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Sisters fault zone (Class A) No. 852

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Synopsis	The Sisters fault zone is comprised of numerous, northeast- and southwest-dipping, northwest-striking normal faults that offset Miocene to upper Pleistocene volcanic rocks and sediments along the eastern margin of the Cascade Range in central Oregon. The structural setting of the Sisters fault zone is open to interpretation, but it probably is a structural transition zone between the northwest-trending, right-lateral (?) Brothers fault zone [819] and the more northerly trending parts of the Metolius normal fault zone [853]. Most of the fault strands that comprise the Sisters fault zone have latest displacements in the middle and late Quaternary, but two fault strands north of Tumalo may offset glacial outwash deposits and thus may have been active in the late Quaternary.
Name comments	Numerous northwest-trending fault strands are included in the Sisters fault zone (Hawkins and others, 1988 #2946, 1989 #2947),

	a broad zone of apparent normal faults that extend from southeast of Bend to northeast of Sisters in central Oregon (Lawrence, 1976 #3506; Peterson and others, 1976 #3735; U.S. Army Corps of Engineers, 1983 #3484; Hawkins and others, 1988 #2946; Geomatrix Consultants Inc., 1990 #3550; 1995 #3593; Ake and others, 2001 #5035; Sherrod and others, 2004 #5172); the Bend area faults of Wellik (2008 #7383) are included as the southern extension of the Sister fault herein. The fault zone was included in the Oregon-Nevada lineament of Stewart and others (1975 #3769). We follow Hawkins and others (1988 #2946) and Ake and others (2001 #5035) by including the nearby, subparallel Green Ridge, Black Butte, Rimrock, and Tumalo faults and the Northwest Rift Zone in a separate structure, the Metolius fault zone [853]. The only informally or formally named fault in our restricted Sisters fault zone is the Skeleton Cave fault of Hawkins and others (1988 #2946). **Fault ID:** This zone is fault number 23 of Pezzopane (1993 #3544), fault number 45 of Geomatrix Consultants, Inc. (1995 #3593), and S1–S of Wellik (2008 #7383).
County(s) and State(s)	DESCHUTES COUNTY, OREGON
Physiographic province(s)	COLUMBIA PLATEAU
Reliability of location	Good Compiled at 1:24,000 scale. *Comments:* Fault traces are from mapping of Wellik (2008 #7383)
Geologic setting	The Sisters fault zone is comprised of numerous northeast- and southwest-dipping, northwest-trending normal faults (Lawrence, 1976 #3506; Peterson and others, 1976 #3735; Walker and Nolf, 1981 #4310; 1981 #4311; U.S. Army Corps of Engineers, 1983 #3484; Hawkins and others, 1988 #2946; Geomatrix Consultants Inc., 1990 #3550; Walker and MacLeod, 1991 #3646; 1995 #3593; Ake and others, 2001 #5035; Sherrod and others, 2004 #5172; Wellik, 2008 #7383) that offset volcanic and sedimentary rocks along the eastern margin of the Cascade Range in central Oregon. Individual faults are closely associated with cinder cones (Wellik, 2008 #7383) and cumulative vertical displacement across the entire zone is likely 20 m (Geomatrix Consultants Inc., 1990 #3550). The structural setting of the Sisters fault zone is open to

	interpretation (Sherrod and others, 2004 #5172): the fault zone may form part of the eastern boundary of the Cascades graben (Taylor, 1981 #4306; 1981 #4307; Sherrod and Smith, 2000 #5165), it may be the surface expression of a right-lateral strike-slip fault system (Walker, 1969 #4296; Stewart and others, 1975 #3769; Lawrence, 1976 #3506; Walker and Nolf, 1981 #4310; 1981 #4311; U.S. Army Corps of Engineers, 1983 #3484), or it may be the northwestern apex of Basin and Range faulting in Oregon (Lawrence, 1976 #3506). Perhaps most likely, the Sisters fault zone may be a structural transition zone between the northwest-trending Brothers fault zone [819] and the more northerly trending parts of the Metolius normal fault zone [853] (Lawrence, 1976 #3506; Hawkins and others, 1988 #2946). The width and distributed nature of the fault zone also suggests that it may in part be of volcanic origin (Ake and others, 2001 #5035).
Length (km)	52 km.
Average strike	N26°W
Sense of movement	Normal, Left lateral *Comments:* The numerous fault strands in the Sisters fault zone are mapped as high angle or normal faults by most workers (Peterson and others, 1976 #3735; Walker and Nolf, 1981 #4310; 1981 #4311; U.S. Army Corps of Engineers, 1983 #3484; Walker and MacLeod, 1991 #3646; Pezzopane, 1993 #3544; Sherrod and Smith, 2000 #5165; Sherrod and others, 2004 #5172; Wellik, 2008 #7383), but if these faults are part of a regional-scale strike-slip fault system (Walker, 1969 #4296; Stewart and others, 1975 #3769; Lawrence, 1976 #3506; Peterson and others, 1976 #3735; Walker and Nolf, 1981 #4310; 1981 #4311; U.S. Army Corps of Engineers, 1983 #3485), then some oblique slip may also be present (Geomatrix Consultants Inc., 1995 #3593); however, the most detailed study concludes there is no evidence of lateral displacement Wellik (2008 #7383). Horizontal slickensides apparent in an exposure of one strand of the Sisters fault zone north of Tumalo State Park (stop one of Taylor, 1981 #4307) indicate that some fault strands in the Sisters fault zone have undergone strike-slip displacement (U.S. Army Corps of Engineers, 1983 #3484). Hemphill-Haley (2001 #5036) used fault patterns to infer a left-lateral component of slip on one fault trace north of Tumalo.

Dip Direction	NE; SW *Comments:* No detailed information on fault dip is available, but several workers refer to vertical or steeply dipping fault exposures and scarps along the Sisters fault (U.S. Army Corps of Engineers, 1983 #3484; Hawkins and others, 1988 #2946; Geomatrix Consultants Inc., 1995 #3593; Ake and others, 2001 #5035; Hemphill-Haley, 2001 #5036; Sherrod and others, 2002 #5169; Wellik, 2008 #7383). Such dips are consistent with a strike-slip or significant oblique sense of slip.
Paleoseismology studies	Two subsurface investigations have been published on fault strands of the Sisters fault zone. Hawkins and others (locality 852-1, Hawkins and others, 1988 #2946) investigated the Sisters fault zone as part of a seismotectonic investigation for nearby Arthur R. Bowman and Ochoco dams operated by the U.S. Bureau of Reclamation. Mark Hemphill-Haley (locality 852-2, Hemphill-Haley, 2001 #5036; Wellik, 2008 #7383) investigated a second location on the Sisters fault zone near Tumalo. Site 852-1: Hawkins and others (1988 #2946) excavated a 20-m-long, 2.9-m-deep trench about 15 km southeast of Bend across a 6-km-long fault strand they informally named the Skeleton Cave fault. This strand is the southeasternmost fault in the Sisters fault zone. The Skeleton Cave fault scarp is 5 to 30 m high, and is developed in basalt mapped as middle to late Pleistocene in age (MacLeod and others, 1995 #3557). However, Hawkins and others (1988 #2946) obtained a K-Ar age of 2.7±0.3 Ma at a nearby site on basalt from the youngest flow offset by the Skeleton Cave fault, so the age of offset deposits is open to question. The trench was sited in a location where Quaternary surficial deposits are ponded against the basalt-armored fault scarp; preliminary drilling had shown that these sediments were well stratified and contained pumicious tephra layers. Unfortunately, buried basalt boulders at the base of the scarp prevented excavation closer than 8 m to the edge of the fault scarp, so the fault zone could not be exposed in the trench. Hawkins and others (1988 #2946) concluded that significant scarp retreat had occurred along the Skeleton Cave fault strand, but could make no other inferences about fault history. Site 852-2: A 3.5-m-deep trench located about 2 km north of Tumalo, across a <3.5-km-long fault strand of the Sisters fault zone revealed possible evidence of multiple faulting events

	(Hemphill-Haley, 2001 #5036; Wellik, 2008 #7383). The fault strand forms scarps >10 m high in late Miocene basalt, and smaller scarps in Pleistocene outwash deposits. The scarp is characterized by anastomosing and en echelon traces suggestive of left-lateral as well as vertical displacement, but the ratio of lateral to vertical slip could not be determined. The trench was located across a relatively simple, 2-m-high east-facing scarp formed in Pleistocene outwash sands and gravels and exposed several units of unconsolidated sand and gravel displaced by a broad zone of near-vertical faults with down-east displacement directions. Hemphill-Haley (2001 #5036) interpreted at least two surface-rupturing events, each with about 1 m of vertical and an unknown amount of horizontal displacement. The timing of both events is unconstrained because datable materials were not recognized. However, the youngest faulted deposit has a well-developed Bt horizon suggesting the deposit is much as 100 k.y. old.
Geomorphic expression	The Sisters fault zone consists of numerous northeast- and southwest-dipping, northwest trending fault strands in relatively flat-lying late Tertiary and Quaternary volcanic rocks; the faults are marked by 2- to 30-m-high colluvium-mantled scarps (U.S. Army Corps of Engineers, 1983 #3484; Hawkins and others, 1988 #2946; Geomatrix Consultants Inc., 1995 #3593; Ake and others, 2001 #5035; Sherrod and others, 2002 #5169; Sherrod and others, 2004 #5172; Wellik, 2008 #7383). Mapped faults are generally less than 20 km long but the longest is 33 km long (Wellik, 2008 #7383). Some near-vertical scarps probably owe their fresh appearance to vertical jointing in and resistance to erosion of the underlying basalt bedrock (Hawkins and others, 1988 #2946). Weldon and others (2002 #5648) observed lineaments across Quaternary deposits on 1:100,000-scale DEMs of the area. According to Wellik (2008 #7383) the Sisters fault zone and Bend area faults are comprised of 28 faults, splays and lineaments ranging in length from 25 km to less than 1 km and observed vertical surface separations a vary, from several meters to tens of meters along strike. Fault S3 does not displace young alluvium deposited along the Deschutes River near Tumalo, but late Quaternary sand is offset approximately 2 m and the Tertiary Deschutes Formation is offset approximately 5 m. Similarly, fault S9 displaces the late Quaternary sand less than 1 m and Tertiary deposits are displaced approximately 5 m.

Age of faulted surficial deposits	The numerous fault strands that comprise the Sisters fault zone primarily offset Miocene to upper Pleistocene basalts and tuffs (Walker and MacLeod, 1991 #3646; MacLeod and others, 1995 #3557; Sherrod and Smith, 2000 #5165; Sherrod and others, 2004 #5172). Offset Quaternary surficial deposits are reported based on detailed mapping (Wellik, 2008 #7383). Sherrod and others (2002 #5169) describe a quarry exposure of one strand of the Sisters fault zone southwest of Tumalo that showed <4 of down-to-the-northeast displacement of the Bend Pumice, 0.4 Ma Tumalo Tuff, and an overlying undated gravel deposit.
Historic earthquake	
Most recent prehistoric deformation	late Quaternary (<130 ka) *Comments:* Most of the fault strands in the Sisters fault zone offset middle to upper Pleistocene (10–760 k.y.) basalts related to Newberry volcano (MacLeod and others, 1995 #3557; Sherrod and Smith, 2000 #5165; Sherrod and others, 2002 #5169; Sherrod and others, 2004 #5172), and thus have been mapped with middle or late Quaternary (700–780 k.y.) displacements by Pezzopane (1993 #3544) and subsequent compilations (Geomatrix Consultants Inc., 1995 #3593; Madin and Mabey, 1996 #3575; Weldon and others, 2002 #5648). Two fault strands north of Tumalo offset glacial outwash deposits and thus have been interpreted as active in the latest Quaternary (Nakata and others, 1992 #3524; Pezzopane, 1993 #3544; Geomatrix Consultants Inc., 1995 #3593); mapping by Wellik (2008 #7383) has identified additional faults active in the late Quaternary, which supports evidence from a trench that suggests the youngest faulted deposits may be as old as 100 ka (Ake and others, 2001 #5035; Hemphill-Haley, 2001 #5036; Wellik, 2008 #7383). Holocene deposits containing Mazama ash are not faulted (Wellik, 2008 #7383).
Recurrence interval	
Slip-rate category	Less than 0.2 mm/yr *Comments:* Data from Hawkins and others (1988 #2946) indicate a vertical displacement of 40 m of 2.7±0.3 Ma basalts across an individual fault strand in the Sisters fault zone; these data yield a vertical displacement rate of about 0.01 mm/yr, which Geomatrix Consultants, Inc. (1995 #3593) applied to the Sisters fault zone.

	Geomatrix Consultants, Inc. (1995) also used data from MacLeod and others (1982 #3722) near the southern end of the Sisters fault zone (12–15 m of vertical displacement of 120–730 k.y. basalts) to calculate somewhat higher vertical displacement rates of 0.02–0.1 mm/yr. Hemphill-Haley (2001 #5036) measured 2 m of vertical displacement in deposits that may be as old as 100 ka on one strand of the fault near Tumalo and Wellik (2008 #7383) documents vertical offset on a number of geologic units. No estimates of lateral displacement have been determined nor has displacement across the zone been addressed.
Date and Compiler(s)	2016 Stephen F. Personius, U.S. Geological Survey Kathleen M. Haller, U.S. Geological Survey
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