Quaternary and Pliocene faults in the La Jencia and southern part of the Albuquerque-Belen Basins, New Mexico--Evidence of fault history from fault-scarp morphology and Quaternary geology

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QUATERNARY AND PLIOCENE FAULTS IN THE LA JENCIA AND SOUTHERN PART OF THE ALBUQUERQUE-BELEN BASINS, NEW MEXICO: EVIDENCE OF FAULT HISTORY FROM FAULT-SCARP MORPHOLOGY AND QUATERNARY GEOLOGY

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INTRODUCTION

The La Jencia and Albuquerque-Belen basins are two of the main structural depressions in the central part of the Rio Grande rift of New Mexico. Within these two basins are many faults that displace basin-fill deposits of Pliocene and Quaternary age and surficial deposits of middle and late Quaternary age. None of the faults I have studied in these basins show evidence of historical ground breakage; however, several show evidence of Holocene movement, and many show evidence of late Pleistocene movement. Recently published neotectonic maps of the Rio Grande rift (Woodward and others, 1975; Hawley, 1978) included many of the faults described in this report; however, no systematic study of ages or amounts of fault movement has been made previously.

This report considers only faults with Quaternary or Pliocene movement and includes information on the amount of fault displacement, the age of displaced deposits, the recency of fault movement, and the morphology of some fault scarps. These data were derived from published and unpublished geologic maps and reports, from low-altitude aerial photography, from studies of Quaternary deposits along the faults, and from an analysis of fault-scarp morphology. Where several sources of map data were available, I used those compiled at larger scales and those that focus on late Cenozoic structure and stratigraphy.

The faults shown on the map (fig. 1) provide direct evidence of Quaternary or Pliocene movement; those faults that lie entirely within Miocene or older rocks are not shown. The reader should be aware of this selection, especially if data from this report are used in hazards assessment, in regional structural analysis, or in other studies.

PLIOCENE AND QUATERNARY GEOLOGY OF THE CENTRAL RIO GRANDE RIFT

Because the main subject of this report is the faults that displace Pliocene and Quaternary deposits in the central part of the Rio Grande rift, I do not discuss the pre-Pliocene geology other than to cite several recent reports, including discussions of the evolution of the Rio Grande rift by Chapin and Seager (1975) and of the geology of the Albuquerque basin by Kelley (1977), the guidebook of the Rio Grande rift compiled by Hawley (1978), and the recent mapping of late Cenozoic basin-fill and surfical deposits in the southern part of the Albuquerque-Belen basin by Machette (1978b, c). The following discussion is drawn from these reports and my own work.

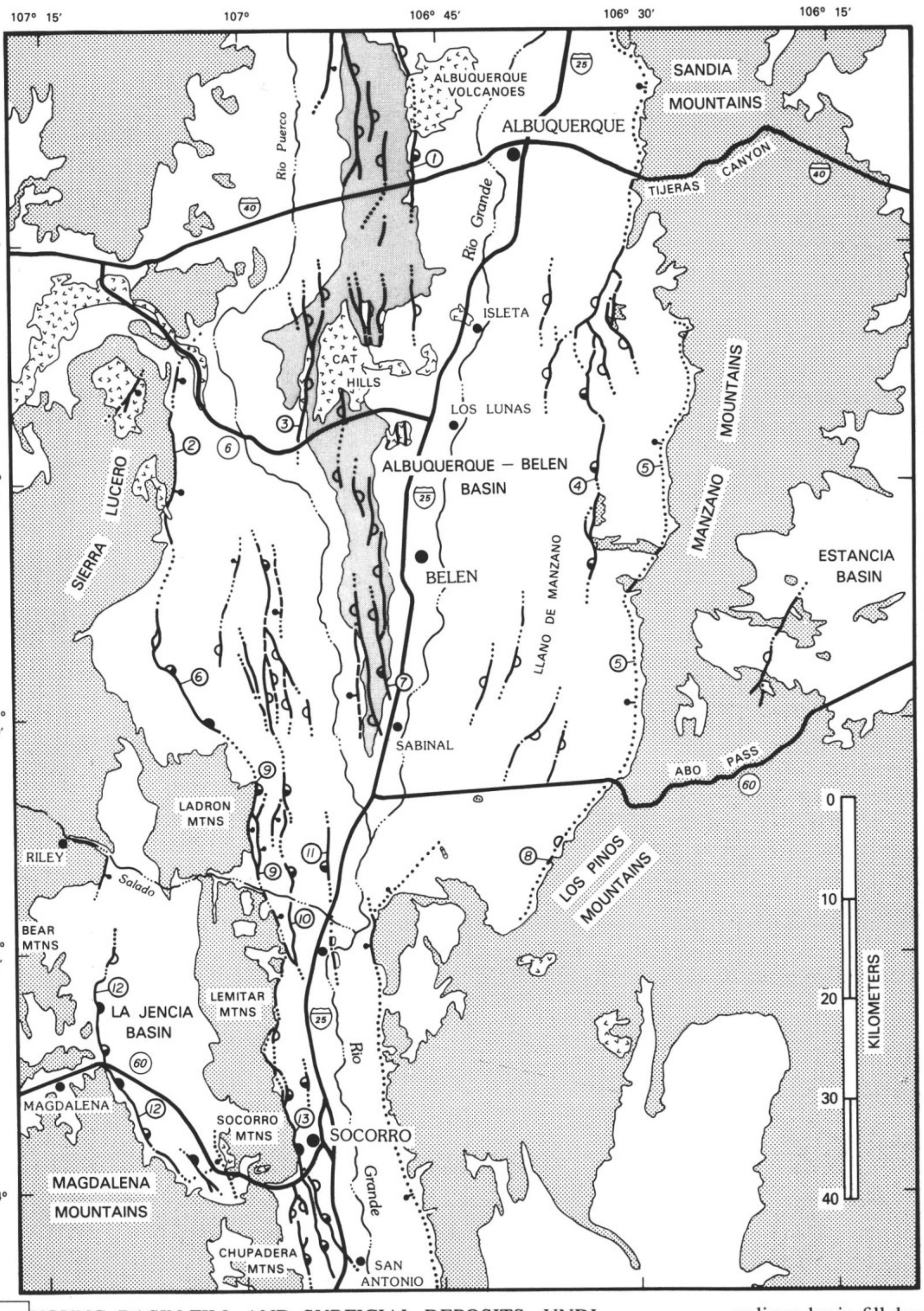
Many of the mountain ranges adjacent to the modern Rio Grande rift were uplifted during late Miocene to early Pliocene time. Thick sections of lower-to-upper? Miocene sedimentary rocks of the Popotosa Formation in these ranges are separated from Pliocene and Pleistocene basin-fill deposits by a marked angular unconformity around the margins of the basins. The Popotosa Formation is extensively faulted and tilted as much as 60'; whereas, the younger basin-fill deposits are moderately deformed only near major faults. The late Miocene to early Pliocene episode of uplift formed basins that are structurally distinct from and more highly integrated than those in which the Miocene Popotosa Formation accumulated. The formation of these new basins and ranges was accompanied by as much as 1,100 m of regional epeirogenic uplift in the southern Rocky Mountains and by increased amounts of annual precipitation and runoff from the elevated mountainous areas. By early Pliocene time, the upper reach of the Rio Grande formed a major drainage system that flowed through a series of structural basins from southern Colorado to southern New Mexico and northern Mexico. Basin-fill sediment of the Sierra Ladrones Formation was deposited by the upper Rio Grande and its tributary streams from about 4.5 to about 0.5 m.y. ago. The distributary end of the upper Rio Grande fluvial system was situated in the basins of southern New Mexico and northern Mexico at altitudes of about 1,200 to 1,400 m above sea level. Contemporaneously, the lower reach of the Rio Grande system and its tributaries such as the Pecos River drained much of southeastern New Mexico, northeastern Mexico, and southern Texas. About 0.5 m.y. ago, the upper and lower reaches of the Rio Grande became connected near El Paso, Texas (Hawley and others, 1976), to form a major river system about 2,400 km long. Since 0.5 m.y. ago, the upper reaches of the Rio Grande in New Mexico and Colorado have been downcutting in response to climatic fluctuations and the gradual upstream gradation caused by a new base level at the Gulf of Mexico.

Aggradation of the Sierra Ladrones Formation formed a widespread constructional surface in the Albuquerque-Belen basin. This surface, called the Llano de Albuquerque, in many places represents the relict 0.5-m.y.-old floodplain of the Rio Grande. The Llano de Albuquerque now lies 100 to 200 m above the modern floodplain of the Rio Grande and forms a widespread datum over much of the central part of the Albuquerque-Belen basin. Below and adjacent to the Llano de Albuquerque, a series of piedmont-slope and associated terrace surfaces, graded to former levels of the Rio Grande and its tributaries, have formed by downcutting during the past 0.5 m.y.

Areas away from the influence of the Rio Grande drainage system are generally characterized by aggrading sequences of surficial deposits. Most of the basins in the central Rio Grande rift are 20 to 40 km wide, and sediment shed from the mountain fronts around the margins of these basins is isolated from the drainage of the Rio Grande system. Additionally, some isolated basins, such as the La Jencia and Estancia, have been topographically closed during parts of the Pleistocene. Thus, in both these sedimentologically isolated areas, the surface materials generally record an interval of mainly late Pleistocene and Holocene deposition.

METHODS FOR DETERMINING AGES OF FAULTING

Two methods are used in this study to determine the ages of fault movement. The first and more traditional method is a stratigraphic



EXPLANATION

CONTACT

FAULT—Solid where age of most recent movement is known, dashed where age of most recent movement is inferred; dotted where fault is suspected or projection of a known fault is concealed. Circled number corresponds to faults in Table 1 and Figures 6-14. Only faults with Quaternary or Pliocene displacement are shown.

Age of most recent fault movement—Age is shown by following symbols on downdropped side of the fault:

Holocene (last 10,000 years)

Late Pleistocene (150,000-10,000 years B.P.)

Middle Pleistocene (750,000-150,000 years B.P.)

Early Pleistocene (2.0-0.75 m.y. B.P.) or Pliocene (5.0-2.0 m.y. B.P.)

YOUNG BASIN-FILL AND SURFICIAL DEPOSITS, UNDIVIDED (HOLOCENE, PLEISTOCENE, AND PLIOCENE)—Young basin-fill deposits of the Sierra Ladrones Formation (middle Pleistocene through Pliocene), consisting of poorly consolidated sandy fluvial deposits, silty or sandy to gravelly piedmont-slope deposits, and locally derived alluvial-fan deposits. The Llano de Albuquerque (shown by fine stippling) is the constructional surface of Sierra Ladrones Formation. Surficial deposits are younger than basin fill and consist mainly of strath and cut-and-fill terrace, piedmont-slope, alluvial-fan, and eolian deposits. Surficial deposits are generally less than 10 m thick and either are inset in channels or lie on basin-fill deposits. Coarsest materials in both groups of deposits are generally concentrated around margins of basins or adjacent to uplifted areas

VOLCANIC ROCKS, UNDIVIDED (PLEISTOCENE AND PLIOCENE)—Basaltic or andesitic rocks less than 5 m.y. old.

OLDER BASIN-FILL DEPOSITS AND BEDROCK, UNDIVIDED (MIOCENE TO PRECAMBRIAN)—Includes Miocene and upper Oligocene basin-fill deposits of the Popotosa Formation and Miocene and older volcanic, sedimentary, igneous, and metamorphic rocks (bedrock). Unit is exposed mainly outside Pliocene-Pleistocene part of Rio Grande rift and in intrarift horsts

Figure 1. Quaternary and Pliocene faults in La Jencia basin and southern part of Albuquerque-Belen basins, New Mexico. Numbers on faults refer to faults discussed in text.

approach, by which the ages of faulted and unfaulted deposits provide limits to the age of faulting; multiple episodes of fault movement can be determined by comparing the cumulative amounts of displacement in deposits of different ages. A second and less traditional method is through a quantitative analysis of fault-scarp morphology, as discussed in a following section.

Stratigraphic Methods

The young basin-fill deposits, surficial deposits, and many of the faults were mapped previously by Kelley (1977) and Machette (1978b, d). In this study, the ages of the surficial deposits are based on a combination of factors such as degree of landform preservation, stratigraphic and topographic position, and soil development. The surficial deposits and young basin-fill deposits are grouped in this study into four age categories to show the age of movements along many of the faults (fig. 1). The oldest deposits, of Pliocene and lower Pleistocene age (5.0-0.75 m.y. B.P.), include locally derived basalt and all but the youngest part of the Sierra Ladrones Formation. The middle Pleistocene (750,000-150,00 years B.P.) deposits include the youngest parts of the Sierra Ladrones Formation, which commonly underlie the Llano de Albuquerque; these deposits also include younger alluvial units such as the alluvium underlying the Llano de Manzano surface and alluvial units F through H of Machette (1978b). The late Pleistocene (150,000-10,000 years B.P.) deposits include the alluviums of Edith Avenue and Menaul Boulevard of Lambert (1968) and alluvial units C through E of Machette (1978b). The Holocene deposits include alluvium that forms terraces, fioodplains, and alluvial-fans, and eolian sand that is common on the leeward side of major stream channels or ancient playa and lake basins.

FaultScarp Morphology

The amount of surface displacement and recency of fault movement were estimated from such morphometric parameters as scarp height and maximum scarp-slope angle measurements, which were taken from topographic profiles of fault scarps. In addition, morphologic variations along fault scarps and along portions of scarps formed in deposits of different ages are used in this study as evidence for differential movement along discrete segments of individual faults. My reconnaissance studies along the Rio Grande rift indicate that some Quaternary faults have broken separately along discrete segments at various times in the past, just as R. E. Wallace (written commun., 1982) has shown for historical fault scarps along a seismic belt trending from central Nevada into eastern California.

Recent studies of the geomorphology of late Quaternary fault scarps and the processes leading to their time-dependent degradation have established the basis by which the relative ages of fault scarps may be determined independently of stratigraphic methods. The relation between fault-scarp height and maximum fault-scarp-slope angle recognized by Bucknam and Anderson (1979) is used as a criterion for determining the recency of fault movement. This relation is based on the premise that scarps formed by high-angle faults are nearly vertical and that the free faces of these scarps rapidly collapse to the angle of repose of the faulted materials (Wallace, 1977). The collapse of free faces probably occurs in as little as a hundred to perhaps a thousand years. After reaching gravitational equilibrium, scarps continue to degrade by the processes of colluviation and slopewash, though at lower rates than by gravitational collapse. The degree of fault-scarp degradation, measured by the height-dependent reduction in maximum scarp-slope angle, provides a quantitative basis for determining fault-scarp ages.

Scarp-morphology data were derived from detailed topographic traverses made perpendicular to the trace of fault scarps, according to the methods of Bucknam and Anderson (1979). Scarp height H (in meters)

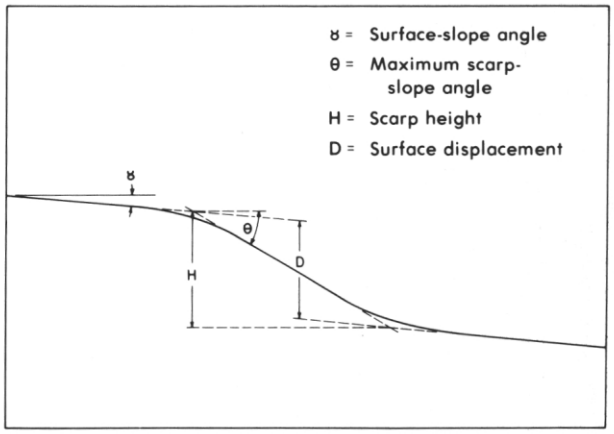


Figure 2. Diagrammatic profile of a fault scarp (modified from Bucknam and Anderson, 1979, fig. 1), showing how scarp height is determined (see text for discussion).

is the graphically determined vertical separation between intersections of the plane formed by the steepest part of the fault scarp (maximum scarp-slope angle 0, fig. 2) and the planes formed by the displaced upper and lower surfaces (surface-slope angle y, fig. 2). The maximum scarp-slope angle 0 is the average of four to six measurements made adjacent to the traverse over a distance of 10 to 20 percent of the scarp width. Each scarp profile (topographic traverse) yields two data pairs (H, 0); to be a statistically valid population, data sets for single, continuous scarps must contain seven or more data pairs. Several data sets were collected along discontinuous fault scarps, or those which form an en echelon pattern or show evidence of segmentation. Scarp data were collected only for faults in unconsolidated deposits (generally Quaternary) because, as yet, the processes and rates of degradation of fault scarps formed in rock are poorly understood.

Bucknam and Anderson (1979) reported a significant correlation between the height H and the maximum slope-angle 0 of topographic scarps formed by faulting and wave erosion. The highest wave-cut parts of the Lake Bonneville shoreline were formed during a relatively brief timespan and, as such, provide a widespread datum for morphometric analysis. Bucknam and Anderson (1979) noted that, when plotted against height, 91 percent of the variation (r^2) in the maximum scarp-slope angle 0 of the shoreline could be explained by the linear-regression equation 0 =3.8 + 21.0 (log **H) (R.** C. Bucknam, written commun., 1980).

The fault-scarp-morphology data presented in this report follow the style of Bucknam and Anderson (1979), as illustrated in Figure 3. Data pairs are plotted as circles, and the correlation coefficient (r^2) and linear-regression equation are shown where appropriate.

Age Calibration for Scarp Morphology Data

The morphometric relations determined from scarps in Utah by Bucknam and Anderson (1979) and from my studies of fault scarps in New Mexico are used here as a basis for assigning relative ages to the fault scarps. Data from two sets of well-dated scarps that were used for calibration are shown as the dashed lines in Figures 3 and 5 through 13. The upper dashed line, indicated by 5K in these figures, is drawn from data collected along two fault scarps in New Mexico: the Cox Ranch fault, near White Sands, on which the most recent movement was about 4,000 years B.P. (L. H. Gile, in Seager, 1980, p. 132; M. N. Machette, unpublished data, 1982); and a segment of the La Jencia fault near Magdalena, on which the most recent movement was about 5,000 years B.P. (M. N. Machette, unpublished data, 1982). The lower

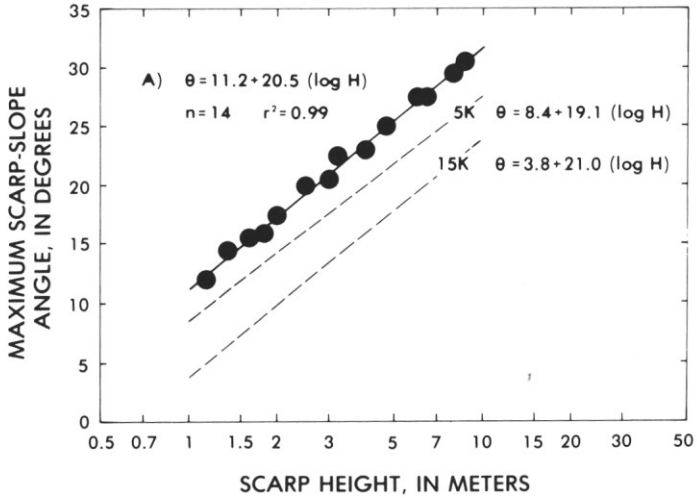


Figure 3. Maximum scarp-slope angle (θ) against scarp height (H) for a hypothetical fault, showing equations for lines of best fit, number of data pairs (n), and coefficients of variation (r^2). Two dashed lines are included for comparison: upper line (5K) is from data for fault scarps 4,000 to 5,000 years old; lower line (15K) is from data of highest wave-cut shoreline of Lake Bonneville, 15,000 years old.

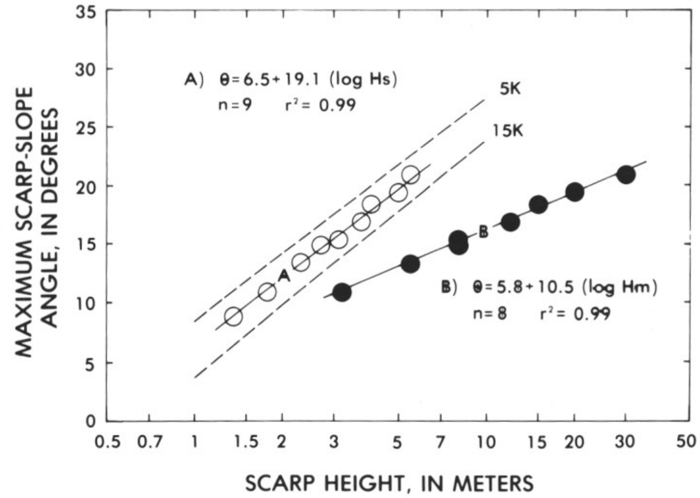


Figure 5. Plot of maximum scarp-slope angle (θ) against single-event scarp height (Hs, circles) and multiple-event scarp height (Hm, black dots) for a compound fault scarp, showing equations for lines of best fit, number of data pairs (n), and coefficients of variation (r^2). Dashed reference lines are same as in Figure 3.

dashed line (15K of fig. 3, 5-13) is drawn from the data of R. C. Bucknam (written commun., 1980) for the highest wave-cut shoreline of Lake Bonneville, Utah, which is here considered to have formed about 15,000 years B.P. (W. E. Scott, written commun., 1980).

To use scarp morphology as a basis for comparing the fault-scarp ages in different areas, the factors that influence the rate of scarp degradation must be considered. These factors include the texture and cohesion of the faulted deposits, the orientation of fault scarps, climate, vegetational cover, and landscape. Scarp-profile sites were chosen to minimize variations in these factors; thus, the morphometric differences in fault scarps reflect the influence of age. I was unable to control, however, some variation in the texture of deposits in which fault scarps formed, and this variation must have an age-independent influence on scarp morphology. Therefore, to avoid overinterpreting the scarp-morphology data collected during this study, the following criteria are used to assign relative ages to fault scarps: (1) fault scarps with data sets above the upper dashed line (5K) indicate a Holocene age, (2) fault scarps with data sets between the two dashed lines indicate either a Holocene or a latest Pleistocene age, and (3) fault scarps with data sets below the lower dashed line (15K) indicate a late Pleistocene (150,000-10,000 years B.P.) or, less likely, middle Pleistocene (750,000-150,000 years B.P.) age.

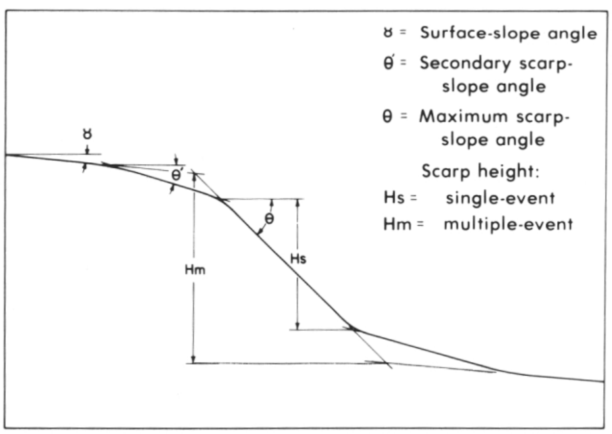


Figure 4. Diagrammatic profile of a compound fault scarp, showing how a single-event scarp height is determined (see text for discussion).

Compound Fault Scarps

Some fault scarps in the study area clearly were formed by multiple fault movements as shown either by the decreasing height of scarps formed in progressively younger deposits or by scarps that have compound scarp-slope angles (Wallace, 1977). Compound scarps are recognized by distinct bevels or facets on the upper- and lower-surface slopes above or below the steepest part of the scarp; these beveled surfaces (secondary scarp-slope angle 0', fig. 4) are the erosional remnants of fault scarps formed during previous surface rupturing. As shown in Figure 4, a younger element of the scarp height (single-event scarp height, Hs) is determined graphically by projecting the angles of the beveled surfaces (0') and measuring the vertical distance between their intersections with the maximum scarp-slope angle (0). Although scarp heights determined in this manner are crude estimates of the most recent element of surface displacement, measurements of Hs are useful because 0 is probably influenced more by recent surface rupturing; whereas, multiple-event scarp heights (Hm) measure the cumulative scarp height produced by recurrent surface rupturing.

The fault-scarp ages indicated by plots of Hs versus 0 are significantly younger than those based on multiple-event scarp heights and generally agree more closely with those determined solely by stratigraphic methods.

QUATERNARY AND PLIOCENE FAULTS

The following discussion of Quaternary and Pliocene faults in the study area is based mainly on field investigations conducted during 1980 and 1981. Table 1 summarizes pertinent data from some of the faults in the study area; these data are keyed to map locations (fig. 1) and to the plots of scarp-morphology data (figs. 6-14).

Bernalillo County Dump Fault (1)

First mapped by Lambert (1968), the Bernalillo County Dump fault was named by Machette (1978a) for the surface rupture that probably is a southward expression of a deep fault zone along which Quaternary

Table 1. Location, recency of movement, and size of some major faults in the Socorro 1°×2° quadrangle, New Mexico. Symbols for age are as follows: h, Holocene; lh, lower Holocene; up, upper Pleistocene; mp, middle Pleistocene; lp, lower Pleistocene or Pliocene. Type of fault movement, as determined from scarp morphology, age dating of faulted deposits, and (or) map pattern, is indicated by the following abbreviated terms: segmented (segm), or recurrent (recur); n.d., no data.

Map No.	Fault name(s)	Location	Age of most recent movement	Measured scarp heights (m)	Age of displaced deposits	Exposed fault length (km)	Type of fault movement	References
1	Bernalillo Co. Dump	Due S of Albuquerque Volcanoes	up, h(?)	covered	mp to up	17	Recur, 90,000-190,000 yrs	Lambert, 1968; Machette, 1978c.
2	Santa Fe (Carrizo, abandoned)	E base of Mesa Lucero	≤lp	n.d.	lp	29	Unknown	Wright, 1946; Kelley and Wood, 1946; Callender and Zilinski, 1976, p. 56-57; Kelley, 1977, p. 40.
3	Cat Mesa	3 km W of Cat Hills	≤mp	n.d.	mp to lp	17	Unknown	Kelley, 1977, p. 47.
4	Hubbell Springs (Ojuelos, abandoned)	20 km E of Belen	up	4-30	up to lp	34	Recur, segm	Read and others, 1944; Reiche, 1949, p. 1203; Kelley, 1977, p. 45.
5	Manzano	W base of Manzano Mtns	≤mp	n.d.	mp(?)	54	Unknown	Read and others, 1944.
6	Coyote Springs	N of Ladron Mountains	up, h(?)	0.8-8.2	up to lp(?)	16	Recur	Kelley and Wood, 1946; Kelley, 1977, p. 40.
7	Sabinal (new area)	0.8 km SW of Sabinal, 20 km S of Belen	≤mp	about 20	mp to lp	19	Recur(?)	Denny, 1941, p. 240.
8	Los Pinos	W base of Los Pinos Mountains	≤mp	5-10	mp(?)	19	Unknown	Wilpolt and others, 1946; Kelley, 1977, p. 36.
9	Loma Peleda	E base of Ladrone Mtns	up	n.d.	up to lp	23	Recur	Denny, 1940, p. 103; Machette, 1978a.
10	Loma Blanca	E base of Sierra Ladrones	up	0.5-7	up to lp	23	Recur, segm	Machette, 1978a.
11	Cliff	2 km W of La Joya	up	6	mp to lp	7	Recur	Denny, 1940, p. 78, fig. 1; Machette, 1978a, b, p. 135.
12	La Jencia (six segments)	E base of Magdalena and Bear Mountains	h	0.5-7	lh to mp	35	6 segms; 4,000 to 7,000 yr recur	Machette, 1980; 1981.
13	Socorro Canyon (new name)	E base of Socorro and Lemitar Mountains	up	0.7-25	up to lp	40	Recur, segm?	Chamberlin, 1980.

basalt of the Albuquerque volcanoes erupted. A dated basalt has a K-Ar age of 190,000 ± 40,000 years (Bachman and others, 1975). Natural exposures of the fault on the northern side of the Bernalillo County Dump, just north of Interstate 40, reveal a sequence of four buried calcic soils that are downdropped to the east and lie in fault contact with fluvial deposits of the Sierra Ladrones Formation. These four soils postdate deposition of the Llano de Albuquerque at about 500,000 years B.P. The pedogenic CaCO, content of the buried soils provide evidence for ages and amounts of surface displacement along the Bernalillo County Dump fault during the past 500,000 years as shown in Table 2

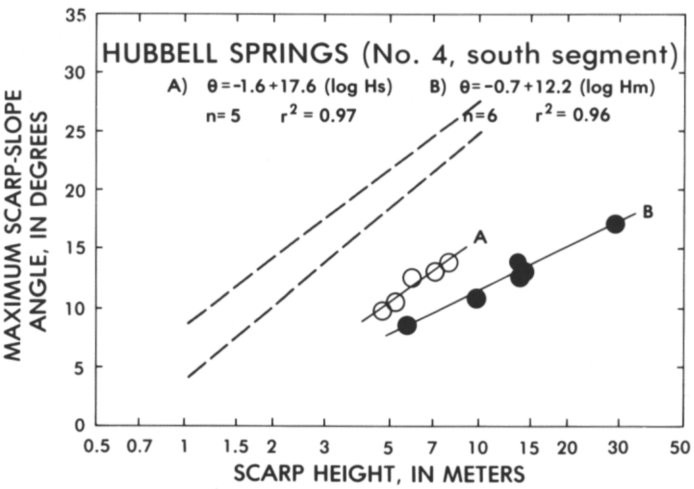


Figure 6. Scarp-morphology data for northern segment of the southern half of Hubbell Springs fault (4 of fig. 1). Maximum scarp-slope angle = θ, scarp heights = Hs and Hm, and dashed reference lines are same as in Figure 3.

(Machette, 1978a). Morphometric analysis along this fault was not possible because the scarp is buried by Holocene eolian sand.

Santa Fe Fault (2)

The Santa Fe fault parallels the base of the Sierra Lucero for a distance of about 29 km and forms the western margins of both the Albuquerque-Belen basin and the Rio Grande rift. Previously called the Carrizo fault by Wright (1946), this name was superseded by the term "Santa Fe fault," which was introduced by Kelley and Wood (1946). The fault places Pliocene and Pleistocene(?) piedmont facies of the Sierra Ladrones Formation against upper Oligocene volcanic rocks and Triassic and older rocks. The fault plane is well exposed and dips about 45° east in the southeastern 1/4 sec. 5, T6N, R2W (South Garcia SE 7.5-minute quadrangle; see also Wright, 1946, fig. 1, and Callender and Zilinski, 1976). Wright (1946) estimated that the Santa Fe fault may have a stratigraphic throw of 1,920 m, most of which is considered in this study to have occurred during Miocene and Pliocene time. The upthrown, western side of the southern section of the Santa Fe fault is marked by extensive Pliocene and Pleistocene(?) travertine deposits. The northern end of the fault is covered by upper Pleistocene surficial

Table 2. Characteristics of faulting events of the Bernalillo County Dump fault.

Faulting event	Age of faulting (years B.P.)	Interval since previous faulting event (years)	Amount of displacement (m)
1)	400,000	100,000	7.8
2)	310,000	90,000	4.1
3)	120,000	190,000	3.0
4)	20,000	100,000	2.1

deposits. Although the most recent movement along the Santa Fe fault is later than Pliocene or early Pleistocene, scarps along the fault have been removed by extensive dissection along the base of the Sierra Lucero. The Santa Fe fault probably extends to the south in the subsurface and connects with the Coyote Springs fault (6).

Cat Mesa Fault (3)

The Cat Mesa fault (Kelley, 1977) is the westernmost of a group of parallel faults that strike north-south throughout the basalt field known as the Cat Hills. The youngest flow in the basalt field has a K-Ar age of 140,000 ± 40,000 years (Kudo and others, 1977). This upper Quaternary basalt flowed onto well-developed calcic soils of the Llano de Albuquerque. The Cat Mesa and adjacent faults cut the Llano de Albuquerque and must be less than 500,000 years old, although some of these faults may also have moved during the late Pleistocene. Pliocene(?) andesite along the upthrown, western side of the Cat Mesa fault is juxtaposed with middle(?) Pleistocene basin-fill deposits of the Sierra Ladrones Formation. Post-Miocene throw on the Cat Mesa fault probably exceeds 100 m.

Hubbell Springs Fault (4)

Possible the most spectacular fault scarps in this part of the Rio Grande rift are those known as the Hubbell Springs fault scarps. The length of the exposed fault is 34 km, although at its northern end it joins a series of northeast-trending faults that might be considered its extensions. The Hubbell Springs fault was first mapped and named the "Ojuelos fault" by Read and others (1944). No detailed investigations of the scarps or Quaternary deposits associated with this major fault had been made before this study except for Reiche's (1949) reconnaissance studies. Reiche (1949, p. 1203-1204) stated that the Hubbell Springs fault "developed during the Pliocene; Quaternary movements were relatively minor, recurrent, and apparently most recent at the south." He also implied that the most recent movement on the fault is Holocene. Although there is ample evidence of multiple fault movements during the Quaternary, observations made during this study do not indicate Holocene movement. Parts of the southern 5 km of the fault were buried by alluvial deposits during latest Pleistocene time; these deposits are correlative with the alluvium of lsaack's Ranch, which Hawley and Kottlowski (1969) recognized in the Las Cruces area. Scarp-morphology data collected along two segments of the Hubbell Springs fault (figs. 6, 7) indicate that the most recent movement of the southern one-half of the Hubbell Springs fault occurred during late Pleistocene time but considerably before 15,000 years ago. Scarp heights along this part of the fault range from as little as 4-5 m in upper Pleistocene deposits to as much as 30 m for compound fault scarps formed in lower(?) Pleistocene or Pliocene deposits. On the basis of airphoto reconnaissance, it appears that the northern one-half of the Hubbell Springs fault has a history of recurrent movement and recency similar to that of the southern one-half.

Manzano Fault (5)

The Manzano fault (Read and others, 1944) has been shown by many authors as a major rift-bounding normal fault at the base of the Manzano Mountains. Movement along this fault probably formed the precipitous front of the Manzano Mountains, although I found no evidence of fault scarps developed in Holocene to middle Pleistocene deposits along the mountain front. The Manzano fault is marked by a wide zone in which early Miocene tuffaceous sedimentary rocks and andesite (as well as older rocks) are steeply rotated into fault contact with Paleozoic and Precambrian rocks. The Manzano fault probably begins near Tijeras Canyon on the north and extends about 56 km south to the Abo Pass area, where it may join the Los Pinos fault (8).

Coyote Springs Fault (6)

The Coyote Springs fault (Kelley, 1977) extends 16 km southward and southeastward from near the southern end of the Santa Fe fault to the northeastern end of the Ladron Mountains; at its southern end it probably connects with the Loma Pelada (9). The Coyote Springs fault may be the central section of a major fault system that forms a large part of the western margin of the Albuquerque-Belen basin. The Coyote Springs fault has scarps that range in height from less than 1 m in upper Pleistocene alluvium to about 15 m in lower(?) Pleistocene basin-fill deposits. Scarp-morphology data (fig. 8) suggest that parts of the fault, especially in the northeastern quarter of the Riley 15-minute quadrangle, may have produced surface ruptures during early Holocene or latest Pleistocene time. The most recent movement along most of the fault probably occurred during the late Pleistocene.

Sabinal Fault (7)

First recognized and studied by Denny (1941), the Sabinal fault is here named for its exposure along the eastern side of the Llano de Albuquerque near the Sabinal triangulation station (elevation 1,564 m

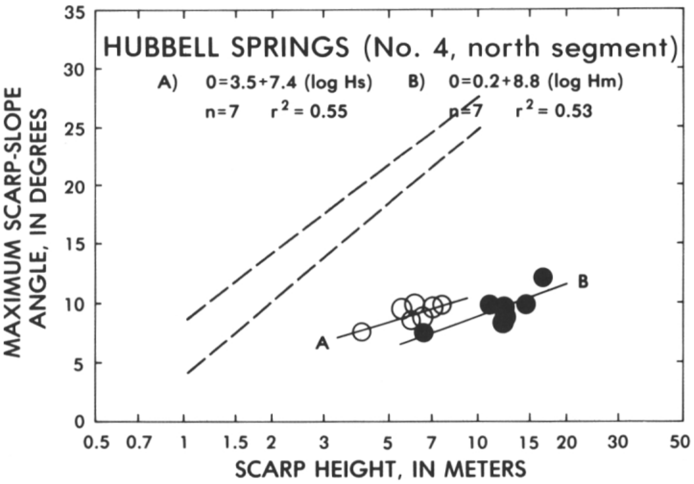


Figure 7. Scarp-morphology data for southern segment of the southern half of Hubbell Springs fault (4 of fig. 1). Maximum scarp-slope angle = θ, scarp heights = Hs and Hm, and dashed reference lines are same as in Figure 3.

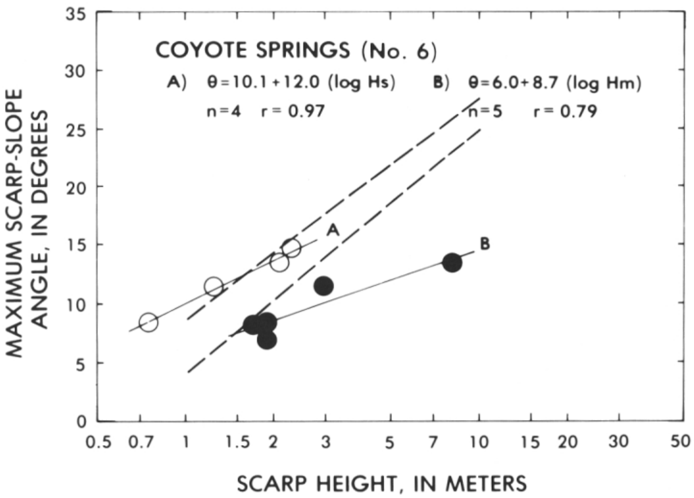


Figure 8. Scarp-morphology data for Coyoto Springs fault (6 of fig. 1). Maximum scarp-slope angle = θ, scarp heights = Hs and Hm, and dashed reference lines are same as in Figure 3.

or 5,132 ft; north-central part of Abeytas 7.5-minute quadrangle). The southern end of the fault is covered by colluvium and young alluvium about 2 km northwest of Sabinal. The fault strikes north-northwest across the southern tip of the Llano de Albuquerque and extends continuously 19 km northward to form a west-facing scarp as much as 20 m high. The northern end of the fault is covered by Holocene eolian sand at a point 7 km west of Belen. The Sabinal fault displaces well-developed calcic soils of the Llano de Albuquerque (see Denny, 1941), and so its most recent movement must postdate formation of the soil. On the basis of this evidence and the general degradation of the scarp, I think that the most recent movement of the Sabinal fault occurred during the late Pleistocene. The Sabina] fault is one of many faults (fig. 1) that cut the Llano de Albuquerque over a broad area about 100 km long and 5-20 km wide; many of these faults probably had several movements during the past 500,000 years.

Los Pinos Fault (8)

The Los Pinos fault was first mapped by Wilpolt and others (1946) as a concealed fault for a length of 19 km along the front of the Los Pinos Mountains. The fault generally lacks surface expressions except near the abandoned Burris and Nunn Ranch (Cerro Montoso 7.5-minute quadrangle), where a 0.5-m-long, 5- to 10-m-high scarp is formed in bouldery, middle(?) Pleistocene alluvial-fan deposits. The Los Pinos fault probably was active during the early or middle Pleistocene, as evidenced by the precipitous front of the Los Pinos Mountains (a fault-line scarp?) and the abundant locally derived alluvial fans at the base of the Los Pinos Mountains, which probably formed in response to uplift of the mountains. The Los Pinos fault may be a southward extension of the Manzano fault (5).

Loma Pelada Fault (9)

The Loma Pelada fault was first mapped and named by Denny (1940) for its proximity to Loma Pelada, a series of barren hills now known as the Sierra Ladrones (eastern foothills of the Ladron Mountains), where it separates Miocene basin-fill deposits of the Popotosa Formation on the west from Pliocene and Pleistocene basin-fill deposits of the Sierra Ladrones Formation on the east (Machette, 1978b). Stratigraphic throw along this fault probably exceeds 1,000 m in Miocene and Pliocene rocks. The fault extends from a point about 3 km southwest of San Acacia northward 23 km along the northeastern margin of the Ladron Mountains; it is covered at both ends by upper Pleistocene alluvium. The Loma Pelada fault has had recurrent movement during the Pleistocene and was most recently active during the late Pleistocene.

Loma Blanca Fault (10)

Mapped and named by Machette (1978b), the Loma Blanca fault strikes north-northwest a distance of 23 km through an area known as Loma Blanca where it displaces the Sierra Ladrones Formation and middle to upper Pleistocene alluvium. In this area the fault forms a 2- to 5-m-wide calcium-carbonate-cemented manganese-rich elastic dike in fluvial sand of the Sierra Ladrones Formation. Terrace gravel (unit Qae of Machette, 1978b) deposited about 120,000 years ago along the northern bank of the Rio Salado (Machette, 1978c) is displaced less than 5 m by the Loma Blanca fault. Near the northeastern end of the Ladron Mountains, a sequence of alluvial deposits is offset between 0.5 m and 7 m; the larger scams are formed in older (upper Pleistocene) alluvium. This relation suggests a history of recurrent movement during middle to late Pleistocene time. Kelley (1977) suggested that the scams along the Loma Blanca fault were formed during the late Holocene; however, scam-morphology data (fig. 9) from these scams indicate that they are older than 15,000 years (late Pleistocene).

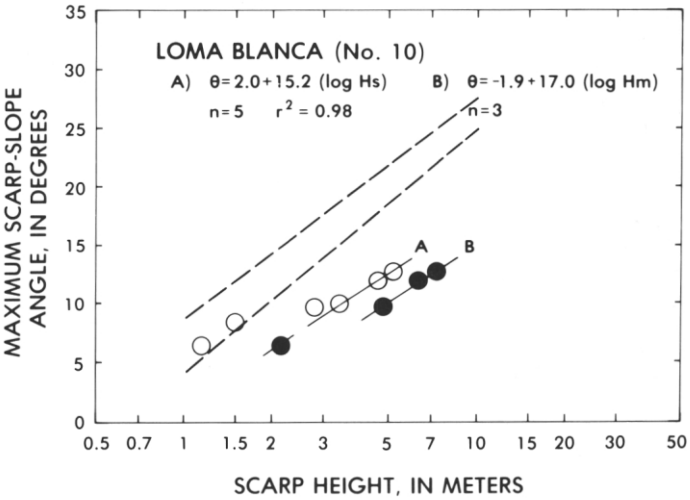


Figure 9. Scarp-morphology data for Loma Blanca fault (10 of fig. 1). Maximum scarp-slope angle = θ, scarp heights = Hs and Hm, and dashed reference lines are same as in Figure 3.

Cliff Fault (11)

The Cliff fault was named by Machette (1978b) for exposures near the Cliff triangulation station (elevation 1,553 m or 5,096 ft; central part of the San Acacia 7.5-minute quadrangle) located about 2 km west of Interstate 25 and north of the Rio Salado (fig. 1). The Cliff fault is a west-side-down normal fault that cuts piedmont facies of the Sierra Ladrones Formation and two old terrace-gravel deposits along the Rio Salado (alluvial units Qag and Qaf of Machette, 1978b), which formed about 220,000 and 180,000 years ago, respectively (Machette, 1978c). Adjacent 120,000-year-old terrace gravel (alluvial unit Qae of Machette, 1978b, c), which is displaced by the Loma Blanca fault, is not displaced by the Cliff fault. This relation and soil data indicate that the most recent movement of the Cliff fault is of earliest late-Pleistocene age (estimated at about 140,000 years ago; Machette, 1978c). The Cliff fault has a stratigraphic throw of at least 100 m in upper(?) Pliocene deposits of the Sierra Ladrones Formation and offsets middle Pleistocene terrace gravel (alluvial unit Qaf of Machette, 1978b) about 6 m.

La Jencia Fault (12)

The La Jencia fault is composed of a series of 0.5- to 7-m-high scams that displace alluvial deposits of Holocene to middle or early(?) Pleistocene age for a distance of 35 km along the western margin of the La Jencia basin and the eastern base of the Magdalena and Bear Mountains, 25 to 40 km west and northwest of Socorro. The La Jencia is a major range-bounding fault that may offset Miocene rocks by as much as several thousand meters; it is considered to form the western margin of the Pliocene and Quaternary Rio Grande rift (the Miocene rift extended farther west).

During the late Pleistocene, the La Jencia fault had a minimum of four and a maximum of seven separate movements along discrete segments (A-F from south to north). Surface rupturing occurred about 33,000 eyars ago (segment D), 15,000 years ago (segment B), 5,000 years ago (segments A, C, E?), and about 3,000 years ago (segment E). Evidence of pre-latest Pleistocene (>150,000 years B.P.) faulting is limited to 1 to 2 m of displacement along segments D-F of the fault. Average recurrence intervals for movement on the La Jencia fault during the past 33,000-year range in length from 4,000 to 7,000 years.

The combined scarp-morphology data set for segments A-D of the La Jencia fault (fig. 10) form a fairly large envelope that spans both the Holocene and late Pleistocene. If the scam data are considered separately in segments, however, data from fault segment A (not shown)

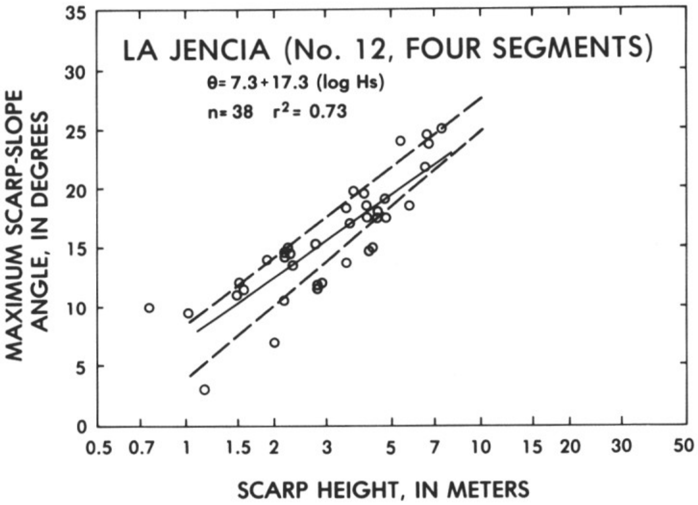


Figure 10. Scarp-morphology data for segments A-D of La Jencia fault (12 of fig. 1). Maximum scarp-slope angle = θ, scarp heights = Hs, and dashed reference lines are same as in Figure 3.

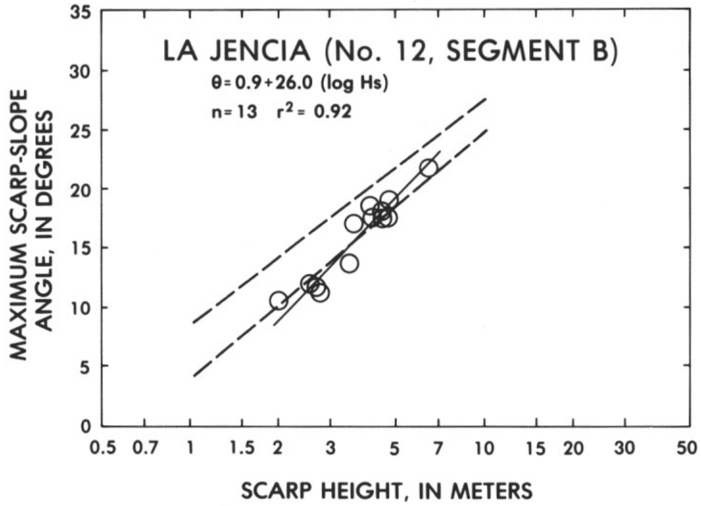


Figure 12. Scarp-morphology data for 15,000-year-old segment B of La Jencia fault (12 of fig. 1). Maximum scarp-slope angle = θ, scarp heights = Hs, and dashed reference lines are same as in Figure 3.

and C (fig. 11) are clearly Holocene and resemble those of other scarps about 5,000 years old. Fault segment B has scarps (fig. 12) that are nearly identical to those of the Lake Bonneville shoreline (15,000 years B.P.), and the scarps along fault segment D (fig. 13, estimated at 33,000 years old) are clearly more degraded than those of the Bonneville shoreline. Thus, estimates of fault-scarp ages based on scarp-morphology data are consistent with the history of faulting constructed from soil-stratigraphic evidence in trench exposures and from the development of surface and buried soils in alluvium and fault-scarp-derived colluvium.

Socorro Canyon Fault (13)

The Socorro Canyon fault is named in this study for a series of closely spaced scarps at the mouth of Socorro Canyon (7 km southwest of Socorro). These fault scarps extend from a point 2 km north of San Antonio (fig. 1) to the mouth of Socorro Canyon. To the north, the Socorro Canyon fault forms the base of the Socorro and Lemitar Mountains, which are composed of uplifted and strongly rotated Precambrian through upper Miocene rocks (Chamberlin, 1980). Vertical offset along the Socorro Canyon fault system since 9 m.y. B.P. is conservatively estimated at 1,200 m on the basis of the elevation of upthrown and downthrown (buried?) rhyolite.

Heights of fault scarps near Socorro Canyon are 0.7 to 0.8 m in uppermost Pleistocene terrace deposits, 3.5 to 5 m in upper Pleistocene terrace deposits, and 15 to 25 m in middle and lower(?) Pleistocene piedmont-slope deposits. Most of the scarp-morphology data (fig. 14) suggest that late Pleistocene movement occurred along these faults, although the smallest scarps could have formed during the Holocene or latest Pleistocene. However, scarps on the two youngest terrace deposits in Socorro Canyon are preserved for a length of only about 150 m, and because these scarps vary little in height, they do not form a well-defined data set in Figure 14. The Socorro fault is considered to be both recurrent and segmented because of the progressively larger scarp heights formed in Pleistocene deposits and the different ages of most recent movement along its length.

CONCLUSIONS

Quaternary and Pliocene faults are abundant in the La Jencia and southern part of the Albuquerque-Belen basins of the central Rio Grande rift in New Mexico. These faults cut surficial deposits of middle to late

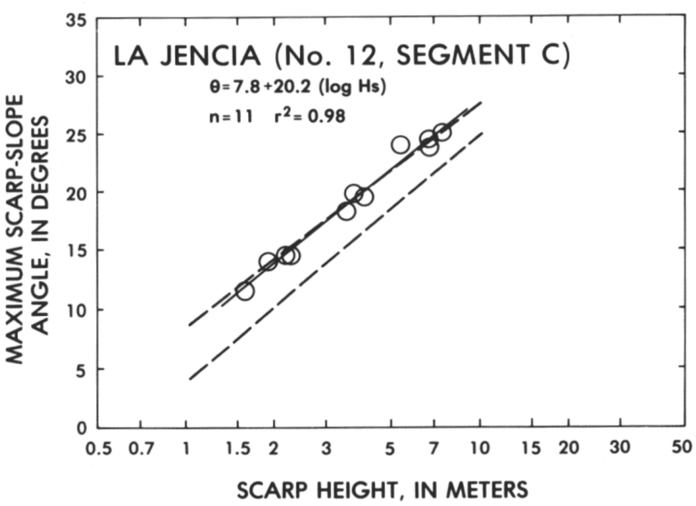


Figure 11. Scarp-morphology data for 5,000-year-old segment C of La Jencia fault (12 of fig. 1). Maximum scarp-slope angle = θ, scarp heights = Hs, and dashed reference lines are same as in Figure 3.

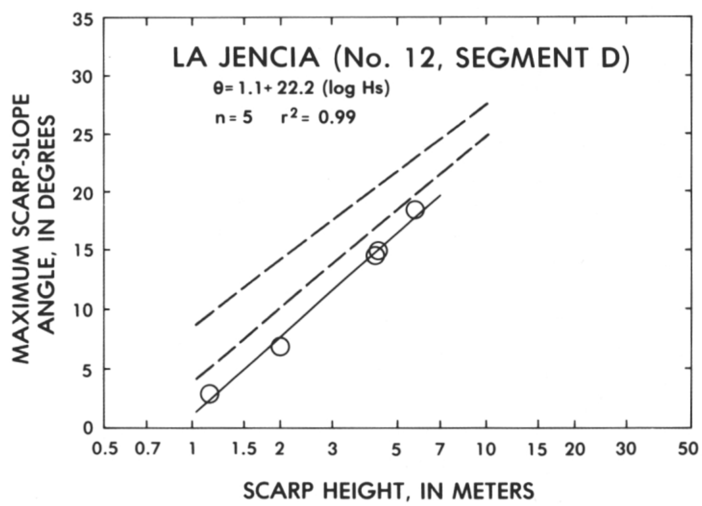


Figure 13. Scarp-morphology data for 33,000-year-old segment D of La Jencia fault (12 of fig. 1). Maximum scarp-slope angle = θ, scarp heights = Hs, and dashed reference lines are same as in Figure 3.

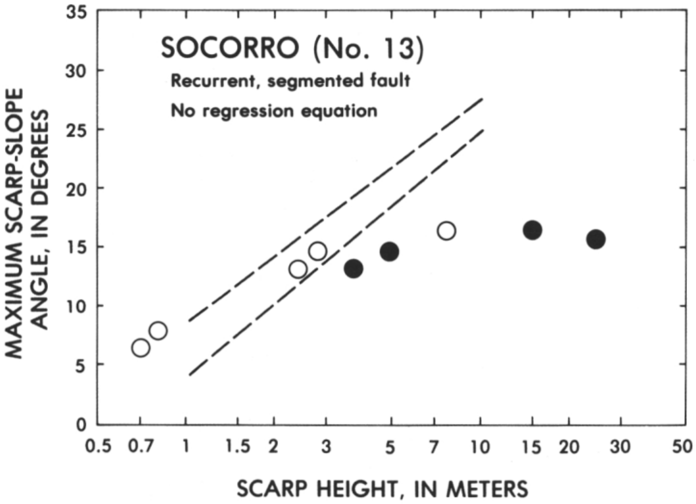


Figure 14. Scarp-morphology data for Socorro Canyon fault (13 of fig. 1). Dashed reference lines are same as in Figure 3.

Pleistocene age or are exposed in basin-fill deposits of Pliocene through middle Pleistocene age. Morphologic, pedologic, and geologic data collected along some of the major Quaternary and Pliocene fault scarps indicate that many were formed during the late Pleistocene (150,000 to 10,000 years B.P.).

Surface rupturing of Holocene (less than 10,000 years) age occurred only on three segments of the La Jencia fault and, possibly, on small segments of the Coyote Springs and Socorro Canyon faults. Faults with early? Holocene or latest Pleistocene surface ruptures include two segments of the La Jencia, the Bernalillo County Dump, the Coyote Springs, the Loma Blanca, and the Socorro Canyon faults. In addition to these faults, those whose most recent surface ruptures date from the late Pleistocene include the Hubbell Springs, the Loma Pelada, and the Cliff faults.

Fault scarps formed in middle Pleistocene to Holocene surficial deposits in the study area are as much as 20 m high; those faults with recurrent movement generally have scarps higher than 7 to 10 m. The highest scarps in the study area, which are formed in lower Pleistocene or Pliocene deposits along the Hubbell Springs (30 m) and Socorro Canyon (25 m) faults, are clearly the product of recurrent movement, as evidenced by increasing amounts of displacement in progressively older surficial deposits.

The La Jencia fault forms the western margins of the La Jencia basin and of the Pliocene-Pleistocene Rio Grande rift in central New Mexico. Scarps of the La Jencia fault are the product of singular movements along discrete fault segments during the latest Pleistocene and Holocene. Evidence of earlier Pleistocene movement was observed only along the northern third of the La Jencia fault, and this is restricted to 1- to 2m-high surface ruptures at about 150,000 years B.P. These data indicate that most of the La Jencia fault underwent a long period of Pleistocene quiescence before an episode of latest Quaternary deformation.

Many faults in the Albuquerque-Belen basin have displaced the Llano de Albuquerque during the past 500,000 years. One such fault, the Bernalillo County Dump fault, has a well-documented history of four episodes of movement with recurrence intervals of 90,000 to 190,000 years. In view of the distribution, size, and number of faults that could have similar recurrence histories, earthquakes and surface ruptures may have been associated with hundreds of fault segments in the Albuquerque-Belen basin during middle and late Pleistocene time. Taken together, these faults and fault segments must have a combined recurrence interval considerably less than that of any individual fault—possibly as short as 1,000 to 10,000 years.

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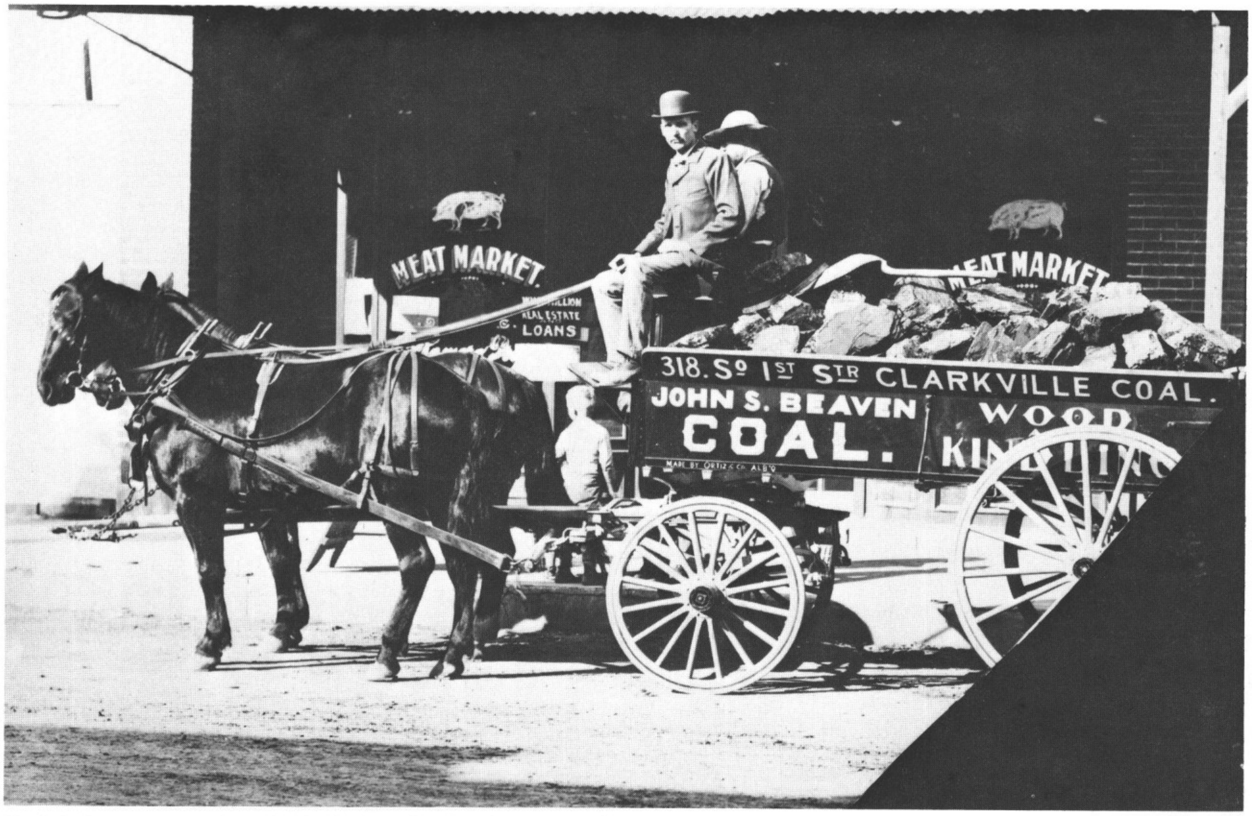

Coal delivery wagon circa 1900. Until well after the turn of the century, many local homes and businesses were heated by coal mined in the Gallup and Madrid areas. Courtesy of Albuquerque Museum Photoarchives.

View looking northwest from the sand hills of the East Mesa about 1890 (Albuquerque Museum Photoarchives).