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Down-plunge structural interpretation of the Placitas area, northwestern part of the Sandia uplift, central New Mexico--Implications for tectonic evolution of the Rio Grande rift

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DOWN-PLUNGE STRUCTURAL INTERPRETATION OF THE PLACITAS AREA, NORTHWESTERN PART OF SANDIA UPLIFT, CENTRAL NEW MEXICO—IMPLICATIONS FOR TECTONIC EVOLUTION OF THE RIO GRANDE RIFT

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Abstract—The northwestern corner of the Sandia uplift involves a transition zone between the uplift and the late Cenozoic Rio Grande rift. Principal structures of the transition zone are two echelon, rift-bounding faults, the Rincon on the west and San Francisco on the east, connected by the northeast-trending Placitas fault zone. The north-trending Rincon normal fault zone is downthrown to the west along multiple high- and low-angle normal faults. Stratigraphic separation of 2400+ m at the south edge of the area decreases northward to its termination in about 3–4 km. The northerly trending San Francisco normal fault is also downthrown to the west and has 1800–2100+ m of stratigraphic separation that decreases southward along multiple splays that connect with the Placitas and Las Huertas faults. The Placitas normal fault zone is downthrown to the northwest and decreases in stratigraphic separation from 1400–1700 m in the northeast as the fault splays to the southwest. The San Francisco and Placitas fault zones appear to be connected and form a complex listric fault system that is now tilted northward, an interpretation supported by the down-plunge view showing the Placitas fault zone dipping gently and the San Francisco fault zone with a steep dip. Additional evidence for listric geometry includes apparent rotation of bedding surfaces in the hanging wall with steep dips toward the Placitas fault and increasing stratigraphic separation northward at higher structural and stratigraphic levels along the San Francisco fault. Right slip along this margin of the Rio Grande rift is indicated by northwest-trending fold axes adjacent to the rift-bounding faults. Low-angle, normal faults nearly parallel to bedding in upper Paleozoic and Mesozoic strata have minor stratigraphic separations (1 to 50 m) and are inferred to have a northerly direction of tectonic transport. These faults are interpreted to be gravity-driven and formed in response to rise and northward tilting of the hanging wall of the Placitas fault. They therefore appear to be younger than the principal movement on the San Francisco and Placitas faults.

INTRODUCTION

The northwestern part of the Sandia uplift is characterized by a nearly complete section of Phanerozoic sedimentary strata, complex structure, and excellent outcrops. Parts of this area were mapped in detail (scale 1:6,000) by Woodward in conjunction with field geology courses at the University of New Mexico. Menne undertook an M.S. thesis (1989a) involving mapping and structural analysis under the supervision of Woodward. The major goal of the thesis was to provide detailed structural data to aid in interpretation of the tectonic development of the Sandia uplift and the Rio Grande rift in central New Mexico.

REGIONAL SETTING

The east-tilted Sandia uplift forms the eastern rift shoulder of the northern Albuquerque basin of the late Cenozoic Rio Grande rift. The Placitas area straddles the boundary between the northern end of the Sandia uplift and the Albuquerque basin. The rift is composed of several north-trending grabens (arranged en echelon north-northeasterly) occurring for a distance of at least 725 km in New Mexico and Colorado (Keller and Cather, 1994) (Fig. 1). Antithetic and synthetic faults commonly occur within the major grabens, forming step faults as well as second-order grabens and horsts. The major grabens are usually referred to as basins.

The Santo Domingo and Albuquerque-Belen basins are generally considered as one tectonic feature. This feature, about 145 km long and 49 km wide, is here called the Albuquerque basin. The northern end of this basin is asymmetric, with the deepest part on the east side where the depth to Precambrian rocks may be approximately 5500 m below sea level (Black and Hiss, 1974), giving maximum structural relief of approximately 8500 m with respect to the eastward-tilted Sandia uplift. The Hagan embayment, an eastward-tilted half-graben marking the northeastern edge of the Albuquerque basin, merges southward through a broad structural slope with the Sandia uplift. Upper Cenozoic volcanic and intrusive rocks, mainly basaltic (Kelley and Kudo, 1978), occur within the Albuquerque basin. The major basin-controlling structure of the northern part of the Albuquerque basin is the Rio Grande fault, a west-dipping listric normal fault having 4500 to 6000 m of throw (Russell and Snelson, 1990, 1994). This fault (Fig. 1) is about 5 km west of the area of this report.

Although the Sandia and Manzano Mountains are commonly considered to be separate physiographic entities, they form a major, east-tilted fault block that includes the Los Piños Mountains to the south. This fault block is about 120 km long and up to 15 km wide. Precambrian rocks are exposed along the western fault-line scarp, and the eastern dip-slope is formed mainly on Pennsylvanian strata dipping about 15° to the east (Kelley and Northrop, 1975).

A geologic map of the Sandia Mountains (Kelley and Northrop, 1975) shows a mosaic of high-angle faults having mostly small displacements and trending to the west, northwest, north, and northeast. High-angle reverse faults in the southeastern part of the Sandia Mountains were suggested to be of Laramide age (Late Cretaceous–early Tertiary) by Kelley and Northrop (1975). However, they noted that there is no stratigraphic evidence to pin down such an age assignment. It seems more likely that these faults formed in response to a local compressional stress field in the hinge or synclinal bend of the eastward-tilted Sandia fault block in the late Cenozoic. Apatite fission-track geochronology by Kelley and Duncan (1984) provides constraints on the timing and rate of uplift of the Sandia fault block. The rise began at about 30 Ma at a rate of 81 m/Ma and continued at this rate until about 15 Ma, leading to at least 1215 m of uplift by the mid-Miocene. Since then the rate of uplift increased to 230 m/Ma, giving a total of 4765 m of uplift. Paleogeographic reconstructions by Kelley and Duncan (1984) suggest that uplifts along the Rio Grande existed prior to the mid-Miocene, but were discontinuous and did not become the relatively continuous uplifts until post-mid-Miocene time.

According to Lozinsky (1988, 1994) sedimentation rates for early Santa Fe deposits (30–15 Ma) are 24–75 m/Ma. During middle Santa Fe time (10–5 Ma), sedimentation rates increased to 204–600 m/Ma and by 10 Ma Precambrian debris was entering the basin. These sedimentation rates agree well with the increased uplift rate beginning about 15 Ma as seen in the fission-track data. Santa Fe Group deposition decreased to 22–23 m/Ma after 5 Ma, when the basin drainage changed from closed to through-flowing drainage with development of the ancestral Rio Grande (Lozinsky, 1988, 1994).

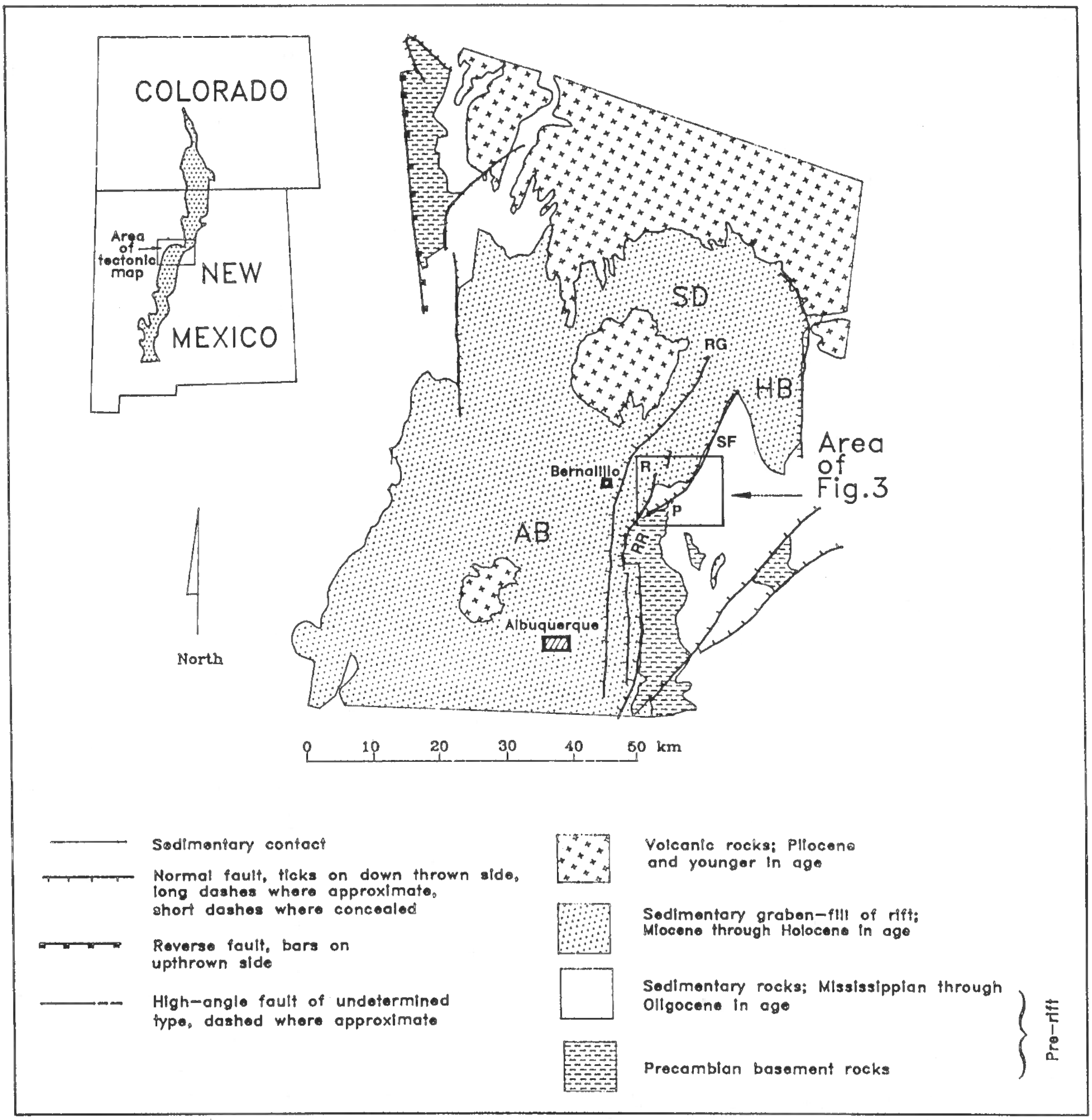

FIGURE 1. Generalized tectonic map showing setting of Placitas area. HB = Hagan basin, R = Rincon fault, RG = Rio Grande fault, P = Placitas fault, SF = San Francisco fault, SD = Santo Domingo basin, AB = Albuquerque–Belen basin, and RR = Rincon Ridge.

ROCK UNITS AND MECHANICAL BEHAVIOR

Rocks ranging in age from Proterozoic to Tertiary are present along the northwestern part of the Sandia Mountains (Fig. 2). In addition, Quaternary alluvium, colluvium, and terrace and pediment deposits occur as thin veneers in parts of the area.

Proterozoic rocks include the Rincon Metamorphics, a sequence of phyllite, schist, gneiss, metaquartzite and amphibolite, and the Sandia Granite, which intrudes the metamorphic rocks (Berkley and Callender, 1979). These rocks are competent and have behaved brittlely during Phanerozoic deformation.

Phanerozoic strata are unconformable on the Proterozoic rocks and have a maximum composite thickness of approximately 7830 m (Menne, 1989b). Numerous disconformities occur within the stratigraphic succession and a complete thickness is not present at any locality. Many of the measured sections are incomplete and some thicknesses are taken from Picha (1982) from the nearby Hagan basin.

Mississippian and Pennsylvanian units, dominantly limestone with subordinate shale and sandstone, are less competent than the Precambrian rocks. Sandstones that dominate the Permian also are less competent than the crystalline rocks.

The Mesozoic and Tertiary strata are mostly shales, with subordinate sandstones and gypsum, and minor limestone. The shale units tend to deform plastically.

The Santa Fe Group is angularly unconformable on the Eocene Galisteo Formation and on the Cretaceous Menefee and Hosta–Dalton units. Clast compositions in the Santa Fe show an inverted stratigraphy of the source rocks, with red sandstones of the Permian Abo Formation and Tertiary volcanic rocks in the basal 10 m, with upward succession of Pennsylvanian Madera limestone fragments, overlain by clasts of Precambrian rocks.

Age	Formation or Group	Thickness (meters)	Lithology
Quaternary	Unnamed	0-50(?)	Alluvium, colluvium, terrace and pediment deposits
Tertiary	Dike		Basalt
	Santa Fe Group	0-4400	Mudstone, sand, gravel
	Galisteo Formation	0-225	Sandstone, mudstone
Cretaceous	Menefee Formation	360-560	Sandstone, shale, coal
	Point Lookout Formation	75	Sandstone (tan to white)
	Upper Mancos Shale	65	Shale, siltstone, sandstone (gray, olive)
	Hosta-Dalton Sandstones	65-115	Sandstone (yellow-brown)
	Lower Mancos Shale	310	Shale, siltstone, sandstone (gray, olive)
	Daknta Formation	22	Sandstone, shale (yellow, gray-black)
Jurassic	Morrison Formation	260	Mudstone, sandstone (variegated)
	Todilto Formation	1-17	Limestone, gypsum
	Entrada Sandstone	35	Aeolian sandstone
Triassic	Chinle Formation	400-500	Mudstone, sandstone, conglomerate (reddish)
	Santa Rosa Formation	60-80	Sandstone, mudstone, conglomerate
	Moenknpi Formation	≤ 30	Mudstone, sandstone (purple-hrown)
Permian	San Andres Formation	20-25	Limestone, sandstone
	Glorieta Sandstone	10	Sandstone
	Yeso Formation	165-210	Sandstone (orange-brown)
	Abo Formation	230-330	Mudstone, sandstone (reddish-brown)
Pennsylvanian	Madera Formation	380-470	Limestone, shale, sandstone
	Sandia Formation	5-59	Limestone, shale, sandstone
	Log Springs Formation	0-4	Hematitic shale and sandstone
Mississippian	Arroyo Peñasco Formation	0-28	Limestone
Proterozoic	Granitic and metamorphic rocks		

FIGURE 2. Rock units in the Placitas area. Modified from Menne (1989a).

These clasts range from pebbles to boulders and the change in lithologies takes place over a stratigraphic interval of about 20 m.

STRUCTURE

General statement

The northwestern part of the Sandia uplift contains a transition zone between the uplift and the Albuquerque basin of the Rio Grande rift. This zone is dominated by two echelon, north-striking, rift-bounding, normal faults, the Rincon on the west and the San Francisco on the east, connected by the northeasterly trending Placitas normal fault zone (Fig. 3). These faults have the largest stratigraphic separations of those in the Placitas area. Numerous additional faults having smaller separations are also present. The distribution of stratigraphic units in this area is shown on a detailed (scale 1:8000) geologic map by Menne (1989a).

Faults

Rincon fault

The north- to northeast-trending, rift-bounding Rincon normal fault forms the western boundary of the northern part of the Sandia uplift and is about 11 km long. The trace curves around the west side of Rincon Ridge and apparently terminates to the south in basin-fill sediments near Juan Tabo Canyon and to the north of Highway 165. The northern end may have several splays, including the Ranchos fault.

Maximum vertical separation has been estimated by Joesting et al. (1961) at 7300 m and by Kelley and Northrop (1975, p. 87) at 8300 m. As the Phanerozoic section on the east side of the fault is tilted to the north, the amount of stratigraphic separation within the study area decreases northward from about 2400+ m and the fault dies out or is buried by Santa Fe Group deposits. In the southwest corner of the area, the fault is covered by pediment deposits, but probably juxtaposes Santa Fe on the west with Precambrian rocks on the east. Northward, the fault places Santa Fe in contact with successively younger Phanerozoic strata beginning with Pennsylvanian formations. Nearby faults appear to abut or merge into this major bounding fault.

Along the northern trace of the fault there is a zone containing multiple faults with varying dips. Two main tectonic slices of Phanerozoic strata are between the fault traces. From west to east, this fault zone juxtaposes Santa Fe against Cretaceous Mancos Shale, Mancos against Jurassic strata, and Jurassic strata against different units of the tilted Phanerozoic sequence. Roadcuts and sinuous fault traces indicate that fault dips are moderate to shallow.

San Francisco fault

The rift-bounding San Francisco normal fault is downthrown to the west and is approximately 6 km east of the Rincon fault. The southern 2 km of the fault are within the study area but the fault extends about 20–30 km to the north from the Tecolote area (Kelley, 1977). To the north, the fault separates the Santo Domingo subbasin and the Hagan basin and either dies out or terminates in Santa Fe deposits north of Espinaso Ridge (Kelley, 1978). Due to alluvial cover, the extension south of Tecolote is speculative. The San Francisco fault dips moderately, with one exposure of 67° west along a trace in the Tecolote valley.

The San Francisco fault juxtaposes Tertiary Santa Fe Group on the west against Pennsylvanian and Permian strata on the east with stratigraphic separation of 1800–2100 m in the northern part of the area. The Santa Fe Group west of the San Francisco fault dips gently to the west, probably as a result of drag. Stratigraphic separation decreases northward from the study area because the fault truncates progressively higher stratigraphic units on the east side of the fault.

Southward in the Tecolote alluvial area, the fault is more complex where it bifurcates into two main southward trends; southwestward it connects with the Placitas fault zone and southward with Las Huertas fault system (Fig. 3). The trend toward the Placitas fault zone has at least two strands juxtaposing Tertiary against Triassic, Jurassic, and Cretaceous formations. The segment connecting with East Las Huertas fault places Mesozoic strata against Pennsylvanian and Permian strata on the east. A small graben of Permian Abo Formation is bounded by the easternmost splay of the San Francisco fault and the Tecolote fault, a splay of Las Huertas fault. Stratigraphic separations across the multiple fault traces in the Tecolote area are roughly equivalent to the separation across the single trace to the north.

Placitas fault zone

The northeast-trending Placitas fault zone is the major connection between the Rincon and San Francisco faults, merging with the San Francisco fault and abutting or merging with the Rincon fault. The fault zone, about 6.5 km in length, is composed of steeply dipping normal faults primarily down to the northwest. The fault zone places Precambrian through Mesozoic strata on the northwest against Precambrian through Pennsylvanian strata on the southeast. At the northeastern end, strata north of the fault dip to the northeast and strike about perpendicular to the Placitas fault trace.

The northeast end of the fault zone is a single trace with stratigraphic separation of about 850-1700 m. Along the middle part of its trace, the fault bifurcates into at least two subparallel segments. The southwest end of the zone has multiple fault traces trending north-northeast to easterly, with maximum stratigraphic separation of 500 m; most faults have less than 100 m of stratigraphic separation. Overall, stratigraphic separation along the Placitas fault zone increases to the northeast. A few northerly trending faults with stratigraphic separations of less than 100 m offset faults of the Placitas fault zone.

Las Huertas fault

The north-trending Las Huertas fault system is about 8 km long and has two splays that define the Cuchilla Lupe horst, Las Huertas graben, and Montezuma salient (Fig. 3). The western splay is downthrown to the east and is interpreted to dip steeply to the east. Stratigraphic separation decreases northward from a maximum of 400 m in the southern part of the area. The fault juxtaposes Permian and Pennsylvanian rocks and terminates to the north against an east–west fault. The eastern splay is a normal fault dipping about 45° west and has 200–500 m of stratigraphic separation in the south, increasing northward to about 1000 m. The fault

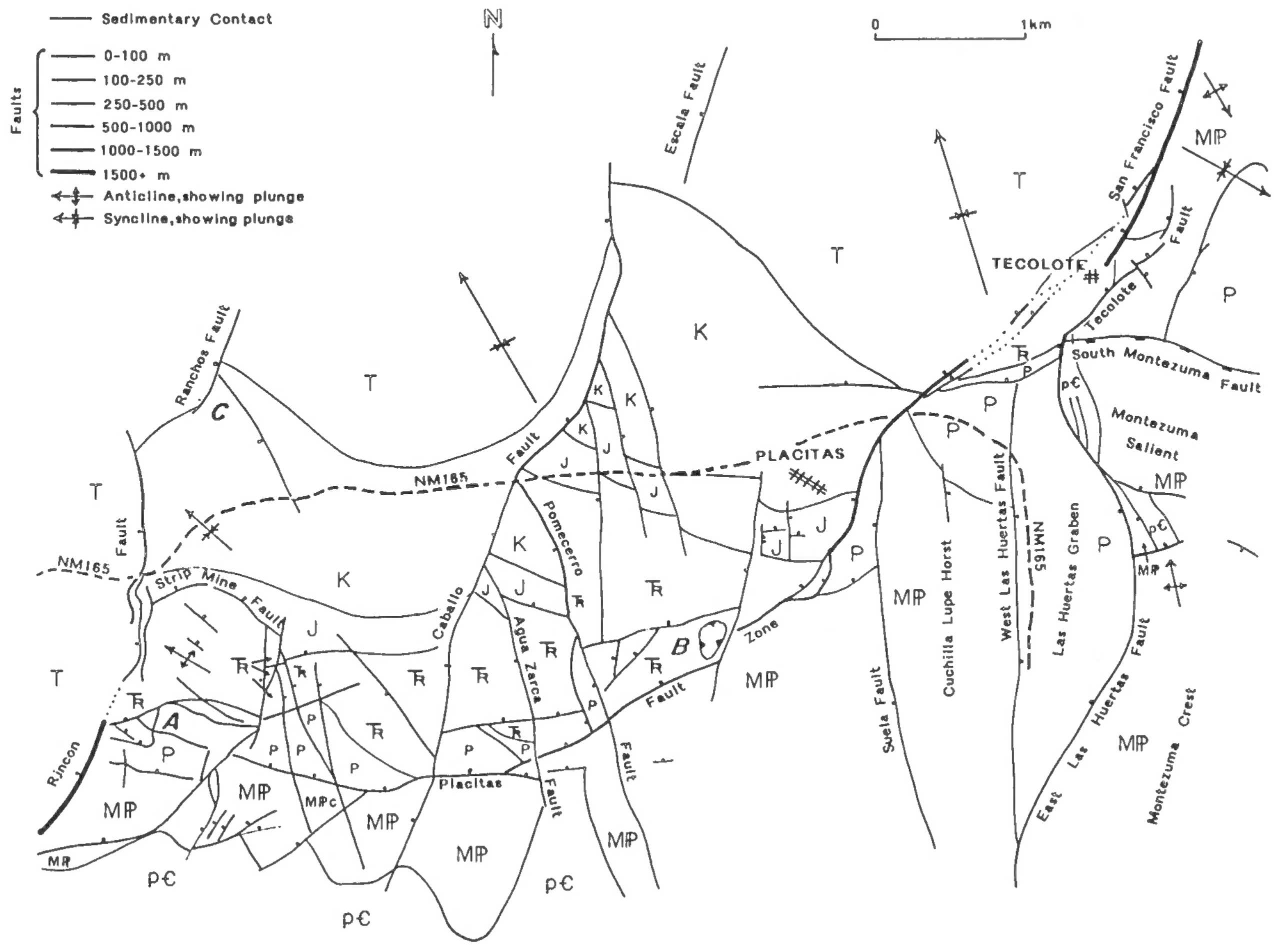

FIGURE 3. Structure map of Placitas area, showing principal folds and faults. Widths of lines for faults indicate stratigraphic separations. Modified from Menne (1989a).

curves around Las Huertas graben, placing Permian rocks on the west against Precambrian through Pennsylvanian rocks on the east. Most faults east of this splay appear to terminate against it. The northern termination of East Las Huertas fault is covered by Quaternary surficial deposits, but probably continues northward into the Tecolote area and may be a splay of the San Francisco fault.

Caballo, Agua Zarca, Pomecerro and related faults

The Caballo, Agua Zarca, and Pomecerro faults form a fault system in the central part of the area that offsets two major blocks present north of the Placitas fault zone (Fig. 3). These three faults have left separation. The Caballo forms the western boundary of the fault system and appears to be the dominant fault, continuing to the north from its junction with the Pomecerro. The Caballo is a normal fault downthrown to the west and dips 70° to the northwest. South of the Placitas fault zone, displacement appears to be as much as 20 m and the fault dies out southward in Precambrian metamorphic rocks. Stratigraphic separation increases northward to a maximum of 500–700 m north of the Pomecerro intersection and then decreases northward and probably dies out in Santa Fe strata.

The Agua Zarca fault, a high-angle, normal fault downthrown to the west, abuts the Caballo fault. Stratigraphic separation along the southern portion is difficult to determine, but is probably about 200 m. Along the rest of the fault, stratigraphic separation is a minimum of 36 m and a maximum of 100–200 m. The Pomecerro normal fault is downthrown to the west and dips steeply. The northern end abuts the Caballo fault and north of the Placitas fault zone the Pomecerro has two splays, with the western fault apparently terminating in the Placitas fault zone and the eastern fault continuing southward to die out in the Madera Formation. South of the Placitas fault zone, the Pomecerro fault has stratigraphic separation of 100–200 m and to the north the eastern splay appears to have as much as 150 m of stratigraphic separation. The western splay may have 300–600 m of stratigraphic separation. Stratigraphic separation on the northern part of the fault increases northward from about 400 m to about 500–600 m.

East of the Pomecerro fault are three subparallel, north-striking, steeply dipping normal faults that probably terminate northward at the Caballo fault. Southward the faults appear to die out in the Chinle Formation or terminate against an east–west fault. The western fault is downthrown to the west and the two eastern faults are downthrown to the east.

Suela fault

The Suela normal fault dips steeply west and forms the western boundary of the Cuchilla Lupe horst. This fault dies out southward in the Madera Formation and stratigraphic separation increases to the north where it is 200 to 600 m.

Strip Mine fault

The Strip Mine normal fault strikes N55°W and dips approximately 30° to the northeast, nearly parallel to bedding of Jurassic and Triassic strata. Locally the fault has cut out the Entrada Sandstone (Jurassic). Stratigraphic separation increases from 50 to about 250–350 m near the northwest end of the fault.

Escala fault

The Escala normal fault is downthrown to the west and occurs within Tertiary strata of the Santa Fe Group and possibly the Galisteo Formation. Other than a change of dip in the Santa Fe strata across the fault, the main evidence for its existence is a scarp of about 100 m that is prominent along most of its length. The southern termination of the Escala fault is probably within the Galisteo Formation. The fault extends about 7 km to the north.

Ranchos fault

The Ranchos normal fault strikes N10°E and terminates against or may be a splay of the Rincon fault. The Ranchos fault juxtaposes Santa Fe Group with the Galisteo Formation. The fault dips approximately 65–75° west and has 60–70 m of stratigraphic separation with the Santa Fe strata exhibiting reverse drag in the hanging wall.

South Montezuma fault

Only the western part of the westerly trending South Montezuma fault is present in the study area. Here, the fault is reverse, downthrown to the north, and mostly dips steeply south with locally vertical dips. The fault places Pennsylvanian strata on the south against mainly Permian strata on the north, with about 100–300 m of stratigraphic separation. The western end of the fault is covered, but terminates against either the Tecolote fault or Las Huertas fault. Eastward the fault becomes nearly parallel to steeply dipping Permian strata (Picha, 1982).

Bedding plane faults

Low-angle faults occurring in the southwestern part of the area closely follow bedding, show extensive brecciation and recementation of adjacent strata, dip less than 30°, and have minor stratigraphic separations ranging from 1 m to as much as 50 m. These faults have an inferred north to northwesterly tectonic transport direction. As the faults are close to bedding, slip is probably much greater than the stratigraphic separation. Typically, these faults occur at the base of resistant sandstone units of the Glorieta, Yeso, and Santa Rosa formations. Brecciated zones are extensively recemented and are up to 4-5 m thick. Younger high-angle faults offset these low-angle faults.

North-trending minor faults

Several northerly trending faults with displacements of < 100 m offset strands of the Placitas fault, as well as a few other faults, and are therefore younger than the Placitas fault zone.

Gravity slide

North of the Placitas fault zone a plate of Pennsylvanian Madera limestone about 300 m across rests on Triassic Chinle strata(Fig. 3, location B). The Madera strata, approximately 5–10 m thick, maintain relict stratigraphy though jostled and fractured extensively.

Folds

Folds in the Placitas area are mainly minor, but have important implications for paleostress directions. Overall, fold axes trend N14–60°W (Fig. 3). Plunges range from 2° to 29°. Two folds are located on the western side of the area, in the Chinle and Mancos formations. The fold axis in the Mancos plunges 29° to the northwest and the fold in the Chinle trends about N60°W and plunges about 4° northwest. Two broad, open synclines about 1–3 km across occur in the Santa Fe Group. One, north of the intersection of the Caballo and Pomecerro faults, plunges 9° at N36°W. The other is north of Tecolote and plunges about 12° at N14°W. Three principal folds are located east of the San Francisco and East Las Huertas faults. The Montezuma syncline plunges 13° at S60°E and the Montezuma anticline plunges about 8° at S30°E. To the south, a more prominent fold on the western face of Montezuma Crest trends N22°W and plunges 10° to the north.

DISCUSSION

In the Placitas area the influx of Precambrian clasts into the Santa Fe Group occurs about 10 to 20 m above the base of this unit, suggesting that the basal part of the Santa Fe is approximately 10 Ma (Lozinsky, 1988, 1994). This indicates that the area was structurally high until about 10 Ma and that the basal Santa Fe strata here correlate regionally with the middle part of the Santa Fe Group that began to accumulate at about 30 Ma. This interpretation is supported by apatite fission-track data indicating that the Sandia uplift began to rise slowly at least 30 Ma ago and that accelerated uplift occurred since about 15 Ma (Kelley and Duncan, 1984). Boulders of Permian rocks are present in the basal Santa Fe Group that rests on Eocene Galisteo Formation with Cretaceous Hosta–Dalton Sandstone just below, indicating minimum structural relief of 2000 m between the uplift and the adjacent site of deposition.

The San Francisco and Placitas faults appear to be connected and form a listric normal fault, downthrown and flattening on the west, that has been tilted northward during continued rise of the Sandia uplift, an interpretation also discussed by Russell and Snelson (1990, 1994). This interpretation is supported by a down-structure (Mackin, 1950) northward view of the area (Fig. 4), rotation of strata in the hanging wall block with dips toward the Placitas fault, and the possible presence of synthetic and antithetic normal faults (Caballo, Agua Zarca, and Pomecerro) in the hanging wall. Also, the Placitas fault is subparallel to bedding in the footwall. Seismic and geologic cross sections through the Placitas area confirm the listric geometry (Russell and Snelson, 1990, 1994). Tectonic unloading of the footwall of the Placitas–San Francisco fault and other faults, such as the Rio Grande fault, closer to the axis of the Albuquerque basin probably led to isostatic rise of the Sandia uplift (May et al., 1991, 1994).

The Placitas fault zone appears to abut or merge with the Rincon fault. Seismic data indicate that the Rincon fault is listric and merges with the gently dipping part of the San Francisco–Placitas fault in the subsurface in the northern part of the area and to the west is truncated by or merges with the Rio Grande fault, a west-dipping listric fault controlling the structure of the northern Albuquerque basin (Russell and Snelson, 1990, 1994). May and Russell (1991, 1994) suggested that erosion along the eastern margin of the basin was accentuated by tectonic unloading and uplift of the footwalls beneath the principal listric faults.

As the Sandia uplift rose and movement continued on the Rincon and San Francisco faults, the Placitas fault may have been reactivated down to the north, essentially lateral or sideways to previous movement. Northerly trending faults either developed anew or were reactivated ancestral synthetic or antithetic faults, eventually propagating through and displacing the Placitas fault to accommodate continued uplift of the Sandia block. May and Russell (1991, 1994) proposed that uplift and erosion of the Placitas area occurred as the locus of active faulting migrated inward toward the Rio Grande fault closer to the basin center. Thus, the San Francisco–Placitas fault is probably no longer active.

The Las Huertas fault system probably developed later than the San Francisco–Placitas fault. It seems likely that late movement on the San Francisco segment propagated southward to form the East Las Huertas fault after the Placitas segment was tilted northward. Displacement along East and West Las Huertas faults is fundamentally different than along the Placitas fault. Las Huertas faults define a graben that forms a keystone block near the crest on an anticline marking the northward plunge of the Sandia uplift (Kelley and Northrop, 1975, map 3). This graben appears to have formed by extension during arching of the Sandia uplift to the south of the Placitas fault.

The westerly trending South Montezuma reverse fault may have formed as a steep, north-dipping normal fault that was later rotated to a steep dip to the south as a result of northward plunge of the Sandia uplift. It may also represent a reverse fault caused by north-directed compression during rise of the uplift.

Although the principal movement of the major rift-bounding faults in the Placitas area appears to be dominantly dip slip, a significant amount of right shift probably occurred also, as indicated by northwest-trending folds in strata ranging from the Madera Formation (Pennsylvanian) to the Santa Fe Group (Tertiary). Kelley (1982, p. 147) presented a left-shift model for the Rio Grande rift that proposed "down-ramping of uplifts, benches, or plunging synclines between faults arranged in relays" (Fig. 5). He thought that simple extension was not likely to produce en echelon, relay faults and ramps, which are more clearly associated with oblique stress and rotation associated with strike-slip regimes. Central to his argument was his recognition of an opposing down-ramping system across the rift area, with north-descending ramps on the east side and south-descending ramps on the west side. In the Placitas area, Kelley noted left separation on the northern ends of the Rincon, Caballo, and San Francisco faults; however, this can readily be explained as normal

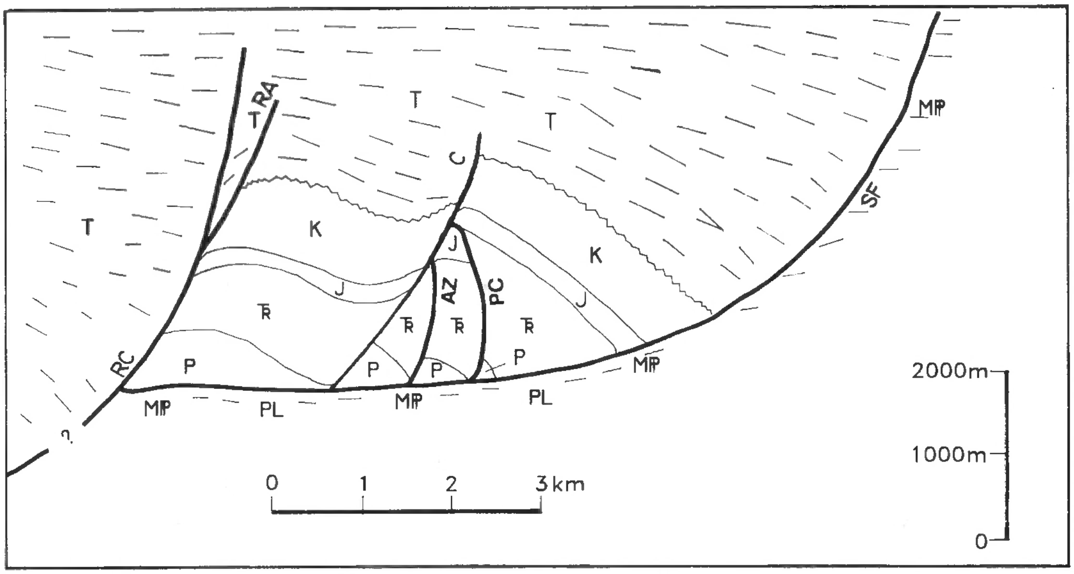

FIGURE 4. Generalized interpretive down-plunge view to the north showing principal structures of the Placitas area. Vertical scale is not related to sea level, but shows approximate thicknesses of rock units. RC = Rincon fault, RA = Ranchos fault, C = Caballo fault, AZ = Agua Zarca fault, PC = Pomecerro fault, PL = Placitas fault, and SF = San Francisco fault. MP = Mississippian and Pennsylvanian, P = Permian, T = Triassic, J = Jurassic, K = Cretaceous, and T = Tertiary. The view is nearly identical with structure section based on interpretation of seismic data by Russell and Snelson (1990).

dip-slip as now seen in rotated strata tilted northward. Left separations of strata across the Rincon and San Francisco faults, as noted by Kelley (1982), appear to be dip separations seen in strata tilted northward after the main episode of listric faulting. Thus, the evidence in the Placitas area supports right shift rather than left shift along the rift-bounding faults.

Low-angle normal faults that are nearly parallel to bedding occur in Paleozoic and Mesozoic strata in the southwestern part of the area. Stratigraphic separation ranges from about 1 to 50 m and the direction of tectonic transport is inferred to be to the north. The major fault of this type occurs in the southwestern part of the area (Fig. 3, location A) involving Permian and Triassic units. These faults are interpreted to be gravity-driven in response to rise and northward tilting of the hanging wall of the Placitas and thus appear to post-date the principal movement on the SanFrancisco and Placitas faults.

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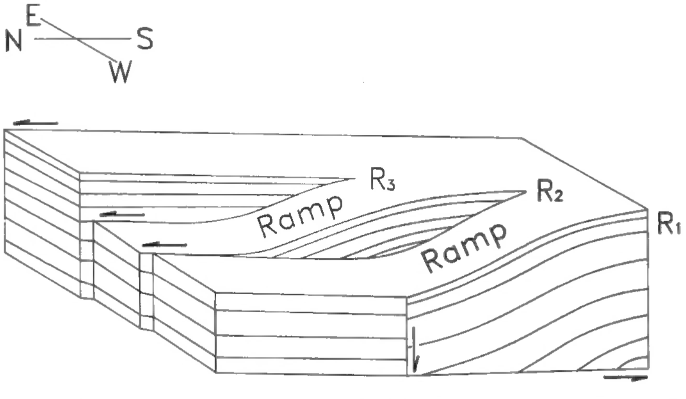

FIGURE 5. View east of isometric model of ramps and associated relay faults (R_1, R_2, and R_3) showing inferred left slip as proposed by Kelley (1982) for north end of Sandia uplift.

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