Candy Mountain - Supporting Information

DESCRIPTION OF MAP UNITS

SURFICIAL QUATERNARY UNITS

Qa — ALLUVIUM/GULLY FACIES (Holocene to Pleistocene) - Channel-fill debris and associated entrenched gullies; alluvium is unconsolidated poorly-sorted rock debris that is infilled with eolian sandy silt in mid-to-lower reaches; includes remnants of older alluvium commonly capped by a petrogenic carbonate horizon.

Qaf — ALLUVIAL FAN DEPOSITS (Holocene) - Mainly unconsolidated, poorly sorted sandy basaltic gravel; locally fan interfluves include gravelly sand to silty sand; deposits on larger fan become sand dominated near mid fan; conically shaped landforms.

Qc — COLLUVIUM (Holocene) - Largely unconsolidated poorly-sorted rock debris deposited through hill-slope processes; interstices locally infilled by eolian sandy silt; includes remnants of older colluvium.

Qco — OLDER COLLUVIUM (Pleistocene) - Compact rock debris deposited by hill-slope processes; interstices locally infilled with eolian sandy silt; typically capped by pedogenic carbonate horizon.

Qd — DUNE SANDS (Holocene) - Mainly loose moderately well-sorted, coarse-to-fine sand; deposited as dune landforms by eolian processes; mainly stabilized dunes with some active blow outs; many dune colonies destroyed by agrarian activities.

Ql — LOESS (Holocene to Pleistocene) - Mainly massive, unconsolidated, homogeneous, moderately well-sorted fine sand to sandy silt; light gray (10YR 7/2) to very pale brown (10YR 7/3); deposited by eolian processes; contains discontinuous horizon of Mount Mazama tephra (~7 thousand years ago (Ka)) (Bacon 1983); includes remnants of older compact very pale brown (10 YR 7/3) capped by pedogenic carbonate

Qls — LANDSLIDE DEPOSITS (Middle to early Late Pleistocene) - Rotational and translational debris slumps and associated debris flows consisting of loose, moderately sorted, generally unstratified, clay, silt, sand and basaltic gravel. Arrows indicate direction of movement. Mass wasting also occurs in the form of soil creep (Holocene) on steep loess-covered slopes; typically form terracettes with occasional shallow tension cracks and/or small slumps; creep features too limited in size to include as mapping unit.

MISSOULA CATACLYSMIC FLOOD DEPOSITS (Pleistocene) - HANFORD FORMATION

Deposits mainly from Missoula floods, but may include deposits from other Pleistocene floods.

Qhg — GRAVEL-DOMINATED FACIES - Three main units that include a multi-lithologic sandy gravel bar on the lower southeast flank of Candy Mountain, a multi-lithologic conglomerate with a petrocalcic cap buried beneath the north and east flanks of Lost Lake Ridge, and unconsolidated basalt boulder deposits buried beneath the north flank Lost Lake Ridge. Gravel units are older than the youngest Pleistocene cataclysmic flood deposits of the Preserve area.

Qhs — SAND-DOMINATED FACIES - Includes multistory beds of unconsolidated fine-to-coarse grained sand and granule gravel with occasional sandy gravel and silt lenses; plane laminated and bedded with some beds ripple laminated; clastic dikes common to facies and Mount St. Helens Set S tephra (~13 Ka) (Mullineaux et. al. 1978) locally present near top of facies; grades laterally to interbedded sand- and silt-dominated facies.

Qhz — INTERBEDDED SAND- AND SILT-DOMINATED FACIES - Rhythmically and graded beds of unconsolidated silt and fine-to-coarse sand; mainly plane-laminated and ripple cross laminated; very pale brown (10YR 7/3) to pale brown (10YR 6/3); clastic dikes ubiquitous throughout facies and discontinuous Mount St. Helens Set S tephra (~13 Ka) (Mullineaux et. al. 1978) common near top of facies; grades laterally to sand-dominated facies.

RINGOLD FORMATION (Mio-Pliocene)

Tru — RINGOLD FORMATION (UNDIFFERENTIATED)* - Formed of mainly clay and sandy clay beds with lenses of sand, sandy gravel and gravelly-clay and varying colors (gray, yellow, blue-green); mainly deposited in low-energy overbank and lacustrine environments with occasional higher energy main-channel sediments; occurs in valley of Keene Road syncline. Equivalent to lower unit member of Wooded Island of Lindsey (1995, 1996).

COLUMBIA RIVER BASALT GROUP - SADDLE MOUNTAINS BASALT (Miocene)

Tim — ICE HARBOR MEMBER - Martindale basalt flow - single flow, black to gray, weathers reddish brown; fine- to medium-grained, coarsely phyric with abundant plagioclase crystals and scattered glomerocrysts of clinopyroxene, plagioclase and olivine; entablature mostly eroded where present it's highly weathered (grussy), basal colonnade with large dense columns [1 to 1.2 m (3 to 4 feet) in diameter]; reversed magnetic polarity (Choiniere and Swanson 1979); K-Ar age ~8.5 million years ago (Ma) (McKee et. al. 1977).

Tem — ELEPHANT MOUNTAIN MEMBER (Undifferentiated) - Two aphyric flows; fine-to-coarse grained; abundant microphenocrysts of plagioclase; normal to transitional magnetic polarity (Rietman 1966, Choiniere and Swanson 1979, Reidel and Fecht 1981); K-Ar age ~10.5 Ma (McKee et. al. 1977).
Temw WARD GAP FLOW - Black, weathers reddish brown; upper blocky flow top, thick lower colonnade with large columns [45 to 60 cm (18 to 24 in) in diameter], thin glassy selvage flow bottom.
Teme ELEPHANT MOUNTAIN FLOW - Black, weathers dark gray to brownish gray; upper rubbly flow top breccia, dense columnar entablature, thin basal colonnade with small columns [15 to 30 cm (6 to12 in) in diameter].

Tp — POMONA MEMBER - One or more flows/flow units; black to gray black, weathers gray to locally black; fine-to-medium grained; phyric with small plagioclase phenocrysts; thin upper crude colonnade, thick hackly entablature, basal colonnade not exposed; reversed magnetic polarity (Choiniere and Swanson 1979, Reidel and others 1984); K-Ar age 12 Ma (McKee et. al. 1977) and 40Ar-39Ar 12 Ma (S.P. Reidel, Washington State Univ. unpub. data, 1991).

Te — ESQUATZEL MEMBER - Single flow; blue-black, weathers brown; fine-to-medium grained; aphyric with rare sparse phenocrysts; well developed hackly entablature , basal colonnade not exposed; normal magnetic polarity (Choiniere and Swanson 1979, Reidel and Fecht 1981).

Tu — UMATILLA MEMBER* (Undifferentiated) - Single cooling unit; black, weathers yellow orange; glassy to very fine grained; sparsely phyric; thick hackly entablature and thin basal colonnade not exposed; normal magnetic polarity (Reitman 1966).

COLUMBIA RIVER BASALT GROUP - WANAPUM BASALT (Miocene)

Wanapum Basalt Members do not crop out in Preserve area, but upper member (Tpr - Priest Rapids Member) is depicted on cross sections.

ELLENSBURG FORMATION (Miocene)

Tel — LEVEY INTERBED - Mainly three overbank units: a capping red (10YR 5/6) blocky sandy siltstone unit, a middle multistory unit of pale yellow (10Y 7/4) normally-graded, siltstone-sandstone beds, and a basal light gray (10YR 7/2) massive sandstone unit; thermally baked on top, pedogenically altered, and locally tuffaceous with occasional discrete tephra horizons.

Trr — RATTLESNAKE RIDGE INTERBED - Overbank sediments that commonly include a thin capping red (10R 6/6) to olive yellow (2.5Y 6/6) baked siltstone, a light gray (10YR 7/2) reworked airfall tuffite, and basal section of epiclastic and volcaniclastic siltstone-sandstone beds that are normally graded yellow (5Y 7/3) to olive yellow (2.5Y 6/6); locally well-developed paleosols (dark gray 5Y 4/1).

Tes — SELAH INTERBED* - Mainly thin massive overbank mudstone with occasional fine sandstone stringers, pedogenically altered. A capping tuffite commonly found throughout much of the Pasco Basin has not been observed in the mapped area.

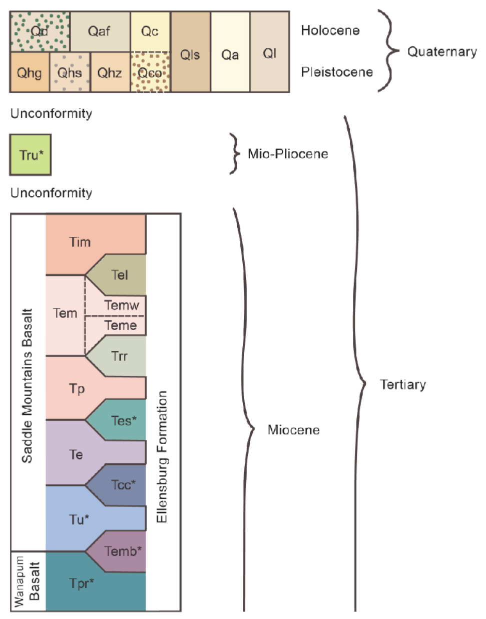
Tcc — COLD CREEK INTERBED* - Mainly a thin massive mudstone that outside the map area is known to be pedogenically altered; occurs along the distal margin of the sandstone-siltstone overbank facies of an ancient fluvial system (Fecht et al. 1987).

Tmb — MABTON INTERBED* - Typically a massive mudstone that is pedogenically altered.

**Geologic units not exposed on earth surface in Preserve and vicinity; depicted on cross section(s); descriptions based on borehole logs and drill cutting descriptions.*

BFZ — BRECCIATED FAULT ZONE - Zone of cohesive to noncohesive fault breccia with varying bedrock clast sizes; commonly includes secondary faults, shears, shatter breccia, rotated clasts and rotated bedrock blocks; locally includes Pleistocene clastic injection dikes and secondary opaline or carbonate minerals.

CORRELATION OF MAP UNITS



EXPLANATION OF MAP SYMBOLS

BEDDING

Strike and dip of unit, dip in degrees

Ash Horizons (Selected)

Ash - Mount Saint Helens Ash

Erratics (Selected)

Eg - Granitic Erratic

Em - Metamorphic Erratic

Candy Mountain Preserve

FOLDS

Doubly Plunging Anticline - Showing Crestline; arrowhead on crestline indicates direction of plunge

Syncline - Showing Troughline; arrowhead on troughline indicates direction of plunge

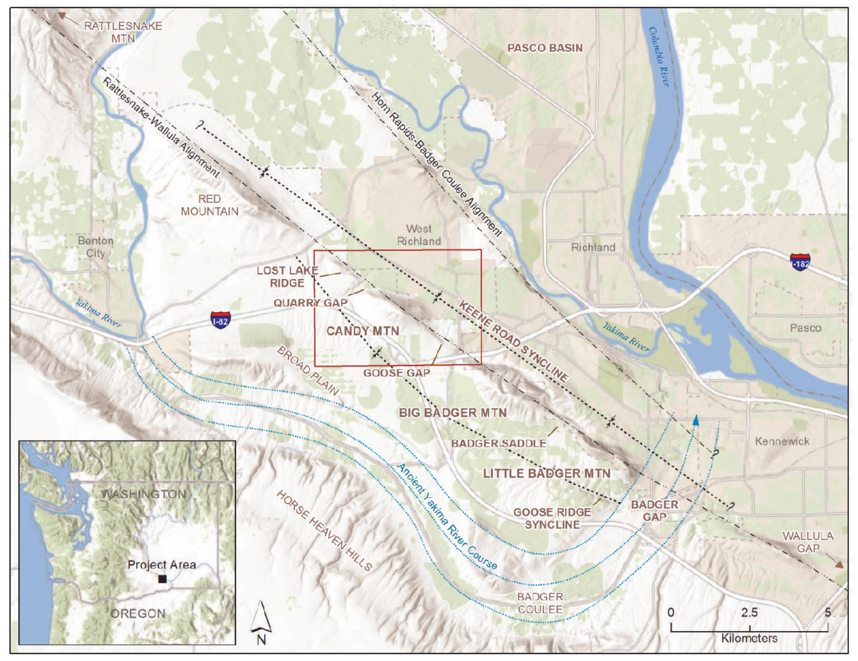
FAULTS

Extensional Fault - Ball and bar on downthrown side; dotted where concealed; queried where probable or unknown

Thrust Fault - Sawteeth on upper plate; dashed where inferred, dotted where concealed, queried where probable

Upper limit of brecciated fault zone

LOCATION MAP



OTHER CATACLYSMIC FLOOD FEATURES

Ice Rafted Debris - clastic material transported within icebergs caught up in cataclysmic flooding and then deposited as dropstones or grounded bergs melted (Bretz 1919). Occur as isolated erratics, erratic clusters, or mounds of diamicton (Fecht and Tallman 1978, Chamness 1994, Bjornstad 2014). Found below 380 m (1250 feet) elevation [maximum stand of Lake Lewis (Baker et. al. 1991)]; mainly strewn across top of Qhz on backslope of Badger Mountain and the Goose Gap syncline, and scattered atop Qhs in the Keene Road syncline. Selected erratics/erratic clusters depicted on geologic map.

Clastic Dikes - Tabular vertical to sub-vertical fractures filled by fluidized injection of clastic sediments. Formed during or soon after cataclysmic flooding and possibly induced by seismicity (Fecht et al. 1999). Common features in Qhz and Qhs deposits found in the valley fill and mantling the broad plain; less common in Tru, Qco and older Ql on the lower ridge slopes; occasionally present within cooling joints in underformed basalt (mainly Tim) and notably occur in rubbly basalt and Ellensburg sediments in fault zones in Goose Gap.

INTRODUCTION

The geologic map of the Candy Mountain Preserve and vicinity was developed to provide Benton County Parks Department and park visitors updated insights into the rock units, sedimentary deposits and structural features of the Preserve area. Understanding the geology is important to protecting the natural habitat of Candy Mountain, as rocks and sediments have direct influence on the biodiversity of the native ecosystem. The characteristics and extent of rocks and sediments are key components that control the distribution of habitat and species in the Preserve area.

The Preserve area is rich in geologic history. This history includes dramatic landscape formed of 1) volcanic flows with interbedded sediments that have been uplifted and faulted to form anticlinal ridges and a synclinal valleys, 2) multiple ice-age floods that scoured the Preserve area and deposited sediments during waning flow, and 3) a thin blanket of wind-blown sediments over much of the Preserve area attesting to the arid climate. The landscape of the Preserve area is dynamic with geologic processes continually working on earth landforms and surfaces.

Many aspects of stratigraphy and structural geology of the Candy Mountain Preserve and vicinity can be observed along the 2.6 km (1.6 mile) Candy Mountain Trail and in road cuts along Kennedy Road and Interstate I-182.

FIELD INVESTIGATIONS

The field investigation phase of the Candy Mountain mapping project was completed during the 2018 field season. The mapping project incorporated results from previous geologic investigations. Earlier investigations included reconnaissance resource mapping (Shedd (1925) and a regional stratigraphic and structural geology study (Laval 1956). Interest in neotectonics of the Yakima folds and thrust belt to support nuclear facility activities resulted in numerous studies of the area (Jones and Deacon 1966, Brown 1968, Farooqui 1977, GRC 1978, Meyers/Price et. al. 1979, WWC 1981, WPPSS 1981). In 1994 the geology map of the Preserve area was revised as part of the Washington State geologic mapping project at 1:100,000 scale (Reidel and Fecht 1994).

GEOLOGIC SUMMARY

Geographic Setting - The Candy Mountain Preserve and surrounding area are located along the SW boundary of the Pasco Basin in the southern part of the Yakima fold and thrust belt. The landscape of the mapped area is dominated by two aligned ridges, Candy Mountain and Lost Lake Ridge. The ridges are part of an alignment of ridges extending from Rattlesnake Mountain to Wallula Gap. Candy Mountain and Lost Lake Ridge are separated along their trend by topographic lows at Quarry and Goose gaps. The ridges are bound by the thinly sediment mantled Goose Ridge syncline to the SW and a sediment-filled valley of the Keene Road syncline to the NE. The Candy Mountain Preserve encompasses much of Candy Mountain and a portion of Goose Gap.

Stratigraphy - Bedrock in the mapped area consists of basalt flows of the Miocene Saddle Mountains and Wanapum Basalts of the Columbia River Basalt Group and intercalated sediments of the Ellensburg Formation. The bedrock crops out on the anticlinal ridges and in the intervening gaps. Overlying the bedrock in the Keene Road syncline are valley-filling fluvial and lacustrine deposits of the Mio-Pliocene Ringold Formation. The Ringold sediments are mainly of the lower unit - member of Wooded Island. Overlying Ringold sediments in the Keene Road syncline and blanketing the lower slopes of the ridges as well as the Goose Ridge syncline are Missoula cataclysmic flood deposits of the Pleistocene Hanford Formation. Gullies eroded into the ridge slopes and within the gaps are partially filled with Holocene alluvial debris. At the mouth of gullies alluvial debris locally has accumulated as alluvial fans that spread out as conical landforms on to the valley floor of the Keene Road syncline. The ridges and intervening gaps are mantled with a veneer of Holocene and Pleistocene loess and colluvial debris. Across the valley floor of the Keene Road syncline Holocene eolian sands developed extensive dune colonies. However, agrarian activity has destroyed the colonies except around Lost Lake.

Structural Geology - Candy Mountain and Lost Lake Ridge form narrow doubly-plunging, open, non-cylindrical anticlinal folds. The anticlines have a north-vergent asymmetrical shape and are elongated NW-SE. The ridges lie along a series of NW-SE trending anticlinal structures of Rattlesnake-Walla Walla River alignment (RAW) (Reidel et. al. 2019).

Quarry and Goose gaps form structural and topographic depressions in the convergence zone between the doubly-plunging anticlines. The land surface through the gaps forms a gentle-to-moderate slope from the Goose Ridge syncline into the valley of the Keene Road syncline.

The Keene Road and Goose Ridge synclines form shallow topographic and structural lows that bound the the ridges and gaps. The Keene Road syncline formed as the Candy Mountain/Lost Lake Ridge anticlinal structures were thrust up and onto the east-dipping limb of an anticlinal ridge located along the Horn Rapids-Badger Coulee alignment (Reidel et. a. 2019). The syncline shows little evidence of deformation on the lengthy gentle eastward-dipping limb. The Goose Ridge syncline forms a narrow shallow low between Candy Mountain-Lost Lake Ridge anticlines and Goose Hill to the SW. The Goose Ridge syncline looses definition NW near the northern boundary of the mapped area.

Faults have been mapped along the forelimb of Candy Mountain and Lost Lake Ridge with faults striking NW-SE parallel to the trend of the anticlines. The lower fault is buried at the base of the forelimbs of Candy Mountain and Lost Lake Ridge and below Quarry and Goose gaps. The fault forms a thrust that displaces bedrock and likely older colluvial and Ringold sediments. The discontinuity separates the anticlinal structures and gaps from the Keene Road syncline. The lower fault is the NW extension of the Badger Mountain fault of GRC (1978). Above the lower fault is an upper thrust sheet/zone that displaces Saddle Mountain basalt flows and Ellensburg sediments. The upper fault crosses the mid-slope of the forelimb of Candy Mountain and extends SE spanning across Goose Gap. The fault is exposed in road cuts in Goose and Quarry gaps, but is mostly obscured beneath a veneer of Ql and hillslope terracettes over the face of Candy Mountain. The lower boundary of the fault is moderately well delineated by a distinct break in slope low along the forelimb. The upper boundary is poorly defined by several subtle benches high on the forelimb. The lower and upper forelimb thrust faults likely converge in the Quarry and Goose Gaps.

Candy Mountain and Lost Lake Ridge anticlinal growth is mainly due to horizontal compressional stresses that caused crustal shortening and resulted in bedrock being thrust up and onto adjacent bedrock. The Candy Mountain structure experienced greater shortening and more internal rotation than Lost Lake Ridge, Quarry Gap and Goose Gap as attested by the presence of an upper thrust zone and greater structural and topographic relief.

The initial emergence of the anticlinal structures began prior to emplacement of the Saddle Mountains Basalt (~13 Ma) based on thinning of basalt flows and interbedded sediments on to and over the structures. The anticlines continued their growth after cessation of volcanism with much of present structural relief occurring post basalt (8.5 Ma).

Faults in the Preserve area have influenced the geometry of the anticlines. The lower thrust fault aligns along the NW-SE trending RAW and primarily influenced the anticlinal elongated shape, north vergence, and NW-SE trend. Whereas, the upper thrust fault on Candy Mountain is responsible for much of the topographic and structural relief of the ridge.

Candy Mountain and Lost Lake Ridge are continuing to emerge, but little evidence was found for ridge growth or fault displacement since fault movement during the Pleistocene. This fault movement is associated with emplacement of Pleistocene-age clastic dikes found in the upper fault zone at Goose Gap.

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REFERENCES

Bacon, C.R., 1983, Eruptive History of Mount Mazama and Crater Lake Caldera, Cascade Range, U.S.A., Journal of Volcanology and Geothermal Research, v. 18, pp. 57-115.

Baker, V.R., B.N. Bjornstad, A.J. Busacca, K.R. Fecht, E.P. Kiver, U.L. Moody, J.G. Rigby, D.F. Stradling, and A.M. Tallman, 1991, Quaternary Geology of the Columbia Plateau, in Morrison, R.B. (ed.), Quaternary Nonglacial Geology, Conterminous U.S., Geological Society of North America, v. K-2, Geological Society of America, Boulder, Colorado. pp. 215-250.

Bjornstad, B.N., 2014, Ice-Rafted Erratics and Bergmounds from Pleistocene Outburst Floods, Rattlesnake Mountain, Washington, USA, E&G Quaternary Science Journal, v. 63, pp. 44–59.

Bretz, J H, 1919, The Late Pleistocene Submergence in the Columbia Valley of Oregon and Washington, Journal of Geology, v. 27, pp. 489–506.

Brown, R.E., 1968, A Study of Reported Faulting in the Pasco Basin, BNWL-662, Battelle Pacific Northwest Laboratory, Richland, Washington, 55p.

Chamness, M.A., 1994, Bergmounds: A Depositional or Erosional Feature? (abstract), Geological Society of America, Abstracts with Programs, v. 26, A-307.

Choiniere, S.R. and D.A. Swanson, 1979, Magnetostratigraphy and Correlation of Miocene Basalts of the Northern Oregon Coast and Columbia Plateau, Southeast Washington, American Journal of Science, v. 279, no. 7, pp. 755-777.

Farooqui, S.M., 1977, Geologic Studies - Wallula Gap to Badger Coulee, Report prepared for Washington Public Power Supply System, Shannon and Wilson, Inc., Portland, Oregon.

Fecht, K.R. and A.M.Tallman, 1978, Bergmounds along the Western Margin of the Channeled Scablands, South-Central Washington, RHO-BWI-SA-11, Rockwell Hanford Operations, Richland, Washington.

Fecht, K.R., S.P. Reidel, and A.M. Tallman, 1987, Paleodrainage of the Columbia River on the Columbia Plateau of Washington State - A Summary, in Schuster, J.E. (ed.), Selected Papers on the Geology of Washington, Bulletin 77, Washington Division of Geology and Earth Resources, Olympia, Washington, pp. 219-248.

Fecht, K.R., B.N. Bjornstad, D.G. Horton, G.V. Last, S.P. Reidel, and K.A. Lindsey, 1999, Clastic Injection Dikes of the Pasco Basin and Vicinity, BHI-01103, Bechtel Hanford Company, Richland, Washington.

GRC, 1978, Geology of the Southwestern Pasco Basin, RHO-BWI-C-25, Geoscience Research Consultants, Report prepared for Rockwell Hanford Operations, Rockwell Hanford Operations, Richland, Washington.

Jones, F.O. and R.J. Deacon, 1966, Geology and Tectonic History of the Hanford Area and Its Relation to the Geology and Tectonic History of the State of Washington and the Active Seismic Zones of Western Washington and Western Montana, DUN-1410, Douglas United Nuclear, Richland, Washington.

Laval, W.N., 1956, Stratigraphy and Structural Geology of Portions of South-Central Wash-ington, PhD. Dissertation, University of Washington, Seattle, Washington.

Lindsey, K.A., 1995, Miocene- to Pliocene-Aged Suprabasalt Sediments of the Hanford Site, South-Central Washington, BHI-00184, Bechtel Hanford Inc., Richland Washington.

Lindsey, K.A., 1996, The Miocene to Pliocene Ringold Formation and Associated Deposits of the Ancestral Columbia River System, South-Central Washington and North-Central Oregon, Open File Report 96-8, Washington Division of Geology and Earth Resources, Olympia, Washington.

McKee, E.H., D.A. Swanson, and T.L. Wright, 1977, Duration and Volume of the Columbia River Basalt Volcanism, Washington, Oregon, and Idaho (abstract), Geological Society of America Abstracts with Program, v. 9, no. 4, pp. 463-464.

Myers, C.W. and S.M. Price et. al., 1979, Geologic Studies of the Columbia Plateau: A Status Report, RHO-BWI-ST-4, Rockwell Hanford Operations, Richland, Washington.

Shedd, S., 1925, Geology of the Prosser and Pasco Quadrangles, Washington, in Culver, H.E., 1926, Abstract of the Report on the Geology and Resources of the Pasco and Prosser Quadrangles, Reports of Investigation No. 1, Washington State Division of Geology, Olympia, Washington.

Reidel, S.P., G.R. Scott, D.R. Bazard, R.W. Cross, and B. Dick, 1984, Post-12 Million Year Clockwise Rotation in the Central Columbia Plateau, Washington, Tectonics, v. 3, no. 2, pp. 251-273.

Reidel, S.P. and K.R. Fecht, 1981, Wanapum and Saddle Mountains Basalt of the Cold Creek Syncline, in Myers, C.W. and S.M. Price, Subsurface Geology of the Cold Creek Syncline, RHO-BWI-ST-14, Rockwell Hanford Operations, Richland, Washington, p. 3-1 to 3-45.

Reidel, S.P. and K.R. Fecht, 1994, Geologic Map of the Richland 1:100,000 Quadrangle, Washington, Open-File Report 94-8, Washington Division of Geology and Earth Resources, Olympia, Washington.

Reidel, S.P., K.R Fecht, T.L. Tolan, and M.A. Chamness, 2019, A RAW Look at the OWL (abstract), Geological Society of America, Abstracts with Programs, v. 51.

Rietman, J.D., 1966, Remanent Magnetization of the Late Yakima Basalt, Washington State, PhD. Dissertation, Stanford University, Stanford, California.

WPPSS, 1981, Final Safety Analysis Report, WPPSS Nuclear Project No. 2, Washington Public Supply System, Richland, Washington, Amendments 18 and 23.

WWC, 1981, Wallula Fault Trenching and Mapping, Report prepared for Washington Public Power Supply System, Woodward-Clyde Consultants, San Francisco, California.