Jump to Navigation

# 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.**

## Saddle Mountains structures, unnamed faults of the Saddle Mountains (Class A) No. 562b

**Last Review Date: 2016-05-19**

***citation for this record:*** **Lidke, D.J., Barnett, E.A., and Haller, K.M., compilers, 2016, Fault number 562b, Saddle Mountains structures, unnamed faults of the Saddle Mountains, 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.**

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| **Synopsis** | **General:** The east-trending Saddle Mountains uplift are part of the Yakima fold and thrust belt, defined by asymmetric, anticlinal folds in the hanging wall of generally blind reverse faults that extend across a region that covers more than 15,000 square kilometers. Thrust faults bound the north side of the Saddle Mountains. Also included in this group are related normal faults that show evidence of Quaternary offset (Reidel, 1984 #5545; Reidel and others, 1994 #3539; West and others, 1996 #3514; West, 1997 #5548). The Saddle Mountains anticline and related folds and some faults of the Saddle and Boylston Mountains, however, are only known to deform Miocene and Pliocene rocks. Quaternary age growth or tightening of the Saddle Mountains folds and other folds in the Yakima fold belt, has been suggested and inferred from several local and regional geologic relations in the Yakima fold belt (Campbell and Bentley, 1981 |

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| | #3513; Reidel, 1984 #5545; Reidel and others, 1994 #3539). 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the strain through active folding and possibly faulting (Pratt, 2012 #7397; Bjornstad and others, 2012 #7394 citing unpublished Zachariasen and others, 2006). Site investigation that address the recency of faulting, and thus folding, have been located on subsidiary faults and age control remains ambiguous. Although the trenches exposed compelling evidence for repeated Quaternary surface faulting. West and others (1996 #3514) and West (1997 #5548) reported on Quaternary normal faults and a graben, which are present in the Smyrna Bench area of the Saddle Mountains, and they interpreted these normal faults as hanging-wall tensional features related to Quaternary movement along the underlying Saddle Mountains fault. They noted that the Saddle Mountains anticline probably cannot accommodate much additional strain by folding and that additional strain would likely instead induce fault slip. Based on the growing consensus that the Saddle Mountains folds are cored by buried Quaternary fault, the faults are reassigned to Class A as opposed to the prior Class B classification.<br><br>**Sections:** This fault has 2 sections. Section, as defined here, differs in lateral extent from the fault sources prescribed by Coppersmith and others (2014 #7402) and includes Saddle Mountains-East and part of the Saddle Mountains-West. |
| **Name comments** | **General:**<br><br>**Section:** Refers to the east-trending faults related to the Saddle Mountains and Manastash Ridge anticlines. The folds are prominent features and are shown and portrayed in numerous geologic maps and reports of this region (Grolier and Bingham, 1971 #5542; West and Shaffer, 1988 #5549; Geomatrix Consultants Inc., 1990 #5550; Reidel and Fecht, 1994 #5565; Schuster and others, 1997 #3760). Named major folds include the Saddle Mountains anticline and syncline, Smyrna monocline, and Crest anticline and monocline (Reidel, 1988 #5546). The Saddle Mountains anticline appears to connect with the Crest anticline and monocline (Reidel, 1988 #5546) and collectively these folds extend from the Columbia River eastward to directly east of the northern part of Scooteney Reservoir. West of the Columbia River, sinuous, east-trending folds and one or more thrust faults extend westward into the Boylston Mountains and farther west to about the Kititatas Valley. These folds and faults in Miocene volcanic rocks west of the Columbia River appear to be continuations of, and are considered part of the Saddle Mountains uplift (Reidel, 1984 #5545). Geologic maps show an inferred north-northwest-striking fault along the Columbia River that cuts the Saddle Mountains uplift (Reidel, 1988 |

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| | #5546; Reidel and Fecht, 1994 #5565; Schuster and others, 1997 #3760). Reidel (1984 #5545) divides the anticlinal uplift of the Saddle and Boylston Mountains into six structural segments based on changes in trend and style of folds along the uplift and one of the segment boundaries approximately coincides with the inferred northwest trending fault along the Columbia River. Section, as defined here, differs in lateral extent from the fault sources prescribed by Coppersmith and others (2014 #7402) and includes only part of the Saddle Mountains-West and all three parts of Manastash Ridge. |
| **County(s) and State(s)** | KITTITAS COUNTY, WASHINGTON<br>GRANT COUNTY, WASHINGTON<br>FRANKLIN COUNTY, WASHINGTON<br>ADAMS COUNTY, WASHINGTON |
| **Physiographic province(s)** | COLUMBIA PLATEAU |
| **Reliability of location** | Good<br>Compiled at 1:100,000 scale.<br><br>*Comments:* Location of faults 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 maps of Tabor and others (1982 #7408), Walsh (1986 #5570), Walsh and others (1987 #3579), Schuster and others (1994 #5566), and Reidel and Fecht (1994 #5565). |
| **Geologic setting** | The Saddle and Boylston Mountains lie in the northeastern 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° to 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 |

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| | #5553; 1994 #3539).<br><br>The south-dipping Saddle Mountains fault is a thrust fault that cuts the north limb of the north-vergent Saddle Mountains anticline, one of the many anticlinal ridges that comprise the Yakima fold belt in south-central Washington. The Saddle Mountains anticline and related folds deform rocks of the Columbia River Basalt Group (Miocene) and overlying sedimentary rock (Pliocene). Quaternary deformation is generally associated with the most tightly folded and structurally complex interval of the anticline (West, 1997 #5548). Quaternary faulting also includes development of grabens and beheading of modern streams in the hanging wall south of the Saddle Mountains thrust fault. This is analogous to surface rupture accompanying the Oct. 10, 1980, El Asnam, Algeria, M 7.3 earthquake (Philip and Meghraoui, 1983 #5544; Meghraoui and others, 1988 #803; Avouac and others, 1992 #5540). Contemporary seismicity in and near the Saddle Mountains also suggests late Quaternary tectonism (Ludwin and Qamar, 1995 #1350). Campbell and Bentley (1981 #3513) and Mann and Meyer (1993 #3535) reported and suggested late Quaternary deformation on other structures in the Yakima fold and thrust belt.<br><br>Using seismic reflection data, borehole logs, and surface geologic data, Casale and Pratt (2015 #7396) tested two proposed kinematic end-member thick- and thin-skinned fault models beneath the Saddle Mountains anticline. Observed subsurface geometry can be produced by 600–800 m of heave along a single listric-reverse fault or about 3–5 km of slip along two superposed low-angle thrust faults. Both models require decollement slip between 7 and 9 km depth. In addition, the seismic reflection profiles show that rocks below the Columbia River Basalt Group are more deformed that the overlying units suggesting deformation preceded the emplacement of the basalts. Coppersmith and others (2014 #7402) estimate average structural relief of Saddle Mountains West to be 320–335 m. |
| **Length (km)** | This section is 104 km of a total fault length of 104 km. |
| **Average strike** | N71°W (for section) versus N71°W (for whole fault) |
| **Sense of movement** | Thrust<br><br>*Comments:* East of the Columbia River, the Saddle Mountains anticline is an asymmetric anticline that commonly displays a steeply dipping to overturned north limb (Grolier and Bingham, 1971 #5542; Reidel, 1984 #5545; Reidel, 1988 #5546). The Saddle Mountains uplift (east and west of the Columbia River) has an undulating crest that reflects the fact that |

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| | the anticlinal uplift is a compound fold that includes anticlines, synclines, and monoclines. South dipping thrust splays, which include the Saddle Mountains fault [562a], are mapped as relatively continuous features along the north flank of the Saddle Mountains anticlinal uplift (Grolier and Bingham, 1971 #5542; Reidel, 1988 #5546; Reidel and Fecht, 1994 #5565; Schuster and others, 1997 #3760). These spatial relations of the Saddle Mountains folds to the south-dipping thrust faults suggest that the folds formed, tightened, and overturned during north-directed, reverse-thrust movement along the underlying south-dipping thrust faults (Reidel, 1984 #5545; Reidel and others, 1994 #3539; West and others, 1996 #3514). |
| **Dip** | 19–33° S<br><br>*Comments:* Where the Saddle Mountains anticline and other folds are asymmetric the northern limbs are of these folds are commonly the steeper limbs (Reidel, 1984 #5545; Reidel, 1988 #5546; Geomatrix Consultants Inc., 1990 #5550), which may indicate that the axial surfaces of these folds dip steeply to the south. Many of these faults are shown on geologic maps as south dipping thrust faults (Reidel and Fecht, 1994 #5565; Schuster and others, 1997 #3760). Mège and Reidel (2001 #7407) report a mean fault dip of 19–33° for the Saddle Mountain thrust fault based on a combination of field measurements and accessible seismic profiles. Based on comparative borehole stratigraphy, Tincher (2009 #7398) concludes the Saddle Mountains thrust dips 30° to the south at depth. The kinematic models of Casale and Pratt (2015 #7396) place specific limits upon the faults constrained by the geometry of the upper basalt layers and topography.<br><br>Numerous dips have been assigned for modeling fault sources in seismic hazard assessments. Geomatrix Consultants Inc. (1996 #4676) used fault dips of 30°, 45°, and 60° in their calculations of slip rates for the Saddle Mountains fault. West and others (1996 #3514) modeled the fault using dips of 20–40°. West and others (1996 #3514) and West (1997 #5548) show moderate to steep dips for normal faults exposed in trenches south of the Saddle Mountains fault in the Smyrna Bench area. |
| **Paleoseismology studies** | Trench 562-5 (Horned Lizard trench, Barnett and others, 2013 #7395) was excavated across a prominent, northwest-side-up, 3- to 4-m-high scarp that extends across and perpendicular to the western end of the Boylston Mountains. The trench exposed faulted 15.5-Ma basalt capped by silty gravels; the section is interpreted to show evidence of at least two earthquakes (Barnett and others, 2013 #7395) although the relation to this fault and the underlying thrust fault is unclear. No datable material was |

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| | recovered from the trench; however, deposition of inferred Mazama ash postdates both earthquakes. Location of the trench is from Barnett and Sherrod (2014 #7555). |
| **Geomorphic expression** | The slightly sinuous, east-trending ridge-like form of the Saddle Mountains is the principal geomorphic expression of the Saddle Mountains anticline and related easterly trending folds. LiDAR data reveals a prominent scarp perpendicular to the western end of the Boylston Mountains (Barnett and others, 2013 #7395). |
| **Age of faulted surficial deposits** | Miocene volcanic rocks and Pliocene sediments as young as about 3.5 Ma are obviously deformed in the Saddle Mountains folds (Reidel, 1984 #5545; 1988 #5546). West and others (West and others, 1996 #3514) and West (1997 #5548) discuss evidence for Quaternary deformation of Quaternary units along the Saddle Mountains fault and along normal faults of a graben in the Smyrna Bench area. Folding of Quaternary units, related to growth or tightening of the Saddle Mountains anticline and related folds of the Saddle Mountains, has not been documented or described. No evidence of deformation of Quaternary units along the faults included in this section of the Saddle Mountains structures has been reported, however, Quaternary deposits are sparse to absent along many of these faults (Reidel and Fecht, 1994 #5565; Schuster and others, 1997 #3760). |
| **Historic earthquake** | |
| **Most recent prehistoric deformation** | undifferentiated Quaternary (<1.6 Ma)<br><br>*Comments:* West and others (1996 #3514) and West (1997 #5548) discuss evidence for deformation of late Pleistocene to Holocene units along the Saddle Mountains fault [562a] and apparently related normal faults, which cut the north flank of the Saddle Mountains anticline. Reidel (1984 #5545) inferred Quaternary growth of the Saddle Mountains folds based on Miocene and post-Miocene uplift of Miocene volcanic rocks in the core of the Saddle Mountains relative to Miocene volcanic rocks in the adjacent synclinal valleys. Quaternary growth or tightening of other ridge-anticline features of the Yakima fold belt has also been inferred from (1) the north-south orientation of the principle stress direction and active seismicity of the region (Reidel and others, 1994 #3539) and (2) interpretation of geometric relations of the folds to normal and strike-slip faults that show Quaternary offsets (Campbell and Bentley, 1981 #3513). West and others (1996 #3514), however, reported that the Saddle Mountains anticline probably cannot accommodate much additional strain by folding and that additional strain would likely instead induce fault slip. However, a |

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| | detailed study of a 1.5-m-high scarp identified by LiDAR (Ladinsky and Kelsey, 2010 #7554; Kelsey and Ladinsky, 2011 #7552; Ladinsky, 2012 #7553) at the Manastash Rige range front near Shushuskin Canyon is interpreted to suggest multiple episodes of Quaternary uplift. The position and incision of Quaternary alluvial and fan deposits at the mouth of the canyon suggest a minimum of three base level-lowering events at the Manastash front. Furthermore, the most recent event is inferred to be latest Pleistocene or Holocene in age based on the lack of well developed loess cover on lowest fan (Kelsey and Ladinsky, 2011 #7552). Additional evidence of late Quaternary faulting is documented by Ladinsky (2011 #7554); however, most of the faults remain uncharacterized and are assigned undifferentiated Quaternary. |
| **Recurrence interval** | *Comments:* Piety and others (1990 #3733) used uplift rates calculated from 13.5 Ma volcanic rocks to estimate recurrence intervals of 490–24,500 years along principle thrust faults underlying the Saddle Mountains uplift, based on displacement per events of 0.02–1.0 m. |
| **Slip-rate category** | Less than 0.2 mm/yr<br><br>*Comments:* Reported rates of deformation are vary from study to study and remain highly uncertain. Assigned slip-rate category is based on the largest uplift rates of Miocene volcanic rocks reported (Reidel, 1984 #5545; Piety and others, 1990 #3733; Geomatrix Consultants Inc., 1996 #4676). Reidel (1984 #5545) compared relative amounts of uplift of volcanic units in the core of the Saddle Mountains and determined that post-Miocene uplift of the Saddle Mountains was relatively constant and about 0.04 mm/yr. Piety and others (1990 #3733) report 550 m of uplift of 13.5 Ma volcanic rocks, which yields an uplift rate of 0.04 mm/yr. Coppersmith and others (2014 #7402) report the average relief of the Saddle Mountains anticline is 300–415 m with a maximums of 175–725 m. Geomatrix Consultants Inc. (1996 #4676) used various uplift amounts and ages for Miocece volcanic rocks and used estimated fault dips of 30°, 45°, and 60° to estimate long-term slip rates of 0.007_0.175 mm/yr for an inferred principle fault underlying the Saddle Mountains. Bjornstad and others (2012 #7394) state that vertical displacement rates of the Saddle Mountains anticline (>0.16 to 0.65 mm/yr, reported as 160 to 650 m/m.y.) compare well with the normal long-term average net slip rate for the Yakima fold and thrust belt. However, table 2.1 (Bjornstad and others, 2012 #7394) reports long-term vertical growth rates for the Saddle Mountains anticline of 6–48 m/m.y. (0.006–0.48 mm/yr). Casale and Pratt (2015 #7396) estimate long-term rates of slip for each of their end- |

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| | member fault models. The thick-skinned model requires about 600–800 m of total heave since the middle and late Miocene. In contrast, 350–450 m of post-Columbia River Basalt Group heave is required of their thin-skinned model resulting in average slip rates of about 0.07–0.09 mm/yr for the deep listric fault and lower slip rates (0.04–0.05 mm/yr) on the upper the shallowly dipping faults. Pleistocene-Holocene displacement rates on the subsidiary Smyrna Bench structure were estimated (West and others, 1996 #3514; West, 1997 #5548) based on normal offsets of Quaternary units in the graben,. West and others (1996 #3514) and West (1997 #5548) concluded that the graben is tectonic and related to movement along the underlying Saddle Mountains fault. West and others (1996 #3514) and West (1997 #5548) also concluded, based largely on similar relations documented for the El Asnam fold and thrust Belt (Philip and Meghraoui, 1983 #5544; Meghraoui and others, 1988 #803; Avouac and others, 1992 #5540), that vertical and horizontal components of slip in the graben should approximate (less than or equal to) vertical and horizontal components of slip along the primary, causative thrust fault. For normal faults in the graben, West and others (1996 #3514) and West (1997 #5548) calculated a minimum, vertical displacement rate of 0.16–0.33 mm/yr, based on displacement of at least 6.5 m of a 20–40 ka paleosol (Busacca, 1991 #3598). According to West and others (1996 #3514) and West (1997 #5548), resolution of at least 6.5 m of vertical displacement on a 30° dipping thrust fault yields a minimum slip of 13 m in the fault plane in 20–40 ka and minimum slip rates of 0.33–0.65 mm/yr, also reported by Bjornstad and others (2012 #7394). |
| **Date and Compiler(s)** | 2016<br>David J. Lidke, U.S. Geological Survey<br>Elizabeth A. Barnett, Shannon & Wilson, Inc.<br>Kathleen M. Haller, U.S. Geological Survey |
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