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Laramide thin-skinned deformation in Permian rocks, Fra Cristobal Range, south-central New Mexico

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LARAMIDE THIN-SKINNED DEFORMATION IN PERMIAN ROCKS, FRA CRISTOBAL RANGE, SOUTH-CENTRAL NEW MEXICO

ERIC P. NELSON[1] and JAMES HUNTER[2]
[1]Geology Department, Colorado School of Mines, Golden, CO 80401; [2]Geoscience Consultants Ltd., 500 Copper NW, #325, Albuquerque, NM 87102

Abstract—The Fra Cristobal Range is a horst along the east edge of the southern Rio Grande rift near Truth or Consequences. The west-central portion of the range exposes Permian strata which have been affected by Laramide(?) thin-skinned deformation. Structures are concentrated in, but not limited to, the Meseta Blanca and Los Vallos Members of the Yeso Formation. Meso- and megascopic folds are upright, mostly subhorizontal, and north-trending (±45°). Cylindrical, box, recumbent, and disharmonic geometries are present. Folds generally are restricted to particular stratigraphic intervals in plates bounded by thrust faults forming complicated duplex structures. Mesoscopic thrust faults show decollement and ramp geometries. Fold vergence and thrust-plane slickenside lineations suggest both east (dominant) and west tectonic transport. No penetrative planar or linear fabrics have been observed, indicating a fairly brittle deformational environment.

East of a rift-related normal fault (Double Peak fault), Permian strata are undeformed, suggesting that the zone of deformation either climbs section eastward (to a now-eroded level), or dies out eastward. This fault may represent a Laramide ramp or a Laramide deformation front. The thin-skinned structural style probably was controlled by the presence of mechanically weak evaporites in the Permian section. The deformation is related to development of a basement-cored uplift. The structures developed in response to either crustal shortening or to gravity sliding off the steep limb of the uplift.

INTRODUCTION

Although the presence of Laramide deformation has been recognized in central and south-central New Mexico for a number of years (Kelley & Silver 1952, Kelley & McCleary 1960, Craddock 1964, Seager 1983, Smith et al. 1983), some areas have received little detailed study. The Fra Cristobal Range, in Socorro and Sierra Counties (Fig. 1), is one area in which structural studies have not been done since the 1950's when the range was mapped in reconnaissance at a small scale without the aid of topographic-base maps (Thompson 1955, Jacobs 1956, McCleary 1960, Cserna 1956). Recent detailed mapping and structural analysis in the range have shown the presence of two fundamentally different Laramide structural styles. Thick-skinned, basement-involved deformation affects lower structural and stratigraphic levels (Precambrian to Pennsylvanian) in the northwestern portion of the range, whereas thin-skinned, decollement-style deformation affects Permian strata in the south-central portion of the range (Fig. 2). This report concentrates on the thin-skinned deformation, primarily exposed in the Walnut Canyon area in the west-central portion of the range. The general geology of the range and details of the thick-skinned deformation are reported by Nelson and Chapin & Nelson (this guidebook).

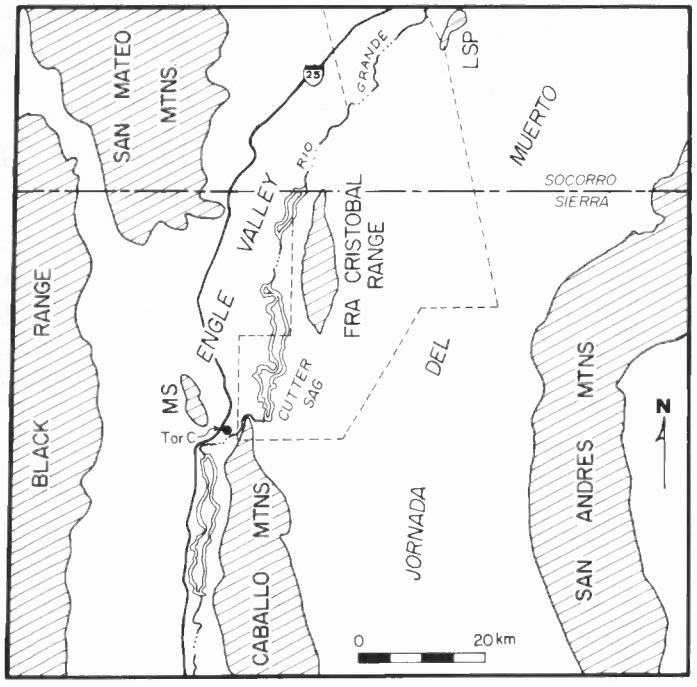


FIGURE 1—Location map of Fra Cristobal Range. LSP = Little San Pascual Mt.; MS = Mud Springs Mtns. Dashed line bounds Pedro Armendaris grants nos. 33 and 34.

GEOLOGIC AND TECTONIC SETTING

The Fra Cristobal Range is a north-trending, normal-fault-bounded uplift along the east side of the Rio Grande rift northeast of Truth or Consequences (Figs. 1, 3). It is bounded on the east by the Jornada del Muerto which is a Laramide synclinal structure now mostly covered by a thin veneer of Quaternary alluvial, eolian, and lacustrine deposits

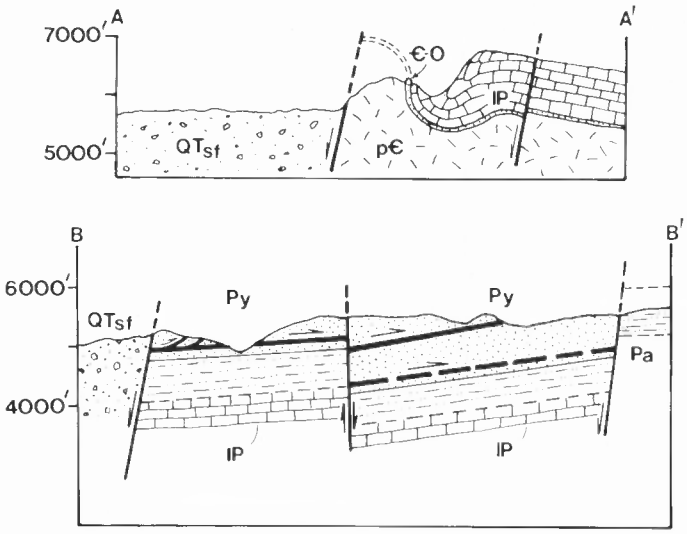


FIGURE 2—Schematic east–west cross sections of Fra Cristobal Range. Approximate location of cross-section lines in Fig. 3. A–A′ shows thick-skinned, basement-involved deformation; B–B′ shows thin-skinned, decollement-style deformation in Permian rocks. p€ = Precambrian basement rocks; C-O = Cambro-Ordovician section; P = Magdalena Gr.; Pa = Abo Fm.; Py = Yeso Fm.; QTsf = Santa Fe Gr.

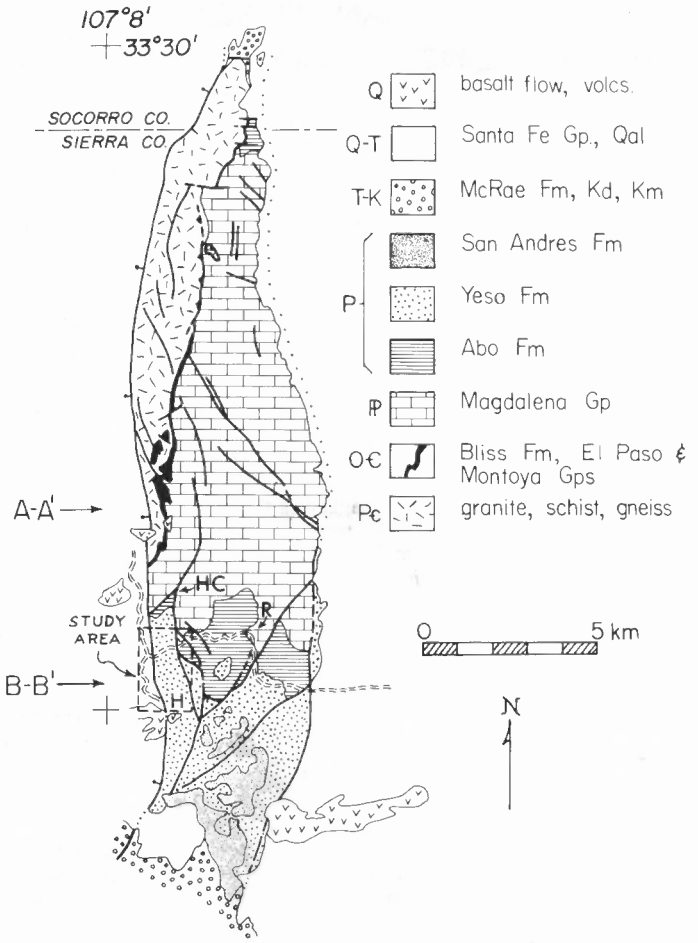


FIGURE 3—Generalized geologic map of Fra Cristobal Range. H = Hamburger Hill; HC = Hackberry Canyon; R = Red Gap. Study area is shown in Fig. 5, A–A′ and B–B′ show approximate positions of cross sections shown in Fig. 2. Geology taken in part from graduate theses mentioned in text and from Van Allen et al. (1984).

and basalt (Van Allen et al. 1984). Strata in the range dip south below gently folded Cretaceous and Tertiary strata exposed in the Cutter sag, a Laramide structural trough which separates the Fra Cristobal Range from the Caballo Mountains to the south. In the northwest portion of the range, Precambrian crystalline-basement rocks are overlain by Paleozoic and Mesozoic strata.

During the Paleozoic, the area was near the southwest (present coordinates) margin of the North American craton and received clastic, carbonate, and evaporite deposition. During this time the area was periodically exposed and eroded as a result of epeirogenic movements. Only very minor tilting and possible high-angle faulting affected the area prior to the Laramide. Pre-Laramide and early Laramide Mesozoic deposition consists of continental and marine deposits typical of the Rocky Mountains province in general (Dakota Formation, Mancos Formation, and Mesaverde Group; Melvin 1963). The Late Cretaceous–Tertiary syn- to post-orogenic McRae Formation rests unconformably on Precambrian basement rocks and Mesozoic strata in the area, and thereby contains stratigraphic evidence for Laramide uplift in the area (Kelley & McCleary 1960, Hunter 1986).

Beginning in the mid- to late Oligocene (28–26 my, Seager & Morgan 1979) the area underwent extensional deformation resulting in development of the Rio Grande rift and structural deepening of the Jornada del Muerto Basin. This deformation resulted in a system of normal faults and related fractures that bound blocks which step down into the rift on the west and into the Jornada del Muerto Basin on the east. Extensional tectonism, accompanied at times by basaltic volcanism, has been active intermittently until very recent times (<1 my), although extensional rates seem to have slowed since the Pliocene (Seager & Morgan 1979).

STRATIGRAPHY

Precambrian granite, granitic gneiss, and schist form the structural and sedimentological basement in the range (Fig. 4). Lower Paleozoic rocks consist of the clastic and carbonate Cambrian and Ordovician Bliss Formation, the dominantly carbonate Ordovician El Paso Group, and the Ordovician Cable Canyon Sandstone (base of Montoya Group). Upper Paleozoic rocks include cyclic carbonate–shale deposits of the Pennsylvanian Magdalena Group, red beds of the Permian Abo Formation, clastics, limestones, and evaporites of the Permian Yeso Formation, and sandstone and carbonate of the Permian San Andres Formation. Within the range (excluding exposures in the Cutter sag and within the Walnut Canyon–West Vein fault zone) rocks correlated with the Cretaceous–Tertiary McRae Formation (Kelley & McCleary 1960, Hunter 1986) are exposed in depositional contact with the Precambrian at the north end of the range and in a fault-bounded detachment slice in the Walnut Canyon area (Fig. 5).

Most of the thin-skinned deformation recognized in the Fra Cristobal Range is concentrated in the lower portions of the Yeso Formation. The true thickness of the Yeso in the Fra Cristobal Range is unknown because of internal deformation, but estimates range from 120 to 395 m. The formation is lithologically quite variable and is locally characterized by abrupt lateral facies changes, especially in the upper members. The

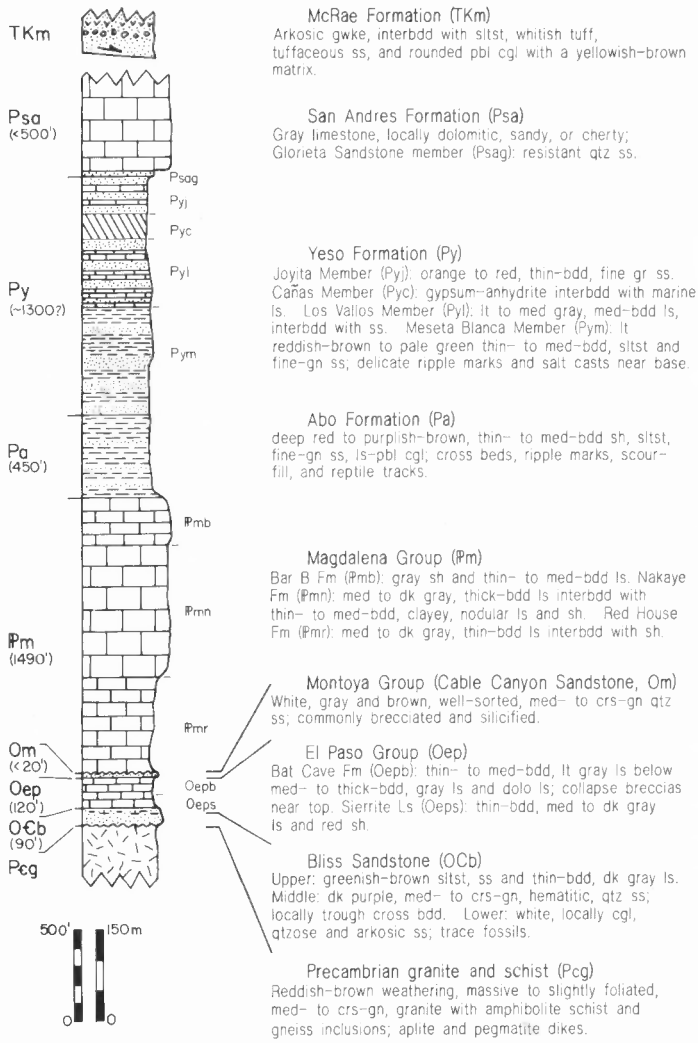


FIGURE 4—Generalized stratigraphic section of the Fra Cristobal Range. TKm is both in tectonic and stratigraphic contact. Compiled from graduate theses mentioned in text.

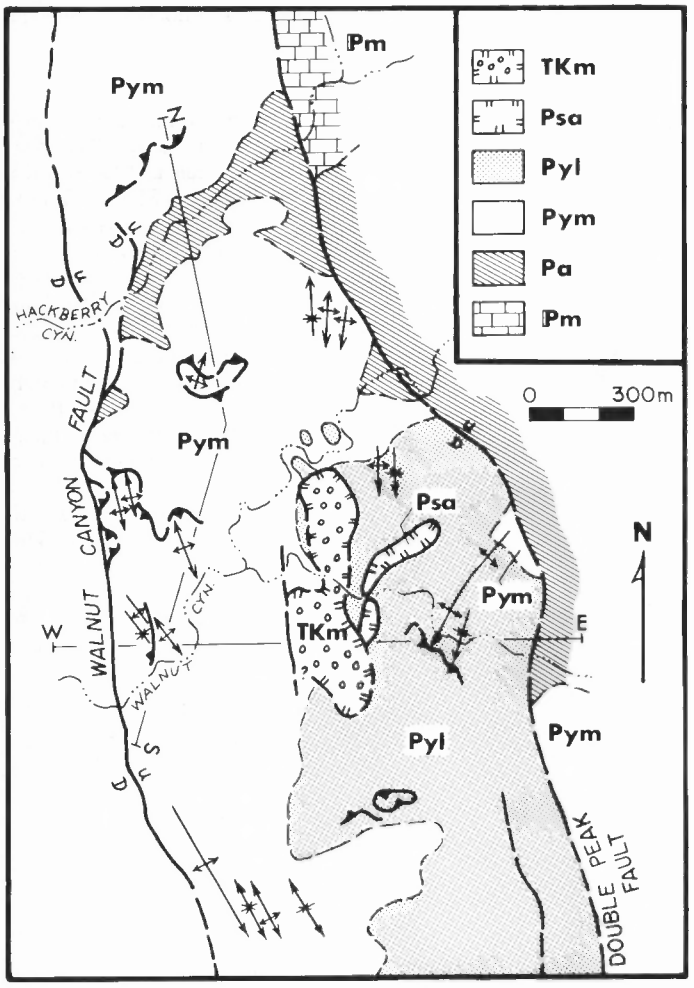


FIGURE 5—Geologic map of Walnut Canyon area (location shown in Fig. 3). Pm = Magdalena Gr.; Pa = Abo Fm.; Pym = Meseta Blanca Mbr., Yeso Fm.; Pyl = Los Vallos Mbr., Yeso Fm.; Psa = San Andres Fm.; TKm = McRae Fm. Rocks west of Walnut Canyon fault are Santa Fe Gr. and unconsolidated alluvium. NS and EW are cross-section lines shown in Fig. 6. Symbols with double tick mark bounding TKm and Psa are low-angle normal faults.

formation comprises four members (Needham & Bates 1943) which are, in stratigraphic succession: Meseta Blanca Member, Los Vallos (or Torres) Member, Cañas Member, and Joyita Member. The Meseta Blanca Member consists of thin- to medium-bedded, light-reddish-brown and pale-green siltstone and fine-grained sandstone with some interbeds of calcareous and sandy shale. Some evaporite-bearing horizons may be present as well. Sedimentary structures include ripple crosslamination, small-scale cross-stratification, and salt-crystal casts, particularly near the basal transition with the Abo Formation. The Los Vallos Member consists of light- to medium-gray-weathering, medium-bedded (0.1–3.0 m thick) limestone interbedded with buff to reddish sandstone. Dolomite, shale, and gypsum are locally present. The Cañas Member consists of laminated dolomitic limestone interbedded with two 10–20 m thick laminated-gypsum units (Hunter & Ingersoll 1981). The Joyita Member consists of medium-bedded, tan to red, fine- to medium-grained sandstone with local interbeds of carbonate.

STRUCTURAL GEOLOGY OF THE WALNUT CANYON AREA

The Yeso Formation is exposed south of Hellion Canyon and Red Gap below cliffs of the overlying San Andres Formation (Fig. 3). Thin-skinned deformation in the Yeso is concentrated in the Meseta Blanca and Los Vallos Members and is best exposed in the Walnut Canyon area (Fig. 4). The structures are exposed in a half-graben bounded on the west by the range-bounding Walnut Canyon–West Vein fault zone and on the east by the Double Peak fault (Figs. 5, 6). The dip of strata in the southern portion of the range east of the Double Peak fault, where not affected by folding, is less than 10° to the south and southeast. To the north, lower Paleozoic rocks and Precambrian basement rocks are involved in thick-skinned deformation (Chapin & Nelson in this guidebook), which differs significantly in style from that in the Walnut Canyon area. The Pennsylvanian Magdalena Group is locally involved in the thick-skinned deformation, but also shows bedding-plane, small-displacement thrusts (Fig. 7). These thrusts may reflect a transition to thin-skinned styles up-section, or a response to thick-skinned shortening, or both.

The Walnut Canyon area was mapped at scales of 1:12,000 and 1:6,000 using topographic and color-airphoto bases. Marker beds were mapped in the Los Vallos Member, but were not found in the Meseta Blanca Member, within which only structural elements (folds, faults, and fractures) were mapped.

Faults

Thrust faults are common at an outcrop scale where decollement and ramp geometries are observed. Some megascopic thrust faults were mapped as boundaries between relatively undeformed plates of subhorizontal, unfolded strata, and relatively deformed plates of folded and faulted strata. These geometries are similar to duplex structures described by Boyer & Elliott (1982). The Hackberry thrust, exposed in the hill north of Hackberry Canyon, is one subhorizontal decollement that is visible because of a roll-over anticline in the upper plate (Fig. 8). The presence of the roll-over anticline demands a ramp geometry to the west along the plane of the thrust. The thrust repeats the monotonous stratigraphy of the Meseta Blanca Member, but because the thrust is cut by the Walnut Canyon–West Vein fault, total displacement along the thrust cannot be estimated. Mesoscopic folds and subsidiary shears are developed along thrust faults where exposed. Most thrust faults are horizontal or dip gently west (Fig. 9). The few slickenside lineations measured suggest an eastward transport, although some minor thrust faults are also west vergent.

Not all tectonic boundaries are subhorizontal or necessarily thrust faults. North of Hamburger Hill (Fig. 5), subhorizontal, undeformed beds in the lower Meseta Blanca can be followed laterally, within a distance of <2 m, into a domain of upright folds (Fig. 10). No offset was observed along this deformation boundary.

High-angle faults are common in this portion of the range (Figs. 5, 9). Although most are north-trending normal faults related to development of the late Tertiary Rio Grande rift, some may have been active previously as reverse faults during the Laramide. This speculation is based on the observation that the northerly trend of Tertiary extensional

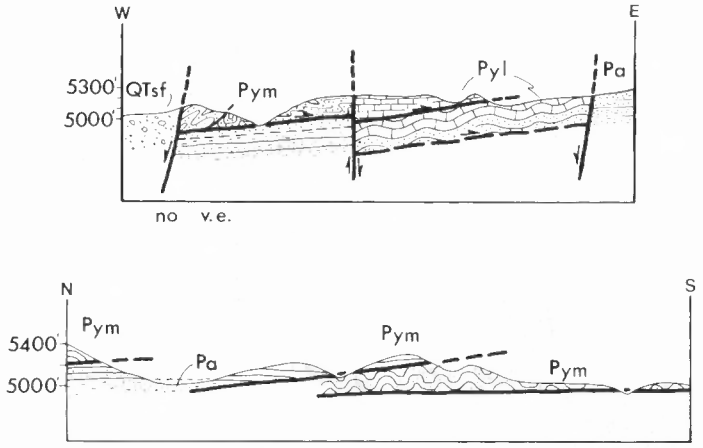
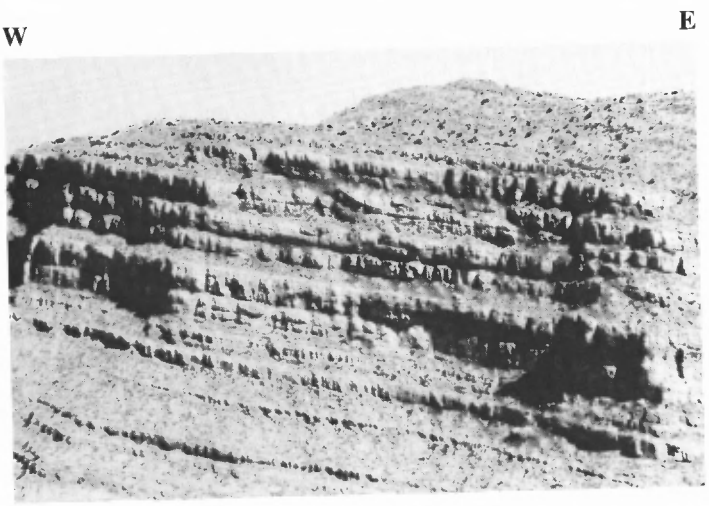


FIGURE 6—Cross sections of Walnut Canyon area. Section lines and symbol explanation shown in Fig. 5. DP = Double Peak fault. Thrust faults shown with teeth on upper plate. Hinge surface traces of folds shown with standard syncline and anticline symbols; plunge direction indicated with single arrow; zero plunge indicated with arrows on both ends of hinge surface trace.



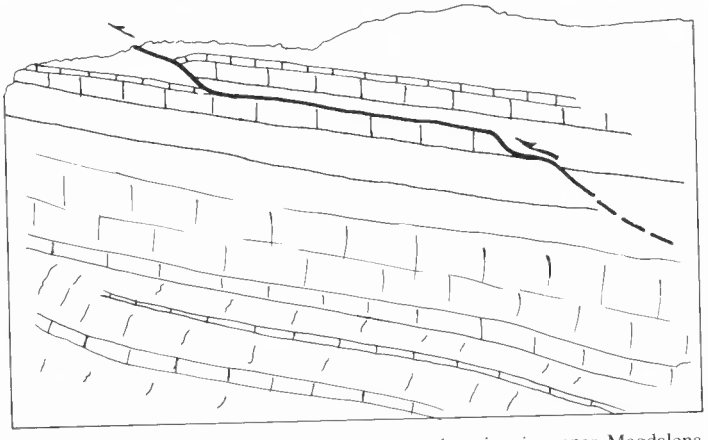


FIGURE 7—Decollement and ramp geometry thrusting in upper Magdalena Group. Offsets of various layers do not seem to balance, probably due to unseen imbrications or because direction of thrusting may be at a high angle to the viewing direction.



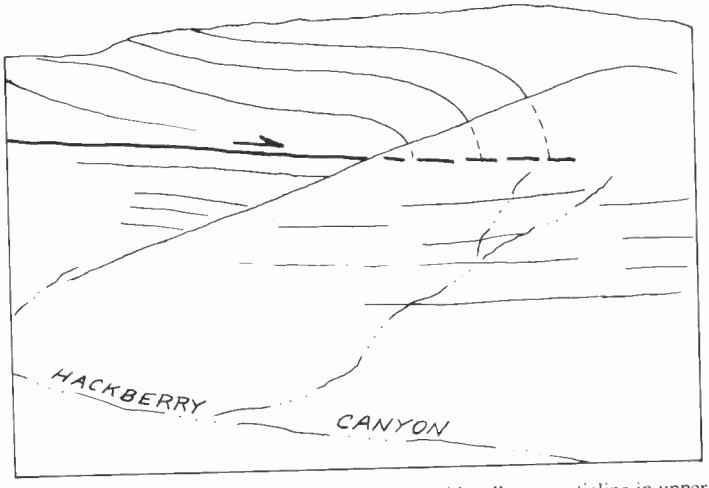


FIGURE 8—Thrust fault in Hackberry Canyon with roll-over anticline in upper plate. Both plates are Meseta Blanca Mbr. of Yeso Fm.

structures is parallel to the trend of older, Laramide, compressional structures. Also, the Double Peak fault appears to be a major, rift-related, normal fault that represents a reactivated Laramide deformation front (all recognized Laramide structures are west of this fault; strata are subhorizontal and undeformed east of it).

Folds

Folds in the Meseta Blanca Member commonly are restricted to specific stratigraphic intervals bounded by thrust faults. Folds are of variable geometry and are mostly upright, subhorizontal, and cylindrical, and trend north or northwest (Fig. 11). Inclined and recumbent folds are developed locally. Most folds are disharmonic and box fold geometries are dominant. Fold amplitudes range from handsample size to over 10 m (Fig. 12). Fold vergence and thrust-plane slickenside lineations suggest both eastward (dominant) and westward tectonic transport. No penetrative planar or linear fabrics have been observed in the area, indicating a fairly brittle deformational environment.

Structural interpretation and discussion

East of the Double Peak normal fault, the Pennsylvanian and Permian sections are undeformed, indicating that the observed deformation either climbs up-section to the east (to a now-eroded level), or rapidly diminishes in intensity to the east. Higher stratigraphic levels (e.g. upper Yeso members and San Andres Formation) are exposed east of the Double Peak fault and south of the Walnut Canyon area, and have not been studied in detail. Laramide deformation may have affected these areas, but has not yet been recognized. The Double Peak fault may thus represent a Laramide deformation front east of which little or no deformation occurred.

To the north, deformation in lower structural and stratigraphic levels exhibits a completely different style, in which Precambrian basement is involved with Paleozoic rocks in thrusting and folding (Fig. 2; Chapin & Nelson in this guidebook). This thick-skinned structural style is similar to the fold–thrust model of Berg (1962) for Laramide uplifts in the northern Rockies. However, geometric aspects of folds suggest a basement-block control during forced folding, as Stearns (1978) proposed. It appears that thick-skinned deformation resulted from a combination of forced folding controlled by basement-block faulting and basement folding in response to crustal shortening and uplift (Chapin & Nelson in this guidebook).

The transition between regions of thick-skinned and thin-skinned deformation appears to be just south of Hellion Canyon (Fig. 3). North of Hellion Canyon the plunge of the Hellion anticline changes from near zero to over 90° in less than 1 km. The strata presumably are draped over the lateral edge of an uplifted basement block. South of Hellion Canyon, the Hackberry thrust imbricates the Meseta Blanca Member just above the Abo–Yeso contact. If the down-to-the-south fault in Hellion Canyon (the Hellion fault) is a post-Laramide structure, this transition between structural styles may be the result of juxtaposition of different structural levels due to younger faulting. If this is the case, then basement-involved structures (such as the Hellion anticline) may exist at depth in the Walnut Canyon area. This implies that Laramide

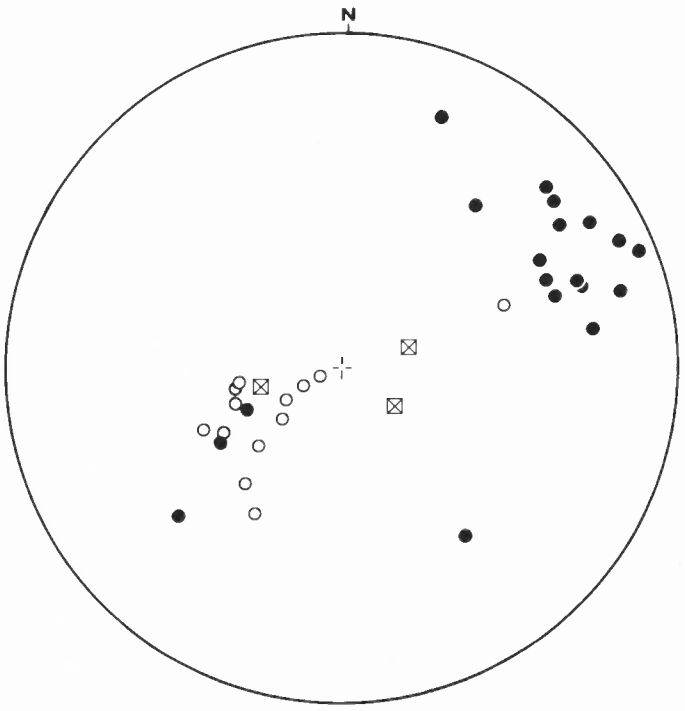


FIGURE 9—Lower hemisphere stereoplot of poles to normal faults (closed circles), slickenlines in normal faults (open circles), and poles to thrust faults (x in box).

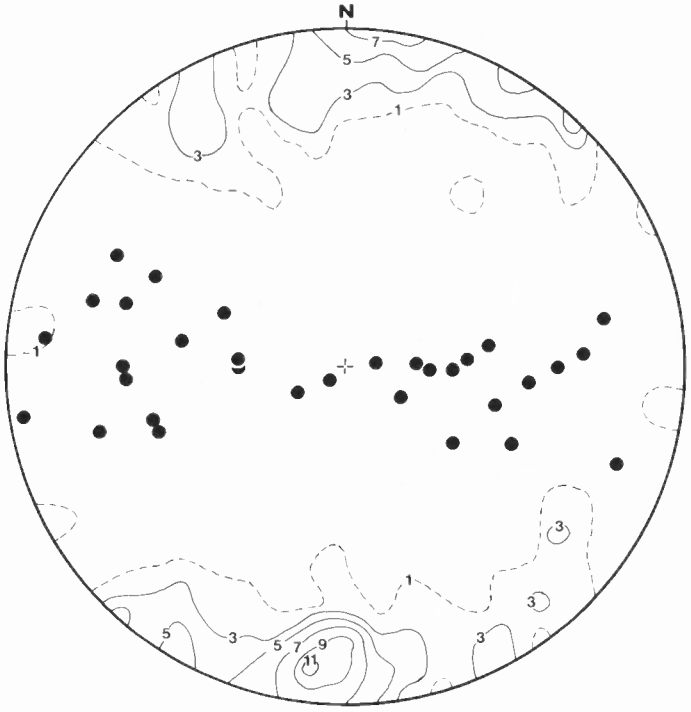


FIGURE 11—Lower hemisphere stereoplot of 93 fold hinges (contours are number per 1% area), and fold axial planes (closed circles) in Walnut Canyon area.

shortening was accommodated by different styles of deformation at different structural levels. Alternatively, the Hellion fault may be a Laramide tear fault which separated blocks undergoing different styles of deformation. In this case shortening was simultaneously accommodated in the two blocks by different structural mechanisms at the same structural level. This alternative does not preclude basement involvement south of the Hellion fault and west of the Walnut Canyon area. We favor the tear-fault hypothesis because the Hellion fault is truncated by the Double Peak fault, suggesting that the Hellion fault is older.

Lithology undoubtedly played a major role in the different styles of deformation exhibited in the range, regardless of the structural level(s) where deformation occurred. The northern structures were controlled by movement of mechanically homogeneous basement blocks and some draping of sedimentary cover. The thin-skinned structures were developed in mechanically heterogeneous sedimentary rocks of vastly different relative competencies (shale, siltstone, sandstone, limestone, and evaporites). Effects of the mechanical properties of evaporite on deformation have been emphasized by Davis & Engelder (1985). Although no evaporite horizons or minerals were observed in the Meseta Blanca

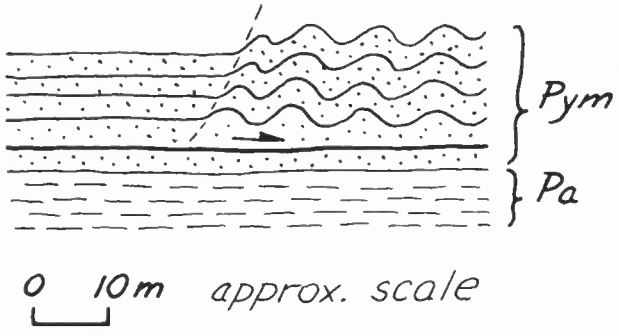


FIGURE 10—Schematic cross section of deformation boundary and decollement near base of Yeso Fm. Pa = Abo Fm.; Pym = Meseta Blanca Mbr. of Yeso Fm.

or Los Vallos Members, salt-crystal casts and molds, some up to 25 cm across, are common near the base of the Meseta Blanca Member (a stratigraphic level where a decollement has formed). The salt crystals, which may have grown interstitially in fine-grained clastic sediment as optically continuous cement, are now replaced by silica. Whatever the origin of the salt, it is likely that it imparted a mechanical weakness during Laramide deformation. The salt was subsequently replaced by silica, probably during circulation of hydrothermal fluids related to Tertiary–Quaternary extension.

The lithological variability and evenly bedded nature of the Yeso Formation resulted in the decollement and ramp geometries observed. These geometries suggest that no basement control was directly involved, at least not at the observed structural levels. Basement (now buried in the rift) may be involved in deformation to the west downdip along an inferred basal decollement. Such basement involvement is necessary (if crustal shortening is assumed to be significant) in order to balance the shortening observed in the Permian section. The Double Peak fault may have acted as a ramp during Laramide deformation (Fig. 13A). An alternative hypothesis is that the basement was involved in Laramide block faulting to the west, analogous to styles farther north in the range, but was offset laterally along the Hellion tear fault. Such a structural style involves significant structural relief which may have created a gravitational potential in strata on the steep limb of the draped cover section. Similar interpretations have been made for Laramide deformation in the Lucero uplift near Belen, New Mexico (Callender & Zilinski 1976), and the Owl Creek Mountains, Wyoming (Wise 1963). In this case the Double Peak fault may have represented a buttress. Strata "sliding" off a Laramide uplift to the west would rumple up against this buttress (Fig. 13B).

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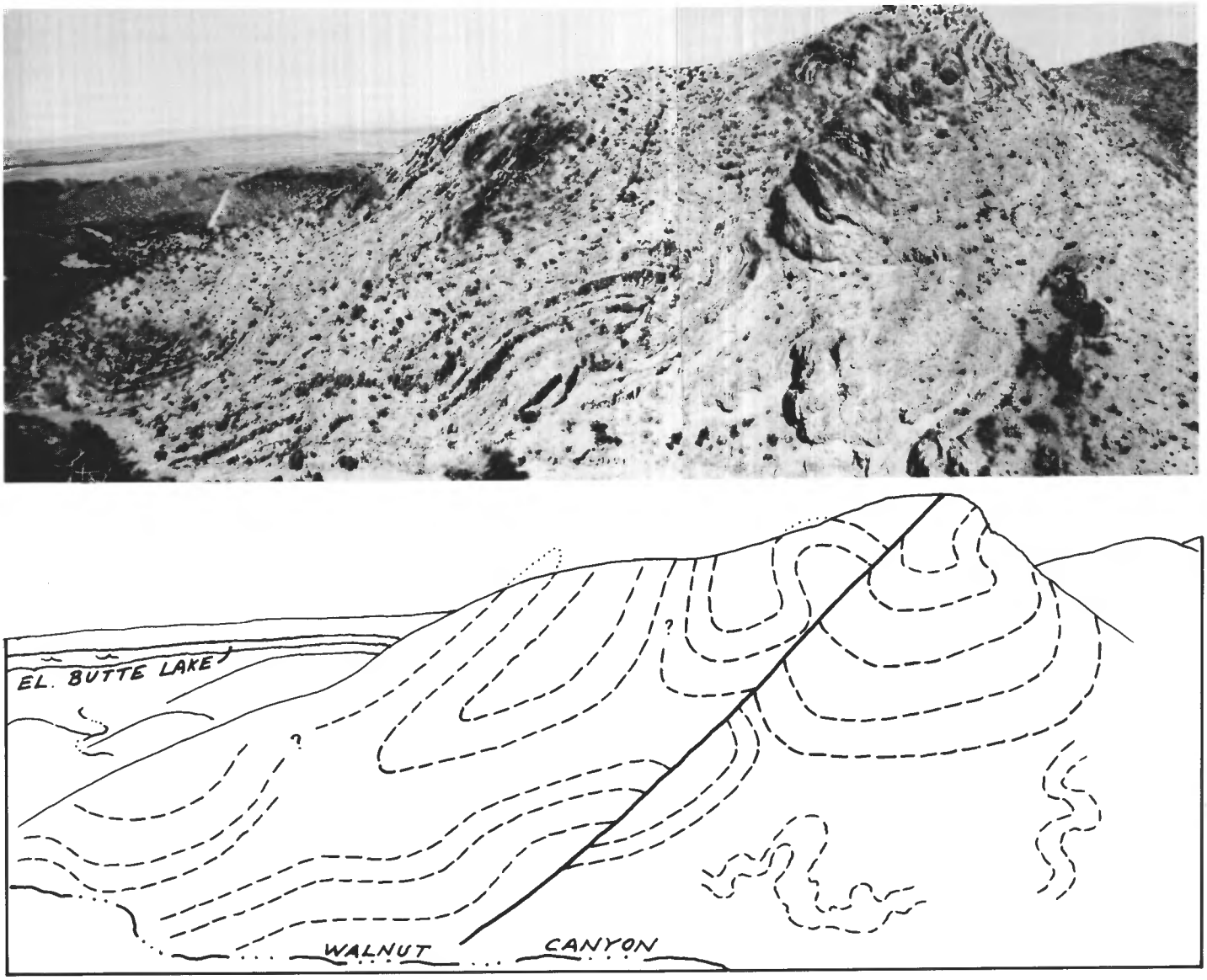


FIGURE 12—Complicated faulting and folding in the Meseta Blanca Mbr. of Yeso Fm. in Hamburger Hill. Hill is about 67 m high.

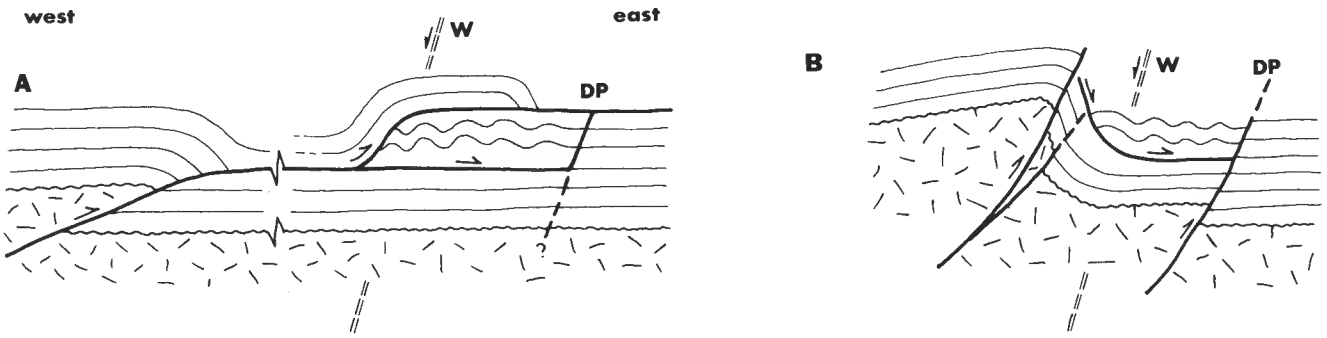


FIGURE 13—Schematic, conceptualized models for the origin of structures in the Walnut Canyon area. Scale is approximate: sections are about 2 km thick. DP = Double Peak fault; W = future site of Walnut Canyon fault zone. **A,** Crustal-shortening model involving duplex development in cover and basement shortening to west. **B,** Model involving gravity sliding of cover section off steep limb of drape fold generated by combination of crustal shortening and basement-block faulting. Folding of basement, if it occurs, probably happens only locally through cataclastic flow. Note that all evidence west of W is buried in the Rio Grande rift today!

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