Quaternary Fault and Fold Database of the United States

As of January 12, 2017, the USGS maintains a limited number of metadata fields that characterize the Quaternary faults and folds of the United States. For the most up-to-date information, please refer to the interactive fault map.

Toppenish Ridge structures, unnamed faults of the Toppenish Ridge uplift (Class A) No. 566b

Last Review Date: 2016-05-12

citation for this record: **Lidke, D.J., Haller, K.M., and Bucknam, R.C., compilers, 2016, Fault number 566b, Toppenish Ridge structures, unnamed faults of the Toppenish Ridge uplift, in Quaternary fault and fold database of the United States: U.S. Geological Survey website, https://earthquakes.usgs.gov/hazards/qfaults, accessed 12/14/2020 03:03 PM.**

Synopsis	**General:** The east-trending Toppenish Ridge structures include faults with known and inferred Pleistocene and Holocene offsets (Bentley and others, 1980 #4693; Campbell and Bentley, 1981 #3513; Campbell and others, 1995 #5552; Repasky and others, 1998 #5554). The Toppenish Ridge anticline and related folds of the Toppenish Ridge anticlinal uplift, as well as most of the faults associated with the uplift, are only known to fold rocks of the Miocene Columbia River Basalt Group. Quaternary age growth or tightening of the Toppenish Ridge folds and other folds in the Yakima fold belt, however, 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). For the Toppenish Ridge area, Quaternary growth or tightening of folds has been inferred from evidence of Quaternary offset along thrust

	faults and normal faults. The normal faults near the crest of the Toppenish Ridge anticline are interpreted as tensional features related to folding above the underlying Mill Creek thrust fault (Bentley and others, 1980 #4693; Campbell and Bentley, 1981 #3513; Campbell and others, 1995 #5552; Repasky and others, 1998 #5554). 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the strain through active folding and possibly faulting (Pratt, 2012 #7397; Bjornstad and others, 2012 #7394 citing unpublished Zachariasen and others, 2006).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 Toppenish Ridge 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 associated with the Toppenish Ridge anticlinal uplift are subdivided and discussed as two sections based on the geometry and character of the faults and based on the uncertainty of the continued development of the folds and some of the faults during Quaternary time. The mostly buried Mill Creek fault (thrust) and some normal faults south of it show evidence for Quaternary activity and they are treated as one section of the Toppenish Ridge structures. The Toppenish Ridge anticline and related folds, as well as some of the unnamed faults associated with the uplift, can only be inferred to have been active during Quaternary time. Sections defined here differ in lateral extent from the fault sources prescribed by Coppersmith and others (2014 #7402). Both of their sections are contained within section 566b.
Name comments	**General:** **Section:** Refers to east-trending anticline segments and some faults that are associated with the similarly trending, and nearly connected, Toppenish and Peavine Ridges. These anticline segments collectively comprise the Toppenish Ridge anticline and this anticline and thrust faults associated with it are shown on several geologic maps of this region (Bentley and others, 1980 #4693; Walsh, 1986 #5189; Walsh and others, 1987 #3579; Korosec, 1987 #5568; Schuster, 1994 #4653; Schuster and others, 1997 #3760). The Toppenish Ridge anticline (Piety and others, 1990 #3733) is commonly divided into three segments, which from west to east are the; Peavine, Satus Peak, and Hembre Mountain segments or anticlines (Bentley and others, 1980 #4693). The Toppenish Ridge anticline is the most prominent structural feature of the Toppenish Ridge structures and it mostly accounts for the anticlinal ridge form of Toppenish Ridge and Peavine Ridge that nearly connect to form a single,

	sinuous east-trending ridge. The Toppenish Ridge anticline extends from the Klickitat River Valley east-northeast along Peavine Ridge and Toppenish Ridge to the Yakima Valley.
County(s) and State(s)	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 Walsh (1986 #5189), Korosec (1987 #5568), Schuster (1994 #4653), and Repasky and others (1998 #5554).
Geologic setting	Toppenish Ridge lies in the south-central part of the Yakima fold 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 continued into the Quaternary (Reidel and others, 1989 #5553; 1994 #3539). Named and unnamed, east-striking thrust faults cut the north and south limbs of the Toppenish Ridge uplift. This uplift forms one of the many anticlinal ridges that comprise the Yakima fold belt in south-central Washington. The south-dipping Mill Creek fault is a poorly exposed thrust fault that cuts the north limb of the Toppenish Ridge uplift. Unnamed normal faults, interpreted to be subsidiary faults of the Mill Creek fault, form graben features along the east end of the uplift. The Mill Creek fault and the unnamed normal faults show evidence for Quaternary faulting

	events, but the folds and other faults of Toppenish Ridge are only known to deform Miocene volcanic and sedimentary rocks, which include the Columbia River Basalt Group. Coppersmith and others (2014 #7402) estimate average structural relief of Toppenish Ridge to be 300–310 m.
Length (km)	This section is 82 km of a total fault length of 82 km.
Average strike	N78°E (for section) versus N80°E (for whole fault)
Sense of movement	Anticline, Thrust *Comments:* The Toppenish Ridge anticline (or uplift) is essentially one continuous anticline that can be divided into three segments that have different geometries; from east to west, the Peavine, Satus Peak and Hembre Mountain segments or anticlines form the Toppenish anticlinal uplift (Bentley and others, 1980 #4693). The Peavine segment is a west-plunging asymmetrical anticline with a steep north limb; the Satus Peak segment is a east-plunging, asymmetric, box-shaped anticline with angular hinges; and the Hembre Mountain segment is an east plunging anticline with many subsidiary warps (Bentley and others, 1980 #4693). Each segment, but particularly the Hembre Mountain segment, changes geometry sharply in areas of northwest-striking cross faults. The cross faults commonly show right-lateral offsets. Thrust or reverse faults, such as the Mill Creek fault [566a] are known or inferred to occur along one or both limbs of these anticlinal segments of the Toppenish anticline. The south dipping Mill Creek fault [566a] is mapped as a continuous feature along the north flank of the Satus Peak segment and it may have extensions along the Peavine and Hembre Mountain segments (Bentley and others, 1980 #4693). These relations of the Toppenish Ridge anticline to thrust faults and right-lateral cross faults suggest that the folds formed, tightened, and overturned during mostly north-directed, reverse-thrust movement along the underlying south-dipping Mill Creek fault [566a] and perhaps other related thrust faults (Bentley and others, 1980 #4693; Campbell and Bentley, 1981 #3513; Geomatrix Consultants Inc., 1988 #1311; Piety and others, 1990 #3733; Geomatrix Consultants Inc., 1990 #5550).
Dip	14–27° S. *Comments:* The western part of the Toppenish anticline plunges west and the central and eastern parts plunge east; where the anticline is asymmetric, the north limb is generally the steep limb (Bentley and others, 1980 #4693). Mège and Reidel (2001 #7407) report a mean fault dip of 14–27° for the Toppenish Ridge thrust fault based on a combination of field measurements and accessible seismic profiles.

Paleoseismology studies	
Geomorphic expression	The slightly sinuous, east-trending ridge-like form of the nearly connected Toppenish and Peavine Ridges is the principal geomorphic expression of the Toppenish Ridge anticline. Miocene volcanic rocks, which form the core of this anticlinal uplift, are obviously deformed in the Toppenish Ridge anticline. Expression of these folds in Quaternary sediments or in the geomorphology developed on Quaternary units has not been conclusively demonstrated. However, horst and graben features, disrupted drainages, and sag ponds are associated with surface ruptures or scarps that are expressed in Quaternary sediments along the crest and northern flank of the Satus Peak segment of the Toppenish Ridge anticline (Rigby and Othberg, 1979 #3738; Bentley and others, 1980 #4693; Campbell and Bentley, 1981 #3513; Woodward-Clyde Consultants, 1981 #5555; Geomatrix Consultants Inc., 1988 #1311; 1990 #5550; Campbell and others, 1995 #5552; Repasky and others, 1998 #5554). Bentley and others (1980 #4693) concluded that these geomorphic features principally mark normal faults that are related to movement along the underlying Mill Creek fault [566a]. Geomorphic expression of the faults included in this section of the Toppenish Ridge structures, however, has not been reported.
Age of faulted surficial deposits	Miocene volcanic rocks are obviously deformed in the Toppenish Ridge anticline (Bentley and others, 1980 #4693; Walsh and others, 1987 #3579; Schuster and others, 1997 #3760). Bentley and others (1980 #4693), Campbell and Bentley (1981 #3513), Campbell and others (1995 #5552), and Repasky and others (1998 #5554) discuss evidence for deformation of Pleistocene and Holocene sediments along the Mill Creek fault [566a] and along normal faults related to horst and graben features south of Mill Creek fault. These faults and faulted Quaternary sediments are discussed in more detail in the Mill Creek fault section [566a]. Folding of Quaternary units, related to growth or tightening of the Toppenish Ridge anticline and related folds, has not been definitively documented or described. Deformation of Quaternary deposits along the faults included in this section of the Toppenish structures has not been reported.
Historic earthquake	
Most recent prehistoric deformation	undifferentiated Quaternary (<1.6 Ma) *Comments:* Bentley and others (1980 #4693), Campbell and others (1995 #5552), and Repasky and others (1998 #5554) discuss evidence for deformation of Pleistocene and Holocene sediments along the Mill Creek

	fault [566a] and along normal faults related to horst and graben features south of Mill Creek fault [566a]. These faults cut the crest and north flank of the Satus Peak part of the Toppenish Ridge anticline. Bentley and others (1980 #4693) and Campbell and Bentley (1981 #3513) inferred some Quaternary fold activity along Toppenish Ridge based on their interpretation that horst and graben features south of the Mill Creek fault [566a] are tensional features related to folding and faulting above the underlying Mill Creek fault. Quaternary growth or tightening of other ridge-anticline features of the Yakima fold belt, related to movement along underlying thrust faults, has also been inferred from the following local and regional relations, (1) correlation of long-term uplift rates of Miocence volcanic rocks (Reidel, 1984 #5545) and (2) the north-south orientation of the principle stress direction and active seismicity of the region (Reidel and others, 1994 #3539). No unequivocal evidence for Quaternary growth or tightening of the Toppenish Ridge anticline and related folds has been documented, however, and no evidence for Quaternary deformation along faults included in this section of the Toppenish Ridge structures has been reported.
Recurrence interval	*Comments:* Piety and others (1990 #3733) used uplift rates calculated from 15 Ma volcanic rocks to estimate recurrence intervals of 170–8,300 years based on uplift per events of 0.02–1.0 m along an inferred principle fault underlying the Toppenish Ridge anticlinal uplift.
Slip-rate category	Less than 0.2 mm/yr *Comments:* Some data is available on uplift rates of Miocene volcanic rocks across the Toppenish Ridge anticline and that data has been used to estimate long-term uplift rates. Piety and others (1990 #3733) report 1800 m of uplift of 15 Ma volcanic rocks, which yields an uplift rate of 0.12 mm/yr. Geomatrix Consultants, Inc. (1996 #4676) used uplift of 500 m of 10.5–15 Ma volcanic rocks and estimated fault dips of 30°, 45°, and 60° to estimate slip rates of 0.019–0.095 mm/yr along an inferred principle thrust fault underlying the Toppenish anticline. Detailed studies by Campbell and others (1995 #5552) and Repasky and others (1998 #5554), which are discussed in more detail in the Mill Creek fault section [566a], may indicate that the slip rate along the Mill Creek fault is in the range of 0.08–0.1 mm/yr during the past 145-180 k.y. However, Repasky and others (1998 #5554) also speculated that slackwater sediments they identified in trench site 566-5 may be old (pre 60 ka) deposits related to glacial floods. They presented two interpretations of these slackwater deposits and favored their interpretation that implies later uplift of these

	sediments and an uplift rate for Toppenish Ridge of at least 1.16 mm/yr during the last 60 k.y. (Repasky and others, 1998 #5554). This uplift-rate estimate of Repasky and others (1998 #5554) is orders of magnitude higher than the estimates of uplift and slip rates discussed above that all suggest much lower rates (<0.2 mm/yr) for possible Quaternary uplift and slip related to these faults and folds. Consequently, faults and folds of this section of the Toppenish Ridge structures are herein assigned a slip-rate category of <0.2 mm/yr until further studies are conducted.
Date and Compiler(s)	2016 David J. Lidke, U.S. Geological Survey Kathleen M. Haller, U.S. Geological Survey Robert C. Bucknam, U.S. Geological Survey, Retired
References	#4693 Bentley, R.D., Anderson, J.L., Campbell, N.P., and Swanson, D.A., 1980, Stratigraphy and structure of the Yakima Indian Reservation, with emphasis on the Columbia River basalt group: U.S. Geological Survey Open-File Report 80-200, 73 p., 1. #7394 Bjornstad, B.N., Winsor, K., and Unwin, S.D., 2012, A summary of fault recurrence and strain rates in the vicinity of the Hanford site: Topical report prepared for the U.S. Department of Energy under contract DE-AC05-76RL01830, 90 p. #3513 Campbell, N.P., and Bentley, R.D., 1981, Late Quaternary deformation of the Toppenish Ridge uplift in south-central Washington: Geology, v. 9, p. 519–524. #5552 Campbell, N.P., Ring, T., and Repasky, T., 1995, Final report, 1994 NEHRP grant earthquake hazard study of the vicinity of Toppenish Basin, south-central Washington: Technical report to U.S. Geological Survey, Reston, Virginia, under Contract 1434-94-G-249, December 22, 1995, 9 p. #7402 Coppersmith, R., Hansen, K., Unruh, J., Slack, C., 2014, Structural analysis and Quaternary investigations in support of the Hanford PSHA, Appendix E *in* Coppersmith, K.J., Bommer, J.J., Hanson, K.L., Unruh, J., Coppersmith, R.T., Wolf, L., Youngs, R., Rodriguez-Marek, A., Al Atik, L., Toro, G. and Montaldo-Falero, V., Hanford sitewide probabilistic seismic hazard analysis: Richland, Washington, Pacific Northwest National Laboratory report PNNL-23361, http://www. hanford. gov/page. cfm/OfficialDocuments/HSPSHA. #1311 Geomatrix Consultants, Inc., 1988, Seismotectonic evaluation of the northern Cascade Mountains geomorphic province for Bumping Lake, Tieton, Keechelus, Kachess, Cle Elum, and Clear Creek Dams: Technical

report to U.S. Department of Interior, Bureau of Reclamation, Denver, Colorado, under Contract 6-CS-81-07310, December 1988, 154 p., 12 pls.

#5550 Geomatrix Consultants, Inc., 1990, Seismotectonic evaluation of the Walla Walla section of the Columbia Plateau geomorphic province for Grand Coulee, North, Dry Falls, Pinto, and O'Sullivan Dams; Soda Lake, north Scooteney, and south Scooteney dikes: Technical report to U.S. Department of the Interior, Bureau of Reclamation, Denver, Colorado, under Contract 6-CS-81-07310, April 1990, 129 p.

#4676 Geomatrix Consultants, Inc., 1996, Probabilistic seismic hazard analysis DOE Hanford site, Washington: Technical report to Westinghouse Hanford Company, Richland, Washington, under Contract WHC-SD-W236A-TI-002, Rev.1, February, 1996, 366 p.

#5568 Korosec, M.A., 1987, Geologic map of the Mount Adams quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 87-5, 39 p. pamphlet, 1 sheet, scale 1:100,000.

#7407 Mège, D., and Reidel, S.P., 2001, A method for estimating 2D wrinkle ridge strain from application of fault displacement scaling to the Yakima folds, Washington: Geophysical Research Letters, v. 28, p. 3545–3548, doi: 10.1029/2001GL012934.

#5658 Mullineaux, D.R., Wilcox, R.E., Ebaugh, W.F., Fryxell, R., and Rubin, M., 1977, Age of the last major scabland flood of eastern Washington, as inferred from associated ash beds of Mount St. Helens set S: Geological Society of America Abstracts with Programs, v. 9, no. 7, p. 1105.

#5659 Mullineaux, D.R., Wilcox, R.E., Ebaugh, W.F., Fryxell, R., and Rubin, M., 1978, Age of the last major scabland flood of the Columbia Plateau in eastern Washington: Quaternary Research, v. 10, p. 171-180.

#3733 Piety, L.A., LaForge, R.C., and Foley, L.L., 1990, Seismic sources and maximum credible earthquakes for Cold Springs and McKay Dams, Umatilla Project, north-central Oregon: U.S. Bureau of Reclamation Seismotectonic Report 90-1, 62 p., 1 pl.

#7397 Pratt, T.L., 2012, Large-scale splay faults on a strike-slip fault system—The Yakima folds, Washington State: Geochemistry, Geophysics, Geosystems, v. 13, Q11004, doi: 10.1029/2012GC004405.

#5545 Reidel, S.P., 1984, The Saddle Mountains—The evolution of an anticline in the Yakima fold belt: American Journal of Science, v. 284, p. 942-978.

#3539 Reidel, S.P., Campbell, N.P., Fecht, K.R., and Lindsey, K.A., 1994, Late Cenozoic structure and stratigraphy of south-central Washington, *in* Lasmanis, R., and Cheney, E.S., eds., Regional geology of Washington State: Washington Division of Geology and Earth Resources, p. 159-180.

#5553 Reidel, S.P., Fecht, K.R., Hagood, M.C., and Tolan, T.L., 1989, The geologic evolution of the central Columbia Plateau, *in* Reidel, S.P., and Hooper, P.R., eds., Volcanism and tectonism in the Columbia River flood-basalt province: Geological Society of America Special Paper 239, p. 247-264.

#5554 Repasky, T.R., Campbell, N.P., and Busacca, A.J., 1998, Earthquake hazard study in the vicinity of Toppenish Basin, south-central Washington: Technical report to U.S. Geological Survey, Reston, Virginia, under Contract 1434-HQ-97-GR-03013, December 1998, 27 p., 7 pls.

#3738 Rigby, J.G., and Othberg, K., 1979, Reconnaissance surficial geologic mapping of the Late Cenozoic sediments of the Columbia Basin, Washington: State of Washington Department of Natural Resources Division of Geology and Earth Resources Open-File Report 79-3, 88 p., 10 pls.

#3760 Schuster, E.J., Gulick, C.W., Reidel, S.P., Fecht, K.R., and Zurenko, S., 1997, Geologic map of Washington-southeast quadrant: Washington Division of Geology and Earth Resources Geologic Map GM-45, 20 p. pamphlet, 2 sheets, scale 1:250,000.

#4653 Schuster, J.E., 1994, Geologic map of the east half of the Toppenish 1:100,000 quadrangle, Washington: Washington Division of Geology and Earth Resources Open-File Report 94-10, 15 p., scale 1:100,000.

#5189 Walsh, T.J., compiler, 1986, Geologic map of the west half of the Toppenish quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 86-3, 8 p., 1 pl., scale 1:100,000.

#3579 Walsh, T.J., Korosec, M.A., Phillips, W.M., Logan, R.L., and Schasse, H.W., 1987, Geologic map of Washington-southwest quadrant: Washington Division of Geology and Earth Resources Geologic Map GM-34, 28 p. pamphlet, 2 sheets, scale 1:250,000.

	#5555 Woodward-Clyde Consultants, 1981, Final report for Task D5, Toppenish Ridge study: Technical report to Washington Public Power Supply System, Nuclear Project WNP-2 and WNP-1/4, Hanford FSAR Geologic Support, San Francisco, California, under Contract C-560, July 15, 1981, 33 p.