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Quaternary Fault and Fold Database of the United States

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Horse Heaven Hills structures (Class A) No. 567

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Synopsis	The Horse Heaven Hills structures form one of the longest fault and fold systems in the southern part of the Yakima fold belt of south-central Washington. The structures can be divided into northeast- and northwest-trending sections that intersect at Chandler Butte near Benton City in southeastern Washington. The structures are primarily expressed as a series of north-verging anticlines that are thought to be underlain by south-dipping thrust or reverse faults. Possible 1- to 4-m-high fault scarps on the north flank of the northeast-trending section of the Horse Heaven Hills between Bluelight and Prosser, Wash., have been described by Rigby and Othberg (1979 #3738) and Piety and others (1990 #3733). Poor exposure and lack of detailed mapping in Quaternary deposits may prevent determination of Quaternary displacement along most of the length of these structures. Quaternary age growth or tightening of other folds in the Yakima fold belt, and perhaps of the Horse Heaven Hills 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), and 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the strain through active folding and possibly faulting (Pratt, 2012 #7397; Bjornstad and others, 2012 #7394 citing unpublished Zachariasen and others, 2006). Based on the growing consensus that the Horse Heaven Hills folds are cored by buried Quaternary fault, the faults are reassigned to Class A as opposed to the prior Class B classification
Name comments	Structures associated with the Horse Heaven Hills can be divided into northeast- and northwest-trending sections whose northernmost extent intersect at Chandler Butte near Benton City in southeastern Washington. The northeast-trending section extends from the Klickitat River at the western end of the Simcoe Mountains, northeastward through the Simcoe Mountains and Horse Heaven Hills to Chandler Butte. The Northwest-trending section extends from Chandler Butte, southeast to directly south of Union Gap along the Columbia River. The northeast- and northwest-trending sections are about 125 km and 55 km in length, respectively. Geomatrix Consultants, Inc. (1995 #3593), and earlier unpublished reports, named these the Horse Heaven Hills NE and NW anticlines or faults. Other names for structures in the Horse Heaven Hills include the Horse Heaven or Horse Heaven Hills anticline, Horse Heaven-Simcoe uplift, Upper and Lower Grayback Mountain faults, Simcoe Mountain anticline, Satus Creek fault system, Milk Ranch fault system, Jump Off Joe anticline, and the Zintel Canyon fault (Newcomb, 1970 #3761; Farooqui, 1977 #4663; Bentley and others, 1980 #4693; Anderson, 1987 #3492; Tolan and Reidel, 1989 #3765). **Fault ID:** These structures are included in fault number 79 of Geomatrix Consultants, Inc. (1995 #3593).
County(s) and State(s)	WALLA WALLA COUNTY, WASHINGTON BENTON COUNTY, WASHINGTON YAKIMA COUNTY, WASHINGTON KLICKITAT COUNTY, WASHINGTON
Physiographic province(s)	COLUMBIA PLATEAU
Reliability of location	Good Compiled at 1:100,000 scale. *Comments:* The location of the fault are 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 mapping by Walsh, (1986 #5189), Korosec (1987 #4658, 1987 #5568), Phillips and others (1987 #4660) Schuster (1994 #4653, 1994 #4654), and Reidel and Fecht (1994 #4657).
Geologic setting	The Horse Heaven Hills and Simcoe Mountains define parts of an anticlinal-ridge uplift that shows a dog-leg form in map view where the crest of the Horse Heaven Hills structure is displaced by about 5 km in a right-lateral sense across the Arlington fault (Anderson and others, 2013 #7411). This anticlinal ridge lies in the south to southeast 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 may have continued through the Quaternary (Reidel and others, 1989 #5553; 1994 #3539). The Horse Heaven Hills structures form one of the longest fault and fold systems in the southern Yakima fold belt of south-central Washington. Named and unnamed, northeast- and northwest-striking thrust faults cut the north and south limbs of this anticlinal uplift that forms one of many anticlinal ridges that comprise the Yakima fold belt in south-central Washington. Possible fault scarps along the north flank of this uplift have been described by Rigby and Othberg (1979 #3738) and Piety and others (1990 #3733). However, folds and faults of the Horse Heaven Hills and Simcoe Mountains are only known to deform rocks of the Columbia River Basalt Group (Miocene). Coppersmith and others (2014 #7402) report the average relief across the anticline is 270 m, 575 m, 485 m, 415 m, and 205 m for their five fault sources.
Length (km)	179 km.

Average strike	N90°W
Sense of movement	Thrust *Comments:* Movement on the Horse Heaven Hills structures is primarily expressed as anticlinal folds that are cut and underlain by thrust or reverse faults in Miocene rocks of the Columbia River Basalt Group (Newcomb, 1970 #3761; Farooqui, 1977 #4663; Swanson and others, 1980 #3574; Bentley and others, 1980 #4693; Anderson, 1987 #3492; Tolan and Reidel, 1989 #3765; Schuster, 1994 #4653; Reidel and Fecht, 1994 #4657; Schuster and others, 1997 #3760).
Dip	24–42° S. *Comments:* Exposures of the thrust or reverse faults that underlie the Horse Heaven Hills are rare, so few dip measurements have been published. Geomatrix Consultants, Inc. (1995 #3593; 1996 #4676) used equally weighted dips of 30°, 45°, and 60° in their evaluations of earthquake hazards associated with the Horse Heaven Hills structures. Mège and Reidel (2001 #7407) report a mean fault dip of 24–42° for the Horse Heaven Hills thrust fault based on a combination of field measurements and accessible seismic profiles.
Paleoseismology studies	The Goose Hill quarry (site 567-1), 1 km northeast of the Horse Heaven Hills frontal fault, exposes a south-dipping reverse fault that offsets a 80–130 ka calcic paleosol (Bjornstad and others, 2012 #7394) by 3 m. Undeformed Lake Missoula slackwater flood deposits in the exposure preclude Holocene deformation
Geomorphic expression	These structures are coincident with (and take their name from) the Horse Heaven Hills, a series of low hills underlain by resistant basalt of the Columbia River Basalt Group. The topographic high expressed by the nearly connected Simcoe Mountains and Horse Heaven Hills is the principle geomorphic expression of the anticlinal uplift and related folds and faults of the Horse Heaven Hills structures. Possible 1- to 4-m-high fault scarps on the north flank of the northeast-trending section of the Horse Heaven Hills between Bluelight and Prosser, Wash., have been described by Rigby and Othberg (1979 #3738) and Piety and others (1990 #3733). Some of these scarps form lineaments recognized by Sandness and others (1982 #3788). However, most of the Horse Heaven Hills structures are buried by thick Quaternary loess and landslide deposits along much of their length (Schuster, 1994 #4653; Reidel and Fecht, 1994 #4657; Schuster and others, 1997 #3760).

Age of faulted surficial deposits	The Horse Heaven Hills structures are primarily expressed in Miocene rocks of the Columbia River Basalt Group, but are buried by Quaternary loess and landslide deposits along much of their length (Schuster, 1994 #4653; Reidel and Fecht, 1994 #4657; Schuster and others, 1997 #3760). However, possible fault scarps described by Rigby and Othberg (1979 #3738) and Piety and others (1990 #3733) between Bluelight and Prosser, Washington along the northeast-trending part of the uplift may offset late Pleistocene (<100 ka) loess deposits and the quarry exposure at Goose Hill suggest a middle Quaternary soil is offset (Bjornstad and others, 2012 #7394).
Historic earthquake	
Most recent prehistoric deformation	undifferentiated Quaternary (<1.6 Ma) *Comments:* The Horse Heaven Hills structures are primarily expressed in Miocene rocks of the Columbia River Basalt Group, but are buried by Quaternary loess and landslide deposits along much of their length (Schuster, 1994 #4653; Reidel and Fecht, 1994 #4657; Schuster and others, 1997 #3760). However, possible fault scarps described by Rigby and Othberg (1979 #3738) and Piety and others (1990 #3733) between Bluelight and Prosser, Washington along the northeast-trending part of the uplift may offset late Pleistocene (<100 ka) loess deposits and the quarry exposure at Goose Hill suggest a middle Quaternary soil is offset (Bjornstad and others, 2012 #7394).
Recurrence interval	*Comments:* Piety and others (1990 #3733) used uplift rates calculated from 15 Ma volcanic rocks to estimate recurrence intervals of 390-50,000 years based on displacement per events of 0.02–1.0 m. (Bjornstad and others, 2012 #7394) suggest that the offset observed in the Goose Hill quarry results from multiple coseismic displacement events since 80–200 ka.
Slip-rate category	Less than 0.2 mm/yr *Comments:* Little slip data in Quaternary deposits are available for structures associated with the Horse Heaven Hills. Rigby and Othberg (1979 #3738) and Piety and others (1990 #3733) report possible 1- to 4-m-high fault scarps in late Pleistocene (<100 ka) loess deposits between Bluelight and Prosser, Washington. Some data is available on uplift rates of Miocene volcanics across the Horse Heaven Hills folds. Anderson (1987 #3492) estimated about 1,350 m of uplift of the 16–17 Ma Grande

	Ronde basalt, about 100 m of uplift of 4.8 Ma flows, and 30 m of uplift of 3.4 Ma flows across the Horse Heaven Hills anticline at Grayback Mountain, near the western end of the Horse Heaven Hills structures. These data yielded average decelerating uplift rates of 0.10 mm/yr (post 17 Ma), 0.05 mm/yr (4.8-3.4 Ma), and 0.008 mm/yr (post 3.4 Ma), respectively (Anderson, 1987 #3492). Piety and others (1990 #3733) report 300–775 m of uplift of 15 Ma volcanic rocks, which yield uplift rates of 0.02–0.05 mm/yr. Geomatrix Consultants, Inc. (1995 #3593) used uplift of 323 m of 10.5 Ma volcanic rocks to constrain uplift rates of 0.03–0.06 mm/yr. Geomatrix Consultants, Inc. (1996 #4676) used uplift of 323–368 m of 10.5 Ma volcanic rocks and estimated fault dips of 30°, 45°, and 60° to estimate slip rates of 0.036–0.07 mm/yr across the Horse Heaven Hills structures. Bjornstad and others (2012 #7394) suggest an oblique slip rate of 0.02–0.04 mm/yr in the late Quaternary and confirms the rate of slip is low and recurrence is long at the Goose Hill quarry.
Date and Compiler(s)	2016 Stephen F. Personius, U.S. Geological Survey Kathleen M. Haller, U.S. Geological Survey Elizabeth A. Barnett, Shannon & Wilson, Inc. David J. Lidke, U.S. Geological Survey
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