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AN INTERPRETATION OF THE STRUCTURAL GEOLOGY OF THE FRANKLIN MOUNTAINS, TEXAS

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INTRODUCTION

Richardson (1909) described the structure of the Franklin Mountains as follows (Fig. 1, Table 1):

1. "The long, narrow Franklin Range, rising 3,000 ft above broad lowlands, resembles a 'basin range' fault block of westward-dipping rocks, but it differs from the type by being complexly faulted internally. [p. 9]
2. "The structure of the Franklin Mountains viewed from a distance appears simple. The strata strike parallel to the trend of the range and dip westward at steep angles. But the simplicity is only apparent, for the distribution of the rocks show that the range is traversed by many faults. As a whole the long, narrow mountain belt bordered by broad waste-covered deserts, the western slopes coinciding with the dip of the rocks and the steeper eastern face exposing eroded edges of the strata, presents the general appearance of an eroded fault block of the basin-range type. [p. 9-10]
3. "On the east [of the range] the position of the hypothetical fault along the base of the range is completely concealed by wash. [p. 10]
4. "On the west the dislocation consists of two parallel faults at the base of the range between the foothills and the main mountain mass. These faults can be followed for several miles and probably border the entire range. The greatest displacement appears in the central part of the range ... indicating a throw of more than 2,500 ft.... The easternmost of these parallel faults along the western base of the mountains has a relatively small throw, indicated by steeply tilted lower Paleozoic strata abutting against the rhyolite porphyry, but farther north the throw is reversed and increased in amount by the cross fault which separates the North Franklin and Central Franklin blocks.... [p. 10]
5. "One of the main faults of the range is the longitudinal one which separates the North Franklin and Cassiterite blocks.
6. "An important transverse fault separates the North Franklin and Cassiterite blocks on the north from the Central Franklin block on the south.
7. "At the southwest end of the range a small wedge-shaped block in which the Hueco limestone outcrops enters the South Franklin block, the Fusselman and Montoya limestone outcropping west of it. [This "wedge-shaped block" of Hueco Ls. is part of the Western Boundary fault zone; the Fusselman and Montoya Ls. form the Crazy Cat landslide—E.M.P.L.J.
8. "... major deformation of the El Paso district probably developed during the close of the Cretaceous period or early in Tertiary time ... [when] the mountain blocks and intervening basins were outlined."

Harbour (1972)[1] mapped (1:24,000) the northern Franklin Mountains. He showed that the "longitudinal fault," "one of the main faults of the range" (Richardson, quote 5 above), was actually a series of low-angle normal faults, one of which Harbour mapped as the base of a landslide south of the Tin Mine. Harbour noted that the "stratigraphic displacement" on his "west limb" (which I refer to as the Western Boundary fault zone) of his "Avispa thrust fault" is more than 7,800 ft at 31°52'30" N. latitude (Figs. 2 and 3), decreasing north to about 2,500 ft in Avispa Canyon where he considered the "Avispa thrust fault" trace to leave the western front of the range and to change trend to become the "important transverse fault," earlier noted by Richardson (quotes 4 and 6). Harbour did not extend the boundary fault north of Avispa Canyon (cf. quote 4 above).

Harbour (1972, p. 67-69) wrote (cf. Richardson, quote 8):

"Cenozoic structural features in the Franklin Mountains trend north to northwest and are a result of both compression and tension, which culminated in uplift of the mountain block above the surrounding basins. Structural features caused by compression include thrust faults and, on the west slope of the mountains, anticlines and synclines. Structural features caused by tension include high- and low-angle normal faults and, probably, the Avispa fault. The pattern of the structural features suggests that compression pre-

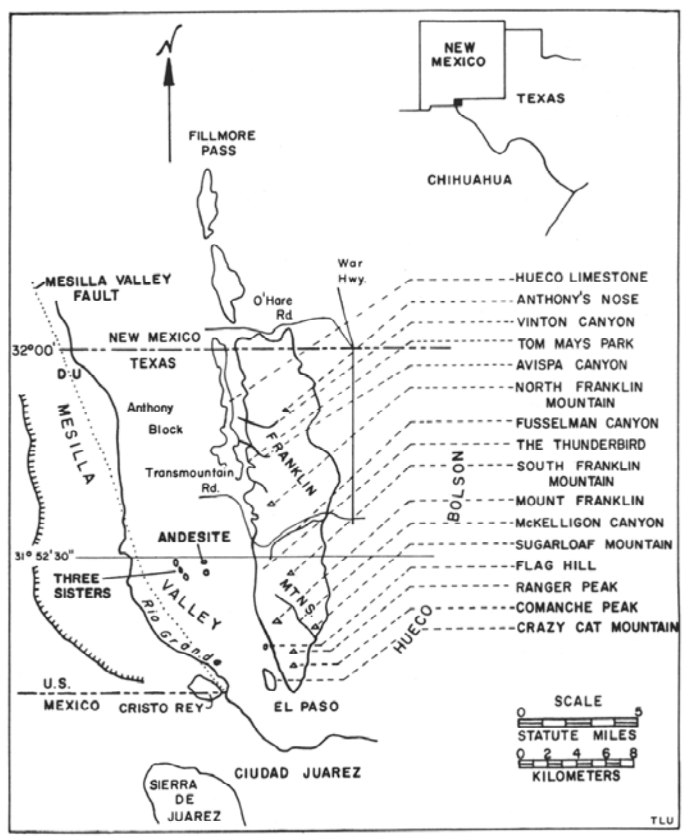

Figure 1. Index and Location Map.

1. The report was prepared after Harbour's death (Harbour, 1972, p. 2) by his friends who noted that they "hope that they have not seriously modified his intended meaning in any part of the report."

System		Formation Name	Thickness
Permian		Hueco	2200 ft (670 m)
		"Upper Unit" (Panther Seep?)	1200 ft (364 m)
Pennsylvanian		Bishop Cap	630 ft (191 m)
		Berino	450 ft (136 m)
		La Tuna	420 ft (127 m)
Mississippian		Helms	225 ft (68 m)
		Rancheria	375 ft (114 m)
		Las Cruces	45 ft (13 m)
Devonian		Percha	90 ft (27 m)
		Canutillo (Middle Devonian rocks of Harbour)	120 ft (77 m)
Silurian		Fusselman	555 ft (168 m)
Ordovician	Montoya Group	Cutter	200 ft (60 m)
		Aleman	120 ft (36 m)
		Upham	50 ft (15 m)
	El Paso Group	Scenic Drive	288 ft (87 m)
		McKelligon Canyon	675 ft (207 m)
		Jose	72 ft (22 m)
		Victorio Hills	290 ft (88 m)
		Cooks	109 ft (33 m)
		Sierrite	121 ft (37 m)

		Bliss	0-300 ft (0-91 m)
Precambrian		rhyolite	

Table 1. Thicknesses of Paleozoic strata in the Franklin Mountains. Data from Harbour (1972), LeMone (1968), and Lovejoy (1973).

ceded tension, for thrust faults are most logically attributed to a single period of compression followed by relaxing tension at which time the mountains were uplifted along a normal fault near their eastern base.

"Regional studies indicate that the pattern of early Cenozoic compressional structural features and later normal faults persists throughout the Basin and Range province in western Texas and southern New Mexico. ... More recent descriptions of New Mexico's Organ Mountains (Dunham, 1935, p. 142-147) ... tend to confirm the conclusions of King (1935, p. 244-251) that in western Texas and northern Mexico uplift of the present mountain ranges took place along normal faults after a period of compression." [see quote from Dunham below]

Harbour noted that compression is believed to have occurred locally in early Tertiary time and that "the age of the ... [boundary] faults ... is uncertain," although noting that "the initial uplift ... is generally placed in Miocene time."

Harbour noted that Dunham (1935, p. 176) "believed that much if not most of the mountain building occurred at the end of Pliocene time." Harbour continued:

"However, proved displacements on faults involving the basin is generally less than 400 ft in this region. Mountain building may still be continuing as shown by recent fault scarps along the fronts of the Franklin ... Mountains."

Harbour also noted (cf. quote 3 above):

"Perhaps the most striking feature of the Franklin Mountains' structures is the curvature of the fault planes. ... Recent fault scarps in the Cenozoic deposits are markedly sinuous and the Fusselman Canyon fault is a high-angle normal fault with a U-shaped trace. Other curving fault planes are the Avispa fault and the low-angle normal faults."

It is of interest to note that Dunham (1935, p. 149-150) actually wrote:

".. there are many gaps in the evidence bearing in Miocene, Pliocene, and Quaternary structural changes. The events ... are not entirely proved by local evidence, but in the absence of such data it seemed advisable to make the story consistent with the general history of the period in the Rio Grande region."

I suggest that an analysis of the structural geology of the Franklin Mountains not only fills some of these gaps, but gives rise to a considerably different tectonic interpretation not consistent with the published general history of the period in the Rio Grande region.

A WORKING HYPOTHESIS

Two concepts underlie my working hypothesis: 1) range tilting occurred mainly late in range uplift; 2) surficial landsliding and subsurficial gravity gliding accompanied range uplift and tilting. Richardson (1909) did not consider these processes. Harbour (1972) mapped landslides to the north and south of the Tin Mine (Fig. 2) and recognized low-angle normal faults on the northeast end of the range. I believe landsliding and gravity gliding explain most of the internal structures of the range; if so, their local and regional tectonic significance is considerably changed.

Range Uplifting and Tilting

Beneath Hueco bolson, 9,000 ft of fill (Mattick, 1966) covers Hueco Limestone bedrock (Cliett, 1969) indicating

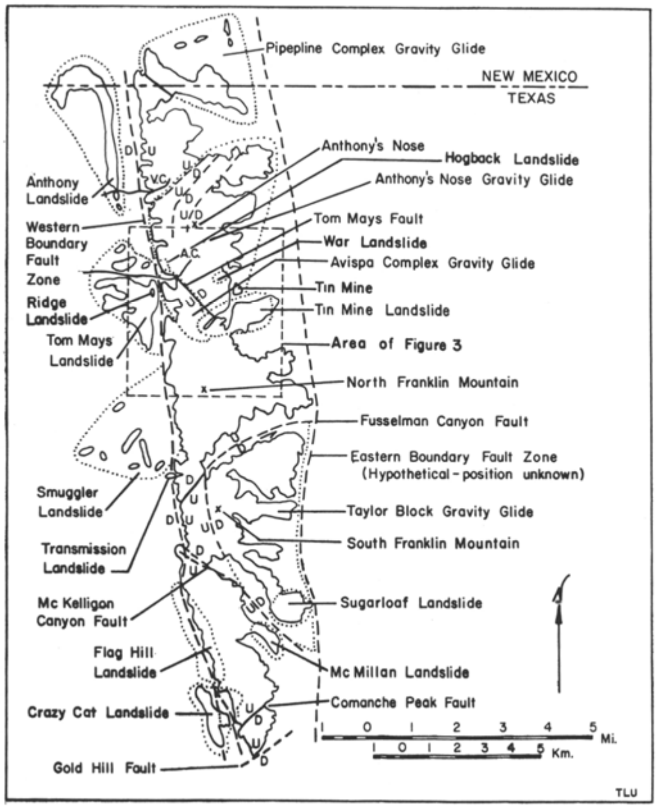

Figure 2. Map of Franklin Mountains showing locations of gravity glide and landslide masses. Dotted lines indicate approximate boundaries of masses; solid lines show outcrop pattern; dashed lines show faults. Note that the part of Fusselman Canyon fault which bounds Taylor block is down on south side, but the part which cuts the main mountain block is down on the north. V. C. is Vinton Canyon; A. C. is Avispa Canyon. Details of the structural geology of the central part of the range are shown in Figure 3.

nearly 30,000 ft of throw on the eastern boundary fault zone east of North Franklin Mountain and about 20,000 ft of throw east of Comanche Peak (Lovejoy, 1975). The upper 40 ft of fill, Camp Rice Formation, contains Pearlette ash 0.6 to 1.5 m.y. old (Strain, 1966 and personal comm.). Sayre and Livingston (1945), Kottlowski (1958) and Lovejoy (1972) agree that upper "Santa Fe" beds have been faulted up about 400 ft on the west on the east side of the range. At that rate of throw, 20,000 ft required 30 to 75 m.y. and 30,000 ft required 45 to 122 m.y. (cf. Lovejoy, 1972).

Because the Western Boundary fault did not displace Fort Hancock beds south of Crazy Cat Mountain, a 4 percent (400 feet up across 10,000 ft width of range) range tilting toward the west (2.3°) occurred in 0.6 to 1.5 m.y. At this rate 35° of tilting required 9 to 23 m.y. (cf. Lovejoy, 1972). Also, in the Organ Mountains, Oligocene flow rocks lie on "Magdalena Series" which dip 35° west (Dunham 1935, p. 143). Dunham (1935, p. 52) noted dip differences of 10° to 20° between the "conglomerate-lava series" and "Magdalena series"; part of the Magdalena Formation and the Hueco Limestone and Cretaceous formations are absent. This angular difference may be partly due to initial dip of fanglomerate and flow rocks. Obviously there was also: a) range uplift and erosion of Pennsylvanian, Permian, and Cretaceous rocks prior to deposition of the Oligocene lavas and b) post-Oligocene range tilting (Lovejoy, 1973).

Landsliding and Gravity Gliding in Franklin Mountains

For this paper I define "landslides" as surface landslips, and "gravity glides" as subsurficial landslips (Table 2 and Fig. 2). Landslips on the east occurred on antithetic normal faults; those on the west occurred on bedding.

I call the landslides which Harbour (1972, Pl. 1) mapped

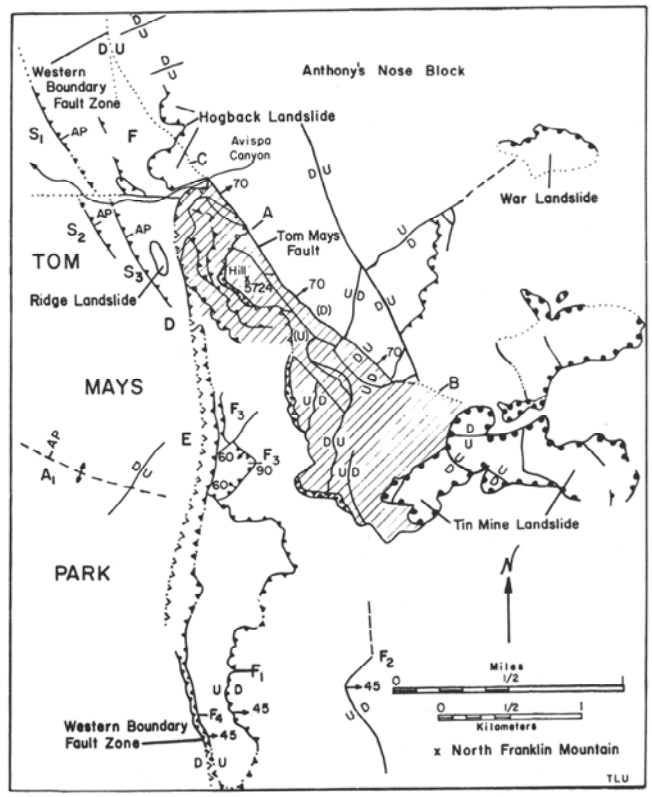

Figure 3. Faults and folds of Tom Mays Park area (from and cf. Harbour, 1972, Plate 1; modified by author). The Avispa gravity glide complex is shaded. F_1 is a 45° east-dipping normal fault similar to F_2. F_3 is a steep to vertical normal fault with less than 100 ft stratigraphic separation. F_4 locally dips 45° east and the east side is up. Tom Mays fault is covered along its southeast extension at (B) by alluvium and the Tin Mine Landslide. Its northwest extension is covered at (C) by the Hogback landslide which moved west. Western Boundary fault north of (C) is covered by alluvium. Western Boundary fault zone seems to be offset south of the junction with Tom Mays fault, but the evidence is not clear. Between (D) and (E) the movement on the earlier western normal fault transfers to the later eastern reverse fault. The fault zone is not exposed north of (D). A reverse east-dipping fault would be difficult to detect in the overturned, east-dipping, contorted Pennsylvanian beds near (F). Black semicircles indicate Harbour's interpreted landslide; black triangles his thrusts and white triangles his Avispa fault. S-synclines, A-anticlines referred to in text.

Gravity glide and landslide masses in the Franklin Mountains

Pipeline gravity glides	Bliss to Hueco on Precambrian	non-brecciated
Anthony's Nose gravity glide	Paleozoic section	non-brecciated
War landslide	El Paso to Fusselman	brecciated
Tin Mine landslide	Precambrian strata to Fusselman on Precambrian	brecciated
Taylor gravity glide block	Precambrian to Fusselman	non-brecciated
Sugarloaf landslide	El Paso to Fusselman on Precambrian	brecciated
McMillan landslide	El Paso and Montoya on Precambrian	brecciated
Crazy Cat landslide	Montoya and Fusselman on El Paso and Cretaceous	brecciated
Flag Hill landslide	Montoya and Fusselman on Montoya and Cretaceous	brecciated
Water Tank landslide	Montoya and Fusselman on El Paso	brecciated
Transmission landslide	Bliss and El Paso on Cretaceous	brecciated
Smuggler landslide	middle and upper Hueco on Cretaceous (?)	unbrecciated
Tom Mays landslide	lower, middle, upper Hueco on Cretaceous (?)	unbrecciated
Anthony landslide	lower and middle Hueco on Cretaceous (?)	unbrecciated
Hogback landslide	La Tuna and Berino on Pennsylvanian section	unbrecciated
Ridge landslide	Pennsylvanian on Hueco	brecciated
Avispa landslide complex	slides of Ordovician through Mississippian on Precambrian to El Paso	unbrecciated

Table 2. Gravity glide and landslide masses in the Franklin Mountains. See Figure 2 for locations.

"Tin Mine landslide complex" and "War landslide" (Figs. 2 and 3). In the northeastern part of his map area Harbour showed hills containing many low-angle antithetic normal faults which I call "Pipeline complex gravity glide." West of the northern Franklin Mountains are hills of Hueco Limestone (Harbour, 1972, Pl. 1). Earlier I called these "Tom Mays landslide" (Lovejoy, 1973, 1975); I now think that they are three landslides: "Smuggler," "Tom Mays," and "Anthony." I interpret the "thrusted" sheets of La Tuna Formation north of Avispa Canyon (Harbour, 1972, Pl. 1; Fig. 3) as "the Hogback landslide"; and breccia (unmapped by Harbour) of La Tuna Formation on Hueco Limestone south of Avispa Canyon 600 ft west of Western Boundary fault as "Ridge landslide." The complex series Harbour (1972, Plate 1) mapped as thrust sheets, including the Avispa thrust sheet, I interpret and name "Avispa gravity glide complex." The east-dipping "thrust" fault (F_1, Fig. 3) displacing Bliss Sandstone and El Paso Limestone west of North Franklin Mountain (Harbour, 1972, Plate 1) I interpret as a range-front, low-angle, antithetic, normal fault.

I also suggest that Anthony's Nose (Harbour, 1972, Plate 1) is in what I term "Anthony Nose gravity glide block" bounded by Tom Mays fault on the south and high-angle, antithetic, normal faults on the north. It resembles "Taylor block" (see below).

Harbour (1972, Plate 1) mapped thrust faults in the Hueco Limestone near Avispa Canyon; these are really inclined synclines (S_1, S2, and 53, Fig. 3) with northeast-dipping axial surfaces on the southwest side of what I call "Tom Mays landslide." I believe these all formed during Tom Mays landsliding toward the southwest. Thus, I think that Harbour's "thrusts" and "anticlines and synclines," which he implied were "early Cenozoic compressional structures" characteristic of the Basin and Range Province, are really due to gravity gliding and landsliding and indicate neither "a period of compression" of early Cenozoic age nor a regionally significant tectonic event.

South of 31°52'30" there was also much landsliding and gravity gliding. "The Taylor block"—bounded on the north and west by the "U-shaped" Fusselman Canyon fault and on the southwest by McKelligon Canyon fault—both of which contain breccias up to 20 ft thick suggesting faulting at shallow depths, formed after earlier, lesser movements had occurred on these two transverse faults (Fig. 2). Indeed, the early movement on the Fusselman Canyon fault was up on the south, whereas Taylor block gravity glides caused a later, much larger movement down on the south. The east side of Taylor block exhibits well developed piedmont scarplets between the alluvial fans of Fusselman and McKelligon Canyons. I suggest that Taylor block is a gravity glide block and the scarplets may represent Recent movement above the toe of the Taylor block. "Sugarloaf landslide" forms Sugarloaf Mountain on Taylor block. Thompson (1974) showed the many faults it contains, but did not consider it to be a landslide. "McMillan landslide," being quarried in McMillan Quarry, is post-Sugarloaf slide, and formed after McKelligon Canyon, into which McMillan slide moved. Crazy Cat landslide (Lovejoy, 1975), lying on the Western Boundary fault zone, has been displaced 15 ft by movement along the fault. The slide is no younger than upper Blancan (Lovejoy, 1975); thus there has been only 15 ft of post-Blancan faulting. Folded Montoya Group beds on the northwest side of the slide are not brecciated proving that not all landslide masses are highly brecciated. "Flag Hill landslide" may be slightly older than Crazy Cat slide although its displacement by Western Boundary fault is not apparent. Flag Hill is slide breccia; lower Pleistocene alluvium (Lovejoy, 1972) covers the breccia on the west. Slide cascade folds which lie in Cretaceous beds are overturned with steeply east-dipping axial planes.

EASTERN BOUNDARY FAULT ZONE

The Eastern Boundary fault has the largest throw of any in the region, possibly 30,000 ft east of North Franklin Mountain and about 22,000 ft east of Ranger Peak (Lovejoy, 1975). Mattick (1967) interpreted the fault to dip 25° east, based on gravity and seismic data. However, Adams (1944) showed that North Franklin Mountain is the highest structural point in Texas. I suggest that gravity glides, landslides and boulder alluvium filled the adjacent edge of the sinking Hueco bolson block as Franklin Mountains rose thus producing a structure which could be geophysically interpreted as a 25° east-dipping fault.

Pediments which formed on the east side of the range later rose with respect to the Hueco bolson. The highest identifiable remnant (elev. 5,240 ft) is north of Fusselman Canyon above Transmountain Road, 1,000 ft above the piedmont slope and 1,200 ft above the old course of the Rio Grande 4 to 6 mi east. Similarly appearing remnants are on the east side of the Organ Mountains. The present topography indicates that granite eroded more rapidly than the carbonate and siliceous rocks of the range, hence granite pediments on the east side may have been easily formed but rapidly dissected following their uplift and tilting. After diversion of the Rio Grande from the east side of the range, a bajada buried the pediments. Some of the youngest pediment surfaces thus buried have recently been uplifted (tilted) and exhumed and are being eroded. Obviously, the present rate of dissection is not that which prevailed when the Rio Grande flowed east of the range.

The pediments or bajadas, or both, and the curved gravity glide fault surfaces may intersect to form "sinuous" fault traces (piedmont scarplets) which Harbour noted as "the most striking feature of the Franklin Mountains structure...." Possibly some of these "striking" curvilinear scarplets are the toes of gravity glide blocks, which in turn mask the actual Eastern Boundary fault.

WESTERN BOUNDARY FAULT ZONE

Richardson (1909, Geologic Map) traced what I call the Western Boundary fault zone (Lovejoy, 1973) north to Vinton Canyon where he mapped a slice of "Bliss Sandstone" in it; he considered the fault to "border the entire range" (quote 4). Harbour (1972, Plate 1), however, correctly mapped the sandstone as "upper member" of the Magdalena Formation. Consequently, because there is no *apparent* stratigraphic separation across the "fault zone" north of Avispa Canyon Harbour did not extend it there. Rather, he considered the Western Boundary fault south of Avispa Canyon to be a western limb of his anticlinally folded "Avispa thrust fault" (which Harbour interpreted to dip west at the surface but east at a depth greater than 400 ft), the recurved northeastern limb of which extended southeast from Avispa Canyon through the center of the range. Harbour (1972, p. 73) noted that if the "inner block" of his "Avispa thrust fault" moved upward "... it is difficult to imagine the mechanics of the movement." Kadhi (1970) also believed that the boundary fault does not extend north of Avispa Canyon and that the El Paso Group and Bliss sandstone (Harbour's "inner block") formed a diapir-like fold. Harbour (1972, p. 73) further noted about his "Avispa thrust": "Conceivably the outer block moved northward or southward and the fault limbs are tear faults, but the movement would have to have been about 10 mi to bring Cretaceous rocks against the El Paso Limestone."

Interpretation of structure in the northern Franklin Mountains, which I propose, is as follows (Lovejoy, 1972, 1973 and 1975): The Western Boundary fault bounds the entire range. North of Avispa Canyon two masses of Hueco Limestone of Anthony landslide and north end of Tom Mays landslide may lie on the highest Cretaceous beds (Boquillas Formation). The zero *apparent* stratigraphic separation north of Avispa Canyon resulted from landsliding; *actual* stratigraphic separation is 6,300 ft. South of Avispa Canyon Western Boundary fault has juxtaposed Hueco Limestone of Tom Mays and Smuggler land slides with El Paso limestone, giving *apparent* stratigraphic separation of 5,500 to 6,000 ft, but because Hueco Limestone may overlie Cretaceous beds, *actual* stratigraphic separation is 8,700 ft. Cretaceous beds at latitude 30°52'30" N. of Western Boundary fault zone project beneath the Hueco Limestone in Smuggler landslide 2,000 ft west of them, giving an *actual* stratigraphic separation there of 8,700 ft. The inferred southwest-trending fault shown on Harbour's map is the edge of Smuggler landslide. "The Transmission landslide" is younger than "Smuggler landslide." "Thrust faults" mapped by Harbour above his "Avispa thrust fault" formed early in range uplifting and are now rotated to a low angle as antithetic normal faults on which slip was southeast parallel with, and southwest of, a major southeast-trending fault which I here term "Tom Mays fault" (Fig. 3). Tom Mays fault, not recognized by Harbour as an important fault, is a 70° northeast-dipping fault with 2,400 ft of stratigraphic separation down on the northeast, and is also the southwest border of Anthony's Nose gravity glide. The southeastern continuation of Tom Mays fault is buried by alluvium and "Tin Mine landslide," and its northwestern end continues under "Hogback landslide." Tom Mays fault and Western Boundary fault zone join northwest of Hogback landslide; north of this junction, stratigraphic separation on the Western Boundary fault has been reduced to 6,300 ft by the 2,400 ft stratigraphic separation on Tom Mays fau lt.

South of 35°52'30" N. latitude, Western Boundary fault zone extends to the end of the range (Lovejoy, 1973, 1975). At the Thunderbird it is 100 ft wide at 4,850 ft elevation and consists of eastern and western faults and an interfault zone. The eastern fault dips 45° *east,* is *reverse,* and has a *minimum* stratigraphic separation of 4,400 to 5,600 ft or 50 to 65 percent of the total; the western fault dips 70 to 90° *west,* is *normal,* and has a *maximum stratigraphic* separation of 3,040 to 4,240 ft or 35 to 50 percent of the total.

At the south end of the range at 4,100 ft elevation, the zone is 1,300 ft wide; the eastern fault has a *maximum* stratigraphic separation of 6,000 ft or 80 percent of the total; the western fault has a *minimum* stratigraphic separation of 1,500 ft or 20 percent of the total; the dip of the eastern fault is not known, but indirect evidence and structural analysis indicate that it is 45 to 60° east, and reverse; the dip of the western fault is not known.

The interfault zone contains slices of resistant beds of formations between those bounding the zone. Dips of the slices are steep west to vertical to steeply overturned east. The interfault zone resulted from slipping of west-dipping beds into the fault zone during faulting and uplift. Perhaps the Western Boundary fault zone is not exposed north of Avispa Canyon because gravity gliding of the infra-Hueco section did not occur, and no erosionally resistant slices formed a wide interfault zone; alluvium covers the trace of the resulting narrow fault zone north of Avispa Canyon. I suggest that this fault bounds the Organ and San Andres Ranges. I also suggest that the normal and reverse faults either diverge with depth or toward the south or both, and that the normal fault is not younger than the reverse fault (cf. Lovejoy, 1973).

OBLIQUE FAULTS

Four important oblique faults in the Franklin Mountains block, from south to north, are the "Comanche Peak," McKelligon Canyon, Fusselman Canyon, and "Tom Mays" faults

(Fig. 2; Table 3). In addition to these, there is possibly at the south end of the range a southwest-trending fault zone, now manifested by tilted Blancan Fort Hancock strata and a linear on aerial photographs, which I call the "Gold Hill fault."

The Comanche Peak fault ends in the Western Boundary fault zone and formed the southern boundary of the slide source area of the Crazy Cat landslide, which the fault predates. The McKelligon Canyon fault zone consists of two parallel faults; the north fault merges with the Western Boundary fault zone and right laterally displaced a basaltic dike about 200 ft (see section on magmatism). The south fault displaced the basalt about 800 ft right laterally and seems to at least partly extend into the wide breccia zone of the Western Boundary fault zone, which, in turn, was intruded by the basalt dike (Lovejoy and Hoffer, 1971). The basalt dike intrudes the Western Boundary fault zone breccia but is itself not brecciated; thus the dike is younger than the breccia. McKelligon Canyon fault is younger than the dike and is at least partly younger than the breccia and apparently older than the breccia. McKelligon Canyon fault does not seem to offset the Western Boundary fault zone, but the extremely thick breccia of that fault zone adjacent to the junction of these two faults implies that both may have been active at the same time.

In Fusselman Canyon, the Fusselman Canyon fault appears to be a major left-lateral strike-slip fault, down on the south; however, where the southwestern part of the fault cuts the Franklin Mountain block just east of the Western Boundary fault zone, movement was down on the north. I suggest that early, small displacement along Fusselman Canyon and McKelligon Canyon faults outlined a block, the Taylor block (Richardson, 1909, p. 8), which subsequently slid to the east, thereby immensely increasing displacements on those two minor faults east of their north-trending joining fault, which is just west of the peak at South Franklin Mountain, and, indeed, reversing the displacement on the originally much smaller Fusselman Canyon fault. This north-trending fault connected these two faults, thus accounting for the "U-shaped" Fusselman Canyon fault trace noted by Harbour above.

The Tom Mays fault was partly mapped by Harbour (1972, Plate 1), but he showed movement down on the south, contrary to movement required to place Precambrian rock on the south opposite Fusselman Formation on the north (Fig. 3). Tom Mays fault seems to join the Western Boundary fault and possibly may have either slightly offset that zone, or at least interacted with it to produce a slight jog in the trend of the zone.

Three northern oblique fault zones are arranged in a pattern which implies greatest uplift near the south end of the range, which is consistent with a decreasing stratigraphic separation on the Western Boundary fault northward from the end of the range.

MESILLA VALLEY FAULT

Although only 6 to 15 ft displacement occurred on Western Boundary fault zone since Blancan time (Lovejoy, 1972, 1975), Blancan throw of 265 ft, and post-Irvingtonian throw of 100 ft up on the east, occurred on what I here call "Mesilla Valley fault," probably located beneath the Rio Grande flood plain (Fig. 1). It extends from El Paso to Las Cruces where it seems to join a similar fault between the Dona Ana and Robledo Mountains (see papers by Seager and Swanberg, this guidebook). A gravity gradient occurs parallel with Mesilla Valley (F. Barrie, pers. comm.). The N20W-trending Mesilla Valley fault (Rio Grande rift?) and the north-trending, Basin and Range Western Boundary fault may intersect near downtown El Paso. Pleistocene range uplift on the Basin and Range Eastern Boundary fault zone and Mesilla Valley fault may be related; if so, the horst between them contains both the elevated Franklin Mountains block and the (relatively) depressed Anthony block of Richardson (1909) between the Western Boundary fault and Mesilla Valley fault (Fig. 1).

THE COURSE OF THE ANCIENT RIO GRANDE IN EARLY PLEISTOCENE TIME

The Rio Grande flowed east of Franklin Mountains in early Pleistocene time; it later changed to its present position (Strain, 1966). "Santa Fe Group" fluviatile sands 1,500 ft thick in Hueco bolson are the well-explored El Paso municipal aquifer (Cliett, 1969). I think this sand is a facies of the Fort Hancock Formation, a bolson "playa" deposit at its type locality 50 mi southeast of El Paso, and that the course next to the range was tectonically controlled by decreasingly intense westward tilting of the Hueco bolson in Blancan and Irvingtonian time. The Fort Hancock Formation is overlain by the Camp Rice Formation, which I consider to be the same as the "mixed rounded gravels" laid down by the Rio Grande on both sides of the Franklin Mountains.

I think that the Rio Grande did not entrench as an antece-

Fault	*Strike/Dip*	*Movement*	*Stratigraphic Separation*	*Slickensides Bearing/Plunge*
Gold Hill	NE app/?	SE-D; ?	?	?
Comanche Peak	N30E/75NW	NW-U; reverse	200± ft	N30E/45NE
McKelligon Canyon				
north	N50W/75NE	NE-D; normal	900± ft	dip slip
south	N50W/70NE	NE-D; normal	500± ft	dip slip
Fusselman Canyon				
southwest end	N40E/75NW	NW-D; normal	200± ft	?
northeast part	N65E?/?	SE-D and L. lat.	2250± ft normal?	?
Tom Mays	N40W/70NE	NE-D and L. lat.? normal	2400 ft	S40E/20 (may be due to Avispa landsliding)

Table 3. Structural data for major oblique faults in the Franklin Mountains.

dent stream in Fillmore Pass in the Franklin-Organ Mountain uplift after 400 ft of uplift on Eastern Boundary fault, following deposition of the Camp Rice Formation (mixed rounded gravels), because the river was diverted by the Mesilla Valley fault. If one takes into account all of the streams called "antecedent" in the Cordillera, this example of a deflection of a major river by a minor fault is of geomorphic significance.

MAGMATISM

From North Franklin Mountain south for 7 mi is a highly fractured and generally partly kaolinized Tertiary felsite sill with a reported age of 28 m.y. (Kottlowski and others, 1973); it is found in the lower El Paso limestone or the Bliss Sandstone or, at the Thunderbird, near the top of the Precambrian rhyolite. However, it megascopically resembles Loma Blanca felsite at Cristo Rey, which is coeval with the Cristo Rey Andesite (Lovejoy, in press). Cristo Rey and Campus Andesite is probably the same age. Campus Andesite is 47.1 ± 2.3 m.y. (Hoffer, 1970). Thus, Loma Blanca felsite is probably 45 to 49 m.y. old. Flow lineations in the top of the Tertiary felsite sill from the south end of the range to South Franklin Mountain generally trend west and toward Cristo Rey. Also, the thickest part of the felsite sill is near Ranger Peak, suggesting that the felsite magma may have come from the Cristo Rey intrusive center. Thus, the Tertiary felsite sill may be 45 to 49 m.y. old. Its apparent younger age might be due to weathering of the felsite. Sill emplacement implies a vertical stress lower than horizontal during emplacement, signifying possible range uplift and erosion as well as horizontal compression at that time.

Andesite plutons at Cristo Rey (Lovejoy, in press), UTEP Campus (Hoffer, 1970), Three Sisters and several other unnamed localities (Fig. 1), including some (not shown) only a few hundred feet west of the Western Boundary fault zone (Lovejoy, 1972), are probably 45 to 49 m.y. old. However, no andesite is found in the Franklin Mountains block. On the north flank of Cristo Rey, N10-20W-trending, west-dipping thrust faults in Cretaceous beds were deformed by the pluton, indicating that east-west compression had occurred there prior to 45 to 49 m.y. ago (Lovejoy, in press).

An east-trending, vertical basalt dike which extends into the Western Boundary fault breccia of the Cutter and Fusselman Formations and has been right-laterally offset about 800 ft by the N50W-trending, 70° north-dipping McKelligon Canyon fault (Lovejoy and Hoffer, 1971), was intruded after most of the displacement on the Western Boundary fault zone had occurred. About 150 ft of left-lateral strike-slip in that fault zone is indicated by offset of the dike. No other similar dikes cut Paleozoic strata in the range, but similar ones occur in the Florida Mountains. Its geometry suggests north-south tension and vertical or east-west compression. Its age is unknown. No intersection of the basalt dike and the felsite sill has been found.

A TECTONIC HYPOTHESIS

Any concept for the genesis of the Franklin Mountains must explain the following: 1) range uplift to the highest structural point in the region; 2) range tilting 35° westward with locally vertical dips along its west side; 3) gentle west-tilting of Hueco Limestone in Hueco bolson and its depression 5,000 ft below sea level with the resulting east-west asymmetry of Hueco bolson; 4) gentle west-tilting of Hueco Limestone and Cretaceous beds of Anthony block and their elevation 4,000 ft above sea level; 5) the 100 mile-long linearity of the Franklin-Organ-San Andres Mountains; 6) an essentially constant width of the range for 100 miles; 7) elevation of the east side of the range 20,000 to 30,000 ft above the adjacent Hueco bolson, but elevation of its west side only 8,000 to 10,000 ft above the Anthony block; 8) a normal fault along the west side of the range on which 25 percent of total stratigraphic separation occurred; 9) a reverse fault along the west side of the range on which 75 percent of total stratigraphic separation occurred; 10) close spatial association between the traces of the normal and reverse faults of the Western Boundary fault zone for a distance of at least 8 mi; 11) a geophysically determined 25° east-dipping subsurface apparent eastern range front; 12) a difference in elevation of the Hueco Limestone of about 8,000 ft across the Franklin Range block; and 13) apparent non-deposition or erosion of Cretaceous marine beds in the Hueco bolson.

In addition, in my opinion, the following interpretations require explanation: 14) a long-continuing course of the Rio Grande along the east side of the range certainly in Blancan and Irvingtonian time, if not longer; 15) formation of the minor normal fault before the major reverse fault along the Western Boundary fault; 16) divergence of the normal and reverse faults on the Western Boundary fault with depth or to the south or both; 17) major uplift occurring early in the Cenozoic with decreasing rate of uplift throughout the Cenozoic to the present; 18) major range tilting occurring late in range uplift; 19) extensive gravity gliding toward the east side of the range throughout range uplift; and 20) landsliding toward both sides of the range late in range uplift.

Figure 4 shows a plausible interpretation of structure which I believe conforms with the requirements listed above.

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Although some of my interpretations of the area mapped by the late Robert L. Harbour differ from his, they are primarily based on his map which I have carefully field checked. Despite the structural complexity and the ruggedness of terrain, he mapped the area accurately and precisely and contributed significantly to the knowledge of the Basin and Range. His map and report will long remain a primary source of geologic data.

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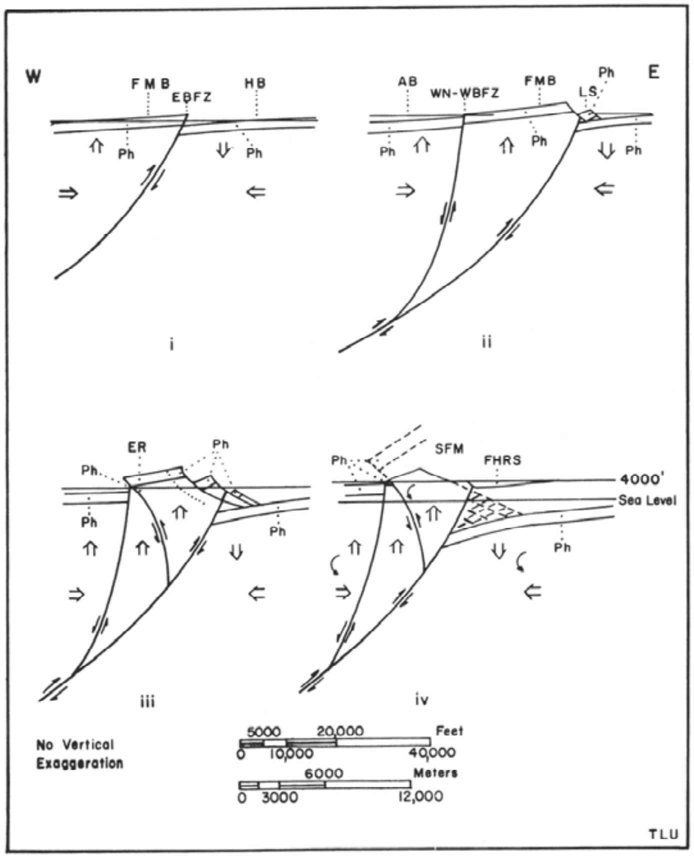

Figure 4. Interpretation of Structural Cross Section Through South Franklin Mountain

i) Prior to tectonism, unfaulted Hueco Limestone (Ph) was depressed to west where Cretaceous marine deposits covered it, and elevated to east where Cretaceous marine deposits were either not deposited or, thinly deposited, were eroded. In early Laramide time the concave-up west-dipping Eastern Boundary fault zone (EBFZ) of Franklin Mountains began to separate Hueco bolson block (HB) from Franklin Mountains block (FMB). Arrows show sense of movements. Horizontal line for reference only; no elevations implied in i, ii, or iii.

ii) With continued thrusting on EBFZ a central block was squeezed upward between EBFZ and the western, normal fault (WN) of the Western Boundary fault zone (WBFZ), separating Anthony block (AB) from Franklin Mountains block. Minor landslipping (LS) began along EBFZ scarp. Note increasing dip of Hueco Limestone. Bolson sediments filled Hueco bolson; landslips and fanglomerate accumulated at foot of EBFZ.

iii) Continuing compression raised and further tilted Franklin block. Eastern reverse fault (ER) of WBFZ formed as Franklin block was narrowed and plastically squeezed upward. Landslipping along EBFZ accelerated.

iv) Interpretation of present structure. Landsliding of Hueco Limestone to west occurred between iii and iv. Dashed Ph shows Hueco Limestone had landsliding not occurred. Fort Hancock river sands (FHRS) (El Paso aquifer) formed because of movement on EBFZ but geometric relationship between them is not known. Landslip and fanglomerate deposits form a buried surface which slopes 25° east. Over half of total range tilting occurred in this last phase of uplift. South Franklin Mountain (SFM). Curved arrows show sense of block rotation.

No attempt to fix geologic date equivalents has been made in this interpretation. Research on this phase of analysis is under way.

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