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Northern Sangre de Cristo fault, Crestone section (Class A) No. 2321a

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Compiled in cooperation with the Colorado Geological Survey

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Synopsis	**General:** The Northern Sangre de Cristo fault is a major down-to-west normal fault within the Rio Grande rift in Colorado. This high-angle normal fault dips to the west and forms the structural boundary between the Sangre de Cristo Range/Culebra Range on the east and the San Luis basin. The San Luis basin is the largest of the major north-trending extensional basins of the northern Rio Grande rift. The fault extends from Poncha Pass to near the Colorado-New Mexico state line. **Sections:** This fault has 4 sections. The Northern Sangre de Cristo fault is divided into sections based on mountain-front and fault-scarp

	morphology for the purpose of this compilation. The entire fault shows evidence that suggests multiple late Quaternary surface displacements, including Holocene movement. The following sections from north to south are: the Crestone section, the Zapata section, the Blanca section, and the San Luis section; these three segments are herein called sections. A fourth section (San Luis) extends generally southward from the south side of the Blanca Peak Massif to Jarosa Creek near the Colorado-New Mexico state line.
Name comments	**General:** The Sangre de Cristo fault zone borders the eastern side of San Luis basin from near Poncha Pass, Colorado, to near Taos, New Mexico. This fault zone has been subdivided into two discrete faults for this compilation: the Northern Sangre de Cristo fault, which bounds the west side of the Sangre de Cristo Mountains in Colorado and the Southern Sangre de Cristo fault, which is in New Mexico. Ruleman and Machette (2007 #7165), Ruleman and others (2008 #7286), and Crone and others (2006 #7753) suggest the geomorphology of the Northern Sangre de Cristo fault and the adjacent range front indicate differing amounts of offset and different faulting histories north of Blanca Peak massif in contrast to the San Luis section defined here, which they prefer to call the Central Sangre de Cristo fault zone. **Section:** The Crestone section of the Northern Sangre de Cristo fault corresponds to segment 'A' of McCalpin (1982 #791). The name "Crestone section" was first used by Widmann and others (1998 #3441) for this compilation and extends from near Poncha Pass on the north to the Great Sand Dunes National Monument on the south. Jack Benjamin and Associates and Geomatrix Consultants (1996 #2703), McCalpin and Kirkham (2006 #7164), and McCalpin (2006 #7285) suggested the Crestone section as defined here spans two or possibly three fault segments; this additional subdivision, although perhaps valid, is not incorporated in this compilation. McCalpin and Kirkham (2006 #7164) document complex interactions between the northern 38 km of the Northern Sangre de Cristo fault and the Villa Grove fault [2319] to the west and suggest a revised segmentation model based on evidence they presence of a nonpersistent segment boundary between the Major Creek and Carr Gulch sites. However, McCalpin and Kirkham (2006 #7164) point out that timing of the most recent surface rupture at Major Creek, Urraca Creek, and Morris Gulch is not constrained tightly enough to provide conclusive evidence of independent rupture. Rupture may propagate along the Villa Grove fault zone [2319] instead of the northern 30 km of the Northern Sangre de Cristo fault during some earthquakes.The Crestone section of the Northern Sangre de Cristo fault corresponds to segment 'A' of McCalpin (1982 #791). The name "Crestone section" was first used by Widmann and others (1998

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County(s) and State(s)	SAGUACHE COUNTY, COLORADO
Physiographic province(s)	SOUTHERN ROCKY MOUNTAINS
Reliability of location	Good Compiled at 1:125,000 scale. *Comments:* All or parts of this section were mapped by Wychgram (1972 #2796; scale 1:24,000), McCalpin (1982 #791; scale 1:50,000), Colman and others (1985 #1954; scale 1:125,000), Tweto and others (1976 #2774; scale 1:250,000), Scott and others (1978 #2735; scale 1:250,000), Witkind (1976 #2792; scale 1:500,000), Kirkham and Rogers (1981 #792; scale 1:500,000), and Colman (1985 #1953; scale 1:1,000,000). The trace used for this compilation is from Colman and others (1985 #1954).
Geologic setting	The Northern Sangre de Cristo fault is a major down-to-west normal fault within the Rio Grande rift. It forms the eastern boundary of the east-tilted half-graben of San Luis basin. The deepest part of San Luis basin lies adjacent to the Northern Sangre de Cristo fault (Gaca and

	Karig, 1965 #2690). Estimates of the maximum thickness of synorogenic basin fill in that part of San Luis basin have widely ranged. Gaca and Karig (1965 #2690) suggested a maximum thickness of about 9.7 km; Huntley (1976 #2698; 1976 #2699) reported it at about 5 km; Stoughton (1977 #2750) at 6,000 m; and Kluth and Schaftenaar (1994 #1183) at 6.4 km. Estimates of the amount of vertical displacement on the Northern Sangre de Cristo fault also vary widely. Kluth and Schaftenaar (1994 #1183) suggested the Northern Sangre de Cristo fault has approximately 9.2 km of vertical separation; geophysical data suggest that total Neogene throw on the Northern Sangre de Cristo fault is at least 4 km (Brister and Gries, 1994 #1178).
Length (km)	This section is 79 km of a total fault length of 164 km.
Average strike	N30°W (for section) versus N19°W,N35°E (for whole fault)
Sense of movement	Normal
Dip	60° W *Comments:* The dip of the Crestone section of the Northern Sangre de Cristo fault is debatable. Scott (1970 #1141) suggested it is near vertical. Tweto (1979 #2767), Burroughs (1981 #2661), and Brister and Gries (1994 #1178) described it as a high-angle fault, a value supported by trench exposures mapped by McCalpin (1981 #2723, 1982 #791). Based on seismic reflection and gravity data, Kluth and Schaftenaar (1994 #1183) concluded the fault dip is about 60°, the value cited herein. Morel and Watkins (1997 #2724), using seismic reflection and drill-hole data, reported it is a low-angle detachment fault that flattens to subhorizontal in Precambrian rocks. Based on reprocessed seismic reflection data, the Sangre de Cristo fault is interpreted to be a high-angle normal fault that soles out at lower crustal depths between 26 and 28 km (Tandon and others, 1999 # 7287).
Paleoseismology studies	Four trenches have been excavated across the fault. About 8.9 m of vertical displacement has occurred since early Pinedale in possibly five surface-faulting earthquakes at sites along the Crestone section of the fault. McCalpin (1982 #791) reports that average vertical displacement is 2.15 m and the maximum is 2.9 m. The most recent event at the northernmost site (Carr Gulch) and the southernmost site (Major Creek) occurred at nearly the same time, and may represent a 90-km or longer rupture (McCalpin and Kirkham, 2006 #7164). Despite the uncertainty of correlating poorly dated events, McCalpin and Kirkham (2006 #7164) point out that surface faulting occurred more frequently

	at Major Creek (5 times) than at Carr Gulch (3 times) since early Pinedale time. Site 2321-1. The site consists of one trench that crossed the fault at Major Creek and displayed evidence of two fault movements that were constrained in time by two radiocarbon ages (McCalpin, 1981 #2723, 1982 #791); the most recent offset (about 8 ka) resulted in about 1.4 m of vertical displacement and the previous (8–13 ka) about 2.4 m (McCalpin, 1982 #791). Largely on the basis of surface offsets of Bull Lake and pre–Bull Lake–equivalent deposits, McCalpin (1981 #2723, 1982 #791) also inferred three prior events between 35 ka and 140 ka and possibly 6 to 12 events between 140 ka and approximately 400 ka. Site 2321-2. Two trenches were excavated near Willow Creek (McCalpin, 1981 #2723, 1982 #791). Evidence of a single surface-faulting event was exposed in the excavation of the Holocene fan suggesting 2.3 m of displacement. A second trench was excavated in Bull Lake alluvium and exposed evidence of perhaps three rupture events suggesting vertical displacement of 1.8-2.9 m per event. No datable material was recovered from the trenches to constrain the timing of surface faulting. Site 2321-5. The Carr Gulch trench was located on the range-front fault scarp on south of the deeply incised channel of Carr Gulch (McCalpin and Kirkham, 2006 #7164). The trench was 26 m long and 2–3.5 m deep. The trench exposed evidence for three paleoearthquakes in the past 27.4 ka; total surface offset of about 4.5 m suggest an average single-event displacement of about 1.5 m. The timing of surface faulting is based on four optically stimulated luminescence (OSL) ages and interpreted to have occurred at about 8 ka, 20 ka, and 22.5–27.5 ka. The offset fan was mapped as Bull Lake alluvium; however four OSL ages, in correct stratigraphic order, and indicate that the alluvial fan deposits on the hanging wall were deposited about 27.4 ka. McCalpin and Kirkham (2006 #7164) preferred explanation of the geomorphology and OSL dates implies (1) the 4.5 m surface offset of the fault scarp does not represent the cumulative post-Bull Lake displacement, because the hanging wall beds are Pinedale in age, much younger than the footwall beds, and (2) neither does the 4.5 m surface offset necessarily represent the cumulative post-Pinedale displacement either, because there may have already been some fault-scarp relief when the Pinedale strata were deposited on the hanging wall.
Geomorphic expression	A series of discontinuous, prominent, west-facing scarps are developed on late Quaternary deposits along the Crestone section of this fault.

	The mountain front is marked by prominent triangular-faceted spurs (Kirkham and Rogers, 1981 #792; McCalpin, 1982 #791). The northern part of the section, north of intersection with Villa Grove fault, does not have scarps except for north of the Hayden Pass road, which is north of the northern termination of the Villa Grove fault (McCalpin and Kirkham, 2006 #7164).
Age of faulted surficial deposits	Pre-Bull Lake, Bull Lake, Pinedale, and Holocene fan alluvium is offset in several areas along the Crestone section of the fault (Kirkham and Rogers, 1981 #792; McCalpin, 1981 #2723, 1982 #791).
Historic earthquake	
Most recent prehistoric deformation	latest Quaternary (<15 ka) *Comments:* Scott (1970 #1141) first reported evidence of young faulting. Later results from trenching at Major Creek indicated the latest rupture occurred shortly before 7,600±120 yr BP, and that a second coseismic surface rupture occurred before 10,100 ±110 yr BP (McCalpin, 1981 #2723, 1982 #791).
Recurrence interval	5.0–11.7 k.y. (<70 ? ka) *Comments:* McCalpin (1981 #2723, 1982 #791) suggested that the part of the Crestone section south of the Major Creek/Kerber Creek fault zone has a recurrence interval of 5.0–11.7 k.y. during post-early Pinedale time (ca. <70 ? ka), whereas the part north of this fault zone is defined by longer recurrence interval. In addition, he reported that the recurrence interval appears to be longer during Pinedale to Bull Lake time and during pre-Bull Lake time. At Carr Gulch, McCalpin and Kirkham (2006 #7164) interpret OSL ages to indicate variable recurrence intervals between events; the recurrence time between Events Z and Y is 12 k.y., and between Events Y and X the recurrence time is only 5 k.y. The time since Event Z is 8 k.y., which is not explicitly stated.
Slip-rate category	Less than 0.2 mm/yr *Comments:* McCalpin (1981 #2723, 1982 #791) reported an average slip rate of 44 mm/k.y. (0.044 mm/yr) for the Willow Creek area. At Carr Gulch, the 4.5 m of surface offset is a maximum estimate for cumulative displacement since 27.4 ka. Regardless, McCalpin and Kirkham (2006 #7164) show in a time-displacement diagram that vertical displacement rate varies for the past two earthquake cycles.

	The single-event vertical-displacement rate between the last two events (0.125 mm/yr) is half that between the prior two events (0.3 mm/yr). Present-day surface velocities from continuous measurements of GPS sites that span the northern part of the Rio Grande rift show extensional deformation is not concentrated in a narrow zone centered on the Rio Grande rift (let alone confined to the Sangre de Cristo fault) but is broadly distributed from the western edge of the Colorado Plateau into the western Great Plains (Berglund and others, 2012 #7270).
Date and Compiler(s)	2015 Robert M. Kirkham, Colorado Geological Survey Kathleen M. Haller, U.S. Geological Survey
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