Jump to Navigation

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Saddle Mountain faults (Class A) No. 575

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Synopsis	The Saddle Mountain deformation zone (Blakely and others, 2009 #7646) consists of numerous mapped faults, including Saddle Mountain East and West faults described and discussed by Wilson (1975 #5721) and Wilson and others (1979 #5663), Canyon River fault of Walsh and Logan (1997 #6225, 2007 #7630), and the Frigid Creek fault of Blakely and others (2009 #7646). According to Blakely and others (2009 #7646), aeromagnetic data suggests the zone of deformation extends at least 35 km, from 6 km southwest of Lake Cushman northward to the latitude of the Seattle, but the total length of the deformation zone may be 45 km. The zone accommodates shortening of Puget Lowland and might possibly be kinematically linked to the Seattle fault [570]. Detailed study of the Saddle Mountain faults, which included trenching and isotopic dating, indicates that the most recent coseismic surface deformation occurred in the Holocene (Wilson, 1975 #5721; Wilson and others, 1979 #5663; Barnett and others, 2015 #7646), and LiDAR reveals fault scarps offsetting Holocene alluvium (Haugerud and others, 2003 #6211).

Name comments	The Saddle Mountain deformation zone (Blakely and othere, (2009 #7646) consists of several short discontinuous north to northeast-striking faults located along the southeast flank of the Olympic Mountains, about 3–4 km northwest of Lilliwaup, Washington, extending from west of Lake Cushman to the Hood Canal to the east. Carson (1973 #5823) first identified the fault scarps of the Saddle Mountain deformation zone in detail; Wilson (1975 #5721) later mapped two faults that cross Saddle Mountain and named them the Saddle Mountain East fault and Saddle Mountain West fault. These two faults are shown on the 1:250,000-scale geologic map by Dragovich and others (2002 #5715). Additional faults including the Canyon River fault of Walsh and Logan (1997 #6225, 2007 #7630), and the Frigid Creek fault of Blakely and others (2009 #7646) were later identified based on interpretation of LiDAR data. Early identification of Canyon River fault from Side-Looking Airborne Radar (SLAR) imagery identified the Spoon Creek lineament (U.S. Army Corps of Engineers, 1983 #6243).
County(s) and State(s)	MASON COUNTY, WASHINGTON
Physiographic province(s)	PACIFIC BORDER
Reliability of location	Good Compiled at 1:250,000 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 Wilson (1975), Gower and others (1985), Witter and Givler (2005), Walsh and Logan (2007), Barnett, written comm., 2008, and Blakely and others (2009).
Geologic setting	The Saddle Mountain fault zone is composed of northeast-striking faults along the southeastern flank of the Olympic Mountains, directly west of the Puget lowlands. According to Blakely and others (2009 #7647), the Saddle Mountain faults, Frigid Creek fault, Canyon River fault, and Sund Creek fault form an en echelon deformation zone that together accommodates north-south shortening inboard of the Olympic Mountain massif. These northeast-striking faults cut volcanic and volcaniclastic rocks of the Eocene Crescent Formation and cut Pleistocene and Holocene glacial and colluvial deposits (Wilson, 1975 #5721; Wilson and others, 1979 #5663). Paleogene to Neogene deformation, which was related to subduction of the Juan de Fuca plate to the west, resulted in complex fold and thrust relations in Tertiary rocks exposed in and along the flanks of the

	Olympic Mountains (Tabor and Cady, 1978 #6221; 1978 #6222; Dragovich and others, 2002 #5715). The faults that make up the Saddle Mountain deformation zone are interpreted to have had Holocene coseismic ruptures that reactivated, an older northeast-trending zone of fractures (Wilson, 1975 #5721; Wilson and others, 1979 #5663; Barnett and others, 2015 #7646). Wilson and others (1979 #5663) suggest that this zone may have initially formed during late stages of Neogene folding and doming of the Olympic Mountains, prior to the development of the northwest-southeast compressive stress orientation that has characterized this region during the Holocene.
Length (km)	15 km.
Average strike	N26°E
Sense of movement	Reverse, Left lateral *Comments:* Based on trench exposures of the eastern and western Saddle Mountain faults, Wilson (1975 #5721), Wilson and others (1979 #5663), and Barnett and others (2015 #7646) reported that these faults show principally reverse offsets along steeply east-dipping fault planes. The rake of striations on the fault plane range between 25° and 65° suggesting a variable component of sinistral slip (Wilson, 1975 #5721; Wilson and others, 1979 #5663; Walsh and Logan, 2007 #7630), Walsh and Logan, 2007 #7630. The Canyon River fault of Walsh and Logan (2007 #7630) is down to the northwest reverse fault.
Dip	67–75° SE *Comments:* Wilson (1975 #5721) and Wilson and others (1979 #5663) report that the eastern Saddle Mountain fault strikes N. 22° E. and dips 75° SE, and report that the Saddle Mountain West fault strikes about N. 19° E. and dips about 67° SE. Walsh and Logan (2007 #7630) report that the fault strikes N. 70° E. and dips 70° SE.
Paleoseismology studies	Results of trenching studies are reported by Wilson (1975 #5721), Wilson and others (1979 #5663), Walsh and Logan (2007 #7630), Blakely and others (2009 #7647), Polenz and others (2010 #7649), Arcos (2012 #7645), and Barnett and others (2015 #7646). Collectively, these studies confirm Holocene coseismic surface deformation. In addition, Schuster and others (1992 #600) investigated rock avalanches at several sites in the southeastern Olympic Mountains to the northwest of the Saddle Mountain faults Saddle Mountain East trench (site 575-1) and Saddle Mountain West

trench (site 575-2). Wilson (1975 #5721) conducted detailed studies of four trenches across and near the Saddle Mountain faults; two of these trenches were excavated along the south flank of Saddle Mountain across the eastern and western Saddle Mountain faults, respectively. A third trench was excavated across the short, northwest-striking Dow Mountain fault that intersects the southern part of the eastern Saddle Mountain fault along the north flank of Dow Mountain, and a fourth was excavated along the southeast shore of Price Lake between the eastern and western Saddle Mountain faults. Only the two trenches (575-1 and 575-2) across the eastern and western Saddle Mountain faults are shown herein. Stratigraphic relations in trenches, and radiocarbon ages from colluvium along the Saddle Mountain East fault and sediment in nearby Price Lake and intermittent ponds, indicate one or more events between about 1.6–1.1 ka, and suggest multiple, older late Pleistocene to Holocene events (Wilson, 1975 #5721; Wilson and others, 1979 #5663).

Southeastern Olympic Mountains, rock-avalanche study sites (575-3). Schuster and others (1992 #600) reported rock avalanches and some limiting radiocarbon ages for these avalanches, which they investigated in the southeastern part of the Olympic Mountains. They presented evidence, which suggests that most or all of these avalanches were triggered by strong ground shaking related to earthquakes in the last few thousand years. Radiocarbon ages from plant remains associated with six of the avalanches imply that three or four of these six avalanches may have happened at or near the same time, about 1,000 to 1,300 yr ago (Schuster and others, 1992 #600). They noted that correlation of these probable earthquake-induced avalanches with a specific fault or faults is not possible, but suggested that the Saddle Mountain faults, Seattle fault zone [570], and Cascadia subduction zone [781] were likely candidates. This area of detailed study sites of rock avalanches in the southeastern Olympic Mountains is herein included with the Saddle Mountain faults based mainly on the proximity of these faults to these rock avalanches. However, as indicated by Schuster and others (1992 #600) these rock avalanches cannot currently be definitively correlated with an event or events along any specific fault or faults.

Site 575-4 (trench TR-1 of Walsh and Logan, 2007 #7630). A trenching investigation of the Canyon River fault was conducted in September 2003. Results of this investigation suggest at least one late Quaternary event of thrusting of Eocene basalt obliquely over a Holocene soil. The trench exposed offset basalts of the upper Crescent Formation and overlying glacial deposits, colluvium and soil along a steeply dipping, NE-striking fault. Based on stratigraphic relations, structure measurements and radiocarbon samples, they conclude that displacement from a single large earthquake vertically separated the both the ground surface and the basalt by 3.35 m; the earthquake occurred about 1,880 yr BP. Numerous slickensides and grooves on the fault surface indicate that motion included left-lateral slip. Walsh and others (1999 #6226) reported results from a ground penetrating radar survey (GPR) conducted to determine depth to bedrock.

Site 575-5 on the Saddle Mountain West fault. Witter and others (2008 #7648) mapped faulted glacial deposits and postglacial colluvium in the Cargill Creek trench. Stratigraphic relations and structural measurements indicate that faulting and folding, with possible dextral movement, produced a fault scarp at least 1.7 m high in two coseismic surface ruptures. Based on radiocarbon dating, the most recent surface rupture occurred after 1700 cal B.P., which is in good agreement with the earthquake timing on other faults in the deformation zone. The prior event occurred between the end of Vashon Stade (17 ka) and about 8,500 cal yr BP.

Site 575-6 on the Frigid Creek scarp, parallel to and 4 km south of the Saddle Mountain fault. The trench revealed conformable oxidized sandy gravels, sandy loams, and sandy silts offset by one event (Blakely and others, 2009 #7647). The 2.5 m of vertical displacement results from movement on a normal master fault that forms a small graben beneath the scarp. Radiocarbon ages constrain the timing of the deformation to 5657–319 cal yr BP.

Site 575-7 Skokomish Delta (Polenz and others, 2010 #7649; Arcos, 2012 #7645) where 1 m of uplift and east-ward tilting of the Skokomish delta is associated with surface rupture of a Saddle Mountain deformation zone fault. Radiocarbon ages from seeds and a tree stump found in the marsh area of the delta indicate that uplift occurred before A.D. 780–990 (Arcos, 2012 #7645). Polenz and others (2010 #7649) identified the Lucky Dog fault for the origin of the uplifted deposit. The fault is a northeast-vergent reverse fault underlying the delta identified by aeromagnetic anomalies, facies and elevation changes in core transects, and lidar analyses, which they infer uplifted a berm across the northwestern section of the delta. They date the facies change to A.D. 1200–1280, based on radiocarbon samples taken from cores. Alternatively, Arcos (Fig. 8, 2012 #7645) suggest that this berm is not the product of an underlying Lucky Dog fault but instead is a constructional beach berm.

Site 575-8 The Banana Slug trench (Barnett and others, 2015 #7646) crosses the Saddle Mountain East fault at the same location as the Saddle Mountain East trench of Wilson and others (1979 #566). The trench

	exposed Crescent Formation Basalt and overlying Vashon glacial deposits that are offset approximately 3.2 m along a N. 22° E. striking, steeply (75°) southeast dipping fault. A single coseismic slip event is constrained by radiocarbon dates that provide a maximum age of 1810–1550 cal yr BP for the soil buried by fault colluvium in the footwall. Slickensides on the fault plane in the basalt suggest a component of left-lateral slip. Site 575-9 Alligator Lizard trench (Barnett and others, 2015 #7646) crosses the Sund Creek fault and exposed Crescent Formation Basalt and overlying glacial and postglacial deposits that are offset by approximately 3.5 m The primary fault dips steeply (75–80°) to the northwest; the fault locally strikes N60°. Stacked colluvial deposits suggest at least two earthquakes with 1.4 m of displacement in the earlier event and 1.6 m in the later event. Radiocarbon ages from samples of the buried soils provide maximum ages for the two earthquakes of 3700–3480 cal yr BP and 1340–1260 cal yr BP. Slickensides on the fault plane in the basalt suggest a component of left-lateral slip. Site 575-10 Price Lake (Barnett and others, 2015 #7646). Price Lake was formed following ground rupture along the Saddle Mountain East fault blocked the east-flowing drainage, which drowned an existing forest, killing the trees and the subsequent deposition of organic deposits on the submerged forest floor (Wilson and others, 1979 #5663). Numerous cores and 11 radiocarbon ages from plant macrofossils and submerged tree stumps constrain the minimum age of the earthquake date the earthquake to 1180–940 cal yr BP (Hughes, 2005 #7650; Barnett and others, 2015 #7646). Two east-dipping reverse faults, which are consistent with scarps identified in LiDAR data are interpreted from a magnetic survey of Price Lake (Blakely and others, 2009 #7647).
Geomorphic expression	Wilson (1975 #5721) and Wilson and others (1979 #5663) report that the eastern Saddle Mountain fault is expressed by west-facing fault scarps that shows a maximum height of 8 m along the crest of Saddle Mountain and similar results are reported by Blakely and others (2009 #7647). They also report that the Saddle Mountain West fault is expressed by a 1.3-km-long, 1- to 4-m-high, west-facing scarp that crosses Saddle Mountain about 0.7 km west of the eastern fault. According to Wilson (1975 #5721) and Wilson and others (1979 #5663), the scarps of these faults influenced the formation and depositional history of a small lake and intermittent ponds that are located directly west of the faults. Haugerud and others (2003 #6211) report that LiDAR topography indicates that the scarps of the Saddle Mountains faults are more numerous than previously recognized. In this LiDAR topography, the 10-km-long, en echelon, Frigid Creek scarps cut across Holocene alluvial fans in a zone that extends southwest

	from Price Lake and Saddle Mountain (Haugerud and others, 2003 #6211).
Age of faulted surficial deposits	Wilson (1975 #5721) mapped the area surrounding the Saddle Mountain faults, conducted detailed studies of trenches across the faults, and obtained radiocarbon dates from organic material in colluvium along scarps and sediment in ponds west of the faults. Based on these studies they reported evidence that indicate offsets of pre-Fraser till (pre-15-ka deposits) and linear features in Fraser-age till (post-15-ka deposits) that imply offset of these deposits as well. Similarly, these faults are shown cutting Fraser-age till on the 1:250,000-scale geologic map by Dragovich and others (2002 #5715). Wilson (1975 #5721) and Wilson and others (1979 #5663) also reported radiocarbon ages from colluvium along the eastern fault and from deposits in the ponds west of the faults that suggest one or more faulting events considerably younger than the youngest faulted glacial deposits. Based on recently acquired LiDAR topography, Haugerud and others (2003 #6211) report that en echelon scarps extend 10 km southwest of Price Lake and Saddle Mountain and cut across Holocene alluvial fans.
Historic earthquake	
Most recent prehistoric deformation	latest Quaternary (<15 ka) *Comments:* Stratigraphic and structural relations and radiocarbon ages from trenching of the Saddle Mountain deformation zone and from sediment in Price Lake, and from intermittent ponds, indicate one or more Holocene coseismic surface ruptures. Barnett and others (2015 #7646) combine radiocarbon dating from trenches and sediment core to constrain the maximum age of the most recent rupture on the Saddle Mountain East fault to 1,180–940 cal B.P. and the data permit simultaneous rupture of the Sund Creek fault and the Saddle Mountain East fault.
Recurrence interval	*Comments:* Although evidence at Cargill, Banana Slug, Alligator Lizard and Price Lake suggest simultaneous rupture in the most recent earthquake, current data suggest earlier events are isolated on individual faults (Barnett and others, 2015 #7646) although the resulting single-event intervals are a few thousands of years. Saddle Mountain East fault shows evidence of a single postglacial earthquake, whereas Saddle Mountain West fault shows evidence of two earthquakes. The Sund Creek fault may have participated in an earlier earthquake than those that ruptured the Saddle Mountain west fault.

Slip-rate category	Between 0.2 and 1.0 mm/yr *Comments:* Deformation rates are poorly constrained because most of the trenches exposed evidence of only one post-glacial event. In addition, Witter and others (2008 #7648) contend that unrecognized lateral displacement may be equivalent to the amount of observed reverse movement implied by scarp height. Both Witter and others (2008 #7648) and Barnett and others (2015 #7646) provide maximum vertical displacement rates based on time that has elapsed since the earthquake.. Vertical displacement up to 3.5 m of Vashon till (13-15 ka) suggest a latest Quaternary rate that would fall in the 0.2-1 mm/yr slip-rate category.
Date and Compiler(s)	2016 David J. Lidke, U.S. Geological Survey Kathleen M. Haller, U.S. Geological Survey Elizabeth A. Barnett, Shannon & Wilson, Inc.
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