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Umtanum Ridge structures, folds and other faults of the Umtanum Ridge-Gable Mountain uplift (Class A) No. 563b

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Synopsis	**General:** The Umtanum Ridge-Gable Mountain structures form one of the fault and fold systems in the central to northern part of the Yakima fold belt of south-central Washington. An east-striking anticlinal uplift is the principle structural feature of these structures and it is mostly responsible for the east-striking ridge topography of Umtanum Ridge, Gable Butte, and Gable Mountain. Quaternary displacements on thrust and reverse faults related to the anticlinal uplift are inferred for most of the structure. The northeast-striking, Central Gable Mountain fault shows evidence of about 6 cm of late Pleistocene to Holocene reverse offset (Washington Public Power Supply System, 1982 #5666), and normal offset on faults on the west side of the uplift are attributed to thrust

	faulting at depth (Sherrod and others, 2009 #7400, 2011 #7399). Quaternary age growth or tightening of other folds in the Yakima fold belt, and perhaps of the Umtanum Ridge-Gable Mountain folds, has been suggested and inferred from several local and regional geologic relations in the Yakima fold belt (Campbell and Bentley, 1981 #3513; Reidel, 1984 #5545; Reidel and others, 1994 #3539). Bender and others, 2016 #7401) conclude that Umtanum Ridge anticline is actively deforming at modest rates. Contemporaneous contraction across the region suggests that the Yakima folds are favorably oriented in the current strain field and accommodate the strain through active folding and possibly faulting (Pratt, 2012 #7397; Bjornstad and others, 2012 #7394 citing unpublished Zachariasen and others, 2006). As summarized by Bjornstad and others (2012 #7394), global positioning system (GPS) "data indicate relatively low (<1 mm/yr) but non-zero convergence across the Yakima fold belt.... In general, these rates are higher than those calculated on Quaternary faults." Based on the growing consensus that the Umtanum Ridge-Gable Mountain folds are cored by buried Quaternary fault, the faults are reassigned to Class A as opposed to the prior Class B classification. **Sections:** This fault has 2 sections. Faults and folds of the Umtanum Ridge-Gable Mountain structures are subdivided and discussed as two sections based on the uncertainty of the continued development of folds, and some faults, during the Quaternary. The Central Gable Mountain fault shows evidence for Quaternary activity and it is described as one of the two sections. Anticline segments and most of the exposed and inferred faults of the Umtanum Ridge-Gable Mountain anticlinal uplift are inferred to have been active during Quaternary time. Sections defined here differ in lateral extent from the five fault sources prescribed by Coppersmith and others (2014 #7402).
Name comments	**General:** **Section:** The Umtanum Ridge-Gable Mountain anticlinal uplift includes several east-trending anticline segments and faults that are associated with the similarly trending topographic highs expressed by Umtanum Ridge, Gable Butte and Gable Mountain. These structural features include the Umtanum Ridge fault (Geomatrix Consultants Inc., 1988 #1311) and other named and unnamed folds and faults that are shown on 1:100,000- and 1:250,000-scale geologic maps of this region (Walsh, 1986 #5570; Walsh and others, 1987 #3579; Reidel and Fecht, 1994 #5565; Schuster, 1994 #5566; Schuster and others, 1997 #3760). Structures associated with the Umtanum Ridge-Gable Mountain uplift extend for about 100 km from the west-end Umtanum Ridge, eastward across Gable Butte and Gable Mountain, to southeast of Hanford.

County(s) and State(s)	GRANT COUNTY, WASHINGTON BENTON COUNTY, WASHINGTON KITTITAS COUNTY, WASHINGTON YAKIMA COUNTY, WASHINGTON
Physiographic province(s)	COLUMBIA PLATEAU CASCADE-SIERRA MOUNTAINS
Reliability of location	Good Compiled at 1:100,000 scale. *Comments:* Location of fault from GER_Seismogenic_WGS84 (http://www.dnr.wa.gov/publications/ger_portal_seismogenic_features.zip, downloaded 05/23/2016) attributed to 1:100,000-scale geologic maps by Reidel and Fecht (1994 #5565), Schuster and others (1994 #5566, and Walsh and others (1986 #5570),The location of the 14-km-long part of the frontal thrust fault near the Yakima River Canyon is from detailed mapping of Miller (2014 #7404).
Geologic setting	Umtanum Ridge, Gable Butte and Gable Mountain appear to define parts of a single anticlinal Ridge that is located in the central part of the Yakima fold and thrust belt, belt, a structural-tectonic sub province of the western Columbia Plateaus Province (Reidel and others, 1989 #5553; 1994 #3539). The Yakima fold belt consists of a series of generally east-trending narrow asymmetrical anticlinal ridges and broad synclinal valleys formed by folding of Miocene Columbia River basalt flows and sediments. In most parts of the belt the folds have a north vergence with the steep limb typically faulted by imbricate thrust faults. According to Reidel and others (1989 #5553) these frontal faults are typically associated with the areas of greatest structural relief. In the few places where erosion exposes the frontal faults deeper in the cores of the anticlinal ridges the faults are seen to become steeper with depth (as steep as 45–70°). Along their lengths the anticlines are commonly broken into segments ranging between 5 and 35 km long with boundaries defined by abrupt changes in fold geometry. Anticlinal ridges of the Yakima fold belt began to grow in Miocene time (about 16–17 Ma), concurrent with eruptions of Columbia River basalt flows, and continued during Pliocene time and may have continued to the present (Reidel and others, 1989 #5553; 1994 #3539). Named and unnamed, east-striking thrust faults cut the north and south limbs of the Umtanum Ridge-Gable Mountain anticlinal uplift. The northeast-striking, Central Gable Mountain fault cuts across the axial trend of the uplift. This uplift forms one of the many anticlinal ridges that comprise the Yakima fold belt in south-central Washington. The Central

	Gable Mountain fault shows evidence for Quaternary activity, but the folds and other faults of the Umtanum Ridge-Gable Mountain structures are only known to deform rocks of the Columbia River Basalt Group (Miocene). Using the top-of-basalt from previous mapping, Coppersmith and others (2014 #7402) estimate average structural relief along Gable Mountain (160 m) and the southeast anticline (90 m).
Length (km)	This section is 116 km of a total fault length of 116 km.
Average strike	N87°W (for section) versus N88°W (for whole fault)
Sense of movement	Thrust *Comments:* The east-striking structures associated with the Umtanum Ridge-Gable Mountain uplift are primarily expressed as anticlinal folds underlain by thrust or reverse faults in Miocene rocks of the Columbia River Basalt Group (Walsh, 1986 #5570; Walsh and others, 1987 #3579; Geomatrix Consultants Inc., 1990 #5550; Reidel and Fecht, 1994 #5565; Schuster, 1994 #5566; Schuster and others, 1997 #3760, Mège and Reidel, 2001 #7407).
Dip	8–70° S. *Comments:* Mège and Reidel (2001 #7407) report a mean fault dip of 28–45° for the Umtanum Ridge thrust fault based on a combination of field measurements and accessible seismic profiles. The fault dips 70° to the south in Miller's (2014 #7404) preferred model.
Paleoseismology studies	Site 563-2 (McCabe Place trench, Sherrod and others, 2010 #7405, 2013 #7399) was excavated in 2009 across a 2- to 8-m-high scarp identified by LiDAR imagery on the south side of Umtanum Ridge and reported by Glass (1977 #3792). The trench exposed normal faults that offset volcaniclastic deposits overlain by unconsolidated deposits. The normal displacement reflects bending-moment deformation above a buried reverse fault (Sherrod and others, 2010 #7405, 2011 #7400). Site 563-3 (Hessler Flats trench, Sherrod and others, 2013 #7399) few details are available at this time. This trench was located southwest of the McCabe Place trench and exposed evidence of possibly two earthquakes. The oldest unit in the trench was weathered basalt that is buried by unconsolidated deposits.
Geomorphic expression	East-trending folds and faults associated with the Umtanum Ridge-Gable Mountain uplift are coincident with the east-trending topographic high

	expressed by Umtanum Ridge, Gable Butte, and Gable Mountain. These low hills and ridges underlain by resistant Miocene volcanic rocks of the Columbia River Basalt Group are the principle geomorphic expression of the anticlinal uplift and related east-trending folds and faults. The northern and southern flanks of the eastern part of the uplift (Gable Butte and Gable Mountain) are mostly buried by Pleistocene and Holocene gravel and dune deposits (Reidel and Fecht, 1994 #5565; Schuster and others, 1997 #3760), which may bury and obscure evidence for faults. An inferred thrust fault is mapped continuously along the north flank of the uplift in the Gable Butte and Gable Mountain area (Reidel and Fecht, 1994 #5565; Schuster and others, 1997 #3760). Geomatrix Consultants Inc. (1990 #5550) reported that their studies revealed no evidence for Quaternary faulting associated with the inferred, buried fault in the Gable Butte and Gable Mountain area. Exposed thrust faults are mapped along the northern flank of the western part of the uplift, Umtanum Ridge area, and they appear to connect with the inferred thrust fault mapped to the east (Walsh, 1986 #5570; Walsh and others, 1987 #3579; Schuster, 1994 #5566). Umtanum Ridge mostly exposes Miocene volcanic rocks and Quaternary deposits are sparse. Geomatrix Consultant Inc. (1988 #1311; 1990 #5550) reported that there was no evidence for Quaternary faulting along northern flank of Umtanum Ridge. Both north- and south-dipping thrust faults are also mapped along the southern flank of Umtanum Ridge and based on remote sensing studies, Glass (1977 #3792) identified possible scarps along the southern flank of Umtanum Ridge in the Wenas Valley area. Later investigations of these reported scarps in the vicinity of Wenas Valley, all concluded that the scarps are related to landslides and not tectonic features (Washington Public Power Supply System, 1982 #5666; West, 1987 #5669; Geomatrix Consultants Inc., 1988 #1311).
Age of faulted surficial deposits	Other than evidence for latest Pleistocene to early Holocene offset along the Central Gable Mountain fault [#563a], no evidence for Quaternary deformation along other faults and folds of the Umtanum Ridge-Gable Mountain uplift has been reported. Miocene volcanic rocks are obviously deformed by faults and folds related to the Umtanum Ridge-Gable Mountain uplift (Walsh and others, 1987 #3579; Schuster and others, 1997 #3760). Washington Public Power Supply System (1982 #5666) report and discuss evidence for deformation of latest Pleistocene to Holocene sediments along the Central Gable Mountain fault [#563a] and this fault and the faulted Quaternary sediments are discussed in more detail in the Central Gable Mountain fault section [#563a]. Based on remote sensing studies, Glass (1977 #3792) identified possible scarps along the southern flank of Umtanum Ridge in the Wenas Valley area. Later investigations of these reported scarps in Wenas Valley by Washington Public Power Supply System (1982 #5666), West (1987 #5669), and Geomatrix

	Consultants Inc., (1988 #1311) concluded that the scarps appear to be developed in Quaternary alluvium but are escarpments related to landslides and not tectonic features.
Historic earthquake	
Most recent prehistoric deformation	undifferentiated Quaternary (<1.6 Ma) *Comments:* With the exception of the Central Gable Mountain fault [563a] and the secondary faults on the southwest side of the anticline (Sherrod and others, 2010 #7405, 2011 #7400, 2013 #7399), no definitive evidence of Quaternary displacement has been described along faults and folds along the northeast flank the Umtanum Ridge-Gable Mountain uplift. Washington Public Power Supply System (1982 #5666) discuss evidence for a late to latest Quaternary event, based on a small offset of latest Pleistocene to early Holocene sediments along the Central Gable Mountain fault [#563a]. However, evidence for Quaternary events along other structures of the Umtanum Ridge-Gable Mountain uplift has not been reported. Quaternary growth or tightening of other ridge-anticline features of the Yakima fold belt, related to movement along underlying thrust faults, has been inferred from the following local and regional relations: (1) correlation of uplift rates of Miocence volcanic rocks (Reidel, 1984 #5545); (2) the north-south orientation of the principle stress direction and active seismicity of the region (Reidel and others, 1994 #3539); and (3) interpretations of geometric relations of the folds relative to normal or strike-slip faults that show Quaternary offsets (Campbell and Bentley, 1981 #3513). In a similar manner, Geomatrix Consultants Inc. (1990 #5550) noted that the late Quaternary offset evident along the Central Gable Mountain fault [#563a] could be related to folding and movement along the inferred thrust fault mapped along the north flank of the uplift. They also noted, however, that there is no evidence for such activity along this frontal thrust fault. Based on the lack of definitive evidence for Quaternary deformation related to these folds and other faults of the Umtanum Ridge-Gable Mountain uplift, they are classified herein as class B structures until further studies are conducted.
Recurrence interval	 *Comments:* All evidence of fault activity associated with the Umtanum Ridge-Gable Mountain uplift is from subsidiary structures. Sherrod and others, 2010 #7405) report evidence for at least three periods of deformation, which is updated to as many as five earthquakes since 47 ka (constrained by Mount St. Helens set C tephra) in Sherrod and others (2013 #7399) exposed in the McCabe Place trench. Piety and others (1990

	#3733) used uplift rates calculated from 10–11 Ma volcanic rocks to estimate recurrence intervals of 940–51,400 years based on displacement per events of 0.02–1.0 m along an inferred principle fault underlying the Umtanum Ridge-Gable Mountain anticlinal uplift.
Slip-rate category	Less than 0.2 mm/yr *Comments:* Sherrod and others report (2013 #7399) possibly 4 m of vertical displacement of Mount St. Helens set C tephra; however, this may not be representative of total displacement on the underlying fault. Published rates of deformation that addresses the Umtanum Ridge structure based on geologic evidence suggest generally low long-term displacement rates in contrast to those modeled using GPS data. Piety and others (1990 #3733) report 214 (?) m of uplift of 10–11 Ma volcanic rocks, and Geomatrix Consultants Inc. (1995 #3593) used uplifts of 102–530 m and horizontal offsets of 300–1,100 m of 10.5–16.0 Ma volcanic rocks along estimated fault dips of 30°, 45°, and 60° to estimate long-term slip rates of 0.011–0.0206 mm/yr for an inferred principle fault underlying this anticlinal uplift. Bjornstad and others (2010 #7394, table 2.1) reports long-term vertical growth rates of 29–54 m/m.y. (0.029–0.054 mm/yr). Total slip on the preferred model fault of Miller (2014 #7404) that best approximates the geometry of the anticline is 440–520 m on a fault that dips about 70°. The reported slip has occurred in the past 15.6 m.y. resulting in a range of slip rates on a 70° fault of 0.028–0.033 mm/yr. Bender and others (2016 #7401) estimate time-averaged shortening rates across south-dipping master reverse faults beneath Umtanum Ridge. These results suggest 0.03±0.01 mm/yr vertical displacement rate, which has remained relatively stable over the past 1.6–2.9 m.y. They assume the average local rate of differential bedrock fluvial incision across the fold is equal to the corresponding average rates of differential rock uplift.
Date and Compiler(s)	2016 David J. Lidke, U.S. Geological Survey Elizabeth A. Barnett, Shannon & Wilson, Inc. Kathleen M. Haller, U.S. Geological Survey
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