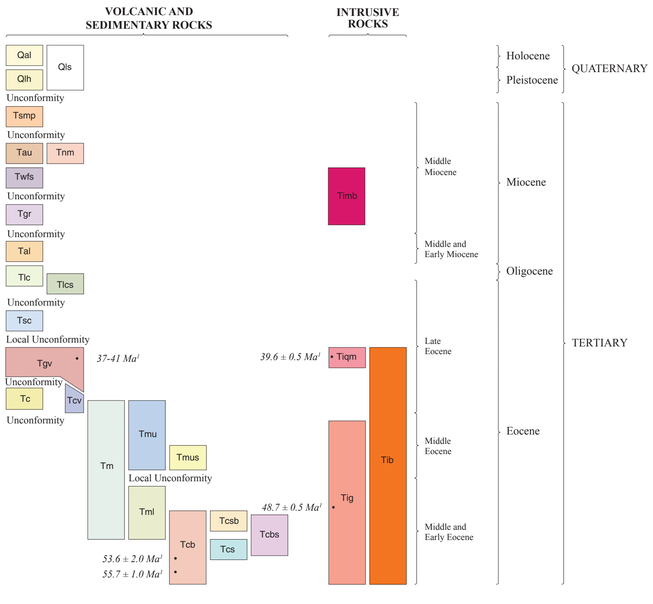
CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

VOLCANIC AND SEDIMENTARY ROCKS

Qal **Alluvial deposits (Holocene)**—Silt, sand, and gravel along rivers and streams; some low-lying river-terrace deposits, thick colluvium, tidal-flat mud, and beach sand along Columbia River

Qls **Landslide debris (Holocene and Pleistocene)**—Landslides very abundant in all rock units; only largest are shown on map

Qlh **Logan Hill Formation of Snavely and others (1958) (Pleistocene)**—Deeply weathered gravel and sand

Tsmp **Saddle Mountains Basalt of the Columbia River Basalt Group; Pomona Member (middle Miocene)**—One basalt flow, as much as 100 m thick west of Mill Creek; exhibits characteristic wavy, irregular columnar jointing; contains as much as 20 percent stubby plagioclase phenocrysts, some having clinopyroxene inclusions; magnetic polarity is reversed (Magill and others, 1982); chemistry[2] is equivalent to that of Pomona Member (Swanson and others, 1979; Wells and others, 2009); unit locally includes underlying flow of Huntzinger of the Saddle Mountains Basalt in Abernathy and Germany Creek drainages (Beeson and Tolan, 2002; Wells and others, 2009); basalt is overlain by deeply weathered basalt conglomerate containing ferruginous bauxite deposits (Livingston, 1966)

Tau **Astoria(?) Formation, upper Member (middle Miocene)**—Thick- to thin-bedded, friable, very fine- to medium-grained, micaceous, arkosic sandstone and silty sandstone; plane-laminated, thin-bedded micaceous siltstone, some having large, low-angle cross bedding sets; large channels in siltstone filled with very coarse sand and transported siltstone blocks; convolute bedding and slump structures common; fossils not yet found in unit

Tnm **Nonmarine sedimentary rocks of Snavely and others (1958) (middle Miocene)**—Poorly consolidated siltstone, sandstone, and conglomerate; contains fossil plants

Twfs **Wanapum Basalt of the Columbia River Basalt Group; Frenchman Springs Member (middle Miocene)**—At least two flows of fine-grained basalt and associated flow breccia, having total thickness of 100 m; flows have well-developed colonnades, that have straight-sided columns as much as 2 m in diameter; flows are very sparsely plagioclase-phyric, with phenocrysts as much as 1.5 cm long; magnetic polarity is normal, and chemistry matches the Frenchman Springs Member on the Columbia Plateau (Swanson and others, 1979; Wells and others, 2009)

Tgr **Grande Ronde Basalt of the Columbia River Basalt Group (middle Miocene)**—One or more flows of dark-gray, aphanitic, aphyric basalt that has well-developed entablature; overlain by three or four flows of light-gray, sugary, fine-grained aphyric basalt with well-developed colonnades; flows locally pillowed at base; hyaloclastite abundant west of Skamokawa; magnetic polarity is normal, and chemistry of upper three flows is similar to high-Mg flows at the top of the Grande Ronde Basalt of the Columbia Plateau (Swanson and others, 1979; Sentinel Bluff Member, Wells and others, 2009); chemistry of lower flows is similar to low-Mg flows of the Grande Ronde Basalt on the Columbia Plateau; flows are separated by basaltic conglomerate and basaltic to arkosic, fine- to very-coarse sandstone and siltstone; separated from the overlying Frenchman Springs Member of the Wanapum Basalt (Twf) by discontinuous arkosic sandstone containing carbonized logs; maximum thickness, 75 m

Tal **Astoria(?) Formation, lower member (middle and early Miocene)**—Thick- to thin-bedded, very fine- to medium-grained, plane-laminated, carbonaceous, micaceous, friable sandstone; basalt- and quartzite-conglomerate lenses locally common; bioturbation and slump structures in places; Molluscan fauna referred to Newportian or Pillarian Stages of Addicott (1976)[3]

Tlc **Lincoln Creek Formation (upper Eocene and Oligocene)**—Tuffaceous siltstone and very fine-grained sandstone; massive to thick bedded, concretionary, bioturbated, with interbeds of glauconitic sandstone and tuff; thin-bedded, laminated siltstone in southwesternmost exposures; Molluscan fauna referred to Blakely Stage of Weaver (1944); Foraminifera referred to Refugian and Zemorrian Stages of Kleinpell (1938)[4]

Tlcs **Sandstone at base of Lincoln Creek Formation (late Eocene)**—Massive to thick-bedded, moderately well-sorted and indurated, fossiliferous, dark-gray, fine-grained arkosic to basaltic sandstone; Molluscan fauna referred to Galvinian Stage of Armentrout (1975) and Lincoln Stage of Weaver (1944)

Tsc **Siltstone of Skamokawa Creek (late Eocene)**—Thin-bedded, laminated, burrowed, concretionary, tuffaceous siltstone; contains thin tuff beds in places; abundant Foraminifera referred to upper part of Narizian Stage of Mallory (1959)

Tgv **Grays River Volcanics (late Eocene)**—Subaerial basalt flows and interbedded siltstone and sandstone; flows show columnar and platy jointing, weathered flow tops, and oxidized, red basal-flow breccias overlying baked and altered sedimentary interbeds; basalts, which are aphyric to densely porphyritic, contain phenocrysts of plagioclase, clinopyroxene, and olivine; Foraminifera from siltstones beneath unit and immediately overlying it are referred to upper Narizian Stage of Mallory (1959); $^{40}Ar/^{39}Ar$ ages of 42 to 37 Ma reported in Chan and others (2012); called "Goble Volcanics" in Wells (1981)

Tc **Cowlitz Formation (late and upper middle Eocene)**—Massive to thin-bedded, plane-laminated and cross bedded, friable, very fine- to coarse-grained, micaceous, arkosic sandstone; interbedded, laminated, micaceous, carbonaceous siltstone, tuffaceous siltstone, and very coarse-grained basaltic, andesitic, and tuffaceous sandstone; thin subbituminous coal as much as 30 cm thick north of Abernathy Mountain; see Livingston (1966) for additional coal localities; see Payne (1998) and Kleibacker (2001) for facies analysis of this unit and adjacent units; Foraminifera referred to upper Narizian Stage of Mallory (1959)

Tcv **Basalt breccia and flows (late and upper middle Eocene)**—Basalt breccia, massive flows and intrusive rock interbedded in the Cowlitz Formation along Columbia River

Tm **Undifferentiated McIntosh Formation and sandstone (Eocene)**—Includes the upper and lower members of the McIntosh Formation (Tmu and Tml, respectively) and the unnamed sandstone (Tmus); shown only in cross section at depth

Tmu **McIntosh Formation, upper member (late and middle Eocene)**—Dark-gray, massive to laminated, thin-bedded, tuffaceous siltstone, silty sandstone, and arkosic sandstone; basalt-cobble conglomerate and slump breccias are found locally; upper part of unit is equivalent in age to the Cowlitz Formation in west half of map area (Rau, 1958); Foraminifera referred to Narizian Stage of Mallory (1959); equivalent to upper part of Henriksen's (1956) Stillwater Creek Member of the Cowlitz Formation; coccoliths from lower part of referable to CP 14a zone (R. Wells sample W92-2a,b,c; D. Bukry written commun., 1992)

Tmus **Unnamed sandstone (middle Eocene)**—Massive to thick-bedded, plane-laminated to crossbedded, friable, fine- to medium-grained, arkosic sandstone interbedded at base of the upper member of the McIntosh Formation (Tmu)

Tml **McIntosh Formation, lower member (lower and middle Eocene)**—Massive to thin-bedded and laminated, very fine- to coarse-grained basaltic sandstone, arkosic sandstone, and laminated, tuffaceous siltstone; sandstone commonly shows graded bedding; sandstones are less common on east flank of Willapa Hills; interbedded in lower part are pillow basalt flows of the Crescent Formation; Foraminifera referred to upper Ulatisian and lower Narizian Stages of Mallory (1959); equivalent to lower part of Henriksen's (1956) Stillwater Creek Member of the Cowlitz Formation

Tcbs **Basalt breccia and sandstone (middle and lower Eocene)**—Massive to well-bedded basalt-lapilli tuff, tuff breccia, basaltic sandstone, siltstone, and conglomerate; lapilli tuff consists of palagonitic vesicular basaltic glass and altered glass shards commonly cemented by calcite and zeolite; graded bedding is common; forms thick sequences interbedded with the lower member of the McIntosh Formation (Tml) and upper part of the Crescent Formation

Tcb **Crescent Formation (lower middle lower Eocene)**—Pillow flows, massive and columnar-jointed flow interiors, pillow breccia, lapilli-tuff breccia, and filled lava tubes of tholeiitic and alkalic basalt; basalt groundmass altered to green and brown clays; zeolite and calcite fracture fillings are ubiquitous; contains minor amounts of mudflow breccia, basaltic sandstone, and interbedded laminated siltstone; includes a few dikes and sills not differentiated on map; unit is interpreted as faulted, deformed, and clockwise-rotated seamount built on oceanic crust (Wells and Coe, 1985), similar to the Siletz River Volcanics of Snavely and others (1968); Foraminifera from interbedded siltstones referred to upper Penutian or Ulatisian Stages of Mallory (1959); $^{40}Ar/^{39}Ar$ ages of 53.6±2.0 and 55.7±1.0 Ma are reported from the unit in the western Willapa Hills (Moothart, 1993); locally subdivided into the following:

Tcsb **Subaerial basalt**—Massive to very vesicular, platy, plagioclase-phyric basalt flows and flow breccias that have weathered tops and baked and oxidized bottom contacts; interbedded with basalt-boulder conglomerate; basalt groundmass is in part altered to clays, and vesicles are filled with calcite and zeolite

Tcs **Siltstone**—Thin-bedded, laminated, tuffaceous siltstone interbedded with pillow basalt of the Crescent Formation

INTRUSIVE ROCKS

Timb **Basaltic intrusive rocks (middle Miocene)**—Dikes and sills of dark-gray, aphanitic, aphyric to sparsely plagioclase-phyric basalt intruding the Lincoln Creek and Cowlitz Formations; could be the (invasive) Grande Ronde Basalt (Tgr) or the Wanapum Basalt (Twf) from adjacent flows; see Beeson and others (1979), Snavely and others (1973), and Wells and others (2009)

Tiqm **Quartz monzonite stock (late Eocene to Oligocene?)**—Light-gray to tan, quartz monzonite to granodiorite with blocky jointing; contains inclusions of the Grays River Volcanics (Tgv); hypidiomorphic-granular, granophyric, and porphyritic textures; see Livingston (1966) for chemical analysis; U/Pb age is 39.6±0.5 Ma (J. Wooden, written commun., 2003; Wells and others, in press)

Tib **Basaltic intrusive rocks (Eocene)**—Dikes and sills of medium- to fine-grained aphyric to extremely porphyritic basalt; many related to the Grays River Volcanics (Tgv), but some may be older

Tig **Gabbro and basaltic intrusive rocks (middle or early Eocene)**—Massive to blocky and columnar-jointed, fine- to very-coarse grained gabbro sill complex; marginal facies are basalt and have well-developed columnar jointing, whereas interiors are very coarse grained to pegmatitic; gabbro and basalt are vesicular and typically flow-banded, result of planar concentrations of vesicles and (or) crystal sorting; interstitial glass generally altered to green clays, and vesicles are filled with clay, calcite, or zeolite; gabbros intrude upper part of the Crescent Formation and along contact between the Crescent Formation and the lower member of the McIntosh Formation (Tml); some gabbro and basalt that intrudes the Crescent Formation may be part of the Crescent Formation magmatism; some may be younger and related to the Grays River Volcanics (Tgv); $^{40}Ar/^{39}Ar$ age of 48.7 Ma from sills reported west of map area (Moothart, 1993)

[1] Radiometric and coccolith ages cited in Description of Map Units

[2] Chemical analyses of the Columbia River Basalt samples by P. R. Hooper

[3] Identification of Molluscan fauna by Ellen James Moore

[4] Identification of Foraminifera by Weldon W. Rau

EXPLANATION OF MAP SYMBOLS

Contact—Approximately located; dashed where location is inferred; dotted where location is concealed. Queried where uncertain (in cross section only)

Fault—Approximately located; dashed where location is inferred; dotted where location is concealed; showing dip of fault plane where known; vertical fault shown by bar across fault; paired arrows and letters on opposite sides of fault show inferred sense of relative displacement in vicinity of symbol; letters U (upthrown) and D (downthrown) show vertical displacement; arrows show lateral displacement on map and vertical displacement in cross section

Fault inferred from side-looking radar imagery (SLRI)—Showing sense of vertical displacement; not field-checked

Thrust fault—Approximately located; sawteeth on upper plate

Slickenlines—On fault plane, showing azimuth and plunge

Inclined

Horizontal—Combined with fault-dip symbol on vertical faults

Folds—Showing fold crestline; showing direction of plunge where it can be inferred; dashed where location is inferred; dotted where location is concealed

Anticline

Syncline

Bedding in pillow lava—Showing up direction; shown only in cross-section within the Crescent Formation

Strike and dip of beds

Inclined—Dips along streams in unit Qal are measured on bedrock

Overturned

Vertical—Top side of bedding shown by placement of 90° dip value

Horizontal

Strike and dip of igneous foliation—Shown only in unit Tig, gabbro and basalt intrusive rocks

Water well with gas show—Showing total depth (TD) of well in feet

INTRODUCTION

This digital map database and the PDF derived from the database were created from the analog geologic map: Wells, R.E. (1981), "Geologic map of the eastern Willapa Hills, Cowlitz, Lewis, and Wahkiakum Counties, Washington." The geodatabase replicates the geologic mapping of the 1981 report with minor exceptions along water boundaries and also along the north and south map boundaries. Slight adjustments to contacts along water boundaries were made to correct differences between the topographic base map used in the 1981 compilation (analog USGS 15-minute series quadrangle maps at 1:62,500 scale) and the base map used for this digital compilation (scanned USGS 7.5-minute series quadrangle maps at 1:24,000 scale). These minor adjustments, however, did not materially alter the geologic map. No new field mapping was performed to create this digital map database, and no attempt was made to fit geologic contacts to the new 1:24,000 topographic base, except as noted above. We corrected typographical errors, formatting errors, and attribution errors (for example, the name change of Goble Volcanics to Grays River Volcanics following current State of Washington usage; Walsh and others, 1987). We also updated selected references, substituted published papers for abstracts, and cited published radiometric ages for the volcanic and plutonic rocks. The reader is referred to Magill and others (1982), Wells and Coe (1985), Walsh and others (1987), Moothart (1993), Payne (1998), Kleibacker (2001), McCutcheon (2003), Wells and others (2009), Chan and others (2012), and Wells and others (in press) for subsequent interpretations of the Willapa Hills geology.

OIL AND GAS POTENTIAL

Commercial quantities of natural gas were discovered at Mist, Oregon, about 10 miles south of the map area, while this mapping project was in progress [1979]. As a result, the eastern Willapa Hills are a target for oil and gas exploration. The Mist gas field and the southern Willapa Hills face each other across the broad, east-west-trending Columbia River syncline that forms a low point in the Coast Range uplift.

The stratigraphic section is similar on both sides of the Columbia River, but facies relations may be more complex on the Washington side. The thick Cowlitz Formation deltaic- and shallow-marine sediments of the type area (Weaver, 1937) are deposited unconformably across older strata and apparently thin rapidly to the west, where they are replaced by laminated siltstones of the same age. This rapid facies change is mapped across the gently south-plunging nose of the eastern Willapa Hills uplift, which is coincident with the axis of the Coast Ranges gravity high. The Willapa Hills structural high may have been an active tectonic feature throughout most of the Tertiary and may have controlled basin geometry and sediment-dispersal patterns. The Cowlitz Formation lies beneath subaerial rocks of the Grays River Volcanics of latest Narizian age, which are in turn overlain by more deep-water siltstones in the western part of the map area. Sandstones of the Cowlitz Formation above the Grays River Volcanics are not exposed, but they may be present in the eastern part of the map area beneath the Lincoln Creek Formation.

The thick, friable arkoses of the Cowlitz Formation and the basal arkoses of the upper member of the McIntosh Formation have good reservoir potential, and they are the most likely reservoir rocks to be found at depth. Siltstones of the McIntosh and Cowlitz Formations may be suitable source rocks, but they have not been tested for source-rock potential. In general, source rocks in the Coast Ranges have marginal to adequate organic richness, but they are commonly thermally immature (Snavely and others, 1977). However, source rocks in the southern Willapa Hills may have been subjected to higher heat flow during late Eocene volcanism and plutonism associated with the Grays River Volcanics. The McIntosh and Cowlitz Formations have abundant herbaceous material that may have provided a source for natural gas.

A series of en echelon northwest-trending folds are present on the south flank of the Willapa Hills uplift. Their structure is complex; the fold axes typically are offset by numerous cross faults. Some of these structures merit further investigation for their petroleum potential. The Wilson Creek uplift may have closure, and several cross faults may have created local traps across the plunging structure. "Marsh gas" has been reported from a 140 ft water well drilled near the axis of this structure (Washington State Dept. of Natural Resources well log 69-559; written communication), but the gas may be a result of decaying organic material beneath a relatively impermeable cover of landslide debris. The Arkansas Creek uplift is another complexly faulted anticline that may have a thick Eocene-age section beneath it. Other possible traps may be present in structures beneath the relatively flat-lying basalts of the Columbia River Group, as well as where sandstones of the Cowlitz Formation are faulted up-dip against impermeable strata. Stratigraphic traps also may be present where sandstones of the Cowlitz or McIntosh Formations pinch out or become channelized in the western-facies deeper water siltstones.

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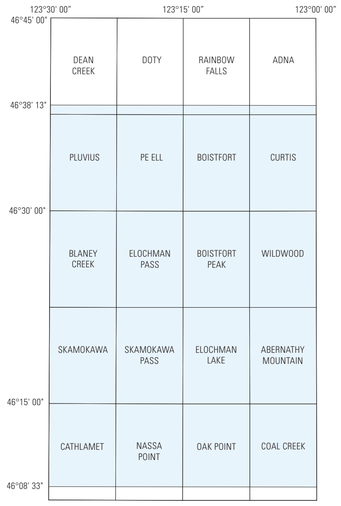
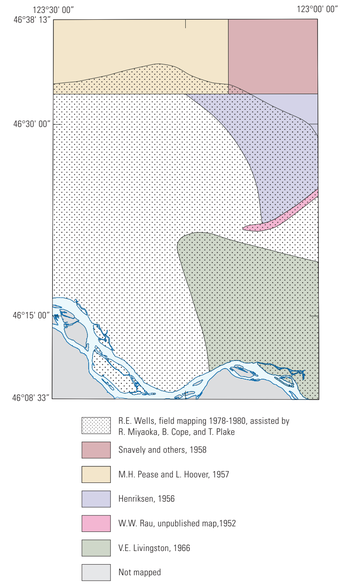
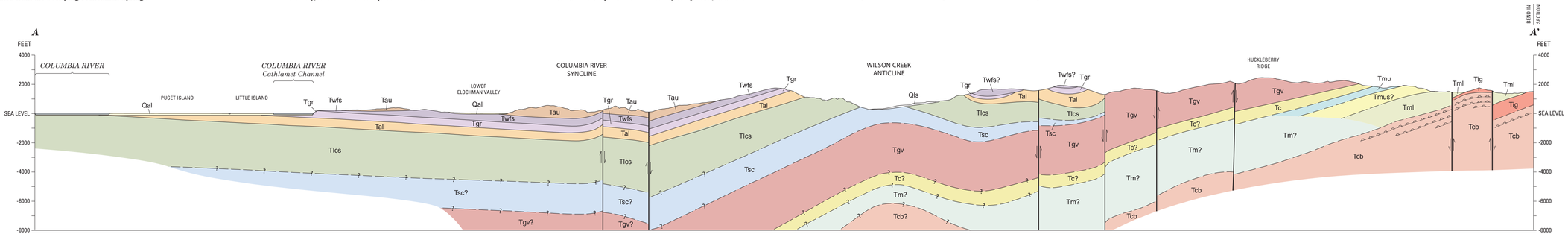
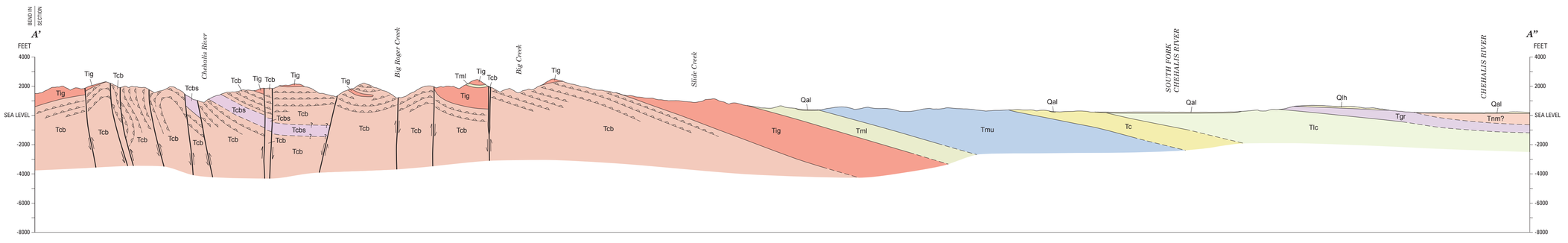


INDEX MAP SHOWING MAP AREA (SHADED) IN RELATION TO U.S. GEOLOGICAL SURVEY 7.5-MINUTE QUADRANGLES

INDEX MAP OF DATA SOURCES







SCALE 1:50 000

1 0 1 2 3 4 5 6 7 8 MILES

1 0 1 2 3 4 5 6 7 8 9 10 KILOMETERS

CONTOUR INTERVAL 40 FEET NORTH OF 46°15' AND 20 FEET SOUTH OF 46°15'
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Preliminary Geologic Map of the Eastern Willapa Hills, Cowlitz, Lewis, and Wahkiakum Counties, Washington

By
Ray E. Wells and Michael G. Sawlan
2014

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