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TECTONIC HISTORY OF THE NORTHERN RIO GRANDE RIFT DERIVED FROM APATITE FISSION-TRACK GEOCHRONOLOGY

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INTRODUCTION

This study is concerned with the uplift history of the mountain ranges that bound the eastern margin of the Rio Grande rift in northern New Mexico (Fig. 1). The principal objectives of this paper are to present the results of fission-track dating of granitic rocks from three ranges on the eastern margin of the rift (Fig. 1), and to use these dates to infer the approximate timing and the rate of uplift and erosion in each range. These data are then used to place constraints on the paleogeographic evolution of northern New Mexico between the Late Cretaceous and the early Miocene. The paleogeography shows that the ranges on the eastern margin of the early rift were not as continuous along the length of the rift as the ranges observed today.

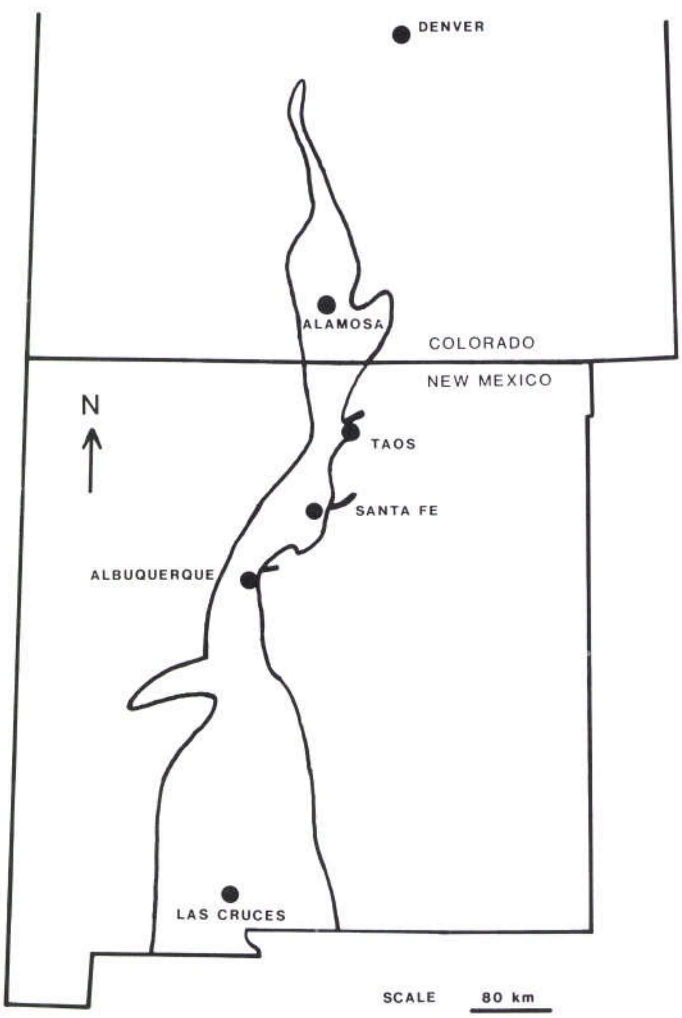

FIGURE 1. Location of fission-track-dating traverses in the Sandia Mountains near Albuquerque, in the Sangre de Cristo Mountains near Santa Fe (Santa Fe Range), and in the Sangre de Cristo Mountains near Taos (Taos Range). Rio Grande rift outlined by heavy, solid lines.

INTERPRETATION OF FISSION-TRACK DATES

Fission tracks in apatite anneal when exposed to relatively low temperatures for times on the order of millions of years (Naeser, 1979). When apatite cools from high temperatures during uplift and erosion, it passes through a temperature range where fission tracks are both annealed and retained (zone of partial stability). The temperature at which tracks effectively accumulate is termed the closure temperature (Haack, 1977). From experimental and field relations (Harrison and others, 1979), the effective closure temperature for apatite is estimated to be 100 + 25°C for cooling acting over 1-10 m.y.

The approximate timing and rates of uplift and erosion are derived from measurement of the variation in apatite fission-track age as a function of elevation in mountain ranges. Since the rocks at higher elevations in a modern mountain range cooled before the rocks now at lower elevations, the apatite ages at the higher elevations are older. The ages at the higher elevations can be used as a minimum estimate of the time of initiation of uplift, and the difference between the ages of the rocks at the higher and lower elevations can be used to calculate an apparent uplift rate. Parrish (1983) defines apparent uplift rate as "the rate at which the critical isotherm (100°C) moves downward with respect to the rock column." The apparent uplift rate equals the uplift—erosion rate only when (1) the critical isotherms remain horizontal, (2) the geothermal gradient remains constant, and (3) uplift equals erosion (Parrish, 1983).

The recent (less than 15 m.y. old) apparent uplift rate can be estimated in the following manner. The approximate present elevation of the 100°C isotherm (and hence zero age) can be found from heat-flow data using the thermal-resistance method of Bullard (1939), given a reasonable estimate of surface temperature and assuming that the thermal conductivity decreases 10% in the 0-100°C range (Birch and Clark, 1940). The apparent uplift rate is calculated from the difference between the zero age recorded at this elevation and the fission-track age at the lowest exposed elevation in the range.

INTERPRETATION OF TRACK-LENGTH MEASUREMENTS

A problem often encountered in interpreting fission-track ages is deciding whether a fission-track age represents the time that a rock slowly cooled through the partial stability zone (Fig. 2a), or whether the age has been partially reset during a recent thermal event (Fig. 2b). Examination of the fission-track-length distribution (Lal and others, 1968) can sometimes be used to distinguish between the thermal histories depicted in Figure 2.

The expected track-length distributions for the two thermal histories are shown in Figure 2. The slow-cooling case is characterized by a unimodal histogram skewed toward the longer tracks (Fig. 2c), while the thermal-event case is characterized by a bimodal histogram (Fig. 2d).

RESULTS

Sandia Mountains

The Sandia Mountains are an east-tilted fault-block composed of Precambrian granitic and metasedimentary rocks overlain by Mississippian to Cretaceous sediments. Samples for dating were taken on the west side of the range from the Sandia granite (1.44 + 0.4 b.y.; Brookins and Majumdar, 1982) and from aplitic dikes that cut the granite.

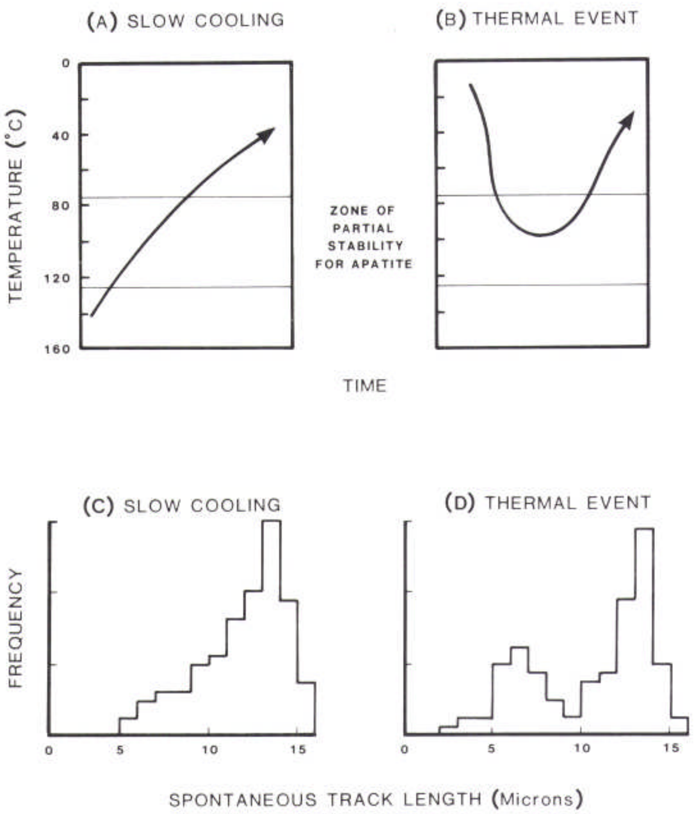

FIGURE 2. Time-temperature curves for (A) slow cooling and (B) thermal event. Expected track-length distributions for (C) slow cooling and (D) thermal event (after Gleadow and Duddy, 1982).

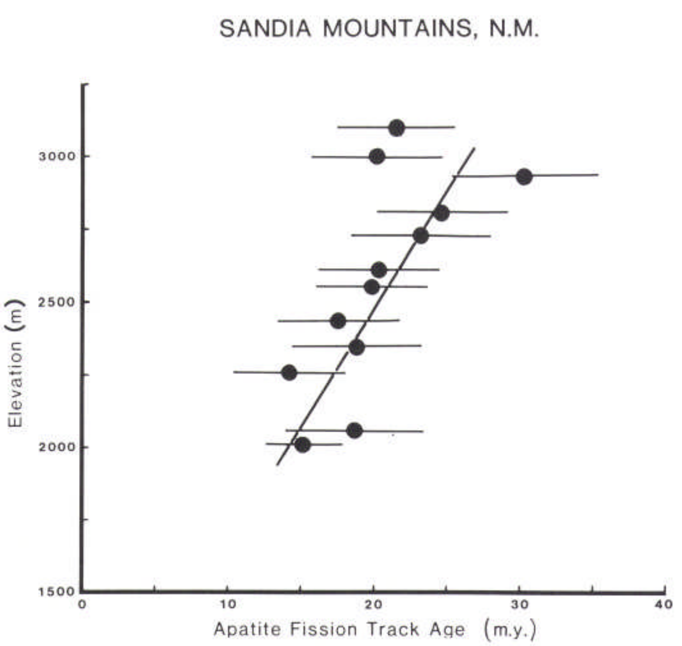

FIGURE 3. Apatite fission-track age vs. elevation for Sandia Mountains. Error bars represent two standard deviations. Solid line represents a least-squares fit to the data, yielding an apparent uplift rate of 81 m/Ma.

The apatite ages for this area (Fig. 3) show a clear relation with elevation, with an apparent uplift rate of 81 m/m.y. The track-length distributions (Fig. 4) suggest that the two highest points on the profile have been partially reset by thermal effects related to mineralization at the La Luz mine sometime in the late Tertiary.

The absence of latest Cretaceous and Paleocene rocks to the east and northeast of the range (Kelley and Northrop, 1975; Gorham and Ingersoll, 1979) implies that the Sandia region probably attained positive relief during the Laramide event. During the Eocene, the area was. eroded to low relief; the Sandia Mountains apparently did not act as a source area for the Eocene Galisteo Formation, which crops out north and cast of the range (Kelley and Northrop, 1975; Gorham and Ingersoll, 1979). The apatite fission-track age of 30 m.y. indicates that the Sandia granite was cooling during uplift and erosion in the Oligocene, at about the time that volcanism was active in the Cerrillos—Ortiz field 19-38 m.y. ago (Baldridge and others, 1980). Stearns (1953) pointed out that the Abiquiu(?) Formation is missing in the northern Sandia region, implying that the northern part of the range was uplifted in pre-Abiquiu(?) time (before 19-25 m.y. ago; Baldridge and others, 1980). This evidence is consistent with the fission-track-age data.

Two samples were collected to the south of the dating traverse at low elevations along the front of the range. The ages become progressively older to the south, suggesting that uplift and erosion during the early Tertiary were more active in the northern part of the range than they were to the south.

Santa Fe Range
(Sangre de Cristo Mountains)

The Santa Fe Range is composed primarily of the Precambrian Embudo Granite (coarse-grained biotite granite, granitic gneiss, and pegmatitic leucogranite; Miller and others, 1963), which forms a large, composite batholith that intrudes older schists, gneisses, and amphibolites. Rb—Sr and K—Ar ages ranging between 1,235 and 1,673 m.y. have been determined for the Embudo Granite in the Picuris Range and near Truchas Peaks, north of the fission-track-dating traverse (Register and Brookins, 1979).

In contrast to the post-Eocene fission-track ages observed in the other areas examined during this study, the apatite ages for this profile (Fig. 5) range from Late Cretaceous to early Eocene, reflecting Laramide uplift. The apparent uplift rate for the region during the Laramide event is 125 m/m.y.

Uplift of the Santa Fe Range during the Laramide event coincides with the deposition of the Paleocene Nacimiento and Eocene San Jose (Cub Mesa Member) Formations in the San Juan Basin (Baltz, 1967), and the Eocene Galisteo Formation in the Galisteo Basin (Gorham and Ingersoll, 1979). During the Eocene, the Santa Fe Range was eroded to low relief (Baltz, 1978). No sediments were derived from the Santa Fe Range until renewed uplift occurred in the late Miocene, when the area acted as the source for the sediments in the Santa Fe Group (Galusha and Blick, 1971).

Taos Range
(Sangre de Cristo Mountains)

Precambrian rocks that crop out in the Wheeler Peak—Gold Hill area in the Taos Range include tonalites, diorites, amphibolites, felsic volcanics and porphyries, and granites (Condie and McCrink, 1982). The U—Pb zircon dates for the tonalites and diorites are on the order of 1.75 b.y. (Condie and McCrink, 1982). The Precambrian rocks have been intruded by Tertiary granites related to the Latir volcanic field and the Questa caldera (Lipman, 1981). The 25.8-27.8-m.y.-old Rio Hondo pluton and the 22-m.y.-old Lucero stock (Rb—Sr dates from Hagstrum and Lipman, 1983) are exposed in the Wheeler Peak—Gold Hill area. Naeser (written comm. 1983) has determined apatite fission-track dates for both intrusions (Fig. 6, open symbols).

Fission-track samples for this study were collected from Precambrian outcrops in the vicinity of Wheeler Peak and from the Tertiary Rio Hondo pluton. The resulting ages (Fig. 6, closed symbols) correlate well with elevation, yielding an apparent uplift rate of 173 m/m.y.

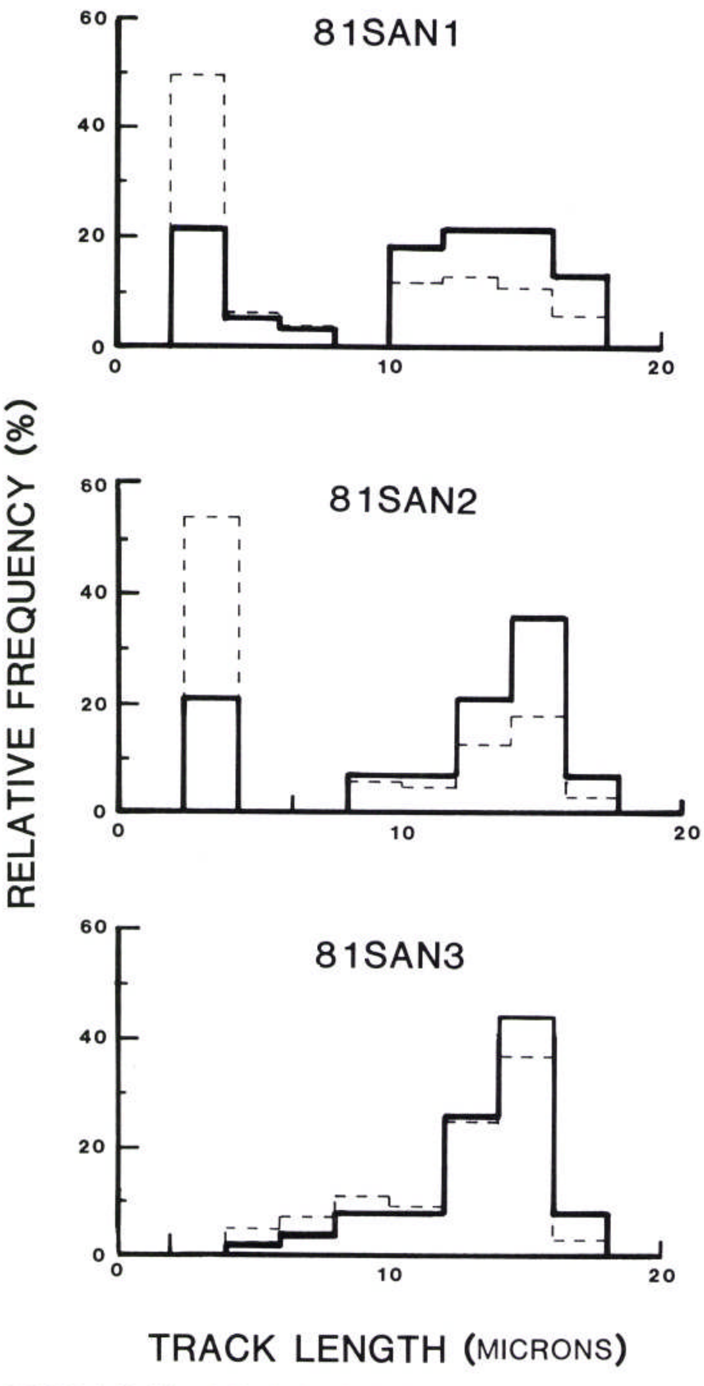

FIGURE 4. Track-length distributions for the three highest samples of the Sandia Mountain traverse (81SAN1, 3,095 m; 81SAN 3, 2,933 m). Solid line represents actual measurements, while dashed line represents the theoretical histogram corrected for measurement bias (Laslett and others, 1982).

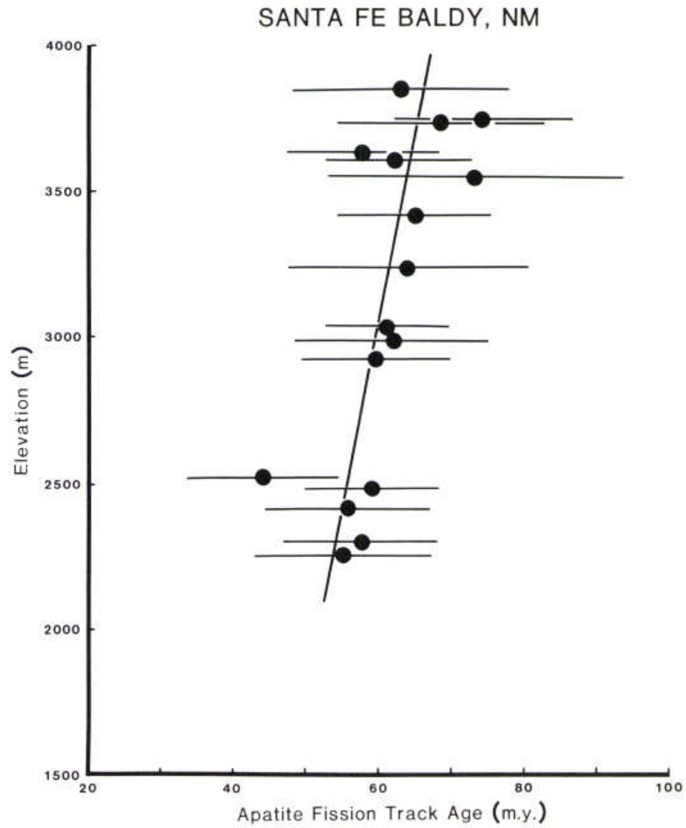

FIGURE 5. Apatite fission-track age vs. elevation for the Santa Fe Range. The least-squares fit gives an apparent uplift rate of 125 m/Ma.

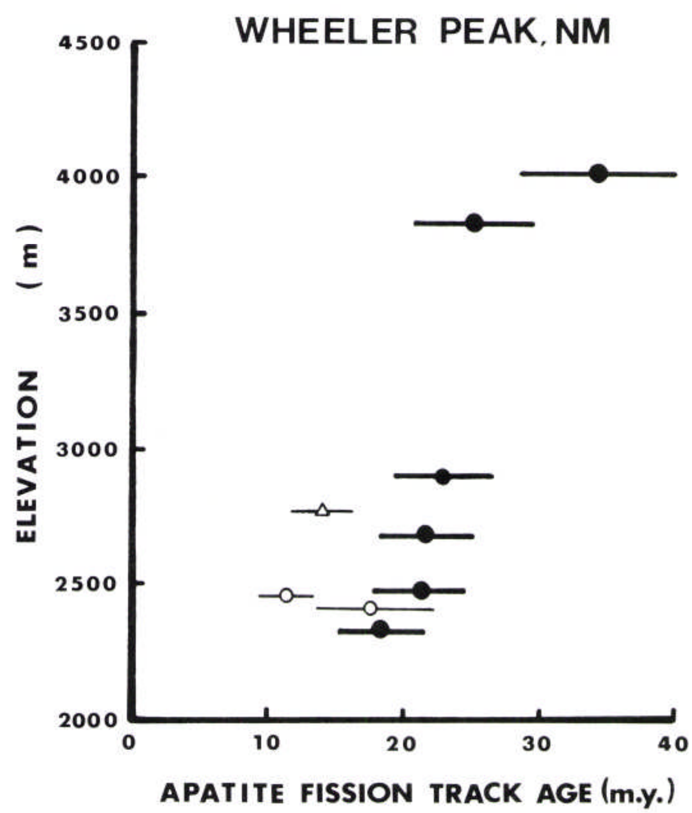

FIGURE 6. Apatite fission-track age vs. elevation for the Taos Range. Open symbols are data from Naeser (written comm. 1983); the open triangle is from the Lucero stock.

However, this correlation is deceptive because measurements of the track lengths in apatite from this traverse (Fig. 7) indicate that only the ages from the two samples at the highest elevations on Wheeler Peak (81WP1 and 81WP2) record uplift and erosion. The length distributions for the other four samples at lower elevations, which are from the Rio Hondo pluton and adjacent Precambrian rocks, are bimodal, suggesting thermal resetting. Apparently, the emplacement of the 22-m.y.-old Lucero stock has partially reset the apatite fission-track ages in the Rio Hondo pluton and the surrounding rocks. Hagstrum and Lipman (1983) and Johnson and others (1983) have also noted that the Rio Hondo pluton has been thermally altered by the Lucero intrusion. Consequently, the partially reset apatite fission-track ages cannot be used to study the uplift history of the area. The only usable dates for this region are the two ages from Wheeler Peak and the 14-m.y. age determined by Naeser for the Lucero stock (Fig. 6, open triangle). Since the Lucero stock age is probably an uplift age, it was used to estimate the apparent uplift rate of the area for the past 14 m.y. A detailed traverse through the Lucero stock is needed so that the more recent uplift history of the Taos Range can be constrained.

The Laramide uplift of the Taos Range portion of the Sangre de Cristo Mountains in the latest Cretaceous is recorded by the deposition of the Raton and Poison Canyon Formations in the Raton Basin (Baltz, 1965). Following the Laramide event, the area was eroded to low relief (McKinlay, 1956; Baltz, 1965). The fission-track ages from Wheeler Peak imply that uplift and erosion were in progress at least 35 m.y. ago; the earliest volcanism in the area occurred at about the same time (McKinlay, 1956).

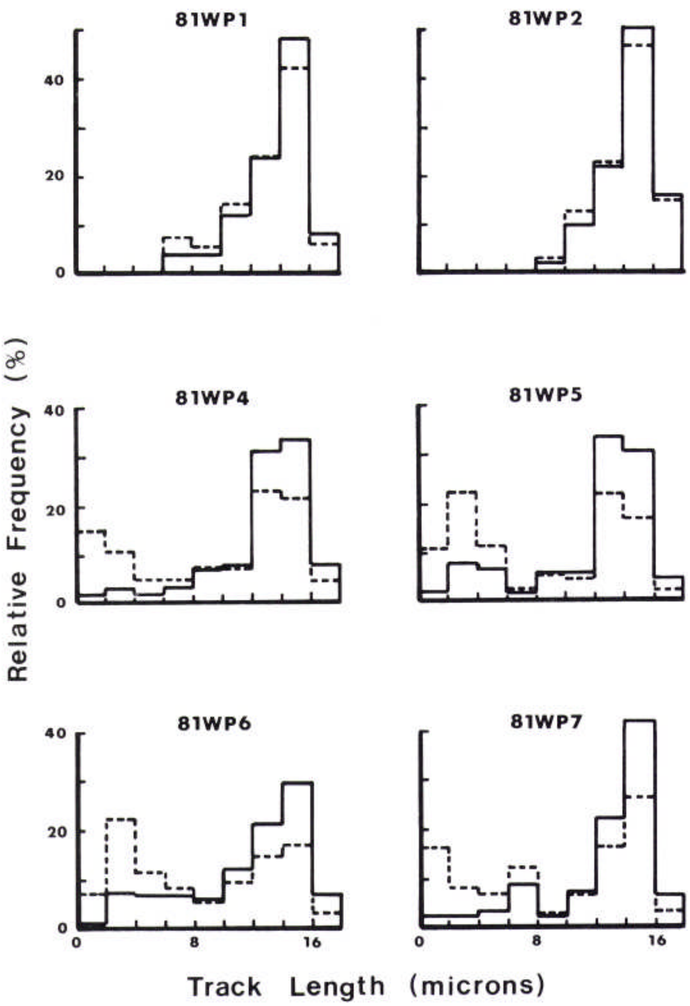

FIGURE 7. Track-length distributions from Taos Range, with 81WP1 at the highest elevation and 81WP7 at the lowest elevation. Symbols as in Figure 4.

DISCUSSION

Summary of Uplift Data for Northern New Mexico

Table 1 summarizes the uplift for the northern Rio Grande rift bas on this and previously published studies. The apparent uplift rates d rived from the fission-track data for each traverse for the past 14- m.y. were calculated using the heat-flow data of Reiter and others (197 and Edwards and others (1978). The apparent uplift rate computed t the Santa Fe profile from the heat-flow and fission-track data is unusual low since it is averaged over 55 m.y.

Apatite fission-track ages presented by Lindsey and others (198 for the eastern side of the Sangre de Cristo Mountains near Creston Colorado, range from 15.0 to 23.7 m.y. at elevations varying betwe 3,290 and 3,930 m. The apparent uplift rate for this area is about m/m.y., which is comparable to the rate found in the Sandia Mountai over the same interval. An eastward tilt of the Sangre de Cristo Mou tains is recorded by the ages from this traverse.

The uplift data of Axelrod and Bailey (1976) are based on study of flora preserved at Bernalillo (near Albuquerque) and Skull Rid (near Santa Fe). Axelrod and Bailey (1976) assumed that the decrea in mean annual temperature recorded by the flora was primarily due rising elevation. Based on their data, they calculated that 1,200 m epeirogenic uplift had occurred in these areas over the past 14 m. (rate = 85 m/m.y.). Unfortunately, the interpretation of Axelrod ai Bailey is dubious because the possible effect of global climatic than on the mean annual temperature (Wolfe, 1978) was not properly co sidered (Baldridge, written comm. 1984).

Scott (1975) and Taylor (1975) found that 1,200 m of relative upl had occurred in the northern Sangre de Cristo Mountains in Coloral since the deposition of the 7-m.y.-old Ash Hollow fauna. Their wo suggests an uplift rate of 170 m/m.y. over a period of 7 m.y., whj is the order of magnitude of the apparent uplift rates estimated frc the heat-flow and fission-track data.

Paleogeography of Northern New Mexico

A schematic paleogeographic reconstruction of northern New Mexj (Fig. 8) was developed on the basis of published sedimentologic studies and fission-track-age results of this study.

During the Laramide (Fig. 8a), the area currently occupied by t Sangre de Cristo Mountains, the Sandia Mountains, the Espanola Basi the San Luis Basin, and the Brazos uplift was elevated to moden relief (Baltz, 1978). This event is recorded by the apatite fission-tra, ages in the Santa Fe Range and by the sediments shed from this highlai into the San Juan and Raton Basins.

TABLE 1. Summary of uplift data for Rio Grande rift in northern New Mexico and southern Colorado.

Location	Time (m.y.)	Rate (m/m.y.)	Source
Sandia Mtns. NM	15-30 0-15	81 230	this study
Santa Fe Range, NM	55-70 0-55	125 55	this study
Taos Range, NM	0-14	210	this study
Sangre de Cristo Mtns., CO	15-24	70	Lindsey and others, 1983
Española and Albuquerque Basins, NM	0-14	85	Axelrod and Bailey, 1976
Sangre de Cristo Mtns., CO	0-7	170	Scott, 1975 Taylor, 1975

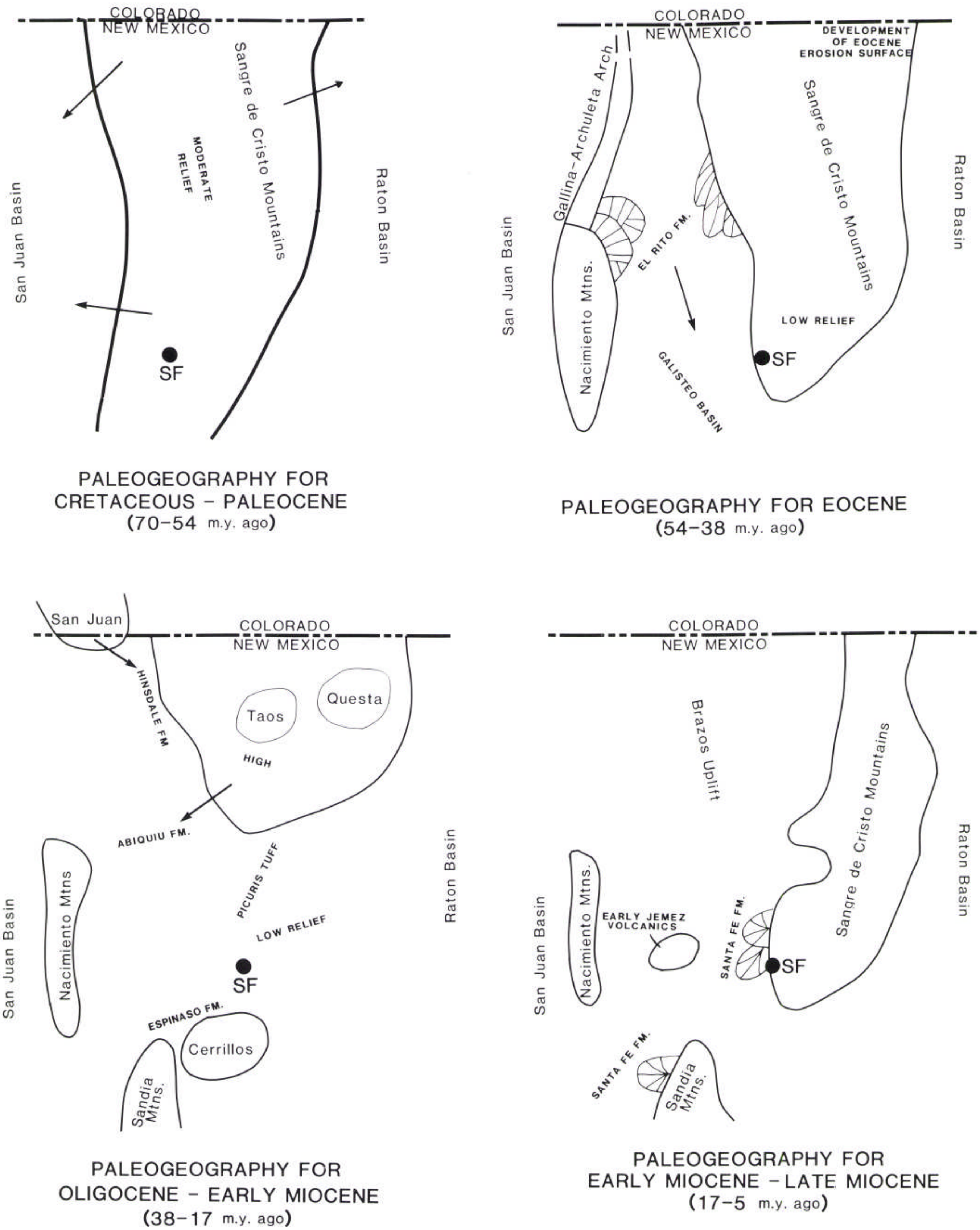

FIGURE 8. Paleogeography of northern New Mexico from fission-track-dating results and published geological studies (see text). Position of Santa Fe depicted by the large dot. After Baltz (1978), Vazzana and Ingersoll (1981), and Logsdon (1981).

The Galisteo Basin formed early in the Eocene (Fig. 8b). The Sangre de Cristo Mountains and the later Nacimiento Mountains were the source areas for the Galisteo Formation (Gorham and Ingersoll, 1979) and for the El Rito Formation (Logsdon, 1981). By late Eocene, the entire area was reduced to low relief (Baltz, 1978). The region near Santa Fe must have remained at low elevations until the culmination of rifting during the Miocene. Otherwise, the record of Laramide uplift indicated by the fission-track ages in the Santa Fe Range would not have been preserved.

The Oligocene to early Miocene was marked by abundant igneous activity, which is exhibited by the development of the San Juan (Lipman and others, 1978), Latir (Lipman, 1981), and Cerrillos—Ortiz (Stearns, 1953) volcanic fields (Fig. 8c). Evidence for early rift volcanism is preserved in a horst block in the Taos Plateau (Lipman and Mehnert, 1979). Volcaniclastic sediments shed off the volcanic highlands during this interval comprise the Los Pinos (Manley, 1981), Abiquiu (Vazzana and Ingersoll, 1981), Picuris (Cabot, 1938), and Espinaso (Kautz and others, 1981) Formations. The Taos Range and the Sandia Mountains were experiencing uplift and erosion at this time, as indicated by the apatite fission-track ages at the higher elevations of these two ranges. The correlation between the time that uplift began and the time that volcanism was active in these areas implies that the two events may be related. The uplifts on the eastern margin of the early rift were discontinuous.

Finally, in the middle Miocene (Fig. 8d) uplift was renewed in the Santa Fe Range, while uplift and erosion continued in the Taos Range and the Sandia Mountains. The Santa Fe Formation is composed of sediments from these uplifts (Galusha and Blick, 1971). Minor volcanism in the Jemez area occurred during this time (Bailey and others, 1969).

The fission-track data provide little information concerning events more recent than late Miocene. The heat-flow and fission-track data indicate that uplift rates for the past 15 m.y. have increased in the Sandia region, and the rates in the Taos Range are comparable to those in the Sandia area.

CONCLUSIONS

(1) The fission-track dates show that the Sandia Mountains began to rise at least 30 m.y. ago, and that the 100 + 25°C isotherm moved through the rock at an apparent rate of 81 m/m.y. until about 15 m.y. ago. The rate of cooling due to uplift and erosion approximately tripled (230 m/m.y.) in the past 15 m.y. The Taos Range was uplifting and eroding by at least 35 m.y. ago, and the apparent cooling rate for the past 14 m.y. in the Taos Range is about 210 m/m.y. In contrast to the other traverses studied, the fission-track dates from the Santa Fe Range record Laramide uplift and erosion at an apparent rate of 125 m/m.y.

(2) The paleogeographic reconstructions suggest that the relatively continuous uplifts that currently bound the eastern margin of the depression in northern and central New Mexico were not present before middle Miocene. The early Oligocene to middle Miocene uplifts in the Rio Grande region were much more discontinuous and seem to have been closely related to volcanic activity.

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Rodeo at Taos Pueblo, ca 1920. Photo by Burt Harwood.