Field Trip Guide: Geology and Art
Cascade Mountains & Columbia Plateau

The Evergreen State College
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The purpose of this field guide is to give you, the student, a general description of the geologic history and formations that we will encounter on our field trip. I have also included references so that you can gain additional, more detailed, information if you wish to. This guide does not replace the field notes that you will be taking! Use this for reference but describe everything that you see in your own notes.

White Pass Region

Geologic History

Volcanism has occurred episodically in the Cascade Range for the past 50 million years (Vance and Naeser, 1977; McBirney and others, 1974; Hammond and others, 1977). The rocks exposed in the region between Mount St. Helens and Mt. Rainier (White Pass) can be divided into the following four groups: (a) pre-Tertiary units, (b) Western Cascade volcanic and sedimentary strata, (c) lava flows of the Columbia River Basalt group and associated sedimentary and volcanic rocks, and (d) late Cenozoic volcanics of the High Cascades. One of the most interesting units exposed along US Hwy 12 is the Tieton Inlier, a Mesozoic terrane.

The Tieton Inlier, a domal uplift consisting of upper Jurassic and lower Cretaceous oceanic rocks, is exposed extensively in the White Pass - Tieton region. This is a pre-Tertiary metamorphic complex that has been divided into two units, the Russell Ranch fm. and the Indian Creek amphibolite (Vance and others, 1987). This inlier is the southern-most exposure of pre-Tertiary basement rocks in the Washington Cascades. These units correlate with melange units found further to the north, in the Snoqualmie - Skykomish region and the Ingalls complex near Ellensburg and Leavenworth.

Exposure of the Eocene volcanic and sedimentary rocks is limited and, when present, are overlain conformably and disconformably in different areas by the Western Cascade Group (Cascade magmatic arc) (Vance and others, 1987). Exposures have local, informal, names but no formal formation names have been proposed. Extensive radiometric dating (55 to 42 Ma) indicates that these sediments can be broadly correlated with the Puget group to the west and the Swauk and Naches fms. to the north (Vance and others, 1987). The basal date (55 Ma) is temporally equivalent to the Swauk and Chuckanut fms. of the Leavenworth region and the upper “Summit Creek Basalt” unit is equivalent to the Teanaway Basalt. The “Summit Creek Sandstone” is the same age as the sediments of the Rosyln Fm. (Vance and others, 1987). Fluvial sandstones in the Summit Creek region have southwesterly paleocurrent directions. This unit grades conformably into the overlying Ohanapecosh fm. (Vance and others, 1987). The thickest sedimentary sequences are found west of the inlier.

The Ohanapecosh fm. is widely exposed in southern Washington between the Columbia River Gorge and Snoqualmie Pass. This unit represents the first volcanic expression of the Tertiary Cascade magmatic arc in southern Washington and marks the end of the Eocene tectonic regime (and Chalis volcanic arc) in the Pacific Northwest (Vance, 1982). The facies have been

interpreted as debris flows and turbidites generated by subaqueous eruptions (Fiske and others, 1963) but evidence, such as the lack of pillows, accumulations of pumice and accretionary lapilli, carbonized wood and nonmarine vertebrate fossils suggest a terrestrial source, if not subaerial deposition (Vance and others, 1987). Fission-track data indicate that the Ohanapecosh fm. was deposited during an interval which at least spans the age range 36 to 28 Ma (Vance and others, 1987).

The Fifes Peak fm. overlays the Ohanapecosh fm. in the White Pass-Tieton River region but an intermediate unit, the Stevens Ridge fm., has been identified in the park to the north (Fiske and others, 1963). Age data and lateral correlations indicate that the Stevens Ridge unit differs significantly in stratigraphic position, lithology, and age with the type Stevens Ridge and, thus, can not be physically correlated. The Stevens Ridge fm., which is a silicic pyroclastic unit, is probably laterally discontinuous and lithologically equivalent to many units within the Fifes Peak fm. and not unique to a single stratigraphic interval in the Washington Cascades (Vance and others, 1987). The long interval of subsidence which allowed the Ohanapecosh fm. to accumulate ended by 27 Ma with an episode of folding, uplift and erosion. The Fifes Peak activity was initiated by violent, large-volume eruptions of silicic pyroclastics from a number of vents; at least one of which was a major caldera (Fiske and others, 1963; Vance and others, 1987). Fifes Peak volcanism lasted from 25.5 to at least 22 Ma, ceasing prior to extrusion of the Columbia River Basalts (16 Ma).

The Grande Ronde Basalt is a subgroup of the Columbia River Basalt group. These flows came from the east from fissures on the Columbia Plateau, moving along valleys and inundating low-lying areas (Schmincke, 1967; Swanson, 1967; Swanson and others, 1975; Hammond and others, 1977). Additional information on these basalt flows can be found in the next section (Yakima to Ellensburg).

Epizonal plutons ranging in composition from diorite to granite and many dikes and plugs of andesite and basalt make up the late Cenozoic volcanics of the High Cascades. Hydrothermal alteration of some epizonal stocks have been dated from 24.0 to 6.2 Ma (Armstrong and others, 1976) but in general these young rocks are unaltered and undeformed. The north-south trending range is superimposed on a divergent fold-fault fabric which trends northwest, parallel to the Olympic-Wallowa lineament (Zeitz and others, 1971; Hammond and others, 1977).

Geologic Units (oldest to youngest)

Tieton Inlayer

Indian Creek Gneiss and Amphibolite: tectonic lense of interlayered amphibolitic, dioritic and tonalitic gneiss, hornblendite, and lesser amounts of quartz diorite pegmatite, cataclastic orthogneiss and mylonite (Hammond and others, 1977). This unit has experienced high-temperature deformation (metamorphism). The base of this unit is not exposed and the age of the protolith is unknown. The age of amphibolite grade metamorphism is approximately 155 Ma (Mattinson, 1972). The unit appears to have been emplaced as a solid mass within the Russell Ranch Fm. and is interpreted as part of an ophiolite (ocean crust) assemblage (Hopson and Mattinson, 1973).

Russell Ranch Formation: highly sheared argillite, graywacke sandstones, slate, bedded chert, chert pebble conglomerate and greenstone with local pillow lavas and tonalite. The base of this unit is not exposed nor is the age well constrained (Campbell, 1975). This unit attains a thickness of more than 3,000 m in the White Pass region. The graywacke is coarse grained and has been interpreted as being deposited as a delta in a freshwater environment (Ellingston, 1968) and as part of a flysch assemblage (Hammond and others, 1977; Vance and others, 1987). The age of the unit has been suggested to be Upper Jurassic to Lower Cretaceous (Vance and others, 1987). The composition and age of this unit is very similar to the malange assemblage exposed further to the north.

Western Cascade Group

Unnamed Eocene strata: various local names are given to these Eocene sequences ("Summit Creek Sandstone", "Spencer Creek Tuff", "Lookout Creek Sandstone"). These sequences contain subaerial basalt flows, micaceous quartzose sandstones and silicic pyroclastic rocks.

Ohanapecosh formation: thick sequence (3,000 m) of volcaniclastic rocks (andesite with lesser basalt and rhyolite) and lava flows, volcanic breccias and sandstones with interbedded andesite lavas, tuffs (pumice, lithic and lapilli) and mud flows (Campbell, 1975; Fiske, 1960; Wise, 1970). Unlike the Eocene sediments which contain quartzose sandstones, nonvolcanic detritus is rare in the Ohanapecosh and younger strata of the Cascades (Vance and others, 1987). This unit is pervasively altered (metamorphosed), mostly in zeolite facies (Fiske and others, 1963; Hartman, 1973). Deposited was both subaqueous and subaerial (Hammond and others, 1977). The age of this unit is Oligocene (Vance and Naeser, 1977).

Fifes Peak formation: dark lava (porphyritic pyroxene andesite) and mud flows, volcaniclastics (tuffs, pumice, breccia). The thickness and facies vary considerably but it attains thicknesses of up to 3,000 m adjacent to the Tieton volcano. The Fifes Peak fm. was deposited unconfomably over the Ohanapecosh Fm. during the late Oligocene to middle Miocene (Fiske and others, 1963; Campbell, 1975; Hammond and others, 1977).

Stevens Ridge member: green, brown and violet volcaniclastic rocks (rhyodacite to dacite), ash flows, light-colored sandstones and siltstones frequently with quartz. As thick as 1,500 m. Deposited in the middle Oligocene to early Miocene. (Vance and Naeser, 1977; Campbell, 1975).

Wild Creek sediments: green, brown and violet volcaniclastic rocks (tuffs and pumice) that were eroded from nearby volcanoes and deposited in quiet water. Fossils (horse and rhino) indicate a late Oligocene - early Miocene age (Swanson, 1964). Up to at least 300 m thick (Hammond and others, 1977).

Tieton facies: dike swarm with hypersthene-augite andesite dikes

Grande Ronde Basalt: thick sequence of basalt flows (subgroup of the Columbia River Group) which have been divided up into a multitude of members (Campbell, 1975; Hammond and others, 1977). Colonnades, vessicles, pillows (with palagonite), porphyritic (plagioclase) and nonporphyritic, occasional petrified wood (Campbell, 1975). Extruded during the middle to upper Miocene, between 16.5 and 8 Ma (Watkins and Baksi, 1974; NcKee and others, 1977).

Vantage Sandstone: fine to medium grained, light-gray friable sandstone with occasional crossbedding located toward the top of the Grande Ronde Basalt. Very similar to the Ellensburg lithologies (Hammond and others, 1977).

Ellensburg formation: gray to brown interstratified beds of laharic breccia, volcaniclastic sandstone, felsite and pumice pebble conglomerate and air-fall tuff grade southwestward into fluvial sandstone and conglomerate containing plutonic and metamorphic clasts derived from a northern and eastern source (Hammond and others, 1977; Sheppard, 1967; Homgren, 1969). Attains thicknesses of 300 m and deposited during the late Miocene to lower upper Pliocene (Campbell, 1975). Near Naches the formation consists of sand, silt, clay, and conglomerate. The sand and silt is made up of pumice, ash, and quartz while the gravel-sized material is tuff and andesite. The Ellensburg fm. was primarily derived from clastics eroded from the volcanoes of the Cascade Range to the west (Schmincke, 1967)

Andesitic and dioritic intrusives of Tieton Basin: dark brown to reddish brown prophyritic hypersthene-augite andesites that occur in a series of northwest trending. The larger plutons include Westfall Rocks and Goose Egg Mtn. Miocene in age (Swanson, 1964; Hammond and others, 1977).

Devils Horns Pyroclastics: pyroclastics and some interbedded andesite flows, 75 m thick, upper Pliocene in age (Campbell, 1975).

Tieton Andesite: dark gray hypersthene-augite andesite porphyry with large plagioclase phenocrysts. Formed at least two intercanyon flows down the Tieton River canyon. Vent in the Goat Rocks region. Age is 690,000 years (Hammond and others, 1977).

Spiral Butte Andesite: light gray, platy hypersthene-hornblende-augite andesite flow with associated yellow tuffs, 30 - 130 m thick. The age is Pliocene to 10,000 years (Hammond and others, 1977).

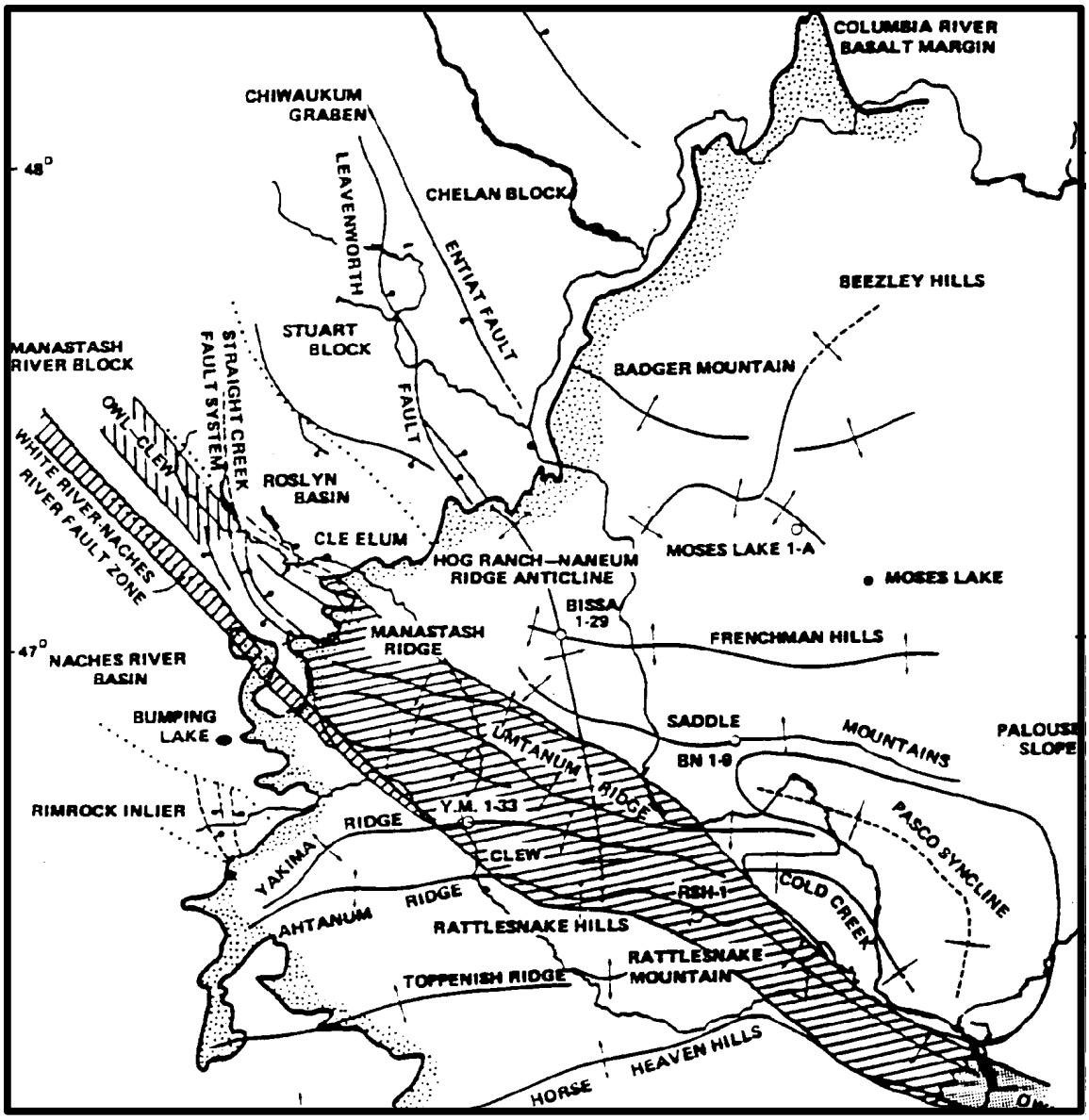
Hogback Mountain olivine basalt: overlays the Ohanapecash Fm. to the west and is Pleistocene in age (Campbell, 1975).

Columbia Plateau

Geologic History

The Columbia Plateau is a broad plain situated between the Cascades and the Rocky Mountains and is characterized by the Columbia River Basalt Group which covers the plateau. Two regional structures cross the central and western part of the plateau: the Olympic-Wallowa lineament and the Hog Ranch-Naneum Ridge anticline. The Olympic - Wallowa lineament (Cle Elem - Wallowa deformed zone) is a rather diffuse zone of anticlines that trend 310° (NW) (Keinle and others, 1977; Reidel and Campbell, 1989). The Hog Ranch-Naneum Ridge anticline is a basement-controlled anticline that extends southward from the North Cascades and forms the western boundary of the Pasco Basin (Tabor and others, 1984; Reidel, 1984).

The Yakima Fold Belt consists of a series of asymmetrical anticlines and synclines which trend east-west, created by a Miocene phase of north-south compression. The synclines tend to have gently dipping north limbs and steep south limbs and the anticlines are cored by thrust faults (south and north dipping). The segment of the Olympic-Wallowa lineament (OWL) that crosses the Yakima Fold Belt is dominated by Rattlesnake Mountain. Folded are the Columbia River Basalts and intercalated sediments of the Ellensburg Fm. Deformation was concurrent with the later eruptions of the Columbia River Basalt Group and fold continued after the cessation of volcanism (ca 6 Ma), leading to as much as 1,000 m of structural relief in the past 10 my (Reidel and others, 1994). The rate of subsidence and fold growth in the Columbia Basin has decreased from the Miocene to Holocene. The total shortening across the Yakima Fold Belt probably does not exceed 25 km.


COLUMBIA RIVER BASALT MARGIN
CHIWAUKUM GRABEN
48°
LEAVENWORTH
CHELAN BLOCK
ENTIAT FAULT
BEEZLEY HILLS
STUART BLOCK
MANASTASH RIVER BLOCK
STRAIGHT CREEK FAULT SYSTEM
FAULT
BADGER MOUNTAIN
OWL CLEW
WHITE RIVER-NACHES RIVER FAULT ZONE
ROSLYN BASIN
CLE ELUM
HOG RANCH—NANEUM RIDGE ANTICLINE
MOSES LAKE 1-A
MOSES LAKE
BISSA 1-29
MANASTASH RIDGE
FRENCHMAN HILLS
47°
NACHES RIVER BASIN
BUMPING LAKE
SADDLE MOUNTAINS
PALOUSE SLOPE
BN 1-9
UMTANUM RIDGE
RIMROCK INLIER
Y.M. 1-33
RIDGE
PASCO SYNCLINE
CLEW
YAKIMA RIDGE
RSH-1
COLD CREEK
AHTANUM RIDGE
RATTLESNAKE HILLS
RATTLESNAKE MOUNTAIN
TOPPENISH RIDGE
HEAVEN HILLS
HORSE

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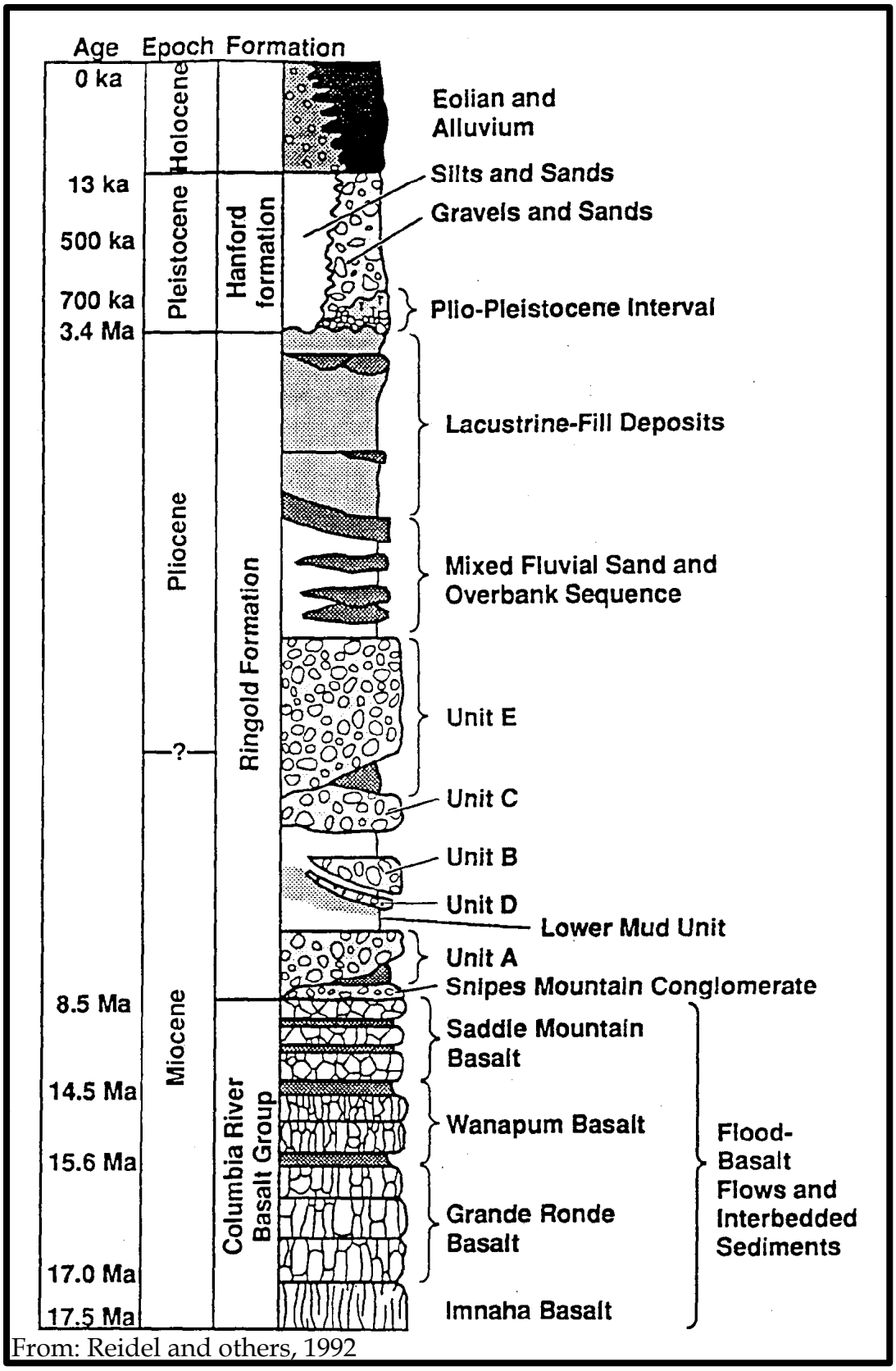


From: Reidel and others, 1992

Geologic Units (oldest to youngest)

Naches fm.: fluvial, feldspathic sandstones, rhyolite flows and tuffs of late Eocene age that occur in the central Cascade Range west of Yakima. The Naches Fm. is primarily confined to the area bounded on the south by the White River-Naches River fault zone and on the north by splays of the Straight Creek fault (Reidel and Campbell, 1989). This unit is lithologically and temporally equivalent to the Swauk fm. to the north.

Columbia River Basalt group: a sequence of approximately 300 continental tholeiitic flood-basalts that were erupted between 17 and 8 Ma. This group has gone through several phases of unit redesignation; presently five formations are recognized: Imnaha, Grande Ronde, Gorge, Wanapum, and Saddle Mountains. The Grande Ronde, Wanapum and Saddle Mountains fms. are the only units exposed in the western plateau. Basalt flows are distinguished by a combination of lithology, chemistry, and paleomagnetic data with chemistry and paleomagnetics being the most reliable (Swanson and others, 1979). In this guide we are employing a mixture of old and new unit designations.

Imnaha Basalt: lowest basalt unit (16.5 Ma)
Grande Ronde Basalt: (16.5 - 15.6 Ma)
- Teepee Butte Member: second oldest member of the CRB
- Rocky Coulee Basalt flow: One meter of well-developed columns , flattened vesicles in upper 6 m. Fine-grained and essentially nonporphyritic.
- Museum Basalt flow: Contains small feldspar phenocrysts, vesicles similar to Rocky Coulee flow pipe vesicles

Vantage Sandstone: fine to medium grained, light-gray, friable sandstone, some crossbedding, some clay and silt interbeds.
Wanapum Basalt: (15.6 - 14.5 Ma) exposed in the Gable anticline, north of the 200 site
- Frenchman Springs Member: Contains three sub-members including the Gingko flow, Sand Hollow flow and Sentinel Gap flow. The Gingko flow contains abundant pillow palagonite, the Sand Hollow flow has an upper and lower columnar zone and the Sentinel Gap flow contains irregular joints and masses of palagonite.
- Squaw Creek Diatomite: white diatomite and some siltstone.

Roza Basalt: large lath-shaped plagioclase phenocrysts and thick columns with platy parting perpendicular to column length.
- Priest Rapids Member: Large columns, weak platy parting, medium to coarse grained, phenocrysts absent
- Pomona Basalt flow: flattened vesicles and fan-shaped columns in entablature

Saddle Mountain Basalt: (14.5 - 8.5 Ma) exposed in the Gable anticline, north of the 200 site

Ellensburg formation: conglomerates and sandstones with interbedded with and overlying Columbia River Basalt flows. Less than 100 m thick and deposited during the Miocene and Pliocene (16.5 to 7.4 Ma) (Smith and others, 1988). Near Naches the formation consists of volcanic debris flows (lahars), sand, silt, clay, and conglomerate. The sand and silt is made up of pumice, ash, and quartz while the gravel-sized material is tuff and andesite. The Ellensburg fm. was derived from clastics eroded from the volcanoes of the Cascade Range to the west (Schmincke, 1967). Further to the east the sediments were deposited by the ancestral Clearwater and Columbia rivers (Fecht and others, 1982; 1987).

Ringold Formation: fluvial gravels, sands, paleosols, vertical accretion, lacustrine alluvial fan deposited during the late Miocene to middle Pliocene. In the Hanford region the Snipes Mountain Conglomerate is the oldest suprabasalt sedimentary unit laterally equivalent to the Levy interbed of the Ellensburg fm., this is the base of the Ringold fm. This unit is up to 185 m thick at the Hanford site but pinches out against structural highs (Lindsey, 1994).
- Wooded Island member - basal fluvial unit (coarse-grained)
- Taylor Flats member - sandy fluvial and overbank
- Savage Island member - lacustrine

Tieton Andesite: in the Naches region the Tieton Andesite is composed of about 70% groundmass (plagioclase and pyroxene) and 30% phenocrysts (plagioclase and augite). Well developed colonade and entablature, 30 - 170 m thick and lower Pleistocene in age.

Plio-Pleistocene unit: a laterally discontinous fluvial unit that is up to 25 m thick, consisting of calcium carbonate-rich, locally derived basalt gravel and sand. The river gravel was derived from the ancestral Yakima, Snake, or Columbia rivers (Lindsey, 1994). This unit is frequently included in the Ringold fm.

Hanford formation: Pleistocene pebble to gravel conglomerate, coarse-grained sand and silt and rhythmites ("Touchet Beds") which were deposited by the cataclysmic Bretz floods. This unit is up to 95 m thick. The rhythmites were

deposited in a temporary lake, Lake Lewis, behind a hydraulic dam that was created at Wallula Gap (water level approximately 370 - 385 m above sea level (Lindsey, 1994).

Swauk Pass Region (Ellensburg to Leavenworth)

Geologic History

During the Paleogene there was (oblique) right-lateral movement on several faults in central Washington including the Straight Creek, Leavenworth, Entiat and Eagle Creek systems (Frizzell, 1979; Vance and Miller, 1981; Tabor and others, 1984; Johnson, 1985; Evans, 1988; Taylor and others, 1988; Evans and Johnson, 1989). Nonmarine clastics were deposited in basins which were created by these movements, forming some of the thickest sequences of nonmarine strata in North America (over 6,000 m). Sediments of the Swauk and Chumstick fms. were deposited in a syntectonic manner in basins separated by the Leavenworth Fault. At times the Leavenworth fault was not active and deposition was continueous across both sub-basins.

In the early Eocene, the fault-bounded mountains were composed of crystalline rocks in central Washington. Fluvial systems built alluvial fans on plains adjacent to the blocks and syntectonic sediments of the Swauk and Chumstick fms. were deposited. During the earliest phase of deposition the source of the sediments appears to have been east of the Entiat-Eagle Creek Faults (based on fine-grained sandstones of Swauk Pass and coarser grained gluvial deposits in the Chumstick Fm.) The Mt. Stuart massif (Cretaceous granitic batholith intruding a Jurassic ophiolite complex, the Pashastin fm.) appears to have been a prominent highland. Lateritic soils, that had developed on the ultramafic terrane, were eroded and redeposited (basal member of the Swauk Fm.). Swauk conglomerate is particularly abundant near the contact with the Mt. Stuart massif (granitic and metamorphic clasts) and the conglomerates to the southeast, away from the massif are primarily light-colored volcanic clasts. Paleocurrents show considerable variability suggesting meandering rivers or multiple sources feeding the basin. Several hundred meters of Swauk clastics accumulated before the Silver Pass Volcanic facies were deposited (Gresens and Whetten, 1977).

The Silver Pass and Swauk clastics were tightly folded along an east-west axis (indicating a north-south compressional phase) and eroded prior to the eruption of the middle Eocene Teanaway Basalt (Tabor and Frizzell, 1977; Gresens, 1979; Ewing, 1980; Gresens, 1987). This deformation occurred between 51 and 47 Ma. The Chumstick rocks in the Chiwaukum Graben have a structural grain that trends northwest, parallel to the trend of the Leavenworth Fault, not the east-west tend seen to the southwest.

The northeast trending Teanaway dike swarm are coeval with the northwest trending bimodal (mafic and felsic) Corbaley Canyon dike swarm (dated at 47 - 48 Ma) located only 50 km away (Foster, 1958; Southwick, 1966; Gresens, 1987). The Teanaway dikes trend 15° and are nearly vertical which suggests a WNW-ESE extensional event during Teanaway time (Gresens, 1987). The Teanaway thins to the east but extends further that eruptives of the Silver Pass Volcanoes. Arkosic clastics continued to be deposited, they are a minor component toward the source of the Teanaway (presumed to be southwest of Mt. Stuart) but thick accumulations of arkose interfinger with thin eastern tongues of Teanaway Basalt in the Chumstick Creek region (Gresens and Whetten, 1977). The age of the basalt is about 47 Ma based on whole-rock K-Ar ages (Gresens, 1987). The Corbaley Canyon dike swarm show a strong northwest trend which indicates NNE-SSW crustal extension (Gresens, 1987).

The Roslyn formation was deposited conformably on the Teanaway as volcanism waned and by late Roslyn time swamps predominated toward the west (now coal seams). The Roslyn fm. was contemporaneous and may have been locally continuous with the Chumstick fm. in the Chiwaukum Graben (Gresens, 1987).

Concurrently, arkosic clastics continued to accumulate in the Chiwaukum graben indicating the Entiat Mountain block was uplifting persistently along the east side of the graben and supplying clastics to the graben along the fault. The Leavenworth Fault Zone, on the west side of the graben, was active at least in the early part of Chumstick Creek time as indicated by fanglomerates and monolithologic fanglomerate breccia deposited along the fault zone (post-Teanaway time). Fanglomerates along the southern Leavenworth Fault Zone in both the Swauk and Chumstick unit indicate a complex history of fault movement and that the highlands west of the fault was not persistent (Gresens and Whetten, 1977; Gresens, 1987). The northwest trending Chiwaukum graben was active over a 6-million year span during the middle Eocene, starting around 46 Ma, and 5,800 m of Chumstick fm. accumulated in it (Whetten, 1977; Gresen and others, 1981; Gresens, 1987).

The finer-grained Nahahum Canyon Member is located at the top of the Chumstick Creek formation which indicates a decrease in the uplift rate along the Entiat Fault (proximal fanglomerates continued to accumulate).

The region was magmatically quiet during the late Eocene and early Oligocene (40 - 34 Ma) and was beveled to a surface of low relief, mantled by deeply weathered bedrock (Gresens, 1987). Correlating, temporally, with the end of the Laramide deformation in western North America (Coney, 1971; 1972). At the end of this period the area from central Washington to the Puget Sound may have been a relatively low-lying plain, perhaps with local monadnocks of more resistant rocks (Gresens, 1987).

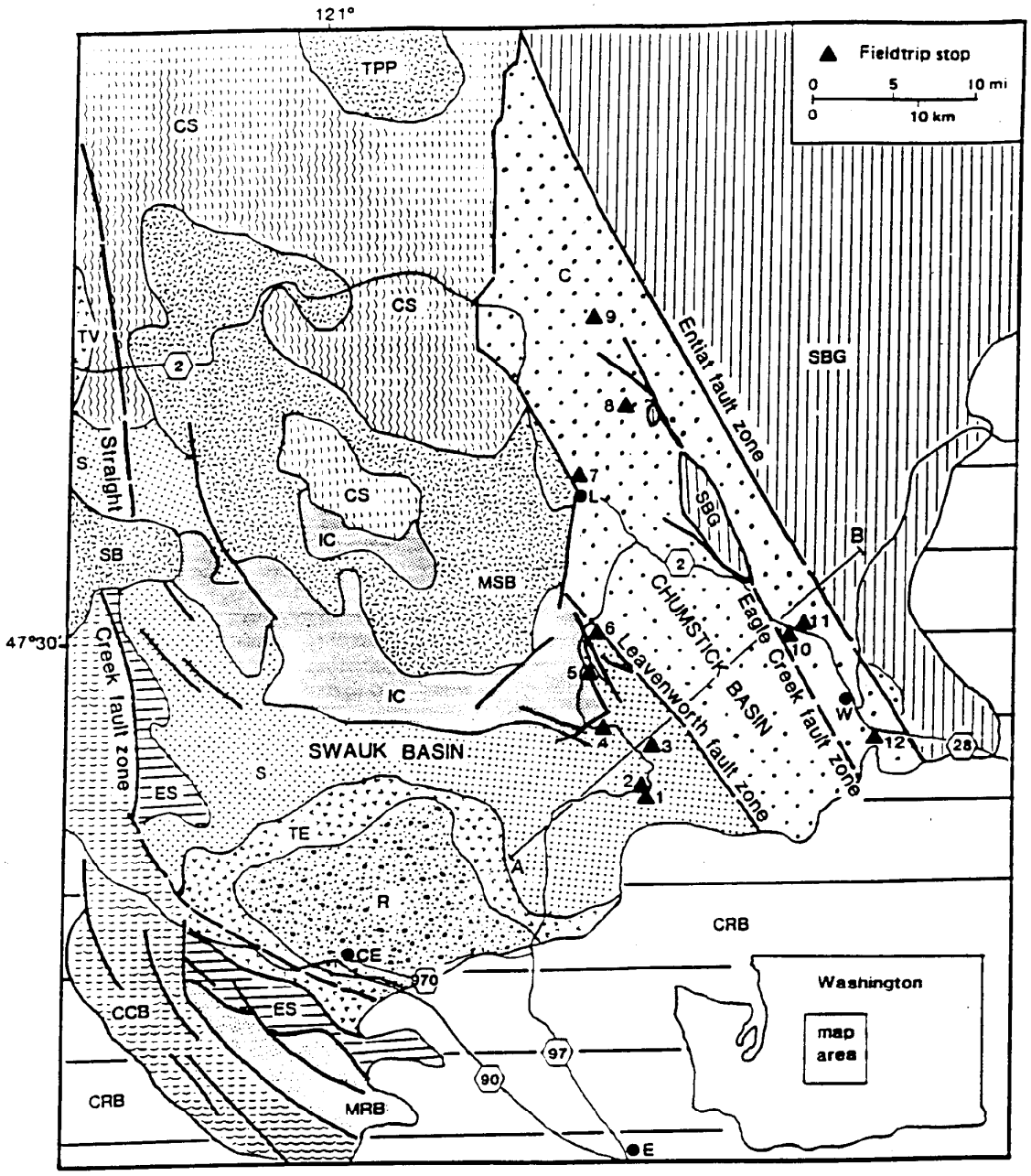
The entire sequence was deformed prior to deposition of the Wenatchee Formation of mid-Oligocene age (Laravie, 1976; Whetten and Laravie, 1976; Gresens, 1976). The age of the Wenatchee fm. is defined by two fission-track dates that average 34 Ma (Gresens and others, 1981) and from palynological data (Newman, 1977). The quartz-rich sand and tuffaceous shale (with local interbedded ash and coal horizons) of the Wenatchee fm. were deposited in a fluvial to lacustrine environments (Gresens and Whetten, 1977). This unit is about 280 m thick. The Wenatchee fm. unconformably overlays the Chumstick fm. (deposited on the erosional surface) and the Swakane Biotite Gneiss on the west and east side of the Entiat fault respectively and its unfaulted nature indicates that there has been no displacement along the Entiat fault since Oligocene time (Gresens and Whetten, 1977).

The Chiwaukum graben underwent compressional deformation between 34 and 29 Ma (Gresens, 1980) at which time rocks of the Chumstick fm. were thrust out of the graben and across the Entiat fault along northeast-directed thrust faults (2.5 - 3.0 km total shortening). This indicates a northeast-southwest crustal compression (Gresens, 1987).

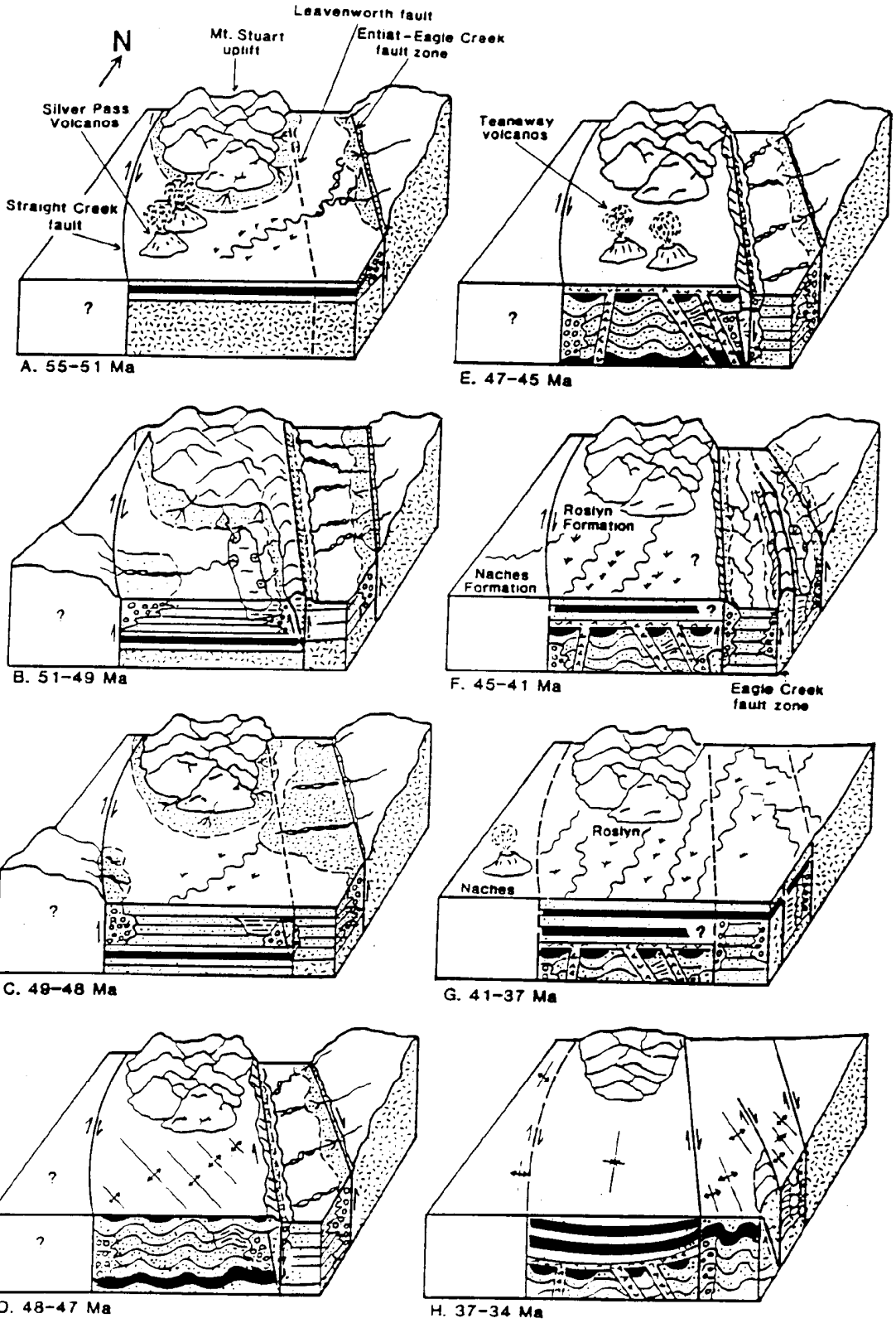
The Wenatchee fm. was folded, faulted (minor thrusts) and eroded within 5 my, prior to the emplacement of the Grande Ronde Basalt (Gresens, 1987). Hornblende andesite sills and dikes of the Horse Lake Mountain complex intruded all sedimentary units in the southern graben in the late Oligocene (average K-Ar age is 29 Ma), their emplacement was synchronous with deformation by northwest trending right-lateral shearing (Bayley, 1965; Gresens, 1983). Bentonitic shales with minor sand stringers and thin carbonaceous interbeds were of Miocene age

(palynological data) were also deposited prior to the extrusion of the Columbia River Basalt Group. The unit has been interpreted as shallow swampy lake and overbank deposits (Gresens, 1987). These unnamed continental sediments are about 50 m thick and are exposed near the town of Malaga (Gresens, 1987).

The Grande Ronde Basalt was extruded and flow was from the SE. The Mt. Stuart block continued to uplift after the emplacement of the Grande Ronde Basalt (Gresens and Whetten, 1977; Gresens, 1987).



From Evans and Johnson, 1989



From: Evans and Johnson, 1989

Geologic Units (oldest to youngest)

Ingalls Complex: the largest, best exposed, and most complete of several middle to late Jurassic ophiolites in western Washington. Structurally the Ingalls complex overlies the Chiwaukum Schist. The Ingalls complex appears to have formed near a transform fault in a backarc or marginal marine basin. It was thrust over the Chiwaukum Schist although the direction of thrusting is not clear (Paterson et al., 1994). Final thrusting occurred between 96 Ma and 93 Ma.

Peshastin Formation: metasediments, tuffs and breccias. Radiolarian chert beds indicate deep marine conditions and U-Pb data indicate a late Jurassic age (Pessagno; Southwick, 1974). The association of turbidites, deepwater shale, radiolarian chert, pillow basalts and ultramafic rock in serpentinized peridotite suggest the terrane is an ophiolite complex which was emplaced along a subduction zone (Southwick, 1974; Hopson and Mattinson, 1973; Miller, 1977).

Swauk Formation: dark-colored lithic to arkosic sandstone, thin to thickly bedded, commonly crossbedded, interbeds of dark carbonaceous siltstone and shale, some conglomerate facies, micaceous arkosic sandstones become more prominent near the Leavenworth Fault zone. The course nature of the unit and presence of leaf fossils, indicate fluvial facies (Tabor and Frizzell, 1977). A fission-track date from a tuff in the Swauk fm., near the town of Liberty, is 49±5Ma (middle Eocene) (Naeser). The Swauk fm. rests unconformably on crystalline rocks. The basal section contains ironstones that are interpreted as diagenetically altered laterites (soils) developed on underlaying serpentinite (Lupher, 1944; Lamey and Holz, 1952; Gresens, 1987). An angular unconformity between the Swauk and Teanaway Basalts indicates a phase of deformation occurred in the middle Eocene. The Swauk sediments were probably derived from the Mt. Stuart granodiorite massif to the north and perhaps locally from uplifts along the southern Leavenworth Fault Zone (Gresens and Whetten, 1977). To the west, the early and middle Tertiary sedimentary and volcanic rocks (Swauk through Roslyn) are intruded by the late Miocene Snoqualmie batholith and associated plutons, obscuring stratigraphic relationships (Gresens and Whetten, 1977). The unit is at least 2,000 m thick near the type locality (Frizzell, 1979). The Swauk is probably correlative with the Chuckanut fm. exposed in the northern Puget Sound region, west of the Cascades (Gresens, 1987), they both contain fossil palmetto leaves which are not found in the Chumstick or Rosyln fms. (diagnostic of climate, not age).

Ironstone member: discontinuous basal beds of fine-grained Ni and Fe-rich mudstone, ironstone, locally interbedded with serpentine fanglomerates (from Ingalls Complex). The ironstone appears to be recrystallized laterite which developed in pre-Swauk time (Tabor and Frizzell, 1977; Lupher, 1944; Lamey and Hotz, 1951).

Silver Pass Volcanic member (Kachess Rhyolite): green, altered volcanic tuff and breccia. Silver Pass is about 51 Ma (middle Eocene), based on zircon fission-track data (Vance and Naeser, 1977). Interfingers with Swauk fm to the west (Foster, 1960; Tabor and Frizzell, 1977). The lower age of this unit is not known but may extend into the Paleocene (Gresens, 1987).

Conglomerate and Monolithologic fanglomerate Breccia: fanglomerates locally derived from granitic and metamorphic rocks. Found in the Tronsen and Mission Creek regions, along the Leavenworth Fault Zone (southwestern margin of the Chiwaukum Graben) (Alexander, 1956; Pratt, 1958; Rosenmeier, 1968; Cashman, 1974; Cashman and Whetten, 1976; Frizzell and Tabor, 1977; Tabor and Frizzell, 1977).

Shaly facies: east of Tronsen Creek are evenly and thinly bedded sandstones, shales and minor pebble conglomerates interpreted as lacustrine (Tabor and Frizzell, 1977).

Arkosic sandstone facies: poorly sorted, thick-bedded, white feldspathic subquartzose sandstone. Found in the east in the younger part of the section. Possible precursor to the Chumstick fm. of the Chiwaukum graben (Tabor and Frizzell, 1977).

Chumstick formation: fluvial arkosic sandstones with interbedded tuff but the upper part is a shaly lacustrine facies. It was deposited in the Chiwaukum graben during Swauk, Teanaway and Roslyn time (48 - 37 Ma). Recent work has fixed the stratigraphic position (based on plant and pollen data) at middle to late Eocene and possibly extending into the lower Oligocene (Newman, 1981; Evans, 1988). The Chumstick fm. contains 17 interbedded air-fall and ash-flow tuff beds of local to regional extent, each with a distinctive trace-element chemistry (McClincy, 1986). The sediments were derived from crystalline highlands east of the Entiat fault (eastern margin of the Chiwaukum graben) (Gresens, 1987). A conservative estimate of the thickness of this unit is 5,800 m (Whetten, 1977; Gresens and others, 1981).

Nahahum Canyon member: dominantly lacustrine, fine-grained unit restricted to the eastern sub-basin of the Chiwaukum graben (between the Entiat and Eagel Creek faults)

Teanaway Basalt: unconformably (angular) over the Swauk fm., the Teanaway consists of basalt flows and pyroclastic material (basaltic to rhyolite) and minor arkosic sediments (Foster, 1960; Rector, 1962; Clayton, 1973; Tabor and Frizzell, 1977). The age has been bracketed between 52 Ma (Silver Pass) and 45 Ma (Roslyn fm.).

Roslyn formation: thick bedded, crossbedded, arkosic sandstone which is white and weathering yellow. Appears to be conformably over the Teanaway, possibly the Teanaway temporarily interrupted continuous deposition of arkosic sediments (Tabor and Frizzell, 1977). Thin laminate shales, plant fossils, thin coal deposits in the upper Roslyn suggest a fluvial to lacustrine environment with a distal source (Bressler, 1951; Clayton, 1973). The thickness of this unit has been estimated to be 1,900 m (Bressler, 1951). An age of 45 Ma (middle Eocene) has been assigned (Tabor and Frizzell, 1977).

Wenatchee formation: mature quartzose sediment which was deposited in the Chiwaukum graben during the lower Oligocene (33 Ma) after folding and erosion of the rocks of the Chumstick Creek region. Deposition occurred in a lower energy fluvial environment.

Grande Ronde Basalt: deposited unconformably (angular) over the Wenatchee fm., the Grande Ronde Basalt was extruded from 16 - 13 Ma. This indicates another phase of deformation occurred in the middle Oligocene to middle Miocene.

Geologic Maps: Tabor and others, 1982, Geologic Map of the Wenatchee 30-minute by 60-minute Quadrangle, Central Washington: USGS Map I-1331.

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Geologic Time Scale

Era	Period	Epoch	Time interval (millions of years)
Cenozoic	Quaternary	Holocene	0 - 0.01
		Pleistocene	0.01 - 1.6
	Tertiary	Pliocene	1.6 - 5.3
		Miocene	5.3 - 23.7
		Oligocene	23.7 - 36.6
		Eocene	36.6 - 57.8
		Paleocene	57.8 - 66.4
Mesozoic	Cretaceous		66.4 - 144
	Jurassic		144 - 208
	Triassic		208 - 245
Paleozoic	Permian		245 - 286
	Pennsylvanian		286 - 320
	Mississippian		320 - 360
	Devonian		360 - 408
	Silurian		408 - 438
	Ordovician		438 - 505
	Cambrian		505 - 570