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GEOLOGIC MAP OF THE WENATCHEE 1:100,000 QUADRANGLE, CENTRAL WASHINGTON

By
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INTRODUCTION

The Wenatchee quadrangle embraces a unique and varied geologic terrane of rocks and sediments ranging in age from possibly Precambrian to Holocene. Because the Tertiary and Quaternary stratigraphic record is fairly complete and because the enigmatic Olympic-Wallowa lineament (Raisz, 1945) crosses the area (fig. 1), the stratigraphic and structural relations displayed are important to an understanding of the Tertiary and Quaternary geologic history of the Pacific Northwest.

Early reconnaissance by I. C. Russell (1893, 1900) and mapping by G. 0. Smith and F. C. Calkins (1903, 1904, 1906) established a bedrock stratigraphy that has withstood later scrutiny remarkably well. Their work has been built upon, rather than replaced, by more recent geologic studies (fig. 2). The most influential early work on Quaternary deposits was by Bretz (1925, 1930) in the Columbia River valley and by Page (1939b) in the Wenatchee River valley.

The Wenatchee quadrangle is the southeastern of four 1:100,000 maps composing the 1:250,000 Wenatchee 1' x 2' sheet. We are mapping and compiling the geology of the four 1:100,000 quadrangles with the purpose of refining Tertiary and Quaternary stratigraphy and structure.

We mapped the Wenatchee quadrangle during the years 1975 through 1978. While there is overlapping responsibility for the map data for some units, the primary mapping responsibilities are: Tabor and Frizzell for the pre-Miocene rocks; Swanson, Byerly, and Bentley for the Miocene Yakima Basalt Subgroup and Ellensburg Formation; and Waitt for the Pliocene and Quaternary deposits.

Acknowledgments

Sharon Allshouse and Eduardo Rodriquez aided in the field in 1975, Jay Coburn, Van Johnson, and Ron Tal in 1976, and Kim Marcus, Margret Goddard, Bill Gaum, and Jorge Rodreguez in 1977. Bill Gaum was particularly helpful with potassium- argon dating done for this project. J. C. Yount helped differentiate the two Holocene drifts in the Enchantment Lakes area. We thank Charles W. Naeser for fission-track data on specific samples (table 1). Naeser and Charles Meyers helped considerably with the fission-track dating achieved by Virgil Frizzell for this

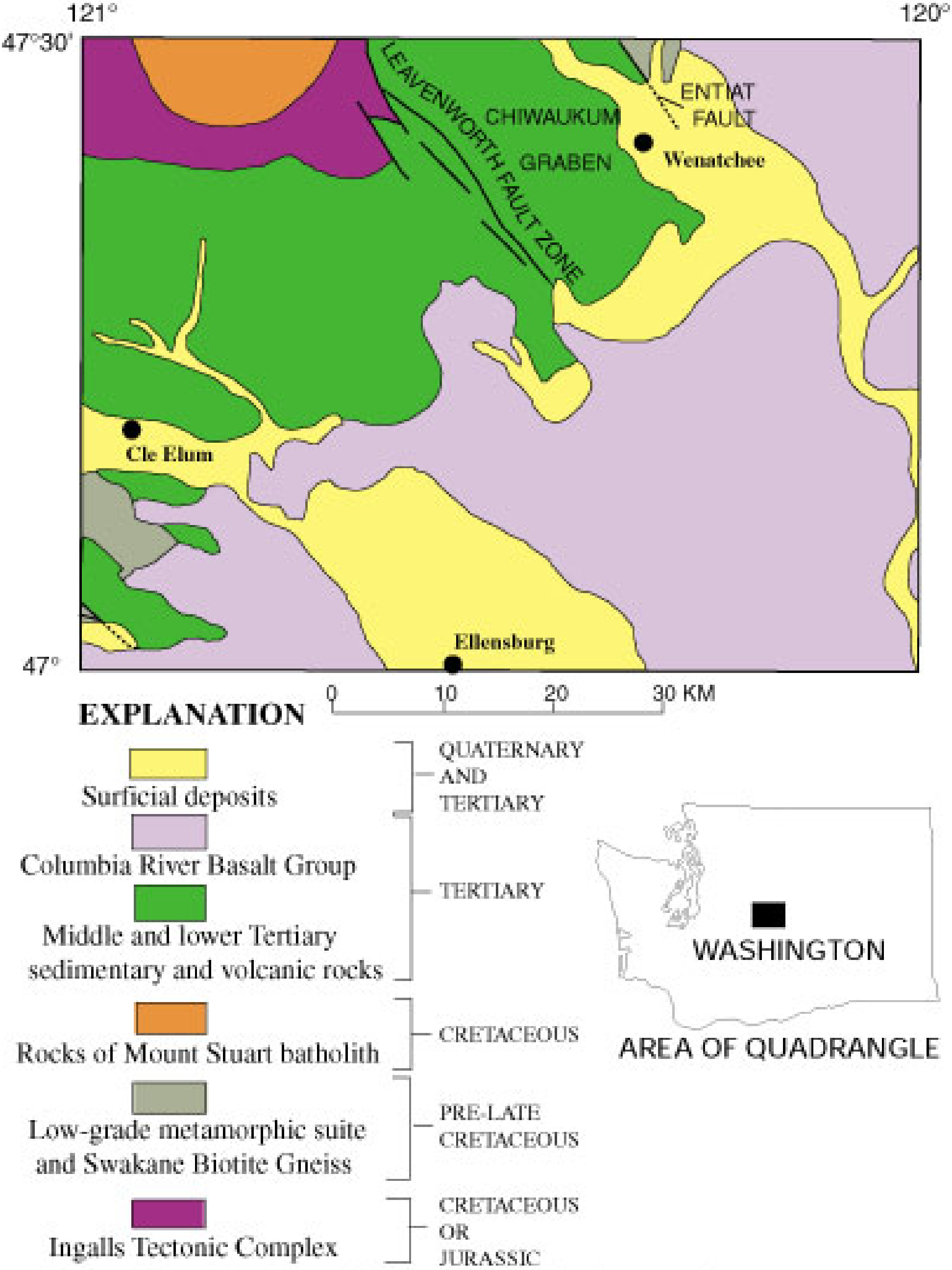

Figure 1. Generalized map of geologic terrane in the Wenatchee 1:100,000 quadrangle, central Washington (color added from original).

study. We have especially profited from discussion with R. D. Brown, R. L. Gresens, R. B. Miller, S. C. Porter, J. A. Vance, C. M. Wentworth, and J. T. Whetten.

Summary of geologic history

The rocks and deposits within the Wenatchee quadrangle can be grouped into six generalized units (fig. 1): (1) Precambrian(?) Swakane Biotite Gneiss in the northeastern part of the quadrangle and the probable Jurassic low-grade metamorphic suite, mostly composed of the Easton Schist, in the southwestern part; (2) the Mesozoic Ingalls Tectonic Complex; (3) the Mesozoic Mount Stuart batholith; (4) lower and middle Tertiary nonmarine sedimentary and volcanic rocks; (5) Miocene basalt flows and interbedded epiclastic rocks constituting part of the Columbia River Basalt Group and interbedded silicic volcaniclastic rocks of the Ellensburg Formation; and (6) Pliocene to Holocene alluvium, glacial, flood, and mass-wastage deposits.

An old terrane of eroded metamorphic and igneous rocks forms the basement for the Tertiary sedimentary and volcanic rocks. The Swakane Biotite Gneiss may be the oldest rock in the area (see below). The low-grade metamorphic suite of phyllite and greenschist was metamorphosed at least as long ago as the Early Cretaceous (Armstrong, 1980). The Ingalls Tectonic Complex is mostly serpentine and serpentinized peridotite but includes tectonic slices of Upper Jurassic metasedimentary and metavolcanic rocks, gabbro, and diabase. The Ingalls was thermally metamorphosed to varying degrees by the intrusion of the Mount Stuart batholith in the Late Cretaceous, about 93 million years ago (Engels and Crowder, 1971; age adjusted for new constants).

In the early Tertiary, differential uplift and erosion of the older rocks produced basins and graben* rapidly filled with fluvial arkose, shale, and conglomerate of the Swauk and Manastash Formations, Chumstick Formation (see Whetten in Gresens and others, 1977, p. 100-108), and basaltic to rhyolitic volcanic rocks including the Silver Pass volcanic rocks of Foster (1960), the Teanaway Basalt, the Taneum Andesite, and the basalt of Frost Mountain. The Wenatchee Formation (Gresens, Whetten, and Naeser, 1981) and possible correlatives lies with angular unconformity on the deformed earlier Tertiary rocks.

Deformation and erosion continued prior to, and perhaps during, eruption of the Miocene Grande Ronde Basalt. The continental tholeiitic basalt flows erupted southeast of the Wenatchee area and lapped up onto the higher Cascade Range. Dacitic debris spread southward and eastward from contemporaneous volcanoes in the southern Cascade Range, and feldspathic sand washed down from the northern Cascades and Okanogan Highlands to interfinger with the growing pile of basalt and form the Ellensburg Formation. The Grande Ronde Basalt and interbedded and overlying sedimentary rocks were tilted southeastward and were folded and faulted (fig. 3) as the modern Cascade Range rose and the Columbia Plateau differentially subsided. The basalt pile displays south- to southeast-trending anticlines and synclines conspicuously shown by the topography, the larger anticlines forming ridges, the synclines, valleys.

Faulting and possibly folding continued at least into the Pliocene, producing fault scarps in the Thorp Gravel in the Kittitas Valley. Growth of the Cascade Range uplifted the west margin of the Grande Ronde Basalt. Major

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*The term "graben" is used in the structural sense, meaning an elongate fault-bounded block downdropped with respect to its neighbors. The term does not imply that the infacing scarps are fault scarps.

EXPLANATION

1. Smith, 1904
2. Weaver, 1911
3. Saunders, 1914
4. Chappell, 1936a
5. Broughton, 1944
6. Lamey, 1950
7. Bressler, 1951
8. Alexander, 1956
9. Pratt, 1958
10. Foster, 1960
11. Beikman and others, 1961
12. Rector, 1962
13. Southwick, 1962
14. Stout, 1964
15. Bayley, 1965
16. Hopkins, 1966
17. Rosenmeier, 1968
18. Clayton, 1973
19. Gualtieri and others, 1973
20. Cashman, 1974
21. Pongsapich, 1974
22. Gresens, 1975
23. Miller, 1975
24. Erickson, 1977
25. Porter, 1969, 1975, 1976
26. Gresens, R. L., written commun., 1977
27. Miller, R., written commun., 1977, 1978
28. Bretz, 1925, 1930, 1969; Bretz and others, 1956
29. Hanson, 1970
30. Long, W. E., written commun., 1971
31. Patton and Cheney, 1971

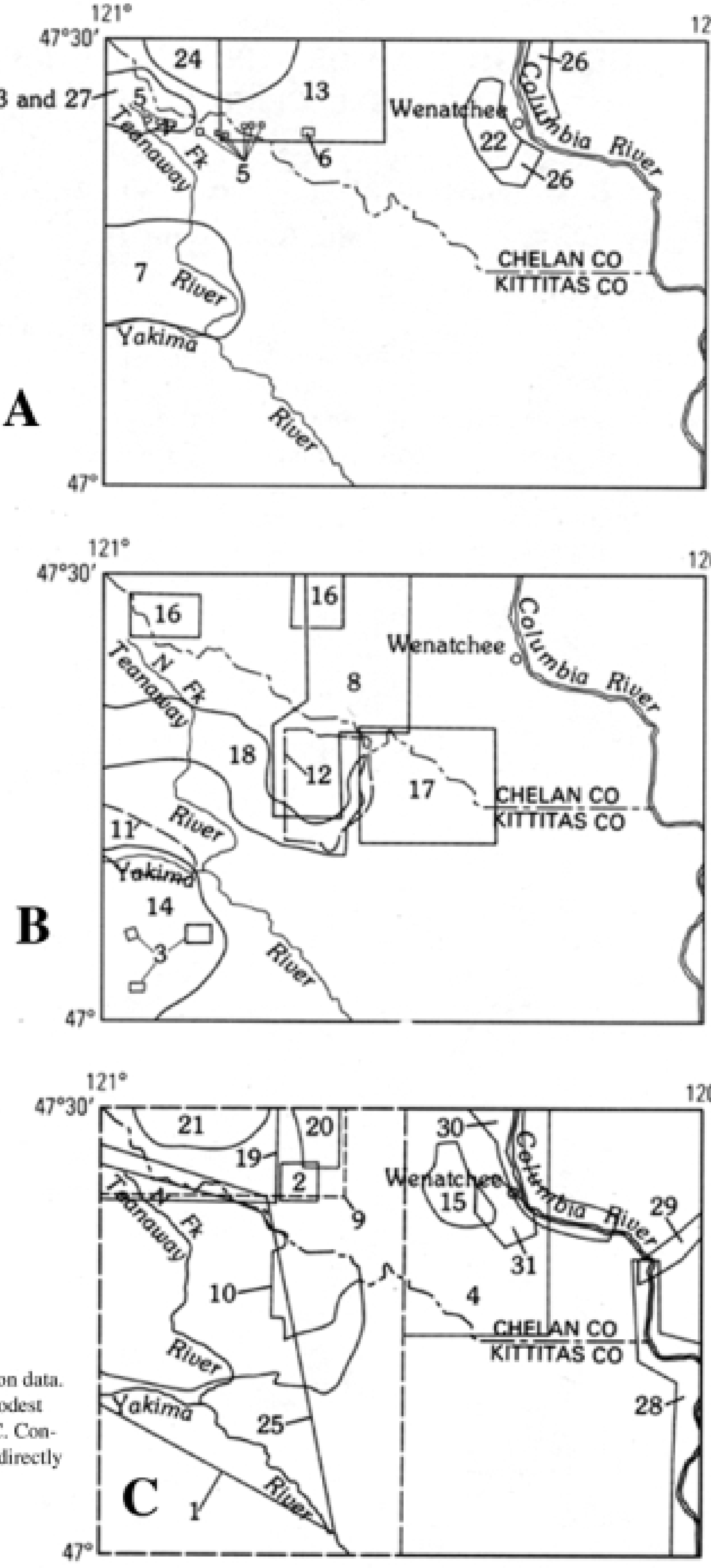

Figure 2. Sources of map compilation data. A, Much data used with little to modest modification. B, Some data used. C. Consulted extensively but data not used directly on map.

rivers and their tributaries incised, carving a regional, generally northwestward-facing erosional escarpment. Landslides, block slides, and debris flows of basalt descended into the incised valleys below. The oldest debris flows now cap divides between the Columbia River tributaries near Wenatchee, but extensive landsliding continues into the present.

Moraines, outwash, lacustrine deposits, and loess record at least three glaciations in the upper Yakima River valley. During the Pleistocene Epoch glaciers intermittently advanced down the major western tributaries of the Columbia River. Quaternary deposits along the Columbia River valley record mainly the sweep of many catastrophic late Pleistocene floods.

GENERAL DESCRIPTION OF UNITS

ROCKS BENEATH THE COLUMBIA RIVER BASALT GROUP

By R. W. Tabor and V. A. Frizzell, Jr.

PRE-TERTIARY BASEMENT

Swakane Biotite Gneiss

The Swakane Biotite Gneiss, named for exposures in the canyon of Swakane Creek, is exposed for at least 100 km northwestward from Wenatchee (Waters, 1932, p. 605; Chappell, 1936a, pl. 1; Page, 1939a, p. 8-16; Cater and Crowder, 1967). It is a remarkably uniform granofelsic gneiss although it contains minor layers of hornblende schist, amphibolite, and rare marble. Waters (1932, p. 616) and later workers (Chappell, 1936a, p. 48-49; Page, 1939a, p. 14-15; Crowder and others, 1966) considered the predominant gneiss to have been derived from clastic sedimentary rocks with rare interbedded basalt and mafic dikes. C. A. Hopson (quoted in Mattinson, 1972, p. 3773) suggested that the Swakane was originally silicic volcanic rocks. This uncertainty of origin makes interpretation of its protolith age difficult. By isotopic analyses of lead and uranium, at least some zircon from the Swakane just north of the Wenatchee sheet originally crystallized before 1,650 million years ago (Mattinson, 1972, p. 3773). If the original rock was mostly volcanic, this represents its age of formation. The rounded appearance of zircons in many specimens suggests detrital origin. The protolith could be sedimentary and the Precambrian zircons could be detrital as well. Consistent Pb-U ages on leucocratic dikes and sills and on metamorphic sphene indicate that the latest episode of regional metamorphism took place in the latest Cretaceous (Mattinson, 1973, p. 3779). The Swakane's protolith could be younger than Precambrian.

Low-grade metamorphic suite

Dark graphitic phyllite and fine-grained* greenschist and blue amphibole schist exposed southeast of Easton west of the Wenatchee quadrangle and striking southeastward into the quadrangle were assigned to the Easton Schist by Smith (1904, p. 3). Smith's Easton included some higher grade gneiss and amphibolite on South Cle Elum Ridge and elsewhere, but Stout (1964, p. 322) restricted the name Easton Schist to the low-grade metamorphic rocks. Phyllite, greenschist, and blue amphibole schist have been traced northward in a discontinuous belt for 160

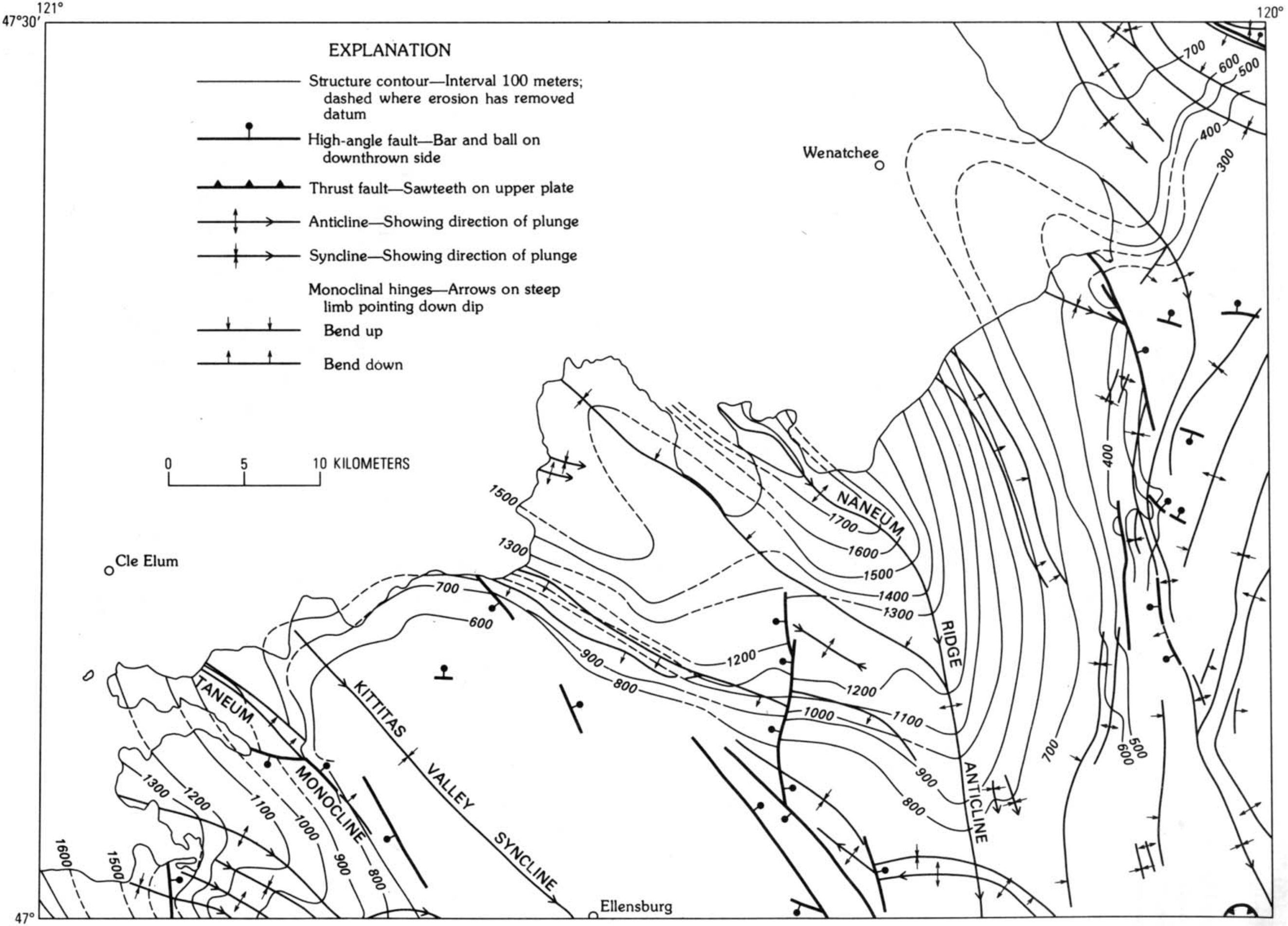

Figure 3.—Structure contour map of the Grande Ronde Basalt. Contours drawn on top of flows of reversed magnetic polarity (unit Tgr2).

km to the Canadian border (Misch, 1952, p. 7, and 1979; Vance 1957, p. 8-9; Yeats, 1964, p. 551). In the area north of the Sauk River (north of the quadrangle), they have been subdivided into the Darrington Phyllite and the Shuksan Greenschist and called the Shuksan Metamorphic Suite (Misch, 1966, p. 109). The phyllite and schist were probably derived from marine sediment and basalt (Misch, 1966, p. 109).

On the basis of numerous K-Ar and Rb-Sr ages ranging from 108 to 265 m.y. (Misch, 1966, p. 109; Engels and others, 1976; Wilson, 1978, p. 37-38; Armstrong, 1980) and initial ratios of strontium, Armstrong (1980) suggests that the Shuksan Metamorphic Suite embraces several accretionary wedges of different ages but all with Mesozoic protoliths and metamorphosed in the Late Jurassic to Early Cretaceous. Although no ages are available for the Easton Schist, its protolith probably formed prior to the Late Jurassic.

Of the Easton Schist as restricted by Stout (1964), only the phyllite with very minor greenschist and blue amphibole schist is exposed in the Wenatchee quadrangle. In the low-grade metamorphic suite, we include outcrops of greenschist and very sparsely exposed medium-grade metamorphic rocks that crop out along the South Fork of

Manastash Creek. These rocks are part of a tectonically mixed zone exposed west of the quadrangle, where greenschist, blue amphibole schist, phyllite, metavolcanic rocks, medium-grade schistose amphibolites, retrogressively metamorphosed gabbro, and serpentinite are imbricated in a broad shear zone. This tectonite zone was first mapped and described by Stout (1964, p. 319, 323, pl. 1), and we include in the zone some rocks mapped as amphibolite by him. The greenschist, blue amphibole schist, and phyllite of the tectonite zone are probably faulted slivers of the Easton Schist; we do not as yet understand the origin of the medium-grade rocks, metagabbro, and serpentinite.

Ingalls Tectonic Complex

The Ingalls Tectonic Complex crops out in a wide belt wrapping around the south end of the Mount Stuart batholith. The most abundant rocks in the belt are serpentinite and serpentinized, peridotite, but the belt includes large and small tectonic lenses and wedges of metamorphosed sedimentary rocks, mafic and intermediate volcanic rocks, and diabase and gabbro. Pratt (1958, p. 43-46) called the ultramafites the Ingalls Peridotite. Earlier workers mapped the tectonic slices as the Peshastin and Hawkins Formations (Smith, 1904, p. 3, 4), the De Roux Creek unit, the Fourth Creek gabbro, and the Esmeralda Peaks diabase (Miller, 1975).

Frost (1973b, p. 8) proposed that the Ingalls Peridotite of Pratt (1958) and Ellis (1959), named for exposures along Ingalls Creek, and certain tectonic slices that Frost mapped be included in the Ingalls Complex. He purposely excluded the Peshastin and Hawkins Formations because they had been already named. We propose that the ultramafites and all the tectonic slices in and associated with the ultramafites, including the earlier designated and apparenfly still valid formations and units mentioned here, be included in the Ingalls Tectonic Complex. Locally, all rocks of the complex are imbricated at all scales, making exclusion of one or more lithologic types arbitrary.

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*Grain size in plutonic rocks: fine grained=<1 mm; medium grained=l mm-5 mm; coarse grained=>5 mm.

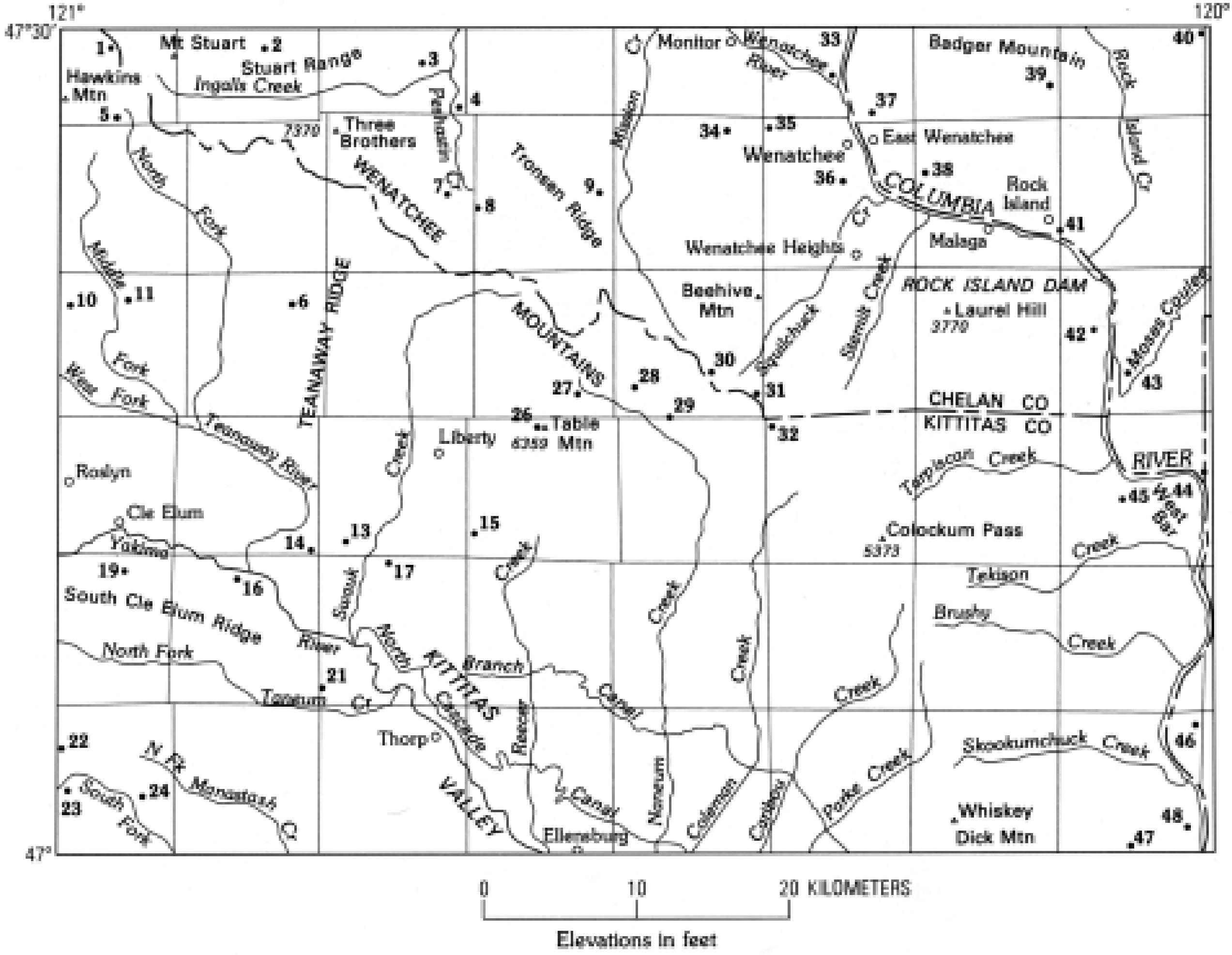

Figure 4.—Number index to location of place names in the Wenatchee quadrangle referred to in text.

Within the unit, flysch-type sandstone and argillite, radiolarian chert, pillow basalt, and ultramafic rock are intimately associated but are also tectonically intermixed: the assemblage is at least partly an ophiolite complex (Hopson and Mattinson, 1973; Miller, 1977; Miller and Frost, 1977, p. 287). Southwick (1974) proposed that the unit consists of ophiolite and island-arc material juxtaposed during subduction. Cowen and Miller (1980) suggest that the extensive serpentinized shear zones in the unit represent parts of an oceanic fracture zone.

The age of gabbro along Ingalls Creek is Late Jurassic according to a Pb-U date on zircon (Southwick, 1974, p. 391). Chert from the ridge north of King Creek contains radiolaria restricted to the Late Jurassic (E. A. Pessagno, Jr., oral commun., 1977). The K-Ar age of hornblende in a statically recrystallized diabase at the mouth of Ingalls Creek along Route 97 (table 1, no. 2) is 85.3 m.y. but this is probably a minimum age of recrystallization, produced by the heat of the 93 m.y. old Mount Stuart batholith. We accept the Late Jurassic age for most components of the complex, although it could conceivably contain tectonic slices of other ages. It was tectonically emplaced prior to the Late Cretaceous.

Units shown on the geologic map and descriptions are modified from Southwick (1962, 1974) in the eastern part of the complex, from Miller (1975) and Miller and Frost (1977) in the western part. Map units are somewhat generalized. Serpentinite is generally recognizable, even at a distance, but may contain small phacoids of the other lithologic types. Very fine grained amphibolite and greenstone commonly are hard to distinguish, even in outcrop; diabase and gabbro are intimately associated and not easily distinguished. Locally, the metasedimentary rock and metatuffs and breccias of the Peshastin and the Hawkins Formations are intimately interbedded or imbricated, and the map patterns represent the predominant lithology.

The metamorphic grade varies from greenschist and prehnite-pumpellyite facies in rocks far removed from the Mount Stuart batholith on the west side of the quadrangle to pyroxene hornfels facies in rocks adjacent to the pluton. The static thermal metamorphism caused by the intrusion is clearly imprinted on older schistose fabric. Most of the metasedimentary and metavoicanic rocks in the Peshastin Creek area are medium grade and partially granoblastic, bearing green hornblende and biotite.

Mount Stuart batholith

The Mount Stuart batholith crops out in the rugged Stuart Range in the northwestern part of the quadrangle and includes Mount Stuart (2,870 m), the second highest nonvolcanic peak in the Cascade Range. The batholith extends northwestward 55 km beyond the quadrangle. Although quartz diorite dominates overall, a considerable amount of granodiorite crops out in the Wenatchee quadrangle (Erickson, 1977a, fig. 2), and in this area Smith (1904, p. 4) called it the Mount Stuart Granodiorite.

We have modified the contacts of Erikson's (1977a, fig. 1) granodiorite phase on the basis of new data and modal and chemical data from Erikson (1977a, p. 191-194, and written commn., 1978) and Pongsapich (1974, pl. 2).

Since its early description by Russell (1900, p. 105-107), considerable work has focused on the calc-alkaline batholith (Smith, 1904, p. 4, 5; Page, 1939a; Pratt, 1958, p. 46-49; Plummer, 1969, p. 10-34; Engels and Crowder, 1971; Pongsapich, 1974; and Erikson, 1977a). The batholith is not markedly discordant with the country rock and shows a consistent faint planar alinement of minerals roughly parallel to its contacts. Although the south end of the batholith is surrounded by ultramafic rock of the Ingalls Tectonic Complex, the contact is marked by a discontinuous selvage of biotite and hornblende schists and other schistose rocks, in part tectonically mixed with the ultramafite. This selvage (contact schist of Smith, 1904) is strongly overprinted by static thermal metamorphism. Schistose metaporphyry in the contact complex and thermally metamorphosed granodiorite porphyry and quartz diorite in the Van Epps Pass [1]* area and in a dike swarm near King Creek may be early intrusive phases of the batholith.

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*Numbers in brackets after place names refer to locations on figure 4, an aid to finding obscure places on the geologic map.

Concordant K-Ar ages of hornblende and biotite and fission-track ages of allanite indicate an age of crystallization at about 93 m.y. (Engels and Crowder, 1971; age corrected for new constants). The evolution of the batholith by fractional crystallization from a mafic magma is detailed by Pongsapich (1974, p. 149-158) and Erickson (1977a).

EARLY AND MIDDLE TERTIARY SEDIMENTARY AND VOLCANIC ROCKS

Russell (1900, p. 118-119) first applied the name Swauk Formation to the sedimentary rocks exposed along Swauk Creek. Smith (1904, p. 5) and Smith and Calkins (1906, p. 4-5) extended the name to similar fluviatile arkosic sandstone in the upper Teanaway and Cle Elum drainages. Spurr (1901, p. 791), Smith (1916, p. 565-566), Galster (1956, p. 36-44), Yeats (1958, p. 128-143), and Ellis (1959, p. 18-43) mapped arkosic rocks northwest across and along the west side of the Cascade divide. Vance (1957, p. 231-238), Jones (1959, p. 116-127), Misch (1966, p. 103), Staatz and others (1972, p. 30-32), Milnes (1976, p. 56-59) and Dotter (1977, p. 36-37) have found isolated wedges of Swauk-like sedimentary rocks in a belt reaching to the Canadian border. They and other workers (see also Miller and Misch, 1963, p. 170) have correlated the Swauk Formation with the Chuckanut Formation west of the Cascade Range. Waters (1930), Chappell (1936a, p. 1), Page (1939a, p. 55), Willis (1953, p. 791), and Cater and Crowder (1967) carried the unit into the Chiwaukum graben and northward into the headwaters of the Chiwawa River. Modal data and stratigraphy of many lower Tertiary sandstone units in western Washington, including those mentioned above, here are detailed by Frizzell (1979).

Most workers refer to the sandstone of the Swauk as arkose. We will use arkose in a general sense for plagioclase -rich sandstone generally containing less than 75 percent quartz (feldspathic subquartzose sandstone). More specific names are applied in the unit descriptions using the terminology of Crook (1960) as applied by Dickinson (1970) to the subquartzose sandstones. Most of the Tertiary sandstone is subquartzose but we generally drop this term in the descriptions.

We restrict the name Swauk Formation to Tertiary sedimentary and intercalated volcanic rocks in the region largely west of the Chiwaukum graben and below the unconformity at the base of the Teanaway Basalt. This region includes the type locality, the exposures along Swauk Creek.

In the Wenatchee quadrangle, the Leavenworth fault zone divides the Tertiary arkosic rocks into two separate, partly contemporaneous sequences (see fig. 1). West of the Leavenworth fault zone, in the western sequence, arkosic sandstone, argillite, and conglomerate of the Swauk Formation interfinger westward with the early Eocene andesitic to rhyolitic volcanic rocks, the Silver Pass Volcanic Rocks of Foster (1960), mostly exposed west of the quadrangle (Gresens and others, 1977, fig. 3, p. 89). The Swauk Formation and the Silver Pass Volcanic Rocks were deformed, uplifted, and eroded prior to eruption and deposition of the Teanaway Basalt. Conformably overlying the Teanaway is the white arkosic sandstone of the middle Eocene Roslyn Formation.

Just east of the Leavenworth fault, in the eastern sequence in the Chiwaukum graben, thin layers of basalt breccia, tuff and flows(?), possibly thin eastward extending tongues of Teanaway Basalt, interfinger with the Chumstick Formation. Interbeds of siliceous tuff in sedimentary rock in the graben are about 45 m.y. old or middle Eocene (Whetten, 1976; Gresens and others, 1977, p. 100-106).

Most of the folded sedimentary rocks in the Chiwaukum graben are included in the Chumstick Formation by Gresens and others (1981), and assigned a middle Eocene age.

Unconformably overlying the Chumstick Formation is the early Oligocene Wenatchee Formation, named by Gresens and others (1977, P. 109), a slightly deformed sequence of quartzose sandstone, conglomerate, and variegated tuffaceous shales and siltstone.

A sequence of sedimentary and volcanic rocks southwest of the Yakima River, herein designated the southwestern sequence, is similar to, and may be directly correlated with, the Swauk-Silver Pass-Teanaway sequence. This sequence, constituted of the Manastash Formation, the Taneum Andesite, and the basalt of Frost Mountain, has been variously correlated and assigned a wide range of ages by earlier workers.

Western sequence

Swauk Formation

The Swauk Formation is dominantly dark-colored feldspathic to lithofeldspathic, fine- to medium-grained* sandstone. In the Swauk Creek area, thin- to thick-bedded**, commonly crossbedded, moderately indurated sandstones are interbedded with dark carbonaceous siltstones and shales. Pebbly sandstone and conglomerate are present throughout the Swauk but most abundant in the conglomerate facies described below. Present in minor amounts are thick beds of light-colored micaceous arkose that appear similar in outcrop to the arkosic sandstones in the Chumstick Formation to the east and become more prominent in the Swauk near the Leavenworth fault zone.

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*Grain-size classification based on the Wentworth scale.

**Bedding thickness: very thin bedded= 1-5 cm; thin bedded=5-60 cm; thick bedded=60-120 cm; very thick bedded=> 120 cm.

The Swauk Formation has several mappable facies. Because of structural complications and lack of marker beds, we are not certain of their relative ages, but we think that the rocks exposed on Tronsen Ridge and east of it are the youngest.

We include isolated outcrops of light-colored arkose and conglomerate in upper Squilchuck Creek in the Swauk Formation because they appear to lie west of the Leavenworth fault, but they could be part of the Chumstick. Modal data and petrography in Description of Map Units are abstracted from Frizzell (1979).

Ironstone deposits.-Discontinuous basal beds of nickel- and iron-rich mudstone, called ironstone, locally interbedded with serpentinite, fanglomerate and arkose ' occur where Swauk sandstone and conglomerate unconformably overlie serpentinite of the Ingalls Tectonic Complex. The ironstone appears to have been derived by re crystallization of transported laterite that developed in pre-Swauk time (Lupher, 1944; Lamey and Hotz, 1951, p. 56, 57). Lupher (1944) called these deposits the Cle Elum Formation because he believed them to be significantly older than Swauk arkose. The ironstone deposits, however, are locally interbedded with arkose and rich in detrital feldspar and quartz. Later workers (see for instance Lamey, 1950; Lamey and Hotz, 1951), like us, consider the iron deposits to be part of the Swauk sequence.

Conglomerate and monolithologic fanglomerate breccia.-Boulder to pebble conglomerate makes up as much as 50 percent of the terrane north of Scotty [8] and Ruby [4] Creeks, where locally derived clasts are predominantly granitic and metamorphic rocks. In the Mission Peak-Mount Lillian [30] area, pebbly conglomerate makes up about 20 percent of the section and clasts are predominantly light-colored volcanic rocks.

The monolithologic fanglomerates in the Swauk and Chumstick are very similar, if not identical, in appearance. The fanglomerates, especially those now included in the Chumstick Formation, were first described by Smith (1904, p. 5) and Chappell (1936a, p. 64-65). Many later workers (Alexander, 1956, p. 23-28; Pratt, 1958, p. 30-34; Rosenmeir, 1968, p. 6- 8; Cashman, 1974; Cashman and Whetten, 1976, p. 1773-1776; Frizzell and Tabor, 1977) have discussed their significance. They probably represent debris-flow deposits on fans at the base of a mountain front. Their abundance in the Leavenworth fault zone, especially those on the now downthrown side of the faults, suggests that they flowed off rapidly rising, fault-block mountains.

Shaly facies of Tronsen Ridge.-On Tronsen Ridge, especially well exposed along the southwest slope, are evenly and thinly bedded alternating layers of sandstone and shale with minor thick-bedded sandstone and rare pebble conglomerate. Finely laminated rocks without crossbedding characteristic of this facies suggest a lacustrine depositional environment. These rocks intertongue with the sandy and conglomeratic rocks of the

more typical Swauk along strike to the north but apparently overlie the conglomerate facies on the southwest.

Arkosic sandstone facies.-Beds of poorly sorted thick-bedded white sandstone are rare in the western part of the Swauk Formation but become more numerous to the east. We have not been able to map these beds except in the area just southwest of Red Hill [9], where thick- to very thick bedded white arkosic sandstone is conspicuously interbedded in the darker shale and sandstone of the shaly facies of Tronsen Ridge. We think that this area of conspicuous arkose may represent the uppermost rocks of the Swauk Formation and herald the dominance of white arkose of the Chumstick Formation in the Chiwaukum graben to the east.

Silver Pass Volcanic Rocks of Foster (1960)

The volcanic rocks at Silver Pass east of Lake Kachess, west of the quadrangle, first described by Smith and Calkins (1906, p. 5) as part of the Kachess Rhyolite, were renamed the Silver Pass Volcanic Rocks by Foster (1960, p. 105-107) for exposures at Silver Pass near French Cabin Mountain west of the Wenatchee quadrangle. In the type area of the Silver Pass, the Silver Pass Volcanic Rocks are interbedded with sandstone of the Swauk Formation, although Foster (1960, p. 105) and Lofgren (1974, p. 33-34) considered the volcanic rocks to lie unconformably on the Swauk.

Interbeds of green altered volcanic tuff and breccia (shown by a diamond symbol on the map) crop out on both limbs of a major anticline north of upper Swauk Creek and on the south limb of an anticline near Liberty. Altered mafic tuff interbedded in arkose crops out sporadically along strike in the monoclinal section of Swauk stretching westward around the headwaters of the Teanaway River to the Cle Elum River. The amount of interbedded volcanic material in the Swauk appears to increase near the type area of the Silver Pass. Fission-track ages of zircon from the tuff interbeds and ash flows in the Silver Pass are approximately the same (see below).

Age of the Silver Pass Volcanic Rocks and the Swauk Formation

Ever since the early mapping at the turn of the century, the stratigraphy of the lower and middle Tertiary rocks of the region has been somewhat confused owing to lack of definitive fossils, facies changes, and some miscorrelation. F. H. Knowlton (in Smith, 1904, p. 5) studied fossil leaves from the Swauk Formation and correlated them with the Eocene (now Paleocene) Fort Union and Late Cretaceous Laramie Formations. Duror (in Smith, 1916, p. 566) agreed with the correlation. Newman (1975), on the basis of palynomorph assemblages, reinterpreted the Swauk Formation to be "no older than early Eocene and as young as middle Eocene."

A tuff bed in the Silver Pass Volcanic Rocks near Liberty yields a zircon fission-track age of 50.4 m.y. (table 1, no. 3). Similar tuffs have fission-track ages of 50.5, 43.6, and 48.6 m.y., respectively (table 1, nos. 4-6). The Silver Pass Volcanic Rocks exposed west of the Wenatchee sheet have zircon fission-track ages of 51±5 and 53±5 m.y. (J. A. Vance and C. W. Naeser, written commun., 1976, 1977). We believe that the Swauk in the Silver Pass area and in the areas where the volcanic interbeds crop out is about 50 m.y. old, that is, early Eocene. The shaly facies of Tronsen Ridge and the arkosic sandstone facies are somewhat younger but we do not know how much younger. They could be equivalent to parts of the Chumstick in the Chiwaukum graben.

Teanaway Basalt

Basaltic rocks exposed in the drainage of the Teanaway River were first described by Russell (1900, p. 130-131), Who assigned them to his somewhat inclusive Columbia Lava. Smith (1904, p. 5-6) used the name Teanaway Basalt for the basaltic and andesitic rocks that unconformably overlie the steeply dipping beds of the Swauk Formation and conformably underlie the Roslyn Formation. The Teanaway is more than basalt. It contains much pyroclastic material, mostly basaltic, but ranges in composition to rhyolite and contains minor arkosic sedimentary rock (Clayton, 1973, p. 35-36) and rhyolite ash-flow tuffs.

Basalt flows are characteristically glassy to very fine grained black rock without phenocrysts; they contain numerous chalcedonic amygdules. We interpret beds of altered basalt breccia and massive basalt in the Chumstick Formation near Devils Gulch to be distal tongues of the Teanaway. Clayton (1973, p. 35-45) has summarized Teanawag volcanism.

The absolute age of the Teanaway Basalt is not easily determined owing to the pervasive alteration of the rocks. Whole- rock K-Ar ages of separate grain-size fractions of basalt from the Teanaway near Silver Creek, west of the quadrangle, range from 39 to 47 m.y. The 47-m.y. age from a coarse fraction with much of the altered matrix fraction removed is probably closest to the true age. Whole-rock K-Ar ages from separate fractions of a basalt dike in the Teanaway dike swarm northwest of Shaser Creek range from about 39 to 47 m.y.; two fractions yield probable minimum real ages of 46.9 and 46.4 m.y. (table 1, no. 7).

Some pyroclastic rocks included in the lowermost Teanaway in the area of the Middle and West Forks of the Teanaway River may be the Silver Pass Volcanic Rocks.

Rhyolite

Scattered within the Teanaway drainage basin are outcrops of friable white rhyolite that are difficult to assign stratigraphically. Many outcrops are massive and subject to considerable landsliding, making identification as flows or intrusions uncertain. Whereas Smith (1904, p. 8) and Foster (1960, p. 110) considered the rhyolite to be post-Roslyn, Clayton (1973, p. 27-28) considered it to be interbedded in the upper part of the Teanaway.

Some of the rhyolite is of flow origin and appears to either directly overlie the Teanaway Basalt or be interbedded in the lower part of the Roslyn Formation. Some rhyolite occurring within the outcrop area of the Teanaway is probably eruptive (see for instance Clayton, 1973, p. 28) but much could be dikes. In several places, rhyolite appears to have chilled lower margins overlying arkose and basalt that appears to have a thin crust of clayey weathering and oxidation. Whether the overlying rhyolite layers are flows or sills is not independently evident, but the weathering of the underlying rocks suggests that the rhyolite was extrusive. Interbedded rhyolite and arkosic sandstone rich in grains of devitrified rhyolite crop out on the south slope of Teanaway Butte.

Well-bedded rhyolite tuff and tuffaceous shale north of Indian Creek [6] clearly lie on the Teanaway Basalt and are probably beneath Roslyn sandstone. A fission-track age of zircon from a tuff bed at this locality (table 1, no. 10) is 55. 1 m.y. but may be contaminated by older detritus (Vance and Naeser, 1977, and written commun., 1977). The age does not fit the regional stratigraphy. A dikelike body of rhyolite on Indian Creek, presumably intruding the Teanaway (table 1, no. 11), has a zircon fission-track age of 22.0 m.y. (J. A. Vance and C. W. Naeser, written commun., 1976). The relations described here and this later age suggest that there was rhyolite volcanism during both late Teanaway and early Roslyn time and post-Roslyn time. An intrusive dacite dome near Wenatchee with a minimum K-Ar age of biotites of about 42 m.y. (table 1, nos. 12, 13) may represent the main episode of Teanaway-Roslyn rhyolite volcanism.

Roslyn Formation

The Roslyn Formation is mostly a thick-bedded nonmarine arkosic sandstone, conspicuously white, weathering yellow. It is markedly less indurated than the Swauk Formation and generally relatively flat-lying except in First Creek [15], where it dips as much as 60'. The formation was named by Russell (1900, p. 123-127) and later described by Smith (1904, p. 6-7) and most definitively by Bressler (1951, 1956). Most evidence, including interbedded basaltic pyroclastic materials and arkose on the west ridge of Teanaway Butte [11] and elsewhere (Clayton, 1973, p. 13), indicates that the Roslyn conformably overlies the Teanaway Basalt, although Bressler (1951, p. 441) felt that the contact was a disconformity. Clayton (1973, p. 35) suggests that continuous arkosic sedimentation of the Roslyn type was only temporarily interrupted by deposition of the Teanaway Basalt. Bressler (1951, 1956) divided the Roslyn into three members, lower, middle, and upper, shown on the map; the descriptions are adopted from his work. Structural data in the upper member from coal mines and drilling is summarized in

Saunders (1914, p. 13) and in Beikman, Gower, and Dana (1961, p. 20). Major folds in the Roslyn from this subsurface data are shown on the map.

Fossil leaves collected from the Roslyn indicated to Knowlton (in Smith, 1904, p. 5) that the Roslyn was younger than the Swauk Formation because no species found is common to these formations. Newman (1975) assigns a late Eocene age to the palynomorph assemblage present in the upper member of the Roslyn Formation. No absolute ages are available for the Roslyn; it appears to be middle and late Eocene and correlatable with the Chumstick Formation, but some or all could be younger than the dated part of the Chumstick.

Eastern (Chiwaukum graben) sequence

Chumstick Formation

In the area of the Wenatchee quadrangle, rocks formally named the Chumstick Formation by Gresens, Whetten, and Naeser (1981) are mostly white micaceous arkosic sandstone with varying but lesser amounts of shale, conglomerate, fanglomerate, and rare siliceous tuff. The formation includes rocks originally called Camas Sandstone by Russell (1900, p. 118) and Alexander (1956, p. 16). White arkose beds in the upper part of the Swauk Formation are not easily distinguished from the arkose of the Chumstick. In general, Chumstick in the Wenatchee quadrangle does not have the diversity of rock types that the Swauk has, for example, dark-colored sandstone, evenly bedded siltstone, and shale.

The Chumstick Formation crops out in the Chiwaukum graben, bounded on the east by the Entiat fault. This fault is well exposed north of the quadrangle along the west side of the Entiat Mountains, but in the Wenatchee area, its position can only be inferred from scattered outcrops. On the west, the Chumstick is bounded by the Leavenworth fault zone, best exposed in lower Devils Gulch, where rocks are commonly sheared and rock types typical of the Swauk and Chumstick are juxtaposed, presumably as fault slivers.

Southeast of Devils Gulch, we assume that a major graben-bounding fault follows the unexposed contact of a thick lens of quartz dioritic to granodiorite fanglomerate that grades eastward into the more common white arkosic sandstone of the Chumstick. Similar fanglomerate and less common monolithologic serpentinite fanglomerate discontinuously parallel the fault zone as far as Peshastin Creek (Cashman, 1974; Cashman and Whetten, 1976; Frizzell and Tabor, 1977).

Within the Chiwaukum graben, a red conglomerate rich in volcanic rock crops out continuously for about 6 km near and adjacent to a main branch fault in the Leavenworth fault zone. Clasts of amygdaloidal basalt and rhyolite suggest that the conglomerate was derived from the Teanaway Basalt and (or) the Silver Pass Volcanic Rocks of Foster (1960). More or less on strike to the south is basalt breccia (probably a tongue of the Teanaway) containing clasts of lithofeldspathic sandstone richer in lithic grains, more like Swauk sandstone, than typical Chumstick sandstone. (See rock descriptions on map).

A belt of sandstone underlying synclinally infolded Wenatchee Formation west of Wenatchee has been mapped as the Swauk Formation by Gresens (1975, 1976, p. 376-377; 1980) on the basis of the absence of K-feldspar, present in amounts to 20 percent in the Chumstick, chloritization of biotite, and steepness of dips. We could not identify these distinct characteristics within Gresen's Swauk north of Number One Canyon [35] and believe that the rocks south of Number One Canyon are similar to quartz dioritic debris flows or mud flows common in the Chumstick along the east side of the Leavenworth fault, where they are clearly interbedded with typical K-feldspar-rich biotite feldspathic subquartzose sandstone of the Chumstick (see also Frizzell, 1979, p. 41, 86, 90). The rocks in this area could be older than much of the Chumstick and possibly as old as the Swauk because this area near the sandstone is cut by numerous diabase dikes similar to those in the Teanaway dike swarm. One diabase dike yields a whole-rock K-Ar age of 47. 1 m.y. (table 1, no. 8), an appropriate age for Teanaway Basalt.

Although fossil-leaf collections from the Chumstick Formation (Brown in Waters, 1930, and La Motte in Chappell, 1936, p. 73-76) indicate that it is the same age as the Swauk, tuffs in the Chumstick yield zircon fission-track ages of about 45 m.y., middle Eocene (Whetten, 1976). In La Motte's correlation, it appears that the ages were based on composite samples collected from both the Chumstick and the Swauk (Chappell, 1936a, p. 70). Palynomorphs from rocks in the Chiwaukum graben indicate a late Eocene age for the Chumstick (Newman, 1971; 1975).

Southwesten sequence

Manastash Formation

The lowermost unit of arkosic to quartzose sandstone, shale, and conglomerate containing minor coal beds was called the Manastash Formation by Smith (1904, p. 7) but later included in the Naches Formation by Stout (1964, p. 324).

No species in the early leaf collections from sandstone of the Manastash Formation occurs in either the Swauk or the Roslyn Formation. Knowlton (in Smith, 1904, p. 7) correlated the Manastash with the Clarno Formation in Oregon, now thought to be upper Eocene and lower Oligocene (Hergert, 1961, Wolfe and Hopkins, 1967, p. 69-73; Swanson and Robinson, 1968, p. 159-160). The age assignment of fossil leaves collected by Stout (1964, p. 327) agrees with Knowlton's Eocene and possibly Oligocene age for this unit.

Newman (1977) reports preliminary palynomorph data suggesting that the Manastash Formation along Taneum Creek is equivalent to the early Eocene Swauk Formation. As will be shown in the discussion of the overlying volcanic rocks, the Manastash presumably is Eocene, 50 m.y., but may have been deposited in a basin separated from the Swauk Formation. Petrographic differences between the Swauk and Manastash are discussed by Frizzell (1979, p. 51-80).

Taneum Andesite

Overlying the Manastash Formation with apparent conformity is a series of andesitic to rhyolitic lavas and pyroclastic rocks that Smith (1904, p. 7) and Smith Calkins (1906, p. 7) referred to as the Taneum Andesite. Most of these rocks were called Keechelus Formation by Stout (1964, p. 329), a name abandoned by Vine (1969).

Smith (1904, p. 7) and Smith and Calkins (1906, p. 7) considered the Taneum to be Miocene, probably because they misidentified the overlying Eocene basalt of Frost Mountain as the Miocene Columbia River Basalt. The Taneum's stratigraphic position and two fission-track ages of 45.3 and 51.8 m.y. (table 1, nos. 15, 16) on zircon from rhyolite ash- flow tuffs above Buck Meadows [24] place it in the early Eocene.

Andesite of Peoh Point

A rather uniform mass of highly altered hornblende-hypersthene dacite porphyry forms Peoh Point [19] and surrounding cliffs. Although it resembles some lavas of the Taneum Andesite or the Silver Pass, the porphyry cuts a probable fault separating the southwestern sequence from the western sequence and thus must be somewhat younger than at least the Taneum Andesite and Silver Pass. It could be the last pulse of Taneum volcanism.

Basalt of Frost Mountain

Exposed in a syncline on Frost Mountain and to the southeast are dense to somewhat glassy basalt flows, commonly columnar jointed and very similar in outcrop appearance to much of the Teanaway Basalt. Similar flows and basalt breccias are more extensive west of the Wenatchee quadrangle.

Smith (1904) included these basalts in the Yakima Basalt. Stout (1964, pl. 1, p. 330 and 324) included some of the basalt in the Yakima and some in the Naches. On our preliminary map (Tabor and others, 1977), we referred the basalt of Frost Mountain and the underlying intermediate to silicic volcanic rocks to the Oligocene on a single whole-rock basalt K- Ar age of about 32 m.y. (table 1, no. 17). We have since accumulated numerous additional whole-rock K-Ar ages from basalt in the unit exposed west of the quadrangle that suggest the flows are at least 47 m.y. old, that is, early Eocene.

In gross lithology, the Manastash and Taneum Formations and the basalt of Frost Mountain are similar to the Swauk- Silver Pass-Teanaway sequence. Their absolute ages are close enough, considering the age spread, to suggest direct correlation within the Eocene.

Hypersthene gabbro

A texturally heterogeneous mass of hypersthene pyroxene gabbro crops out on the west side of the upper Middle Fork of the Teanaway. By its shape and geometry, we assume that it intrudes sandstone of the Swauk Formation, but we have observed no contacts with the sandstone. The gabbro is cut by many diabasic dikes; if related to them, it represents an earlier phase.

Diabase and gabbro

South of the Yakima River, several elongate and irregular masses of diabase and gabbro crop out. These masses have been described by Stout (1961), who suggested that they were feeders for the Yakima Basalt; more recent studies (see Teanaway dike swarm) indicate that they probably were not. Small irregular masses of diabase and gabbro occur within the area of the Teanaway dike swarm north of the Yakima River, but only two bodies near Swauk Creek are large enough to be shown on the map.

Teanaway, dike swarm

Ever since Russell (1900, p. 121-122) and Smith (1904, p. 6) mapped and described the spectacular swarm of diabasic and basaltic dikes intruding the region around the headwaters of the Teanaway River and east of it, geologists have speculated on their origin and structural controls. Smith's (1904) map representation of the northeast trending dikes is mosty diagrammatic; in some areas, dikes are probably even more numerous than shown. Our field estimates of abundance are only approximate. Several workers (Chappell, 1936b, p. 384; Stout, 1961, p. 352; Southwick, 1966) have proposed that the dikes are of two ages. Foster (1958, p. 649) discussed a model for emplacement of the Teanaway dike swarm and the Teanaway Basalt; on structural arguments, he concluded that most of the dikes could not have fed the basalt flows, although they were probably related. In the most definitive study, Southwick (1966, p. 1-15) tentatively concluded that despite Foster's objections, the holocrystalline dikes fed the Eocene Teanaway Basalt and the younger "glassy" dikes the Miocene Yakima Basalt. As interpreted from more complete chemical and petrologic data and regional flow directions (see section on Columbia River Basalt Group) indicating that the Yakima flows came from southeast Washington, none of the dikes or other diabase masses (including the Camas Land Diabase) in the Wenatchee quadrangle were feeders for the Yakima Basalt Subgroup (Swanson, 1967, p. 1102; Schmincke, 1967a, p. 1003).

A whole-rock K-Ar minimum age for a basalt from the dike swarm north of Shaser Creek [7] is about 47 m.y. (table 1, no. 7), the same as the probable best age of a flow in the Teanaway Basalt (see section on Teanaway Basalt). Further, we have noted that the dikes are most abundant north of Yellow Hill [10], a very thick accumulation of pyroclastic rocks and flows that may represent a major eruptive center for the Teanaway Basalt, as suggested by Clayton (1973, p. 41). Because basalt dikes do not intrude the Roslyn Formation, they are probably older than the Roslyn, but absence of deformation and even younger dikes in the Roslyn suggests a unique tectonic setting or a structural block resistant to intrusion. The basalt dikes are numerous in the lower parts of the Teanaway Basalt, although they are so similar in appearance to Teanaway flows that it is difficult to estimate their abundance. A few altered diabase dikes occur in the basal parts of the Chumstick Formation, mostly west of the East Fork of Mission Creek and in the canyons west of Wenatchee. A whole-rock K-Ar date on diabase west of Wenatchee is about 47 m.y. (table 1, no. 8). The evidence favors the premise that most, if not all, of the dikes fed the Teanaway Basalt. Probably some younger dikes and diabase-gabbro masses occur, but none fed the Yakima Basalt Subgroup.

Diabase dikes intruding the Manastash and Taneum Formations are locally common. We do not show their frequency south of the Yakima River.

Camas Land Diabase of Southwick (1966)

The Camas Land Diabase forms a sill-like body southeast of the Mount Stuart massif. This sill was first described by Russell (1900, p. 122) and Smith (1904, p. 6), but Southwick (1966, p. 14-15) has made the most thorough study of the body. He concluded, on the basis of chemistry and petrography, that it was not related to the dike swarm but might be related to the Picture Gorge Basalt. Chemically analyzed samples of Picture Gorge Basalt, however, known only from north-central Oregon, are consistenfly higher in iron and lower in silica and aluminum than the Camas Land Diabase (D. A. Swanson, written commun., 1977). Numerous diabase dikes and small masses in the area near the sill probably are related to it.

Miscellaneous dikes, sills, and plugs

In the area just west of Wenatchee, numerous dikes, sills, and plugs ranging from basalt to rhyolite in composition intrude the Wenatchee and Chumstick Formations. Associated with the belt of rhyolitic to dacitic intrusions between the city of Wenatchee and the syncline in the Wenatchee Formation is a zone of silicified sandstone that is locally gold- bearing (Patton and Cheney, 1971). The intrusions probably range considerably in age. Biotite from the holocrystalline core of an intrusive dacite dome on the south side of Dry Gulch [36] (described in detail by Coombs, 1952) has K-Ar ages of about 43 m.y. A zircon fission-track age of about 51 m.y. (J. A.

Vance and C. W. Naeser, written commun., 1978, see table 1, nos. 12-14) from the dome appears to be too old as judged by the age of the intruded Chumstick Formation. Hornblende from one of the largest andesite dikes in the complex has a minimum K-Ar age of about 35 m.y. (table 1, no. 29) (R. L. Gresens, wriften commun., 1978).

Wenatchee Formation

The unconformity beneath rocks formally designated the Wenatchee Formation by Gresens and others (1981) was first recognized by Chappell (1936a, p. 93-94). The Wenatchee is generally distinguished from underlying sandstone and shale of the Chumstick Formation by its gentle dips, quartz-rich composition, and variegated shales. Gresens (1976; and Gresens and others, 1977, p. 114-123) has subdivided the Wenatchee into several fairly continuous members that we do not show. Leaves collected from the Wenatchee Formation suggest a middle Eocene age and are different from assemblages in the Swauk and Chumstick Formations (J. A. Wolfe, written commun., 1976). Tuffaceous beds in the Wenatchee yield zircon fission-track ages of about 34 m.y. (table 1, nos. 22-24), about early Oligocene (Gresens and others, 1977, p. 109). Palynomorph assemblages also yield an Oligocene age (Newman, 1975). Considering the middle Eocene age of the underlying Chumstick, an early Oligocene age is the most probable.

Rocks between Stemilt Creek and Malaga and in landslide blocks just southwest of Malaga are questionably assigned to the Wenatchee Formation because they appear to be in the appropriate structural position, have similar overall lithology, and yield, from a tuffaceous bed, an Oligocene apatite fission-track age of sorts, 35.6--20.3 m.y., (table 1, no. 21). Gresens (written commun., 1978) does not consider these rocks to be part of his Wenatchee Formation and considers them probably Miocene on the basis of absence of nearly pure quartz sandstone and micaceous shale in the Malaga outcrops and presence of Miocene pollen. Variegated shale and quartz-rich sandstones presumably part of a massive block landslide mostly of Grande Ronde Basalt exposed along the Columbia River southwest of Rock Island are included here in the Wenatchee(?) Formation.

Altered rhyolitic ash-flow tuff overlies typical Teanaway Basalt on the west side of Table Mountain, north of Lion Rock [26]. The pyroclastic rock has been included in the Teanaway by previous workers (compare Clayton, 1923, pl. 2) but a zircon fission-track age from this locality of about 33 m.y. (J. A. Vance and C. W. Naeser, Jr., wriften commun., 1977) (table 1, no. 19) indicates that the tuff is younger and probably correlative with silicic tuffs in the Wenatchee Formation. Similar ash-flow tuff containing interbeds of tuffaceous arkose crops out near Swauk Creek east of Swauk Prairie [13]. A fission-track age of zircon from the later tuff is about 33 m.y. (table 1, no. 20). Some arkose and tuff beds have steep dips suggesting structural complexity that we do not understand. The tuffs and associated sandstone are not lithologically like the Wenatchee Formation in its type locality, but west of the Swauk Creek locality, near the Teanaway River, red and green shale and sandstone are lithologically more like the Wenatchee. We have included all these in the Wenatchee(?), realizing that they may belong to different units.

Homblende andesite porphyry complex of Horse Lake Mountain

Horse Lake Mountain (34] (locally called Twin Peaks) is underlain by a complex of hornblende andesite porphyry dikes and sills and what appears to be older altered and in part recrystallized diabase and gabbro intruding the Chumstick Formation. The older mafic rocks may be part of the Teanaway dike swarm, as mentioned here. Early descriptions of the porphyry are by Chappell (1936a, p. 97-129). Bayley (1965) mapped several stocks in the complex but each stock appears to consist of thick sills separated by very thin sandstone beds.At the head of the south branch of Number One Canyon [35] is a porphyry breccia dike in which an andesite porphyry matrix surrounds angular inclusions of arkose and argillite. It has a fine-grained andesite margin with only a few inclusions but is crowded with flow-alined plagioclase crystals. Hornblende porphyry dikes cut the breccia dike. The breccia dike and many sills are characterized by euhedral hornblende crystals to several centimeters long.

Potassium-argon ages of hornblende crystals from dikes and sills in the complex range from about 25 to 30 m.y. (table 1, nos. 25-28). Most dates are about 30 m.y., placing the age of the intrusions in the late Oligocene.

Diamictite

On the eastern side of the Columbia River valley 5 km north of Wenatchee are two small patches of diamictite composed mostly of angular andesite clasts with a trace of rounded river gravel. The diamictite deposit fills channels cut in the Wenatchee Formation but contains no clasts of, and therefore predates, the Yakima Basalt Subgroup. The diamictite probably originated as debris flows from an unidentified nearby volcanic center.

COLUMBIA RIVER BASALT GROUP

By D. A. Swanson, G. R. Byerly, and R. D. Bentley

Yakima Basalt Subgroup

The Columbia River Basalt Group underlies much of the southeastern half of the quadrangle and extends far east and south, forming the Columbia Plateau of eastern Washington and adjacent Oregon and Idaho. The Yakima Basalt Subgroup (Swanson and others, 1979b) is divided into three formations, in ascending order, the Grande Ronde, Wanapum, and Saddle Mountains Basaits. Only the Grande Ronde and Wanapum Basalts occur within the Wenatchee quadrangle. Evaluation of potassium-argon ages and paleontologic evidence relative to the late Cenozoic time scale of Berggren and Van Couvering (1974, p. 172) indicates that the Grande Ronde Basalt is of late early and middle Miocene age (16.5 to 14 m.y.) and the Wanapum Basalt of middle Miocene age (Swanson and others, 1979b).

The basalt once covered an erosional surface of moderate local relief in the quadrangle. Map relations along the North Fork of Manastash Creek imply a prebasalt hill at least 150 m high. A buried ridge 200 m or more high underlain by the Swauk Formation is exposed on Naneum Ridge east of Pearson Creek [291. The basalt flows lapped up against a highland not far beyond the present-day margin of the field, as shown by a general northwestward thinning of stratigraphic units and the southeast current directions indicated by sandstones interbedded with the basalt.

Apparently all of the basalt was erupted from vents farther east or southeast of the quadrangle. Flow directions, measured chiefly on foreset-bedded lava deltas, consistenfly show west and northwest movement, except in a small area on Wenatchee Mountain, where directions are northeasterly [31]. The northeast directions probably record deflection of flows by a prebasalt hill, although Chappell (1936b, p. 384) thought that they indicated a more westerly source for the basalt.

Grande Ronde Basalt

In the Wenatchee quadrangle, the Grande Ronde Basalt consists predominantly of tholeiitic basalt flows that are nonporphyritic or contain only rare small plagioclase phenocrysts.

Lithologic similarity and discontinuous jointing habits make field identification and correlation of single flows across unexposed areas difficult. Elsewhere on the Columbia Plateau, we have determined remnant magnetic polarity with a portable fluxgate magnetometer and have been able to subdivide the formation in the field (Swanson and Wright, 1976; Swanson and others, 1979b; Hooper and others, 1979). Results of field measurements agree closely with those obtained by conventional laboratory techniques (Choiniere and Swanson, 1979). We found that the most reliable field measurements are obtained on oxidized parts of a flow, especially the base and top, where magnetic stability is highest (Swanson and Wright, 1976). Few flows with such oxidized zones were found in the Wenatchee quadrangle. We discovered by trial and error that samples with glassy rinds, formed by rapid quenching against water or sediment, give far more reliable results than samples that are neither oxidized nor quenched, presumably because the small grain size of magnetic minerals favors magnetic stability. Samples with glassy margins yield less consistent results than samples that are oxidized but are nonetheless usable with care. As glassy material is abundant throughout most of the quadrangle, we were able to establish a magnetostratigraphy in the field with reasonably consistent measurements; anomalous readings were easily identified and corrected. The map units-lower flows of normal magnetic polarity, flows of reversed magnetic polarity, and upper flows of normal magnetic polarity-are the result of this work and are time correlative with similar units recently mapped on the Columbia Plateau (Swanson, 1978; Swanson and others, 1979a).

Lower flows of normal magnetic polarity

The lower flows of normal magnetic polarity crop out only along Naneum Creek, where at least two invasive flows (see following description of upper flows of normal magnetic polarity) make up the unit. These normally magnetized flows correlate with magnetostratigraphic unit N, of Swanson and others (1979b).

Flows of reversed magnetic polarity

The flows of reversed magnetic polarity form a unit recognizable throughout the quadrangle and equivalent to magnetostratigraphic unit R2 of Swanson and others (1979b). No measured section contains more than six flows, but chemical analyses indicate that some flows pinch out between sections and, together with field observations, suggest the presence of at least nine flows of different composition.

We mapped two subunits within the flows of reversed magnetic polarity in places where they are readily distinguishable in the field from other reversely magnetized flows: the invasive flow of Hammond (Hammond sill of Hoyt, 1961) on and northwest of Naneum Ridge [32] and the invasive flow of Howard Creek in the Table Mountain area. Each invasive flow (see below) is chemically distinctive, unusually thick (more than 50 m in most places), and has a flat, nonscoriaceous or hyaloclastic upper surface chilled against sedimentary rock of the Ellensburg Formation. The two invasive flows are separated from one another by a prebasalt ridge along the east side of Pearson

Creek [291, but chemical data suggest that in some places south of the ridge the Hammond occurs as a thin subaerial flow below the invasive flow of Howard Creek. Both flows are certainly more extensive than is shown on the map; they lose their distinctive field appearance as they merge southward and southeastward into correlative pillowed and subaerial flows.

Upper flows of normal magnetic polarity

The upper flows of normal magnetic polarity, part of magnetostratigraphic unit N2 of Swanson and others (1979b), form the most widespread and thickest unit of basalt in the quadrangle. No more than eight flows were recognized in any section; complex pillowed flows and hyaloclastites make identification of many flow contacts rather arbitrary. Chemical analyses combined with observed contacts suggest the presence of at least eleven flows of seven different compositions.

In the northeastern part of the quadrangle, we divided the upper flows of normal magnetic polarity into four subunits: the basalt of Rocky Point [43], which may be two flows in places; the invasive flow of Duffy Creek [40], mapped only in the extreme northeast corner of the quadrangle; the invasive flows of Keane Ranch [41], which contain several flows of at least three different chemical compositions; and the basalt of Beaver Creek [39].

The basalt of Rocky Point is overlain at Cape Horn [45] by a flow (not mapped) that chemically matches the invasive flow of Duffy Creek; ftom this, we tentatively conclude that the Duffy Creek is younger than the basalt of Rocky Point. South of Badger Mountain, the invasive flows of Keane Ranch give way to a complex assemblage of pillow basalt and hyaloclastite included in the upper flows of normal magnetic polarity; this assemblage is well exposed in cliffs north and south of the mouth of Moses Coulee. Southward, the basalt of Beaver Creek becomes increasingly more difficult to distinguish from underlying flows; we mapped it only as far south as the mouth of Moses Coulee.

The uppermost flows of the upper unit of normal magnetic polarity west of the Columbia River are extensive but chemically and lithologically so similar to each other that we have not subdivided them. These flows include the Table Mountain and Mission Peak members of Rosenmeier (1968), which we feel are the same flow. Thick hackly jointed flows are the youngest flows throughout the area between Mission Ridge and the southwest corner of the quadrangle, where Mackin (1961, p. 9-12) named he Museum and Rocky Coulee flows at the top of the Grande Ronde section. The Table Mountain member of Rosenmeier (1968, p. 27-28) and the Museum and Rocky Co Wee flows may be correlative. Flows chemically similar to Rosenmeiers's Table Mountain member occur west of Kittitas Valley above a reversely magnetized flow chemically similar to the invasive flow of Howard Creek.

The Grande Ronde Basalt in the Wenatchee quadrangle differs markedly from temporally correlative flows in most other areas on the Columbia Plateau because the lava flowed into rivers draining the ancestral Cascade Range, forming pillow basalt, hyaloclastite, and invasive flows, some related by facies changes to one another. Pillows and intermixed hyaloclastite formed when lava was quenched as it entered water, probably shallow lakes created as the advancing flows dammed rivers draining southeastward.

Foreset-bedded lava deltas (Moore and others, 1973) formed in places where current action was slight and water depth was several meters or more. The best example of such a delta is exposed in cliffs 4 km south of the mouth of Moses Coulee (Fuller, 1931, fig. 1) and in lower Moses Coulee. The foreset layers in lava deltas dip in the direction of flow; most flow directions indicated on the map were measured on such deposits.

Relations among discontinuous flow lobes, pillowed units, and granular hyaloclastite are very complicated where exposed in cliffs along the east side of the Columbia River valley between Rock Island Dam and the area opposite Cape Horn [45]. The discontinuous nature of these depositional units probably reflects complex lava-water interactions such as episodic flooding of molten lava by water, burrowing of lava into its own hyaloclastic debris, and perhaps locally strong current action within the constanfly changing lake and streams into which the lava was advancing.

Basalt flows that burrowed into fine-grained unconsolidated sediments, forming local peperites (chaotic mixtures of sediment and invasive volcanic rock) and rather extensive sills, are termed invasive flows (Byerly and Swanson, 1978). Peperites, best described for rocks of the Columbia Plateau by Schmincke (1967b, p. 326-328), are recognized by the presence of abundant basalt fragments, many with chilled glassy margins, mixed with disturbed fine-grained sediment (now weakly lithified). Fragments range in size from a few millimeters to tens of centimeters across. Such peperites are commonly associated with pillow basalt and hyaloclastite and probably formed as basalt flows that encountered sediment on lake or stream bottoms or on broad alluvial plains.

Another kind of peperite developed locally above sheetlike invasive flows in sill-like relation to sediment. These peperites apparently formed as steam blasts that injected molten basalt upward from the invasive flow into the invaded sediments. They commonly flank the margins of satellite dikes rooted in the underlying invasive flow. Such "explosive" peperites are exposed in places above the invasive flow of Hammond just east of Rock Island Dam.

Sills formed by invasive flows are 5 to 120 m thick, and some, such as the Hammond, Howard Creek, and unmapped units in the northeastern and southwestern parts of the quadrangle, cover hundreds of square kilometers. The upper surfaces of these bodies are nearly planar to slightly undulatory, contain few vesicles, and have glass selvedges indicating rapid quenching against the enclosing sediment. Locally, thin dikes and sills sprout from the top and intrude the host sediments. In places such as the bluff north of the mouth of Rock Island Creek, dikes rooted in the invasive flow of Hammond as far as 15 m above the top of the flow provide an estimate of the minimum thickness of sediment invaded by the flow. Sediments commonly are slighdy baked along the upper contact of the invasive flow, and a thin layer closest to the flow is black as a result of reduction during baking.

The sill-like bodies are interpreted to be invasive flows, not sills in the classic sense, for the following reasons: (1) all these bodies cut sediments only; (2) no feeder dikes have been found; (3) the bodies represent the distal part of a complex assemblage that changes from non-nal flows in the southeast through pillowed flows and hyaloclastites into peperites and sills; (4) flow directional data in lava deltas show that lava moved toward the sill-like bodies, not away from them; (5) microprobe analyses of glassy selvedges (Byerly and Swanson, unpubl. data, 1978) confirm correlations made across the facies changes and show that the invasive flows fit perfectly into the chemical stratigraphy established in nearby areas; and (6) the magnetic stratigraphy show no anomalies: all flows and interlayered invasive flows in the lower and upper parts of the section have normal polarity, and all in the middle part have reversed polarity. We interpret each invasive flow to have formed, before the next higher flow, as lava advanced across low areas and burrowed into unconsolidated sediments.

Wanapum Basalt

Frenchman Springs Member

The Frenchman Springs Member is the oldest member of the Wanapum Basalt in the quadrangle. Frenchman Springs Coulee, the type locality of the member, is only 2 km east of the mouth of Whiskey Dick Creek [48], in the extreme southeast corner of the quadrangle. The member is about 75 m thick there but thins westward and northward; remnants near the crest of the Naneum Ridge anticline and between West Bar and Badger Mountain are less than 5 m thick.

The Frenchman Springs overlies the Vantage Member of the Ellensburg Formation in most places in the quadrangle. On Badger Mountain, the Vantage is too thin to show on the map. Absence of the Vantage near the crest of the Naneum Ridge anticline suggests that the anticline began to rise before Frenchman Springs time. The lowest flow in the member has a pillowed base in most places. Silicified wood is abundant in the Vantage and the overlying pillowed zone. Ginkgo Petrified Forest State Park, bordering the southeast corner of the quadrangle, was established to protect an extensive silicified forest along the base of the Frenchman Springs Member.

Roza Member

The Roza Member crops out only in the extreme southeast corner of the quadrangle. The Roza is about 30 m thick along the east side of the Columbia River and thins westward to less than 10 m thick near Kohler Spring [47].

Priest Rapids Member

The Priest Rapids Member occurs only in a faulted anticline along Caribou Creek in Kittitas Valley. It overlies a thin tuffaceous interbed resting depositionally on the vesicular top of a flow in the Frenchman Springs Member; the Roza Member is missing. We recognized the Priest Rapids in the field chiefly by its reversed magnetic polarity (Rietman, 1966) and tentatively confirmed its identity by its high $Ti0_2$ and P_20_5 content as determined by electron microprobe analysis of a glass selvedge from the flow.

Ellensburg Formation

The Ellensburg Formation consists of weakly indurated sedimentary rocks and is extensively interbedded with the Yakima Basalt Subgroup in the Wenatchee quadrangle. The formation generally is poorly exposed because of extensive landsliding and vegetation. Some of the places where the Ellensburg is best exposed are: (1) roadcuts along South Cle Elum Ridge between Taneum Point and the vicinity of Skull Spring, (2) east side of Swauk Creek south of Swauk Prairie [17] in Hidden Valley, (3) roadcut in a landslide(?) block above the Yakima River 3.5 km east-southeast of its confluence with the Teanaway River, (4) roadcuts and natural exposures above the invasive flow of Hammond east of the town of Rock Island, (5) along Dry Gulch [42] 4 km south-southwest of Rock Island Dam.

Most deposits interbedded with basalt are less than a few meters thick; only those thicker than 5 to 8 m are shown on the map. Thick interbeds, as much as 20 to 30 m, occur in a few places such as localities (3) and (4) listed above.

We have divided the formation into two distinct units within the quadrangle. In and southwest of Kittitas Valley, the Ellensburg is dominanfly volcaniclastic, consisting of tuffaceous sandstone, siltstone, conglomerate, and laharic deposits. Feldspathic sandstone and siltstone and mixtures of feldspathic sandstone and tuffaceous debris occur uncommonly. Andesitic and dacitic detritus in the Ellensburg, mosdy south of the Wenatchee quadrangle, was described by Schmincke (1967a, p. 1006-1011; compare references therein). Pumice clasts and many euhedral crystal fragments, some with glass adhering to them, indicate that most or all of the material was freshly erupted from volcanos in the ancestral Cascade Range, not eroded from older volcanic rocks.

Northeast of Kittitas Valley, micaceous feldspathic sandstone and siltstone dominate, and volcaniclastic material is nearly absent. The quartzo-feldspathic detritus was derived from erosion of older rocks such as the Swauk Formation and Chumstick Formation and the Swakane Biotite Gneiss. Sedimentary structures such as cross beds and imbrication suggest that the subarkosic facies of the Ellensburg was deposited on broad flood plains by small streams flowing southward and southeastward. We found no coarse conglomerate in the subarkosic facies that would indicate the channel of a large river. Carbonaceous leaf-bearing claystones are evidence that swamps and shallow ponds existed in places.

The ancestral Yakima River, heading in the volcanically active Cascade Range to the west, carried large volumes of freshly erupted andesitic and dacitic debris eastward into present-day Kittitas Valley, greatly diluting the comparatively small volume of quartzo-feldspathic material eroded by tributaries of the Yakima draining highlands north of the valley. This relation suggests that an ancestral Kittitas Valley existed and therefore that structures controlling the Kittitas Valley downwarp were active before or during deposition of the oldest preserved Ellensburg sediments between the reversely magnetized basalt flows of the Grande Ronde Basalt. In the eastern part of the quadrangle, westward thinning of the Vantage Member and other subarkosic Ellensburg interbeds, evidently deposited by tributaries to the ancestral Columbia River, suggests that a ridge in the general vicinity of the present-day Naneum Ridge anticline separated the ancestral Columbia and Yakima drainages.

SURFICIAL DEPOSITS AND GEOMORPHOLOGY

By R. B. Waitt, Jr.

Nature of surficial units

The surficial units on the map are three-dimensional bodies of sediment having bases and tops. Many of them are not divided on lithologic criteria but are distinguished from one another principally by relative geographic position and geomorphic criteria. Surface form is not subordinated to the lithologic and textural character of the deposit, although generally there is some correspondence of surface form to the nature of the underlying material. Most such units partly depend on inferred time relations or on inferred geologic history.

Since 1961 surficial units elsewhere that are comparable to many of those of the Wenatchee sheet have been regarded as lithostratigraphic units, especially when they acquire formal names. The means of distinguishing these units, however, could scarcely be more removed from the guidelines of Articles 4 and 5 of the Code of Stratigraphic Nomenclature (American Commission on Stratigraphic Nomenclature, 1970). These units are of a character not addressed by the Code: geomorphically defined local chronogeographic units (Waitt, 1981). Each suite of sediments lumped under acommon name- Lakedale Drift, Indian John subdrift, Columbia flood deposit, older diamictite- constitutes a local chronogeographic unit.

Departing from modern practice with lithostratigraphic units, though not from historic precedent in alpine terrain, I apply the same proper-name prefix to the depositional landforms as designate the body of sediment underlying the landform. Moraines and terraces, after all, are the very criteria that define the bodies of drift or alluvium. An Indian John moraine and Indian John terrace thus refer to the moraine and outwash terrace that distinguish the Indian John subdrift from neighboring chronogeographic units.

Many chronogeographic units are further divided lithologically into facies. Till, mainstream (outwash) gravel, sidestream gravel, and lacustrine sand and mud are so distinguished within the Indian John subdrift. Such subdivisions are lithologic and in a few places even lithostratigraphic in nature; nonetheless, moraines, terraces, and other landforms influence map contacts.

Chronologic calibration of eastern Cascade and surficial deposits depends on (1) stratigraphic relations of various deposits and tephra layers, (2) a few directly pertinent radiocarbon dates and a few more that, being related to some widespread suite of sediment such as catastrophic - flood gravel, are inferentially applicable, and (3) assumed synchrony of the maximum alpine advance to the Evans Creek Stade in western Washington,and of the maximum stand of the Okanogan lobe of Cordilleran ice to the dated maximum stand of the Puget lobe (Armstrong and others, 1965; Mullineaux and others, 1965; Richmondand others, 1965; Halstead, 1968; Easterbrook, 1969; Porter, 1970; Heusser, 19 72,1973; Waitt and Thorson, 1982).

Mass-wastage deposits

Landslide and related deposits range (1) in volume from incidental shallow slumps to accumulations exceeding 5 kM3, (2) in composition with the great variety of the bedrock, (3) in maximum grain size from pebbles to blocks as wide as 0.3 km, (4) in surface form from nearly featureless to high relief and hummocky, and (5) in age from Pliocene(?) to modern. Discussion is limited to the largest and stratigraphically most significant deposits.

By far the greatest concentration of mass-wastage deposits large and small, ancient and young, occurs where the well- jointed permeable Yakima Basalt Subgroup overlies the weakly lithified and less permeable Roslyn,

Wenatchee, and Ellensburg Formations on steep valley sides, especially along the regional updip escarpment of the basalt.

The oldest such deposits are basaltic diamictite (older diamictite) capping divides between Columbia River tributaries southwest of Wenatchee. Of these the most conspicuous descends at a mean gradient of 57 m/km as a continuous surface from the scarp beneath Mission Peak (30] to its toe on Wenatchee Heights overlooking the Columbia. This and several remnants on other divides must have originated as debris flows that descended along ancient valleys toward the Columbia. The topography has since completely inverted: the ancient valleys are now diamictite-capped bedrock divides below which modern streams like Squilchuck Creek have incised as deep as 350 m. The deposits are undated, but the implied longevity of drainage evolution suggests a Pliocene age.

Nearly identical diamictite (younger diamictite) caps divides between and descending parallel to tributaries of Stemilt, Squilchuck, and other creeks. These deposits, perhaps derived from the higher older diamictites, probably also were debris flows channeled along ancient tributary valley floors. Because the incision of the high older diamictite surfaces and the excavation of the present drainage basins had to have been underway, these deposits clearly belong to a more recent episode in the drainage evolution than the older diamictites. But topographic inversion and 180 m of incision of the tributary system into bedrock imply a Pliocene age for these deposits.

Other analogous diamicton deposits variously occupy lower divides and modern valley floors. They represent the more recent chapters of the debris-flow filling of valleys and derangement of drainage. The young deposits are large-block slides at their coherent extreme and mudflows at their fluidal extreme.

Parts of the larger slides along the regional updip escarpment of the basalt are distinguished by their content of huge intact blocks of basalt, some preserving interbedded Ellensburg strata. In most places the blocks are elongate parallel to, and are steeply backtilted toward, the source-area scarp. Near Mission Peak [30] however a 2-kM2 area of enormous nonrotated blocks has merely pulled away a short distance from in-place basalt, as indicated by long gaping fissures tens of meters broad and deep that separate individual blocks.

Because the larger slides and blockslides surrounding Lookout Mountain [14] occur where glaciers or moraines temporarily ponded lakes, and because the toes of the even larger slide complexes near Malaga and Rock Island [41] are in areas that were temporarily drowned by catastrophic floodwater, one could speculate that saturation by these bodies of water promoted the landslides (Porter, 1969)-just as reduced coherence along the newly saturated waterline of manmade reservoirs causes landslides (Jones and others, 1961). Both at Lookout Mountain and near Wenatchee, the landslides underlie and therefore predate deposits referred to the episodes of ponding. The slides below Lookout Mountain underlie mainstream outwash gravel of the Swauk Prairie subdrift; the enormous landslide complexes near Wenatchee are overlain by undeformed deposits of the Missoula floods that were channeled down Moses Coulee and later down the Columbia valley. In any case, numerous landslides occur almost continuously along the regional escarpment in places high above the limits of ponded water.

During the Holocene Epoch, small landslides have occurred in widely varied localities. Many small slides are in cirques that until about 12,000 B.P. were occupied by glaciers. Historic slides caused the June 1916 damming of Stemilt Creek by a slide from an irrigation-saturated part of Wenatthee Heights (Wenatchee Daily World, 12 June 1916) and the destruction in 1971 of part of U.S. Highway 97 by a landslide (Martin Kaatz, written commun., 1975) into the Yakima River from a scarp in the Thorp Gravel near Thorp.

Glacial and alluvial sequence in Yakima drainage basin

The stratigraphy of the Kittitas and upper Yakima Valleys, which harbor the most complete post-Miocene sequence in the eastern Cascades, was discussed at some length by Porter (1965, 1969, 1975, 1976) and Waitt (1977b, 1978, 1979) and therefore needs but brief discussion here.

Thorp Gravel

Originally mapped as part of the Miocene Ellensburg Formation (Smith, 1904), a thick gravel that forms a conspicuous high-level terrace in Kittitas Valley was named the Thorp Drift by Porter (1976) and renamed the Thorp Gravel by Waitt (1979). The Thorp comprises a mainstream (Yakima River) facies rich in durable intermediate-volcanic clasts evidently largely derived from the underlying Ellensburg Formation, and a sidestream facies composed of clasts of Grande Ronde Basalt derived from the northern side of Kittitas Valley. Both facies are incised as deeply as 30 m by small streams, are deeply weathered, and are cemented with montmorillonite and hematite.

Porter (1976) inferred that the Thorp is outwash, but Waitt (1979) suggested that it is a Yakima River aggradation caused by uplift of anticlines that cross the river to the south within the structural zone of the Olympic-Wallowa lineament. The Thorp may correlate with the Ringold Formation in Pasco Basin (Waitt, 1978, 1979), which also has been interpreted as an aggradation caused by tectonism (Flint, 1938; Newcomb, 1958; Brown and McConiga, 1960).

Zircon from three tephra layers in the middle and upper part of the Thorp (mainstream facies) has fission-track ages of about 3.8 to 4.4 m.y.; hornblende from the stratigraphically intermediate tephra has a K-Ar age of 4.5 m.y. (table 1, nos. 31-33). If the rise of anticlines caused aggradation of the Thorp, these ages date the deformation. Terraces of the sidestream gravel, interrupted by three east-trending faults apparently related to regional bedrock structures (Waitt, 1979), are the youngest demonstrably deformed deposits in the quadrangle.

Lookout Mountain Ranch Drift

The Lookout Mountain Ranch Drift forms broad-crested moraines in Horse Canyon [17] and on Lookout Mountain outside and upslope of the outermost Kittitas moraines [14]. Originally correlated with the Thorp (Porter, 1969, 1976), the drift is significantly less weathered and cemented than the Thorp and otherwise seems considerably younger; accordingly it was formally named by Waitt (1979). The surfaces of the Lookout Mountain Ranch moraines are less sharp than those downslope considered to be Kiftitas in age and they have fewer and more weathered stones and a redder soil.The Lookout Mountain Ranch Drift is tentatively correlated with the 0.75-m.y. Sherwin Drift of the eastern Sierra Nevada (Waitt, 1979).

Kittitas Drift

Because of their similar degrees of weathering and soil development, two sets of moraines and outwash terraces-the Indian John and the Swauk Prairie-distinguished on chronogeographic criteria. were grouped by Porter (1975,1976) underthe common name Kittitas Drift. I accept Porter's field evidence and his grouping; but because the subdivision is not lithostratigraphic in essence, I demured from Porter's designation "Members" and substituted instead "phases" (Waitt, 19 79)." Phases," however, was but an expedient, and now this term is replaced by "subdrift" (see Waitt, 1981).

The large volumes of the Kiftitas moraines and the well-developed reddish argillic soil of the Kittitas Drift suggest its correlation with the penuitimate glacial deposits at West Yellowstone and on Mauna Kea, both dated 130,000 to 140,000 years old (Pierce and others, 1976; Porter and others, 1977)-ages common to Marine Isotope Stage VI of Emiliani and Shackelton (1974, time scale D).

Swauk Prairie subdrift.-The outer limit of glaciers during the penuitimate glaciation is marked by the voluminous morainal embankments of Thorp [21] and Swauk [13] Prairies and by nested moraines in a saddle on the western part of Lookout Mountain (Porter, 1976). Gravel beneath till at Thorp Prairie indicates that the glacier overrode its own outwash train. New but temporary exposures in 1977 in eastern Swauk Prairie reveal two till layers separated by 4 m of clay and sand (older lacustrine facies), evidence that the morainal embankment parfly accumulated during an early glaciation, stade, or incidental ice-marginal fluctuation.

Downvalley of the moraines at Thorp Prairie, the outwash terrace can be traced 15 km along the southern side of Kittitas Valley. Terraces of basaltic sidestream gravel in northern Kiftitas Valley are correlated with the Swauk Prairie mainstream terrace on the basis of their height above Indian John terraces.

Indian John *subdrift*.-An inconspicuous moraine at Indian John Hill [16] on the southern side of the Yakima River and, across the valley, a distinct left-lateral moraine on the southern slope of Cle Elum Ridge delineate the terminus of the Yakima valley-glacier that deposited the Indian John subdrift. At Indian John Hill a thin till layer capping a thick section of outwash (mainstream) gravel indicates advance of the glacier across its proglacial outwash train. From the frontal slope of the Indian John moraine, a prominent outwash terrace extends discontinuously at least 30 km down the Kittitas Valley. A conspicuous terrace of basaltic sidestream gravel in northern Kittitas Valley grades southward to the mainstream terrace, establishing the chronogeographic correlation of sidestream surfaces in northern Kittitas Valley with the Yakima mainstream terraces.

Lacustrine facies of Kittitas Drift.-Thin-bedded fine sand and mud containing dropstones indicate extensive ice-marginal lakes in the Yakima valley near Cle Elum and its tributary, the lower Teanaway valley. The stratigraphic and relative geographic positions of the deposits indicate at least three episodes of ponding:

(1) A proglacial lake formed when the advancing Swauk-Prairie-age glacier dammed the lower Teanaway and Swauk valleys and later advanced into that lake. The evidence is the clay stratigraphically separating the two tills at Swauk Prairie (refeffed to above) and, according to landowners, an extensive "blue-clay" layer encountered by wells penetrating the surficial till of Swauk Prairie.

(2) Outside the Indian John moraine and 40 to 50 m higher than the inferred surface of the post-Indian John lake (below), rhythmically thin-bedded silt and clay containing dropstones as large as 4 cm at altitude 680 m on Cle Elum Ridge are evidence of a lake that probably drained eastward into Swauk Creek via a channel at altitude 685 to 690 m across the Swauk Prairie moraine.

(3) The youngest lake, recognized by Porter (1969, 1976),is represented by silt containing faceted dropstones that overlies Indian John(?) till in the lower Teanaway valley. A terrace of sand and gravel at altitude 640 m on both sides of the Yakima valley upvalley of the Indian John moraine is marginal stream and deltaic deposits of a lake dammed by Indian John subdrift in the Yakima River canyon south of Lookout Mountain. The topset-foreset contact of a small hanging delta in NEI/4 SWY4 sec. 6, T.19 N., R.16 E. is at altitude 630 m. Thick sections of silt and clay in boreholes near Cie Elum indicate that the lake extended at least 15 km upvalley of the Indian John moraine (Porter, 1969, 1976).

A thick fill of sand and gravel (sidestream alluvium, Swauk Prairie subdrift) forming extensive flat surfaces at altitudes 610 to 740 m in the three forks of the Teanaway valley evidently is fill graded to a local baselevel determined by a long- lived lake that followed retreat of the glacier from the Swauk Prairie moraine-either or both of lakes (2) and (3). The surface of the fill rises to 850 m up each of the forks of the Teanaway, reflecting the grade of streams that delivered debris to the head of the lake(s).

Lakedale Drift

Porter (1976) named the Lakedale Drift and divided it from oldest to youngest into the Bullfrog, Ronald, Domerie, and Hyak "Members." Most of these deposits and all of their definitive exposures are upvalley of the Wenatchee quadrangle, where I have no dispute with Porter's division. To escape the implication that the divisions are lithostratigraphic in the sense of the Code of Stratigraphic Nomenclature, I here redesignate the "Members" as informally named subdrifts (after Waitt, 1981).

Bullfrog subdrift.-During the last glaciation the Yakima valley-glacier barely terminated within the Wenatchee quadrangle. The terminal moraines, first noted by Campbell and others (1915), embellish a prominent outwash terrace that can be traced discontinuously to the southern boundary of the map. Sidestream terraces in northern Kittitas Valley appear to be graded to, and therefore are correlated with, the Bullfrog mainstream terrace.

The heads of several tributaries of the North Fork Teanaway River harbored small Lakedale-age glaciers. The deposits are too thin to show on the map and are largely obscured by Holocene slope debris. Naneum Creek, which heads on Table Mountain (1859 m altitude), contains moraines from two glaciations. Sharp-crested lateral moraines at altitude 1460 m in Naneum Creek, here correlated with the Lakedale Drift, are enclosed within more massive, broader crested, distinctly more weathered older moraines correlated with Kittitas Drift. Other moraines occur upvalley along Owl Creek [27] and along the West Fork Naneum Creek, where one moraine dams a small pond. The weak soil and scant weathering of the outermost younger drift identify it as the terminal moraines of the Lakedale Drift.

Porter (1975, 1976), inferring the Bullfrog to be the early stade of the Fraser Glaciation, tentatively correlated it with the Evans Creek Drift of the Puget Lowland, which is roughly 18,000 years old (Marine Isotope Stage II). Colman and Pierce (1976), using Porter's (1975) weathering-rind data, suggested the alternative that the Bullfrog is "early Wisconsin" (Isotope Stage IV). The scant soil, however, more accords with an age of 20,000 yr or less.

Ronald and Domerie subdrifts.-The Ronald and Domerie subdrifts each are defined by an outwash terrace near Cle Elum that is traceable to moraines upvalley, beyond the map boundary. These divisions are not otherwise recognized in the Wenatchee quadrangle, although there are apparent correlatives in the Chelan 1: 100,000 quadrangle to the north. Projecting ice profiles across the Cascade crest, Porter (1976) speculated that the Domerie correlates with the 14,000-yr- B.P. maximum stand of the Puget lobe of Cordilleran ice during the Fraser Glaciation.

***Hyak* subdrift.**-The Hyak subdrift is defined by moraines near the head of the Yakima Valley 40 km upvalley of the map boundary. On moraines in other valleys correlated with the type Hyak because of similarity of geographic locale high in glaciated valleys, the surface stones everywhere are fresh and the soils weak. Mazama tephra (6700 yr B.P.) and St. Helens Yn tephra (3400 yr B.P.) (Mullineaux, 1974) have been found on several moraines correlated with the Hyak. Porter (1976) obtained a minimum- limiting radiocarbon age of 11,050 yr B.P. for the Hyak near Snoqualmie Pass and, from relations of correlative moraines to Glacier Peaks tephra near Stevens Pass, a maximum age of about 12,000 yr B.P.

Glacial sequence in Wenatchee drainage basin

Pleistocene sequence *in* Ingalls and Peshastin valleys

In the Ingalls-Peshastin valley, Hopkins (1966) mapped three drift sheets, which he termed "older," "intermediate," and "younger" drifts; the younger correlates with the Lakedale Drift. But some of Hopkins "older" drift, as in Hansel Creek [3], is indistinguishable from the "intermediate" drift according to my application of his criteria (boulder frequency, granite- weathering ratios); and the right-lateral moraine of Hopkins' "intermediate" drift has weathering characteristics that, according to his data, typify "older" drift. Division of the pre-Lakedale deposits must await a detailed relative-age study; here they are grouped with the Kittitas Drift.

The Lakedale Drift comprises an outer set of moraines in Peshastin valley that is correlated with the Bullfrog subdrift in Yakima valley, and an inner set of moraines far upvalley that is correlated with the Hyak subdrift.

Holocene glacial deposits *in* Enchantment Lakes area

Hundreds of meters above moraines in the Wenatchee drainage basin refeffed to the Hyak subdrift are two sets of moraines in the upper basin of the Enchantment Lakes area [2] (Waitt and others, 1982). The inner cluster of moraines (Brynhild moraines) and its enclosed rock surface display almost no soil, sparse and small lichens, and shallow weathering pits. The outer moraine (Brisingamen moraine) and its enclosed rock surface are heavily covered with large lichens and have weathering pits that are deeper and more numerous than on the Brynhild moraine and its enclosed rock surface. The Brisingamen underlies the Mazama tephra and therefore predates 6700 yr B.P. Weathering pits, weathering rinds on stones, and other data indicate that the rock surface outside the Brisingamen moraine, last glaciated in Hyak time, is considerably older than the Brisingamen. The Brisingamen therefore is early Holocene, whereas the essentially unweathered Brynhild is no more than a century old (Waitt and others, 1982). Unstudied moraines apparendy correlative with these moraine sets occur in the headwaters of Ingalls Creek and the Teanaway River and widely beyond the northern boundary of the quadrangle.

Deposits related to catastrophe in the Columbia River valley

The Columbia River in some form has conveyed sediment from the interior of Washington to the Pacific since the Miocene Epoch or earlier. Almost nothing of the early record remains, for the present valley contains a very incomplete Pleistocene record and only a fragment of the Pliocene. Like no other drainage basin in the world, the Columbia and the lower segments of its tributaries are overwhelmed by sediment of very brief catastrophes-so much so that almost none of the sediment in these areas is interpreted according to normal river dynamics. The most significant events are (1) huge landslides that physically ponded the Columbia and its tributaries; (2) catastrophic floods as deep as 350 m that swept away or buried older sediment with coarse gravel along the Columbia and rapidly disgorged finer suspended load into the tributaries; and (3) physical damming of the Columbia by a huge flood bar that accreted laterally across the Columbia out of Moses Coulee. The history of these events is incompletely understood, and much of the critical evidence lies beyond the quadrangle boundaries.

The uniqueness of the Columbia flood deposits cannot be overemphasized: in the entire geologic literature on fluvial deposition, only deposits in the Channel Scabland discussed by J Harlen Bretz are directly similar to the deposits discussed below. Pliocene(?) conglomerate 150 m above the modern Columbia River upvalley of Wenatchee indicates that the river and its tributaries have downcut only 150 m in the past few million years. Wisconsin-age gravel 200 m above the river does not indicate more recent valley incision by that amount, but rather a flow of water capable of depositing bedload gravel 200 m above the river. No other drainage basin on earth has been affected by fluvial events of comparable magnitude.

Chronologic calibration of flood-gravel units depends on their relations to Cordilleran ice-sheet deposits in the Chelan area and near the head of Moses Coulee and their relation to Glacier Peak tephra in the Chelan area and Mount St. Helens tephra in the Pasco Basin, all well beyond the map boundaries (Waitt, 1977a; 1980).

Thin-bedded silt in the lower Wenatchee valley is polygenetic. Because some of the specific relations of several silt bodies to each other and to specific casual events in the Columbia are obscure, they are mapped as a broad single unit. Correlation to events downvalley that may have caused them are speculated on below.

Deposits of landslide-dammed lakes

Enormous preflood landslides and blockslides that descended into the Columbia River from both valley sides downstream of Wenatchee clearly were capable of damming the river. Steeply rotated blocks of Grande Ronde Basalt as long as 2 km derived from the southern valley side occur not only on the southern side of the river near Rock Island but also in the river and on the northern bank. These and other similar deposits upriver seem to be the toe of a huge landslide that, before it was deeply eroded by floodwater, could have ponded the river to about altitude 320 m. The uppermost ("a") terrace along the lower Wenatchee River consists of sand derived from nearby tributaries. The terrace and a sand body graded to it from higher altitude evidently is a sidestream deposit built into a long-lived lake that stood at altitude 320 m. Rhythmites in the Wenatchee valley near Dryden (off map) and in Columbia tributaries farther south signify multiple floods from Lake Missoula (Waitt, 1980); but boulders of quartz diorite from the Mount Stuart batholith ice rafted from upvalley and embedded in nearby silt near Dryden suggest a long-lived lake at altitude 320 m, in which terminated a contemporaneous glacier from upvalley (Waitt, 1977b). This could have occurred only if the glacier upvalley was at its maximum Lakedale stand, which suggest that the ponding by the landslides near Rock Island occurred about 18,000 to 19,000 yr B.P., the time of the alpine-glacier maximum (Evans Creek Stade) in western Washington. One of the landslides near Malaga underlies undeformed gravel of the Moses Coulee floods of estimated age 16,000 yr B.P. and both slides by gravel of the Columbia floods of about 13,000 yr B.P.

Catastrophic-flood deposits

It has long been suspected that a relatively small catastrophic flood modified the glaciated segment of the Columbia above Wenatchee in late Wisconsin time (Waters, 1933) and that at least one great pre-Fraser flood descended the Columbia (Bretz and others, 1956). Contrary to Bretz's opinion (1928, 1969), it has been shown that some of the great late Wisconsin Missoula floods that swept the Channeled Scabland also swept down the Chelan-Wenatchee segment of the Columbia (Waitt, 1972, 1977a, b).

Baker (1978) and Waitt (1978) argued that the eodence in eastern Washington admits of only four or fewer great Missoula floods in late Wisconsin time. But more recent data from southem Washington indicate 40 or more late Wisconsin great j6kuIhIaups from glacial Lake Missoula (Waitt, 1980i. Although this remarkable and unique regional history must be kept in mind when interpreting local depositional sequences, there is positive field evidence in the Wenatchee quadrangle of only five great episodes of catastrophic flooding-here called pre-Wisconsin, early Columbia River, Moses Coulee, late Columbia River, late. But the deposits of each episode may be the result of several individual fluvial catastrophes.

Pre-Wisconsin flood deposits.-In East Wenatchee an accumulation at least 50 m thick of cobble gravel derived from upvalley underlies Fancher Field [37] and is capped by 0.5 to 2 m of caliche (not necessarily entirely pedogenic) that in turn is overlain thickly by loess. The deposit is distinguished from the abundant Wisconsin-age flood gravel nearby by its higher altitude, absence of huge boulders, and caliche cap. Foreset beds dipping downvalley in sets 3 to 4 m high suggest that it may be a flood gravel. This deposit is traced southward a few kilometers as a sand and gravel body that locally contains large boulders, has many weathered stones, shows downvalley dipping crossbeds, is commonly capped by caliche, and above altitude 400 m is not capped by younger flood gravel.

***Early Columbia Riverflood* deposits.-The** thickest and most voluminous flood deposit along the Columbia is an enormous bar of cobble gravel at Pangborn airfield [38] in the position of an enormous point bar on the inside of the large bend in the valley below Wenatchee. The surface of the bar, as high as 205 m (altitude 385 m) above the river, is embellished with 6-m-high giant current dunes spaced at 215 m. The downvalley dip of the lee slopes of the dunes and of the 15-m-high crossbeds in the gravel indicates the downvalley flow of the flood. The slight weathering and a nonargillic soil that is calcareous but without platey caliche indicate that the deposits are late Wisconsin. Unweathered angular ice-rafted erratics derived from near Lake Pend Oreille, Idaho (Waitt, 1977b) occurring as high as altitude 485 m indicate that floodwater about 350 m deep swept through the Wenatchee area. Formerly identified with the last great Scabland flood, this event (events?) was thought to have occurred after the Okanogan lobe of Cordilleran ice retreated north of the Columbia River, or about 13,500 yr B.P. or later according to inferred relation to the Puget Lowland chronology (Waitt, 1972, 1977a, 1977b). The higest surfaces swept by postglacial floods near Chelan (upvalley of map boundary), however, are only about 215 m above the Columbia River. The 300-m-deep flood(s) in the Wenatchee area, whose effects can be mapped upvalley to but not beyond the glacial limit, therefore seems to predate blockage of the Columbia by the Okanogan lobe.

***Moses Coulee* flood** deposits.-An early Fraser flood or series of floods debouched into the Columbia River valley from Moses Coulee (Bretz, 1930) while the Okanogan lobe of Cordilleran ice blocked the "Big Bend" segment of the valley but before the ice attained its maximum Fraser position (Hanson, 1970). If the advance of Okanogan lobe was synchronous with advance of the dated Puget lobe, the Moses Coulee flood must have occurred 16,000 to 15,000 yr B.P.Waift and Thorson (1982) agree however, that the two lobes probably were not strictly synchronous. Tall foreset bedding dips up the Columbia River valley in subangular cobble basaltic gravel (Moses Coulee floods gravel); cobble gravel near Moses Coulee fines upvalley to granule gravel near Malaga. This deposit apparently is a huge sub - fluvial fan of flood gravel that spread entirely across and physically blocked the Columbia River. The Columbia could have been blocked by a tributary fan only if upvalley Cordilleran ice indeed completely blocked floodwater from descending the Columbia, for a synchronous downvalley flood would have kept free a channel along the outer margin of the bar. Thirteen meters of thin- bedded silt overlying Moses Coulee flood gravel near Rock Island Dam may record the lake dammed by the fan, whose maximum altitude near Moses Coulee would have dammed a lake to altitude 275 m. Yet the lack of intercalated clay and the presence of intercalated wedges of basaltic gravel in the silt suggest that the silt was rapidly deposited by later Moses Coulee floods, and perhaps some of it as the suspended load of later floods backflooding up the Columbia during a lengthy interval when the Okanogan lobe fully blocked off the Moses Coulee floodway.

Late Columbia River flood deposits.-The most extensive of the flood deposits along the Columbia River are bars 60 to 90 m above the river; between Rock Island and Moses Coulee they are mere veneers overlying eroded Moses Coulee flood deposits. This gravel is distinguishable as a flood deposit by its rare content of huge boulders and its depositional landform of giant current dunes. It is distinguished from the underlying basaltic Moses Coulee flood gravel in some places by its abundant rounded clasts of varied lithology that could only have derived from up the Columbia. It is distinguished atop the Moses Coulee bar only by a downvalley paleocurrent indicated by surficial current dunes. Below Moses Coulee the distinction between the deposits of late Columbia River floods and the older phase of the late floods is less definite.

Deposits of lakes after early Columbia River floods.-Voluminous hanging deltas (sidestream delta- terrace) at the mouths of Squilchuck and Stemilt Creeks, which postdate the spectacular effects of Columbia flooding at higher altitudes (gravel of early Columbia River floods), indicate a long-lived lake ponded to altitude about 260 m. The agent of ponding is inferred to be the huge bar of basaltic gravel built athwart the Columbia by the Moses Coulee floods. In the lower Wenatchee valley near Monitor, rhythmites of silt individually fine upward into clay layers many millimeters thick, evidence of a long-lived lake at altitude 275 m or higher. Many other patches of silt overlying Columbia flood gravel, rhythmically bedded but lacking discrete layers of clay, may be deposits of the suspended load that settled during brief hydraulic pondings of several of the latest Lake Missoula jakulhlaups.

***Late-flood deposits*.-**A bar near Malaga below the tops of delta-terraces at tributary mouths is embellished with giant current dunes that are not overlain by lake silt (older phase deposits). Because these dunes are younger than the late Columbia River flood deposits by at least the many decades required to accumulate the deltaic material, this bar was built by a flood or floods distinctly younger than the Columbia River floods. As the lower end of the bar is only 18 m below a surface referred to the late Columbia River floods, the assignment of downvalley features like West Bar to the late flood(s) is judged only on their height above the river. Although the precise correlation of floodswept surfaces near Wenatchee with those near Chelan is somewhat speculative, these flood deposits of relatively low altitude probably correlate with low- altitude deposits near Chelan that are not overlain by, and therefore postdate, the Glacier Peak tephra. The origin of the water for these late floods is uncertain: it may have been the last of the Lake Missoula floods, which were much smaller than the greatest of the Lake Missoula floods (Waitt, 1980), or it may have been the bursting of ice-dammed lakes in the Pend Oreille River and elsewhere on the upper Columbia after the last of the Missoula floods.

Several very low altitude surfaces cut below the bars of the older phase are studded with large boulders. Whether lag deposits or newly contributed material, the boulder fields and other geomorphic aspects of these younger-phase bars indicate their association with an episode of flooding. These surfaces may represent either the wane of the last older-phase flood or a discretely younger and smaller flood.

Wenatchee valley terrace deposits.-A flight of terraces in the lowermost Wenatchee valley and adjacent Columbia River valley have somewhat ambiguous relations to the flood history. The highest ("a") terrace, composed of material derived from side streams, seems related to preflood ponding by the great landslides near Malaga. The next lower ("b") terrace, composed partly of Wenatchee River gravel, is capped by sand that may be backwash from the Moses Coulee and Columbia River floods and therefore at least partly predates the floods. The gravel of an intermediate-level ("c") terrace overlies gravel of either or both of the early Columbia or late Columbia floods. The lowest ("d") terrace is on the same gradient as late-flood gravel immediately upvalley. The intermediate and low-level terraces therefore seem to have formed in succession during the later part of the flood history.

Unlike outwash terraces in the Yakima Valley, outwash terraces in the Wenatchee valley cannot be traced more than a few kilometers downvalley from the moraines near Leavenworth (20 km upvalley of map boundary). The weak A-C soils of the two most prominent low-altitude terraces in the lower Wenatchee valley indicate that both are late Wisconsin. The upper terrace-gravel, much too high for a Lakedale outwash terrace, is overlain by silt either backflooded from the Columbia floods or deposited in the post-early-Columbia-flood lake. The lower terracegravel in Wenatchee valley evidently postdates the youngest of the silt. The terraces record aggradation of the Wenatchee valley, probably caused by damming of the Columbia or Wenatchee River by flood bars, perhaps during several flood events in Columbia River valley.

Holocene alluvial deposits

Holocene alluvial deposits occur in all drainages. Mixed-lithology mainstream deposits are distinguished on the map from the lithologically more restricted and more angular debris from sidestreams, a distinction mapped in all of the older units in Kittitas Valley. Most of the Holocene gravel of the Columbia River is drowned in lakes behind Rock Island and Wanapum Dams.

Throughout the map area, small steep-gradient fans at the mouths of very small tributaries are differentiated from the more gently graded valley-floor alluvium of the trunk streams and sidestreams. Mazama tephra (about 6700 yr B.P.) intercalatedin some of the fansshowstheir Holocene age; in formerly glaciated alpine valleys like Ingalls Creek, these late- glacial to Holocene fans coalesce into almost continuous aprons along the lower slopes of valleys.

Of the colluvium, talus, loess, eolian sand, rock-glacier deposits, bog deposits, and other surficial Holocene debris that variously occur through the area, only the most extensive are shown on the map.

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