

Recurrent Quaternary normal faulting at Major Creek, Colorado: An example of youthful tectonism on the eastern boundary of the Rio Grande Rift Zone

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LOCATION AND ACCESS

A well-preserved fault scarp resulting from recurrent Quaternary normal faulting occurs at the western edge of the northern Sangre de Cristo Mountains of south-central Colorado, at the mouth of west-draining Major Creek (Fig. 1). The site is approx-

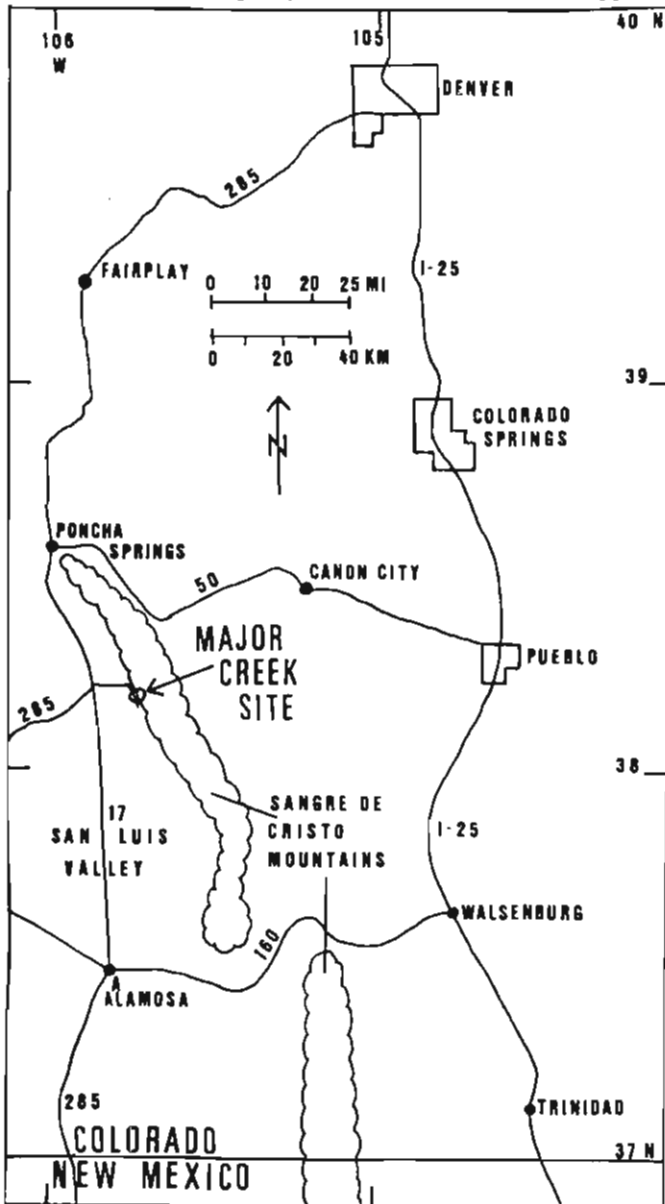


Figure 1. Regional location map for the Major Creek site. Detailed access directions given in text refer to this figure and Figure 2.

imately 56 mi (90 km) north-northeast of Alamosa, Colorado, and may be approached from Colorado 17 between Alamosa and Poncha Springs, Colorado. Turn east off of Colorado 17, 50 mi (80 km) north of Alamosa, opposite the junction with U.S. 285, onto a dirt road that leads due east for 6 mi (10 km) across the valley floor toward Valley View Hot Springs. Instead of turning off to the hot springs, bear right and follow the road as it turns south to parallel the range front. The road will continue south past the mouth of Garner Creek [1 mi (1.7 km) south of the hot springs turnoff] to the upper part of the Major Creek alluvial fan [2 mi (3.2 km) south of the hot springs turnoff]. Approximately 0.25 mi (400 m) north of the crossing of Major Creek (Fig. 2) turn onto a dirt driveway leading due east to the head of the fan where the fault scarps occur. Entry through the locked gate will require permission from the landowner on the north side of the fanhead, Dr. Ben Eismann, Dept. of Surgery, University of Colorado Health Science Center, Denver, CO 80262. The fault scarps on the south side of the road (including the 1980 trench site, Profile 35 on Fig. 2) are owned by Mr. Stan Pavlin, 4004 Hillside Dr., Pueblo, CO 81008; permission is also necessary for access to this property.

SIGNIFICANCE OF THE SITE

The Major Creek fanhead displays one of the best multiple-event fault scarps within the Rio Grande Rift Zone. Quaternary alluvial fan deposits of five ages are offset by a single strand of the Sangre de Cristo Fault Zone. Detailed scarp profiling, soil description, and scarp trenching yield a coherent picture of multiple surface-faulting earthquakes (as many as 13) in roughly the last 400,000 years, with displacements of 5.2 ft to 7.2 ft (1.6 m to 2.2 m) per event. The last such event occurred about $7,660 \pm 140$ B.P. The timing and style of faulting are important for two reasons: (1) they indicate the probable way in which the structural relief of the Rio Grande Rift has developed by numerous small-scale earthquake displacements, and (2) they identify the Sangre de Cristo Fault as one of Colorado's few active faults, based on both Holocene activity and recurrent late Pleistocene activity. The significance of this locality in relation to regional tectonics is described in recent reports on Quaternary faulting for Colorado (Kirkham and Rogers, 1981; Colman, 1985) and for the northern Rio Grande Rift Zone (McCalpin, 1983; Colman and others, 1985).

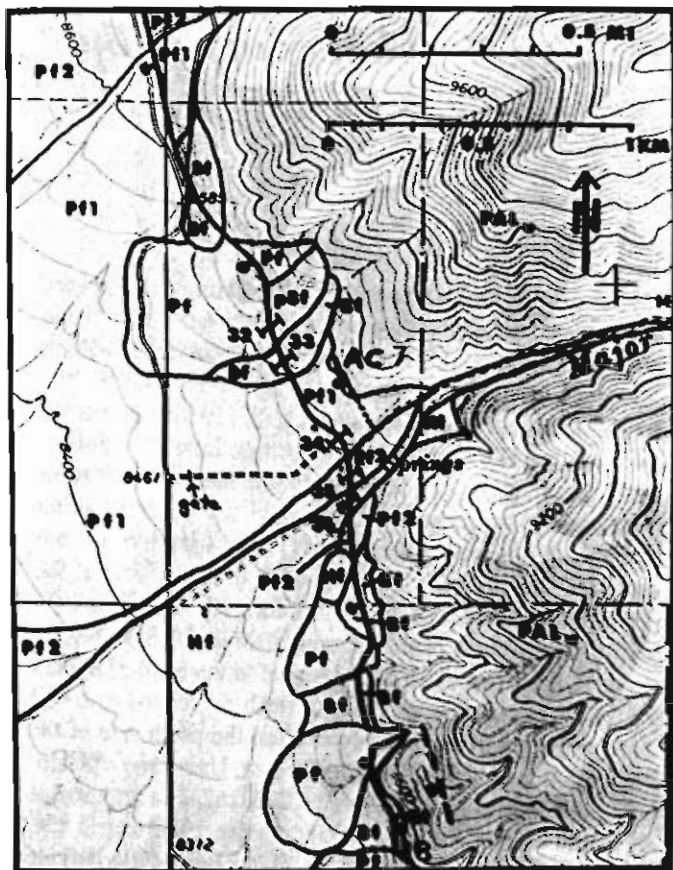


Figure 2. Geologic map of the Major Creek area. Hf—Holocene fan; P11—early Pinedale fan; P12—mid-late Pinedale fan; Pf—Pinedale fan, undivided; Bf—Bull Lake fan; pBf—pre-Bull Lake fan; Palu—Paleozoic bedrock, undivided. Fault scarp is a heavy line with bar and ball on downthrown side; subsidiary(?) fault segments to E are dashed lines. The numbered barred lines across the scarp show profile locations of Figure 3. Base map: Valley View Hot Springs 7½' quadrangle; contour interval = 40 ft (12.19 m).

SITE INFORMATION

The heads of many alluvial fans on the west side of the Sangre de Cristo Mountains are offset by fault scarps, but the scarps at Major Creek show clearly the geomorphic relations with a sequence of Quaternary terraces. A set of five climatically induced fan terraces is inset into the head of the Major Creek alluvial fan (Fig. 2). Although the range-bounding Sangre de Cristo Fault offsets all five terraces, some terraces are present both above *and* below the scarp. Such geometry indicates that the terraces are not purely strath terraces cut into the upthrown block (as described by Soule, 1978), because strath terraces would not continue below the scarp. Instead the terraces owe their origin to changes in stream regimen, presumably accompanying climatic change, and resemble non-faulted fanhead terraces common elsewhere along the range front and elsewhere in Colorado.

The fault scarp is simple in geometry as defined by Slemmons (1957, p. 367), meaning that a single high-angle break offsets surfaces that preserve their original depositional gradient. The scarp becomes progressively higher as it offsets older fan deposits, indicating recurrent movement contemporaneous with episodes of fan formation. Deposits of five ages (Fig. 2) offset at the fanhead are correlated to glacial episodes in the Sangre de Cristo Mountains by McCalpin (1983, p. 9–37), based on relative-dating criteria and by comparison to nearby fans that can be traced directly to late Pleistocene moraines. Figure 3 shows scarp profiles across each faulted unit; the age of the unit and the vertical displacement it has undergone are given in Table 1. The number of faulting events may be estimated by assuming that the smallest scarp (#36, 5.2 ft—1.6 m—throw) represents a single event or alternatively, that the second smallest (#35, 12.5 ft—3.8 m—throw) represents two events. The number of inferred fault events with displacements of 5.25–7.25 ft (1.6–2.2 m) ranges from 5 since Pinedale time to 13 since mid-Pleistocene time

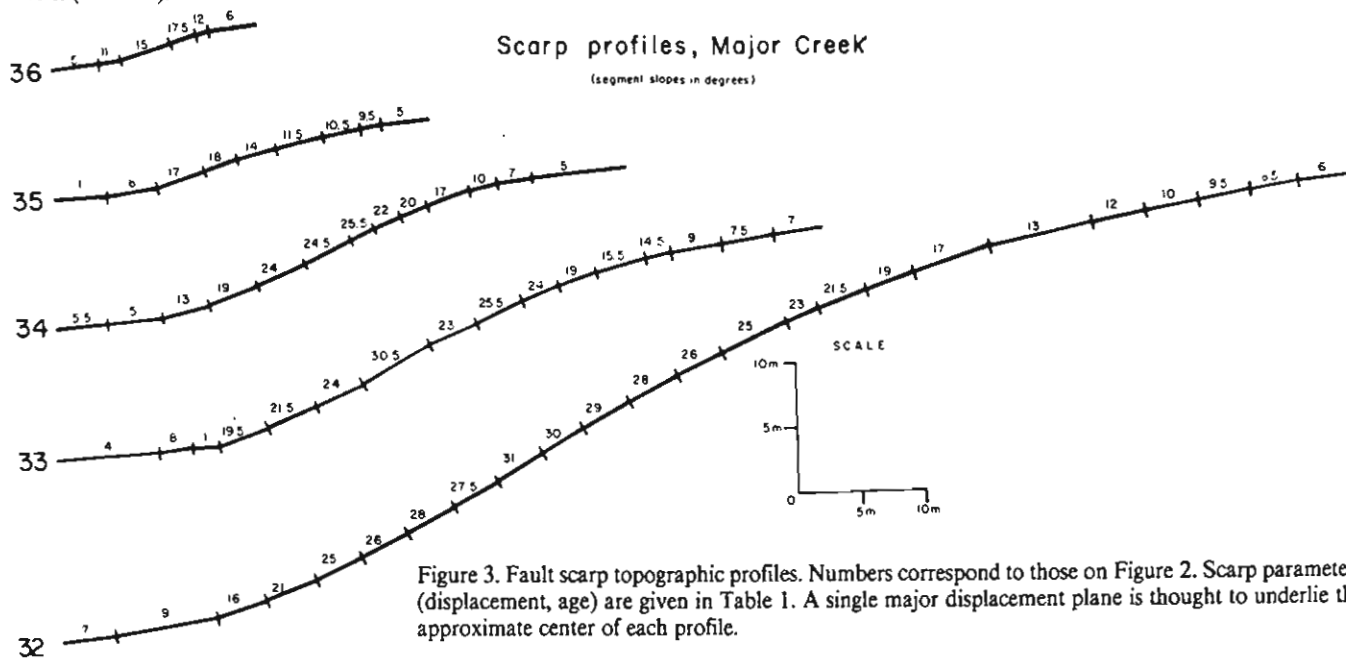


Figure 3. Fault scarp topographic profiles. Numbers correspond to those on Figure 2. Scarp parameters (displacement, age) are given in Table 1. A single major displacement plane is thought to underlie the approximate center of each profile.

TABLE 1. FAULT SCARP PARAMETERS, MAJOR CREEK SITE

Profile Number ¹	Deposit Offset ²	Total Vertical Fault Displacement ³		Number of Fault Events ⁴	Deposit Age (ka) ⁵	Recurrence Interval (ka) ⁶
		ft	m			
36	Hf1	4.6	1.4	1	8	8.0
35	Pf2	12.5	3.8	2	13	5.0
34	Pf1	29.2	8.9	5	25	4.0
33	Bf	44.3	13.5	7	150	62.5
32	pBf	76.7	23.4	13	400	41.6

- ¹Corresponds to numbers on Figure 2.
- ²Hf1, early Holocene; Pf2, mid-late Pinedale; Pf1, early Pinedale; Bf, Bull Lake; pBf, pre-Bull Lake.
- ³Measured by graphical projection of upper over lower surface, assuming a 70° fault dip.
- ⁴Calculated by dividing an average 1.6-2.2 m displacement per event into the total vertical fault displacement, rounded to the nearest even number.
- ⁵Ages from local C14 dates, and via correlation to dated glacial deposits elsewhere in the western U.S. (see McCalpin, 1983, Fig. 32 and Table 10).
- ⁶Calculated by dividing the number of fault events (column 4) into the length of time in which they occurred (difference between ages in column 5); Example: 2 events (7 minus 5) occurred between 150 ka and 25 ka, so 125 ka divided by 2 events = 62.5 ka per event.

(Table 1, column 4). To confirm all assumptions, the scarp at surface profile #35 was trenched; the log is presented as Figure 4.

Study of the trench confirmed that two faulting events had occurred since deposition of unit Pf 2. The first event offset lenticularly bedded, sandy to cobbly late Pinedale alluvium and created a topographic trough in which clayey, organic-rich sag pond deposits had begun accumulating by at least 10,400 ± 240 B.P. The base of sag deposits was not exposed. Faulting is therefore roughly bracketed between the formation of the mid-late Pinedale terrace (approximately 15,000 B.P.) and 10,400 ± 240

B.P. A second fault event severely deformed this soft muck and created a free face that dumped 5.9 ft (1.8 m) of coarse colluvium onto the sag deposits. The uppermost sag deposit carried an organic A horizon that dated at 7,660 ± 140 B.P.—presumably no younger carbon was added after burial. The mean residence time of organic material in the A horizon may be hundreds or thousands of years, so the date of latest faulting may be somewhat younger than 7,660 B.P. Fault scarp profiling of the younger scarps (#35, #36) does not yield a comparably young date in relation to other published scarp height-slope angle data (e.g.,

LOG OF TRENCH, MAJOR CREEK
(SW ¼, Sec. 7, T45N, R11E)
Profile SC 35

by
James McCalpin

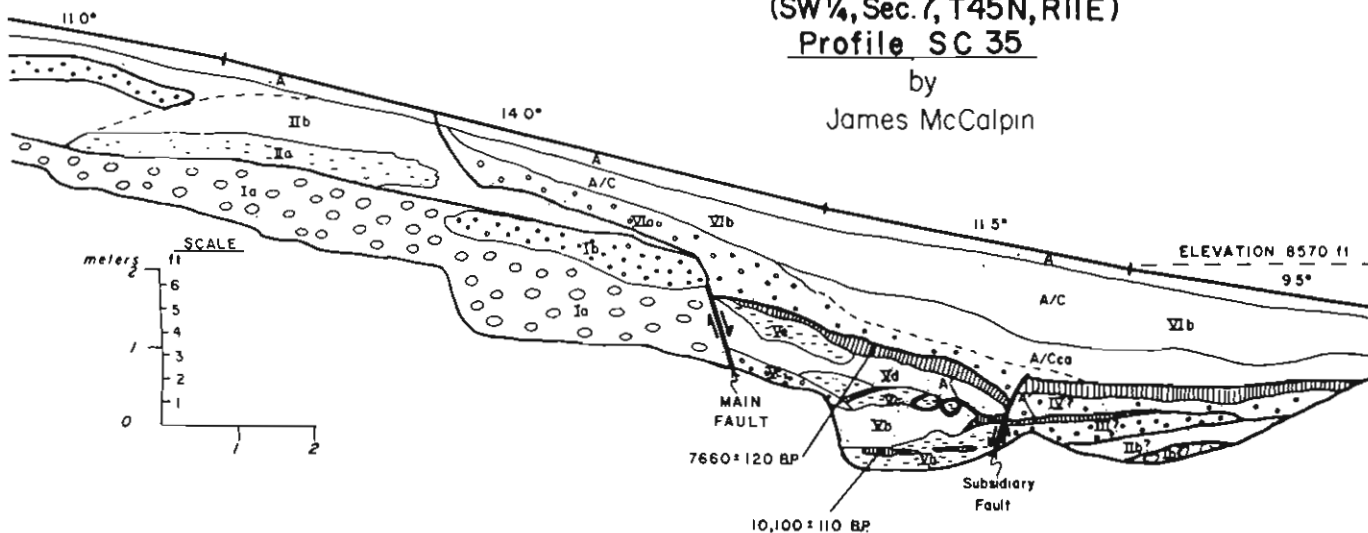


Figure 4. A portion of the log of a trench across profile 35 in mid-late Pinedale alluvium. Heavy lines bound six depositional units: I through IV—mid-late Pinedale alluvium; V—early Holocene tectonic colluvial wedge; VI—mid-Holocene tectonic colluvial wedge. Facies of major units are shown by thinner lines and lower case letters, soil horizons developed on deposits by upper case letters like A/C. Two colluvium-producing fault events are inferred.

Bucknam and Anderson, 1979), because fine sands in which the scarps are developed are highly erodable.

Faulting recurrence intervals for several time periods were calculated based on scarp data. Resulting recurrence intervals seem to be considerably shorter since the Early Pinedale (Table 1, column 6). This conclusion, also reached for most other faulted fanheads along the Sangre de Cristo Fault, has two possible causes: (1) seismicity has rapidly increased within the last 25,000 years on this fault, or (2) not all earlier faulting events resulted in rupture on this fault trace. If (2) is true, as we examine longer pieces of Quaternary history, we may miss more and more fault events that occurred on other less visible traces.

Possible evidence to favor the second hypothesis is found immediately southeast of Profile 33. The base of the range front approximately 425 ft (130 m) east of the scarp here is very steep and linear. A 165-ft (50-m) high outcrop on this face exposes hydrothermally altered Paleozoic carbonate rock now altered to variegated clays (marked AC on Fig. 2). This alteration may be the result of shearing and fluid migration along a second, less active normal fault that parallels the measured scarp. However, no Quaternary deposits are offset by a projection of this suspected fault across the narrow Major Creek valley.

Larger features of the fault-generated range front are also visible on the approach to Major Creek. Well-developed facets truncate ridge lines above the fault zone, as described for other areas by Wallace (1978). Between narrow faceted ridges, elongate drainage basins extend perpendicularly to the range crest. Faceted spurs exhibiting multiple benches and steps are best displayed in the 12.5-mi (20-km) long range segment stretching from Major Creek south to San Isabel Creek. Steps sloping valleyward at 20° to 34° are separated by lower-angled ridge crests with 7° to 15° slopes. Four persistent facet sets have crests at approximately 10,825 ft (3,300 m), 9,512 ft (2,900 m), 9,180 ft (2,800 m), and 8,760 ft (2,670 m). The higher, larger facets are severely gullied, but the two lower sets are inset within the larger set and exhibit less dissection. The lowest facet set includes numerous small, very steep, ungullied planar facets that rise directly above fault scarps in Quaternary deposits. This geometry suggests that periodic rapid uplift of the mountain block has alternated with tectonic quiescence and range-front parallel retreat within the late Cenozoic. Recurrence interval data in Table 1 also show that variable activity occurs within shorter time spans and suggest that intervals between individual earthquakes or swarms of earthquakes have varied widely in the late Cenozoic.

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