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Quaternary Fault and Fold Database of the United States

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Cheraw fault (Class A) No. 2330

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Compiled in cooperation with the Colorado Geological Survey

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Synopsis	The Cheraw fault was originally mapped by Sharps (1976 #2741) as part of a regional geologic mapping program (1:250,000 scale). Scott (1970 #1141) first suggested that the fault might be a potential source of earthquakes, but despite Scott's suggestion, no detailed studies of the fault were conducted during the next two decades. In 1994, Crone and others (1997 #2680) excavated a trench across the scarp, documented a record of late Quaternary surface ruptures on the fault, and confirmed the fault as a potential source of future strong earthquakes. This documentation establishes the Cheraw fault as only the second confirmed late Quaternary surface-rupturing fault in the stable continental region of the west-central United States. The other is the Meers fault

	[1031] in Oklahoma.
Name comments	The Cheraw fault was first recognized during regional geologic mapping in the late 1960s and 1970s (Sharps, 1976 #2741), but was not formally named until Kirkham and Rogers (1981 #792) named it for the small town of Cheraw, Colorado, which is located about 10 km south of the scarp. **Fault ID:** Fault 173 in Kirkham and Rogers (1981 #792), fault 156 in Witkind (1976 #2792), and fault number Q80 of Widman and others (1998 #3441).
County(s) and State(s)	KIOWA COUNTY, COLORADO CROWLEY COUNTY, COLORADO OTERO COUNTY, COLORADO
Physiographic province(s)	GREAT PLAINS
Reliability of location	Good Compiled at 1:24,000 scale. *Comments:* The fault was previously mapped at 1:250,000 scale by Sharp (1976 #2741) and Scott and others (1978 #2735). The trace herein is from 1:24,000-scale mapping (Crone and others, 1997 #2680; figure 2) further constrained by satellite imagery and topography at scale of 1:50,000. Reference satellite imagery is ESRI_Imagery_World_2D with a minimum viewing distance of 1 km (1000 m). Zellman and Ostenaa (2014 #7284) suggest a 15-km-long unmapped extension of the fault extends to the northeast; the extension is not included as it is not currently shown on a published map. Along much of its trace, the fault is conspicuous because of its down-to-the-northwest sense of throw that opposes the southeasterly regional slope. This sense of motion results in overland flow that forms local ponds against the scarp and enhances vegetation adjacent to the scarp (the region has a semi-arid climate, and vegetation is sparse). The increase in the density of vegetation along the scarp makes it a distinctive feature that is relatively easy to map on aerial photographs.
Geologic setting	The Cheraw fault is on the High Plains of southeastern Colorado, about 100 km east of Pueblo, and about 140 km east of the range front of the Rocky Mountains (Crone and others, 1997 #2680). Structurally, the fault is located above the west-northwesterly sloping basement surface between the north-trending Las Animas

arch to the east and the Denver basin to the northwest (Curtis, 1988 #2682); accordingly, the fault lies on the western side of the arch and along the southeastern margin of the basin. The down-to-the-northwest sense of motion that occurred during late Quaternary faulting events has the same vertical sense as the cumulative tectonic relief on the Precambrian crystalline rocks. The Las Animas arch is a prominent, but relatively low-relief, 300-km-long, positive structural element in southeastern Colorado. The crest of the arch is approximately 20-40 km east of the fault. Minor uplift probably occurred along the arch in late Paleozoic time, but most of the present structural relief formed in Laramide time when the gentle westward slope on the western side of the arch developed as a result of downwarping of the Denver basin (Curtis, 1988 #2682). As the basin subsided, Cretaceous rocks were tilted westward from their original eastward-sloping depositional gradient. There is little evidence that throw on the fault has substantially offset the bedrock (only tens of meters is demonstrable), thus the fault does not appear to have a long history of recurrent movement. For example, the cumulative throw on the fault is less than the thickness of the Smoky Hill Shale Member (150 to 215 m thick), because neither the Fort Hays Limestone Member nor the Pierre Shale (all upper Cretaceous), which are stratigraphically below and above the Smoky Hill Shale Member, respectively, are exposed along the fault.

As part of his regional mapping, Sharps (1976 #2741) drew a structure-contour map on the top of the lower Cretaceous Dakota Sandstone. The subsurface control for the structure contours is sparse, and the elevation control suggests that the contours could contain a significant amount of uncertainty. Nevertheless, a direct interpretation of the contours indicates about 6 to 8 m of down-to-the-northwest throw on the fault, which is comparable with the amount of throw on early Quaternary alluvial deposits elsewhere along the fault. The Cheraw fault disrupts the gradual westward gradient of Cretaceous rock that rises up onto the arch; immediately east of the fault, these rocks have a gradient of about 5 m/km, and west of the fault they have a gradient of about 8 m/km. Even if the cumulative offset of Cretaceous rocks is four or five times greater than the estimated 6 to 8 m, the average Neogene slip rate on the fault is very low, and the fault could not have a long history of movement at rates comparable to the latest Pleistocene rate.

Length (km)	45 km.
Average strike	N44°E
Sense of movement	Normal *Comments:* The sense of motion on the fault is not well known, but is inferred to be down-to-the-northwest motion on a normal fault based on the attitude of near surface faults exposed in the trench across the scarp (Crone and others, 1997 #2680).
Dip	66° NW *Comments:* Reported dip is based on the average dip of the main fault as mapped by Crone and others (1997 #2680) in the trench across the fault. This 3- to 4-m-deep trench provided the only known exposure of the fault.
Paleoseismology studies	Abandoned Ranch site (2330-1). The only detailed paleoseismic study of the fault is that of Crone and others (1997 #2680). In that study, they excavated a 110-m-long trench across a 3.6-m-high scarp southeast of an abandoned ranch and reported evidence of two latest Pleistocene faulting events and an early Holocene event. The timing of these events was constrained by one radiocarbon age on charcoal fragments, four radiocarbon ages on soil organic concentrates, and nine thermoluminescence (TL) age estimates. The trench exposed Cretaceous Smoky Hill Shale bedrock in the footwall of the fault, but only exposed a mixture of scarp-derived colluvium and paludal deposits on the hanging wall side. Within the colluvial sequence, there is clear evidence of three events, including faulted organic-rich soil A horizons. The timing of the latest Pleistocene events, which are listed in the following section, raises the possibility that the surface-faulting events have as a temporal cluster. The latest Pleistocene deposits at the trench site described by Crone and others (1997 #2680) were deposited in a low-gradient paleo-stream channel that was cut into Cretaceous shale. The length of time required to cut and widen this channel through older Pleistocene alluvial deposits and into the bedrock is thought to be on the order of 100,000 years or longer. The cumulative vertical offset on the Pleistocene erosional surface cut on the Cretaceous shale is 3.2 to 4.1 m, which represents the total offset from the three post-latest Quaternary (<25 ka) events. In contrast, lower Pleistocene Rocky Flats Alluvium, which has an estimated age of about 1.2 Ma, is only

	offset about 7 to 8 m by the fault. Thus, the frequency of surface-faulting earthquakes that occurred in latest Quaternary time (past 25 k.y.), could not have been sustained throughout all of the Pleistocene because the scarp on the Rocky Flats Alluvium would be more than 100 m high.
Geomorphic expression	In his regional mapping, Sharps (1976 #2741) showed the fault as approximately located where it crosses the upper Cretaceous Smoky Hill Shale Member of the Niobrara Formation, and showed it as inferred or concealed where it crosses lower Pleistocene Rocky Flats Alluvium and middle (?) Pleistocene Verdos Alluvium. Kirkham and Rogers (1981 #792) reported that vegetation changes, linear ponds, breccia, and perhaps tectonically blocked stream channels were associated with the weathered, but distinct scarp. Unruh and others (1994 #2778) recognized topographic scarps 3-4 m high, vegetation lineaments, sinkholes, and ponded sediments. Locally, the fault forms a rounded, but distinct scarp on lower Pleistocene Rocky Flats Alluvium; here the fault offsets the alluvium about 7 to 8 m vertically (Crone and Machette, 1995 #2679). At the trench site of Crone and others (1997 #2680), the scarp is 3.6 m high and has a maximum slope angle of 11°. Based on fault-scarp morphology studies in the nearby Basin and Range Province of the Western United States, a fault scarp of this size having this morphology would be inferred to be considerably older than the Holocene age indicated by the trenching studies. However, comparing the scarp on the Cheraw fault with Basin and Range fault scarps is complicated by the fact that the Cheraw scarp is the product of multiple surface-faulting events, whereas Basin and Range scarp-morphology studies tend to focus on single rupture events. In addition, eolian (loess) deposition and ponded alluvium has partially buried the hanging wall of the Cheraw scarp fault, both of which contribute to the scarp's subdued morphology. The net result is that, morphologically, the scarp appears to be an older feature than was documented by the trenching study. Evaluation of seismic data, and mapping of fault scarps based on topographic profiles based using the National Elevation Data (NED) 10-meter Digital Elevation Model (DEM) shows additional complexity in surface faulting than previously recognized (Zellman and Ostenaa, 2014 #7284). These data suggest maximum apparent vertical offset across the scarps along

	much of the fault of about 5-6 m of which at least 3.2 m is late Quaternary.
Age of faulted surficial deposits	Lower Pleistocene (Rocky Flats Alluvium), middle (?) Pleistocene Verdos Alluvium, locally unnamed latest Pleistocene loess and alluvium, and Holocene colluvium.
Historic earthquake	
Most recent prehistoric deformation	latest Quaternary (<15 ka) *Comments:* The age of the most recent event is relatively well constrained by radiocarbon and TL age estimates (Crone and others, 1997 #2680), although these estimates only provide maximum limit on the timing of events. Detrital charcoal fragments deposited within a faulted A-horizon (soil) have AMS radiocarbon age of 8.4 ka. Based on the proximity of these charcoal fragments to the paleo-ground surface, Crone and others (1997 #2680) argued that the most recent event has an age of about 8 ka (early Holocene). Earlier, less detailed investigations by Unruh and others (1994 #2778) suggested latest movement was early to middle Pleistocene.
Recurrence interval	8 k.y. (<25 ka) *Comments:* Crone and others (1997 #2680) estimated that surface-rupturing events on the fault occurred at about 8 ka, 12 ka, and 20 to 25 ka based on trenching. They also speculated that events older than about 25 ka must have occurred before about 100 ka because of the time needed to incise, widen, and backfill the paleo-stream channel that is now filled with latest Pleistocene deposits. Based on this temporal pattern, they speculated that the fault's long-term behavior is characterized by temporal clustering of earthquakes, in which relatively short time intervals of activity (e.g., 15-20 k.y.) are separated by long intervals of quiescence (e.g., 100 k.y.). If correct, this pattern of temporal clustering makes it difficult to assign a realistic recurrence interval for the fault. The suggested 8 k.y. average recurrence interval is based solely on the estimated timing of the latest Pleistocene and Holocene events documented in the trenching study. This recurrence interval may only apply to periods of time when the fault is in an active phase; during a quiescent phase, surface-faulting earthquakes may not occur for hundreds of thousands of years. Unruh and others (1994 #2778) estimated a recurrence

	interval of 10-50 k.y.
Slip-rate category	Less than 0.2 mm/yr *Comments:* The latest Pleistocene to Holocene slip rate on the Cheraw fault is much less than 1 mm/yr. Unruh and others (1994 #2778) calculated a slip rate of 0.01 to 0.001 mm/yr. A rigorous calculation of latest Pleistocene to Holocene slip rates yields values of 0.23 to 0.09 mm/yr based on the data of Crone and others (1997 #2680). During the time interval between 20-25 ka and 8 ka, two surface-faulting events occurred. The cumulative vertical offset of these two events ranges between 1.6 m and 2.7 m. A maximum latest Pleistocene slip rate would be based on the shortest time interval between these events (20 ka to 8 ka) and the maximum vertical offset in that time interval (2.7 m); this yields a slip rate of 0.225 mm/yr. Similarly, a minimum latest Pleistocene slip rate would be calculated by taking the longest time interval between events (25 ka and 8 ka) and the minimum vertical offset during that time interval (1.6 m); this yields a slip rate of 0.094 mm/yr. These slip-rate values apply to periods of time when the fault is in an active phase. More simplistic calculations (but not rigorously correct) of latest Pleistocene-Holocene slip rates are between 0.14 to 0.18 mm/yr. These rough slip rates are determined by dividing the amount of offset (3.6 m) on the oldest faulted deposits by the age of the deposits (20 to 25 ka); these resulting slip rates are similar to the more rigorous values described above. The long-term slip rate on the Cheraw fault would be extremely low if one were to include the effect of quiescent phases of activity. The best estimate of a long-term slip rate is less than or equal to 0.007 mm/yr based on a cumulative offset of about 8 m on the 1.2 Ma Rocky Flats Alluvium. However, because of the apparent temporal clustering of events, one might question whether using a single slip-rate value is an appropriate way to characterize the rate of movement on this fault.
Date and Compiler(s)	2015 Anthony J. Crone, U.S. Geological Survey, Emeritus Kathleen M. Haller, U.S. Geological Survey
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