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New Mexico Geology, v. 5, n. 4 pp. 69-76, Print ISSN: 0196-948X, Online ISSN: 2837-6420.
https://doi.org/10.58799/NMG-v5n4.69

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New Mexico GEOLOGY
• Science and Service
Volume 5, No. 4, November 1983

Laramide wrench faults, basement-cored uplifts, and complimentary basins in southern New Mexico

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Abstract

The chief mode of Laramide deformation of the foreland area of south-central and adjacent parts of southwest New Mexico was uplift of relatively simple basement blocks similar in style, but smaller in size, to some of those of the central Rocky Mountains. Uplifts trend generally west-northwest, and are asymmetric with steep, southwest-dipping, reverse-faulted northeast margins. Broad, less-deformed southwest flanks plunge into deep Wind River-type basins filled with lower Tertiary clastic rocks 1–2 km (3,000–7,000 ft) thick. The general style of deformation seems to extend into the northern margin of southwest New Mexico terrane previously regarded as part of the Cordilleran "overthrust" belt. In this latter region, right slip as well as vertical uplift and associated transpressional thrusting distinguishes at least some marginal upthrusts; basins may be a mixture of both Wind River and Echo Park types. This interpretation of Laramide tectonic styles in southern New Mexico has important implications for the search for petroleum in the Pedregosa and various late Tertiary basins of southern New Mexico.

Introduction

Corbitt and Woodward (1973), Drewes (1978, 1982), and Woodward and DuChene (1981) have emphasized the importance of large-scale regional overthrust faulting in extreme southwest New Mexico and southeast Arizona during the Laramide (Cordilleran) orogeny (Drewes, 1978), some of which is controversial (Davis, 1979). Less well known is the array of west-northwest to northwest-trending basement-cored block uplifts and complimentary basins that have been recognized in the foreland area to the north and northeast of the overthrust belt (Fig. 1; Seager, 1975, 1981; Brown, 1982; Brown and Clemons, 1983). The purpose of this paper is to review the structural characteristics of these uplifts and basins and to show that some of the high-angle faults in the overthrust belt, previously considered to be examples of regional sled-runner type overthrusts, might also be interpreted as boundary faults of basement-block uplifts. Furthermore, some of these steep faults display evidence for significant right-lateral strike-slip motion and associated transpressional (convergent wrenching) and transtensional (divergent wrenching) structures (Reading, 1980).

ACKNOWLEDGMENTS—Many of the ideas expressed in this paper matured through discussions with Glen Brown, C. E. Chapin, R. E. Clemons, G. Mack, and S. Thompson III. I thank Exxon for permission to use drill hole data from their No. 1 Prisor well, and C. E. Chapin, S. Cather, G. Mack, and F. E. Kottlowski for their reviews of the manuscript. I especially want to thank the New Mexico Bureau of Mines and Mineral Resources and F. E. Kottlowski, Director, for their continuing support of my geologic research in southern New Mexico.

Paleotectonic setting and stratigraphy

Precambrian granitic and metamorphic rocks form the basement of all of south-central and southwest New Mexico and adjacent parts of Arizona. During the Paleozoic the region was buried by a south- and southwestward-thickening wedge of marine rocks—mostly carbonates. More than 4 km (13,500 ft) thick in the southwest corner of New Mexico and about 2.5 km (8,200 ft) thick near El Paso, the Paleozoic section thins northward to less than 1 km along a line between Silver City and Truth or Consequences (Kottlowski, 1963; Greenwood and others, 1977; Thompson, 1982). Epeirogenic uplift in Middle Ordovician, Early Silurian, and Late Silurian–Middle Devonian is represented by unconformities in the sedimentary record; these unconformities are partly responsible for the overall northward thinning. Thickness variations also reflect late Paleozoic subsidence of the Pedregosa Basin in the southwest corner of New Mexico and adjacent parts of Arizona, as well as subsidence of the Orogrande Basin in the south-central part of New Mexico (Greenwood and others, 1977; Kottlowski, 1965). Approximately 3 km (10,000 ft) of Pennsylvanian and Permian marine strata accumulated in the Pedregosa Basin and half that amount in the Orogrande Basin. Between the two basins, Pennsylvanian and Permian rocks thin across a positive area near the Florida Mountains (Kottlowski, 1958, 1960).

Triassic and Jurassic rocks generally are absent over most of southern New Mexico, although marine Jurassic rocks are known from a deep oil test southwest of Las Cruces (Thompson and Bieberman, 1975; Uphoff, 1978; Thompson, 1982). These Jurassic carbonates probably thicken southward into the Chihuahua trough where Jurassic evaporites are diapiric and may be responsible for Laramide decollement and "thin-skinned" folding in the Chihuahua tectonic belt, including the Sierra Juarez (Haengii and Gries, 1970).

In Cretaceous time the Burro uplift–Deming axis (Elston, 1958; Turner, 1962) extended northwestward from the West Potrillo Mountains through the Florida Mountains into Arizona, separating 4.5-km (15,000-ft)-thick Lower Cretaceous marine and nonmarine rocks to the south from thin or missing sections on the foreland region to the north (Zeller, 1965, 1970; Hayes, 1970). Upper Cretaceous and lower Tertiary rocks, mostly synorogenic clastic and volcanic rocks, are nearly 4 km (13,500 ft) thick south of the Burro uplift (Zeller, 1965, 1970; Hayes, 1970). North and northeast of the Burro uplift, marine and nonmarine Upper Cretaceous rocks are as much as 1.9 km (6,500 ft) thick where they have been preserved in Laramide basins (Kelley and Silver, 1952). Syn- to post-orogenic uppermost Cretaceous and lower Tertiary fanglomerates, red beds, and sandstones are of comparable thickness in the same basins (Doyle, 1951; Bushnell, 1953; Kelley and Silver, 1952; Seager, 1981).

Age of Laramide deformation

Clast composition of thick fanglomerate units within the Hell-to-Finish and Mojado

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Also in this issue

Coming soon

Sunset Ridge fluorite deposit
Stratigraphic nomenclature history of marine Upper Cretaceous rocks in Socorro County

Formations of southwest New Mexico record Early Cretaceous uplift and erosion of Paleozoic and Precambrian rocks from the Burro uplift and/or deformation southwest or west of New Mexico (Zeller, 1970; Drewes, 1978; G. Mack, personal communication, 1983). Laramide deformation commenced in latest Cretaceous time with movement phases recorded by angular unconformities between the Mojado (Lower Cretaceous) and Ringbone formation (Upper Cretaceous–lower Tertiary), between the Ringbone and the Hidalgo volcanics, and between the Hidalgo volcanics and relatively undeformed middle Tertiary volcanic rocks (Zeller, 1965, 1970). Loring and Loring (1980) have dated thrusts cutting the Hidalgo volcanics as Paleocene in age, about 60 m.y. old.

Rejuvenation of at least the southeast part of the Burro uplift during the Laramide is suggested by lower Tertiary fanglomerate (Love Ranch equivalent) outcrops in the Fluorite Ridge–southern Cooke's Range area near Deming (Fig. 1). The fanglomerate, a very coarse grained, proximal-fan facies, was derived largely from Precambrian rocks which must have been exposed south of Fluorite Ridge, as Paleozoic and Mesozoic rocks are still present to the north. Presumably this uplifted terrane also exposed the Precambrian rocks of the Florida Mountains which in many places are nonconformably overlain by lower Tertiary fan debris (Brown and Clemons, 1983; G. Mack, personal communication, 1983) and are cut by high-angle Laramide faults discussed later in this paper. Farther east and northeast in south-central New Mexico, precise dating of Laramide movement phases has so far not proved possible, although available evidence also indicates a culmination of Laramide deformation in latest Cretaceous–early Tertiary time (e.g., Kelley and McCleery, 1960; Seager, 1981).

The orogenic deposit associated with Laramide deformation in the San Andres–Caballo–Las Cruces areas is the Love Ranch Formation (Kottlowski and others, 1956) consisting mostly of fanglomerate and, in Laramide basins, finer grained red beds, brown sandstones, and coal (Fig. 2). Upper parts of the Love Ranch are relatively undeformed, overlap the margins of deeply eroded uplifts, and interfinger with upper Eocene volcanic rocks; they are therefore largely post-orogenic and of late Eocene age. Lower parts of the formation are strongly deformed adjacent to Laramide faults and interfinger with strata of McRae lithology, a unit whose lowest beds are Late Cretaceous in age (Bushnell, 1953). Consequently, lower parts of the Love Ranch are synorogenic and may be as old as latest Cretaceous. Near basin centers (South Jornada and Potrillo Basins), complete sections of Love Ranch Formation are 1–2 km thick and probably range in age from Late Cretaceous to late Eocene, although the bulk of the formation probably is Tertiary. These relationships support a latest Cretaceous to early Tertiary age for Laramide deformation in south-central New Mexico, deformation that was complete by late Eocene (40–43 m.y. B.P.) time. So far, dating of individual movement phases or recognition of the two-fold evolution of Laramide deformation described by Chapin and Cather (1981) has not proved possible.

Structural style, south-central New Mexico

In south-central New Mexico the chief mode of Laramide deformation was uplift and tilting of large basement fault blocks accompanied by subsidence of complimentary (Green River–Wind River type) basins. The structural style is similar to that of the Laramide Rocky Mountains of Wyoming and the Colorado Plateau (e.g., Kelley, 1955; Stearns, 1978), although southern New Mexico structures display more structural relief than those of the Plateau and less than those of the Rockies. Small parts of uplifts are exposed in the Caballo, San Andres, Robledo, and Organ Mountains, and at San Diego Mountain (Kelley and Silver, 1952; Bachman and Myers, 1969; Seager, 1975, 1981; Seager and others, in preparation). Large parts of the central and southern Jornada del Muerto and Mesilla Basins contain remnants of Laramide basins.

Laramide uplifts trend west-northwest to northwest, are bordered by steep-faulted margins that face east-northeast to northeast, and are flanked by broad domains of gently folded or tilted rocks. (Farther north, in the northern Caballo and Fra Cristobal ranges, Laramide structures swing into a more northerly trend, becoming parallel with the central and northern New Mexico Rockies). Uplift margins are distinguished by narrow zones of steep to moderately dipping reverse and thrust faults, which dip southwest and modify monoclinal flexures. Uplift along these margins ranges from 1 to 5 km (3,500–17,000 ft), and the monoclinal folds seemingly are drapes across the edges of basement fault blocks. The Bear Peak fold and thrust zone in the southern San Andres Mountains is a good example, and this zone also illustrates some of the subsidiary thrusts that can develop in the compressed beds on the downthrown side of the fault zone (Fig. 3a).

An uplift margin exposed in the central and southern Caballos changes along strike from simple, like the Bear Peak fold and thrust zone, to more complex (Fig. 3b,c). In this example, the level of erosion of the footwall, from high in the Paleozoic section to the Precambrian, reveals that the uplift-margin fault dips more steeply (~ 60°) where it transgresses Precambrian rocks, flattening to 30–40° at higher levels. The marginal fault also bifurcates locally into two strands, each associated with a monoclinal flexure or large overturned fold (Fig. 3c). The hanging wall rocks of this uplift, also exposed in the southern Caballos, were broadly folded and eroded locally to the Precambrian by late Eocene time (involving erosion of 2.5 km [8,200 ft] of Paleozoic and Mesozoic rocks), as indicated both by clasts of Precambrian rock in Love Ranch fanglomerate and by local nonconformities between Precambrian granite and Love Ranch Formation.

Exposures in the San Andres and Caballo Mountains reveal the general nature of Laramide uplift margins but offer little insight into the overall geometry of the uplifts and basins. In this regard structures and unconformities in the San Diego Mountain–Robledo Mountains area, together with deep drillhole information in southern Doña Ana County, enhance our interpretation. These have permitted reconstruction of a major west-northwest-trending Laramide uplift, facing east-northeast, whose southern flank dips southward a few degrees into a complimentary (Wind River-type) basin (Potrillo Basin) filled with lower Tertiary sedimentary rocks more than 2 km (6,500 ft) thick (Fig. 4).

In overall geometry the structure resembles the Wind River range of Wyoming and adjoining parts of the Wind River basin. The northern margin of the uplift, exposed at San Diego Mountain, is a west-northwest-striking thrust fault dipping southward 35°. Precambrian granitic rocks form the hanging wall and a small exposure of folded Paleozoic rocks forms the footwall. Near this marginal thrust, Love Ranch fanglomerate depositionally overlies Precambrian rocks indicating uplift and erosion of 2–2.4 km (6,500–8,000 ft) of Paleozoic and Mesozoic rocks near the thrust in latest Cretaceous or early Tertiary time. Farther south, over an area 35 km (22 mi) broad, including the modern Robledo Mountains, thin post-orogenic Love Ranch fanglomerate overlies successively younger Paleozoic strata up to Lower Permian Hueco Limestone. This erosional truncation suggests that the southern flank of the uplift

New Mexico GEOLOGY
• Science and Service
Volume 5, No. 4, November 1983
published quarterly by
New Mexico Bureau of Mines and Mineral Resources
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Circulation: 1,400

Printer: University of New Mexico Printing Plant

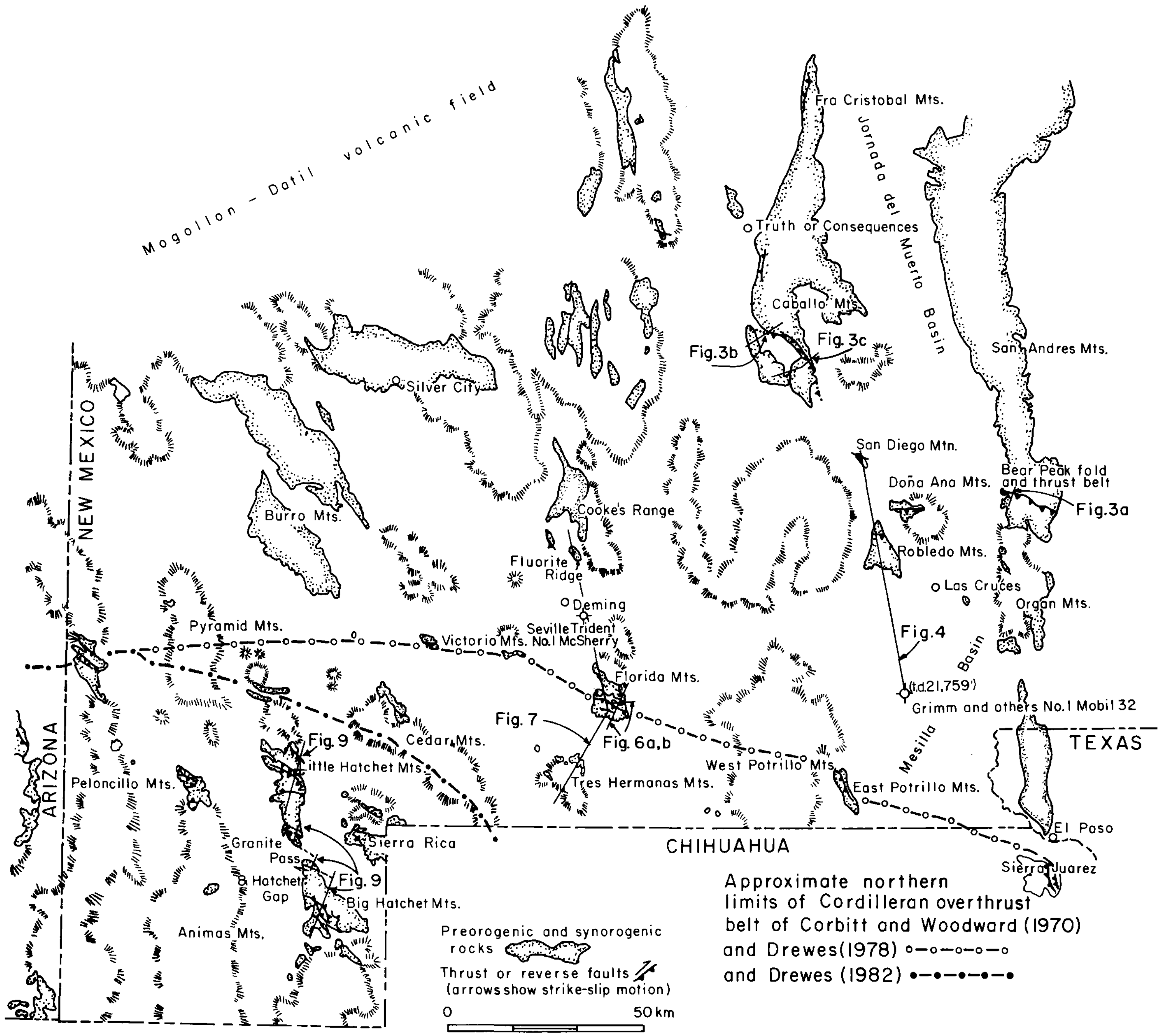

FIGURE 1—Location map, southwest New Mexico; note location of Figs. 3, 4, 6, 7, and 9 structure sections.

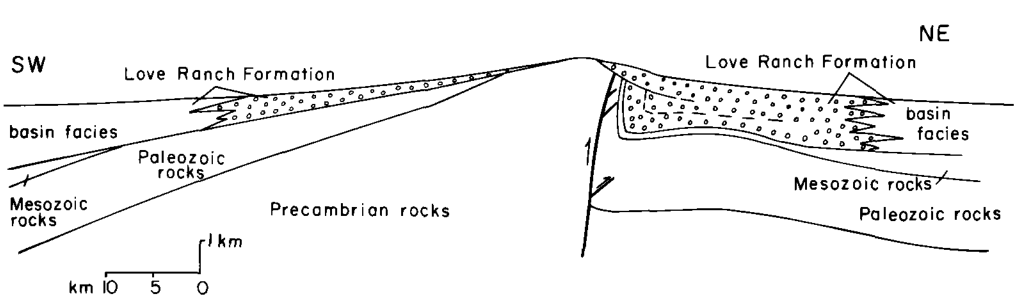

FIGURE 2—Diagrammatic section showing features of Laramide uplifts and basins in south-central New Mexico; note syn- and post-orogenic relationships in Love Ranch Formation adjacent to uplift margins.

dipped south a few degrees. Thirty km (18 mi) still farther south, in the Grimm and others American Arctic Limited No. 1 Mobil 32 oil test, Cretaceous and Jurassic rocks overlie the Hueco, and basinal clastic rocks (sandstone, coal, fine-grained red beds) correlative with the Love Ranch are more than 2 km (6,500 ft) thick (Thompson and Bieberman, 1975; Uphoff, 1978; Thompson, 1982). Thus the uplift is strikingly asymmetric, with a broad southern flank that dips perhaps 10–12° southward into a deep, complimentary basin. The slope is interrupted in at least one place by a steep, south-dipping reverse fault, with displacement of approximately 300 m (1,000 ft), that is exposed in the northern Robledo Mountains. Whereas the north-south cross-sectional geometry of this uplift is fairly well constrained, its eastern and western limits are unknown because of cover of young rocks.

Florida–Big Hatchet–Little Hatchet Mountains

A major northwest-trending reverse fault in the southern Florida Mountains, previously interpreted as the front edge of a regional overthrust (Corbitt and Woodward, 1973; Woodward and DuChene, 1981), has recently been reinterpreted as the upthrust margin of a basement block (Brown, 1982; Brown and Clemons, 1983). The fault dips approximately 85° southwest (after removal of late Tertiary tilt). Brown (1982), Brown and Clemons (1983), and Clemons and Brown (in press) argued for predominantly vertical movement along the fault. However, compelling evidence for substantial right-lateral slip also is indicated primarily by large-scale drag of Paleozoic footwall rocks in the footwall adjacent to the southeast exposures of the upthrust (Fig. 5). Adjacent to the fault, the southern limb of the drag fold seemingly has been segmented into complex thin slices bordered by low-angle faults, which are stacked and sheared out in the footwall along the length of the fault to the northwest (Fig. 6). Most of the faulting resulted in younger rocks displaced over older (normal faults), but some produced typical thrust relationships of older over younger. Both styles of faulting "root" downward into the major reverse fault and are considered to be a product of transpression in the fault zone. Numerous high-angle normal faults also indicate local extension in the zone. Another indication of strike slip along the major reverse fault is the dissimilar Precambrian rocks on either side of the fault (Fig. 5), which also yield different K–Ar ages (Clemons, in press). However, a component of northeast motion is also indicated by thrust-faulted, northeast-vergent folds, located in footwall rocks. Collectively, the structures indicate oblique right slip on the major steep fault, with a small component of movement toward the northeast, and strong transpression of bedded footwall rocks. If the length of the sheared-out limb of the drag fold is a reliable index, the amount of strike slip could be 5–6 km (3–3.5 mi), which is probably at least as much, if not more, than the vertical component of movement.

The uplifted basement block in the southern Florida Mountains appears to be only one component of a much broader, faulted basement uplift, as shown in Fig. 7. The basin adjacent to the northern flank of the uplift is identified by the full section of Paleozoic and Cretaceous rocks exposed in the Fluorite Ridge–Goat Ridge–Cooke's Range area a few kilometers north of Deming. Very coarse grained proximal-fan deposits of early Tertiary age (Starvation Draw member of Rubio Peak Formation; Clemons, 1982) overlie Cretaceous rocks in this area and were derived largely from Precambrian and lower Paleozoic rocks. The uplift margin exposing these Precambrian–Paleozoic rocks presumably was located not far south of the Fluorite Ridge area in an area now covered by bolson grav-

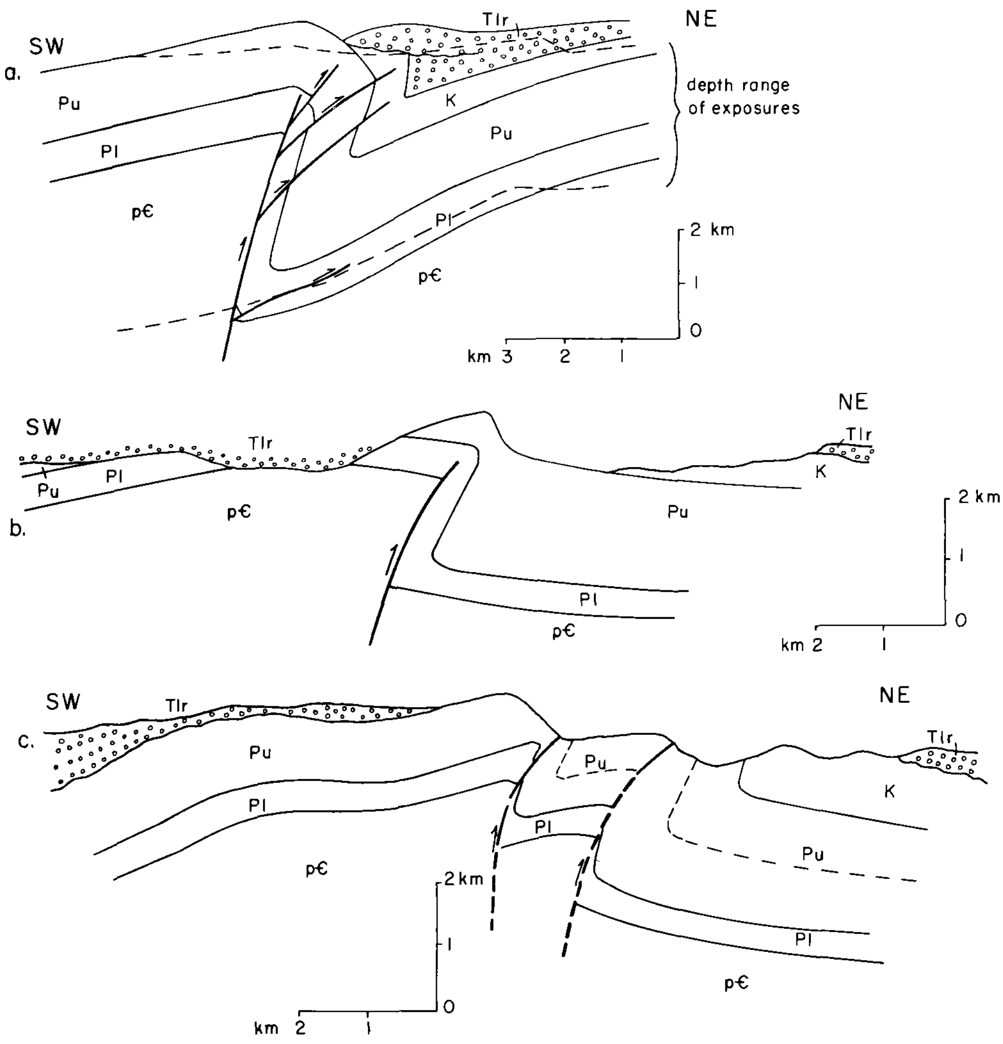

FIGURE 3—a.) Composite cross section through Bear Peak fold and thrust belt, southern San Andres Mountains. b,c.) Cross sections through Laramide uplift in southern Caballo Mountains. Effects of late Tertiary block faulting have been removed from all three sections. **Tlr**–Tertiary Love Ranch Formation, **K**–Cretaceous rocks, **Pu**–upper Paleozoic rocks, **Pl**–lower Paleozoic rocks, and **p€**–Precambrian rocks.

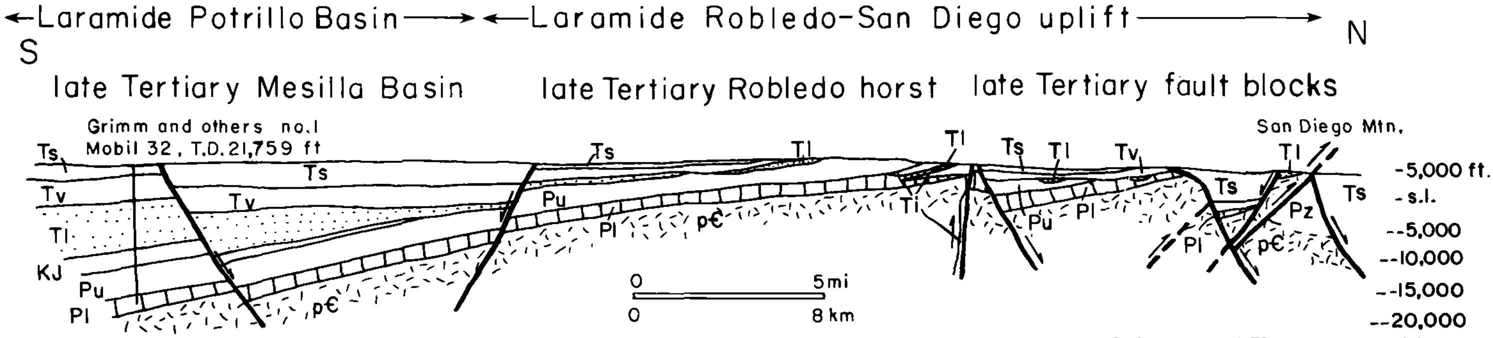

FIGURE 4—Cross section through Laramide Potrillo Basin and Robledo–San Diego uplift. Note overlap and thinning of Tl unit onto uplift and truncation of Pu and Pl units beneath the Tl unconformity. **Ts**–Santa Fe Group (Tertiary), **Tv**–middle Tertiary volcanic rocks, **Tl**–lower Tertiary fanglomerate, sandstone, and coal (Love Ranch and correlative units), **KJ**–Cretaceous–Jurassic rocks, **Pu**–upper Paleozoic rocks, **Pl**–lower Paleozoic rocks, **p€**–Precambrian rocks, and **Ti**–Tertiary intrusive rocks.

els. Farther south, near Deming, the Seville Trident No. 1 McSherry well penetrated Precambrian rocks at 11,590 ft beneath Quaternary–Tertiary basin fill and Tertiary volcanic rocks (S. Thompson III, written communication, 1983). Significantly, no lower Tertiary fan deposits (Starvation Draw Member and Lobo Formation of Lemley, 1982) were found above the Precambrian. Still farther south, outcrops in the Florida Mountains reveal thin Lobo fan deposits nonconformably above Precambrian or lower Paleozoic rocks, and two steep faults, both downthrown to the north, have been mapped. One of these faults was described in the previous paragraph. The nearly full section of Paleozoic rocks exposed in the Tres Hermanas Mountains, southwest of the Florida Mountains, seemingly represents the southern flank of the broad uplift. Thus, the broad uplift spans the region from just south of Fluorite Ridge to the southern Florida Mountains, an area where Precambrian and lower Paleozoic rocks were deeply eroded and widely exposed in early Tertiary time. Individual fault blocks stairstep down to the north or northeast as a result of movement on steep faults with major strike-slip components of motion. The uplift is presumed to have had the same northwesterly trend as the faults. Its location along strike with the earlier Mesozoic Burro uplift suggests that the Laramide block uplift may have been reactivated along Burro uplift structures.

Somewhat similar structural relationships exist at Granite Pass and Hatchet Gap between the Big Hatchet and Little Hatchet Mountains (Fig. 1). Zeller (1970, 1975) mapped drag and second-order folds south of Hatchet Gap which suggest an important right-lateral component of movement on a major west-northwest-trending steep fault (Fig. 8). This fault, and the southwest-dipping reverse fault which juxtaposes Precambrian granite and Lower Cretaceous sedimentary rocks at Granite Pass (just north of Hatchet Gap), may be interpreted as oblique-slip upthrusts marginal to an uplifted basement block. (A Laramide age for these faults is interpreted because of their reverse-fault geometry, their northwest trend which is truncated by late Tertiary, north-trending, range-boundary faults, and the intrusion of the Granite Pass fault by a stock of mid-Tertiary granite.) The uplifted block includes all of the modern Big Hatchet Mountains (Fig. 9). Generally, Paleozoic strata in the Big Hatchet range dip southwestward, although broad folds are present. Fold axes and northeastward-dipping thrusts indicate tectonic transport toward the southwest over large parts of the range, a relationship that seems more consistent with horstlike block uplift of the range and/or transpression of hanging wall rocks (Fig. 9), rather than regional northeast overthrusting (S. Thompson, III, written communication, 1983). North of Granite Pass, thick Cretaceous and Tertiary sedimentary rocks and Hidalgo volcanic rocks of the Little Hatchet Mountains were preserved in the basin footwall of the faults of Granite Pass

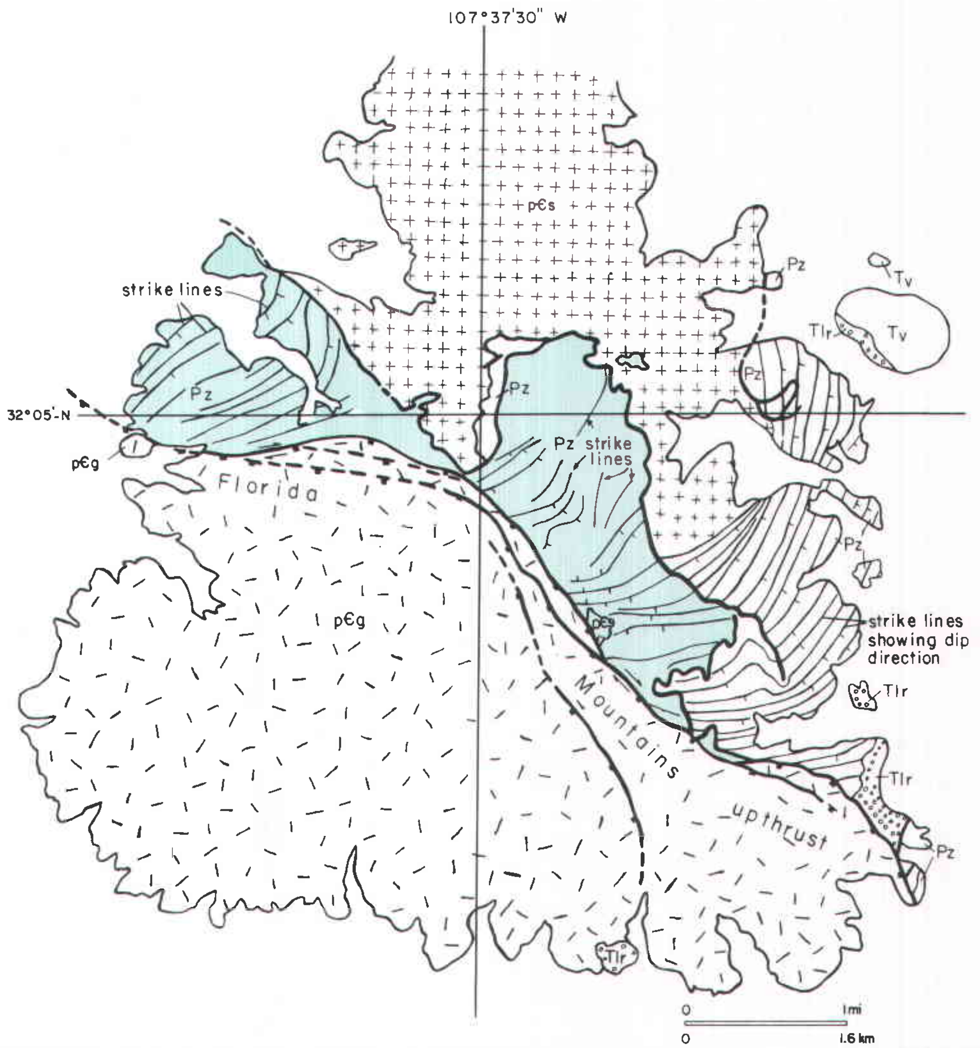

FIGURE 5—Geologic map of southern part of Florida Mountains; geology after Brown (1982), Clemons and Brown (in press), and Clemons (in press). Lines with tick marks are strike lines showing dip direction. Note large drag in Paleozoic strata at southeast end of range and different Precambrian rocks on either side of Florida Mountains "upthrust," both of which are taken as evidence of significant right slip on "upthrust." The blue-shaded area is complexly broken by closely spaced normal and thrust faults; it is bounded by low-angle faults which steepen downward to merge with Florida Mountains upthrust. **Tv**–middle Tertiary volcanic rocks, **Tlr**–Love Ranch fanglomerate, **Pz**–Paleozoic sedimentary rocks, **pЄs**–Precambrian syenite, and **pЄg**–Precambrian granite.

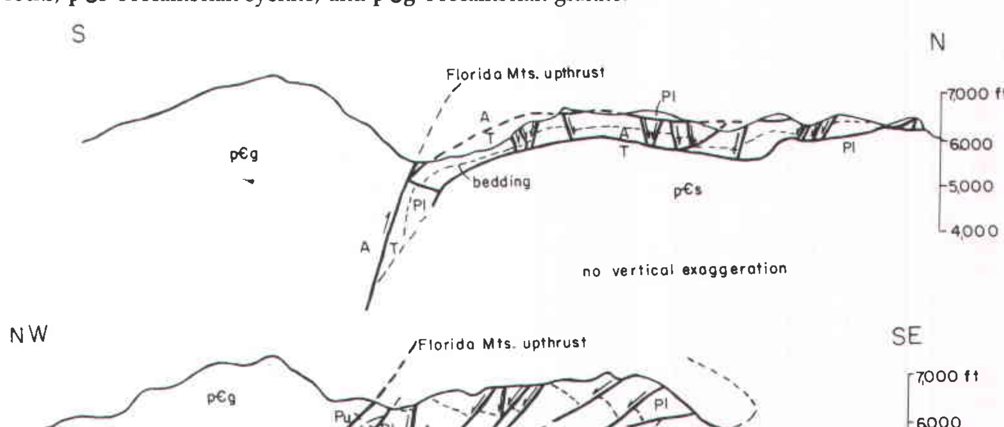

FIGURE 6—Cross sections across Florida Mountains "upthrust" (oblique-slip reverse fault) taken from Brown (1982) and Brown and Clemons (in press). Thrusting in footwall rocks seems to be result of transpression. See Fig. 1 for location. **Tlr**–Love Ranch fanglomerate, **Pu**–upper Paleozoic rocks, **Pl**–lower Paleozoic rocks, **pЄs**–Precambrian syenite, **pЄg**–Precambrian granite, **A**–strike-slip movement away from viewer, and **T**–strike-slip movement toward viewer.

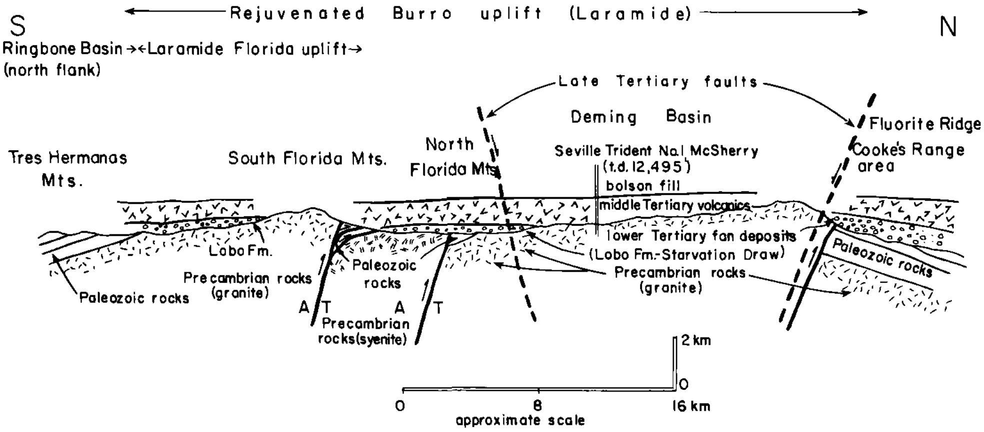

FIGURE 7—Diagrammatic section from Fluorite Ridge southward through Florida Mountains to Tres Hermanas Mountains; effects of late Tertiary faulting and middle Tertiary intrusives have been omitted in order to emphasize interpreted Laramide structure. Major feature is broad, block-faulted Laramide uplift, stepped down by steep faults toward north, and exposing in early Tertiary time a broad area of Precambrian and lower Paleozoic rocks. The Laramide Florida uplift is southernmost block of the broad uplift, and the broad uplift itself appears to be a Laramide rejuvenation of the earlier Mesozoic Burro uplift. Evidence for strike slip along boundary faults is discussed in text. A–strike-slip movement away from viewer, T–strike-slip movement toward viewer. See Fig. 10 for interpreted areal distribution of uplifts and basins and see Fig. 1 for location of cross section.

and Hatchet Gap. The Upper Cretaceous–lower Tertiary Ringbone formation of the Little Hatchet Mountains may be interpreted as a molasse deposit (~ 2 km [7,000 ft] thick) derived from the Big Hatchet block (G. Mack, personal communication, 1983). Thrust faults in the Little Hatchet Mountains support previous interpretations of overthrusting (Corbitt and Woodward, 1973), but may also be interpreted as products of local compression or transpression adjacent to the major oblique-slip reverse faults at Granite Pass and Hatchet Gap. The situation here may be analogous to the low-angle faults adjacent to the Florida Mountains oblique-slip upthrust, with the exception that the Florida Mountains faults have undergone a deeper level of erosion and indicate transtension as well as transpression caused by strike-slip motion on the nearby upthrust.

Discussion and summary

In summary, the chief mode of Laramide deformation of the foreland area of south-central New Mexico was uplift of relatively simple northwest to west-northwest-trending basement blocks similar in style but smaller in scale than some of those of the central Rocky Mountains. Most uplifts are asymmetric, with steep, reverse-faulted northeast margins, and broad, less-deformed southern flanks, which plunge into complimentary basins filled with lower Tertiary clastic rocks 1–3 km (3,000–10,000 ft) thick (Fig. 10). The general style of deformation appears to extend into the northern margin of terrane previously regarded as part of the Cordilleran "overthrust" belt. In this latter region significant right-lateral strike slip, as well as major vertical uplift, appears to distinguish marginal upthrusts. Thus, the uplifts in this area may be partly the result of convergent wrenching (transpression; Wilcox and others, 1973; Reading, 1980), and the widely described complex thrust faulting may be a secondary effect adjacent to the major steep faults (Thompson, 1982). Drewes (1978, 1982b) and Drewes and Thorman (1980a, b) also have inferred strike slip on northwest-trending faults in southwest New Mexico and southeast Arizona, but they proposed left-lateral rather than right-lateral movement.

The predominantly vertical or oblique-slip wrench movement of basement blocks described in this article are viewed as a consequence of regional compression. Chapin and Cather (1981) review evidence for east-northeast compression in early Laramide time (Late Cretaceous–late Paleocene) and northeast compression in late Laramide time (latest Paleocene-middle Eocene) in New Mexico. The predominantly west-northwest trend of major uplift margins near Las Cruces suggests that σ_1 (greatest principle stress) was oriented more nearly north-northeast in that area, a direction closer to the late Laramide than to the early Laramide directions of Chapin and Cather (1981). In fact, little evidence can be found to define the early Laramide direction of compression in south-central New Mexico.

Similarly, little evidence exists from the central Caballo Mountains southward for a zone of right-lateral shearing, following the Rio Grande, which Chapin and Cather (1981) suggest may have accommodated northward crowding of the Colorado Plateau relative to the Great Plains. Farther north in New Mexico, Chapin and Cather (1981) make a convincing case for its existence. Laramide basins south of the Caballos are viewed as Wind River types, resulting from compression, not Echo Park types resulting from a north-south couple as suggested by Chapin and Cather (1981) for the Cutter Basin (our southern Jornada Basin of Fig. 10).

Nevertheless, significant right-slip on northwest-trending upthrusts does seem to be an important component of the tectonic picture in southwest New Mexico, and basins exhibiting features of both Echo Park and Wind River types may be expected. Although it is beyond the scope of this paper to evaluate the origin of strike-slip in depth, three possible causes might be considered:

1) If late Laramide σ_1 in southern New Mexico was oriented north-northeast, any northwest-trending steep fault, such as the south Florida Mountains fault, should exhibit a component of right-slip movement;
2) Perhaps, south of the Caballo range, Chapin and Cather's (1981) north-trending right-lateral couple was distributed as right-oblique slip on some of the northwest-trending upthrusts of the region, such as the south Florida and Hatchet Gap faults;
3) Oblique convergence of the Farallon and North American plates in late Laramide time may have caused strike slip on faults in the foreland area of southern New Mexico. In general, however, the northwest-trending uplifts of south-central and southwest New Mexico are nearly orthogonal to the Farallon–North American Laramide plate convergence (Coney, 1976, 1978; Dickinson and Snyder, 1978), which suggests wrenching on northwest-trending faults should be subordinate to vertical component of slip.

Right-lateral motion of small displacement also is indicated by the series of "buckles" on the Pecos Slope (Kelley, 1971). They are orthogonal to the trend of basement uplifts of south-central New Mexico (Fig. 10) and may be interpreted as tears separating domains of north-northeast compression, basement uplifts, and crustal shortening in south-central New Mexico from unshortened crust in southeast New Mexico (C. E. Chapin, personal communication, 1983). Similar tears may extend as far west as the Tularosa Basin, as little evidence for major Laramide compression has been reported from the Sacramento–Hueco Mountain–Otero Mesa area (C. E. Chapin, personal communication, 1983).

Besides describing the style of Laramide structures in south-central New Mexico, the main purpose of this paper is to point out that some structures in southwest New Mexico, previously regarded as examples of regional overthrusts, also may be interpreted as products of block uplift on steep to moderately dipping reverse faults, some of which display evidence for important strike-slip movement coupled with vertical movement. Some smaller scale folds, thrusts, and normal faults in the footwall of the major uplifts may be the product of compression, transtension, or transpression caused by northeastward crowding of the uplifts combined with important right-lateral slip. These new interpretations have an obvious importance for the search for petroleum in southwest New Mexico basins.

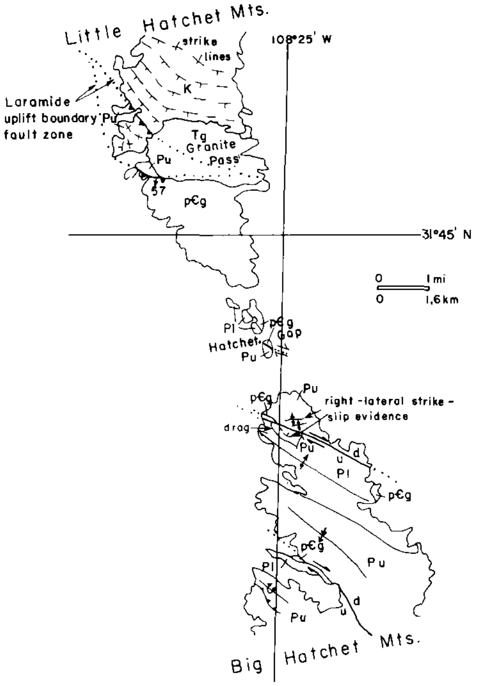

FIGURE 8—Geologic map of Granite Pass–Hatchet Gap area between Little and Big Hatchet Mountains (after Zeller, 1970, 1975). **Tg**–Tertiary granite, **K**–Cretaceous rocks, **Pu**–upper Paleozoic rocks, **Pl**–lower Paleozoic rock, and **p€g**–Precambrian granite.

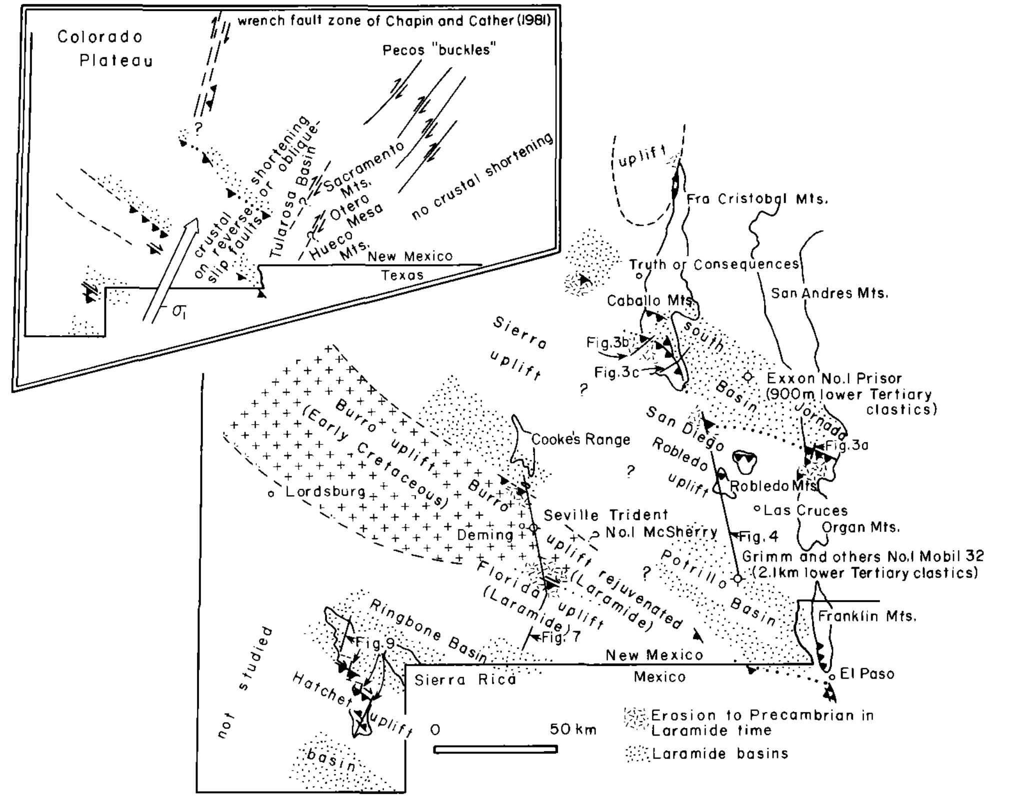

FIGURE 10—Interpretive paleotectonic map of southwest New Mexico in Laramide time showing inferred pattern of west-northwest-trending Wind River, as well as mixed Wind River–Echo Park(?)-type basins, and southwest-dipping, northeast-facing, basement-cored block uplifts (uplifts locally have southwest-facing thrust margins, as in the Big Hatchet Mountains). Uplifts in southwest New Mexico exhibit important oblique right slip and associated transpressional structures on boundary faults. Control for uplifts and basins is from cross sections and wells indicated on map, as well as from nature of outcropping pre-middle Tertiary rocks in mountain ranges beyond these sections (Fig. 1). Laramide uplifts were inferred in modern mountain ranges where pre-late Eocene erosion cut deeply into Paleozoic rocks, or locally into the Precambrian rocks; Laramide basins were inferred where nearly complete sections of Paleozoic and Mesozoic rocks are still present today, and/or where thick Upper Cretaceous–lower Tertiary basin-filling rocks are known. Nevertheless, diagram is highly speculative in that data points are few and widely separated (see Fig. 1). General northwest trend of structures is based on trend of exposed uplift boundary faults. Inset in upper left suggests Pecos "buckles" are tears separating compressed and shortened crust of southwest New Mexico from uncompressed and unshortened crust of southeast New Mexico.

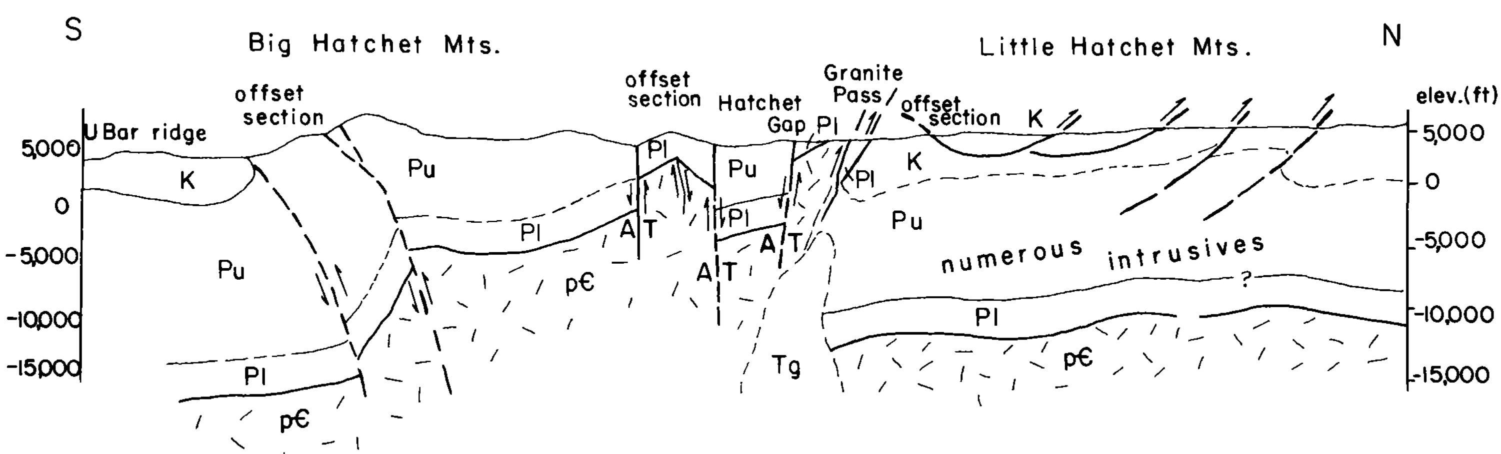

FIGURE 9—Diagrammatic section through the Little Hatchet–Big Hatchet Mountains (see Fig. 1 for location and note offsets of section). Big Hatchet Mountains are interpreted as basement-cored block uplift, the Little Hatchets as compressed block (transpression?) in front of marginal oblique-slip reverse faults. **Tg**–Tertiary granite, **K**–Cretaceous rocks, **Pu**–upper Paleozoic rocks, **Pl**–lower Paleozoic rocks, and **p€**–Precambrian rocks, **A**–strike-slip movement away from viewer, **T**–strike-slip movement toward viewer.

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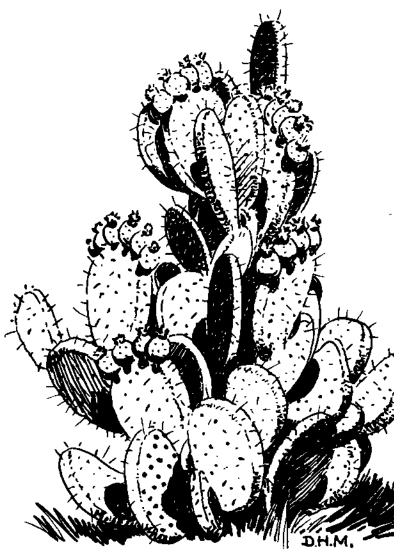

Short course in water-well design

"Optimizing the yields of water wells," an intensive two-day short course, will be offered by the Continuing Education Department of New Mexico Institute of Mining and Technology in Socorro, New Mexico.

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Instructors for the course include W. K. Summers, president and senior geologist, W. K. Summers & Associates, Inc. of Socorro. Mr. Summers' firm is active in design of wells and ground-water resource management programs. Michael D. Campbell, author of "Water Well Technology" and B. G. Hammock, authority in preparation of plans, specifications, and contract management, will add their areas of expertise to the course. One continuing education unit is offered for completion of the course.

Luncheons, a cocktail party, and Southwestern barbecue are planned in conjunction with the short course, offering participants a chance to meet and mingle with each other. The costs of the social functions are in addition to the course fee.

The course fee is $175.00 for those registering after October 1. Complete information, including course outline, may be obtained by contacting the Continuing Education Department, NMIMT, Campus Station, Socorro, NM 87801, or by calling W. K. Summers, Socorro (505) 835-2095.