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1997, pp. 57-64. https://doi.org/10.56577/FFC-48.57

in:

Mesozoic Geology and Paleontology of the Four Corners Area, Anderson, O.; Kues, B.; Lucas, S.; [eds.], New Mexico Geological Society 48th Annual Fall Field Conference Guidebook, 288 p. https://doi.org/10.56577/FFC-48

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TECTONICS OF THE FOUR CORNERS REGION OF THE COLORADO PLATEAU

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Abstract—The Four Corners region is in the central part of the Colorado Plateau, a structurally unique province that has undergone only moderate Laramide (Late Cretaceous–Paleogene) deformation compared with surrounding areas. This province is characterized by monoclines separating large, tilted blocks, with basins and asymmetric uplifts forming the major tectonic elements. The north-trending Monument and Defiance uplifts and the circular San Juan dome are bounded by the Blanding, San Juan, and Black Mesa basins. The Four Corners platform, of intermediate structural height, connects the Defiance uplift with the San Juan dome, and separates the Blanding and San Juan basins. The Ute, La Plata, and Carrizo intrusive centers are composed mainly of intermediate felsic porphyries that form laccoliths, stocks, necks, dikes, and sills. The structural and tectonic features are the results of northeast movement of the Colorado Plateau during the Laramide orogeny. Two phases of crustal contraction have been proposed, with the first phase of maximum compressional stress oriented E–W to NW–SE and the second oriented NE–SW to N–S. North-trending structures were inferred to be caused by the first phase and west-trending features caused by a second phase. Recent work, however, has indicated that there is no systematic variation in initiation and cessation of movement on individual Laramide structures. Northeast movement of the Colorado Plateau resulted in left shift on the north side of the plateau where it is bounded by the Uinta uplift and right shift on the east side adjacent to the Nacimiento uplift. East-trending, regional piercing lines formed by stratigraphic pinchouts, truncations, and facies changes of Paleozoic and Mesozoic strata in New Mexico allow a maximum of 5–20 km of Laramide right-lateral offset along the east side of the Colorado Plateau. Nonetheless, some workers have proposed 60–170 km of Laramide right slip along a north-trending zone up to 100 km wide on the east side of the plateau, even though the data clearly indicate this is an excessive estimate. Right shift within the plateau occurred along the sinuous, north-trending Defiance monocline.

INTRODUCTION

The Four Corners region lies in the central part of the Colorado Plateau (Fig. 1), a structurally unique province that has been only moderately deformed compared to the more intensely deformed regions around it. The Colorado Plateau appears to have behaved as a relatively stable structural unit during Laramide (Late Cretaceous-Paleogene) deformation. Monoclines separating large, gently tilted blocks characterize the plateau (Kelley, 1955a), with wide basins and asymmetric uplifts forming the major tectonic elements. Most uplifts are bounded on one side by a major monocline, and the other side of each uplift grades into the adjacent basin through a gentle slope. The basin-uplift boundary on the gently dipping slope is arbitrarily chosen, usually based on the extent of a given stratigraphic unit. The boundary on the monoclinal side is structurally defined with numerous gradations from gently dipping, open monoclines to overturned and thrust structures. Maximum structural relief across the major monoclines is as much as 4200 m (Kelley, 1955b). Basement faults ranging from low-angle thrusts to high-angle faults commonly grade upsection or along strike into monoclines, indicating draping of strata over faulted basement blocks. Most monoclines have sinuous traces, and a few, such as the Defiance, are contorted because of numerous diagonal cross folds. Minor monoclines also occur within many of the basins and uplifts.

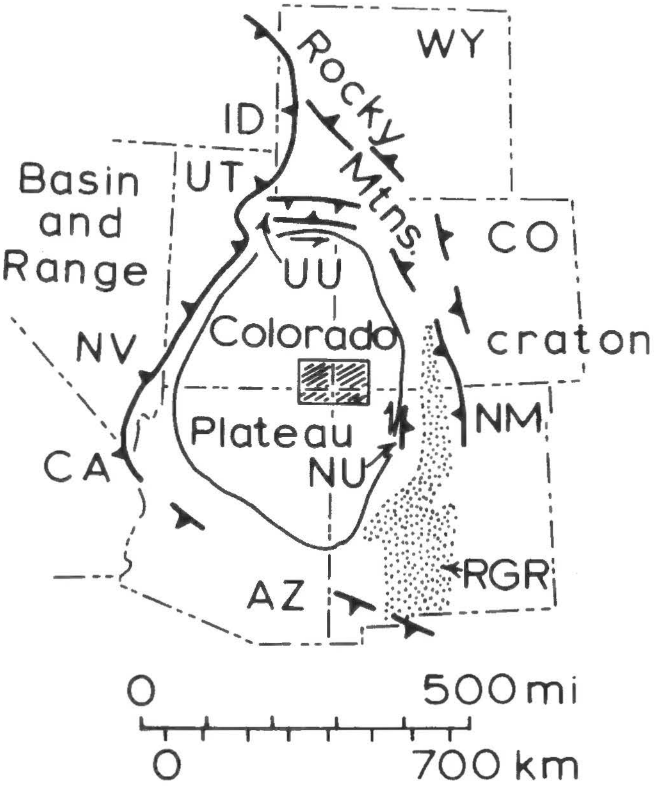

FIGURE 1. Location of Colorado Plateau and adjacent areas. Four Corners region hachured and Rio Grande rift (RGR) stippled. NU = Nacimiento uplift, UU = Uinta uplift.

The tectonic boundaries of the Colorado Plateau are marked by the Basin and Range province on the west, south, and southeast, the Uinta uplift on the north, and the Rio Grande rift and Southern Rocky Mountains on the east (Kelley and Clinton, 1960). The Basin and Range province and the Rio Grande rift are of Neogene age and postdate the principal development of the Colorado Plateau.

Most features shown on the tectonic map of the Four Corners region (Fig. 2) are of Cretaceous and Cenozoic age. However, deformation during the Precambrian and the late Paleozoic resulted in crustal anisotropy that locally had strong influence on development of younger structures.

The Colorado Plateau is underlain by crust about 40 to 45 km thick, whereas the crust under the Basin and Range province to the west and south is about 20 to 40 km thick (Smith, 1978; Prodehl, 1979; Prodehl and Pakiser, 1980). Keller et al. (1978) reported that the crust of the Rio Grande rift to the east of the plateau is 30 to 35 km thick. Sheehan et al. (1995) noted average crustal thicknesses of 43.1±0.9 km for the northeast Colorado Plateau, 50.1±1.3 km for the Colorado Rocky Mountains, 49.9±1.2 for the Colorado Great Plains, and 43.8±0.4 km for the Kansas Great Plains. These findings require significant support for the high elevations of the Rocky Mountains to come from the mantle rather than Airy-type crustal roots. Gravity lows associated with the San Juan Mountains have been explained as batholiths in the subsurface beneath calderas rather than as areas with deep crustal roots (Plouff and Pakiser, 1972).

The Colorado Plateau and adjacent areas that comprise the continental interior of the western United States have high elevations that Humphreys and Dueker (1994) inferred to be about 1 km too high with respect to crustal thicknesses. The anomalously high elevations are explained by the presence of a buoyant upper mantle having high temperatures and low density.

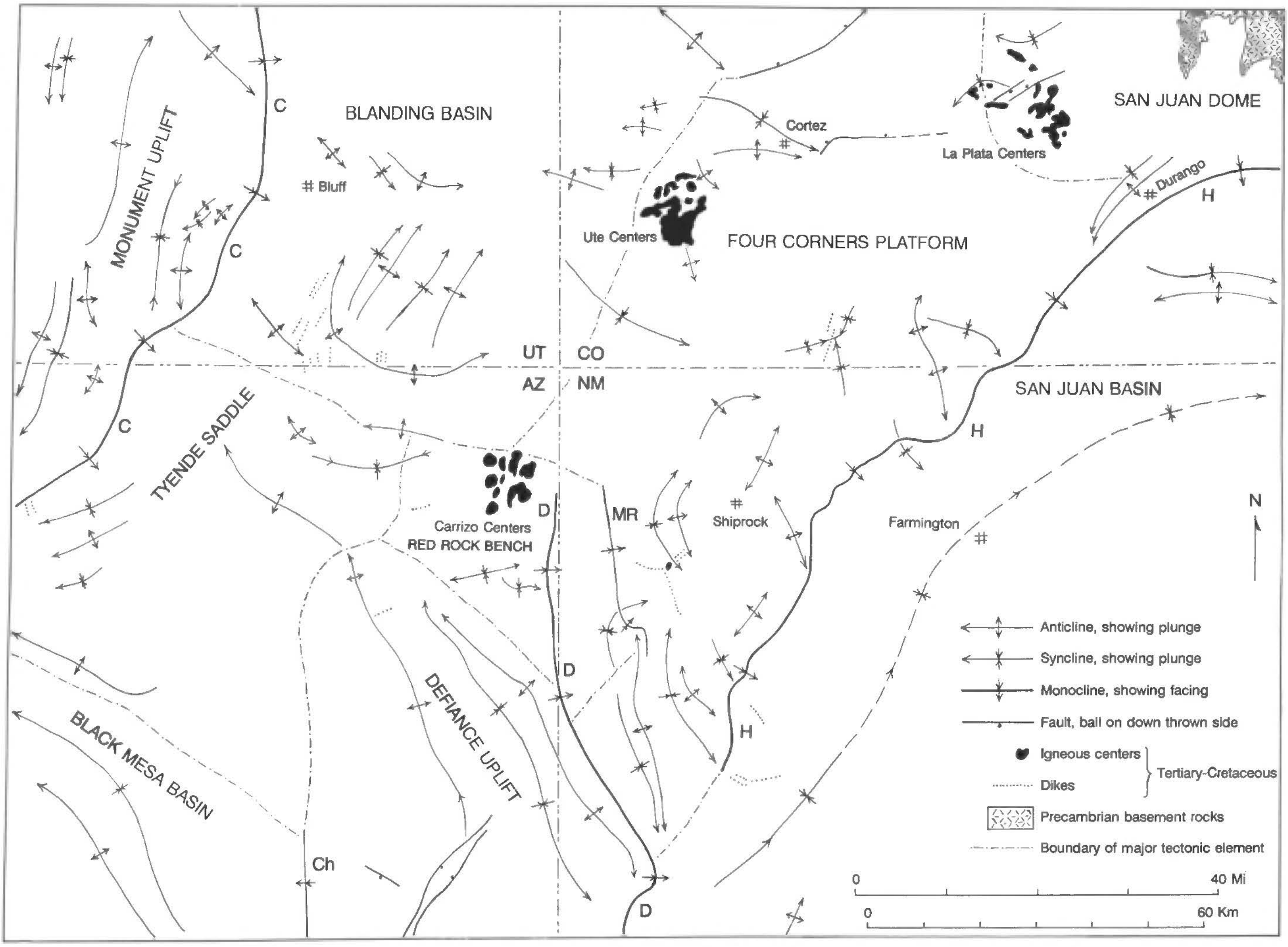

FIGURE 2. Generalized tectonic map of the Four Corners region. Modified from Hackman and Wyant (1973), Haynes et al. (1972), Kelley (1955b), O'Sullivan and Beikman (1963), Steven et al. (1974), and Tweto (1979). C = Comb monocline, Ch = Chinle monocline, D = Defiance monocline, H = Hogback monocline, and MR = Mitten Rock monocline.

ROCK UNITS

Precambrian igneous and metamorphic rocks form the basement in the Four Corners region. These are competent rocks that deform brittlely at low temperatures and confining pressures. The principal exposures of these rocks are in the southwestern part of the San Juan dome (Fig. 2).

Other rocks that also are preorogenic with respect to Laramide deformation are Paleozoic and Mesozoic strata. Paleozoic carbonate, sandstone, and orthoquartzite units are more ductile than the Precambrian rocks, but are more competent than the thick mudstone intervals of the upper Paleozoic and Mesozoic. Cretaceous shales, in particular, tend to deform plastically.

Synorogenic strata of Laramide age are represented by the McDermott Formation (Upper Cretaceous), Animas Formation (Upper Cretaceous and Paleocene), Ojo Alamo Sandstone (Upper Cretaceous and Paleocene), Nacimiento Formation (Paleocene), and San Jose Formation and correlative strata of the Blanco Basin Formation (lower Eocene) in the San Juan Basin. These units are not shown on Figure 2.

The Chuska Sandstone (upper Eocene–lower Oligocene?) of the Defiance uplift is a postorogenic unit that unconformably overlies the Defiance monocline in a few localities. Basalt flows (Pliocene) overlie the Chuska Sandstone. Volcanic rocks of the San Juan Mountains, mainly Oligocene and Miocene, are postorogenic with respect to Laramide deformation and are not shown on Figure 2.

TECTONIC FRAMEWORK

The major tectonic elements of the Four Corners region include the Monument uplift, Blanding basin, Four Corners platform, San Juan Basin, Defiance uplift, Black Mesa basin, and the San Juan dome and volcanic field (Fig. 2). In a physiographic sense the San Juan volcanic field has not been considered to be part of the Colorado Plateau (Fenneman, 1930). However, as Kelley (1955b) noted, this volcanic field overlies a structural part of the plateau. In addition, there are three laccolithic centers—Ute, La Plata, and Carrizo. Widely scattered dikes and volcanic necks are mostly Oligocene.

Monument uplift

The Monument uplift is about 145 km long, 48 km wide, and trends northerly. It is markedly asymmetric, with the steep eastern limb defined principally by the east-facing, slightly arcuate Comb monocline. There is at least 1500 m of structural relief between the uplift and the Blanding basin to the east. The Comb monocline, slightly sinuous near its southern end, has a maximum dip of 45° (Kelley, 1955a). The western flank of the uplift merges with the White Canyon slope that dips gently into the Henry basin. The southeastern edge of the uplift is bounded by the Tyende saddle, which connects the Blanding basin with the Black Mesa basin to the south. Numerous minor open anticlines and synclines, mostly trending northerly to northeasterly, are present within the uplift.

Blanding basin

The Blanding basin has a maximum north-south length of about 100 km and is as much as 80 km wide. It is a relatively shallow basin, having no more than 150 m of closure (Kelley and Clinton, 1960). The basin is asymmetric, with a steep western limb near the foot of the bounding Comb monocline on the west. To the southeast the basin is bounded by the Red Rock bench. The Blanding basin is connected with the Black Mesa basin by the Tyende saddle. Elsewhere, the Blanding basin merges through gently dipping strata with the adjoining tectonic divisions of the plateau. To the east is the Four Corners platform and to the northeast is the Paradox fold and fault belt. Numerous open, upright anticlines and synclines having various trends are present in the basin. Most are less than 25 km long.

Four Corners platform

The Four Corners platform is intermediate in structural height between the surrounding basins and uplifts. The platform trends northeasterly for about 175 km and its width ranges from about 30 to 65 km. The southeast boundary of the platform is the Hogback monocline. There is at least 1800 m of structural relief between the platform and the deeper part of the San Juan Basin. To the southwest, the Mitten Rock and Defiance monoclines mark the boundary between the platform and the Red Rock bench and the Defiance uplift. On the northeast the San Juan dome bounds the Four Corners platform. Most folds within the platform have various trends, ranging from northerly in the south part to westerly in the north. A few small, southeasterly plunging folds are present along the Hogback monocline.

San Juan Basin

Only the northwestern part of the San Juan Basin is shown in Figure 2; in its entirety it is nearly circular and approximately 160 km in diameter. It is markedly asymmetric, with the axial trace defining a concave-southward arc near the northern margin of the basin adjacent to the Hogback monocline. The northwest boundary of the basin is the Hogback monocline, which dips as much as 60° and has up to 1200 m of structural relief in the area shown in Figure 2. Several small, south- to southeast-plunging cross folds result in a sinuous trace of the monocline. East of Durango, the San Juan Basin is bounded on the north by the San Juan dome. This boundary is marked by the Hogback monocline. Two slightly arcuate, open, easterly trending folds, concave to the south, are present in the north part of the basin near Durango.

Defiance uplift

The Defiance uplift trends north, is about 150 km long and 55 km wide, and is markedly asymmetric with a steep eastern limb. Maximum structural relief is at least 2400 m. Only the northern part of the uplift is shown on Figure 2. The eastern boundary is mostly the east-facing Defiance monocline, which dips 20°–90° and has 900 to 1800 m of structural relief. Sinuosity of the trace of the monocline is due to southeast-plunging cross-folds. The western boundary of the uplift is defined partly by three monoclines having mostly moderate dips and small structural relief; only the Chinle monocline is present in the area shown on Figure 2. Elsewhere, the western flank dips 2°–3° into the Black Mesa basin along a broad, regional homocline. To the north, the uplift merges with the Red Rock bench, which is intermediate in structural height between the uplift and the Four Corners platform. A few northeast- and northwest-striking high-angle faults with small displacements are present in the part of the uplift shown on Figure 2. Folds within the uplift trend northwest.

Black Mesa basin

The Black Mesa basin is shallow, nearly symmetric, and is about 130 km across. Only the northeastern part of the basin is shown on Figure 2. There is about 1800 m of structural relief between the deepest part of the basin and the top of the Defiance uplift (Elston, 1960). To the northeast the Tyende saddle connects the Black Mesa and Blanding basins.

San Juan dome

The San Juan dome is nearly circular and about 100 km in diameter. The dome is slightly more extensive than the overlying San Juan volcanic field, particularly along the southwest side in the area north of Durango. Here, Precambrian basement rocks are exposed. Maximum structural relief between this part of the dome and the adjacent San Juan Basin is about 6200 m, with as much as 3500 m of the relief taken up by the Hogback monocline (Steven et al., 1974). The monocline dips as much as 60° and forms the southern boundary of the dome with the San Juan Basin. The southwestern margin of the San Juan dome is transitional with the Four Corners platform. Structural relief between the dome and the platform is generally about 1200 m (Haynes et al., 1972). The San Juan volcanic field consists of extrusive and subordinate related intrusive rocks mainly of Oligocene and Miocene age, with at least 11 major calderas (Steven et al., 1974).

INTRUSIVE CENTERS

The Ute, La Plata, and Carrizo igneous centers, composed mainly of laccoliths, stocks, necks, dikes, and sills, are the principal areas of intrusions in the Four Corners region. Strata are domed around these centers (O'Sullivan and Beikman, 1963; Haynes et al., 1972). The intrusive rocks are porphyritic and mainly of intermediate compositions, ranging from diorite to syenite and quartz diorite to granodiorite. In addition to these intrusive centers are sparse, widely scattered dikes and a few volcanic necks and diatremes. Most of these rocks are mafic, ranging from basalt to lamprophyric minette and monchiquite (O'Sullivan and Beikman, 1963; Haynes et al., 1972).

LARAMIDE DEFORMATION

It is generally agreed that Laramide deformation of the Colorado Plateau involved crustal shortening (Kelley, 1955b; Dickinson et al., 1988). Compressive stress for this deformation is attributed by most workers to shear between the continental lithosphere and underlying subhorizontal oceanic lithosphere subducted beneath the Laramide province (Dickinson and Snyder, 1978).

Northeast movement of the Colorado Plateau with respect to the Rocky Mountain foreland on the north and east was suggested by Kelley (1955b) on the basis of echelon folds on the northern and eastern edges of the plateau. These folds were interpreted as indicating left shift on the north margin of the plateau and right shift on the eastern margin. Although Kelley (1955b) made no estimate of the amount of right shift, one of his students proposed 5 km of right slip where the San Juan Basin adjoins the Nacimiento uplift of the Southern Rocky Mountains (Baltz, 1967). Right shift has also been proposed within the Colorado Plateau on the east side of the Defiance uplift, where the sinuous Defiance monocline is crossed by SE-plunging folds (Kelley, 1955a). Kelley and Clinton (1960) proposed two phases of Laramide deformation in and adjacent to the Colorado Plateau, with the first maximum compressional stress oriented E–W to NW–SE and the second oriented SW–NE. Hamilton (1980) suggested that internal deformation in the Laramide province involved a few degrees of clockwise rotation of the Colorado Plateau with respect to the craton. Rotation of the plateau around an Euler pole east of the Laramide province requires northward movement of the plateau with respect to the Rocky Mountain region. Recent paleomagnetic studies by Molina-Garza et al. (in press) indicate that the Colorado Plateau rotated clockwise 1° to 8° with respect to the cratonic interior of North America.

Chapin and Cather (1981) and Gries (1983) inferred that north-trending structures were related to E–W crustal shortening and formed in latest Cretaceous to Paleocene time and that west-trending structures were related to N–S crustal contraction and are Eocene features. Dickinson et al. (1988), however, indicated that the onset of Laramide deformation in Maastrichtian (latest Cretaceous) time began throughout the province with no systematic spatial differences in timing of inception of deformation. Cross (1986) also concluded that there is no systematic variation in initiation and cessation of movement on individual Laramide structures. Dickinson et al. (1988) proposed that the diverse structural trends developed contemporaneously across a region of varied crustal structure and reflect heterogeneous strain caused by shear between the continental lithosphere and flat-lying, subducted oceanic lithosphere below. In a study of the mechanics of the monoclines of the Colorado Plateau during the Laramide, Yin (1994) assumed that there was one episode of greatest regional compressive stress oriented N60°E and interpreted the resultant monoclines as drag folds verging toward a NNW-trending arch in the middle of the plateau.

Many of the long, NW-trending folds extending across boundaries of major tectonic elements, as in the Defiance uplift and Black Mesa basin (Fig. 2), may represent NE–SW compression and perhaps are regional folds that developed prior to rise of the major uplifts. The NW-trending grabens in the Defiance uplift and La Plata igneous centers also support a

NE–SW principal compressional stress with NW–SE extension. Northeast-striking, steeply dipping, mafic dikes that postdate the Laramide deformation are present in the Four Corners platform (Condon, 1991) and the Blanding basin (Haynes et al., 1972). These dikes may have been emplaced along extensional fractures parallel to the direction of maximum compressional stress. However, the diverse trends of many folds in the Four Corners region, particularly those in the Blanding basin (Fig. 2), are not readily explained by one direction of regional maximum horizontal compressional stress. Rather, local stress fields resulting from crowding by rising uplifts or basin subsidence may have controlled some of the fold trends.

When the axis of a large basin—where the earth's curvature is a factor—subsides with respect to the margins of the basin, the strata undergo compression perpendicular to the axis (Dallmus, 1958). This is because the chord is shorter than the arc it subtends, and, as the arc subsides and approaches the chord, there will be second-order folds parallel to the basin's axis. The folds in the northern part of the San Juan Basin (Fig. 2) are interpreted to have formed in this manner.

Radial folds are common in the San Juan Basin and are readily seen where they cross the Hogback monocline and plunge toward the center of the basin (Fig. 2). These folds formed in response to greater subsidence in the basin center than along the margins; the circumference of strata on the basin margin is forced to occupy a smaller circumference as the beds are depressed and pulled toward the center of subsidence. This results in local compressional stress fields tangential to the basin margin. These folds mostly have small amplitudes and large wave lengths.

Since the work of Kelley (1955b) and Baltz (1967), there has been general agreement that the eastern margin of the San Juan Basin portion of the Colorado Plateau has undergone Laramide right shift with respect to the Nacimiento uplift of the Rocky Mountain foreland (Fig. 1). Chapin and Cather (1981) estimated that the Colorado Plateau moved 60 to 120 km to the north-northeast relative to the craton to the east. They based their estimate largely on the presumed amount of crustal shortening across thrust and reverse faults to the north of the plateau in the Wyoming province (Fig. 1). They further suggested that the decoupling occurred within a north-trending zone up to 100 km wide marked by the Nacimiento fault system on the west (eastern margin of the San Juan Basin), with most of the strike-slip motion on faults now buried by the sedimentary fill of the late Cenozoic Rio Grande rift.

Karlstrom and Daniel (1993) proposed that features in Proterozoic rocks in northern New Mexico supported 100 to 170 km of northward Laramide movement of the Colorado Plateau along several north-striking right-slip faults in the same zone noted by Chapin and Cather (1981). They reported that the intersection of a regionally subhorizontal isobaric metamorphic surface with subvertical stratigraphic units and pre-existing structures created piercing lines that could be used to indicate net displacement since 1.4 Ga. Displacements of about 15 km across the Tusas-Picuris fault (Karlstrom and Daniel, 1993) and 37 km across the Picuris-Pecos fault (Miller et al., 1963) appear to be reasonable estimates, but these amounts of offset were constrained only as post-1.4 Ga. Miller et al. (1963) inferred that the right slip on the Picuris-Pecos fault probably occurred during the Precambrian.

These estimates of large amounts of Laramide right slip on the east side of the Colorado Plateau lack supporting data. East-trending, regional piercing lines formed by stratigraphic pinchouts, truncations, and facies changes of Paleozoic and Mesozoic strata allow maximum Laramide right lateral offset of only 5–20 km along the east side of the Colorado Plateau.

In southern New Mexico, Cambrian through Devonian strata thin and are truncated northward beneath unconformably overlying upper Paleozoic strata. Truncated edges form regional piercing lines showing no significant right slip on the east side of the Colorado Plateau (Figs. 3A–C). In a structural sense, the isopach lines represent vertical surfaces; there are no indications of right-lateral offset. In addition, east-trending facies tracts of the Cambian Bliss Formation (Fig. 3A) and the transition between the Permian continental Abo and marine Hueco Formations (Fig. 3D) lack any expression of right-lateral offset.

In north-central New Mexico, Jurassic strata are truncated southward by a regional, low-angle unconformity beneath overlying Cretaceous strata (Dobrovolny et al., 1946; Silver, 1948). Paleotectonic maps of the Jurassic System by McKee et al. (1956) show zero isopach lines for three stratigraphic intervals (B, C, and D), where the Entrada Sandstone, Todilto and Summerville Formations, and the Morrison Formation, respectively, are truncated by overlying Cretaceous strata (Figs. 4A–C). Although the precise placement of the zero isopach lines can be argued, the isopach lines clearly indicate that 60–170 km of right slip cannot be accommodated along the eastern margin of the Colorado Plateau. Near Carthage, New Mexico, about 88 km south of the wedge-edge of the Morrison Formation shown on Figure 4C, there is approximately 1.0–3.3 m of possible Morrison strata present above Triassic strata and below the Cretaceous Dakota Formation (Hunt and Lucas, 1987). There is no indication of any Morrison Formation between the wedge-edge shown on Figure 4C and Carthage or farther south than Carthage. Hunt and Lucas (1987) suggested that the Morrison was preserved from erosion either by being deposited in a topographic low or by a local downwarp before deposition of the overlying Dakota Formation. These outcrops do not define a regional piercing line and therefore cannot be used to determine strike-slip movement.

One of the most convincing piercing lines in Mesozoic strata is the wedge-edge of the lower, limestone-dominated Luciano Mesa Member of the Todilto Formation (Fig. 4D). This thin (mostly <10 m thick), distinctive unit represents deposition in a large salina lake basin during the Middle Jurassic (Kirkland et al., 1995). The upper member of the Todilto consists of gypsum that is areally more restricted than the Luciano Mesa Member and represents progressive drying of the evaporite basin. Isopach lines of the Luciano Mesa Member suggest little or no offset of this unit on the east side of the Colorado Plateau. Furthermore, restoration of 60–170 km of purported Laramide right slip along north-striking faults would produce a Todilto paleodepositional basin geometry that is unlikely.

Piercing lines defined by stratigraphic pinchouts and facies tracts are provided by Upper Cretaceous strata in northern New Mexico. Detailed studies by Molenaar (1973) and Black (1979) show the northeast pinchout of the Hosta-Dalton Sandstone, a transgressive-regressive sequence in the Mancos Shale, and the northeast, seaward extent of the regressive Gallup Sandstone, also within the Mancos Shale (Fig. 5). The line marked by the Hosta-Dalton pinchout continues along trend from the San Juan Basin across the Rio Grande rift and into the Hagan Basin on the east side of the rift. The Gallup Sandstone pinchout, an erosional edge truncated by an unconformity at the base of the upper Mancos Shale, can be traced in the subsurface to the center of the rift (Black, 1979). In detail, the map views of these lines are probably somewhat sinuous; Figure 5 shows regional trends that eliminate local irregularities. These lines do not show right-lateral offset of 60–170 km suggested by earlier workers.

A narrow belt of northwest-trending, oil-productive, basal Niobrara-age (Tocito) sandstone bars (Fig. 5) that are seaward of the Gallup Sandstone in the San Juan Basin extend across the Rio Grande rift into the Hagan Basin and Santa Fe embayment of the rift (B. A. Black, written commun., 1996). In 1985, oil was discovered in these sandstones at the Black Oil Co.-Ferrill No. 1 well in the Santa Fe embayment on the east side of the rift, further confirming their correlation with the Tocito of the San Juan Basin.

The Tres Hermanos Formation consists of a regressive-transgressive wedge that prograded eastward into the Western Interior Seaway during Turonian time. The progradation was limited to west-central New Mexico, with the apex extending to the central part of the state (Hook et al., 1983). The northern limit of the Tres Hermanos lies between 32°22' and 32°52' N. latitude on the west side of the Rio Grande rift, and thus is constrained within a distance of about 48 km. The northern limit is not as well constrained on the east side of the rift; however, the medial, non-marine part of the formation has about the same thickness on both sides of the rift (Hook et al., 1983), with a slightly lesser thickness on the east side, representing seaward thinning. The occurrence of this facies on both sides of the rift at the same latitude precludes major right slip following deposition. Restoring 60–170 km of right slip on the east side of the Colorado Plateau would result in an impossible geometry of the Tres Hermanos depositional system.

In summary, regional piercing lines, isopach intervals, and facies changes for strata ranging from Cambrian through Cretaceous in age provide compelling evidence that constrains the amount of right slip on the east side of the Colorado Plateau to a maximum of 5–20 km during Late Cretaceous and younger time.

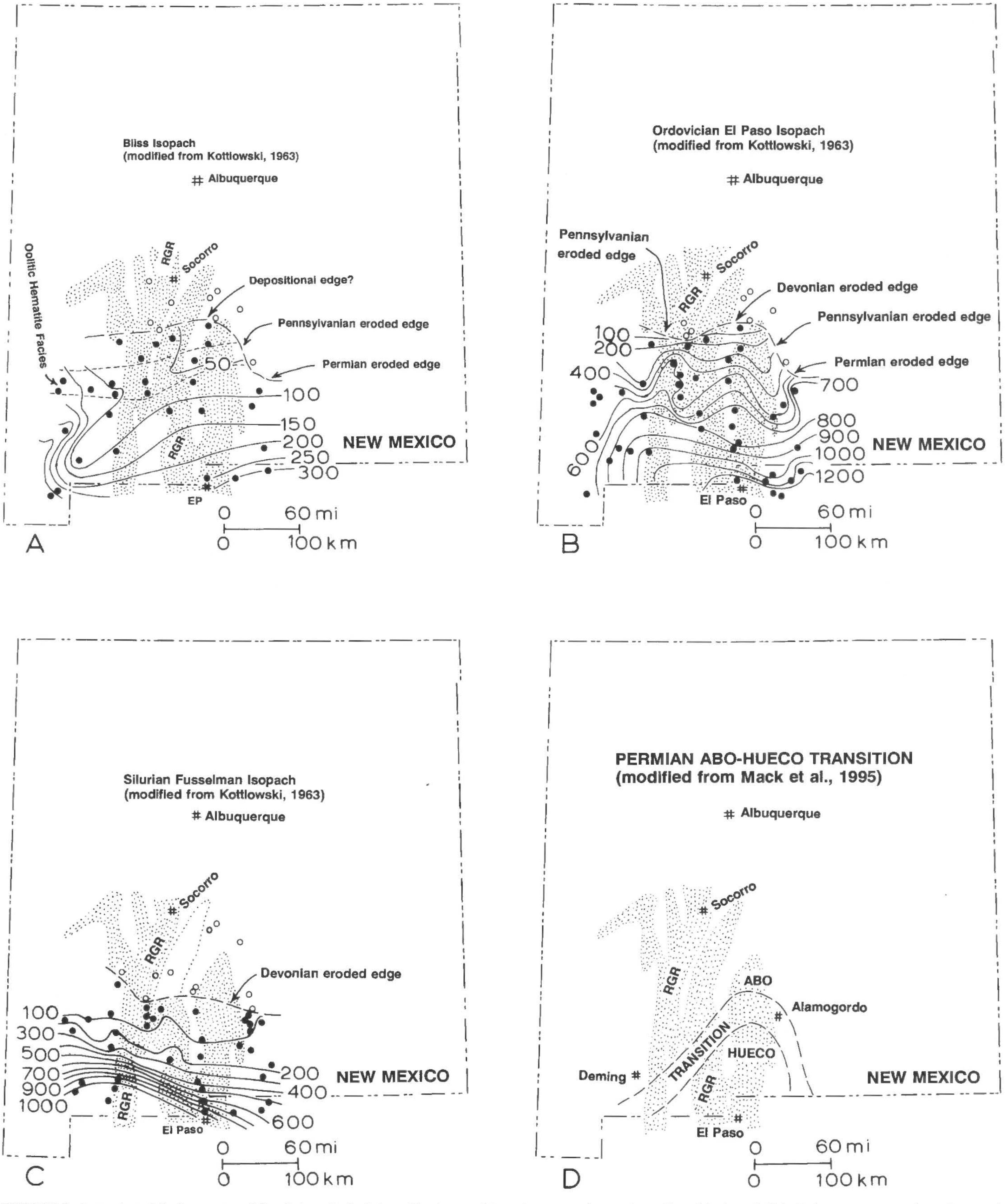

FIGURE 3. Isopach and facies maps of Cambrian, Ordovician, Silurian, and Permian strata in southern New Mexico. Solid circles are measured sections and open circles indicate where unit is absent beneath overlying Paleozoic strata. Isopach intervals in feet. Rio Grande rift (RGR) is stippled. A, Bliss Sandstone (Cambrian and Ordovician), modified from Kottlowski (1963); B, El Paso Group (Ordovician), modified from Kottlowski (1963); C, Fusselman Dolomite (Silurian), modified from Kottlowski (1963); D, Transition between continental deposits of Permian Abo Formation and marine Hueco Formation, modified from Mack et al. (1995).

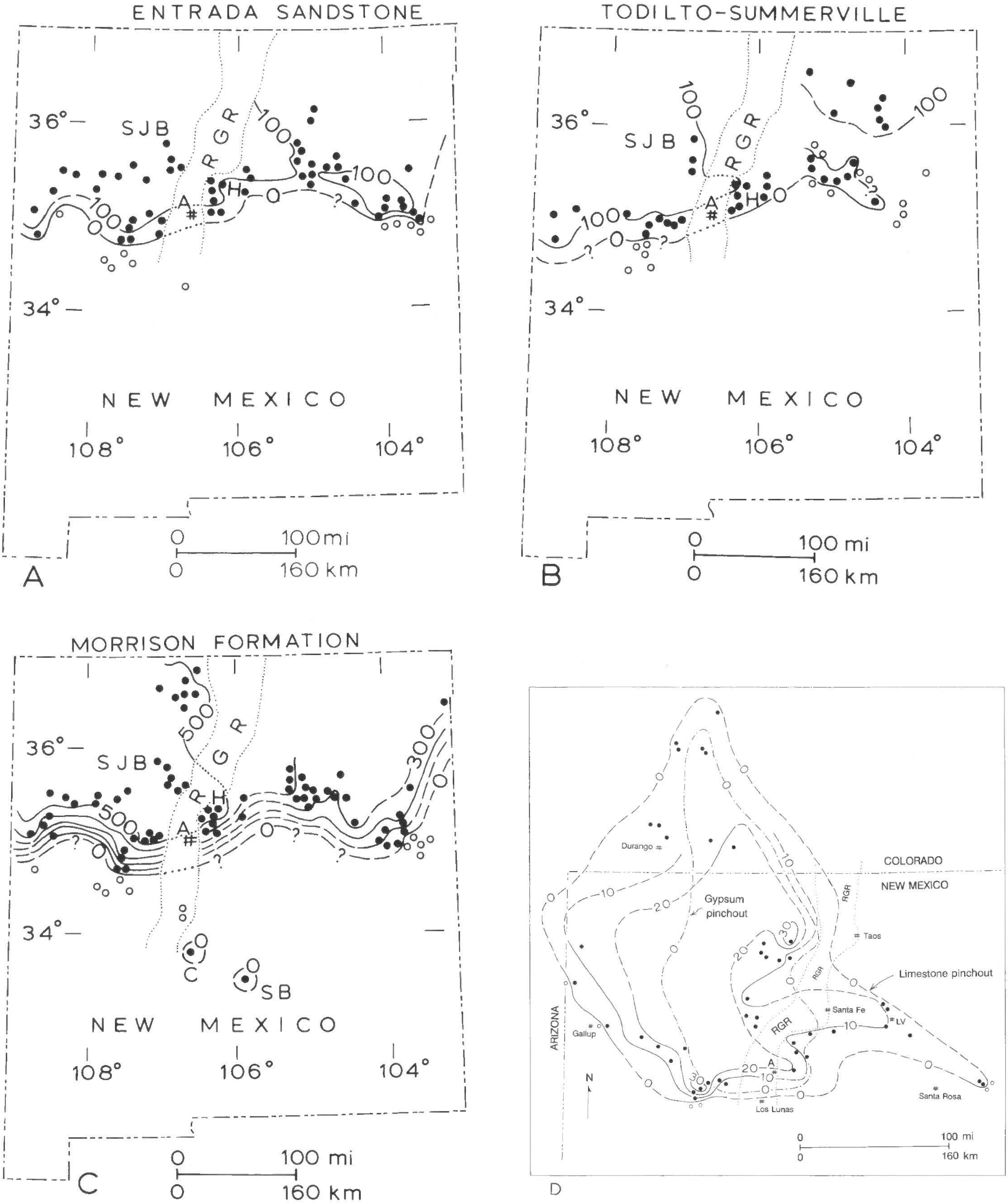

FIGURE 4. Isopach maps (in feet) of Jurassic strata in northern New Mexico. Solid circles are measured sections and open circles indicate where unit is absent beneath overlying Mesozoic strata. A = Albuquerque, C = Carthage, H = Hagan basin, LV = Las Vegas, RGR = Rio Grande rift (with dotted outline), SB = Sierra Blanca basin, and SJB = San Juan Basin. A, Entrada Sandstone (modified from McKee et al., 1956); B, Todilto and Summerville Formations (modified from McKee et al., 1956); C, Morrison Formation (modified from McKee et al., 1956); D, Approximate depositional limits of Todilto Formation and isopachs of limestone member (modified from Ash, 1958, and Kirkland et al., 1995).

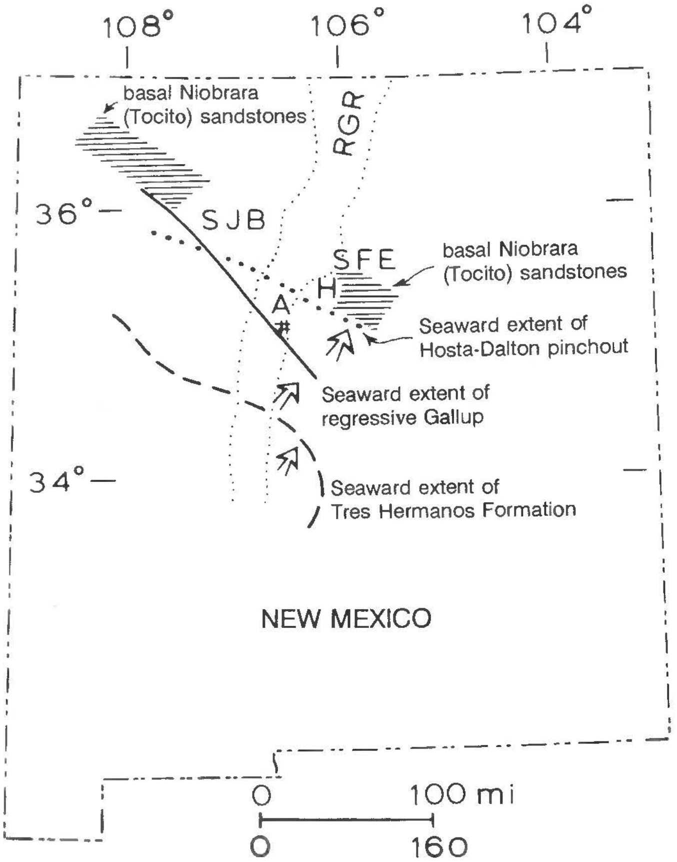

FIGURE 5. Seaward pinchouts of Cretaceous Hosta-Dalton Sandstones, regressive Gallup Sandstone, and Tres Hermanos Formation, and extent of basal Niobrara (Tocito) bar sandstones. Modified from Molenaar (1973), Black (1979) and Hook et al. (1983).

ACKNOWLEDGMENTS

We thank John W. Geissman and Bruce A. Black for reviewing the manuscript. Their comments were very helpful.

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