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LARAMIDE BASEMENT-CORED UPLIFT AND BASINS IN SOUTH-CENTRAL NEW MEXICO

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Abstract—The west–northwest-trending, basement-cored Rio Grande uplift and complementary Love Ranch and Potrillo Basins were the result of late Paleocene and Eocene compressional deformation in south-central New Mexico. The Rio Grande uplift consists of one or more asymmetrical blocks that dip southwest and face northeast. Along the northeastern margin, Precambrian crystalline rocks were raised by movement on southwest-dipping reverse and thrust faults exposed in the Bear Peak area of the southern San Andres Mountains, at San Diego Mountain, and in the southern Caballo Mountains. Northeast-vergent folds and subsidiary thrust faults in Paleozoic rocks are associated with the basement faults. The Rio Grande uplift is bordered to the northeast by the Love Ranch Basin, which contains up to 600 m of siliciclastic rocks of the Love Ranch Formation. Basin-margin facies are primarily alluvial-fan conglomerate, locally syntectonically deformed, derived in large part from the Precambrian granitic core of the Rio Grande uplift. Basin-center facies consist of poorly exposed sandstone and shale.

The southwestern flank of the uplift, which is best exposed in the Robledo Mountains, consists of southwest-dipping Paleozoic carbonate rocks that locally are repeated by west-trending normal faults. About 30 m of fluvial conglomerate of the Love Ranch Formation were deposited in canyons that dissected the southwestern flank of the uplift. Imbrication paleocurrent data indicate that the canyons flowed southward, and the absence of Precambrian clasts suggests that the canyons were separated from the crystalline core of the uplift by a drainage divide, probably normal-fault escarpments. The southwestern flank of the Rio Grande uplift plunges into the Potrillo Basin that contains 2.1 km of sandstone, shale, and minor conglomerate that were penetrated by the Grimm and others oil-test well. The Potrillo Basin is bounded to the south by Laramide folds and faults in the East Potrillo Mountains.

INTRODUCTION

Laramide (latest Cretaceous to Eocene) deformation in the continental United States has been recognized as far south as south-central and southwestern New Mexico and west Texas (Lasky 1947, Kelley & Silver 1952, Zeller 1970, Corbitt & Woodward 1973, Seager 1975, 1981, 1983, Gries 1980, Reaser 1982, Brown & Clemons 1983, Seager & Mack in press A). In the central and northern Rocky Mountain foreland, the location and trend of Laramide structural features are easily delineated because many of the uplifts were rejuvenated during the Pliocene and dominate present topography. In southern New Mexico, however, Laramide tectonic features are buried by post-Laramide volcanics and dissected by Basin and Range normal faulting. Consequently, the Laramide structural and stratigraphic record is fragmentary, and Laramide tectonic features must be reconstructed from widely scattered data points.

The data used in interpreting Laramide history fall into two categories, structural and stratigraphic (Fig. 1). Locally, Laramide folds and faults supply direct evidence concerning the location, trend, and style of Laramide uplifts. The Laramide structures generally trend west–northwest to north–northwest, do not involve upper Eocene and younger rocks, and are cross-cut by upper Tertiary normal faults. The exposures of Laramide structures are few and discontinuous, however, and must be supplemented by data from the syn- and post-tectonic Love Ranch Formation (late Paleocene?–Eocene). Thickness, grain size, facies, provenance, and subcrop relationships of the Love Ranch Formation combine to constrain the nature of the Laramide uplifts and basins. For example, the core and flank of an uplift have the deepest levels of erosion, but a thin, largely post-tectonic, conglomeratic veneer. In contrast, the basin center has the shallowest level of erosion and the thickest, finest-grained terrigenous sediment. The basin-margin facies is the coarsest, commonly consisting of proximal alluvial-fan conglomerate of variable thickness. Basin-margin facies may overlie rocks as young as Late Cretaceous along the edge of the basin or may onlap Precambrian or Paleozoic rocks along the flank of the uplift. The basin-margin facies is also commonly syntectonically deformed. Furthermore, the composition of basin-margin and basin-center facies reflects the erosional history of the core and flanks of the uplift.

The combination of structural and stratigraphic data has resulted in the reconstruction of a Laramide uplift and two complementary basins that occupy an area from the Caballo Mountains to about 50 km south of Las Cruces (Fig. 2). The uplift and basins were previously recognized by Seager (1983) and named Rio Grande uplift and Love Ranch and Potrillo Basins by Seager & Mack (in press A). The Rio Grande uplift has a west–northwest trend and is cored by Precambrian crystalline basement. The northern margin is marked by southwest-dipping reverse or thrust faults and west–northwest-trending folds, whereas the southern flank dips gently southward (Fig. 2). The uplift is bounded on the north by the Love Ranch Basin, which contains up to 600 m of syn- and post-tectonic terrigenous sediment. The south flank of the uplift plunges into the Potrillo Basin, which contains as much as 2 km of terrigenous sediment.

The purpose of this paper is to present the evidence supporting the paleogeologic and paleogeographic interpretation in Fig. 2. Although many unanswered questions still remain concerning Laramide history in south-central New Mexico, enough data have accumulated to provide a broad regional picture of major tectonic features.

AGE OF DEFORMATION

The age of Laramide deformation in south-central New Mexico is constrained by the age of syn- and post-tectonic sedimentary rocks of the Love Ranch Formation. The Love Ranch Formation was named for about 600 m of conglomerate exposed near the abandoned Love Ranch in the southern San Andres Mountains (Kottlowski et al. 1956). The formation was subsequently mapped in adjacent areas, such as the Organ Mountains, Robledo Mountains, San Diego Mountain, and Caballo Mountains (Seager et al. 1971, 1986, Seager 1981, 1982). The age of the Love Ranch Formation is based on stratigraphic relationships and on one palynomorph locality that yielded a late Paleocene to Eocene date. The Love Ranch Formation overlies rocks that range in age from Precambrian to Cretaceous. The youngest formation directly underlying the Love Ranch Formation is the McRae Formation, which contains latest Cretaceous dinosaurs (Bushnell 1953, Lozinsky et al. 1984). In the northeastern part of the Caballo Mountains, the Love Ranch Formation overlies a few hundred meters of conglomerate and sandstone of the basal part of the McRae Formation, but the contact is poorly exposed. That the contact is unconformable is suggested by the fact that the McRae Formation is much thinner in the northeastern Caballo Mountains, where the Love Ranch Formation overlies its basal member, than in the type area near Elephant Butte dam. These formations suggest

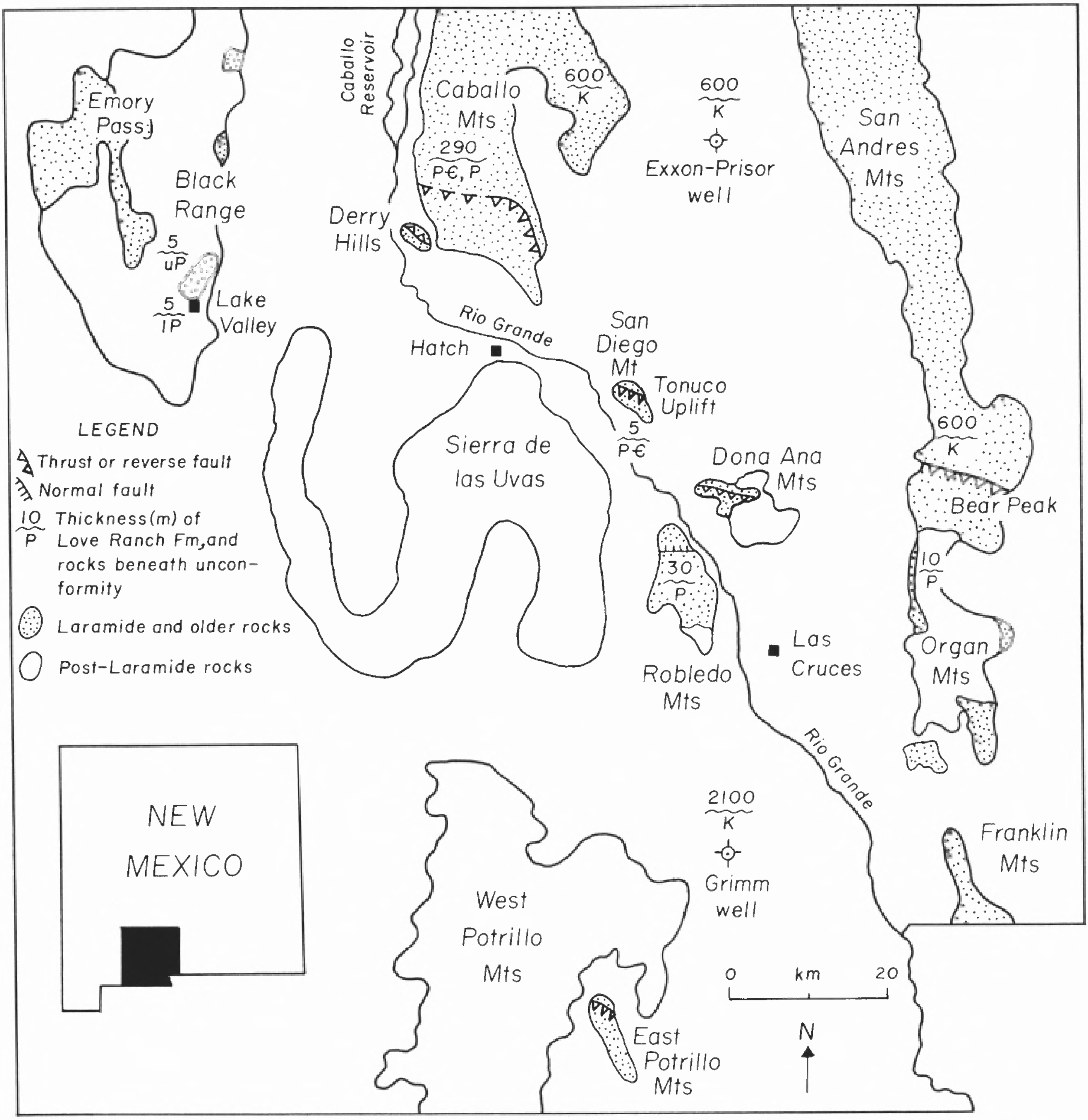

FIGURE 1—Location map. See "legend" for description of data. P€ = Precambrian rocks; P = Paleozoic; lP = lower Paleozoic; uP = upper Paleozoic; K = Cretaceous.

that the upper part of the McRae Formation was removed by erosion prior to deposition of the Love Ranch Formation.

The Love Ranch Formation is overlain by the Palm Park Formation, which consists of volcanic and volcaniclastic rocks that have been radiometrically dated at 40–43 my (early late Eocene) (Seager & Clemons 1975). The Love Ranch–Palm Park contact is conformable and gradational, suggesting that the upper part of the Love Ranch Formation is probably middle or early late Eocene in age.

The only index fossils that have been found in the Love Ranch Formation come from the Grimm well in southern Doña Ana County (Fig. 1). About 2,170 m of reddish or brownish shale, sandstone, and conglomerate are found between middle Tertiary volcanics and Cretaceous sandstone and shale, and are correlated with the Love Ranch Formation (Thompson 1982). The lower 247 m of this section contain palynomorphs that indicate a late Paleocene or early Eocene age (Thompson 1982). Thus, the bulk of the section is probably Eocene.

In summary, the age of the Love Ranch Formation appears to be early Tertiary, with the bulk of the sediment of Eocene age. If so, the deformation in south-central New Mexico that was responsible for deposition of the Love Ranch Formation was "late" Laramide (Gries 1983).

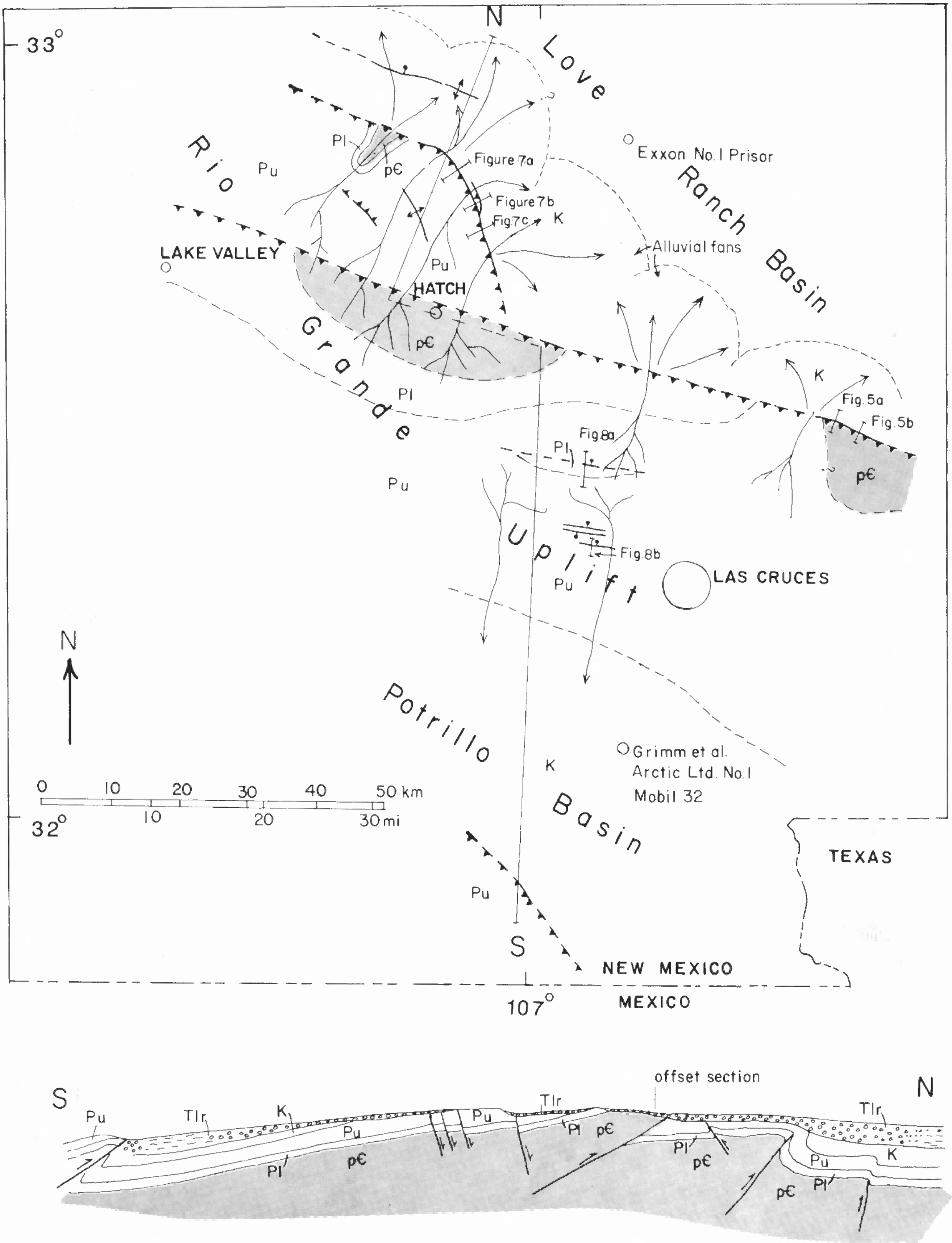

FIGURE 2—Paleogeologic map and restored cross sections of Rio Grande uplift and Love Ranch and Potrillo Basins. Paleogeologic map shows distribution of rocks and structures just below the Love Ranch Formation. K = Cretaceous rocks; Pu = upper Paleozoic rocks including rocks of Mississippian, Pennsylvanian, and Permian age; Pl = lower Paleozoic rocks including rocks of Cambrian, Ordovician, Silurian, and Devonian age; PЄ = Precambrian rocks; Tlr = Tertiary Love Ranch Formation.

Conglomerates of the McRae Formation may indicate an "early" phase of Laramide deformation in the northern Caballo Mountains and southern Fra Cristobal Range, but this phase will not be discussed here.

LARAMIDE PALEOGEOLOGY AND PALEOGEOGRAPHY

The core of the Rio Grande uplift is composed of Precambrian crystalline basement and Paleozoic carbonate rocks and extends from the Bear Peak region of the southern San Andres Mountains west-northwestward to the southern Black Range (Figs. 1, 2). Laramide reverse and thrust faults that involve Precambrian basement in the core of the uplift are exposed at two locations along its trend. A southwest-dipping reverse fault brings Precambrian granite in contact with Paleozoic limestone in the Bear Peak area of the southern San Andres Mountains (Fig. 1). South of the fault, the Love Ranch Formation consists of a thin (<10 m) veneer of conglomerate unconformably overlying Paleozoic rocks. At San Diego Mountain, a southwest-dipping fault thrusts Precambrian granite over silicified Paleozoic carbonate rocks (Figs. 1, 2). Just south of the fault, about 5 m of Love Ranch pebble conglomerate unconformably overlies Precambrian granite, indicating as much as 2.5 km of uplift and erosion prior to onlap by the Love Ranch Formation. Along the eastern margin of San Diego Mountain, the Precambrian basement dips beneath Cambrian and Lower Ordovician sedimentary rocks, suggesting the existence of a structural sag between San Diego Mountain and the southern San Andres Mountains (Seager et al. 1971). Between these two mountains, the Rio Grande uplift is buried beneath the Jornada del Muerto Basin, but its presence is revealed by a seismic profile (see Keller et al. in this guidebook).

The Precambrian core of the Rio Grande uplift is not exposed west of San Diego Mountain, but its exposure during Laramide time is attested to by the abundance of Precambrian granitic and metamorphic clasts in the Love Ranch Formation in the southern Caballo Mountains. In the southern Black Range, less than 5 m of Love Ranch conglomerate unconformably overlie lower Paleozoic carbonate rocks near Lake Valley and Pennsylvanian to Permian rocks farther north and west. This area is interpreted as the northwestward extension of the core or northern flank of the Rio Grande uplift. The evidence for the depth of Laramide erosion in the southern Black Range is contradictory. The Love Ranch Formation overlies only Paleozoic rocks and contains no Precambrian clasts, suggesting that the basement was not exposed. However, in the Emory Pass region of the Black Range, middle Tertiary volcanic rocks directly overlie Precambrian basement, indicating substantial uplift and erosion prior to mid-Tertiary volcanism.

The core of the Rio Grande uplift is bounded on the north by a structurally lower block of deformed Paleozoic rocks, which is exposed in the southern Caballo Mountains (Fig. 1, 2). This zone is about 25 km wide between San Diego Mountain and the southern Caballo Mountains and is, like the core of the uplift, bordered by a zone of basement thrusts and flexures. Love Ranch cobble and boulder conglomerate, dominated by Precambrian detritus, was shed northward across this block, across its marginal flexure, and into the Love Ranch Basin. At one location, Love Ranch conglomerate, sandstone, and shale infilled a canyon that was several km wide and was floored by Precambrian basement (Fig. 3).

The Love Ranch Basin is north of the Rio Grande uplift and contains up to 600 m of terrigenous sedimentary rocks. The basin-margin facies is up to 600 m thick and is well exposed in the southern Caballo and southern San Andres Mountains (Fig. 1). The basin-margin facies consists primarily of conglomerate, with clasts up to several meters in diameter, and subordinate sandstone, shale, and a few thin (<2 m) lacustrine limestones near the top of the section. Most of the sediment was deposited on alluvial fans by debris-flow, streamflood, and sheetflood processes, and was dispersed northward or northeastward, transverse to the trend of the uplift. The lacustrine limestones probably were deposited downslope of the fan toe. In the southern San Andres Mountains, the lower part of the Love Ranch Formation is deformed into a west-northwest-trending, north-vergent, overturned syncline, which probably was related to movement on the Bear Peak reverse fault (Seager 1981). The upper part of the Love Ranch Formation in the Bear Peak

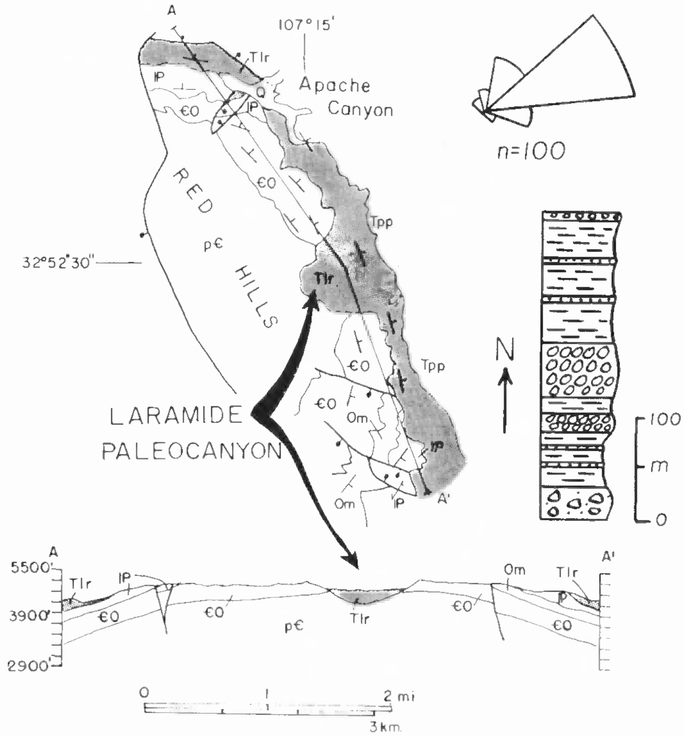

FIGURE 3—Geologic map of the Red Hills area, southern Caballo Mountains, showing Laramide paleocanyon floored by Precambrian granite and filled with Love Ranch fanglomerate (see stratigraphic column to right of map). Rose diagram shows that paleocurrents in Love Ranch alluvial fans moved from southwest to northeast or east-northeast. Paleocurrent directions were taken from imbrication. p€ = Precambrian granite; €O = Cambrian Bliss and Ordovician El Paso Formations; Om = Ordovician Montoya Formation; IP = Pennsylvanian rocks; Tlr = Tertiary Love Ranch Formation; Tpp = Tertiary Palm Park Formation; Q = Quaternary alluvium.

region was only weakly affected by Laramide deformation and unconformably onlaps the folded Love Ranch conglomerate.

Within the Love Ranch Basin, the Love Ranch Formation is at least 600 m thick and overlies Cretaceous rocks: the uppermost Cretaceous McRae Formation in the northeastern Caballo Mountains, the Upper Cretaceous Gallup and Mancos Formations in the southern San Andres Mountains, and Upper Cretaceous(?) rocks in the Exxon no. 1 Prisor well (Fig. 1). The relative abundance of sandstone and shale increases toward the center of the basin and the maximum clast size decreases to a few centimeters.

The southern flank of the Rio Grande uplift consists of Paleozoic carbonate rocks that dip gently southward, locally repeated by steep Laramide normal faults of both large and small displacement (Fig. 2). The principal evidence for the southern dip is the subcrop relationship. A thin (<30 m) veneer of Love Ranch conglomerate unconformably overlies successively younger Paleozoic rocks southward (Fig. 2). For example, in the northern Robledo Mountains the Love Ranch overlies the Silurian Fusselman Dolomite. In the central and southern Robledo Mountains the Love Ranch overlies Mississippian and Permian rocks, respectively. The dip of the southern flank of the Rio Grande uplift averages about 10° or less to the south-southwest. The Love Ranch Formation is not well exposed in the Organ Mountains where it overlies Pennsylvanian and Permian rocks.

The southern flank of the Rio Grande uplift was dissected by a network of southerly flowing streams occupying canyons that backfilled with post-tectonic Love Ranch conglomerate. The best exposures of these canyons are in the Robledo Mountains. In one example, a lower Tertiary canyon at least 100 m wide can be traced for about 1 km in a north-south direction. A smaller canyon enters the main canyon from the west-northwest (Fig. 4). The canyons are incised into the Permian

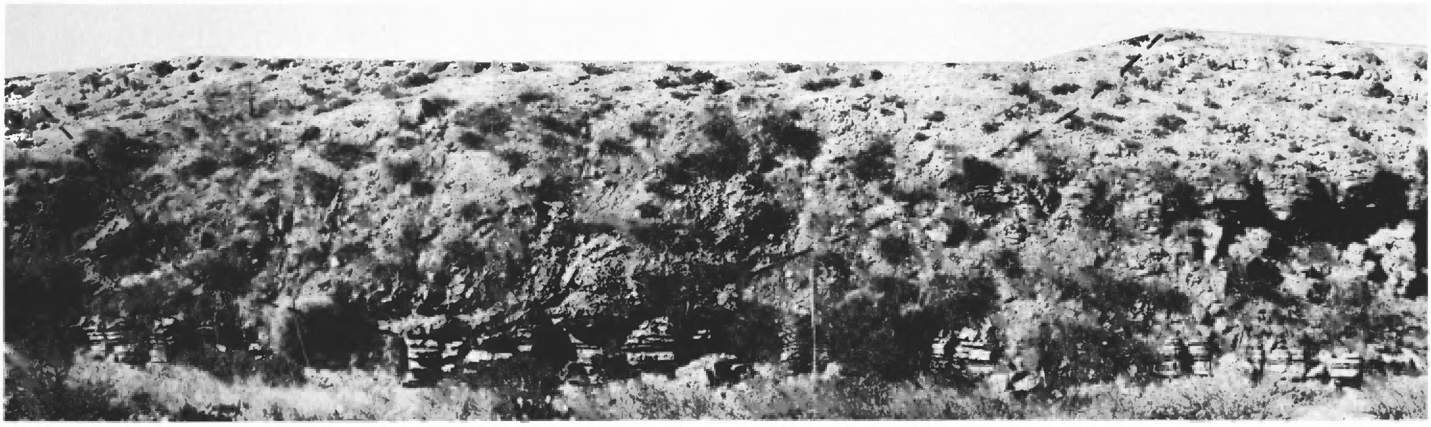

FIGURE 4—Photo of cross section of Laramide paleovalley filled with Love Ranch conglomerate. Exposure is in southern Robledo Mountains and view is south nearly down axis of paleovalley. Paleovalley is about 150 m deep and only lower 30 m are shown in photo.

Hueco and Abo Formations and contain 20 m of grain-supported, imbricated, pebble and cobble conglomerate. Imbrication paleocurrent data from the Love Ranch Formation in the southern Robledo Mountains indicate southward current flow.

The southern flank of the Rio Grande uplift dips into the Potrillo Basin (Fig. 2). Love Ranch sedimentary rocks are not exposed south of the Robledo and Organ Mountains, and evidence for the existence of the Potrillo Basin comes from the Grimm and others American Arctic Limited no. 1 Mobil 32 oil-test well, which is located about 30 km south of Las Cruces (Fig. 1). The Grimm well penetrates about 2.1 km of sandstone, shale, conglomerate, and coal that overlie Upper(?) Cretaceous sedimentary rocks and are overlain by middle Tertiary volcanic rocks (Thompson & Bieberman 1975, Uphoff 1978, Thompson 1982). These predominately fine-grained, terrigenous rocks are interpreted to represent basin-center facies of the Love Ranch Formation. The southern limit of the Potrillo Basin is probably the northern end of the East Potrillo Mountains, where north–northwest-trending folds and thrust faults in Permian and Lower Cretaceous rocks are interpreted to be Laramide in age (Fig. 1; Seager & Mack in press B).

Provenance

The Love Ranch Formation in the Caballo Mountains displays evidence of unroofing of crystalline basement. The lower 100 m or less of the clastic wedge consists of Paleozoic carbonate and sandstone clasts that are joined upsection by clasts of Precambrian granitic and metamorphic rocks. The appearance of Precambrian clasts suggests erosion of the Paleozoic and Mesozoic sedimentary cover and unroofing of the crystalline core of the Rio Grande uplift. In contrast, Love Ranch conglomerates in the southern San Andres Mountains consist exclusively of clasts of Paleozoic rocks. Not until the appearance of arkosic sandstones in the uppermost part of the stratigraphic section is there evidence for unroofing of the crystalline basement. In the southern Black Range, the Love Ranch Formation contains only clasts of Paleozoic rocks and there is no direct evidence that the Precambrian basement was exposed. Assuming that the thickness of Paleozoic and Mesozoic rocks was roughly constant throughout the study area, an interpretation supported by regional mapping (Seager et al. 1982), the zone of maximum uplift and erosion was south of the Caballo Mountains and the magnitude of uplift and erosion decreases eastward and westward.

Conglomerates that infilled channels along the southern flank of the Rio Grande uplift are composed exclusively of clasts of Paleozoic sedimentary rocks. The lack of clasts of Precambrian rocks suggests that a drainage divide existed between the core of the uplift and the southern flank. This divide was probably an erosional, fault-controlled escarpment of Pennsylvanian carbonate rocks exposed today in the northern Robledo Mountains (Figs. 1, 2, 8).

Andesite-porphyry clasts appear in the upper part of the Love Ranch Formation in the Caballo Mountains and coexist with clasts of Paleozoic

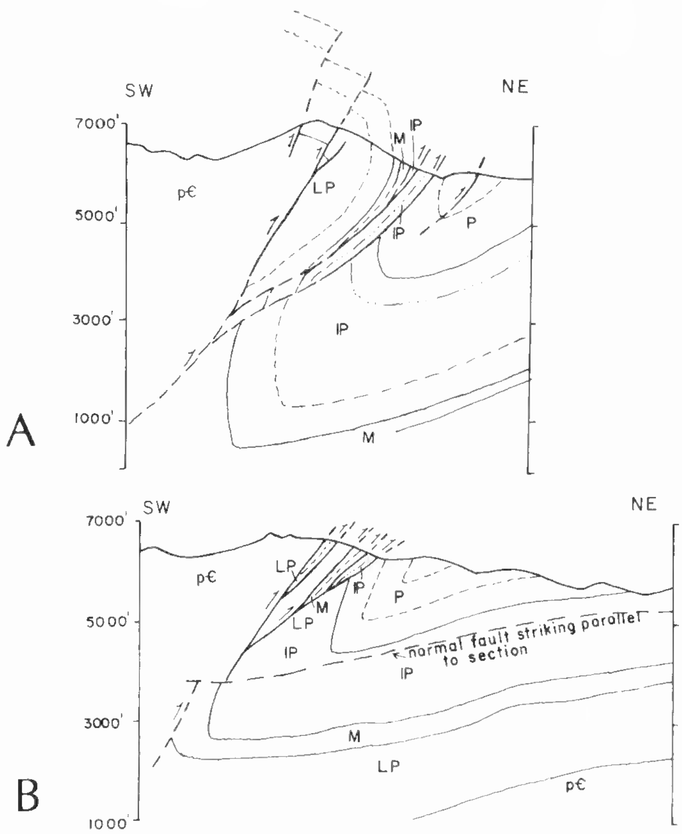

FIGURE 5—Cross sections of Bear Peak fold and thrust belt in southern San Andres Mountains. P = Permian rocks; IP = Pennsylvanian rocks; M = Mississippian rocks; LP = lower Paleozoic rocks including rocks of Cambrian, Ordovician, Silurian, and Devonian age; PЄ = Precambrian rocks. See Fig. 2 for location of sections.

and Precambrian rocks. The volcanic clasts increase in abundance upsection and eventually the Love Ranch Formation grades into the base of the Palm Park Formation, whose middle and upper beds consist almost exclusively of volcanic clasts. Do the volcanic clasts represent erosion of pre-Laramide rocks, such as the Cretaceous andesites that are exposed in the Black Range (Hedlund 1979), or do they represent an early phase of Palm Park volcanism? It is unlikely that Cretaceous volcanic rocks originally covered the study area prior to Laramide uplift, because the volcanic clasts appear in the upper part of the section rather than at the base of the Love Ranch section. Furthermore, the volcanic

FIGURE 6—Photo of major thrust exposed in northern part of Tonuco uplift. This thrust is interpreted as forming the northern boundary of Rio Grande uplift. View is southeast, thrust surface dips about 30° southwest. Sheared Precambrian granite forms hanging wall, partly silicified Paleozoic limestone or dolomite the footwall.

clasts more closely resemble Palm Park volcanics and the Love Ranch–Palm Park contact is conformable and gradational, which suggests that the volcanic clasts represent an early phase of Palm Park volcanism. If so, then the coexistence of volcanic, Paleozoic, and Precambrian clasts in the Love Ranch Formation indicates that the Rio Grande uplift was still supplying gravel-sized clasts to the Love Ranch Basin at the onset of Eocene volcanism. More information is needed on the composition and age of the volcanic clasts before their significance can be fully evaluated.

STRUCTURAL GEOLOGY

General

As shown in Fig. 2, the Rio Grande uplift is interpreted as consisting of one or more asymmetric blocks, which trend west–northwest, dip southwest, and face northeast. Although the uplift appears to be a single block east of San Diego Mountain, farther west, as along section N–S (Fig. 2), it includes two major blocks. The southern block, uplifted highest and eroded to the Precambrian during Laramide time, contains the "core" of the uplift. The northern block, exposed in the southern Caballo Mountains, is structurally lower and, with few exceptions (Fig. 2), was eroded into Paleozoic rocks during the Laramide. This block represents a structural "bench" between the main uplift to the south and the Love Ranch Basin to the north. Both blocks are bordered on their northeastern margin by relatively narrow zones of basement thrusts or reverse faults that together with associated folds indicate tectonic transport to the north–northeast to east–northeast.

Structural margins of uplifts

Exposures of the faulted northeastern margin of the main Rio Grande uplift are well displayed in the southern San Andres Mountains and at San Diego Mountain (Tonuco uplift), and the margin is also revealed in a seismic section between the two exposures (see Keller et al. in this guidebook). Described by Seager (1981), the Bear Peak fold and thrust zone of the San Andres Mountains is shown in representative sections of Fig. 5. The zone features a major west–northwest-trending reverse fault dipping 60° or less southward. Much of the hanging wall consists of Precambrian granite. Below the fault, the footwall is compressed into a large overturned syncline, whose overturned limb is sheared repeatedly by subsidiary thrusts. Locally, overturned beds beneath the thrusts dip only 10° or so southward, having been rotated through an angle of 170°. Even the upright limb of the fold is locally broken by flat thrusts that must branch from, or intersect, the main steeper fault zone at a high angle. Tear faults are locally conspicuous.

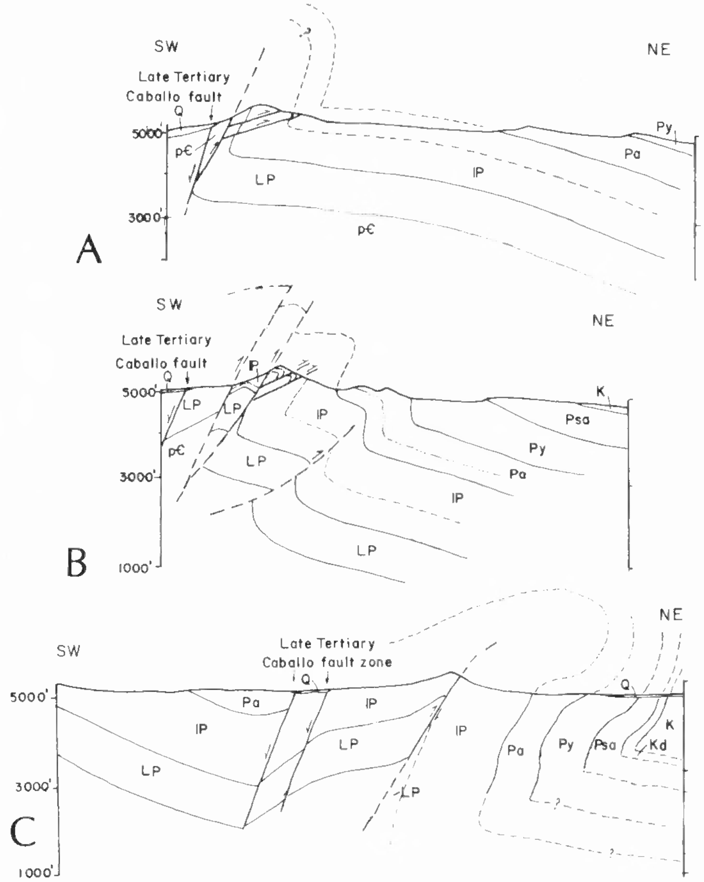

FIGURE 7—Cross sections of northeastern margin of Rio Grande uplift in southeastern Caballo Mountains. Q = Quaternary gravel and conglomerate; K = Cretaceous rocks; Ps = San Andres Formation; Py = Yeso Formation; Pa = Abo Formation; IP = Pennsylvanian rocks; LP = lower Paleozoic rocks including rocks of Cambrian, Ordovician, Silurian, Devonian, and Mississippian age; PЄ = Precambrian rocks. See Fig. 2 for location of sections.

Stratigraphic separation across the zone is at least 3 km and may be as much as 5 km, yet the width of the deformed belt is only 1–2 km.

Another exposure of the northeastern margin of the Rio Grande uplift is present on the northern flank of the Tonuco uplift (San Diego Mountain). At this locality, the margin consists of a major thrust fault striking northwest and dipping 30° southwest. Precambrian granite in the hanging wall has moved relatively northeastward over silicified Paleozoic rocks in the footwall (Fig. 6). Although small, the exposure of this fault is important because thin Love Ranch conglomerate depositionally overlies the granite only a few tens of meters or so above the fault surface. Thrust uplift in this part of the Rio Grande uplift was apparently sufficient to cause erosion of 2,700 m or more of Paleozoic and Mesozoic strata from the hanging wall.

The northeastern boundary of the structurally lower "bench" of the Rio Grande uplift can be traced along the eastern and central part of the southern Caballo range. Exposed almost continuously for 25 km, the zone of tight, overturned folds and associated faults is only about 1 km wide, although locally it widens to 2 km in response to bifurcation of structures. Like the Bear Peak and San Diego Mountain structures, vergence is toward the north–northeast to east–northeast. Unlike those structures, however, the conspicuous deformation in the Caballo range is by folding rather than by faulting. This may reflect the generally deeper levels of erosion and greater uplift in the Bear Peak–San Diego Mountain area.

The central structure in the Caballo deformed belt is an overturned, faulted anticline–syncline pair, the overturning commonly approaching recumbent geometry (Fig. 7). Locally, the structure bifurcates into two fold pairs which step the section down to the northeast (Fig. 7b).

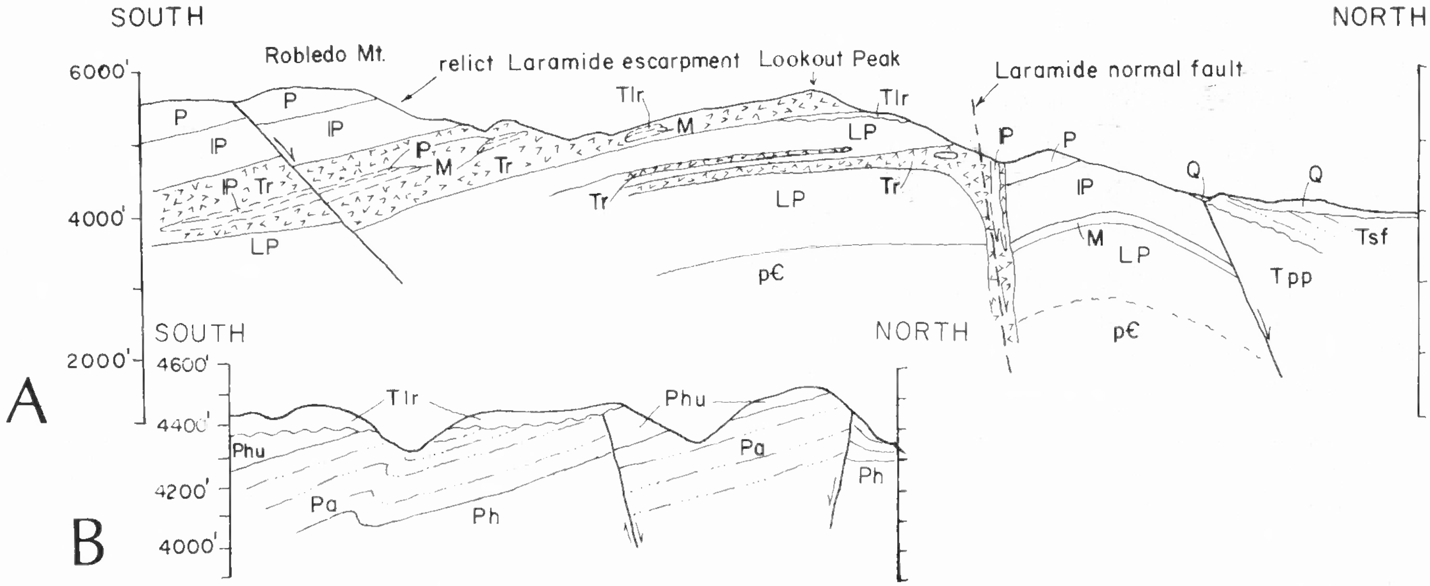

FIGURE 8—Cross sections illustrating evidence for Laramide high-angle normal faults in the Robledo Mountains. Note in section (a) how Love Ranch Formation overlies deeply eroded strata on footwall of normal fault, whereas much younger strata are preserved in hanging wall. This relationship indicates pre-Love Ranch faulting and erosion as does the angular unconformity above normal faults in section (b). Q = Quaternary rocks and sediment; Tsf = Santa Fe Group; Tr = rhyolite sills; Tpp = Palm Park Formation; Tlr = Love Ranch Formation; P = Permian rocks; Phu = upper Hueco Formation; Pa = Abo tongue of Hueco Formation; Ph = lower Hueco Formation; IP = Pennsylvanian rocks; M = Mississippian rocks; LP = lower Paleozoic rocks including Cambrian, Ordovician, Silurian, and Devonian rocks; PЄ = Precambrian rocks. See Fig. 2 for location of sections.

Maximum structural relief across the zone may approach 4 km. At high structural levels, minor thrust faults disrupt anticline cores or offset overturned fold limbs (Fig. 7b, c). At lower levels, thrust or reverse faults are more important. They display up to a few hundred meters of stratigraphic separation and juxtapose upright lower Paleozoic rocks in the core region of anticlines against overturned limbs (Fig. 7b). At still deeper levels, a single exposure shows that these faults transect basement at an angle of 60° (Fig. 7c). All of these faults dip southwesterly. Northeast-trending tear faults of small displacement are locally present.

Southwest-vergent structure

About 15–20 km southwest of the Caballo deformed belt is another fold–thrust belt. This, however, appears to be an intrauplift feature, which displays southwest vergence. Exposed in the Derry Hills, the zone trends northwest and can be traced only about 2 km before it passes beneath Quaternary gravel (Fig. 1). About 1 km wide, the zone consists of a tightly overturned syncline in Pennsylvanian strata, facing southwestward, above which older Pennsylvanian and lower Paleozoic rocks moved relatively southwestward. Faults appear to be steep reverse faults and are closely spaced. Open folding is locally present in hanging-wall rocks. Because of silicification and superimposed late Tertiary faults, the structure is complex.

Normal faults on southern flank of uplift

Normal faults interrupt the southerly dip of the southwestern flank of the Rio Grande uplift in several places. Essentially strike faults, they trend west to northwest and dip unusually steeply for normal faults (70–90°). Many are downthrown toward the north. Stratigraphic separation generally is a few tens to approximately 100 meters, but at least one fault, exposed in the northern Robledo Mountains, features 250–300 m of stratigraphic separation (Fig. 8a).

The Laramide age of these faults is indicated primarily by the deeper level of erosion of footwall blocks relative to hanging-wall blocks by Love Ranch time. That is, Love Ranch conglomerate depositionally overlies older beds on upthrown blocks compared to adjacent downthrown blocks (Fig. 8a). At one locality, Love Ranch conglomerate can be seen to onlap across both hanging wall and footwall, as well as the intervening fault surface (Fig. 8b).

The normal faults produced northwest-trending fault-line scarps of modest to substantial relief in upper Paleozoic strata, which then acted as local or regional drainage divides. A good example is the escarpment of Pennsylvanian rocks in the northern Robledo Mountains which is a relict fault-line scarp created by the Laramide fault at the northern tip of the Robledo Mountains (Fig. 8a).

DISCUSSION

We used both stratigraphic and structural evidence from south-central New Mexico to constrain the style of Laramide deformation in this foreland region. The picture that has emerged suggests that a structural style very similar to parts of the Wyoming province prevailed in south-central New Mexico. Deformation was characterized by uplift of northwest-trending, rigid basement blocks bounded on the northeast side by narrow fold–fault belts and flanked on the southwestern sides by southwest-dipping slopes interrupted locally by fault-line scarps. This asymmetric style of uplift is bordered by similarly asymmetric complementary basins filled with as much as 2,000 m of syn- to post-orogenic sedimentary rocks. We interpret the Rio Grande uplift and its complementary basins to be similar in overall structural style to the Wind River uplift and its complementary Wind River and Green River Basins, although we recognize that the southern New Mexico structures exhibit less structural relief and probably smaller areal extent (Prucha et al. 1965, Chapin & Cather 1981, Gries 1983). The Rio Grande uplift also is a composite uplift, consisting of at least two blocks which step the basement and cover rocks down to the north in stair-step fashion. The relatively low dips (<60°) of boundary thrust or reverse faults and strongly overturned to nearly recumbent associated folds show that the southern New Mexico uplifts, like the Wind River Range, are the products of strong regional compression accompanied by substantial crustal shortening as well as vertical uplift (e.g. Smithson et al. 1979).

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