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TEXAS LINEAMENT REVISITED

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INTRODUCTION

The type locality of the Texas Lineament and for the Texas direction of wrench faulting includes the corridor between Van Horn and Sierra Blanca, Texas (Albritton and Smith, 1957; Moody and Hill, 1956). This corridor has been the principal route of travel across this region from time immemorial: it includes the route of the Butterfield Stage Coach Line, two railroads and the main highway between Van Horn and El Paso. Across this corridor the difference in geology is profound: a stable platform on the north (thin shelf carbonates of Permian and Lower Cretaceous age on Precambrian rocks in the Diablo Plateau) and a mobile subsiding trough on the south (thick Cretaceous carbonates and clastics on Mesozoic evaporites of the Chihuahua Tectonic Belt, which have been thrust northeastward against the margin of the platform). Albritton and Smith (1965) found no evidence for strike-slip movement at Sierra Blanca or eastward, and because they found no continuation eastward beyond the Carrizo Mountains they doubted that large strike-slip movement had occurred along this segment of the zone. A gravity and magnetic study of this region by Wiley (1970, 1972) showed that the major geophysical anomalies in Eagle Flat turned southward along the south edge of the Carrizo Mountain and became coincident with the exposed Rim Rock fault that extends southward for 96 km nearly to Presidio. These faults mark the northeastern margin of the Chihuahua tectonic trough, structures that have been active since mid-Mesozoic time. An equivalent Late Paleozoic border must lie in this same zone (probably to the southwest) but its exact location is uncertain. For the rest of the Paleozoic there are no stratigraphic data to support any movement along this zone (horizontal or vertical; Wiley and Muehlberger, 1971). Because recurrent deformation, metamorphism and intrusion along this zone suggests that there is a fundamental crustal discontinuity, it will continue to be studied by many in an effort to unscramble the successive effects and true history of this region.

LANDSAT imagery has given new impetus to the study of lineaments with a consequent rash of papers showing lines all over maps; some of these lines are geologically meaningful, for others the meaning is obscure to unknown. LANDSAT images show a band of linear features, 16 km wide at most, that extends from El Paso, through Sierra Blanca, Marfa, Persimmon Gap and into northern Coahuila through the Pico Etereo igneous area to Valle el Infante. This band can be identified on Figures 4 and 5; parts are readily found on Figures 2 and 3. It includes the type area of the Texas Lineament; thus, this remarkably straight band of linear features must constitute the trace of the Texas Lineament across Trans-Pecos Texas. A parallel line 80 km to the south in northern Mexico, which includes the west-northwest-trending segment of the Rio Grande downstream from Presidio, forms the boundary between nearly north-trending elements on the south and west-northwest-trending elements on the north. This 80-km-wide band includes virtually the entire zone of west-northwest-trending structures in this region. Albritton and Smith (1957) defined the Texas Lineament as a zone and described its appearance west from Van Horn, Texas. LANDSAT views suggest that the Texas Lineament across Trans-Pecos Texas is this 80-km-wide band. Possible extensions in either direction are beyond the scope of this paper.

This paper will focus on tectonic features and events of Trans-Pecos Texas with forays into the surrounding region as necessary to indicate the relationships and larger implications of this restricted area.

The set of maps accompanying this paper shows the orientation and type of structure known to have been active during each orogenic period that has affected Trans-Pecos Texas. This set of maps should be considered a progress report, because many of the faults identified in the field cannot be uniquely assigned to a specific deformational episode and, thus, are shown for only the latest movement for which stratigraphic evidence is available; others have been active in virtually every phase of deformation. I have attempted to show only data (observable field relations) on these maps. Thus, they are sparse because interpreted structures that seem necessary because of the regional pattern are not included (as is usually the case). The text is mainly explanatory material for the maps.

The overriding theme is that the Texas Lineament is a zone of recurrent movement that separates more stable crust on the north from less stable crust on the south. Dip-slip (normal, steep reverse, or thrust) movements are widely demonstrable. Strike-slip movement can be documented for episodes but the amount of slip necessary to produce the observed effects is in miles rather than in hundreds of miles. This paper discusses the region from its probable birth about 1.4 b.y. ago to the present.

PRECAMBRIAN HISTORY

Throughout most of Trans-Pecos Texas nothing is known about the underlying basement. Denison (this guidebook) shows the data for the Van Horn region. Beyond that the nature of the basement in this vast region is known from samples from only three wells in a small region abot 80 km south of Van Horn (with metamorphic ages about 950 m.y.) and from samples taken in numerous wells on and adjacent to the Central Basin Platform along the east edge of the region. Basement rock in both areas is dominantly granitic in composition. The New Mexico end of the Central Basin Platform belongs to the Chaves granitic terrane (ca. 1350 m.y. old), the remainder, including the Pecos Arch, to the Llano terrane (ca. 1000 m.y. old). At the southeast corner of the map area, Late Precambrian sheared mafic metamorphic rocks underlie the Late Paleozoic Devils River Uplift (Nicholas and Rozendal, 1975). The entire central slice of the map from the Delaware Basin south into Mexico has basement beyond all exploratory drilling to date (6061 m or more).

In northern and central Mexico known Precambrian rocks are absent and, except along the margin of the Gulf of Baja California (in Sonora), the nearest exposures of Precambrian rocks are found hundreds of miles to the south of the lineament. The cause of this profound difference across the lineament may be an eastward extension of a large branching rift system initiated about 1,450 m.y. ago. This rift system broke off the chunk of the western and southwestern North American craton that now constitutes the core of

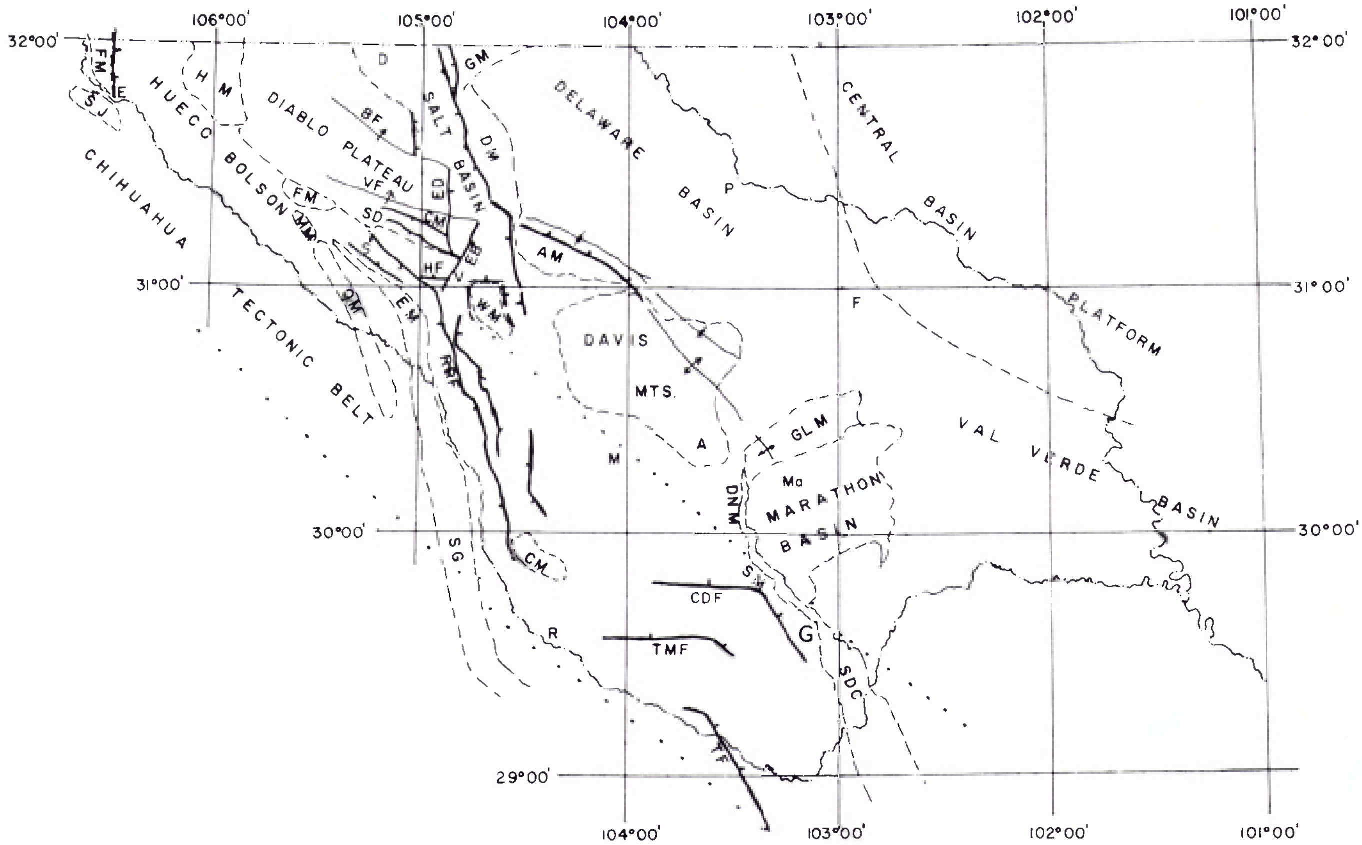

Figure 1. Principal physiographic and tectonic features of Trans-Pecos Texas. Pecos River forms eastern boundary and the Rio Grande the western and southern boundaries of the area. Adjacent parts of Mexico, New Mexico, and West Texas are also included. Cities: E–El Paso, S–Sierra Blanca, V–Van Horn, D–Dell City, M–Marfa, A–Alpine, Ma–Marathon, P–Pecos, R–Presidio, F–Ft. Stockton. Mountain ranges: FM at New Mexico border–Franklin, HM–Hueco, FM–Finlay, MM–Malone, QM–Quitman, EM–Eagle, WM–Wiley, AM–Apache, DM–Delaware, GM–Guadalupe, CM–Chinati, GLM–Glass, DNM–Del Norte, SM–Santiago, SDC–Sierra Del Carmen, SG–Sierra Grande, SJ–Sierra Juarez. Flexures (monoclines): BF–Babb, VF–Victorio. G–Persimmon Gap. Faults, ticks on downthrown side: ED–East Diablo, CM–Cox Mountain, SD–South Diablo, HF–Hillside, EB–East Baylor, RRF–Rim Rock, CDF–Chalk Draw, TMF–Tascotal Mesa, TF–Terlingua. Modified from Wiley, 1970. Dotted lines mark two major lineaments seen on LANDSAT images. These are used as the north and south boundaries of the Texas Lineament in this paper.

the Siberian Platform (Sears and Price, 1978). Across this rifted margin were deposited the thick Precambrian miogeoclinal wedges of the Belt, Uinta and Death Valley region. Younger packages are found in the Grand Canyon, southern Arizona and in West Texas-southeastern New Mexico. Even younger sedimentary wedges along this margin apparently represent a later rifting stage about 850 m.y. ago (Stewart, 1976; including the Van Horn sandstone?).

The earliest movement recognized along the Texas Lineament is left-slip in Stockton Pass, southern Arizona (Swan, 1975). Here, a north-trending regional foliation that crosses the west-northwest-trending fault zone has undergone a total of about 6.4 km left-slip displacement during and immediately following the intrusion of a 1370 ± 70 m.y. granite. Assuming that the Texas Lineament is a zone 160 km wide and that the deformation across his map area is characteristic of that within the entire zone, Swan concludes that a total of 160 km of left-slip is possible. Diabase dikes, 1150 m.y. old, intrude the fault zone.

In West Texas, the oldest known unit is the Carrizo Mountain Formation composed of metamorphosed arkose (interpreted as metarhyolite by Denison and Hetherington, 1969), quartzite, schist, phyllite, slate and limestone 5,758 m in thickness, which has been intruded by sill-like masses of igneous rocks, now amphibolite and metarhyolite (King and Flawn, 1953; Flawn and Muehlberger, 1970; King, 1976). Denison and Hetherington (1969) determined several whole-rock Rb-Sr ages on the metarhyolites and obtained a best-fit isochron of 1238 ± 65 m.y. They were unable to determine whether the scatter is a result of differences in the age of formation or whether it is an effect of metamorphism that affected these rocks about 1000 m.y. ago. (Denison and others, 1971). These units are well exposed in the road cuts along I-10 west of Van Horn.

The Carrizo Mountain Formation lies on the Streeruwitz thrust plate which Wiley (1970, 1972) demonstrated extended under the outcrops of the Eagle Mountains, a minimum displacement for the Streeruwitz thrust fault of 19.2 km. How much farther south this thrust plate might extend is unknown. Thrusting and metamorphism are essentially contemporaneous and mark the Precambrian major tectonic event (ca. 1000 m.y.) of this region. The metasedimentary Allamoore (including volcanic and talc phyllite rocks) and sedimentary Hazel Formations that underlie the Streeruwitz thrust fault are exposed in a broad band west of Van Horn and constitute the fill of a tectonic foredeep that became involved in the terminal phases of thrusting. Folds strike slightly north of west, metamorphism and deformation decrease northward, all of which suggests that the direction of thrusting was nearly north. In contrast, strike of the Carrizo Mountain Formation on the thrust sheet is about N45°E. Geophysical data led Wiley (1970) to the conclusion that the thrust plate is broadly folded about a west-northwest axis. The west-northwest grain of this region, appears to have been established in the waning stages of this Precambrian orogeny (King, p. 119, in King and Flawn, 1953). King further indicates that using pattern of younger events alone could lead to erroneous tectonic interpretations because of the reactivation of this pattern in successive deformations that had quite different directions of principal stresses. A similar sequence of metasedimentary Precambrian formations is found in the Franklin Mountains near El Paso. Here they are overlain by as much as 425 m of rhyolite flows and are intruded by granite, the isochron age of which is 953 ± 13 m.y. (Franklin Mountains igneous terrane of Denison, this volume).

Thus, a major west-trending thrust belt and associated igneous activity (Franklin Mountains igneous rocks; Denison and Hetherington, 1969) straddled the Van Horn region about 1000 m.y. Much of central Texas underwent orogeny during this period (Llano orogeny of Muehlberger and others, 1967). To explain the presence of oceanic crust (serpentinite) exposed in the southern Llano uplift and the thrusting and igneous activity of Trans-Pecos Texas, Garrison and Ramirez (1979) postulate the closing of a wedge-shaped ocean at this time. The narrow end of the wedge is presumed to be in the vicinity of El Paso. The presence of basalts, volcanic conglomerates and thin siliceous units that overlie carbonates and underlie quartzite in the Allamoore Formation attest to tectonic unrest within what had been shallow marine environments (best shown by stromatolite reefs in the Castner Limestone in the Franklin Mountains; Harbour, 1960; called Castner Marble by Hoffer, 1976).

The postorogenic Van Horn Sandstone lies with sharp angular unconformity across the older Precambrian rocks (King and Flawn, 1953). It is a coarse arkosic red sandstone and conglomerate that was deposited as a coalesced alluvial apron by a fluvial system draining from north to south. The transition to marine environments is not preserved (McGowen and Groat, 1971), but based upon grain-size changes toward the southernmost outcrops along the northeastern edge of the Carrizo Mountains, it is possible to speculate that shoreline might have been only a few kilometers farther south, namely along the same boundary that was so clearly active from Late Paleozoic times onward.

The Van Horn Sandstone was tilted, block-faulted and beveled (high area along Eagle Flat) before deposition of the overlying basal Ordovician Bliss Sandstone (King, 1965). This relatively modest deformation in Cambrian(?) time can be contrasted to the extensive faulting and volcanism in the early phases of development of the southern Oklahoma aulacogen (Ham, Denison, and Merritt, 1964; Hoffman, Dewey, and Burke, 1974), where major igneous and sedimentary sequences were deposited prior to the Late Cambrian transgression that submerged all of Texas and Oklahoma.

LATE PALEOZOIC

All products of Late Paleozoic deformations are lumped on Figure 2. Unfortunately, this hides the long and complex history that can be demonstrated for some areas. A brief summary by area is given here; details can be found in the references cited.

Several Early Paleozoic deformational episodes can be recog-

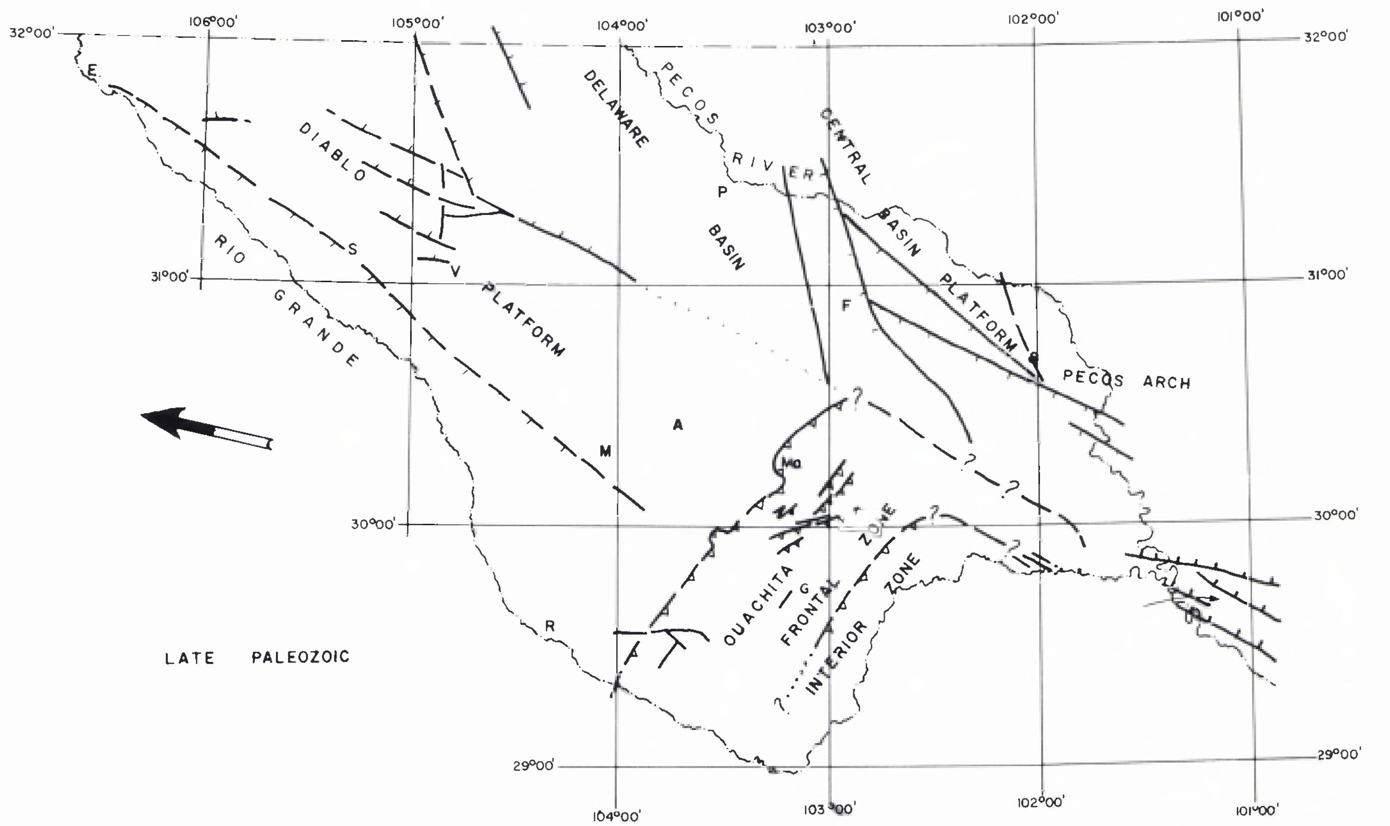

Figure 2. Known Late Paleozoic faults. High-angle faults bound all areas except the Ouachita belt, which is probably allochthonous. Symbols: triangles=thrust faults; ticks=high-angle normal faults. Sources for faults cited in text and references. Small arrow in southeast corner of map points to Devils River uplift. Large arrow shows approximate sense of motion of Mexico relative to Texas.

nized throughout this region beginning in Early Ordovician with the truncation of the Ellenburger Group (Galley, 1959; El Paso Formation: Le Mone, 1969). The broad Tobosa Basin, the shallow predecessor to the Permian Basin (Galley, 1959), preserves the best record of these epeirogenic(?) events; how they may relate to more remote orogenic events (Taconic, Acadian, and Antlers orogenies) is beyond the scope of this paper.

The Van Horn region furnishes the stratigraphic documentation for the successive deformations of the Diablo Platform (King, 1965; Albritton and Smith, 1965), a structural element first clearly recognizable by Early Permian time. The Hueco Limestone (Wolfcampian) lies across the truncated edges of Early Pennsylvanian and older rocks. The Hueco lies on Precambrian units along the southern margin and on younger units north of the Cox Mountain fault. The next west-northwest-trending structure to the north, the Victorio flexure, was a major north-side-down fault in pre-Hueco and post-Early Pennsylvanian time, experienced no movement while the Hueco Limestone (a shelf carbonate) was deposited across it, and then underwent renewed north-side-down movement so that it marks the shelf-basin transition during Leonardian time. The Babb flexure (northernmost west-northwest-trending structure) had a similar history.

The southern margin of the Diablo Platform is shown continuing southeastward toward Marfa. At that point it was submerged beneath the near approach of the Ouachita thrust front. The Ouachita boundaries are from Flawn and others (1961) with minor modifications from Pearson (1978), Hills (1970), and my guesstimates. These rocks reached their present position in Early Permian (Wolfcampian) time from an unknown original location to the southeast. Assuming that these thrust belts are allochthonous, then the Pennsylvanian turbidite basins that are now part of the thrust sheet (Tesnus, Dimple and Haymond Formations) were deposited somewhere south of Del Rio, Texas (southeast corner of the map, fig. 2). This region is now occupied by the Devils River Uplift which, as it rose, could have produced the northwestward tilt that would allow the thrust sheet to be emplaced. Devonian metamorphic isotopic ages on granitic clasts in the Haymond Formation (Denison and others, 1971), however, indicate a source other than the Devils River Uplift; sediment current directions indicate a southeasterly source area (King, 1937). Once the thrust sheet was in place it formed the southern shore of the Delaware Basin, which continued to subside until at least Late Permian time. The subsidence was greater along the northern margin, as shown by reef-to-basin relief of about 605 m, with less than half that along the southern margin (King; 1937, 1948).

The Central Basin Platform is beyond the map area for the most part. It is a highly faulted, structurally elevated block that began to develop in the Mississippian, and which underwent major uplifting in the Pennsylvanian and Early Permian (Galley, 1959; although an older paper, it is still an excellent summary of Permian Basin geology). Only the principal bounding faults along the south and west sides are shown in Figure 2 (Hills, 1970). The structurally highest portion lies east of Fort Stockton and exends along the Pecos Arch, where Precambrian rocks lie directly beneath the Permian shelf limestones. Thus, both the Diablo and the Central Basin Platform were developing at the same time; both have the southern margin as the stucturally highest part; and both became shallow-marine platforms in Early Permian time. The major difference is that the Diablo Platform has been involved in several more recent tectonic events, which have reactivated many of the older faults and have generated many new ones that have fragmented the platform.

The prominent lineament that extends southeastward from the Babb and Victorio flexures, along the north front of the Apache and the Davis Mountains nearly to Alpine, marks the Permian Guadalupian reef front. The lineament disappears for a distance where it crosses the Hovey Channel (opening of the Delaware Basin southwestward toward the Permian sea) and Glass Mountains (Guadalupian reef front along the southeastern margin of the Delaware Basin). If projected southeastward (dotted line of fig. 2) it coincides with the northeastern edge of the Ouachita thrust sheet and the edge of the Devils River Uplift. This line roughly coincides with one of the segments of the Texas Lineament shown in Muehlberger (1965), Wiley (1970) and Wiley and Muehlberger (1971). Its meaning or reality is still shrouded with an opaque veil.

The Deming axis of Turner (1962) consists of a series of Late Paleozoic uplifts extending across southern New Mexico to the Diablo Platform. The northwest trend of each uplift across this belt and the regional west-northwest trend of the alignment of uplifts suggests that this region was subjected to a right-lateral couple (i.e., the Mexico side moving to the west (–northwest?) relative to the Texas–New Mexico side) during this orogenic episode. Permian metamorphic isotopic ages at Sierra Mojina, 150 km south of El Paso (Denison and others 1971), on metarhyolite shows that collision events extended southward into Mexico.

GULF OF MEXICO OPENING

In the mid-Mesozoic, events related to the Gulf of Mexico opening that affected the margins of Trans–Pecos Texas can be identified. The main development was the formation of the Chihuahua Trough, the border of which lies along Eagle Flat and the Rim Rock fault to the south (Wiley, 1970, 1972; Albritton and Smith, 1965; DeFord and Brand, 1958). DeFord and Haenggi (1971) show the spectacular tenfold thickening of Lower Cretaceous units from the platform near Van Horn southwestward to the Rio Grande, where 3,030 m of rock can be measured. These rest on evaporites of earliest Cretaceous or Jurassic age. Marginal to this evaporite basin are the marine Jurassic rocks exposed in the Malone Mountains west of Sierra Blanca (Albritton and Smith, 1965). No rocks of this age are included in any of the thrust sheets of the Chihuahua tectonic belt (Underwood, 1963; Jones and Reaser, 1970; Haenggi and Gries, 1970) along the Rio Grande margin except in the Malone Mountains, which lie at the northern end of the frontal thrusts.

LARAMIDE

Laramide effects continued from Late Cretaceous to early mid-Eocene time. Stratigraphic evidence for successive episodes as shown by unconformities or deposits of coarse-grained sediments are best preserved in Big Bend National Park (Maxwell and others, 1967). Here five distinct orogenic pulses are recorded, beginning in the early Coniacian (about 88 m.y. ago), before the post-Laramide leveling of the region that was followed by widespread silicic, ignimbritic volcanism in late Eocene and early Oligocene times (see summary by McDowell, 1979; the major period of igneous activity was between 40 and 31.5 m.y. ago, although volcanism continued to 16.3 m.y. ago as evidenced by the Cox Mountain basalt northwest of Van Horn).

In most of Trans–Pecos Texas, because the stratigraphic record is incomplete and the Late Cretaceous(?) episode of emplacement of mafic sills and dikes of the Big Bend region has yet to be satisfactorily dated, the visible result (the existing geometry) must be a composite of motions yet to be unscrambled.

Figure 4 shows only the eastern margin of the Chihuahua tec-

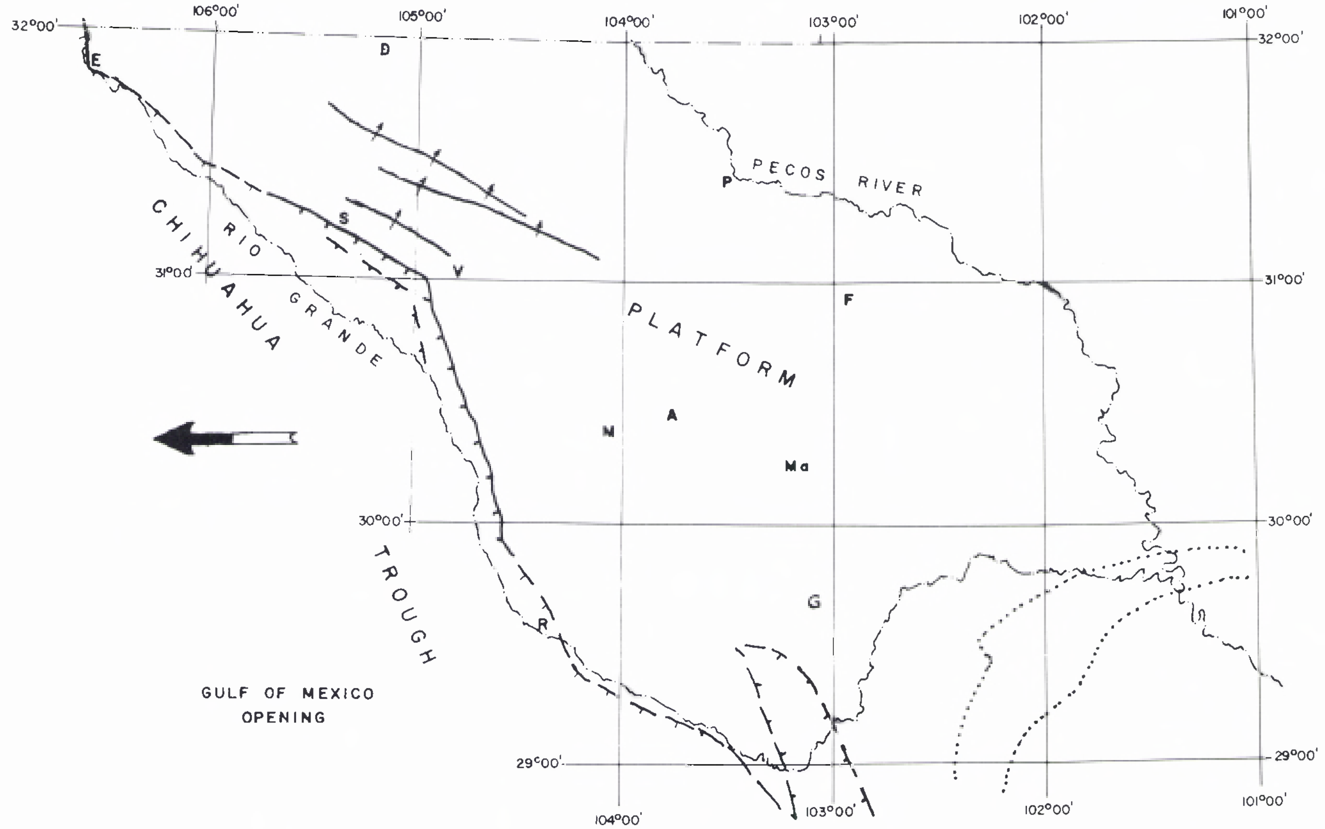

Figure 3. Known mid-Mesozoic (Gulf of Mexico opening) faults. The principal feature is the prominent fault separating the subsiding Chihuahua Trough from the platform; reentrant into the south tip of the Big Bend is based on shapes of structures (tight asymmetrical folds) compared to those on either side. Monoclinal downwarps north of Sierra Blanca–Van Horn from King (1965). The dotted lines in the southeast corner of the map mark the boundaries of the mid-Cretaceous (Washita and Fredericksburg) reef. The landward kink lies along the northern border of the Texas Lineament as used in this paper. Symbols: as in Figures 1 and 2. Small arrows point toward down side of monocline. Large arrow shows approximate sense of motion of Mexico relative to Texas.

tonic belt, where it collided against the buttress of the stable Mesozoic platform. The overthrust margins are shaped by the platform margin and everywhere the sense of thrusting was toward the east and to northeast.

Sierra Samalayuca (55 km south of El Paso) exposes a thick pre-Neocomian (Jurassic or older) sequence of sandstone, shale and conglomerate (Berg, 1969). It is interpreted as a submarine fan deposit with a northeasterly source that is not now exposed. It was metamorphosed during mid-Late Cretaceous time (85 m.y. average age; Santonian–Coniacian, Denison and others, 1971) and now rests in thrust contact to the north on unmetamorphosed Neocomian sedimentary rocks.

Small thrust blocks on the platform margin west of Van Horn and Sierra Blanca as well as one near the Rio Grande southeast of Persimmon Gap (St. John, 1966) mark the outer recognized limits of thrusting. Beyond these a few low-amplitude folds that deform Cretaceous strata, north of Sierra Blanca and in the Glass Mountains north of Marathon, are here intepreted to belong to this episode. These folds may well be related to the development of nearby faulted monoclines (upthrusts or drape folds by other usages) that are spectacularly displayed along the western margin of the Marathon region southward to Big Bend Park—the Del Norte–Santiago–Sierra Del Carmen Ranges (King, 1937; Eifler, 1943; Graves, 1954; Maxwell and others, 1967; Cobb and Poth, this volume) and south of the Rio Grande in Coahuila, Mexico (Smith, 1970). The location of the Rio Grande appears to be controlled by these structures and it has picked a route around them wherever possible. In only a few places has it been superposed across Laramide or younger structures: in these places it is generally in narrow canyons as south of Sierra Blanca and in Santa Elena and Mariscal Canyons in Big Bend Natinal Park.

Black (1975) shows a Laramide structure along the Salt Basin. I have drawn it near the eastern margin in the zone of Late Cenozoic normal faults because that position approximates the control of Rio Grande rift graben margins by earlier Laramide uplifts (Chapin, 1971) or, in part, by Pennsylvanian uplifts (Cordell, 1976). This reactivation of Laramide faults but with the opposite sense of displacement is well shown by the structures along the western margin of the Marathon Basin (Eifler, 1943) and the Persimmon Gap area (Cobb and Poth, this volume).

Between Van Horn and Alpine–Marfa only Cenozoic rocks are at the surface; thus, whether either dotted line shown across this region (fig. 4) is real for Laramide structures is unknown (the southern one is visible on LANDSAT images but that may represent only Late Cenozoic movements).

The Marathon region is a broad dome (King, 1937) that formed during the Larmide events with later uplift during Late Cenozoic events. The topographic basin has resulted from the removal of the overlying Cretaceous cover thus exposing the Ouachita thrust belt.

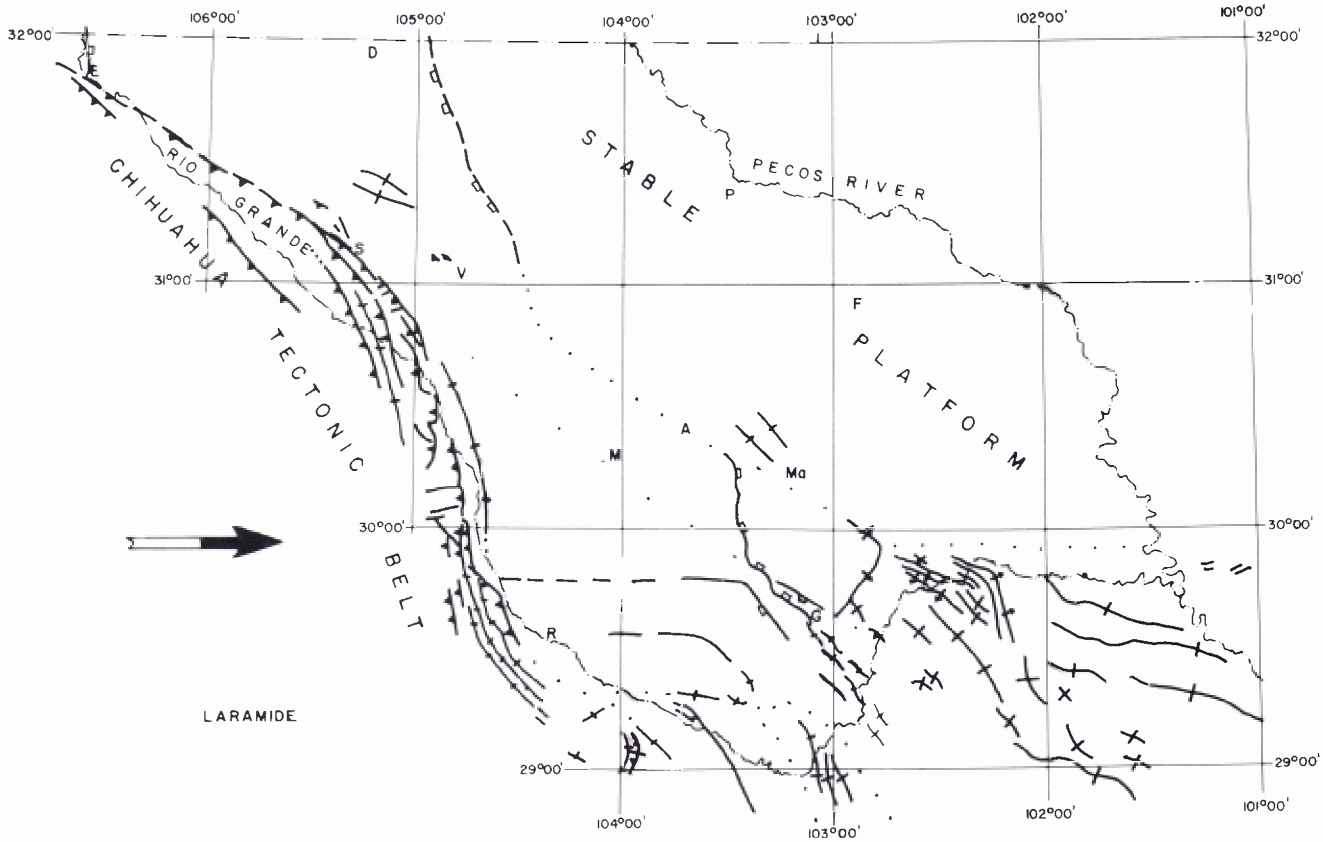

Figure 4. Known Laramide faults and folds. Symbols: as in Figures 1 and 2, plus: short bar across fine line=anticline (open folds in Texas, mainly monoclines in Mexico); open rectangles=upthrown side of faulted monoclines. Large arrow shows approximate sense of motion of overthrust sheets and of Mexico relative to Texas.

The east-trending alignment (northward termination) of structures just south of latitude 30° across the map area is striking. It is especially well developed east of the Big Bend. Webster (1979) has mapped an en echelon system of grabens north and east of Del Rio (only two of these are shown at the east edge of fig. 4) that requires a left-lateral east-striking shear couple during the Laramide. This is consistent with the pattern of Figure 4 in which I suggest that the Mexican and Big Bend segments of the map area moved east relative to the area farther north.

The long, east-trending fault just north of Presidio is marked by a major gravity anomaly (as much as 20 mgal; sense of motion is down to the north). The minor displacements along it in the Cenozoic rock units require that it had important motions in earlier orogenic episodes. It is shown here on Figure 4 as a Laramide structure; it may, however, be a Paleozoic or Precambrian element as well.

LATE CENOZOIC

The Late Cenozoic structure map (fig. 5) shows every trend found on the earlier ones; thus, we clearly see the effects of the preexisting grain on the locations of these latest faults. Many of these trends are visible in Precambrian rocks: west, west-northwest, north-northwest(?), and northeast. Each of these directions is seen in features on the Late Paleozoic map. Northeast trends are barely seen in the Laramide structures (east of Persimmon Gap where the major faulted fold parallels the front of the interior zone of the Ouachita thrust belt) and also barely in the Late Cenozoic structures (along the eastern margin of the Salt Basin graben).

The southern ends of grabens related to the Rio Grande rift extend into the map area and terminate at, or turn southeastward along, the northern border of the Texas Lineament (Hueco Bolson and Salt Basin). The Presidio graben is the only graben in Trans–Pecos Texas other than the Hueco and Salt Basin grabens that includes faults that cut Quaternary map units (Muehlberger and others, 1978). The shapes of the grabens and their locations along Laramide structures suggests that this region is extending in a direction nearly parallel to the Texas Lineament or slightly more westerly. The first-motion solution of Dumas and others (1980) for the Valentine earthquake of 1931 also shows the west-northwestward motion of southern part of the map area relative to the northern part. The first-motion diagram is presumed to lie on their Valentine fault (northwest-trending fault shown terminating(?) near Marfa, fig. 5), which they interpret as a transform terminating the south end of the Salt Basin graben (a spreading center in their usage). Whether this fault extends southeastward as shown or continues as far as the visible LANDSAT lineament into northern Mexico is unknown at present.

Dike swarms furnish important information on stress orientation at the time of their injection (minimum compressive stress is perpendicular to the plane of the dike). Unfortunately most dike systems in Trans–Pecos Texas are undated and thus only their relative stratigraphic position is known. Dike systems parallel all major fault trends in the region.

The best studied system is the Rim Rock dike swarm about 55 km south of Van Horn (Dasch and others, 1969). In this area, the Rim Rock fault, the boundary fault of the Chihuahua tectonic belt and the Texas platform, makes a northwestward dogleg in its mainly north-trending course to its intersection with the Texas Lineament (Wiley, 1970, 1972). Northwest-trending dikes, dated at 22 m.y. b.p., are cut by compositionally different north-trending dikes, dated at 19 m.y. b.p. These dikes are associated with the early stages of development of a major graben along the west side of the Rim Rock fault.

Southeast of Presidio a system of west-northwest-trending dikes is parallel to the Late Cenozoic normal faults and to the Rio Grande. The youngest ignimbrite, the Santana tuff, (26.3 m.y. old; McDowell, 1979) lies across the earliest of these faults in this region between Presidio and Lajitas (McKnight, 1970) and thus sets the approximate date for the beginning of Basin and Range deformation in this area. Basaltic volcanism began at about this date over the entire region.

Two prominent dike swarms in the western part of Big Bend National Park (neither one yet dated isotopically) are one associated with Sierra Quemada, where dikes trend essentially parallel to the major northwest-trending graben, and another with Dominguez Mountain, where they are nearly perpendicular to the graben and extend westward into Mexico. Clearly, much work remains to be done to unscramble the numerous events that have distorted this complex region.

SUMMARY

This succession of maps shows the pervasive influence of preexisting grain on later tectonic features. This grain, dominated by structures trending in the northwest quadrant is visible from the earliest record of this region. If Sears and Price (1978) are correct in proposing that the southwestern edge of the North American craton is a result of rifting about 1400 m.y. ago, then we have a reason for this long-surviving boundary: it separates a cratonic margin on the north from accreted terrain on the south. This region and the Cordilleran belt of western North America have accreted major blocks but have never been subjected to continent-continent collision since the rifting event; thus the crust there has never been reconverted to "normal" continental crust that underlies cratonic regions.

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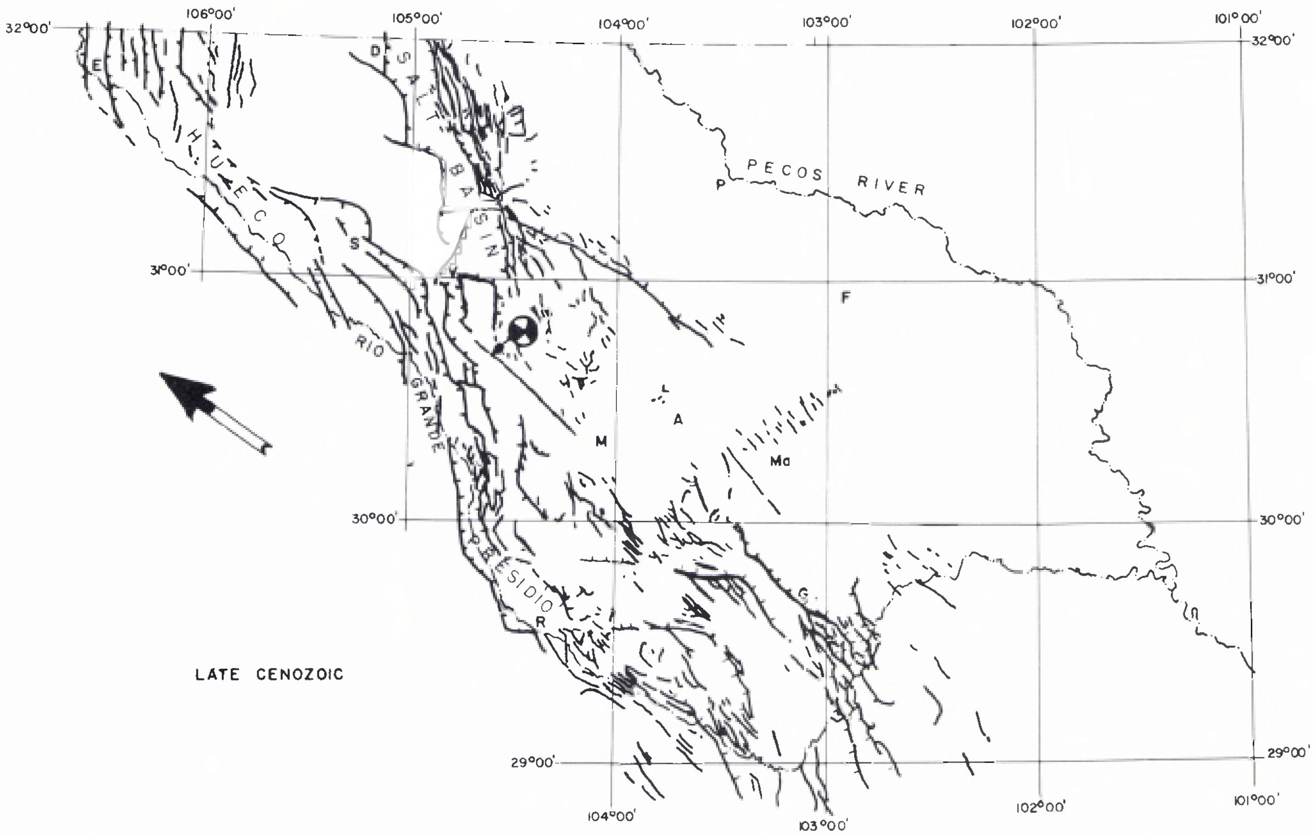

Figure 5. Known Late Cenozoic faults. Tick marks on major graben border faults. Main sources: Geologic Atlas of Texas—Van Horn–El Paso, Pecos, Marfa, Ft. Stockton, and Emory Peak–Presidio sheets; King, 1937; Smith, 1970; Henry, 1979. Also shown is first-motion diagram from Dumas and others (1980) for Valentine earthquake; shaded quadrants=compression; arrow from diagram points to the Valentine fault, the fault assumed to have moved during the August 16, 1931, Valentine earthquake.

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Alkali sacaton plant and spikelet, *Sporobolus airoides*.