slabs of Chumstick sandstone crop out boldly in sec. 23, T. 22 N., R. 20 E., and there are exposures in drainages and along the Malaga Road in the NE 1/4 of the sec. The marked discordance in strikes and dips permits placement of three northwest-trending faults. It is not possible to determine the orientation of the fault planes or relative motion on the faults. Nor is it possible to ascribe an origin or age to the faults; that is, whether related to the fault separating Nahahum Canyon rocks from Swauk rocks, post-Wenatchee thrust faulting, or simply proximity to the projection of the Entiat fault zone.

UNUSUAL FOLD STRUCTURE IN THE NAHAHUM CANYON MEMBER OF THE CHUMSTICK FORMATION

An unusual structure is present in sec. 30, T. 23 N., R. 20 E., and sec. 24, T. 23 N., R. 19 E. Rocks having an easterly component of dips flatten to horizontal or near-horizontal attitude. The most accessible locality to view the structure is on the road across northern sec. 30. Between Hill 1772 and the border between the Wenatchee and Monitor quadrangles (NW 1/4 sec. 30, T. 23 N., R. 20 E.) the road makes two horseshoe bends. At the northern (upper) bend, Nahahum rocks strike northwest and dip 30° NE. At a roadcut a short distance west, the beds lie flat. The hinge of the fold is at about 1,600 ft elevation. The same relationship is present on the next ridge to the south-southeast, where flat-lying beds crop out on the ridge at an elevation of 1,600 ft, but beds striking north and dipping 30° E. occur a short distance down the ridge. A third point is in the next drainage to the south, just northwest of the center of sec. 30, at an elevation of 1,400 ft. Within a single outcrop, beds roll over from nearly flat (dipping south-southeast) to a dip of 20° E. A fourth point is about 1 1/2 miles to the northwest, in a roadcut along the Sleepy Hollow Road at northern sec. 24, T. 23 N., R. 19 E., due north of the center of the section. Beds dipping 30° SE. roll over to nearly flat (10° S.) from east to west across the roadcut. These are at an elevation of 800 feet. The area between the first three points and the fourth point is a landslide deposit with no bedrock exposure. The four points defining the hinge of the fold lie on a plane that strikes N. 20° W. and dips about 15° SW. The origin and age of this structure are not known.

INTERNAL SHEARING WITHIN THE CHUMSTICK FORMATION

Sheared or disrupted shale beds in the Chumstick Formation suggest that the incompetent shales accommodated slippage along bedding planes between the more competent sandstone beds during deformational events. Good examples of sheared shale are seen along the new logging road across the northern part of sec. 3, T. 22 N., R. 19 E. A good exposure of internally disrupted bedding in shale of the Nahahum Canyon Member is in a northwest-trending drainage at sec. 23, T. 22 N., R. 20 E., about halfway between the valley floor and the mesa of Wenatchee Heights. This is the first drainage upvalley from the mouth of Squilchuck Canyon, on the southeast side of the canyon. Internal shearing cannot be ascribed to any particular deformational event.

REGIONAL TILT AND EROSIONAL STRIPPING OF WENATCHEE FORMATION

Profiles of the base of the Wenatchee Formation (fig. 14) show a regional tilt, apparently due to arching of the Cascade Range. In Squilchuck Canyon, 275 m (900 ft) of Wenatchee Formation underlie basaltic mass wasting debris. In the northern part of the Entiat Range, only thin patches of Wenatchee are preserved between basalt and Swakane Biotite Gneiss. This suggests that arching of the ancestral Cascade Range began before deposition of Yakima Basalt, and that Wenatchee Formation was thinned by erosion of the rising highland. The absence of Wenatchee Formation in the northern part of the Chiwaukum graben is attributed to pre-Yakima Basalt erosional stripping of the formation.

COMMENTS ON THE BOUNDING FAULTS OF THE CHIWAUKUM GRABEN

Although the Entiat fault must project through the Wenatchee quadrangle as a major fault zone, it is not well exposed within the quadrangle. The Leavenworth fault zone passes near, but just outside of, the southwest corner of the Monitor quadrangle. Thus Wenatchee and Monitor quadrangles are not well suited for a detailed study of the faults. However, some observations that relate to the geometry or history of the faults are presented here.

ENTIAT FAULT

Although regional tilting of the Wenatchee Formation is consistently upward to the northwest along the crystalline block of the Entiat Range (profile A in fig. 14), along profiles B and C, the base of the formation, resting on older sedimentary units, reaches a maximum elevation and then plunges to the northwest. In general, near the city of Wenatchee, the base of the Wenatchee Formation is now slightly higher to the west of the Entiat fault, which precludes major uplift of the eastern side of the fault since early Oligocene time. Laravie (1976), assuming that the Entiat is a normal fault, concluded that there has been no renewed motion of the Entiat fault at the extreme northern end of the Chiwaukum graben. However, he suggested that there has been major post-Miocene renewed displacement along a segment of the Entiat fault near the exposure of crystalline rocks in the Eagle Creek anticline. His suggestion is based on geomorphic evidence (displaced erosion surface) and occurrences of Yakima Basalt at low elevation in the graben. The basalt occurrences are somewhat suspect, and they could be mass wasting deposits. But if Laravie is correct, a sagging motion would be required to explain the lack of renewed uplift in the extreme north of the graben and near Wenatchee, but major post-Miocene displacement midway between them. The change in profiles B and C (fig. 14) could be taken as evidence supporting the scissor's movement that is required by sagging. However, the critical data at the north end of the profiles is from an area where the Fairview Canyon sill complicates the geologic relations.

LEAVENWORTH FAULT

The Leavenworth fault zone may be crossed with fairly good exposure by taking the Devils Gulch trail that begins at the eastern border of the Monitor quadrangle in sec. 18, T. 22 N., R. 19 E., and crosses the fault zone in sec. 19, within the Liberty 15-minute quadrangle. Southwest-dipping Chumstick beds that are the continuation of the homoclinal, conglomerate-poor sequence in the Monitor quadrangle are exposed along the trail or inferred from outcrops on the north side of the trail for a distance of about 0.4 miles from the trailhead. This is followed by a narrow belt of sandstone with conglomerates of monolithologic basalt and felsic volcanics (described in the section on Chumstick Formation), having bedding discordant to the homoclinal beds, that crops out north of the trail and is inferred from float of conglomerate along the trail. This belt is considered to be a tectonic sliver of lower Chumstick rocks. From this point to the point where the trail bends south into Devils Gulch, lithologies are chaotic and sheared. Sandstone that resembles Chumstick and probable Swauk sandstone having better induration and a darker, slightly greenish color both occur along the trail and are tectonically intermixed. Rocks are locally veined with quartz, including veins in an outcrop of sheared basaltic conglomerate. Some rocks are slightly slaty and resemble low-grade metamorphic rocks.

If the general trend of the Leavenworth fault zone is projected to the southeast from the first crossing of the fault zone along the Devils Gulch trail, it would be expected to cross into the Monitor quadrangle in the southern part of sec. 19, T. 22 N., R. 19 E. However, exposures along the ridge in the far southeast corner of sec. 19, which is at the extreme southwest corner of the Monitor quadrangle, are Chumstick Formation that is part of the homoclinal sequence. In order for the Leavenworth fault zone to miss the Monitor quadrangle, it must swing to a more southerly strike from the position of the fault in Devils Gulch. This is consistent with the general irregularity of the Leavenworth fault zone.

SUMMARY OF GEOLOGIC HISTORY

The timing of some geologic events recorded in the rocks of the Wenatchee-Monitor area is uncertain, as evident from the detailed description of units and geologic relationships. The summary of geologic history, which must always be viewed as interpretive, presents the author's judgment of the most probable interpretation, based on the current state of knowledge.

The pre-Late Cretaceous crystalline rocks (Swakane Biotite Gneiss) indicate deposition and metamorphism of a dominantly sedimentary protolith of eugeosynclinal rocks. Small quartz diorite plutons locally intruded the unit prior to metamorphism. The rocks probably were uplifted during regional Middle to Late Cretaceous orogenic activity that is well documented for the north Cascades.

Within Paleocene and early Eocene time, erosion exposed the Swakane Biotite Gneiss and created the surface upon which the Swauk Formation was deposited in early Eocene time. The fluvial and lacustrine feldspathic rocks of the Swauk may have covered the entire area, including the terrane east of the Entiat fault. Swauk deposition ended by about 50 m.y.b.p. and the formation was folded about essentially east-west axes before deposition of the Teanaway Basalt. The Teanaway intruded the Swauk as northeast-trending dike swarms at about 47 to 48 m.y.b.p. and poured out upon the post-Swauk surface in the terrane west of the Monitor quadrangle. Shallow felsic intrusve rocks (Wenatchee Dome, Rooster Comb) may have been emplaced into Swauk near the present eastern border of the Chiwaukum graben.

The Chiwaukum graben was initiated about 46(?) m.y.b.p. as a rhombochasm (pull-apart basin) along the right-lateral strike-slip Entiat fault. The irregular Leavenworth fault zone is essentially the normal-fault tensional border of the rhombochasm, although its southern end may be the complementary strike-slip boundary of the eastern side of the structure. Fluvial and lacustrine feldspathic sediments of the Chumstick Formation accumulated as the pull-apart basin opened over a period of perhaps 6 million years during the middle Eocene. The Chiwaukum graben thus was the locus of deposition of a thick sedimentary sequence, although deposition probably extended beyond the confines of the graben and the Chumstick may have been physically connected with the Roslyn Formation to the west. Fanglomerates with clasts representative of lithologies of adjacent terranes were shed into the graben along its borders, producing monolithologic conglomerates of granodiorite, serpentinite, and Teanaway Basalt along the Leavenworth fault zone.

Igneous activity during deposition of the Chumstick included both eruptive and intrusive rock types. Volcanic eruptions to the north produced felsic ash-flow and air-fall tuffaceous horizons. The tuffs are thick in the north end of the graben (average, 20 ft) but are thinned to an average 1 to 4 ft in the Wenatchee and Monitor quadrangles. Mafic igneous rocks intruded the Chumstick several times, including the 48-million-year-old Eocene gabbro in the lower part of the section in the Wenatchee quadrangle and a 42-million-year-old gabbro reported in the northern part of the graben. The large gabbroic Camas Land sill, lying west of the Monitor quadrangle, probably was intruded during this time interval, but it has not been precisely dated.

During subsidence of the Chiwaukum graben, a subsidiary horst was present along nearly the entire exposed length of the eastern side of the graben coincident with the present position of the Eagle Creek anticline. The horst may have been discontinuous, and the lithology of the horst blocks are Swakane Biotite Gneiss in the northern part of the graben and Swauk Formation to the south (within the Wenatchee and Monitor quadrangles). The horst blocks apparently moved northwest during strike-slip faulting on the Entiat fault, because the geographic positons of the two blocks match the relative positions of crystalline basement and Swauk Formation in the terrane west of the Leavenworth fault. However, movement on the Entiat fault must have rotated at least the southern horst block; Swauk bedding within the block trends northwest and is near-vertical, in alignment with the trend of the Entiat fault, but is discordant to Swauk bedding west of the Leavenworth fault (where it strikes approximately east-west and dips south). Foliation of Swakane Biotite Gneiss in the northern horst block also may be discordant to typical Swakane foliation, judging from structural data on the map by Whetten and Waitt (1978). The Eagle Creek anticline, though modified by younger compressional deformation, is considered to be primarily an extensional structure formed by differential subsidence over and adjacent to horst blocks during opening of the graben.

Graben activity ended about 40 m.y.b.p., coincident with the end of Laramide deformation elsewhere in western North America. This initiated a period of tectonic and magmatic quiescence of approximately 5 to 6 million years duration. During quiescence, middle Eocene topography was greatly reduced, leaving the area as a relatively featureless plain of low relief and probably low elevation. The erosion surface formed at this time is part of the Telluride erosion surface that was developed over most of the western United States. Prior to deposition of the Wenatchee Formation at 34 m.y.b.p., the area probably bore a resemblance to the present southeastern United States. A mature topography was deeply mantled with a saprolitic weathering rind in which feldspars and mafic minerals had been chemically altered to clay minerals and sesquioxides.

Tectonic activity resumed in the early Oligocene. The first material eroded from incipient uplifts was saprolite. It was winnowed rapidly by stream action to produce the distinctive quartz sandstones of the Wenatchee Formation, which are chemically mature but texturally immature. Volcanism also had commenced again, and fine ash was carried to the Wenatchee area from a distant source. The source most likely was to the south, near the John Day area of Oregon, where thicker tuffaceous beds and felsic flows of similar age are interbedded with the John Day Formation. Most of the fine ash was mixed with fine sediment winnowed from sapropelic material by stream activity, but thin ash beds locally were buried and preserved. Parts of the Wenatchee Formation were repeatedly subjected to subaerial exposure during deposition of the unit, during which times the normally blue to gray organic-rich muds were reddened by weathering processes. Shallow lakes and ponds also formed in Wenatchee time, providing catchment basins for local deposition of lacustrine facies.

The character of the upper member of the Wenatchee Formation suggests that uplift and(or) volcanic activity occurred in a nearby area.

This supplied the coarse volcanic detritus typical of the unit.

The Wenatchee Formation had minimal or no cover of younger sedimentary rocks when deformed by northeast-southwest compressive stress between 34 and 29 m.y.b.p. Relatively minor stacked thrust faults carried Chumstick Formation out of the graben and onto the gneissic basement east of the Entiat fault. The overlying Wenatchee Formation also was cut by the thrusts and was folded in a unique style. Thust faults that are reported within Chumstick rocks in the northern part of the Chiwaukum graben may correlate with the documented post-Wenatchee age thrusts.

At about 30 m.y.b.p., but perhaps occurring over a period of several million years, the Horse Lake Mountain intrusive complex was emplaced. Intrusion was synchronous with northwest-trending, right-lateral strike-slip deformation that cut obliquely across the southern part of the Chiwaukum graben. Chumstick bedding was rotated and distended within a shear couple, allowing passive emplacement of the many sills and associated dikes of hornblende andesite. Due to the thinness of the Wenatchee Formation and a lack of overlying younger rocks, magma intruded as sills in inclined Chumstick bedding was channeled into the unconformity between the Wenatchee and Chumstick Formations, making the largest single intrusive mass of the complex — the Canyon Number One stock and composite sill. The Wenatchee Pinnacles probably are part of the same intrusive event, though they are not dated. Hydrothermal activity associated with these intrusions caused several periods of silicification, primarily of previously or contemporaneously brecciated rocks, and deposited economic amounts of gold and other metals.

It is conceivable that the shear couple that allowed passive emplacement of the Horse Lake Mountain intrusive complex and the minor thrust faulting that affects the Wenatchee Formation are contemporaneous. There is some evidence that thrusting may have been oblique to the Entiat fault. Compression in a northerly direction could result in the west-northwest-trending, right-lateral shear couple associated with intrusion of andesites as well as north-northeast-directed thrust faults along the eastern border of the Chiwaukum graben.

High-angle faults of uncertain age cut both the Wenatchee Formation and andesites of the Horse Lake Mountain complex. Some of them may result from post 34 m.y. and(or) post 29 m.y. rejuvenation of high-angle faults of the Eagle Creek anticline that began in Chumstick time.

The Wenatchee Formation was thinned erosionally, progressively more to the northwest, before deposition of the Columbia River Basalt Group. An unnamed shaly unit of Miocene age was deposited on the Wenatchee Formation, also prior to basalt deposition, at least in the area near the city of Wenatchee. The Wenatchee Formation and the Miocene shales probably thicken to the south and connect with, respectively, the lower and upper members of the John Day Formation of Oregon (see Fisher and Rensberger, 1972).

The Columbia River Basalt Group was deposited over an interval of several million years, beginning in the middle Miocene. It probably covered all of the Wenatchee and Monitor quadrangles.

The ancestral Columbia River and its tributaries breached the basalt flows, and erosional destruction of basalt continued as Cascade uplift arched the flows gently upward to the west. By Pliocene time, basaltic mass wasting debris covered large parts of the area. With further erosion, basalt debris locally acted as a protective cap that resulted in inverted topography in the terrain west of the Columbia River. The terrain east of the Columbia River consists largely of basaltic landslide debris that continues to creep and slide in modern time.

Catastrophic flooding down the Columbia River valley occurred during Pleistocene time. The river was dammed downstream of Wenatchee, creating a lake that existed for perhaps 1,000 to 2,000 years. Deposits related to the lake are still preserved in at least one tributary valley; later flooding removed lake deposits from the main Columbia River valley. Terraces composed largely of gravel with minor sand were deposited by flood waters east of the Columbia River, and both water- and ice-transported erratics were left in widely scattered localities. Windblown loess was deposited in the area and formed particularly thick mantles over the terrain east of the Columbia River. Caliche horizons formed locally in loess.

A number of occurrences of unnamed sedimentary units of unknown age and correlation are present in the area. They are poorly exposed and of small extent. They are probably of Pliocene to Pleistocene age.

There is no evidence for late Cenozoic movement on the Entiat fault in the Wenatchee area, although possibly late Cenozoic normal faulting took place along the Entiat fault in the northern part of the graben.

Volcanic ash from the eruption of Mount Mazama (Crater Lake) in southern Oregon 6,600 years ago was deposited in the Wenatchee area. Pockets of ash are preserved locally at bottoms of valleys and intermittent drainages. The area received a light dusting of ash from the eruption of Mount St. Helens on May 18, 1980. Hardly any trace of this ash fall is preserved.

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BRIAN J. BOYLE, Commissioner of Public Lands
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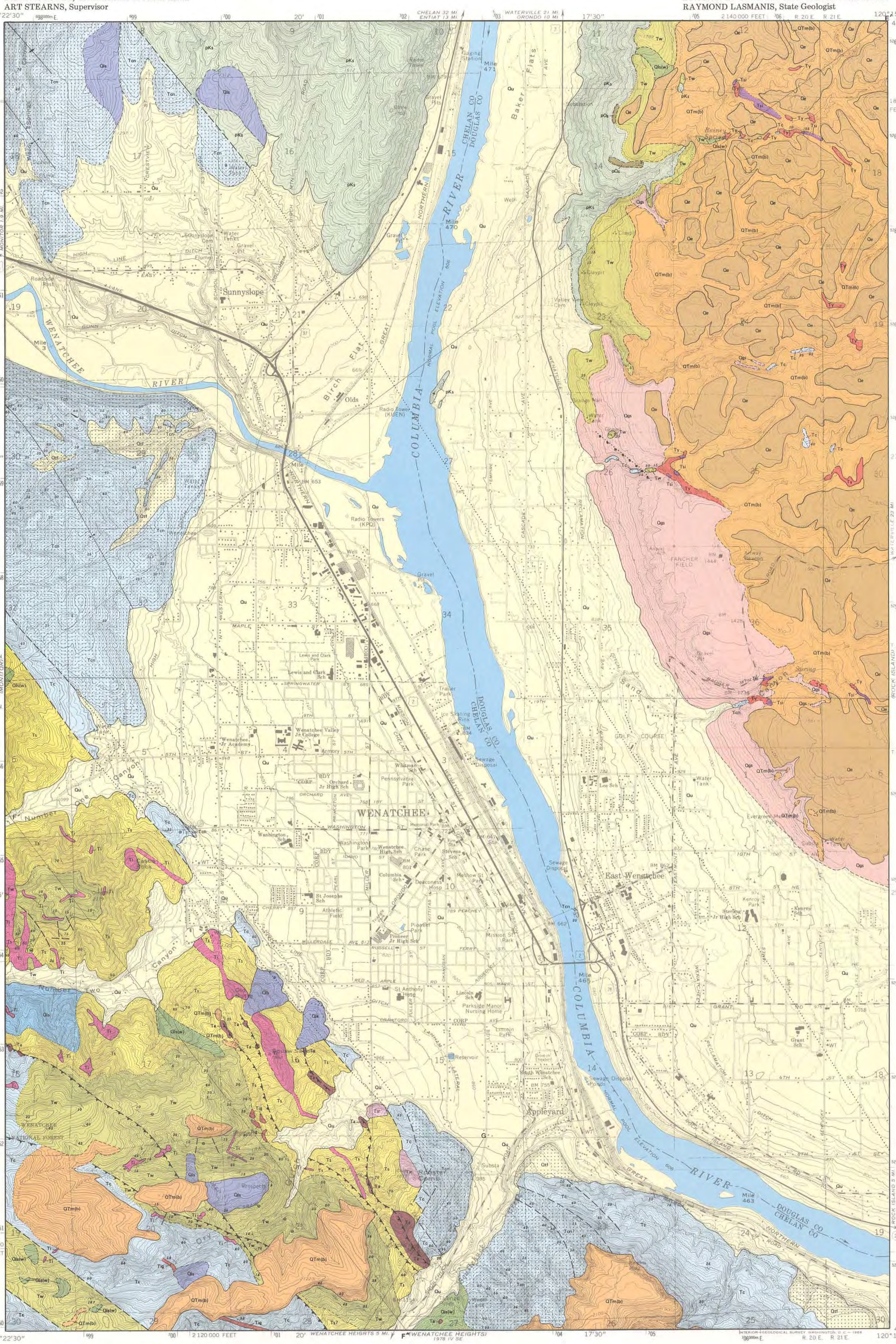
DIVISION OF GEOLOGY AND EARTH RESOURCES
RAYMOND LASMANIS, State Geologist



Base map from U.S. Geological Survey 7½-minute Wenatchee Quadrangle
Cartography by Keith G. Ikerd

UTM GRID AND 1966 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

QUADRANGLE LOCATION

DESCRIPTION OF UNITS

SURFICIAL DEPOSITS

Qe Eolian deposits (Pleistocene to Recent), east of the Columbia River, mostly underlain by mass wasting debris

Qu Fluvial deposits, alluvial fans, and other undifferentiated deposits of Pleistocene to Recent age

Qls Landslide deposits

Qls(w) Landslide deposits composed of debris from the Wenatchee Formation

Qtf Terrace deposits of lacustrine or deltaic origin related to damming of the Columbia Valley during the Spokane Flood

Qgs Sand and gravel deposits mainly as giant bar deposits east of the Columbia River formed during the Spokane Flood

QTm(b) Mass wasting deposits that probably range in age from Pliocene to Recent. Composed mostly of debris from the Columbia River Basalt Group. Includes debris flows, talus deposits, and local stream-rounded cobbles

SEDIMENTARY AND EXTRUSIVE IGNEOUS ROCKS

pQs Unnamed sedimentary rocks of uncertain age and correlation, occuring east of the Columbia River

Ty Yakima Basalt, a Subgroup of the Columbia River Basalt Group. Occurrences shown east of the Columbia River are mostly not in place, but are massive blocks of basalt within a terrane of mass wasting debris

Tsi Interflow sedimentary beds of feldspathic sandstone and shale that are within the Miocene Columbia River Basalt Group. Some occurrences are relatively coherent masses within a terrane of mass wasting debris; others may be only slightly, if at all, displaced from their original depositional position

Tw Wenatchee Formation of Oligocene age. Includes a lower member composed of bluish-gray tuffaceous shale, siltstone, and dirty sandstone interbedded with buff-colored beds of quartz sandstone. Thin coal seams and tuff horizons occur locally. Reddish-stained intraformational paleosols are common. The upper member is white conglomeratic sandstone

Tc Chumstick Formation of middle to late Eocene age. Consists primarily of buff to tan feldspathic sandstone interbedded with shale, siltstone, and conglomerate. Thin coal seams occur locally. Includes all of the lower part of the Chumstick but also is used for coarser facies of the upper (Nahahum Canyon) member that are indistinguishable from Tc

Tcn Nahahum Canyon Member of the Chumstick Formation. Consists primarily of brown shale and siltstone with interbedded buff to tan sandstone. This depositional facies of the Chumstick Formation is restricted to the upper part of the unit; time-equivalent coarser beds representing influence of alluvial fan deposition are mapped as Tc

Ts Swauk(?) Formation of late Eocene age. Well-indurated light- to dark-gray felspathic sandstone interbedded with shale and conglomerate. Commonly contains thick calcite veins

METAMORPHIC ROCKS

pKs Swakane Biotite Gneiss of pre-Late Cretaceous age. Consists of relatively homogeneous quartz-feldspar-biotite gneiss, locally schistose. Contains minor interbeds of amphibolite and marble. Quartzofeldspathic pegmatites occur mainly concordant to foliation, but locally are cross cutting

INTRUSIVE IGNEOUS ROCKS

Tig Unnamed gabbro intruded into the lower part of the Chumstick Formation, dated at 48.3 ± 2.8 mybp

Tir Biotitic rhyodacite porphyry. These are the felsic rocks of the Wenatchee Pinnacles. Age is uncertain, but is within the range of 43 to 51 mybp

Ti Hornblende andesite, possibly with minor amounts of dacite in the mafic rocks of the Wenatchee Pinnacles. Most of the unit mapped as Ti is the Horse Lake Mountain complex. Similar appearing rocks of the Wenatchee Pinnacles are given the same designation. The andesites of the Horse Lake Mountain complex have an average of 30 mybp; mafic rocks of the Wenatchee pinnacles are not dated

HYDROTHERMALLY ALTERED ROCKS

Ta Hydrothermally altered rocks associated with intrusive rocks. Alteration largely is as bleaching and silicification of breccia zones

LEGEND

Contact
Dashed where approximately located; dotted where concealed

Normal fault
Dashed where approximately located; dotted where concealed; queried where uncertain.

Thrust fault
Dashed where approximately located; dotted where concealed. Sawteeth on upper plate

Anticline

Syncline
Dotted where concealed

15?
Strike and dip of inclined beds. Dip queried where uncertain

25
Strike and dip of overturned beds

Horizontal beds

Strike of vertical foliation

GEOLOGIC MAP OF THE WENATCHEE QUADRANGLE, WASHINGTON

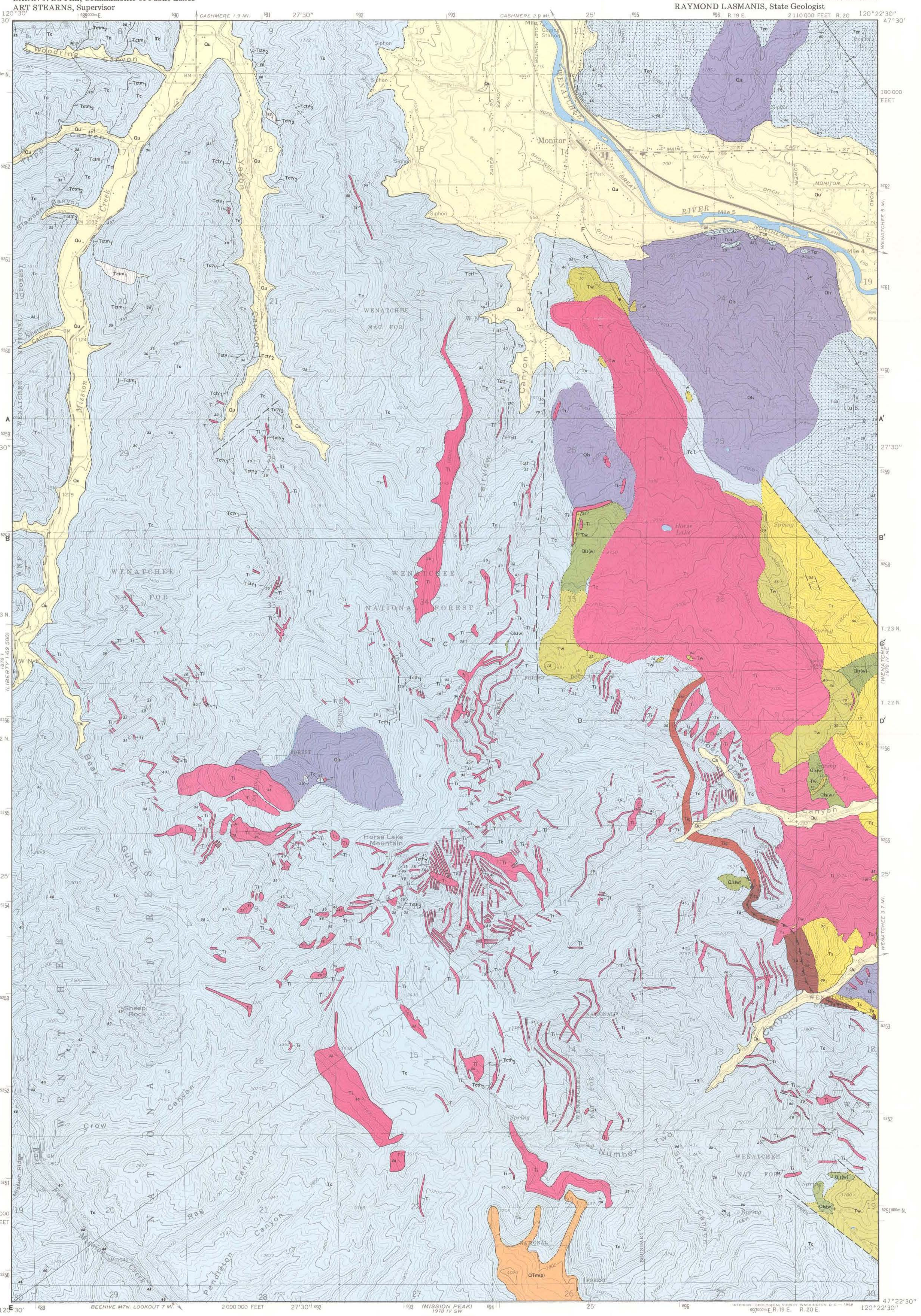
BY
RANDALL L. GRESENS

1983

WASHINGTON STATE DEPARTMENT OF NATURAL RESOURCES
BRIAN J. BOYLE, Commissioner of Public Lands
ART STEARNS, Supervisor

DIVISION OF GEOLOGY AND EARTH RESOURCES
RAYMOND LASMANIS, State Geologist

BULLETIN 75
PLATE 2

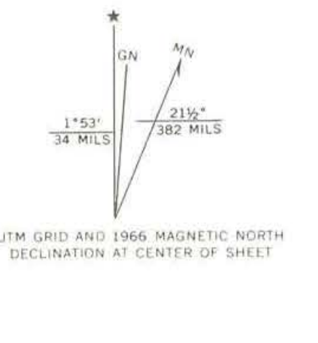


Base map from U.S. Geological Survey 7½-minute Monitor Quadrangle

Cartography by Mark D. MacLeod

SCALE 1:24 000

CONTOUR INTERVAL 40 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929



UTM GRID AND 1966 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

QUADRANGLE LOCATION

DESCRIPTION OF UNITS

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Qls(w) Landslide deposits composed of debris from the Wenatchee Formation

QTm(b) Mass wasting deposits that probably range in age from Pliocene to Recent. Composed mostly of debris from the Columbia River Basalt Group. Includes debris flows, talus deposits, and local stream-rounded cobbles

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$Tctm_2$, **$Tctm_1$** Tuff beds of Mission Creek

$Tcty_1$, **$Tcty_2$**, **$Tcty_3$** Tuff beds of Yaxon Canyon

$Tcth_1$, **$Tcth_2$**, **$Tcth_3$** Tuff beds of Horse Lake Mountain

Tctf Tuff bed of Fairview Canyon

Mappable tuff beds within the lower part of the Chumstick Formation. Thickness ranges from 1 to 7 feet and colors include white, light gray, and olive green. Tuff beds typically are fine grained and often include weak to well-developed fluvial bedding and detrital admixture. Local pumiceous facies are present. Tuff is hard and brittle, and frequently is iron stained along fractures and in Liesegang ring structures. Zeolitization is common. Dashed where approximately located; dotted where concealed

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LEGEND

Contact
Dashed where approximately located; dotted where concealed

Normal fault
Dashed where approximately located; dotted where concealed; queried where uncertain. D and U show relative movement

Thrust fault
Dashed where approximately located. Sawteeth on upper plate

Anticline

Syncline
Dotted where concealed

Strike and dip of inclined beds. Dip queried where uncertain

Strike and dip of overturned beds

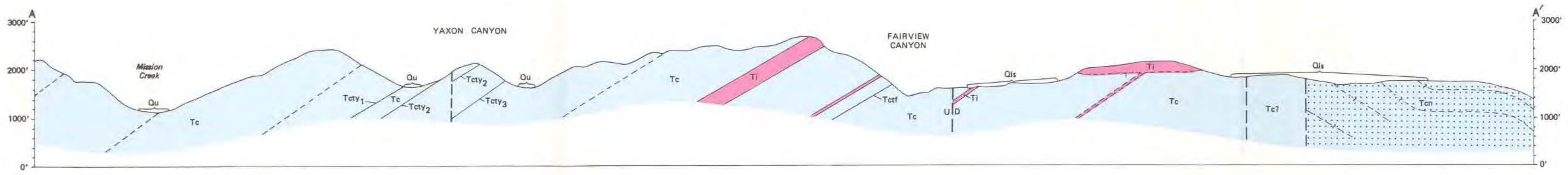
Horizontal beds

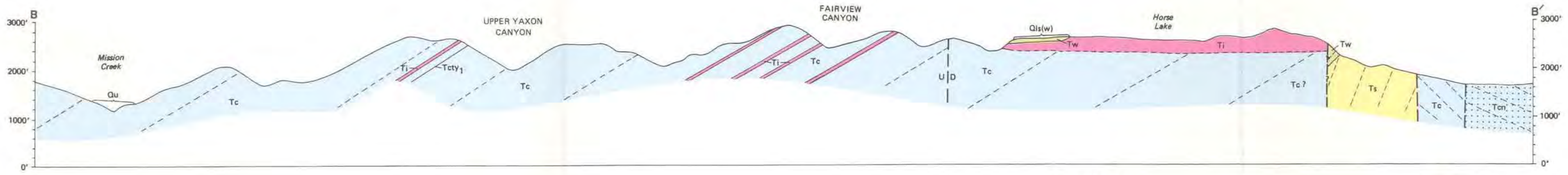
GEOLOGIC MAP OF THE MONITOR QUADRANGLE, WASHINGTON

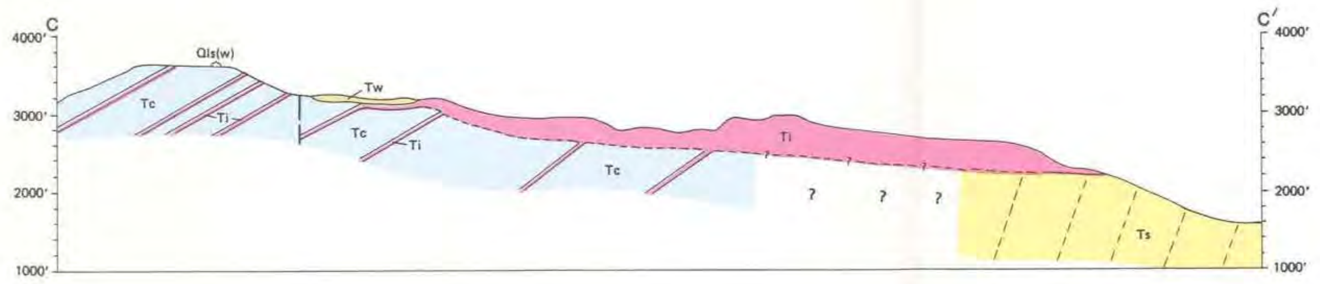
BY

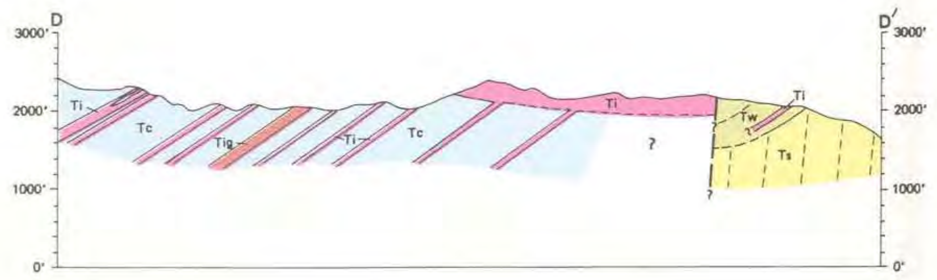
RANDALL L. GRESENS

1983

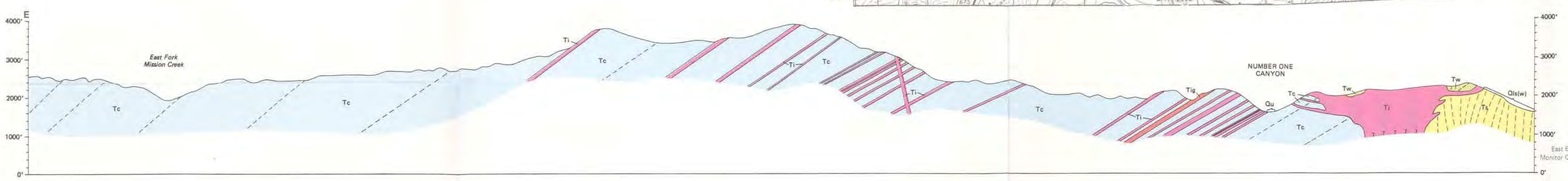


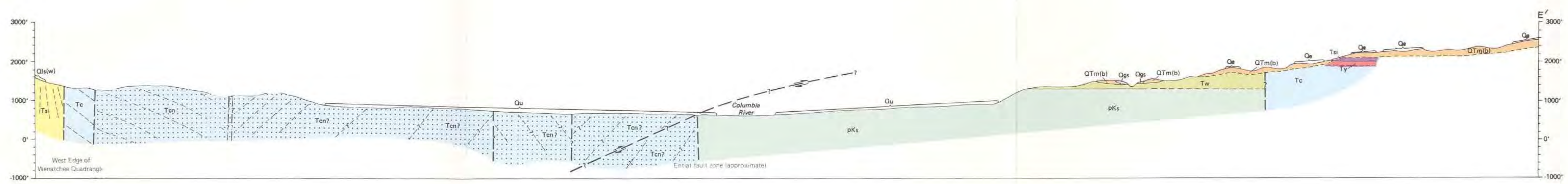






Elevations on cross sections in feet above sea level





LEGEND

———— - - - ? - - -
Contact

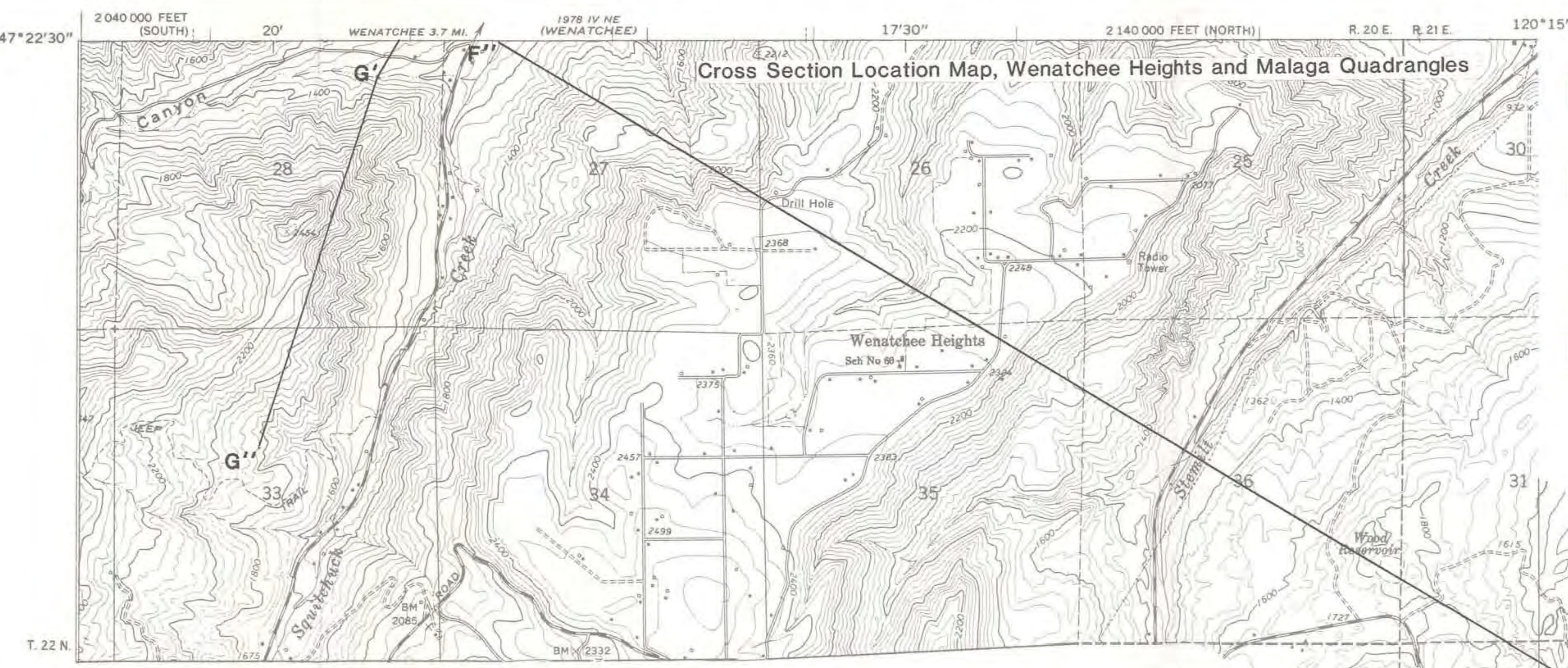
Dashed where approximately located; queried where uncertain

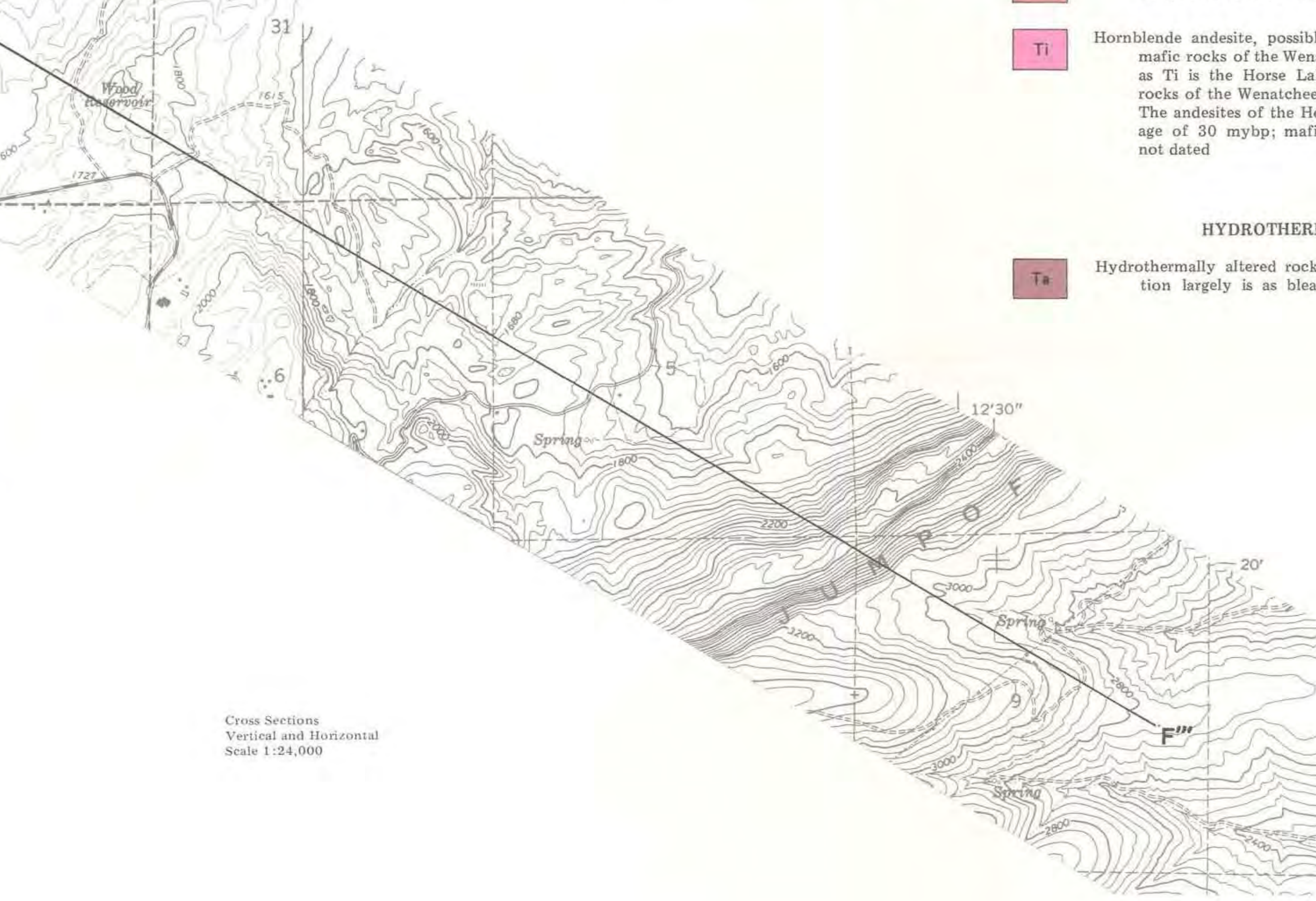
Normal fault

Dashed where approximately located; queried where uncertain; D and U show direction of movement

Thrust fault

Dashed where approximately located; queried where uncertain. Arrows show direction of movement. Circled dot shows movement toward viewer; circled cross shows movement away from viewer





Cross Sections
Vertical and Horizontal
Scale 1:24,000

DESCRIPTION OF UNITS

SURFICIAL DEPOSITS

Qe Eolian deposits (Pleistocene to Recent), east of the Columbia River, mostly underlain by mass wasting debris

Qu Fluvial deposits, alluvial fans, and other undifferentiated deposits of Pleistocene to Recent age

Qls Landslide deposits

Qls(w) Landslide deposits composed of debris from the Wenatchee Formation

Qgs Sand and gravel deposits mainly as giant bar deposits east of the Columbia River formed during the Spokane Flood

QTm(b) Mass wasting deposits that probably range in age from Pliocene to Recent. Composed mostly of debris from the Columbia River Basalt Group. Includes debris flows, talus deposits, and local stream-rounded cobbles

SEDIMENTARY AND EXTRUSIVE IGNEOUS ROCKS

Ty Yakima Basalt, a Subgroup of the Columbia River Basalt Group. Occurrences shown east of the Columbia River are mostly not in place, but are massive blocks of basalt within a terrane of mass wasting debris

Tsi Interflow sedimentary beds of feldspathic sandstone and shale that are within the Miocene Columbia River Basalt Group. Some occurrences are relatively coherent masses within a terrane of mass wasting debris; others may be only slightly, if at all, displaced from their original depositional position

Tsu Unnamed sedimentary beds of Miocene age, consisting primarily of bentonitic shale with minor poorly consolidated beds of feldspathic sandstone and conglomerate

Tw Wenatchee Formation of Oligocene age. Includes a lower member composed of bluish-gray tuffaceous shale, siltstone, and dirty sandstone interbedded with buff-colored beds of quartz sandstone. Thin coal seams and tuff horizons occur locally. Reddish-stained intraformational paleosols are common. The upper member is white conglomeratic sandstone

Tc Chumstick Formation of middle to late Eocene age. Consists primarily of buff to tan feldspathic sandstone interbedded with shale, siltstone, and conglomerate. Thin coal seams occur locally. Includes all of the lower part of the Chumstick but also is used for coarser facies of the upper (Nahahum Canyon) member that are indistinguishable from Tc

Tcn Nahahum Canyon Member of the Chumstick Formation. Consists primarily of brown shale and siltstone with interbedded buff to tan sandstone. This depositional facies of the Chumstick Formation is restricted to the upper part of the unit; time-equivalent coarser beds representing influence of alluvial fan deposition are mapped as Tc

$Tcty_1$, **$Tcty_2$**, **$Tcty_3$** Tuff beds of Yaxon Canyon
Tctf Tuff bed of Fairview Canyon

Mappable tuff beds within the lower part of the Chumstick Formation. Thickness ranges from 1 to 7 feet and colors include white, light gray, and olive green. Tuff beds typically are fine grained and often include weak to well-developed fluvial bedding and detrital admixture. Local pumiceous facies are present. Tuff is hard and brittle, and frequently is iron stained along fractures and in Liesegang ring structures. Zeolitization is common. Dashed where approximately located; dotted where concealed

Ts Swauk(?) Formation of late Eocene age. Well-indurated light- to dark-gray felspathic sandstone interbedded with shale and conglomerate. Commonly contains thick calcite veins

METAMORPHIC ROCKS

pKs Swakane Biotite Gneiss of pre-Late Cretaceous age. Consists of relatively homogeneous quartz-feldspar-biotite gneiss, locally schistose. Contains minor interbeds of amphibolite and marble. Quartzofeldspathic pegmatites occur mainly concordant to foliation, but locally are cross cutting

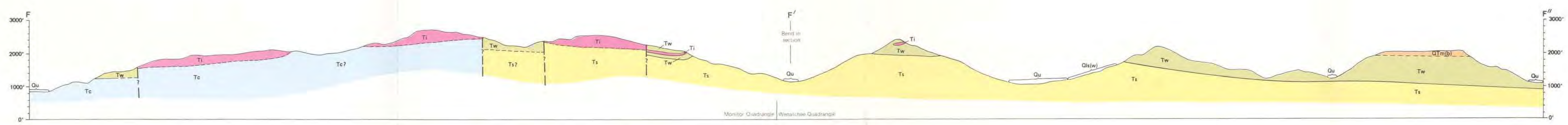
INTRUSIVE IGNEOUS ROCKS

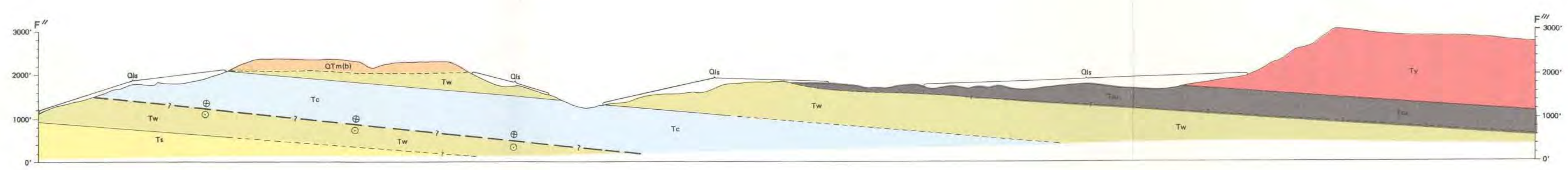
Tig Unnamed gabbro intruded into the lower part of the Chumstick Formation, dated at 48.3 ± 2.8 mybp

Ti Hornblende andesite, possibly with minor amounts of dacite in the mafic rocks of the Wenatchee Pinnacles. Most of the unit mapped as Ti is the Horse Lake Mountain complex. Similar appearing rocks of the Wenatchee Pinnacles are given the same designation. The andesites of the Horse Lake Mountain complex have an average of 30 mybp; mafic rocks of the Wenatchee pinnacles are not dated

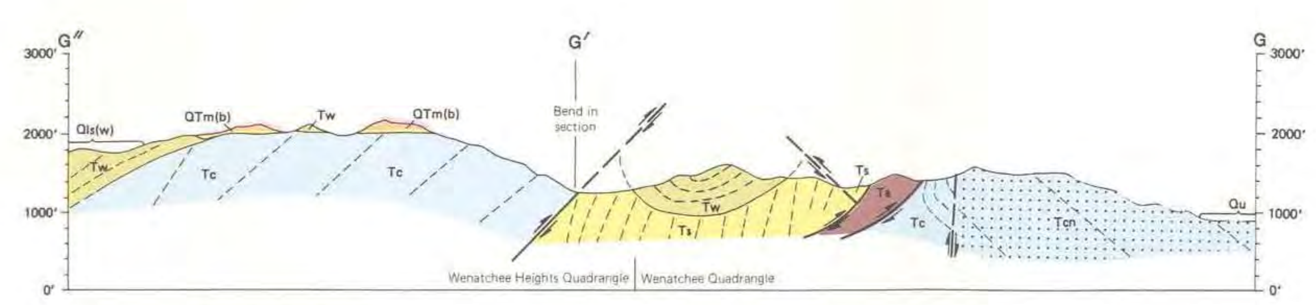
HYDROTHERMALLY ALTERED ROCKS

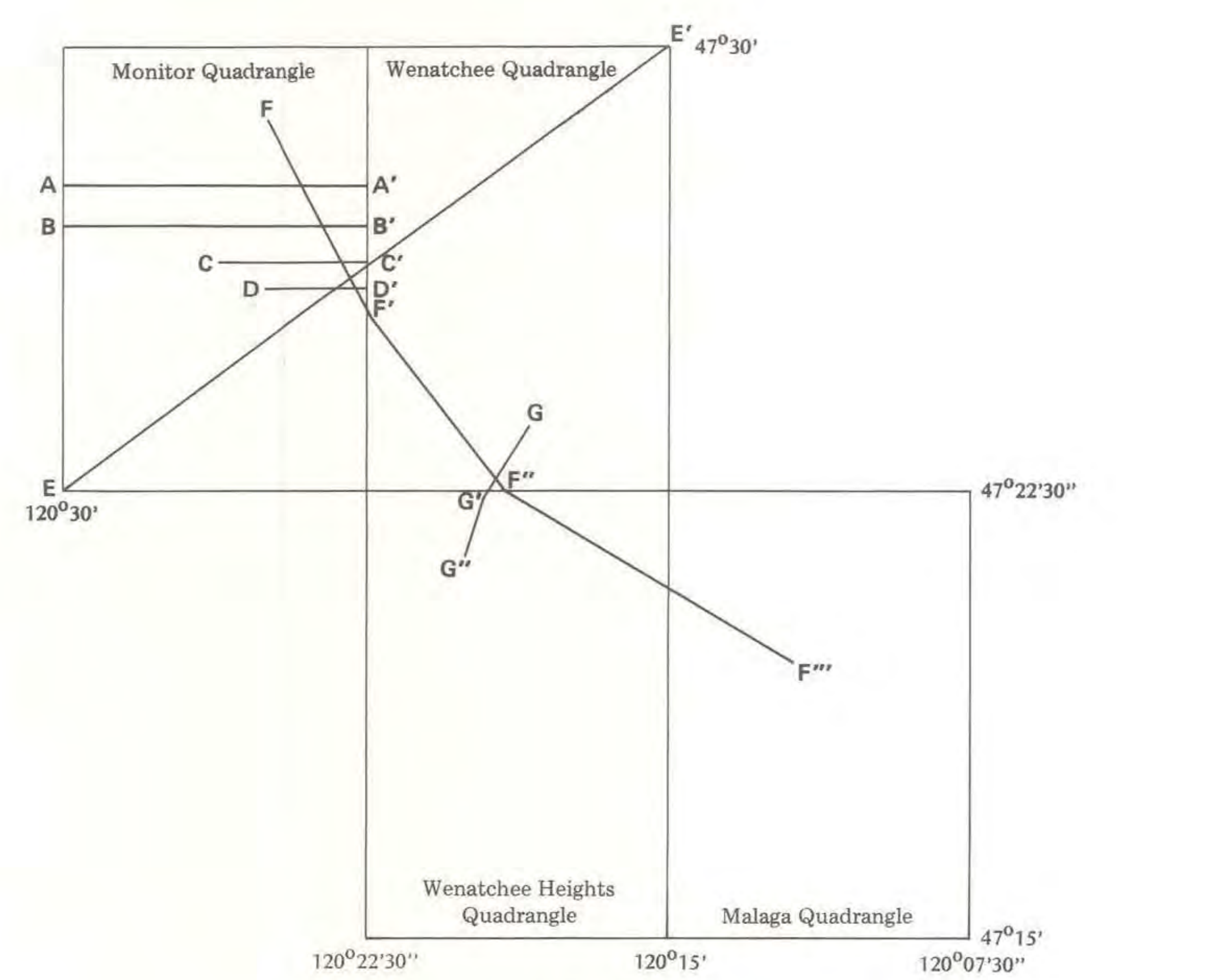
Ta Hydrothermally altered rocks associated with intrusive rocks. Alteration largely is as bleaching and silicification of breccia zones





Editor's note: Several of the cross sections, especially G-G′-G″, are not in agreement with the geologic maps. Rather than inadvertently changing the author's intent, we have refrained from changing either the geologic maps or the cross sections unless the changes clearly rectified errors or were unmistakably indicated by the text.





Cross Section Index Map

GEOLOGIC CROSS SECTIONS OF THE WENATCHEE, MONITOR, WENATCHEE HEIGHTS, AND MALAGA QUADRANGLES, WASHINGTON

BY
RANDALL L. GRESENS

1983

Cartography by Keith G. Ikerd and Mark D. MacLeod