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Steens fault zone, Alvord section (Class A) No. 856c

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Synopsis	**General:** The nearly 200-km-long Steens fault zone is the most topographically prominent normal fault system in the northern Basin and Range province of western North America. The fault separates the eastern flanks of Steens Mountain and the Pueblo Mountains from the western margins of the Alvord Desert and Pueblo Valley in southern Oregon and northern Nevada. Steens Mountain and the Pueblo Mountains are west-tilted fault blocks comprised of Miocene volcanic rocks, whereas the adjacent Alvord Desert and Pueblo Valley are structural basins filled with thousands of meters of Tertiary-Quaternary sedimentary fill. **Sections:** This fault has 6 sections. Although detailed studies along the entire fault zone have not been reported, six sections are inferred based on geometry and timing of most-recent surface faulting at selected sites (but not on all sections) along the zone.

	Hemphill-Haley and others (1999 #4038) proposed that the Steens fault zone in Oregon be divided into five segments. Herein we retain the five segment names delineated by Hemphill-Haley and others (1999 #4038) as section names, and add a sixth, northernmost section based on mapping of Pezzopane (1993 #3544). From north to south, these sections are the Crowley [856a], Mann Lake [856b], Alvord [856c], Fields [856d], Tum Tum [856e], and Denio [856f] sections. At the north end of the zone, faults in the Crowley section [856a] offset Miocene volcanic rocks a few hundred meters, and may have moved as recently as the middle and late Quaternary. Faults in the adjacent Mann Lake section [856b] offset Miocene volcanic rock a minimum of 1600 m, and also may have moved as recently as the middle and late Quaternary. The adjacent Alvord section [856c] forms the steep eastern flank of the High Steens, and has offset Miocene volcanic rock 2–4 km. Trench and fault scarp investigations indicate one or more Holocene surface-faulting events along the Alvord section, so both the long-term (Miocene) and Quaternary slip histories indicate that this section is the most active part of the Steens fault zone. Slip apparently decreases south of the Alvord section. Faults in the adjacent Fields section [856d] offset Miocene volcanic rock a minimum of 1400 m, and show their youngest movement (latest Quaternary) on short faults that lie on the playa east of the range front. Faults in the Tum Tum section [856e] appear to be slightly older than the youngest movement on the playa strands of the Fields section [856d], but are younger than the latest movement on the range front strand of the Fields [856d] and Mann Lake [856b] sections. Trenching of the fault in the Denio section [856d], which is the southernmost part of the Steens Mountain fault zone, clearly demonstrates Holocene movement.
Name comments	**General:** The Steens fault zone forms a steep escarpment between the uplifted Steens Mountain and Pueblo Mountains, and the western margin of Pueblo Valley and the Alvord Desert. These faults have been mapped by Willden (1964 #3002), Slemmons (1966, unpublished Vya 1:250,000-scale sheet), Greene (1972 #3560), Walker and Repenning (1965 #3559), Brown and Peterson (1980 #3585), Hemphill-Haley (1987 #3960), Walker and MacLeod (1991 #3646), Dohrenwend and Moring (1991 #281), Pezzopane (1993 #3544), Madin and others (1996 #3479), Weldon and others (2002 #5144), and Personius and others (2006 #7386). The fault zone includes faults mapped as the Alvord-Steens fault zone of Pezzopane (1993 #3544) and Pezzopane and Weldon (1993 #149), and the Steens fault, Alvord Desert graben,

	and Pueblo Mountain faults of Pezzopane (1993 #3544). Geomatrix Consultants, Inc. (1995 #3593) used the name Steens-Alvord Graben faults for all structures in the Alvord Desert area, and delineated three fault source zones: the northern segment, the Western Margin fault zone, and the East Alvord graben fault. The Steens fault zone extends into northern Nevada as the Pueblo Mountains fault zone of dePolo (1998 #2845). Hemphill-Haley (1987 #3960) named several small structures in the zone (Alvord, Dune Field, Embayment, Kueny Ditch, Serrano Point, Serrano Springs, Smyth Wells, and Wildhorse Creek faults), and included them in a larger Steens fault zone. Hemphill-Haley and others (1989 #3958, 1999 #4038) later proposed that the Steens fault zone be divided into five segments. Herein we retain the name Steens fault zone for the entire structure in Oregon and Nevada, and use the five segment names delineated by Hemphill-Haley and others (1999 #4038) as section names. A sixth, northernmost section is informally defined herein on the basis of mapping by Pezzopane (1993 #3544) and Weldon and others (2002 #5144). **Section:** This section was informally named the Alvord segment by Hemphill-Haley and others (1989 #3958, 1999 #4038) after the Alvord Desert, the large, deep basin formed in the hanging wall of the fault zone. The Alvord segment of Hemphill-Haley and others (1989 #3958, 1999 #4038) consists of the Alvord, Dune Field, Embayment, Kueny Ditch, Serrano Point, Serrano Springs, Smyth Wells, and Wildhorse Creek faults of Hemphill-Haley (1987 #3960). Geomatrix Consultants, Inc. (1995 #3593) included the Alvord segment of Hemphill-Haley and others (1989 #3958, 1999 #4038) in their West Margin fault zone. Oldow and Singleton (2008 #7384) identify several strands of the fault in their study that include the Serrano fault, West Alvord fault, Alvord fault, and the East Alvord fault. **Fault ID:** These structures are fault numbers 47, 48, and 49 of Pezzopane (1993 #3544), fault number 62 of Geomatrix Consultants, Inc. (1995 #3593), and fault number V9 of dePolo (1998 #2845).
County(s) and State(s)	HARNEY COUNTY, OREGON
Physiographic province(s)	BASIN AND RANGE
Reliability of location	Good Compiled at 1:100,000 scale.

	Comments: Fault locations are simplified from 1:24,000-scale mapping of Hemphill-Haley (1987 #3960) (reprinted at about 1:70,000 scale in Narwold, 1999 #4045) for the southern part of the section, and are from 1:100,000-scale mapping of Weldon and others (2002 #5648), based on 1:500,000-scale mapping of Pezzopane (1993 #3544), for the northern part of the section.
Geologic setting	The Steens fault zone is marked by nearly continuous range-bounding faults on the east side of the Pueblo Mountains and Steens Mountain. The fault zone extends from near Crowley, Oregon, to the southern end of Bog Hot Valley in northern Nevada. The Pueblo Mountains and Steens Mountain are major west-tilted fault blocks (Stewart, 1978 #2866); the adjacent Alvord Desert and Pueblo Valley are structural basins (grabens) filled with 1–2.5 km of Tertiary-Quaternary sedimentary fill (Cleary and others, 1981 #7385, 1981 #5649; Oldow and others, 2005 #7388). The region is underlain by Miocene volcanic rocks, primarily the Steens Basalt (Willden, 1964 #3002; Walker and Repenning, 1965 #3559; Greene and others, 1972 #3560; Brown and Peterson, 1980 #3585; Minor and others, 1987 #3746; Minor and others, 1987 #3747; Walker and MacLeod, 1991 #3646). The Steens fault zone is the longest, most prominent normal fault zone in the Basin and Range province of eastern Oregon, and appears to truncate the southeastern end of the northwest-trending Brothers fault zone (Lawrence, 1976 #3506). Total Miocene vertical displacement of 1.75±0.25 km is reported for a location near Baltazor Hot Spring (Personius and others, 2007 #7387), and Brown and Peterson (1980 #3585) estimated offsets of 2,100–3,000 m in Miocene rocks at the southern end of the Alvord section.
Length (km)	This section is 36 km of a total fault length of 197 km.
Average strike	N1°E (for section) versus N12°E (for whole fault)
Sense of movement	Normal *Comments:* Faults in this section are mapped as normal or high-angle faults by Walker and Repenning (1965 #3559), Brown and Peterson (1980 #3585), Greene (1972 #3560), Walker and MacLeod (1991 #3646), Pezzopane (1993 #3544), Hemphill-Haley (1987 #3960), and Hemphill-Haley and others (1989 #3958, 1999 #4038). Hemphill-Haley and others (1989 #3958, 1999 #4038) could not rule out a component of lateral slip in their

	Dust Bowl trench exposure.
Dip	72° E. *Comments:* Dip measurement is from the Bath House trench exposure of a fault plane in late Quaternary lacustrine deposits (Hemphill-Haley and others, 1989 #3958, 1999 #4038).
Paleoseismology studies	Hemphill-Haley and others (1989 #3958, 1999 #4038, 2000 #3959) conducted trench investigations at two sites along the Alvord section. They described evidence of Holocene displacement at both locations. Site 856-1. The Bath House or Hot Springs trench (named after the nearby Alvord hot springs) was excavated across a 2.5-m-high scarp developed on intermediate-aged lacustrine and alluvial deposits (Hemphill-Haley and others, 1989 #3958, 1999 #4038, 2000 #3959). A distinctive debris-flow deposit exposed in both the footwall and hanging wall indicates about 2 m of vertical displacement and additional 1.5 m of warping, for a total apparent vertical displacement of 3.5 m. A single unequivocal colluvial wedge deposit was exposed near the top of the exposure, but a folded and tilted debris-flow (Hemphill-Haley and others, 1989 #3958, 1999 #4038) or colluvial-wedge (Hemphill-Haley and others, 2000 #3959) deposit at the bottom of the hanging wall exposure may be evidence of an additional faulting event. A small piece of detrital charcoal from the base of the upper colluvial wedge yielded a conventional radiocarbon age of 8,190±2,240 yr BP (6,800 to 12,300 cal yr BP), and a second small piece of detrital charcoal from the upper part of the colluvial wedge yielded a conventional radiocarbon age of 470±350 yr BP (250 to 720 cal yr BP). The older sample yields a maximum-limiting age and the younger sample yields a minimum-limiting age for the most-recent event exposed in the Bath House trench (Hemphill-Haley and others, 1989 #3958, 1999 #4038). Site 856-2. The Dust Bowl or Dune/Playa trench was excavated across a 1.1-m-high scarp developed on sand dune and lacustrine deposits (Hemphill-Haley and others, 1989 #3958, 1999 #4038, 2000 #3959). The trench exposed about 2 m of lacustrine silt, sand, and clay beds and minor dune sand; none of these deposits could be correlated across the fault. In the hanging wall, three packages of lacustrine sediment were separated by two angular unconformities. No radiocarbon ages were obtained from this

	trench, but the oldest lacustrine package contained the Mount St. Helens Sg ash, which has bracketing radiocarbon ages of 12–13 ka (Mullineaux, 1986 #3773), and the middle lacustrine package contained an undated mixed ash. A single, near vertical fault plane was exposed in the trench, but no fault-scarp colluvial deposits were identified. Hemphill-Haley and others (1989 #3958, 1999 #4038, 2000 #3959) interpreted two or three faulting events in the last 11–13 ka, based on the presence of the two angular unconformities; the youngest event caused the near-vertical fault zone and the 1.1-m-high fault scarp. The Dust Bowl trench apparently exposes evidence for more events and less displacement than at the Bath House trench. The reduced amounts of displacement may be attributable to the location of the Dust Bowl trench near the end of the Alvord segment; the larger number of events may reflect older sediments in the Dust Bowl trench, and this location may record a more complex fault history due to its proximity to the nearby Fields segment (Hemphill-Haley and others, 1989 #3958, 1999 #4038). The focus of investigation at site 856-4 addresses reconstruction of shorelines that rim the basin that formed during late Quaternary pluvial conditions resulting in displacement data for faults in the basin. Oldow and Singleton (2008 #7384) refer to two sets of faults on Serrano Point and their informally named Alvord point. The study relies on Terrestrial Laser Scanning that is geospatially referenced by the Global Positioning System to produce high-resolution images. The variation in shoreline altitude measured across faults and on opposing sides of the basin result in cumulative offset across the basin. The Serrano terrace highstand, which is inferred to correlate to marine oxygen-isotope stage 6, is vertically offset a total of 137.5±3.6 m based on summation of vertical reconstruction offsets, of which 52 m is directly measured across exposed faults. Total vertical displacement of the younger Alvord terrace series highstand (stage 2) is 72.5±2.8 m, of which 29.5 m is directly measured across exposed faults.
Geomorphic expression	Faults in the Alvord section form a steep north-trending range front escarpment between the eastern margin of the "High Steens" part of Steens Mountain, and the Alvord Desert (Hemphill-Haley and others, 1989 #3958, 1999 #4038). The northern part of the section is marked by a single, nearly continuous 1.4- to 2.5-m-high fault scarp on late Quaternary surficial deposits; the southern part of the section branches into several splays of various orientations at Serrano and Alvord Points, and eventually dies out

	on the floor of the Alvord Desert playa (Hemphill-Haley, 1987 #3960; Hemphill-Haley and others, 1989 #3958, 1999 #4038, 2000 #3959). The Alvord section is separated from the Mann Lake section to the north by a 2-km-wide left step in the range front, and overlaps and is separated from the Fields section to the south by a 5-km-wide right step in the range front.
Age of faulted surficial deposits	Hemphill-Haley (1987 #3960), and Hemphill-Haley and others (1989 #3958, 1999 #4038, 2000 #3959) report offsets in Holocene surficial deposits along most of the length of the Alvord section.
Historic earthquake	
Most recent prehistoric deformation	latest Quaternary (<15 ka) *Comments:* Hemphill-Haley and others (1989 #3958, 1999 #4038, 2000 #3959) used trench data described above and fault-scarp degradation analysis to infer a Holocene (possibly middle or late Holocene) age for the most-recent event on the Alvord section. Pezzopane (1993 #3544), Madin and others (1996 #3479), and Weldon and others (2002 #5648), also infer that latest movement on faults in the Alvord section occurred in the Holocene.
Recurrence interval	*Comments:* Oldow and Singleton (2008 #7384) conclude the rate of fault displacement was nonperiodic and the basin underwent elevated activity in the late Pleistocene and early Holocene; they report earthquake recurrence on individual faults that varies from 100–500 yr to 9,000 yr resulting in an aggregate return time of earthquakes in the study area of 150–550 yr. Recurrence data from the studies of Hemphill-Haley and others (1989 #3958, 1999 #4038, 2000 #3959) are somewhat contradictory. Evidence from the Dust Bowl trench suggests two or three events that post-date the 11–13 ka age of sediments containing the Mount St. Helens Sg ash. However, Hemphill-Haley and others (1989 #3958, 1999 #4038) also use the presence of similar-sized fault scarps in late Quaternary and older Pleistocene alluvial-fan deposits to suggest recurrence intervals of tens of thousands of years on the northern part of the section.
Slip-rate category	Between 0.2 and 1.0 mm/yr *Comments:* Vertical displacement rates presented by Oldow and

	Singleton (2008 #7384) vary through time. Offset of 15- to 20-ka Alvord terraces occurred at 3.6–7.3 mm/yr based on cumulative offset of 72.5±2.8 m, whereas displacement of the 130- to 200-ka Serrano terraces ranges from 0.7–1.1 mm/yr based on cumulative offset of 137.5 ±3.6 m. Hemphill-Haley (1987 #3960), and Hemphill-Haley and others (1989 #3958, 1999 #4038) report a long-term (Miocene) slip rate of 0.3–0.4 mm/yr across the Alvord section. Assigned slip rate category is based on the similar long-term vertical displacement rates even though horizontal rates derived by Oldow and Singleton (2008 #7384) are up to 4.2 mm/yr, which exceed those suggested by geodetic modeling.
Date and Compiler(s)	2016 Stephen F. Personius, U.S. Geological Survey Kathleen M. Haller, U.S. Geological Survey
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