

SHALLOW STRUCTURE OF THE SOUTHERN ALBUQUERQUE BASIN (RIO GRANDE RIFT), NEW MEXICO,  
FROM COCORP SEISMIC REFLECTION DATA

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**Abstract.** Detailed examination of COCORP Line 1A across the Rio Grande rift suggests that in contrast to listric faults and close-spaced steep normal faults proposed by others, a folded detachment surface and a set of fan-shaped reverse faults exist beneath the Albuquerque Basin. The folded detachment is thought to be the subsurface projection of the curved, low-angle Jeter fault exposed on the northeastern corner of the Ladron Mountains. Evidence indicates that both the folding of the detachment and thrusting along the reverse fault took place about 10 m.y. ago. This interpretation infers that at that time the area occupied by the present Albuquerque Basin was undergoing compression rather than extension. This compression might have resulted from the clockwise rotation of the Colorado Plateau relative to the Great Plains. Subsequently, compression apparently gave way to extension. This may have been caused by crustal relaxation as rotation of the plateau gradually ceased.

#### Introduction

The Rio Grande rift is a conspicuous tectonic element in the western part of North America. Despite detailed mapping and publication of many papers since the 1930's, its origin still evokes much controversy. Seismic reflection surveys carried out by the Consortium for Continental Reflection Profiling (COCORP) in the rift near Socorro, New Mexico have successfully obtained deep structural data along six profiles. The detailed structure of the upper crust has been revealed much more clearly than is possible by other geophysical methods. We are now in a better position to consider the geological development of the rift, based on this new three-dimensional data.

Two interpretations have been suggested for the COCORP Rio Grande rift data. Brown et al., [1979, 1980] inferred from the shallow portion of Line 1A and Line 1 that a large, buried "intergraben horst" exists beneath the Albuquerque Basin north of the Sierra Ladron, and that high-angle normal faults characterize the shallow

crust, especially on the flanks of the "horst". They believe that the key structural features represented by the reflection data are consistent with crustal extension. Cape et al., [1983], on the other hand, suggested that extension in this region has been accommodated along listric faults. In addition, Jurdy and Brocher [1980] presented a velocity model for the portion of the same seismic sections between 0 and 1.4 s derived from calculation of refracted wave velocities. In their model, the distribution of time-stratigraphic units confirms the existence of extreme structural relief and also indicates that the Paleozoic cover is thin or even missing on the "horst".

Both Brown et al., [1979, 1980] and Cape et al., [1983] associated the structural features on the sections across the Albuquerque Basin with extensional tectonics, although their geometric interpretations are quite different. After reviewing the seismic reflection data on Line 1A and considering the regional geological setting, it seems to the writer that the Cenozoic structural evolution of the rift is much more complicated than either interpretation suggested earlier, and that a simple extensional model cannot explain all the structural features shown on the seismic reflection section or indicated by regional investigation of surface geology. For this reason, a new geometric and mechanical model is presented here. The writer hopes that the presentation of this model will contribute a new perspective to the ongoing discussion about the origin of the Rio Grande rift.

#### Interpretation and Analysis

Line 1A is located within the southern part of the Albuquerque Basin, the largest basin within the Rio Grande rift system. The line begins in the east on Tertiary-Quaternary deposits, then runs west and northwest to the Sierra Lucero, on the edge of the Colorado Plateau (Figure 1). Line 1A is perhaps the most important of the profiles in this area, not only because it is the longest (61 km), but also because it reveals the

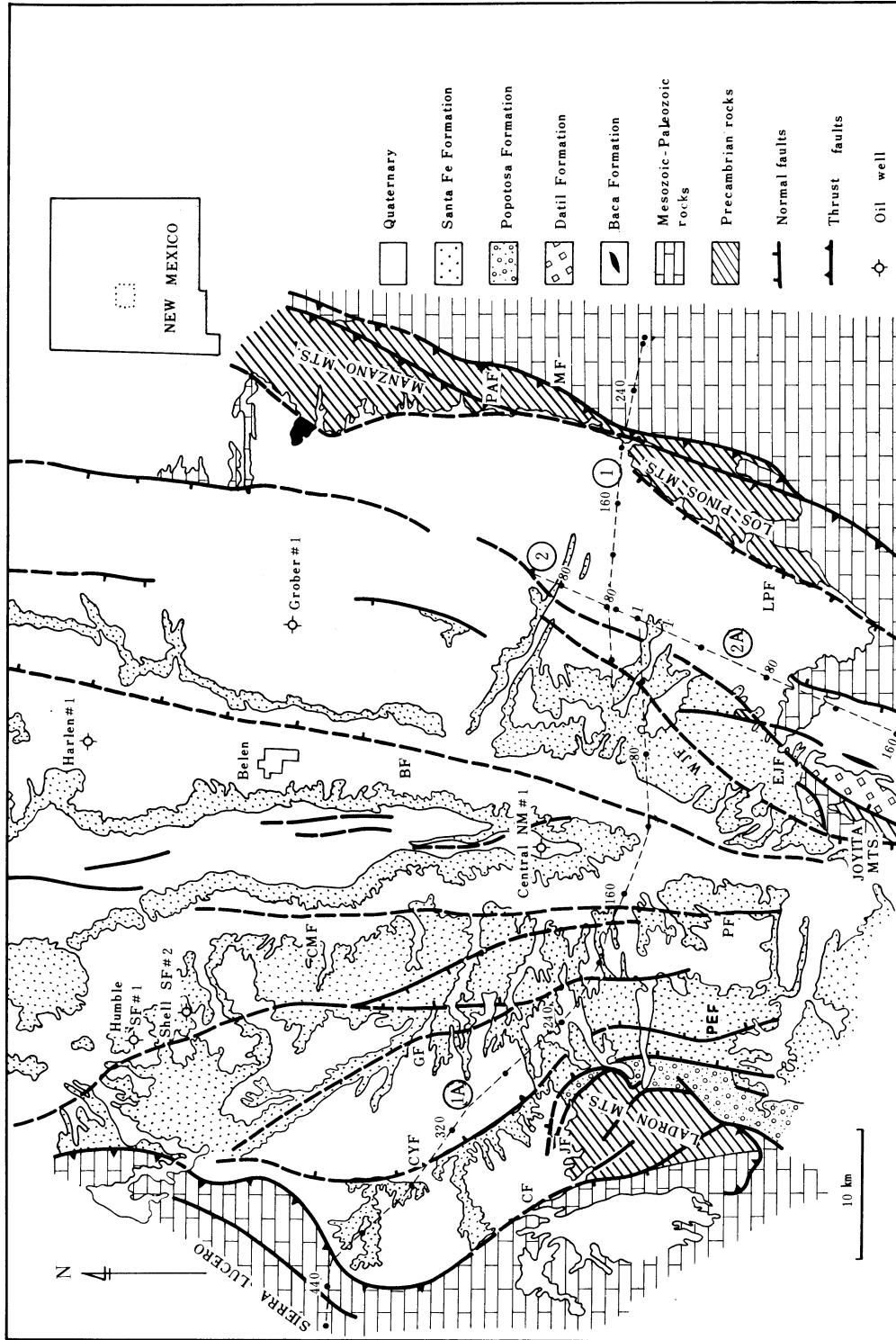


Fig. 1. Location of COCORP seismic reflection lines and geology of the southern Albuquerque Basin. Line numbers are circled, and vibration points are labeled. Geology is simplified from Kelley [1977]. CF = Comanche fault, JF = Jeter fault, CYF = Coyote fault, PEF = Pelado fault, CMF = Gabaldon fault, CWF = Cat Mesa fault, PF = Puerco fault, BF = Belen fault, WJF = West Joyita fault, EJJ = East Joyita fault, LPF = Los Pinos fault, PAF = Paloma fault, MF = Montosa fault.

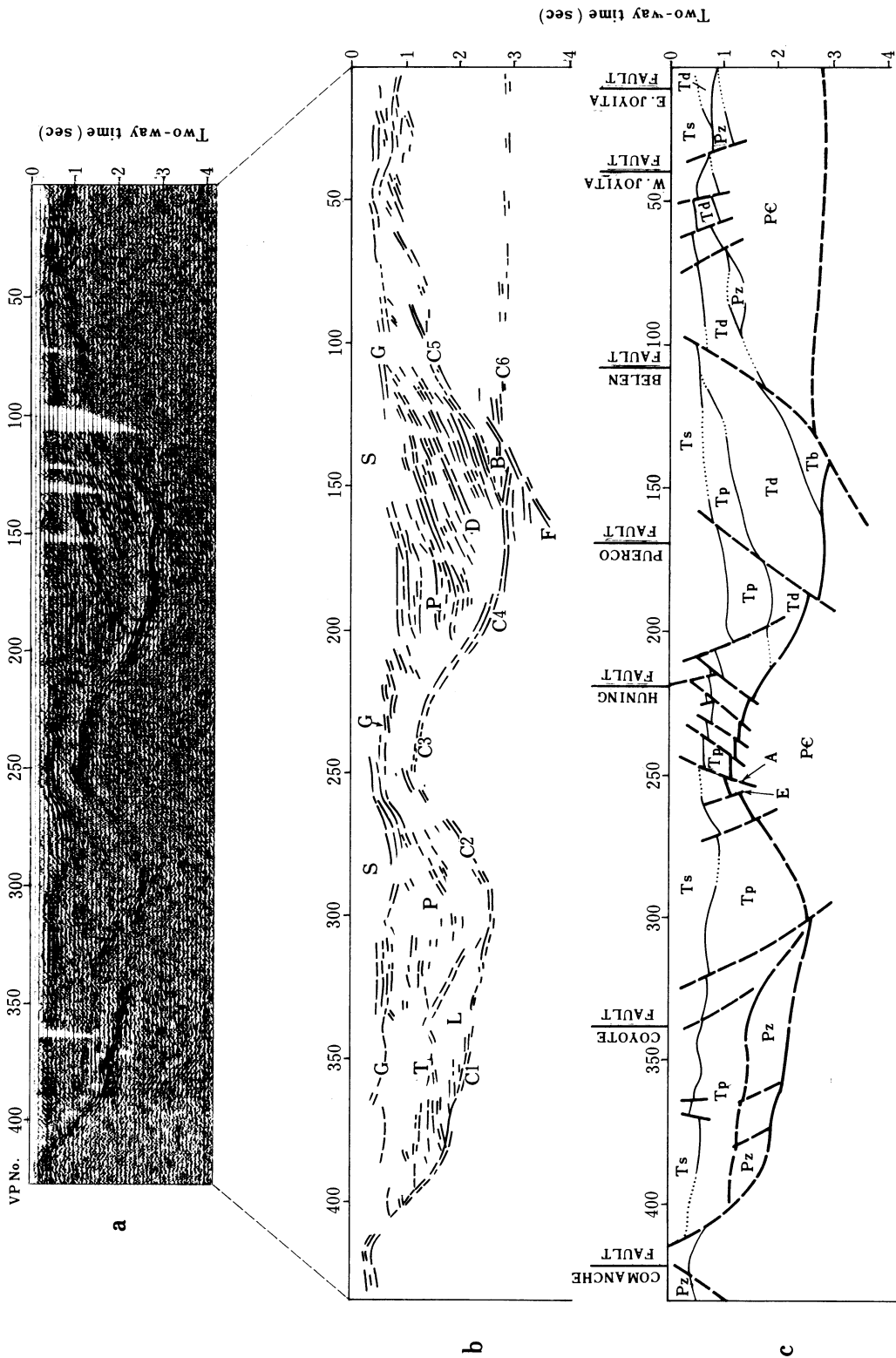


Fig. 2. Seismic section from Line 1A and its interpretation. (a) Unmigrated seismic reflection section of Line 1A. VP spacing is 134 m, vertical scale in two-way travel time. (b) Line drawing emphasizing prominent features on the same seismic section and showing labeled reflections discussed in text. (c) Interpreted time section. Pz = Precambrian rocks, Pz = Paleozoic rocks, Tb = Baca Formation, Tp = Popotosa Formation, Ts = upper Santa Fe group, A and E = typical reverse faults.

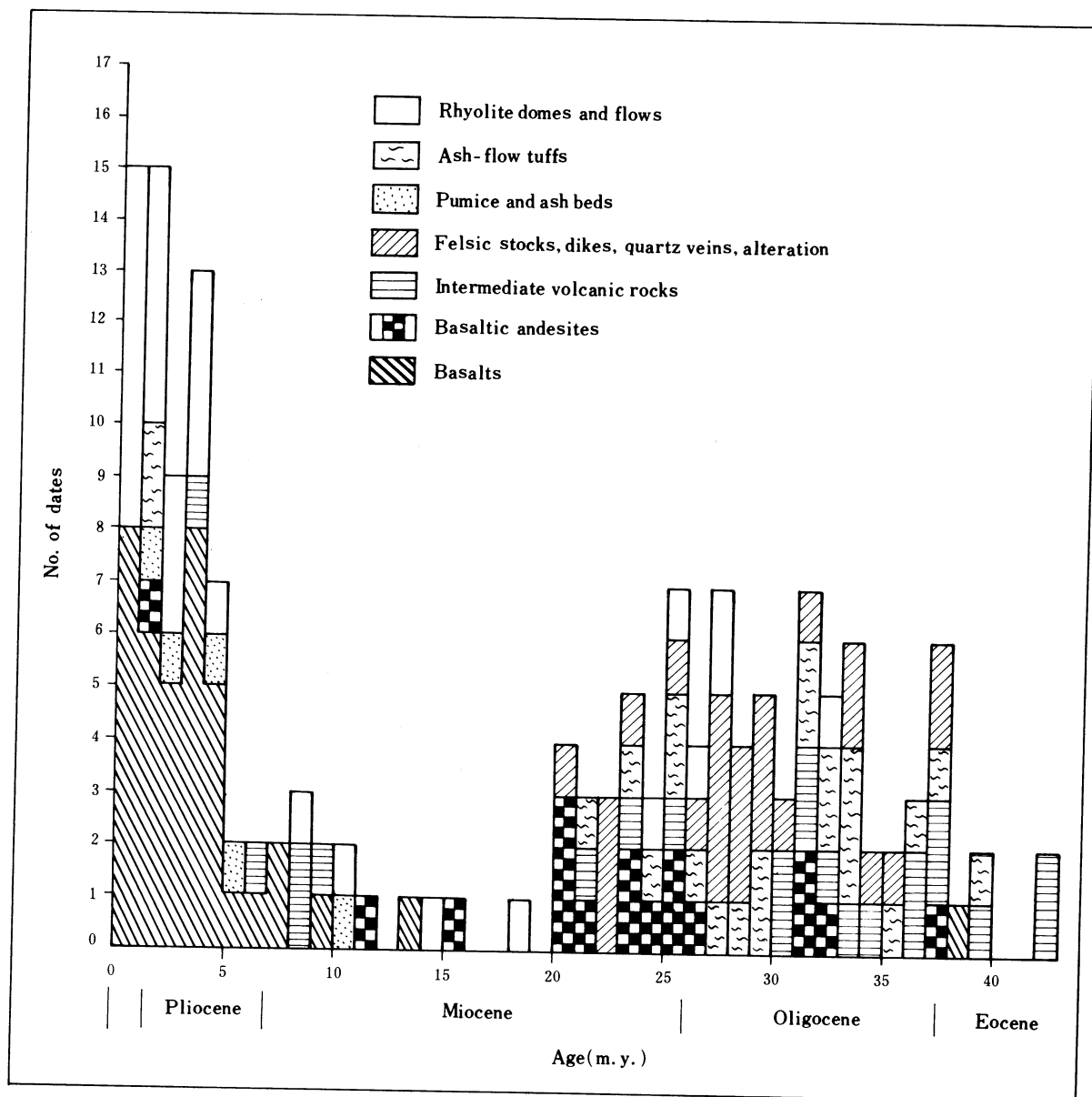


Fig. 3. Histogram of 161 K/Ar and fission-track dates on igneous rocks of late Eocene to Holocene age in New Mexico [Chapin and Seager, 1975].

spectacular structure of the central basin. Both migrated and unmigrated seismic reflection sections of Line 1A are the basis of the interpretation presented here. Because the reflections shown on the unmigrated section are much clearer than those on the migrated one, and in the interest of saving space, the latter is not displayed in this paper.

#### Reflections S

In the uppermost portion of the seismic section (Figure 2), a set of prominent reflections

labeled S can be traced. Though they are offset by a series of high-angle faults, these reflections appear to have little structural relief and low apparent dips across the entire section. The strata represented by S rest on the underlying rocks unconformably (VP 10-130, 270-340) and near conformably (VP 130-210). These reflections are interpreted here to represent the upper Santa Fe Group (Sierra Ladron Formation of Machette, 1978). At the surface the upper Santa Fe Group (late Miocene-Pliocene) is widely exposed along Line 1A and exhibits gentle dips. Even at the eastern edge of the Ladron Mountains, where a

Quaternary	Alluvial sand and gravels. ~~~~~ 5th disturbance
Pliocene	Upper Santa Fe Group Sandstone, mudstone, arkose conglomerate and fanglomerate. 600-2000 m.
Miocene	~~~~~ 4th disturbance Popotosa Formation Fanglomerate, mudstone, sandstone and local andesitic flows. 900-1520 m.
Oligocene	Datil volcanics Volcanic fanglomerate and tuff. >2000m.
Eocene	Baca Formation Conglomerate, sandstone and mudstone >100m.
Cretaceous	~~~~~ 3th disturbance(Laramide orogeny) Sandstone, shale and coal(marine and nonmarine facies). 1100-1250 m.
Jurassic	~~~~~ 2nd disturbance Sandstone, mudstone, gypsum and limestone (continental facies). 100-340 m.
Triassic	Mudstone, sandstone and conglomerate (continental facies). 0-340 m.
Permian	Sandstone, limestone, and mudstone. 1140-1600 m.
Pennsylvanian	~~~~~ 1st disturbance Limestone, shale and sandstone. 440-640 m.
Precambrian	Gneiss, schist, greenstone, quartzite and plutonic granitic rocks.

TABLE 1. Stratigraphic column, and interpreted tectonic events for the southern Albuquerque Basin and its outer region. Compilation based mainly on the information given by Kelley [1977].

series of faults are developed, the dips in the upper Santa Fe Group rarely exceed 35 degrees. The exposed contact relationship between the upper Santa Fe Group and older sequences is commonly an angular unconformity except in the La Sencia Basin, southwest of the Ladron uplift, and perhaps in some portion of the Albuquerque Basin [Chamberlin et al., 1983; Kelley, 1977; Chapin and Seager, 1975]. These characteristics are in accord with those of reflections observed on the seismic section.

Reflection G is interpreted to represent the basal boundary of the upper Santa Fe Group. It probably represents an erosional unconformity between the upper Santa Fe Group and older rock

sequences (see the fourth disturbance in Table 1). Since the underlying uppermost Popotosa Formation yields a K-Ar age of 10.7 m.y. [cited in Chapin and Seager, 1975], it is believed that uplift and erosion likely took place about 10 m.y. ago. The fact that reflection G can be clearly distinguished on the seismic section is quite significant. First, its occurrence implies that the upper Santa Fe Group in the vicinity of the Ladron uplift can be separated in the subsurface as a unit distinct from the underlying Popotosa Formation. Second, since reflection G represents a structural disturbance, it is logical to expect that a change of tectonic environment may have occurred after deposition of the Popotosa Formation.

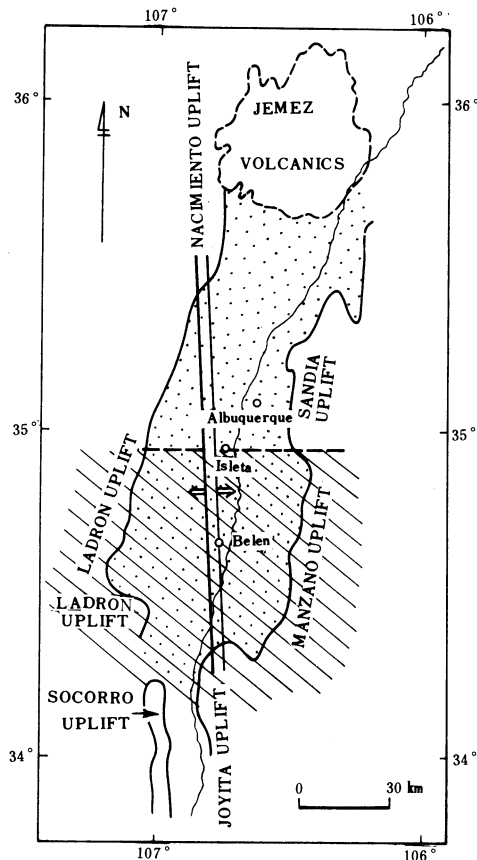


Fig. 4. Reconstruction of paleotectonics within the Albuquerque Basin during late Jurassic - early Cretaceous. Compilation based on Kelley's opinion [1977, 1979]. Fine dots represent the Albuquerque Basin; an anticline pattern with N-S trending - paleo-uplift in late Paleozoic; the oblique line - upwarped area in late Jurassic - early Cretaceous.

The variation in thickness of the upper Santa Fe Group can be estimated from depth conversion of the two-way travel time to reflection G. Above the "horst" the thickness of the upper Santa Fe Group is only about 600 m. Stratigraphic thickness of 1200 to 1400 m occurs on both sides of the "horst" at about VP 280 and VP 200, respectively. Elsewhere, the upper Santa Fe Group tends to be thinner. It is difficult to compare the thickness expressed above with those measured in drill holes, because it is unknown whether the basin sequences sampled in the holes include the Popotosa Formation. It is clear, however, that the upper Santa Fe Group is at least 1400 m thick at VP 200 and may be as much as 2000 m thick east of the Pelado fault [Kelley, 1977]. The upper Santa Fe Group is the true fill of the rift, as its distribution is generally limited to the present basin [Chapin and Seager, 1975; Woodward, 1977]. The basal time boundary

of the upper Santa Fe Group is believed to be about 10 m.y. This correlates approximately with the time of transition from andesitic volcanism to basaltic volcanism in New Mexico (Figure 3). Also, as Kelley [1977] pointed out, gravelly facies, regardless of composition, occur mostly in the upper part of the upper Santa Fe Group. Thus the stratigraphic record reveals that the intensity of block-faulting within the basin increased during the later period of sedimentation of the upper Santa Fe Group. The coincidence of block-faulting and change to basaltic volcanism suggests some genetic relation between them.

#### Reflections P, D and B

Reflections P, D and B are sandwiched between events G and C (Figure 2). Brown et al., [1980] interpreted these reflections as part of the Cenozoic graben-fill, and Cape et al., [1983] believe that they consist of Mesozoic-Paleozoic and Tertiary sequences. Jurdy and Brocher [1980] stated that the Paleozoic rocks (4.7 km/s) are limited to areas near VP 340 and east of VP 160, whereas the Mesozoic rocks (3.7 km/s) occur only at the top of the "horst". In general, Jurdy and Brocher's opinion is supported by local field relationships. Kelley [1977] mentioned that variations in thickness of the pre-basin formations are mainly the result of several erosional episodes. He emphasized three important erosion surfaces, designated events 1, 2, and 3 in Table 1. He suggested that the first hiatus lasted from late Pennsylvanian to Permian, during which time the orientation of the crest line of the uplifted area was approximately coincident with the longitudinal axis of the present basin. The northern end of the crest line is located at the Nacimiento uplift, and the southern end at the Joyita uplift (Figure 4). I infer that the Pennsylvanian rocks in the subsurface along the crest line are thin or even absent. The second disturbance, as Kelley [1977] stated, which may have influenced the existing thicknesses of pre-rift rocks, took place in late Jurassic to early Cretaceous. In this interval, an east-west hinge line was upwarped broadly, north of which the crust relatively subsided. As a result, most of the Triassic and some Permian beds in the southern part of the Albuquerque Basin were eroded. Late Cretaceous to middle Eocene Laramide deformation was the third disturbance that reduced the thickness of the pre-rift beds. Apparently, the limited distribution of the Cretaceous rocks at the surface is closely related to the Laramide orogeny. Based on the analyses discussed above, it is unlikely that Mesozoic and Paleozoic rocks are widespread beneath the Albuquerque Basin at the latitude of the COCORP survey. Therefore, in this paper the reflections P and D are interpreted to represent middle and late Tertiary rocks rather than older rocks.

The middle and late Tertiary sequences of this

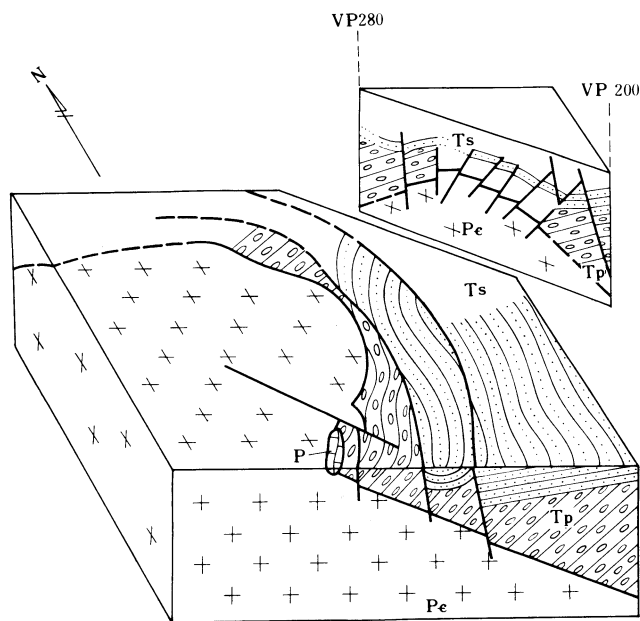


Fig. 5. Three-dimensional diagram showing the plunging feature of the Jeter fault and the relationship between it and the event C2-C4 on the seismic section of Line 1A. VP - projected vibrator point, Pe - Precambrian rocks, P - Pennsylvanian rocks, Tp - Popotosa Formation, Ts - upper Santa Fe group. Compilation based mainly on the information provided by Kelley [1977].

area comprise the Datil volcanics and the overlying Popotosa Formation (Table 1). The former is mainly exposed within the Joyita uplift [Kelley, 1977]; and the latter along the east and west flanks of the Ladron uplift. On the seismic section, the strong layered reflections D probably represent the Datil volcanics. This interpretation is based on the following considerations. First, the Datil volcanics contain much interbedded lavas and tuffs, which would give the large impedance contrasts necessary to produce the bright reflection events that appear on the seismic section. Second, the strike of the Datil volcanics exposed in the Joyita uplift is NNE through the eastern segment of Line 1A. Third, the La Jara Peak basaltic andesite, which is the major unit in the upper portion of the Datil volcanics [Osburn and Chapin, 1983], is exposed at Black Butte, only 2 km south of the eastern end of Line 1A. These observations indicate that the Datil volcanics are present on the eastern section of Line 1A.

According to the local stratigraphic column, reflections P may originate from within the Popotosa Formation. Their weak reflection character probably result from monotonic lithology of these clastic rocks. The relatively steep dips of these reflections and the apparently unconformable relationship between them and the overlying

upper Santa Fe Group match the characteristics of the Popotosa Formation observed at the surface.

If the interpretation given above is correct, both the Datil volcanics and the Popotosa Formation have considerable thicknesses within the basin. On the basis of rough estimates, the thickness of the Datil volcanics beneath the surface reaches about 2600 m. According to Osburn and Chapin's data [1983], in the southern margin of the Albuquerque Basin the Datil volcanics above the Baca Formation and below the Popotosa Formation are as thick as 4000 m or so. Hence, it is not surprising that they occupy as much as 1.3 s two-way time on the seismic section. No precise thickness for the Popotosa Formation can be proposed, since its interior structural features are not yet well understood [Kelley, 1979]. Osburn and Chapin [1983] estimated a 900 m thickness for the surface exposures of the Popotosa Formation in the Socorro area. Chapin and Seager [1975] stated that the thick Popotosa Formation was deposited in an enclosed basin, and referred to this as the "Popotosa Basin" in order to distinguish it from the present rift basin. They inferred that the Popotosa Basin had a width in Miocene time of about 65 km, and extended from the Los Pinos Mountains on the east to the Gallinas Mountains on the west. This large basin is generally thought to have undergone segmentation into several narrow basins and uplifts during late Miocene-Pliocene time. This segmentation corresponds to the fourth tectonic disturbance shown in Table 1. It is reasonable to assume that the segmentation resulted from a significant change in the regional tectonic framework.

At about VP 150, a weak reflection area (B) is sandwiched between C4, C5 and F. This area probably represents either conglomerate or coarse sandstone rocks, belonging to the Baca Formation.

#### Event C

The most spectacular shallow features of Line 1A are reflectors C1-C4, which outline the "mid-graben horst" (Figure 2). Brown et al., [1980] presented three possible interpretations of C1-C4, including: 1) a possible correlation with the La Jara Peak basaltic andesite of the Datil volcanics, 2) an upper Cretaceous sedimentary layer, and 3) the top of the Precambrian basement or a basal horizon within the Paleozoic sequence. Cape et al., [1983] suggested that C1 and C4 represent major listric faults, while C2 and C5 are depositional contacts between the Precambrian basement and the overlying Paleozoic and Mesozoic sediments. What is suggested here is that C1-C4 represents a detachment plane that separates the underlying Precambrian rocks, having no apparent reflection events, from the overlying younger sediments. At VP 140 this detachment is apparently truncated by a west-dipping fault (F); thereafter, it (C6) appears to be discontinuous and obscured eastward.

As pointed out by Cape et al. [1983], it is

clear that C1 and C4 are faults, because the overlying reflections L, P and D are truncated by C1 and C4. To determine whether the two faults are independent of one another or different segments of the same fault, it is necessary to review the surface geology in the Ladron Mountains. The mountains lie along strike with the midgraben "horst" a few kilometers to the southwest.

Kelley [1979, 1977] described the curved, low-angle Jeter fault which extends approximately 10 km around the northeastern corner of the Ladron Mountains (Figures 1 and 5). He reported that on the east side of the mountains the fault dips 20°-30° toward S 80° E. Northward the strike of the fault surface curves around toward the west so that at the north end of the mountains the fault dips 20°-30° toward N 10° E. This geometry implies that the hinge of the convex Jeter fault plunges approximately N 55° E. This plunge direction is consistent with the orientation of the Ladron uplift implied by its associated Bouguer gravity anomaly [Cordell et al., 1978]. The hanging wall of the Jeter fault, where exposed, is primarily composed of Popotosa Formation and faulted blocks of Paleozoic, Mesozoic, and Cenozoic rocks, including various volcanic units [Chamberlin et al., 1983]. The footwall, where exposed, is composed of Precambrian crystalline rocks. These relationships are consistent with the geometry of strata above and below reflections C2, C3 and C4 on the seismic section. Accordingly, it is likely that C2-C4 is the projection of the Jeter fault on the seismic section. In other words, C3 can be correlated with the hinge position of the convex Jeter fault surface, and C2 (VP 260-300) and C4 (VP 150-230) correspond to its E-W trending segment on the north side of the mountains and its N-S trending segment on the east side of the mountains, respectively. Each of these segments are therefore thought to represent parts of a single, continuous fault surface referred to here as the Jeter detachment.

Reflection C1 extends continuously from VP 300 to VP 410. At about VP 380 C1 begins to shallow steeply toward the west. Though C1 is actually separated from C2 by an eastward dipping fault, there is a strong suggestion that the two were originally continuous. Cape et al., [1983] described the same geometry, but on their generalized cross-section of the southern Albuquerque Basin they show a listric fault that would cut C2 and extend eastward beneath the "horst". Their interpretation seems to be less probable since it does not accord with the outcrop features just described.

Reflection T is also interpreted as a fault here, based on the observation that reflections above and below are clearly truncated by it. Toward the east and west, T is intersected by C1 at VP 310 and VP 400 (Figure 2). T may be a branch of the detachment, and therefore the rock mass (L) bounded by T and C1 could be a struc-

tural lens formed during the period of displacement of the Jeter detachment. The writer presumes reflection L to represent Paleozoic rocks. Jurdy and Brocher [1980] came to a similar inference, based on their finding a layer with a refraction velocity of 4.7 km/s at this position. Two faults have been recognized within the structural lens. They may indicate eastward displacement of the upper plate along the detachment surface relative to the lower one if they are normal faults.

In the above discussion I have taken C1-C4 as a continuous detachment fault. However, this fault appears to be truncated by a high-angle fault (F). East of F a short reflection (C6) with strong amplitude occurs at 2.7 s. Farther east the reflection becomes obscured. This may not be surprising since east of VP 140 the detachment occurs within Precambrian rocks. The similarity in lithology above and below the detachment along that portion results in little impedance contrast across the fault.

In the Ladron Mountains the youngest rocks cut by the Jeter detachment belong to the Popotosa Formation (early-middle Miocene). The upper Santa Fe Group was not subjected to significant deformation. Therefore, movement on the Jeter detachment must have largely predated deposition of the upper Santa Fe Group.

The seismic section indicates large structural relief on the Jeter detachment. At the top of the "horst", the detachment surface occurs at 1 s, whereas on both sides of it, the lowest points occur at 2.6-2.8 s. This means that the structural relief on the detachment surface is about 3 to 4 km within a horizontal distance of 6 km. What mechanism produced such large structural relief is a very important question that should be answered if one wants to reconstruct the evolutionary history of the basin. Brown et al., [1980] postulated that the "horst" was cut by a series of steeply dipping, step-like normal faults, implying that its formation was related to block faulting. Cape et al., [1983] attributed the origin of the "horst" to listric faulting. Neither explanation appears likely to the author since the existence of these kinds of faults cannot be distinguished unequivocally on the seismic section. Rather, it appears that the large structural relief of the detachment surface was mainly caused by folding, and subsequent high-angle reverse faulting.

#### High-angle faults

The seismic section of Line 1A reveals a number of high-angle faults, as shown on Figure 2. Their high apparent dips suggest that they are nearly perpendicular to the section. They can be classified into two different types according to the depth to which they extend. One type of fault offsets and extends beneath the Jeter detachment surface; the other type appear to die out at relatively shallow depth within the sedi-

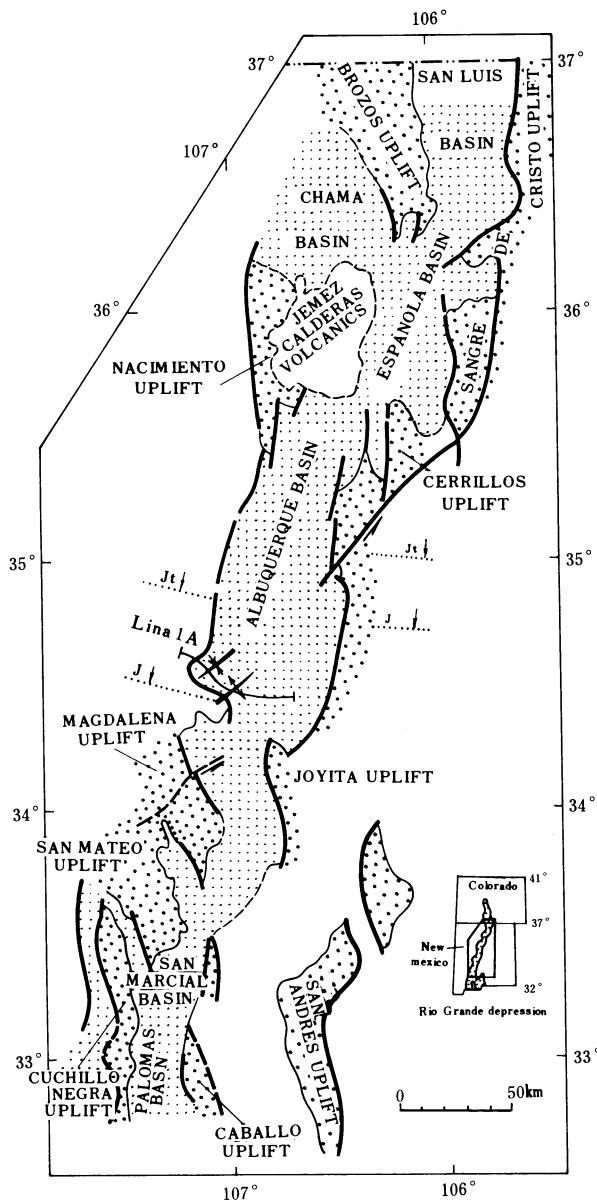


Fig. 6. Schematic tectonic map of the Rio Grande rift in New Mexico. 1 - uplift area, 2 - basin area, 3 - antiform and synform, 4 - fault, 5 - wedge edge of Jurassic formation (Jt - Todilto Formation, J - Morrison Formation). Modified and simplified from Kelley [1979].

mentary section. The latter are characteristically normal faults with small offsets, such as the faults east of VP 80 and west of VP 300. Undoubtedly, they were formed under extensional stress, though the amounts of their horizontal extensions appear limited.

The first kind of fault is of greater inter-

est, for the characteristics of these faults indicate that they had a complicated history. They occur mostly between VP 150 and VP 330, and are especially centered on the "midgraben horst". A critical observation is that they dip toward the west on the eastern flank of the antiform and toward the east on the western flank of the antiform. Thus, their spatial distribution is a fan-shaped pattern. Another interesting characteristic is that at the top of the "horst" the hanging walls of these faults appear to be displaced upward relative to the footwalls along the folded detachment surface. The basal boundary of the upper Santa Fe Group also appears to be displaced upwards. On Figure 2, faults E and A are representatives of this type of structure. All of these appear to be reverse faults. Since the point of change of dipping direction is just at VP 250, the crest of the antiform, it is reasonable to infer that the formation of these faults is related to folding of the detachment.

Further away from the antiform, however, the displacement situation on steep faults looks more complicated (Figure 2). The direction of displacement of hanging walls relative to footwalls along the basal boundary of the upper Santa Fe Group is in the opposite sense from that along the detachment surface. The coexistence of these contradictory offset indicators implies that these faults have been reactivated under different stress conditions.

This implies at least two stress periods. During the first period (compressional), fan-shaped reverse faults were formed subsequent to the detachment generation. This compressional episode probably continued through the beginning of upper Santa Fe Group deposition. After that, the stress field became extensional and a number of small-scale normal faults were formed. That the offsets of all the normal faults appear small on the seismic section, and that most of these faults observed at the surface cannot be traced deeply into the subsurface (Figure 2), are indications that the high-angle normal faulting was not as significant as is generally assumed.

#### Initiation of Rifting

As yet, the problem of when onset of Rio Grande rift extension occurred has not been solved. This is because the distribution and structural features of the early-middle Miocene rocks beneath the upper Santa Fe Group, and correlative sequences are unknown. Chapin and Seager [1975] and Chapin [1979] suggested that the inception of the rift in the vicinity of Socorro occurred 29 m.y. ago. Their inference has been generally accepted and cited by many geologists [Brown et al., 1980; Cape et al., 1983; Woodward, 1977; Chamberlin et al., 1983]. Their conclusion is based mainly on the following facts: numerous normal faults with an average trend of N 10° W are distributed across a belt as much as 17 km wide in the Magdalena district

(Figure 6), about 40 km SSW of the Ladron Mountains. Along these faults a number of stocks and dikes are intruded that range in age from 30 to 28 m.y. The youngest sequences penetrated by the intrusive rocks, called the Potato Canyon tuff, is as old as about 31 m.y. In addition, some faults and intrusive rocks are unconformably overlain by the oldest Popotosa basin deposits, fanglomerates and interbedded lava flows of the Arroyo Montosa unit (25 m.y.).

There are two problems with Chapin and Seager's conclusion. First, the orientation of these normal faults (N 10° W) is different from the general NNE trend of the rift in New Mexico. This difference implies that these faults probably represent second or even third order structures derived from, and controlled by, some first order structure. Their orientation probably does not accurately reflect the regional extension direction since the local stress field usually differs from the general one. The local extension represented by a set of N-10°-W-trending normal faults, therefore, should not be used to indicate the nature of the regional deformation.

Second, they argued that the existence of an enclosed Popotosa Basin in the Socorro area is an important criterion for setting an initial time of rifting at 29-26 m.y. At present this argument is suspect, since the true aerial distribution and detailed deformation pattern of the Popotosa Formation is unknown.

As mentioned earlier, folding of the Jeter detachment beneath the southern Albuquerque Basin probably took place about 10 m.y. ago, and reverse faulting probably occurred a little later than the folding, since these faults displace the basal layer of the upper Santa Fe group. Both the folding and the faulting indicate the existence of a compressional stress field, possibly NWW-trending, in the vicinity of the Ladron Mountains area about 10 m.y. ago. The detachment itself was also possibly formed during the same stress phase. These relationships, along with the fact that the true rift fill, the upper Santa Fe group, is strictly controlled by the present rift boundaries, suggest that extension across the rift started only about 10 m.y. ago. This time for initial rifting coincides with the previously mentioned transition from andesitic to basaltic volcanism.

#### Mechanism of Rifting

As with the Rio Grande rift as a whole, the mechanism of formation of the Albuquerque Basin has long been in debate. The key to the problem may lie in our understanding of the Jeter fault's behavior. Possible origins [cited from Chamberlain et al., 1983] of the Jeter fault include: (1) younger-over-older westward thrusting, (2) gravity sliding associated with domal uplift of the Ladron block, and (3) low-angle normal faulting related to crustal extension. I propose yet another potential model for it. That is, the

Jeter fault may be the exposed portion of a major compressional detachment fault that underlies much of the Socorro area. De Voogd et al., [Cornell University, unpublished data, 1985] have re-interpreted Abo Pass Line 1, which overlaps the eastern segment of Line 1A and runs east through Los Pinos Mountains onto the Paleozoic rocks. Their reprocessed seismic section clearly shows a west-dipping fault. It seems to the writer that this fault may project eastward to the Paloma and Montosa faults, commonly interpreted as Laramide thrust, and to the west it might connect with reflector C6 at 2.7 s on the seismic section of Line 1A. If this inference is correct, the Jeter fault and the Paloma and Montosa faults could be different segments of the same detachment. Therefore, the compressional detachment fault may underlie all of the southern Albuquerque Basin. Since the 1930's, various mechanisms have been suggested for the Rio Grande rift. This is not surprising, as geologists emphasize the different geological phenomena they have observed and have viewpoints with different tendencies. The principal differences among the theories are primarily whether the rift formed by extension across its length, or by transcurrent faulting along its length, though either class of explanation includes a number of variations. The opinions of Chapin and Seager [1975], Brown et al. [1980], and Cape et al. [1983] belong to the former, and Kelley's hypothesis [1977, 1979] that the Rio Grande rift formed by left-lateral transcurrent movement, which took place during the time from the Laramide orogeny to the early Cenozoic, belongs to the latter.

Kelley's arguments in support of a transcurrent faulting model are as follows: first, along a number of border faults of the Albuquerque Basin sinistral offsets can be observed in the field. For example, the wedge edge of Jurassic formations on the western side of the rift are displaced southward relative to those of the eastern side (Figure 6). Kelley [1977] estimated the displacement value of the left offset to be as much as 35-40 km; second, a series of NW-trending, en-echelon uplifts and grabens occur on both sides of the basin (Figure 6). These uplifts and grabens are oriented approximately N 5°-20° W, and are bounded by high-angle faults, indicating local extension normal to uplifts. Since these faults are arranged as a series of right-stepping, en-echelon faults and have an average angle of 35° between them and the axial trend of the rift, Kelley inferred that both the faults and uplifts resulted from left-lateral, transcurrent movement parallel to the axis of the Albuquerque Basin. On this basis, the faults with N 5°-30° W trend, including those in the Magdalena district reported by both Chapin and Seager [1975] and Laughlin et al. [1983], can be viewed as second-order structures relative to the longitudinal transcurrent faults, as shown on Figure 6.

Kelley [1977, 1979] attributed all these

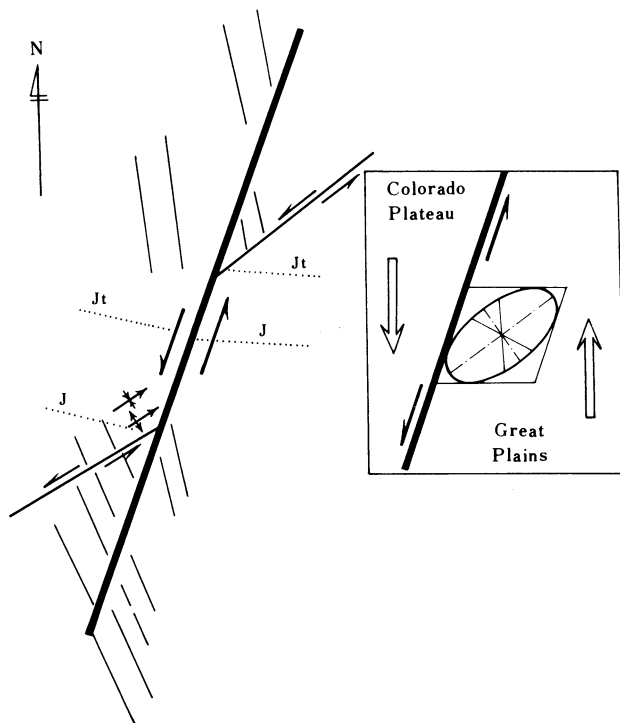


Fig. 7. Schematic tectonic interpretation of the pre-late Miocene structures in the Rio Grande rift area, northern and central New Mexico, based on structures shown in Figure 6. Heavy line - the major transcurrent fault; fine NNW-trending line - the second order boundary fault of uplift; fine NE-trending line - the second order transpressional fault; dotted line - wedge edge of Jurassic formation (Jt = Todilto Formation, J - Morrison Formation); antiformal and synform pattern - the structural relief on the Jeter detachment surface. The right mounted figure showing that the various kinds of structures in this area may have resulted from a left-lateral shear couple.

structural phenomena to Laramide-age movement and suggested that later rifting initiated in Miocene time. He did not postulate what relationship existed between the Laramide structural setting and later rifting geometry, or what happened during the time interval from the Laramide movement to late Miocene. The information derived from COCORP suggests an answer. That is, the left-lateral, transcurrent displacement might have lasted until about 10 m.y. ago. The best indications are the existence of the folded detachment plane and the fan-shaped reverse faults.

This left-lateral, transcurrent movement could have resulted from clockwise rotation of the Colorado Plateau relative to the Great Plains (Figure 7). The clockwise rotation of the Colorado Plateau possibly initiated during the Laramide orogeny and continued intermittently until late

Miocene. Since 10 m.y. ago, the rotation may have gradually ceased, and the compression-shear stress field in this area may have been replaced by a relaxed stress field. Under this condition, preexisting faults were reactivated in normal sense, and some new faults were formed. The NNE trend of the Albuquerque Basin indicates that the basin is probably controlled by the first-order structure, namely, the left-lateral, transcurrent faults. The second, or subordinate, faults also show their effect by complicating the outline of the basin. Associated with relaxation, predominantly basaltic lava was erupted in the area. The culmination of the relaxation might have occurred in Pliocene time, for both the strongest basaltic eruption and most rapid accumulation of the upper Santa Fe group occurred during that period.

#### Summary

1. Neither a simple listric fault pattern, nor a close-spaced, step-like fault pattern appears adequate to explain the complicated structures revealed by COCORP Line 1A, especially after a folded detachment surface, associated with a set of fan-shaped reverse faults, is recognized.

2. That the detachment has only involved rocks older than late Miocene and that reverse faults have mainly affected the same sequence indicate that there was a compressional stress field instead of an extensional field in the basin area before about 10 m.y. ago.

3. The compressional condition prior to late Miocene was probably caused by a couple that resulted from the clockwise rotation of the Colorado Plateau relative to the Great Plains. The rotation possibly began during the Laramide orogeny, though subsequently it might have been intermittent.

4. Since 10 m.y. ago the compressional stress field may have gradually been replaced by a normal one, a phenomenon that was set off by the cessation of clockwise rotation of the Colorado Plateau. This change of the stress field from compression to relaxation brought about the apparent variation of the style of tectonic deformation. During the latter period the tectonics has been characterized by normal faulting and eruption of basaltic flows.

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this paper, however, are wholly my own. Institute for the Study of the Continents Contribution No. 18.

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