Development and deformation of Quaternary surfaces on the northeastern flank of the Jemez Mountains

Charles D. Harrington and Aldrich, Merritt J., Jr.

1984, pp. 235-239. https://doi.org/10.56577/FFC-35.235

in:

Rio Grande Rift (Northern New Mexico), Baldridge, W. S.; Dickerson, P. W.; Riecker, R. E.; Zidek, J.; [eds.], New Mexico Geological Society 35th Annual Fall Field Conference Guidebook, 379 p. https://doi.org/10.56577/FFC-35

This page is intentionally left blank to maintain order of facing pages.

DEVELOPMENT AND DEFORMATION OF QUATERNARY SURFACES ON THE NORTHEASTERN FLANK OF THE JEMEZ MOUNTAINS

CHARLES D. HARRINGTON' and **M. J. ALDRICH,** Jr.
Mail Stop D462, Los Alamos National Laboratory, Los Alamos, New Mexico 87545
('Permanent address: Department of Marine, Earth and Atmospheric Sciences, North Carolina State University, Raleigh, North Carolina 27650)

INTRODUCTION

The eastern Jemez Mountains volcanic pile overlies the western margin of the Espanola Basin, one of three en-echelon basins forming the central portion of the Rio Grande rift. The Jemez Mountains have served as a major source of volcanics (between approximately 13 and 0.13 m.y. ago; Gardner and Goff, this guidebook) and volcaniclastic materials (from approximately 10 m.y. ago to present) into this portion of the basin. The local basin dynamics therefore reflects not only regional tectonic events related to the development of the central rift, but also the more localized volcanic and tectonic pulses within the Jemez Mountains. During the Pliocene and Quaternary, a sequence of erosional surfaces developed along the northeastern flank of the Jemez Mountains. Their surfaces slope away from the mountains and grade toward the axial streams (Rio Chama or Rio Grande) of the Espanola Basin.

Studies of the Quaternary development of the Espanola Basin include investigations by Bryan (1938), Manley (1976), Kelley (1979), and Dethier and Manley (in press). In this paper we present a progress report on a tectonic—geomorphic study of an area west of Hernandez, New Mexico, in the northeastern Jemez Mountains—northwestern Espanola Basin (Fig. I).

QUATERNARY EROSION SURFACES

Surface Characteristics

The primary topographic features within the study area (Fig. 1) are three erosional surfaces that developed across this portion of the northeastern Jemez Mountains during the Quaternary. The surfaces gradually

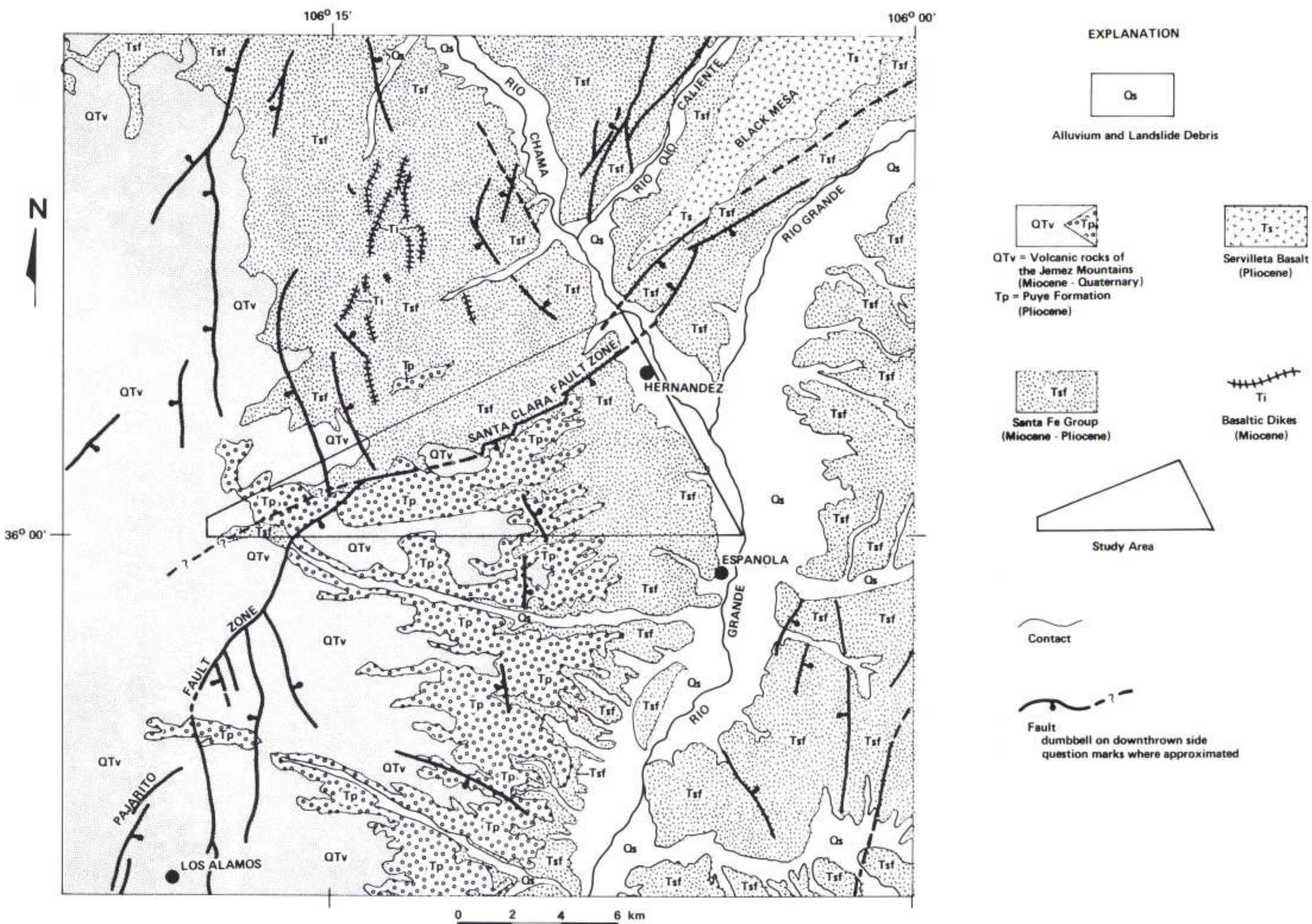


FIGURE 1. Location of field area along and south of the Santa Clara fault zone, northeast Jemez Mountains. Modified from Kelley (1978) and Dethier and Manley (in press).

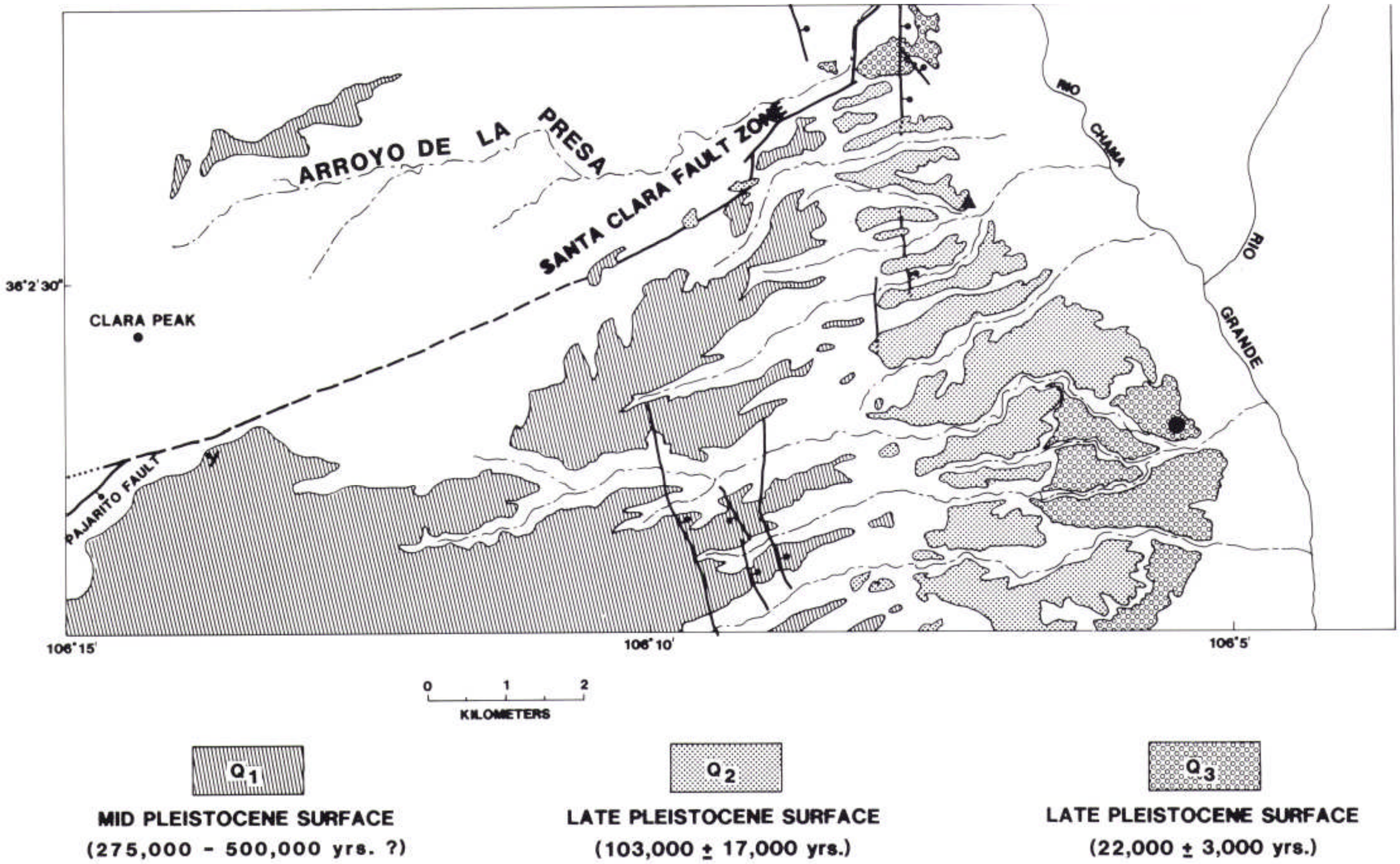


FIGURE 2. Quaternary surfaces within the study area west of Hernandez, New Mexico. Δ – Location of dated sample from Q_2 surface; o – location of dated sample from Q_3 surface.

descend in elevation, forming a series of three steps that slope northeast to east and cut across the upper Santa Fe Group (Chamita Formation and Ojo Caliente Member of the Tesuque Formation, Miocene), Puye Formation (Pliocene), and Bandelier Tuff (Quaternary). They are primarily erosional surfaces (including pediments) with a relatively thin gravel and sand veneer. The two lower surfaces also extend as terraces up major arroyos at elevations below the next higher (older) surface.

Remnants of the highest, and oldest, surface (Q_1) have the greatest areal extent, descending from elevations of 2,200 m near the mountains to 1,920 m along its eastern margin (Fig. 2). The surface, which cuts across the Bandelier Tuff, Puye Formation, and parts of the Santa Fe Group, is graded to the northeast with an average surface slope of 15 in/km (1.5%), which is significantly gentler than the slopes of the two younger surfaces (Fig. 3). Projection of this profile gradient east to the Rio Grande indicates base level on the axial stream at Q_1 time was 1,895 m, 185 m above the present Rio Grande elevation (1,710 m). Relief on the Q_1 surface is generally less than 10 m except along major arroyos and several scarps where it steps down to the east. The scarps are structural in origin and are related to a series of younger, north-trending faults. Capping deposits on the Q_1 surface consist mainly of a thin veneer of cobble gravel and sand. Although the Q_1 surface has undergone some regrading since formation, the primary type of its erosional modification has been arroyo incision and enlargement. Major arroyos that head on the Q_1 surface were incised as much as 100 m before they stabilized during Q_2 surface formation. These arroyos had wide valley floors (200-300 m) when the Q_2 surface formed. Remnants of these arroyo floors remain as terraces lying well above (>20 m) present channel elevations. These terrace segments are graded downstream onto remnants of the Q_2 surface.

The Q_2 surface extends basinward from the foot of the dissected scarp (elevation of 1,840 m), which separates this surface from the Q_1 surface (Fig. 2). The Q_2 surface is cut into the Chamita Formation and Ojo Caliente Member, has an average width of 4 km, an elevation of 1,780 m at its basinward margin, and a surface gradient of 29 m/km (3%). Projection of this erosional surface to the Rio Grande indicates base-level elevation was approximately 1,755 m during Q_2 time, 45 m above the present Rio Grande (Fig. 3). The Q_2 surface is capped by alluvial-fan and colluvial deposits along its western margin, while farther downslope to the east the erosional surface is veneered with gravel and sand deposits generally 3-6 m thick, with thicknesses of 10 m near the Rio Grande (Dethier and Manley, in press). The surface is displaced in several places by north-trending faults producing a series of steps, up

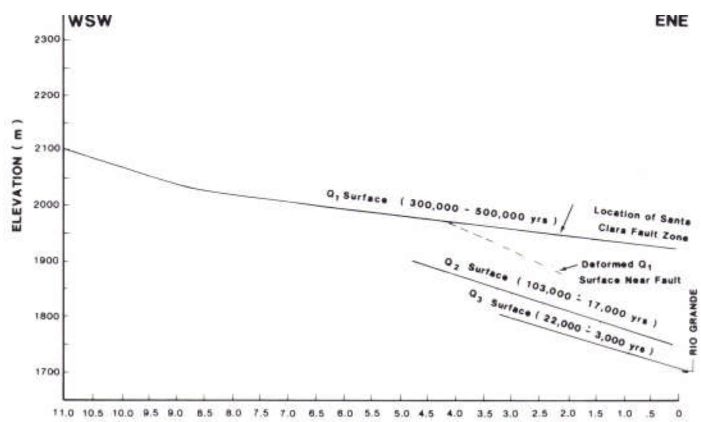


FIGURE 3. Profiles of Quaternary surfaces south of the Santa Clara fault zone and west of Hernandez, New Mexico. The Q_2 and Q_3 surfaces slope more eastwardly than the Q_1 surface and do not cross the Santa Clara fault zone.

to 30 m high, which step down to the east. Relief on the surface, not related to structure, is less than 10 m. Erosion by eastward-flowing streams incised the Q_2 surface by 43 m (2 km west of the Rio Grande) before reaching grade during formation of the Q, surface. Narrow terrace remnants, which flank arroyos cut into the Q, surface and grade to Q, remnants, are parts of these graded valley floors.

The Q, surface, cut primarily across the Chamita Formation, has the most limited areal extent of the three surfaces and generally lies basinward of the Q, surface (Fig. 2). The surface slopes eastward from maximum elevations of 1,795-1,735 m at its eastern margin. Surface gradients on the surface are 27 m/km and project to an elevation of 1,720 m at the Rio Grande, 10 m above present river level (Fig. 3). The Q_3 surface is erosional in its upper reaches and is generally capped by a veneer of sand and gravel less than 7 m thick. In its lower reaches the surface is aggradational, suggesting a rise in Rio Grande base level during its formation. Displacement of the Q, surface has occurred along various north-trending faults producing stepped topography similar to the Q, and Q surfaces.

Time of Formation of Erosional Surfaces

The time of formation for the oldest erosional surface (Q,) within the area can be estimated based on several lines of geologic evidence. For the two younger surfaces, ^{230}Th-^{234}U dating has yielded absolute minimum dates of formation (see Appendix).

The Q, surface truncates both members of the Bandelier Tuff, thus establishing its maximum age as less than 1.1 m.y. Soils on the Q, surface have a well-developed horizon of carbonate accumulation. Gile and others (1966) have found that such carbonate accumulation in soils develops through a particular sequence of morphological stages that are time dependent (see Dethier and Demsey, this guidebook). Based on correlation with soils on dated geomorphic surfaces bordering the Rio Grande valley in the Albuquerque Basin (Bachman and Machette, 1977), the presence of such soil-carbonate stages can be used to obtain an approximate time of surface stabilization and beginning of soil development. The oldest soils found on the Q, surface within the study area contain a laminar carbonate horizon and thus would be classified as stage IV (Gile and others, 1966). The presence of such advanced soil horizons suggests that the Q, soil is a minimum of 250,000 years old (Bachman and Machette, 1977). Additional evidence for the minimum age of Q,-surface development can be derived from estimates of erosion rates. The Q, surface lies 90 m above the Q_2 surface that in turn lies 43 m above the Q, surface. Utilizing the ^{230}Th-^{234}U dates of formation for the two lower surfaces (discussed below), the 43 m of arroyo incision of the Q_2 surface occurred in approximately 80,000 years. If equal incision rates are assumed (the authors realize that such an assumption is tenuous, at best) during dissection of the Q, surface, then the Q, surface formed approximately 170,000 years before the Q, surface, or 275,000 years ago. We believe that an age for the Q, surface of 275,000-500,000 years is likely. Such an age estimate is broadly correlative with the highest (Q,) surface of Dethier and Demsey (this guidebook) north of our area.

Soils on the Q_2 surface have a stage-Ill pedogenic carbonate horizon. Such a stage suggests a minimum age for this surface of approximately 100,000 years (Bachman and Machette, 1977). Carbonate coatings were extracted from pebbles from the K horizon of soils on this surface. ThU dating of the carbonate yielded an age of 103,000± 17,000 years (see Appendix). This date for the Q_2 surface is consistent with other geologic data from the area, but does not correlate with any ages estimated by Dethier and Demsey (this guidebook) for surfaces to the north.

The youngest Quaternary erosional surface (Q,) within the area is also capped by deposits with pedogenic horizons of carbonate accumulation. The more developed soils have carbonate-horizon morphologies similar to stage II of Gile and others (1966). Th–U dating of carbonate coatings from pebbles extracted from the Q, surface soil shows that these coatings are 22,000 ± 3,000 years old. This age is consistent with geologic and soil data related to this surface and indicates our Q, surface correlates with either the Q, or Q_4 surface of Dethier and Demsey (this guidebook).

QUATERNARY TECTONICS

Several faults and fault zones have exerted an influence on the development of the present-day topography (Fig. 2). These include the Pajarito fault zone, Santa Clara fault zone (new name), and a series of north-trending faults. The Pajarito fault zone bounds the area on the west, and has normal, east-side-down displacement. The Santa Clara fault zone trends northeast and has had a complex history of oblique-slip motion in which the south side has moved down relative to the north side. A number of generally north-trending down-to-the-east normal faults are also present in this area.

Quaternary movement on the Pajarito and Santa Clara fault zones resulted in rotation of the Q, surface, decreasing its gradient and changing its slope direction from east to northeast. Evidence that the Q, surface was initially graded to the east and later rotated is derived from analysis of drainage channels cut into it (Fig. 4). Major arroyos incised into this surface trend east across the slope of the surface rather than parallel to the slope dip. If this surface formed with an original northeast slope, major arroyos should trend parallel to the slope direction. Most of the tributaries to the major east-draining arroyos, which head within the area of the Q, surface, trend northeast, parallel to the present-surface slope. Only a few tributaries enter the north side of the larger east-trending arroyos. This asymmetry may be the result of formation of the tributaries after tilting of the Q, surface to the northeast. Alternatively, the tributaries may have formed prior to rotation of the surface, but only those with courses approximately parallel to the new slope were not abandoned and destroyed. Evidence for deformation of the Q, surface by movement along the Santa Clara fault zone is the marked increase in gradient along the surface near the fault. In sections 12 and 14 of T21N, R7E, the Q, surface is cut across beds of the Puye Formation. The base of the Puye at this location is at 1,890 m, while 0.5 km to the south its elevation is 1,920 m—a slope of 61 m/km. This slope on the base of the Puye differs in orientation and far exceeds its slope in other areas. The Q, surface along the same traverse has a surface gradient of 45 m/km, approximately three times its gradient away from the fault (Fig. 3). Projection of the lower-gradient portion of the Q, surface to the fault zone places the surface at an elevation approximately 50 m higher than that obtained by a similar projection of the portion with the steeper gradient. Thus, depression of the block southeast of the Santa Clara fault zone by about 40 m following formation of the Q, surface is indicated.

East-draining arroyos near (within 1 km) the Santa Clara fault zone, which head in the Puye, have extensive gravelly valley fills. These fills are preserved as terraces composed mostly of cobble-sized gravel in the upper reaches and pebble-sized gravel downstream. The surfaces of these terraces grade downstream to remnants of the Q_2 surface. Arroyos farther to the south of the fault zone do not contain such fills. These gravelly valley fills probably resulted from reduction of gradients along the east-trending arroyos by downwarping of the area during movement along the Santa Clara fault zone following formation of the Q, surface. Later, these fills were regraded to the Q surface level as that surface formed. There apparently has been no appreciable movement on the Santa Clara fault zone since the development of the Q_2 surface.

Normal Faults

North-trending normal faults cut all three surfaces. Movements along these normal faults, which generally trend perpendicular to surface slope, have created a series of stepped surface segments, most of which are down-to-the-east. As none of the faults completely cross the area, the number and location of steps along east–west profiles differs at various locations. Most of these north-trending faults show Quaternary displacement, some in excess of 10 m. Recent displacement along several of these faults is indicated. One north–northwest-trending fault, showing several recurrent movements, has displaced a basalt boulder gravel formed on the Q, surface (22,000 ± 3,000 years) a minimum distance of 10 m. Soil profiles across the fault are significantly different, suggesting latest movement was quite recent. Other north-trending faults within the area also indicate similar recent movements. The down-to-the-east movement on these faults probably increased gradients and

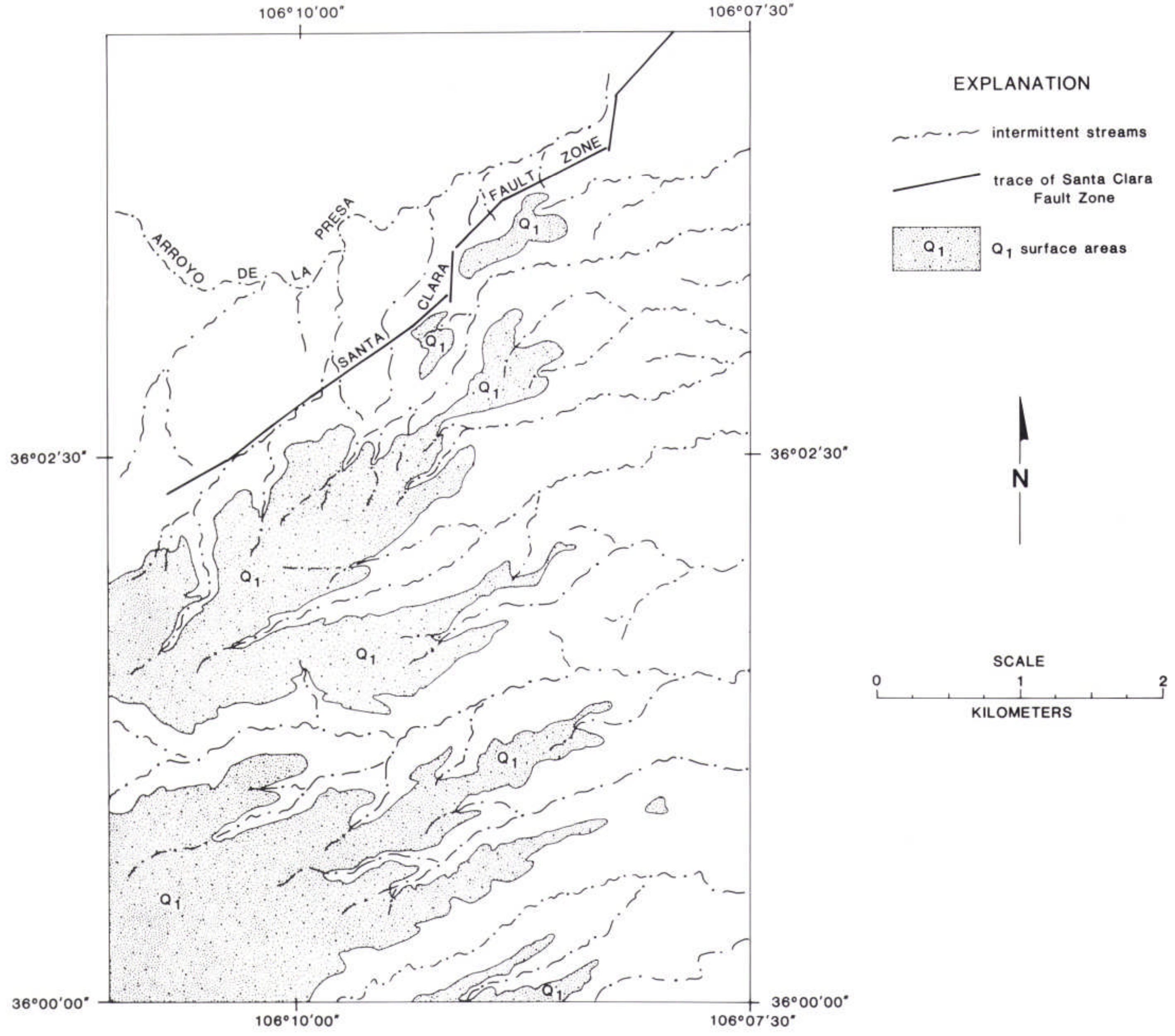


FIGURE 4. Drainage map of streams heading on or crossing the Q_1 surface within the study area.

erosive ability along the east-trending arroyos. The periods of arroyo incision that marked the termination of development of the Q, and surfaces were significantly influenced by displacements on the north-trending faults.

DISCUSSION

Tectonic—geomorphic analysis along and south of the Santa Clara fault zone permits a general reconstruction of Quaternary geomorphic and tectonic events affecting this portion of the northeastern Jemez Mountains and central Rio Grande rift.

The oldest erosional surface (Q,) is believed to have formed within the interval from 275,000 to 500,000 years B.P. Prior to the formation of this surface, significant movement had occurred along the Santa Clara fault zone. Analysis of slickensides indicates this movement was dominantly oblique slip. South of the fault, the Puye Formation overlies the Chamita Formation (upper Santa Fe Group); however, 2 km north of the fault a Puye(?) outcrop directly overlies the Ojo Caliente Member (middle Santa Fe) at an elevation of 2,040 m (Dethier and Manley, in press). Adjacent to the fault on the downdropped block the Chamita-Ojo Caliente contact is at 1,980 m, thus suggesting that a minimum of 60-m uplift with an unknown amount of lateral displacement occurred following deposition of Santa Fe Group sediments, but prior to deposition of the Puye. This time interval (-4.5-3.0 m.y.) represents an erosional episode leading to the development of an erosion surface called the Ortiz by Bryan (1938). Continued motion on the Santa Clara fault zone during and following deposition of the Puye Formation is indicated. The thick (>100 m) wedge of Puye beds south of the fault zone differs markedly from the few scattered outcrops to the north. The latter are elongated outcrops that occur adjacent to major arroyos and generally parallel their trend. These deposits may represent gravel fills in paleochannels cut in the erosional surface. If true, this suggests that either the wedge-like Puye deposits were never deposited north of the fault or, more likely, the upper Puye beds were so thin north of the fault zone that they eroded away between --2.1 and 1.5 m.y. ago. In either case an elevated area must have existed north of the fault zone following formation of the pre-Puye erosion surface. Although the amount of uplift that occurred between the beginning of Puye deposition and formation of the Q, surface is not known, it was certainly of a much lesser magnitude than that which immediately followed deposition of the Santa Fe Group.

Both the Pajarito and Santa Clara fault zones were active following formation of the Q, surface (275,000-500,000 years B.P.). Deformation of the Q, surface along the Santa Clara fault zone indicates approximately 40 m of downwarping of this surface by movement on the fault.

The period of erosion that led to the dissection of the Q, surface terminated in the development of the Q, surface, culminating prior to 103,000 years ago. Deformation of this surface has been dominated by motion along the north-trending normal faults. Displacements on these faults have segmented the surface producing a sequence of steps (up to 25 m in height) generally down-to-the-east. No strong evidence exists for significant vertical motion on the Santa Clara fault zone during or following formation of the Q_2 surface. It is not clear if the initiation of dissection of the Q_2 surface was related to lowering of base level along the axial drainage by movement on faults near the southern margin of the Espanola Basin, but the possibility of this having happened seems reasonable. Certainly, dissection of the Q_2 surface within the study area was markedly influenced by movement along the north-trending faults.

There are indications that the period from 120,000 to 100,000 years ago was a time of extension within the central rift. Machette (1978) found that movement occurred along the County Dump fault in the north Albuquerque Basin 120,000 years ago. McCalpin (1982), based on analysis of offsets in various-age glacial deposits, reported that displacements occurred on a number of faults along the west flank of the Sangre de Cristo Mountains in Colorado (eastern margin of San Luis Basin) about 120,000 years ago. Apparently, movement on the north-trending faults west of Hernandez also occurred at this time.

Formation of the Q, surface was completed by about 22,000 years ago. Movement on several of the north-trending faults occurred during and subsequent to this time. During the formation of this surface the lower reaches of Arroyo de la Presa extended across the Santa Clara fault zone. The Arroyo de la Presa no longer follows this portion of its Q channel, but instead turns north around an outcrop of a steeply dipping basalt flow, following a longer course to the Rio Grande than its Q, channel. We suggest that recurrent movement on the north- and northwest-trending faults increased gradients along the Q, paleochannel, causing rapid incision. The stream occupying the paleochannel was hindered by the presence of a resistant basalt flow cropping out across the channel. Increased gradient along an adjacent arroyo permitted rapid headward extension of the stream at an elevation below that of the Q, paleochannel. This stream eventually captured the Arroyo de la Presa stream, rerouting it north around the margin of the flow. Arroyo incision of the Q, surface has continued for the past 22,000 years at more rapid rates than those which existed earlier in the Quaternary, except for periods in the Holocene when alluvial terraces were formed (see Dethier and Demsey, this guidebook). Stratigraphic and geomorphic (soils) evidence indicates that recurrent movements are still occurring on the north-trending normal faults.

The ultimate cause of incision and abandonment of the Quaternary erosional surfaces is not certain. The role of climate in the development, or termination in development, of geomorphic surfaces is difficult to assess. Episodic climatic shifts which occurred during later Quaternary time, and the attendant changes in vegetation and discharge of water and sediment, must have produced a pronounced effect on surface development. Gile and others (1981) found that in the Las Cruces area of New Mexico times of climatic change from semiarid to arid conditions (associated with change from pluvial to interpluvial intervals) were marked by valley incision and a concomitant increase in landscape instability. The arid conditions were characterized by significant decreases in effectiveness of vegetative cover and increases in erosion and sedimentation. Climatic shifts from arid to semiarid climates were times of increasing landscape stabilization and more continuous vegetative cover (Gile and others, 1981).

Comparison of the timing of late Quaternary surface development and valley incision in the northeast Jemez Mountains to the Las Cruces area indicates that these areas have virtually the same landscape-evolution chronology. Valley incision in the Las Cruces area, which initiated dissection of the Tortugas and Picacho surfaces (<150,000 and <25,000 years, respectively), generally coincides with the beginning of valley incision into the Q2 and Q, surfaces in the Espanola area. This coincidence in timing of late Quaternary landscape development suggests that climatic changes had a significant influence on the formation of surfaces within the northeast Jemez Mountains.

It is not clear whether climatic influences or basin-margin tectonics were the predominant cause of surface dissection. However, there 6 strong evidence that the terminations in development of the Q_2 and Q surfaces were significantly influenced by recurrent movements along the north-trending faults.

APPENDIX

U–Th ages of pedogenic-carbonate rinds from the underside of peb bles were determined by T. L. Ku. Activity ratios of ^{234}U/^{238}U and 'Th ^{214}U were calculated from the radiochemical data in Table A-1. The ages derived from these ratios indicate the time elapsed since carbonate illuviation began. Uncertainties given represent one standard deviatior derived from counting statistics.

Sample 2-84-MJA, 36°03'05"N, 106°07'20"W. Q_2 surface. San Juar Pueblo 7/2' quadrangle, New Mexico. Activity ratio ^{23}1.1/^{238}U 1.31 ±.14 ^{23}Th/^{234}U .632 ± .065. Age 103 ± 17 Ka.

Sample 4-84-MJA, 36°03'13"N, 106°07'57"W. Q, surface. Chili 7'/2 quadrangle, New Mexico. Activity ratio ^{234}u/^{238}U 1.19 ± .11, 23,11/234L .185 ± .019. Age 22 ± 3 Ka.

REFERENCES

TABLE A-1. Radiochemical data on leachate (L) and residue (R).

Sample	f_L		Disintegrations per minute per gram of total sample			
			^{238}U	^{234}U	^{232}Th	^{230}Th
2-84-MJA	0.899	L	.662±.024	.856±.029	.045±.003	.553±.012
		R	.214±.010	.233±.011	.194±.010	.220±.010
4-84-MJA	0.828	L	3.05±.12	3.61±.14	.058±.002	.912±.015
		R	.599±.024	.690±.027	.097±.005	.529±.020

Bachman, G. 0., and Machette, M. N., 1977, Calcic soils and calcrete in the southwestern United States: U.S. Geological Survey, Open-file Report 77-794, 163 pp.

Bryan, K., 1938, Geology and ground-water conditions of the Rio Grande depression in Colorado and New Mexico; *in* Rio Grande joint investigation in the Upper Rio Grande Basin in Colorado, New Mexico and Texas: National Resources Committee, Regional Planning, pt. 6, pp. 197-225.

Dethier, D. P., and Manley, K. (in press), Geology of the Chili quadrangle, Rio Arriba County, New Mexico: U.S. Geological Survey, Miscellaneous Field Studies Map MF.

Gile, L. H., Peterson, F. F., and Grossman, R. B., 1966, Morphological and genetic sequences of carbonate accumulation in desert soils: Soil Science, v. 101, no. 5, pp. 345-360.

__, Hawley, J. W., and Grossman, R. B., 1981, Soils and geomorphology in the Basin and Range area of southern New Mexico—Guidebook to the Desert Project: New Mexico Bureau of Mines and Mineral Resources, Memoir 39, 222 pp.

Kelley, V. C., 1978, Geology of the Espanola Basin, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Geologic Map 48.

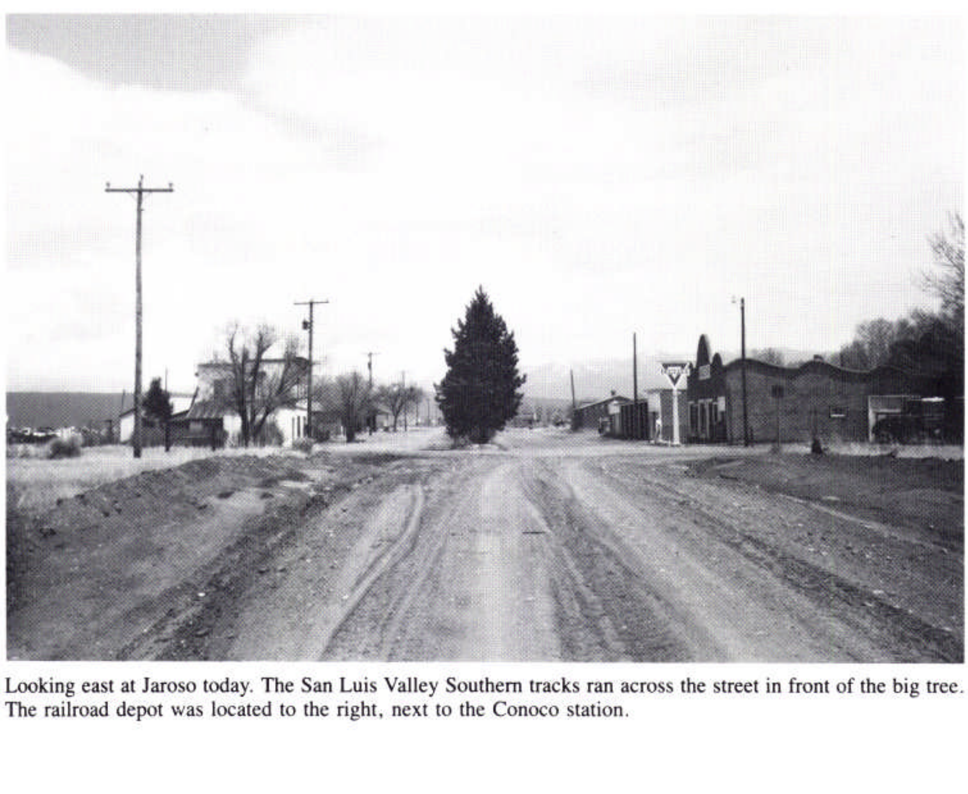
__, 1979, Geomorphology of the Espanola Basin: New Mexico Geological Society, Guidebook 30, pp. 281-288.

Machette, M. N., 1978, Dating Quatemary faults in the southwestern United States by using calcic paleosoils: U.S. Geological Survey, Journal of Research, v. 6, no. 34, pp. 369-381.

Manley, K., 1976, The late Cenozoic history of the Espanola Basin, New Mexico: Ph.D. thesis, University of Colorado, Boulder, 171 pp.

McCalpin, J. P., 1982, Quatemary geology and neotectonics of the west flank of the northern Sangre de Cristo Mountains, south-central Colorado: Colorado School of Mines Quarterly, v. 77, no. 3, 97 pp.

The San Luis Valley Southern train at Jaroso in 1955. The grain elevator and the Conoco terminal in the background constitute the industrial district of Jaroso (photo by Bob Richardson).



Looking east at Jaroso today. The San Luis Valley Southern tracks ran across the street in front of the big tree. The railroad depot was located to the right, next to the Conoco station.