THE UNIVERSITY OF TEXAS AT AUSTIN
BUREAU OF ECONOMIC GEOLOGY

TO ACCOMPANY MAP—GEOLOGIC
QUADRANGLE MAP NO. 40

GRAVITY, MAGNETIC, AND GENERALIZED GEOLOGIC MAP OF THE VAN HORN—SIERRA BLANCA REGION, TRANS-PECOS TEXAS

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[1] Atlantic Richfield Company, Dallas, Texas.

INTRODUCTION

PURPOSE

The Van Horn—Sierra Blanca region lies athwart part of the boundary between two contrasting geologic provinces. The contrast between these two provinces, splendidly displayed by Holocene landforms in the present map area, has a history that dates back to at least Late Precambrian time. This remarkable contrast led R. T. Hill (1902) to suggest the possibility of a transcontinental fracture zone passing near Van Horn and along the boundary of the provinces. Later workers called Hill's fracture zone the Texas lineament (Ransome, 1915) or the Texas direction of wrench faulting (Moody and Hill, 1956). Where it is exposed in the region, the Rim Rock fault (fig. 1) seems to form part of the boundary between the provinces. Numerous workers have suggested a long-enduring history of

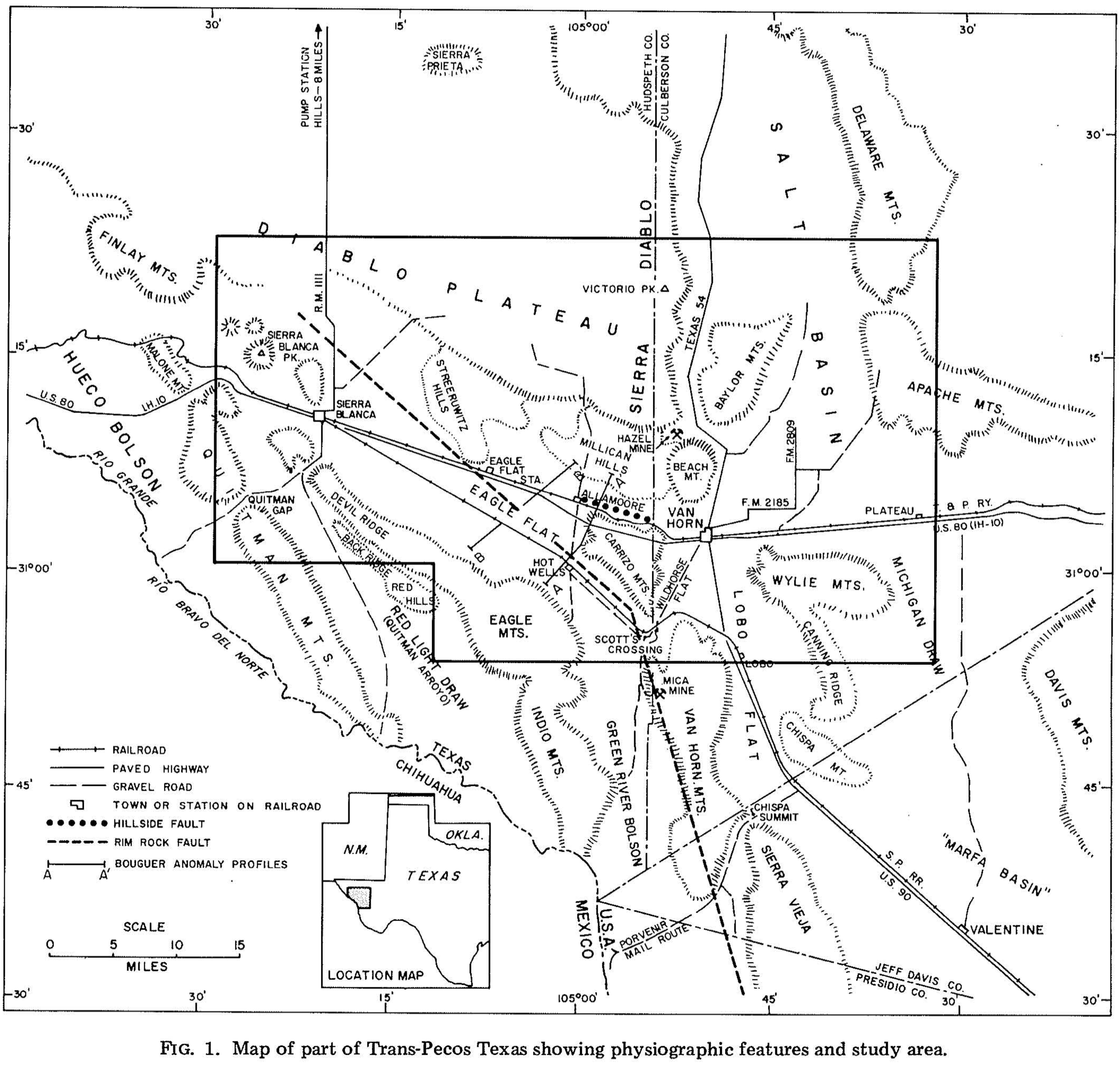

FIG. 1. Map of part of Trans-Pecos Texas showing physiographic features and study area.

strike-slip movement along the Hillside fault (fig. 1).

The Van Horn—Sierra Blanca region has been mapped in detail geologically, but because nearly half of the total area of the region is covered by late Cenozoic basin-fill and because subsurface control is sparse, it has not been possible to understand the region in detail in three dimensions. This report summarizes the methods and results of a ground magnetometer and gravimeter survey undertaken in an attempt to obtain a clearer understanding of the tectonic history of the region and of the structural significance of the Hillside and Rim Rock faults.

LOCATION

The Van Horn—Sierra Blanca region is in southeastern Hudspeth and southwestern Culberson counties, Trans-Pecos Texas (fig. 1). The towns of Van Horn, Allamoore, and Sierra Blanca are in the mapped area. Access to the region is by Federal and State highways, Farm-to-Market highways, and graded county roads (fig. 1). The principal businesses of the region are cattle ranching and talc mining, and many roads and trails in the region are privately maintained to serve these businesses and are on private land. Many of the more interesting geological features of the region are accessible only by private road. The property rights of the private landowners must be observed, and permission to enter should be obtained from the owner.

PREVIOUS INVESTIGATIONS

The most comprehensive geological work in the region is that of King and Flawn (1953), King (1965), and Albritton and Smith (1965). Significant contributions to the stratigraphic and tectonic knowledge of the region have also been made by Hay-Roe (1957), DeFord (1958a, 1969), Twiss (1959b), Underwood (1963), Haenggi (1966), Barnes (1968), and Haenggi and Gries (1970). Additional sources are cited in the text. King (1965) gave an extensive bibliography beginning with the Perry Boundary Survey Report of 1857. R. T. Hill (1902, 1928), on the basis of his field mapping, suggested that a transcontinental fracture system might traverse northern Chihuahua. He also added, seemingly as an afterthought, that a similar fracture system might traverse Trans-Pecos Texas near Van Horn. This idea was given a name, the Texas lineament, by Ransome (1915) and a type locality, Eagle Flat, by Albritton and Smith (1957). Amplification and clarification of the idea were given by Baker (1927, 1935) and Muehlberger (1965). Moody and Hill (1956) incorporated the idea into their system of wrench fault tectonics and called it the Texas direction of world-wide wrench faulting.

ACKNOWLEDGMENTS

The map and this report are based on a doctoral dissertation (Wiley, 1970). Professor William R. Muehlberger supervised the dissertation and contributed time, ideas, and enthusiasm. Professors Ronald K. DeFord and Peter T. Flawn, The University of Texas at Austin, contributed freely of their wide knowledge of the region. Professor James E. Case, The University of Missouri at Columbia, assisted in the structural interpretation of the geophysical data. The writer expresses appreciation for their aid and encouragement.

This project would have been impossible without the cooperation of the ranchers and landowners in the region. Almost without exception, they allowed free access to their land, and their hospitality and help are hereby acknowledged.

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REGIONAL GEOLOGIC SETTING

TECTONIC FRAMEWORK

The Van Horn—Sierra Blanca region straddles the boundary between two geologic provinces that have had markedly dissimilar geologic histories. As tectonic elements, these provinces are the Diablo platform on the north and northeast and the Chihuahua trough—Chihuahua tectonic belt on the south (fig. 2). As topographic entities, the blocky Diablo Plateau and Sierra Diablo are on the north,

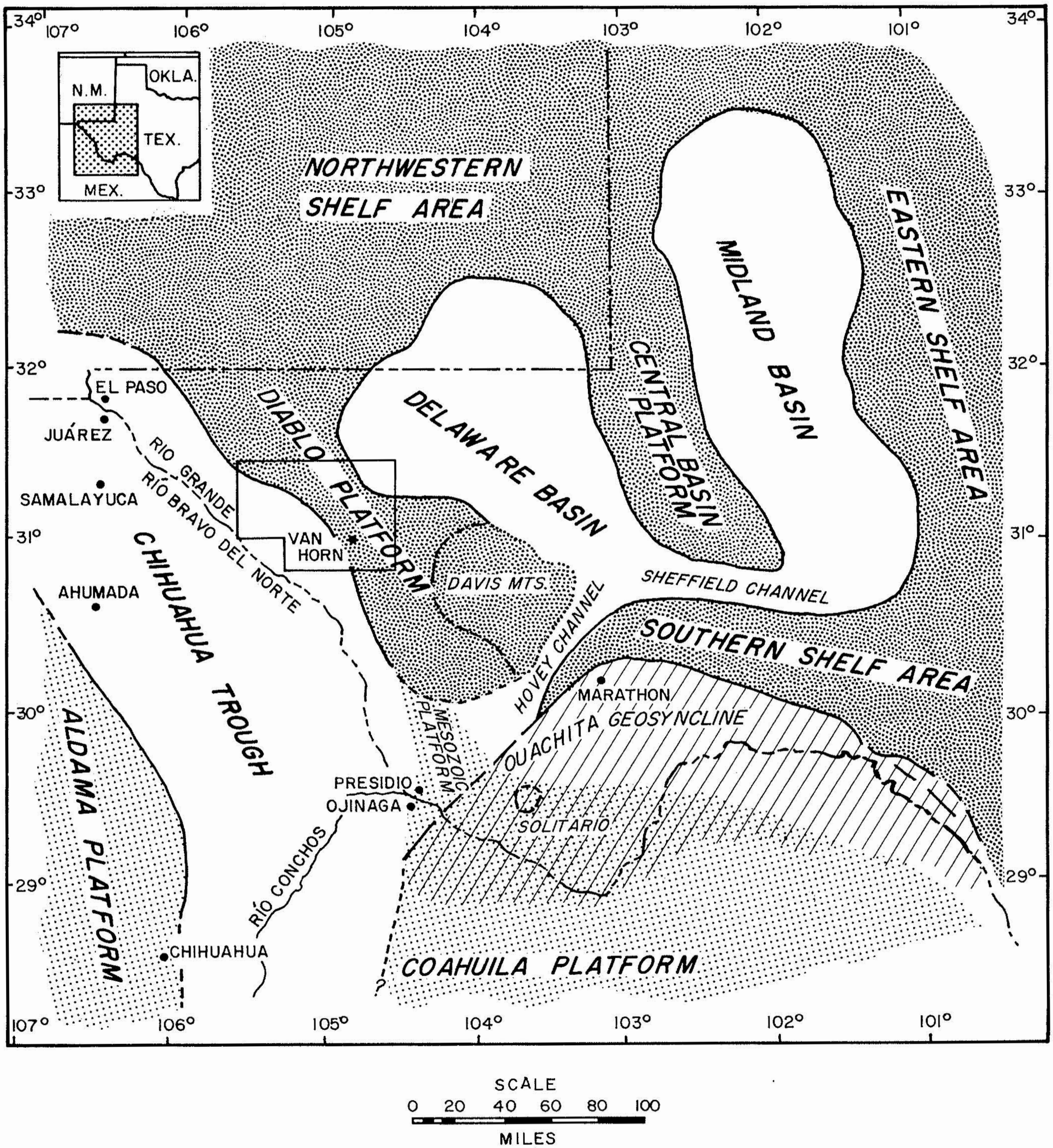

FIG. 2. Tectonic framework of West Texas and northeastern Mexico. (Modified from DeFord, 1969; Haenggi, 1966; King, 1965; and Albritton and Smith, 1965.)

whereas linear ranges, e.g., Indio, Eagle, and Quitman Mountains, are on the south. The boundary between the provinces is beneath Eagle Flat, an elongate structural and topographic depression that trends west-northwest from south of Van Horn to north of Sierra Blanca (fig. 1).

At least 2,500 feet of pre-Permian Paleozoic rock was deposited in the Van Horn—Sierra Blanca region near the site of the Diablo platform of Permian time. About 7,000 feet of Permian rock was deposited on the platform, but because of regressive offlap, probably much less than half this amount was ever deposited at any one place. Possibly as much as 2,500 feet of Mesozoic rock, mostly Lower Cretaceous, was deposited on the platform. Of the total of perhaps 15,000 feet of Paleozoic and Mesozoic rock deposited on the platform, much has been eroded and less than 8,000 feet remains. More than 18,000 feet of Cretaceous rock plus an unknown thickness of older Mesozoic and Paleozoic rock was deposited in the Chihuahua trough or ancestral depositional basins. Throughout the region, these rocks are underlain by Precambrian rocks that include about 35,000 feet of metasedimentary and meta-igneous rock. Several thousand feet of Cenozoic volcanic and sedimentary rocks overlie Permian and Cretaceous rock in the Wylie, Van Horn, and Eagle Mountains. Late Cenozoic bolson fill is more than 1,500 feet thick in Eagle Flat and in Salt Basin.

All of these rocks have been mapped and described in detail by earlier workers. Much of this mapping is summarized on the Van Horn—El Paso Sheet of the Texas Geologic Atlas (Barnes, 1968). The generalized geologic base for the present geophysical map is mostly from that Atlas sheet but is also from the maps by Hay-Roe (1957), Twiss (1959b), and Underwood (1963).

TECTONIC HISTORY

The basement of the Diablo platform (fig. 2) was formed by Late Precambrian orogeny in the Van Horn mobile belt and was intermittently active during the Paleozoic Era (Flawn, *in* Flawn et al., 1961, pp. 57, 145). Strong uplift of the platform occurred in Pennsylvanian time, probably at the same time as the Ouachita Orogeny in West Texas. Direct evidence is lacking, but probably the Coahuila platform evolved, at least in part, at the same time and to the south of the Diablo platform (fig. 2).

Ordovician to Mississippian rocks deposited in much of the area of the present Sierra Diablo and Hueco Mountains and eastward in the Permian Basin were faulted and gently warped during Pennsylvanian uplift of the Diablo platform. By early Wolfcamp (Permian) time, the Delaware basin was a strong negative area northeast of the Diablo platform; probably the Chihuahua trough was also evolving at the same time to the southwest.

The Delaware basin filled during Permian time and received less than 2,000 feet of sediments during the Mesozoic Era. The Chihuahua trough, however, was strongly negative by Late Jurassic time and received more than 20,000 feet of Jurassic and Cretaceous sediment. Laramide folding and thrusting rammed this thick succession of rock against the stable Diablo platform in the Van Horn—Sierra Blanca region. Tertiary volcanism, mid-Tertiary block faulting, and late Tertiary to Holocene normal faulting closed the tectonic history of the region.

The present topography of the Van Horn—Sierra Blanca region most strongly reflects the mid-Tertiary tectonic history. However, the northwest trend of the Quitman and Malone Mountains and Devil Ridge (fig. 1) reflects the structural and, in part, the stratigraphic strike of the Mesozoic Chihuahua trough—Chihuahua tectonic belt. The east and northeast border of the Chihuahua trough was controlled by the Diablo platform which was formed along the Precambrian boundary between stable crust on the north and the unstable Van Horn mobile belt on the south. The Streeruwitz thrust fault (fig. 3) marked this boundary in the Precambrian. Eagle Flat also follows this boundary and not only is the "type locality" of the Texas lineament (Albritton and Smith, 1957, 1965) but also includes the Hillside fault, cited by Moody and Hill (1956) as a part of the Texas direction of wrench faults.

GEOLOGIC BASE MAP

Geologic data on the base map are generalized into six map units. Rocks of Late Precambrian age are shown as two map units. The older Precambrian map unit (pЄl) comprises the Carrizo Mountain Group and its associated 1,250 m.y. intrusive rocks. The younger Precambrian map unit (pЄu) consists of the Allamoore, Hazel, and Van Horn Formations, all of which are younger than the Carrizo Mountain Group. All Paleozoic rocks are shown by a single map symbol (Pal); they consist of mostly Ordovician and Silurian rocks in the Baylor and Beach Mountains and mostly lower Permian (Wolfcamp and Leonard Series) rocks elsewhere. Mesozoic rocks (K) comprise Lower Cretaceous formations and a minor amount of Upper Cretaceous rock in the northeast Eagle and central Van Horn Mountains. Cenozoic rocks include Tertiary intrusive and extrusive rocks (T) and Quaternary alluvium and fill (Q). Tertiary and Quaternary gravel and fill near the mountain fronts are shown as Quaternary (Q).

Structure shown on the map is generalized from the source geologic maps; none of the structure shown is interpreted from the geophysical data. Faults shown include the Streeruwitz thrust fault (fig. 3), Laramide thrust and tear faults, the Hillside fault (fig. 3), Cenozoic basin-range faults, and most other faults having a known throw in excess of 500 feet. Enough of the remaining faults having smaller displacement are shown to suggest the fault pattern. Fold axes are not shown.

GENERALIZED STRATIGRAPHY

Older Precambrian Rocks (p€l)

The metasedimentary and meta-igneous rocks of the Carrizo Mountain Group are the oldest rocks known in the Van Horn—Sierra Blanca region. They crop out in the Carrizo Mountains, in small parts of the Eagle, Van Horn, and Wylie Mountains, probably underlie most of Eagle Flat, and have been encountered in wells east and south of Van Horn (Hay-Roe, 1957; Denison et al., 1969). The Carrizo Mountain Group consists of more than 19,000 feet of metamorphosed quartzite and arkose as well as mica-schist, slate, talcose phyllite, and limestone. About 2,100 feet of rhyolite intruded the group as sill-like bodies and accompanied tilting, folding, and regional metamorphism about 1,250 m.y.b.p. (Denison and Hetherington, 1969; King and Flawn, 1953).

The Carrizo Mountain Group was transported over the younger Precambrian Allamoore and Hazel Formations along the Streeruwitz thrust fault. It was during this orogeny, dated at 950 to 1,000 m.y.b.p. by Denison and Hetherington (1969), that about 5,600 feet of diorite intruded the Carrizo Mountain Group as sills. Near the close of this orogeny, retrograde metamorphism cataclastically fractured the metarhyolite and converted the diorite to amphibolite (King and Flawn, 1953, p. 63).

Younger Precambrian Rocks (p€u)

The younger Precambrian map unit (p€u) includes the severely deformed Allamoore and Hazel Formations and the little disturbed Van Horn Sandstone.

Allamoore and Hazel Formations.—The Allamoore and Hazel Formations crop out west of Van Horn in a roughly 8-mile-wide belt between the Texas and Pacific Railway on the south and the south-facing escarpment of Sierra Diablo on the north. The Allamoore consists of about 2,500 feet of limestone and dolomite, but minor thicknesses of conglomerate, talcose phyllite, and volcanic flow and pyroclastic rock are included. The Hazel consists of more than 5,000 feet of interbedded conglomerate and sandstone (King, 1965, pp. 23-27). Both formations are complexly folded and faulted and seem to be mixed tectonically in the southern part of their outcrop belt. Scattered exposures of the Streeruwitz thrust fault zone along the southern part of the Allamoore outcrop show that the Carrizo Mountain Group was thrust northward over the Allamoore and, although not demonstrable, presumably over the Hazel as well (King and Flawn, 1953). The deformation and mixing of the Allamoore and Hazel Formations probably accompanied the movement of the thrust fault. The Hazel is less deformed in the northern half of the outcrop belt, thus suggesting that the present outcrop of the Streeruwitz thrust fault may be close to its original maximum northward extent.

The Allamoore and Hazel Formations have not been dated isotopically but, because of their involvement in 1,000 m.y. thrust faulting, must be older than 1,000 m.y. Non-fault contacts between the Carrizo Mountain Group and the Allamoore Formation are not known, but King (1965, p. 22) concluded on what he termed "tenuous evidence" that the Allamoore and Hazel were younger than the Carrizo Mountain Group. No contacts between the Hazel and the Carrizo Mountain Group are known; in all known exposures of the Streeruwitz thrust fault, the Carrizo Mountain Group overlies the Allamoore Formation.

Van Horn Sandstone.—The Van Horn Sandstone is mapped with the Allamoore and Hazel Formations. It consists of 1,000 to 2,000 feet of crossbedded conglomerate and coarse sandstone. It unconformably overlies all older rocks exposed in the Van Horn—Sierra Blanca region and is tilted and broadly arched but is not metamorphosed. King (1965, pp. 29-30) considered the age of the unfossiliferous Van Horn Sandstone to be Precambrian or Precambrian(?), but other workers have suggested that it is younger, possibly mid- or Late Cambrian (McGowen and Groat, 1971, p. 7).

PALEOZOIC ROCKS (Pal)

Rocks ranging in age from Ordovician through Permian are combined on the map as Paleozoic (undifferentiated). The lower Permian (Wolfcamp) Hueco Limestone is the lowest Paleozoic rock exposed or present in most of the mapped area, but 2,000 to 2,600 feet of mostly carbonate rocks of Ordovician through Pennsylvanian age crop out in the Baylor and Beach Mountains and in Sierra Diablo. They are probably present beneath most of Salt Basin and are encountered in wells farther east.

Permian rocks of the Wolfcamp and Leonard Series crop out in the Wylie and Baylor Mountains and in Sierra Diablo. Carbonate and clastic rocks of the Guadalupe Series (Permian) crop out in the Apache and Delaware Mountains along the east border of the mapped area (table 1). About

TABLE 1. *Permian rock units, Van Horn—Sierra Blanca area.* (From King, 1965; Albritton and Smith, 1965; Barnes, 1968; and Wood, 1968.)

SERIES	FORMATION	THICKNESS (*FEET*)	
MESOZOIC AND CENOZOIC ROCK			
MAJOR UNCONFORMITY			
GUADALUPE	Capitan	900 ±	Reef and reef talus limestone
	Seven Rivers Formation	160	Limestone and dolomite; grades northward into Capitan
	Munn Formation	450	Dolomite and limestone in Apache Mountains
	Sandstone tongue of Cherry Canyon Formation	150-190	Sandstone in western Delaware basin grading eastward to limestone, dolomite, sandstone in Apache Mountains
	Brushy Canyon Formation	1000+	Sandstone and shale of Delaware basin
UNCONFORMITY			
LEONARD	Briggs Formation and unnamed	630-1800	Briggs Formation in Malone Mountains=gypsum, limestone, dolomite. Unnamed carbonate equivalent in Finlay Mountains (to 1800 ft.). Both partly equivalent (?) to Cutoff Shale, Victorio Peak Limestone, and Bone Spring Limestone
			UNCONFORMITY
	Cutoff Shale	275	Shale, siltstone, limestone of Diablo platform--Delaware basin margin; thins eastward and southward
			GRADATIONAL
	Victorio Peak Limestone	900-1500	Limestone and dolomite of Diablo platform--Delaware basin margin; replaced by Bone Spring Limestone in basin
			GRADATIONAL
	? Bone Spring Limestone	1050 (Maximum)	Chiefly black limestone of Delaware basin with reefs on Victorio and Blabb flexures; thins north and south of Victorio flexure
UNCONFORMITY			
WOLF-CAMP	Hueco Limestone: "Main Body"	0-1400	Limestone of platform and dolomite of Diablo platform--Delaware basin margin
			GRADATIONAL
	Hueco Limestone: Powwow Mem.	0-250	Conglomerate, arkose, shale, limestone
MAJOR UNCONFORMITY			
LOWER PALEOZOIC AND PRECAMBRIAN ROCKS			

10 miles west of Sierra Blanca, west of the mapped area, folded carbonate and evaporite rocks of the Briggs Formation (Leonard Series) crop out in the Malone Mountains. These rocks may be present beneath Sierra Blanca but must pinch out eastward because Cretaceous rocks unconformably overlie the Hueco Limestone in the Streeruwitz Hills and in the Eagle Mountains between Sierra Blanca and Van Horn.

In sharp contrast to the Precambrian history, the early part of the Paleozoic Era in northern Trans-Pecos Texas was a time of quiet deposition and minor uplift, tilting, and faulting. Farther south, in the Marathon region, the Ouachita geosyncline began to form as early as Late Cambrian time. Deformation of the Marathon segment of the Ouachita geosyncline began in Late Mississippian time and ended during the Wolfcamp Epoch (Flawn, *in* Flawn et al., 1961, p. 58).

In northern Trans-Pecos Texas, tectonic adjustment that began in the Late Mississippian or Early Pennsylvanian Epochs was probably related to the Ouachita Orogeny in the Marathon region. The differential warping of these adjustments formed the Diablo and Central Basin platforms and the intervening Midland and Delaware basins. These adjustments may also have formed ancestral counterparts of the Late Mesozoic Coahuila platform and Chihuahua trough. Parts of the Diablo and Coahuila platforms and of the Chihuahua trough and Delaware basin are in the Van Horn—Sierra Blanca region (fig. 2).

North of the Baylor Mountains, the present west side of Salt Basin roughly coincides with the west side of the Delaware basin and the east and north sides of the Diablo platform. The southeast and south sides of the Diablo platform are bounded by the Marathon segment of the Ouachita geosyncline and the Paleozoic Hovey channel (fig. 1; and DeFord, 1958a, p. 56; 1969). Amsbury (1957, fig. 5), Atwill (1960, pp. 21-22), Haenggi (1966, fig. 8, p. 136), López-Ramos (1969), and Gries and Haenggi (1970) showed that the Chihuahua trough formed the west and southwest boundaries of the Diablo platform.

The Coahuila platform extends south into Mexico about 350 miles from the Ouachita front at Marathon (DeFord, 1958a, p. 56). Haenggi (1966, pp. 136-137) and López-Ramos (1969) suggested that an ancestral Coahuila platform was contemporaneous with the Paleozoic Diablo platform and that the Chihuahua trough had been a negative feature during much of the Paleozoic Era.

The overthickened succession of lower Permian rock in Hovey channel (Amsbury, 1957, p. 26) marks approximately the Paleozoic boundary between the Diablo and Coahuila platforms (fig. 2) but the nature of the boundary or join is not understood.

Several northwest-trending structural adjustments occurred in or near the Van Horn—Sierra Blanca region during the uplift of the Permian Diablo platform. From north to south, these include the Babb and Victorio flexures, several broad, open, east-trending anticlines and synclines, and the Hillside fault. The reefs of the Leonard Series are well developed along the Victorio and Babb flexures, thereby implying that the flexures were forming during the Leonard Epoch. It is not known what influence the flexures may have had on the later Capitan reef.

The Hillside fault is exposed along the Texas and Pacific Railway between Allamoore and Van Horn where it is the boundary between the Carrizo Mountain Group on the south and younger rocks on the north. The fault strikes about N. 70° W. and is nearly vertical. It is downthrown at least 1,000 feet but the displacement may be much more (King, 1965, p. 114). The most recent displacement on the Hillside fault was post-Cretaceous but King (1965, p. 105) showed that it had an earlier history. The Powwow conglomerate member of the lower Permian Hueco Limestone, in exposures up to about a mile north of the fault, contains a large proportion of angular metarhyolite fragments derived from the Carrizo Mountain Group south of the fault. The metarhyolite fragments decrease in number and size away from (north of) the fault, thus suggesting a high-standing pre-Hueco scarp as a local source of the coarse fragments. King (1965, p. 114) suggested that this was a fault scarp along a Late Pennsylvanian or Early Permian Hillside fault. Several authors have interpreted the Hillside fault as a major element of transcontinental wrench faulting. The grading of the angular metarhyolite fragments away from their seemingly nearby source shows, however, that wrench faulting could not have occurred along the Hillside fault after Pennsylvanian time.

The estimated density of Paleozoic rocks in the region ranges from about 2.4 to 2.7 gm/cm^3; the estimated average density is 2.63 gm/cm^3.

Mesozoic Rocks (K)

Only Cretaceous rocks represent the Mesozoic

TABLE 2. *Nomenclature of Mesozoic rocks, Van Horn—Sierra Blanca area.*

ERA	PERIOD	SERIES	FORMATION	THICKNESS (FEET)	
CENOZOIC VOLCANIC AND SEDIMENTARY ROCKS					
					UNCONFORMITY
MESOZOIC	CRETACEOUS	UPPER	Chispa Summit and Boquillas Formations	200-840 ±	Chispa Summit: shale, marl, flaggy limestone; Delaware basin and margin Boquillas: flaggy limestone; Diablo platform
			Buda Limestone	122-240	Limestone with basal conglomerate in Apache Mountains, limestone elsewhere
			Boracho Formation	180-428	Shale, sandstone, limestone in Apache and Wylie Mountains; equivalent to Benevides, Espy-Loma Plata, and Eagle Mountain Formations
			Eagle Mountain Sandstone	80-300 ±	Sandstone, shale, siltstone, sandy limestone; south of Diablo Plateau
		LOWER	Espy Limestone (=Loma Plata Limestone)	175-1094 ±	Limestone, marl, shale, and sandstone on Diablo platform, chiefly limestone to south; formerly widespread, now eroded from most of Diablo Plateau
			Benevides Formation (=Kiamichi Formation)	84-235	Sandstone with minor limestone, shale, and marl interbeds; chiefly south of Diablo Plateau
			Finlay Limestone	40-800	Chiefly limestone with minor sandstone and marl interbeds; present over most of region
			Cox Sandstone	400-1737	Sandstone in north grading to 50 % limestone and 50 % sandstone in south; present over entire region
			Yearwood Formation	160-225	Sandstone, shale; limestone; on Diablo platform only; not west of Van Horn Mountains
			Campagrande Formation	0-800	Limestone, marl, shale, sandstone, conglomerate; not south of U.S. Highway 80. Lowest Cretaceous on platform
			Bluff Formation	1000-1500(?)	Sandy limestone with sandstone and shale interbeds; not south of U.S. Highway 80 east of Van Horn Mountains
			Yucca Formation	0-5000	Interbedded limestone, shale, conglomerate grading south to sandstone, shale, and conglomerate; absent on Diablo platform
					CONFORMABLE?
			Torcer Formation	400 ±	Limestone, sandstone and shale with basal quartzite; Malone and northwestern Quitman Mountains
	JURASSIC	UPPER	Malone Formation	850-1000	Limestone, siltstone, sandstone, conglomerate, and minor gypsum; Malone Mountains
					CONTACT CONCEALED
			Unnamed evaporites	0-3000 ±(?)	Gypsum, halite, anhydrite, and minor dolomite Exposed in Chihuahua
					BASE NOT EXPOSED - UNCONFORMITY
PERMIAN AND OLDER ROCKS					

Era in the mapped area. Jurassic carbonate, clastic, and evaporite rocks crop out in the Malone Mountains 10 to 12 miles west of Sierra Blanca and possibly underlie Cretaceous rocks in the Quitman Mountains and Devil Ridge. The Lower Cretaceous formations from the Yucca up through the Espy (or Loma Plata) crop out south and west of the Southern Pacific Railroad except in the Van Horn Mountains. Lower Cretaceous rocks north of the Southern Pacific include Campagrande through Espy Formations (table 2). Upper Cretaceous rocks crop out in the Apache and Wylie Mountains and in parts of the Van Horn and eastern Eagle Mountains. Eagle Flat lies athwart the southeast- and south-trending margin between the Mesozoic Diablo platform on the north and the Chihuahua trough on the south (fig. 2). North and east of Eagle Flat, on the Diablo platform, Cretaceous carbonate, clastic, and argillaceous rocks are only about 2,000 feet thick and are thin platform or shelf facies equivalents of the Bluff through Espy (Loma Plata) Formations. South of Eagle Flat, these units thicken abruptly, and in the Eagle and Quitman Mountains more than 12,000 feet of Lower Cretaceous carbonate and clastic rocks are present.

The rocks in the Chihuahua trough were thrust north and northeastward and were extensively folded during the Laramide Orogeny in northern Mexico and Trans-Pecos Texas. In contrast, the thin succession of Mesozoic rocks on the Diablo platform was little disturbed until broken by mid-Tertiary high-angle faults.

The estimated average density of Cretaceous rocks in the mapped area is 2.51 gm/cm^3. The range of estimated density is between 2.32 and 2.63 gm/cm^3 with slightly higher values being estimated for the platform facies rocks than for the trough facies rocks. These estimates are based on estimated mineralogical content in measured stratigraphic sections reported by earlier workers and are subject to considerable error. The method of estimation and sources of data are in Wiley (1970, table 7).

Cenozoic Rocks (T, Q)

Tertiary volcanic and intrusive rocks are widespread south of Eagle Flat and southeast of Van Horn; some of the volcanic units can be traced from the Wylie and Van Horn Mountains east to the Davis Mountains and south through Sierra Vieja into Mexico. Wilson and others (1968) showed that the age of the extrusive rocks of Sierra Vieja ranges from late Eocene to late Oligocene or early(?) Miocene. Although the extrusive rocks of the region have not been correlated in detail from the Van Horn Mountains westward, field relations suggest that extrusive rocks in the Quitman Mountains are probably at least time-equivalent with the extrusive rock of the Sierra Vieja country (Albritton and Smith, 1965).

Rhyolite laccoliths of possible Oligocene age (Albritton and Smith, 1965) intruded Lower Cretaceous rock near Sierra Blanca; the largest of these forms Sierra Blanca Peak. Miocene(?) and younger rhyolite and quartz monzonite stocks intruded Tertiary volcanic and older rocks in the Eagle, Van Horn, and Wylie Mountains. A few scattered late(?) Tertiary basalt plugs crop out where they intruded thin platform Mesozoic and Paleozoic rocks north of Eagle Flat and west of Salt Basin (King, 1965, pl. 1).

Late Tertiary and Holocene sedimentary rocks are present in much of the region. For the most part, these are poorly consolidated, poorly sorted alluvial fan and bolson-fill clastic deposits, but some of the older basin-fill is better cemented and resistant.

The Eocene to Miocene(?) volcanism was followed by strong uplift and block faulting in mid-Tertiary time (DeFord and Bridges, 1959; Wilson, 1965; Dasch et al., 1969). During this episode of faulting, the Rim Rock, Neal, and Mayfield faults (bounding the Van Horn Mountains) were displaced about 4,000 feet (Twiss, 1959b), and other major faults in the region were displaced lesser amounts. Minor normal faulting, with seeming diminishing severity, has continued into Pleistocene and Holocene time (King, 1965).

At least 600 feet of vertical displacement occurred along the Hillside fault after the end of Cretaceous deposition on the Diablo platform, possibly during the mid-Tertiary block faulting. There is no evidence of the displacement having any significant lateral component in the Cenozoic Era.

The estimated average density of the early to mid-Tertiary igneous rocks is 2.65 gm/cm^3. The estimated average density of late Tertiary to Holocene sedimentary rocks is 2.05 gm/cm^3. This figure was confirmed by gravimeter "density profiles" as described by Nettleton (1940).

GEOLOGIC INTERPRETATION OF GRAVITY AND MAGNETIC ANOMALIES

METHODS

Gravity and magnetic data shown on the map were obtained in the field by the writer between June 1966 and October 1968. The survey comprises 1,566 gravity and 1,703 magnetic control points, or approximately 1.3 points per square mile. The Bouguer gravity anomaly, contoured in blue, is reduced with a Bouguer density of 2.67 gm/cm^3. The red contours depict the vertical component of magnetic intensity after removal of a regional gradient. Additional information regarding the geophysical data and their probable accuracy and precision is given in the Appendix.

Much of the discussion following is based on qualitative interpretation of the geophysical anomalies. This means that a geologic interpretation is made over several anomalies simultaneously without resorting to mathematical representations of their causative bodies. The result is a generalized or schematic interpretation.

Quantitative interpretation of several large anomalies yielded subsurface geologic data of regional significance. These interpretations are based on the two-dimensional profile matching methods discussed by Nettleton (1940, 1942), Grant and West (1965), and many others. Both the methods of ideal geometric shapes (Nettleton, 1940, 1942) and of line integrals (Hubbert, 1948) were used as appropriate.

ASSUMPTIONS

Density and Magnetic Susceptibility

Geologic interpretation of gravity and magnetic anomalies requires knowledge of density and magnetic susceptibility of the rocks involved in the interpretation. Direct measurement of these properties requires fresh, unweathered rock samples, preferably core plugs. Because suitable samples of the rocks in the Van Horn—Sierra Blanca region were not available, these properties were estimated from mineralogical or gross petrological composition. The estimated densities and susceptibilities are tabulated in Wiley (1970, pp. 83-87), and densities are probably within about ± 0.15 gm/cm^3 of the average true density.

Estimates of magnetic susceptibility of rocks are hazardous, because of the large range of susceptibility produced by weathering or by small changes in the percentage of constituent magnetic minerals (Nagata, 1961, pp. 128-129; Lindsley et al., 1966, pp. 548-549). The estimated values used are broad approximations based on an empirical equation

$$k = 0.001 \times Mp$$

where k is susceptibility in c.g.s. units (accurate to ± 0.001 c.g.s. units) and Mp is the volume percent of magnetic minerals in the rock (expressed as an integer number). This equation gives susceptibilities about 50 percent larger than those suggested by Nagata (1961, p. 129) and about equal to those given by Lindsley et al. (1966, fig. 25-3, p. 548). It is safe to assume that the magnetic susceptibility of most sedimentary rocks younger than Precambrian is nearly zero, at least within acceptable ranges of error.

Both density and susceptibility of particular rock units are assumed constant over the range of the interpretation. Except in the Carrizo Mountains, errors introduced by this assumption are probably smaller than errors in estimation of density and susceptibility.

Additional Assumptions Related to Magnetic Anomalies

The following assumptions are made to facilitiate interpretation of magnetic anomalies:

(1) All magnetic anomalies are associated with local magnetic fields induced in concentrated magnetic minerals;

(2) remnant magnetization is probably an important contributor to the observed anomalies but is assumed negligible because of the aforementioned lack of rock samples suitable for measurement;

(3) the external inducing magnetic field (earth field) dips 60° N. 13° E. over the entire map area (Deel and Howe, 1948).

Regional Gradients

The regional change of the vertical component of magnetic intensity and of the Bouguer gravity anomaly (the regional gradient) is, in most places, the effect of large, deep-seated structural or stratigraphic features superimposed on the effects of shallower features. The Bouguer gravity anomaly map of the United States (Woollard and Joesting, 1964) suggests that the regional gradient of gravity in the region is less than 1 mgal per mile and is much less than that in most of the region. Moreover, complex structure and the resulting overlapping gravity anomalies in most of the mapped area made it hazardous or impossible to choose a meaningful regional gradient of gravity. Accordingly, the regional Bouguer anomaly was assumed not significant for most of the areas interpreted quantitatively, and no attempt was made to evaluate or remove such a regional anomaly. The regional vertical component of magnetic intensity has been removed by reference to standard magnetic charts (Deel and Howe, 1948).

REGIONAL SUBDIVISION

The known geology of the region, supplemented by the trend and style of the gravity and magnetic anomalies in the map area, suggests subdivision of the region into four tectonic blocks: (1) Salt Basin graben in the eastern third of the map having north-trending surface structure and low amplitude anomalies; (2) the Diablo Plateau area in the north-central part of the map having west and west-northwest-trending structure and anomalies of zero to low amplitude; (3) the Carrizo Mountains—Eagle Flat area in the south-central part of the map having moderate to high amplitude anomalies and diverse surface structure; and (4) the Devil Ridge—Quitman Mountains part of the Chihuahua tectonic belt in the southwest part of the map, which has west-northwest-trending surface structure and low to medium amplitude anomalies.

SALT BASIN GRABEN

Salt Basin trends about S. 10° E. for 130 miles from about 30 miles north of the Texas boundary in Otero County, New Mexico, through Culberson and Jeff Davis counties, Texas, until it merges physiographically with the broad, south-southeast-trending plain west of the Davis Mountains (fig. 1). Near Van Horn, Salt Basin splits into three south-trending basins—Michigan Draw basin on the east and the Wildhorse and Lobo basins on the west. The Wylie Mountains, uplifted along faults, lie between the Michigan Draw and Wildhorse and Lobo basins.

The Bouguer gravity anomaly decreases from east to west at about 0.8 mgal per mile across Salt Basin north of the Wylie Mountains and in Michigan Draw. Generally northward-trending anomalies of from 1 to 6 mgal are superimposed on the regional anomaly. The total variation in the vertical magnetic component is less than 200 gammas, and the amplitude of the few well-defined magnetic anomalies is less than 100 gammas. Bouguer gravity anomaly and magnetic values decrease from the edges toward the center of Wildhorse and Lobo basins. These gradients are not constant but average about 3.5 mgal and 125 gammas per mile.

Hay-Roe (1957) and Wood (1968, p. 5) used the term "half-graben" to describe Salt Basin, thus implying a major bounding fault on only one side. The gravity data support this conclusion and also suggest several small horsts and grabens within the broader basin.

Hay-Roe (1957) showed that the Wylie Mountains were bounded on the east and west by large-displacement normal faults. He suggested that the north flank of the Wylie Mountains might also be fault bounded but did not find convincing geologic evidence. Geophysical evidence does not suggest faulting at the north end of the Wylies but suggests instead that the Permian rocks of the Wylie Mountains dip northward beneath the alluvium of Salt Basin without displacement.

The northward-elongated gravity minimum in Michigan Draw east of the Wylie Mountains is associated in part with the East Wylie fault which drops Permian and older rocks into the Michigan Draw basin. The minimum may also indicate locally thick basin fill or a syncline or narrow graben in Paleozoic rocks beneath the alluvium.

Wildhorse and Lobo basins are two small drainage basins—Wildhorse on the northwest and Lobo on the south and southeast. They are separated by a low northeast-trending drainage divide between the Van Horn and Wylie Mountains (fig. 1). Major faults mark the boundaries of the basins at the Wylie and Carrizo Mountains and these are represented in steep gravity and magnetic gradients toward the center of the basins. Farther south, Lobo basin is a half-graben, bounded on the west by the Neal-Mayfield fault system at the Van Horn Mountains (Twiss, 1959b) and on the east by seemingly unbroken, gently basinward-dipping Tertiary volcanic rocks (Hay-Roe, 1957). A broad gravity maximum trends north-northeast from the north end of the Van Horn Mountains (near control points 757-758) about parallel to the front of the Carrizo Mountains 3 miles to the west. This anomaly suggests a north-northeast-trending horst that extends as far north as Van Horn and which possibly extends northward into Salt Basin near the east front of the Baylor Mountains.

DIABLO PLATFORM AND FOOTHILLS

Sierra Diablo, the Diablo Plateau, and their foothills, the Baylor and Beach Mountains and the Millican and Streeruwitz Hills (fig. 1), compose a convenient unit for discussion even though they are not strictly related tectonically. In much of this area, Bouguer anomaly values decrease northward at an almost constant 1.5 mgal per mile. The few recognizable exceptions to this gradient are small areally and have amplitudes less than 2 mgal. Magnetic anomalies range from 50 to about 300 gammas in the Millican and Streeruwitz Hills where meta-igneous rocks crop out. Farther north, on the Diablo Plateau, magnetic intensity is nearly constant, thus giving no information on the geometry of the magnetic basement. Perhaps the magnetic basement is deeply buried. The gravity contours describe an arcuate pattern, that is, they trend south-southwest in the Baylor Mountains, southwest at Beach Mountain, west in the Millican Hills, and west-northwest in the Streeruwitz Hills and Diablo Plateau. This pattern may be an indication of a broad, northwest-trending thickening of the sedimentary section.

Most of the smaller gravity and magnetic anomalies are the effects of near surface structural complexity. Gravity maxima are associated, in many places, with outcrops of Allamoore and minima with adjacent outcrops of Hazel Formation. Volcanic rocks in the Allamoore Formation produce large magnetic maxima (400 to 600 gammas) but the anomalies are small areally. Rocks of the Hazel Formation seem to have low and uniform magnetic susceptibility because, regardless of structural simplicity or complexity exhibited by these rocks, magnetic intensity is nearly constant throughout the outcrop belt of the formation.

DEVIL RIDGE, QUITMAN MOUNTAINS, AND SIERRA BLANCA PEAKS

Thrust-faulted and folded Lower Cretaceous rocks in the Chihuahua tectonic belt trend northwest from the central Eagle Mountains across the southwest part of the mapped area. These rocks hold up Devil Ridge, Back Ridge, and the Quitman Mountains, each of which is the upper plate of a major Laramide thrust fault (Underwood, 1963; Albritton and Smith, 1965, pl. 1). These thrust plates are characterized by low amplitude gravity and magnetic anomalies that trend northwest approximately parallel to the northwest trend of the ranges. The geophysical anomalies suggest that the maximum thickness of the thrust sheets is probably less than 8,000 feet (possibly much less) and that the magnetic basement is deeply buried.

North and northeast of the northern Quitman Mountains are the five Oligocene(?) laccoliths that support peaks and ridges collectively known as Sierra Blanca Peaks (Albritton and Smith, 1965). These laccoliths, although not included in the geophysical survey, are of interest because the large gravity and magnetic anomaly 6 miles north-northeast of the town of Sierra Blanca suggests a similar, but completely covered, laccolith. The laccolith was probably intruded along a fault or fault zone that trends about northwest.

EAGLE FLAT AND CARRIZO MOUNTAINS

Eagle Flat and the Carrizo Mountains occupy most of the central and west-central parts of the mapped area (fig. 1). Eagle Flat is about 40 miles long and 4 to 10 miles wide; it is bounded on the east and north by the Van Horn and Carrizo Mountains, the Millican and Streeruwitz Hills, and the Diablo Plateau. Green River Bolson (Twiss, 1959a, p. 127), a southward extension of Eagle Flat, is about 15 miles long and 5 miles wide (fig. 1). A low drainage divide between the Eagle and Van Horn Mountains separates them. Green River Bolson and Eagle Flat are bounded by the Indio and Eagle Mountains and Devil Ridge on the west and southwest.

Gravity and magnetic anomalies in the Carrizo Mountains are elongated approximately parallel to the northeast strike of the metamorphic rocks in the eastern part of the mountains. More or less equidimensional outcrops of amphibolite and metarhyolite predominate in the west part of the mountains and are associated with gravity and magnetic anomalies that have similar shapes. The maximum amplitude of gravity and magnetic anomalies is about 6 mgal and 600 gammas.

Several small bodies of Carrizo Mountain metarhyolite, of Permian, and of Lower Cretaceous rock are exposed through the bolson fill and alluvium of Eagle Flat, but direct knowledge of the deeper parts of the basin is lacking. The largest gravity anomaly in the mapped area is 40 miles long and 2 to 3 miles wide; it is a roughly linear zone in Eagle Flat in which Bouguer gravity anomaly values decrease southwestward as much as 22 mgals. From about 6 miles north of Sierra Blanca, this anomaly trends southeastward to the Streeruwitz Hills, along the south side of the Carrizo Mountains, to the Van Horn Mountains near Scott's Crossing (fig. 1). It continues southward from Scott's Crossing along the west flank of the Van Horn Mountains into Jeff Davis and Presidio counties.

No distinctive magnetic anomaly is associated with the linear gravity anomaly, but 1 to 3 miles to the north, a narrow, sinuous magnetic maximum, with amplitude exceeding 1,000 gammas, trends east-southeast across northern Eagle Flat between the Streeruwitz Hills and the Carrizo Mountains. South of the linear gravity anomaly, one magnetic anomaly has an amplitude larger than 250 gammas; elsewhere in Eagle Flat, magnetic anomaly amplitude ranges from zero (undetected) to about 100 gammas.

Rim Rock Fault

The Rim Rock fault crops out from the north end of the Van Horn Mountains at the south edge of the mapped area for 78 miles south to the Chinati Mountains, 28 miles north of Presidio, Texas (fig. 3). The fault strikes south to south-southeast and is downthrown to the west throughout its length. Its stratigraphic separation exceeds 3,000

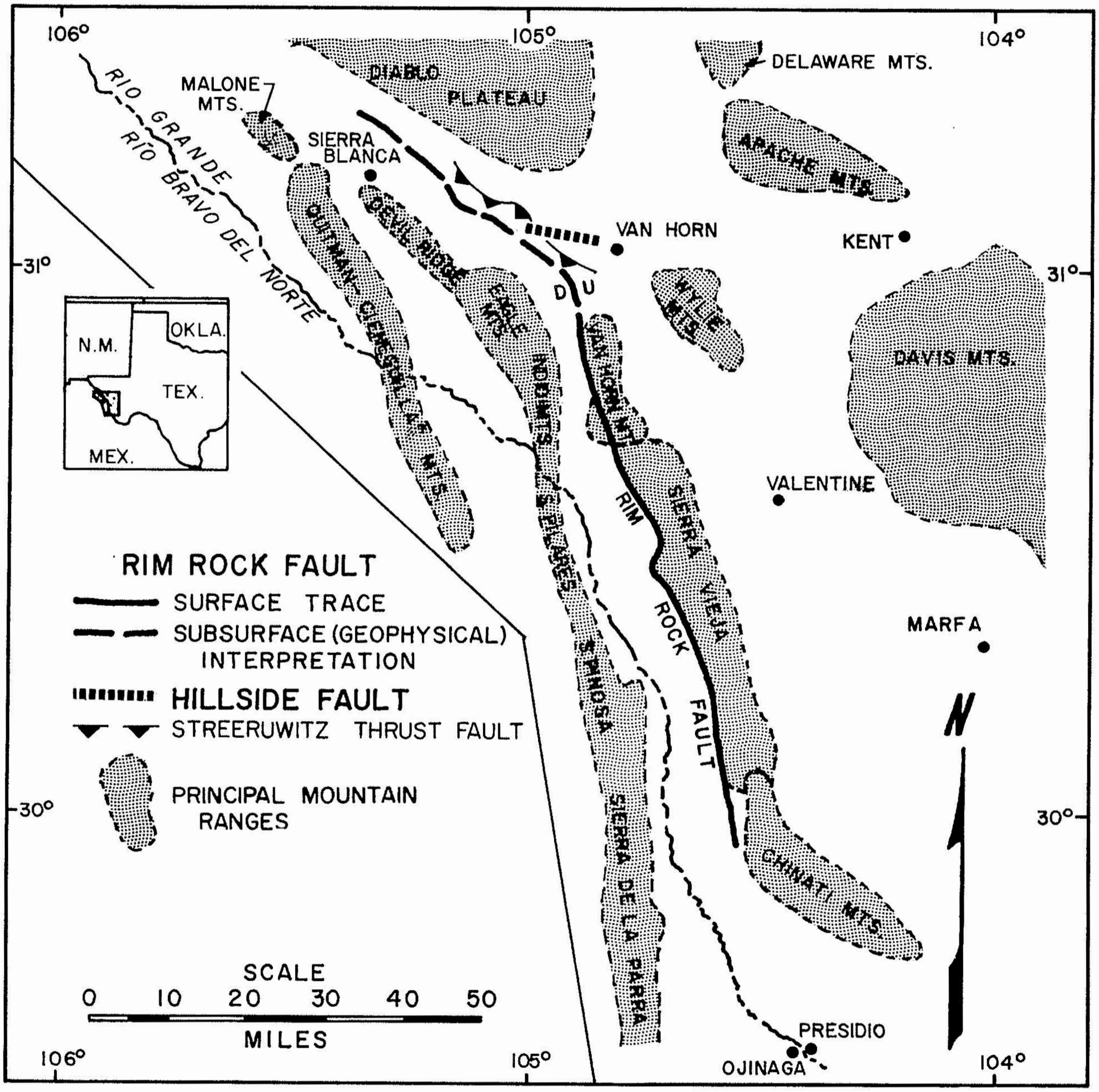

FIG. 3. Rim Rock fault in Trans-Pecos Texas.

feet in the northern Van Horn Mountains and possibly exceeds 4,000 feet (Twiss, 1959a, p. 110). The Rim Rock fault is the structural boundary between the Van Horn Mountains and the north part of Green River Bolson and the south part of Eagle Flat. The fault is not exposed in the alluvium-filled valley north of the Van Horn Mountains, but to the northwest, the high-standing escarpment that forms the boundary between Eagle Flat and the Carrizo Mountains is indicative of major faulting. Precambrian metamorphic and Permian sedimentary rocks of the Carrizo Mountains are abruptly truncated along this escarpment.

The aforementioned linear gravity anomaly that closely parallels the southwest side of the Carrizo Mountains turns southward near Scott's Crossing (fig. 1) and closely follows the trace of the Rim Rock fault along the west side of the Van Horn Mountains. Gravity profiles, drawn approximately normal to the trend of the anomaly, exhibit the open "S"-shaped, or step, curve that is characteristic of the gravity response to a high-angle fault (i.e., a large and abrupt horizontal change of rock density). A reconnaissance gravity survey (outside the mapped area) in the southern Van Horn Mountains along the county road to Porvenir (Porvenir mail route) crosses the outcrop of the Rim Rock fault 20 miles south of Scott's Crossing. The fault intersects this profile near the mid-point of a 14-mgal westward decrease in Bouguer gravity anomaly that takes place in about 2 miles. At the trace of the fault, the gradient of the gravity anomaly is 10.4 mgal per mile, the maximum along the profile. Because of structural complexity and sparse gravity control, a completely satisfactory quantitative interpretation of this profile was not possible. The closest approximations suggested density contrast between 0.4 and 0.5 gm/cm^3 and minimum throw between 3,500 and 2,600 feet (Wiley, 1970, fig. 11; p. 119). The steep gradient of the anomaly suggests that much of the anomaly results from shallow density contrasts, perhaps less than 6,000 feet deep. Twiss (1959b, cross-section A-A′) suggested displacement of about 4,000 feet along the fault at Mica Mine, between Scott's Crossing and the reconnaissance gravity profile. Estimates of displacement along the segment of the fault between Mica Mine and the southern Van Horn Mountains have not been reported.

Because no gravity measurements were made in the 18 miles between the aforementioned profile and the south edge of the map, it is possible that the gravity anomaly adjacent to the northern Van Horn Mountains is not the same as that encountered farther south at the trace of the exposed Rim Rock fault. It is probable, however, that the two anomalies are one because in both places (1) an abrupt 14- to 16-mgal westward decrease of Bouguer gravity anomaly occurs as a step-anomaly; (2) the maximum gradient of gravity in both places is high, 10 to 13 mgal per mile; (3) the maximum and minimum Bouguer anomaly values are the same, -134 mgal and -149 mgal; and (4) the anomalies trend south to south-southeast and are seemingly associated with the well-exposed Rim Rock fault. Therefore, because of marked geophysical similarities and mapped geological continuity, the Rim Rock fault seems the most probable cause of the linear gravity anomaly extending north and northwest from the northern Van Horn Mountains. Thus, the Rim Rock fault extends about 40 miles northwest along the gravity anomaly from its last known exposure to the west end of the surveyed area north of Sierra Blanca, Texas.

Interpretation of Profiles

The Rim Rock fault gravity anomaly trends N. 50° W. from Scott's Crossing 17 miles across Eagle Flat to the Eagle Flat section house on the Texas and Pacific Railway near control point 76. Gravity profiles A-A′ and B-B′ (fig. 4), each approximately normal to the trend of the anomaly, exhibit characteristics of the gravity response to high-angle faults similar to that already discussed. Structural interpretation of these profiles was accomplished by the method of semi-infinite horizontal slabs. The results of these interpretations are tabulated in table 3.

TABLE 3. *Results of interpretation of profiles A-A′ and B-B′.*

Profile	Direction from station	Fault trace at station	Average density contrast	Throw *(feet)*	Distance N. 50° W. from Scott's Crossing—station 360
A-A′-1	N. 40° W. 1470	4	0.50 gm/cm^3	4,300	8.4 miles
B-B′	N. 44° W. 751	290	0.44 gm/cm^3	3,000	13.2 miles

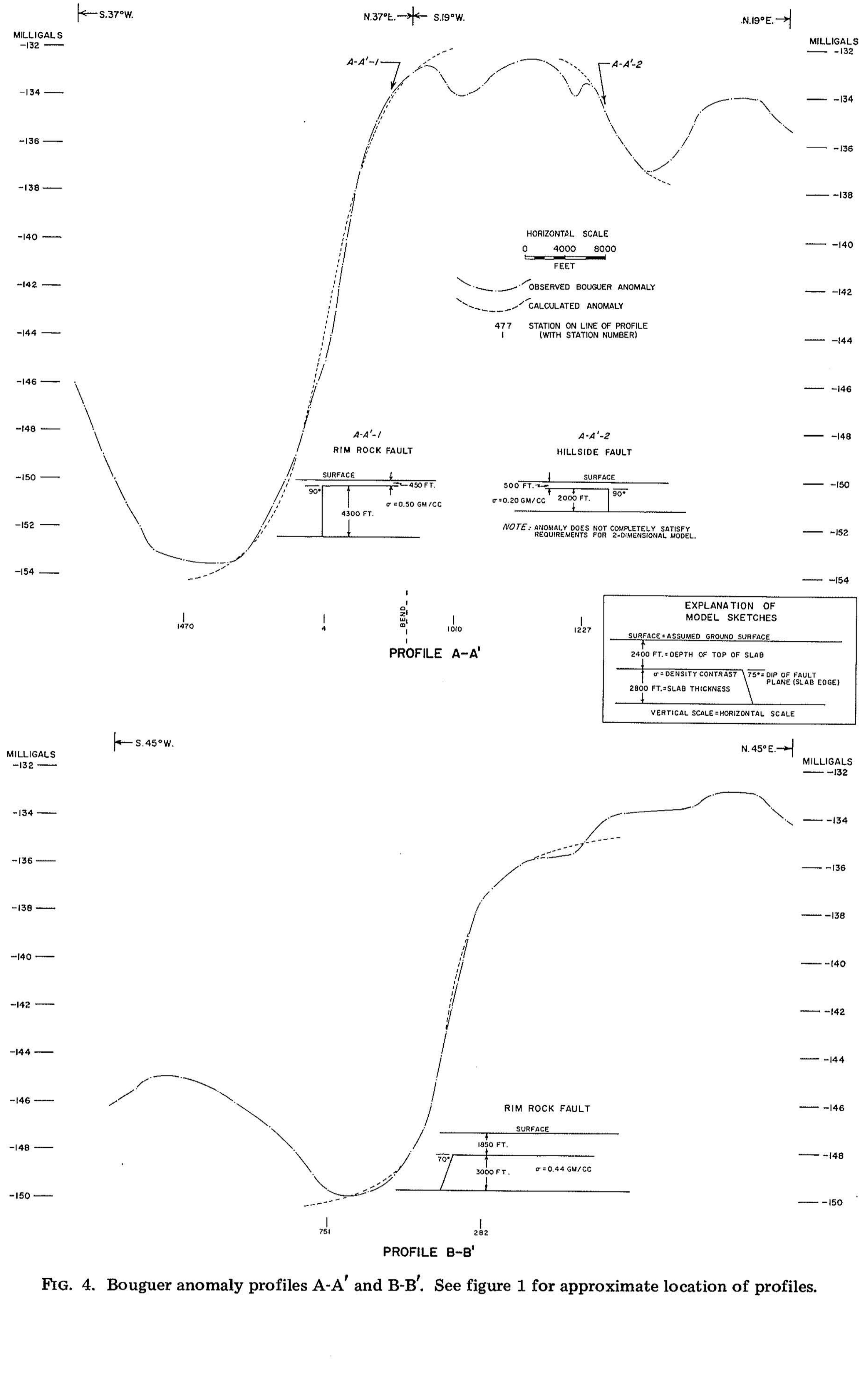

FIG. 4. Bouguer anomaly profiles A-A′ and B-B′. See figure 1 for approximate location of profiles.

About 20 miles west of Van Horn along the Texas and Pacific Railway, near the Eagle Flat section house, the trend of the Rim Rock fault gravity anomaly changes from N. 50° W. to N. 70° W. The anomaly maintains this new direction for about 6 miles along the south side of the Streeruwitz Hills, but several small anomalies, probably indicating faults, split off from the principal anomaly about midway of this distance and trend N. 50° W.

West of the Streeruwitz Hills, the Rim Rock fault gravity anomaly resumes its N. 50° W. trend but is not as well defined as farther east. Near the west end of the Streeruwitz Hills, the gravity survey suggests southward downthrow of about 2,000 feet (using density contrast of 0.40 gm/cm^3). The gradient of gravity west of the Streeruwitz Hills suggests the continuity of a fault or, more probably, a fault zone 1 to 2 miles across. The fault zone may have displacement as much as 3,500 feet. The reason for the branching and abrupt changes in strike of the Rim Rock fault is not known. Possibly, the mid-Tertiary Rim Rock fault in part follows the N. 70° W. trends established during Precambrian deformation (King and Flawn, 1953).

From the foregoing geological and geophysical evidence, it is apparent that the Rim Rock fault changes strike direction at the north end of the Van Horn Mountains and extends at least 40 miles across Eagle Flat and that it divides Eagle Flat into a structurally higher north part and lower south part. The Rim Rock fault was active in Oligocene and Miocene time (DeFord and Bridges, 1959, pp. 292-293), but because of its close proximity to the west and southwest edges of the much older Diablo and Coahuila platforms, it must have a considerable earlier history.

Streeruwitz Thrust Fault

Carrizo Mountains.—The metamorphic rocks of the Carrizo Mountain Group exposed in the Carrizo Mountains and elsewhere in and around Eagle Flat were thrust northward over younger Precambrian sedimentary rocks along the Streeruwitz thrust fault (fig. 3). The thrust surface is nowhere well exposed but where seen is a poorly exposed and weathered contact between metarhyolite of the Carrizo Mountain Group and mostly carbonate rock of the Allamoore Formation north and northwest of Allamoore and in the Streeruwitz Hills (King, 1953, pp. 102-103). A similar, if somewhat speculative, contact was described as an emergence of the thrust by King and Flawn (1953) and is shown on King's map (1965, pl. 1) near the Hillside fault between Van Horn and Allamoore. These scattered exposures and lineations in the metarhyolite suggest that transport was northward but yield no indication of the true geometry of the fault. Gravity and magnetic anomalies associated with the Carrizo Mountain Group and the thrust fault provide a basis for some further speculations, however.

Although Precambrian magnetic metamorphic rock is juxtaposed with nonmagnetic Cenozoic bolson fill along the Rim Rock fault on the southwest side of the Carrizo Mountains, magnetic anomalies that can be clearly associated with the Rim Rock fault are small areally, discontinuous, and have amplitudes generally less than 100 gammas. The magnetic anomaly parallel to the Hillside fault is large, about 400 gammas, but the associated gravity anomaly is small, 2 to 5 mgal, depending on location. This suggests that near the Rim Rock fault, the metamorphic rocks in the upper plate of the thrust are either thinner or that their magnetic susceptibility is lower than at the Hillside fault, 6 miles to the north. By assuming, with possible large error, a constant susceptibility contrast of 0.0025 c.g.s. units between magnetic rocks of the upper plate of the thrust and sedimentary(?), nonmagnetic rocks of the lower plate, the maximum thickness of the upper plate is about 4,500 feet. This maximum occurs near the Hillside fault, about at the location of Interstate Highway 10. The minimum thickness is about 1,500 feet and occurs near the Rim Rock fault.

The susceptibility of the rock beneath the thrust cannot be accurately estimated because the rock type is not known. However, at every known exposure of the Streeruwitz thrust fault, metarhyolite of the Carrizo Mountain Group overlies carbonate rock of the Allamoore Formation along a thrust fault contact (King and Flawn, 1953, pls. 1, 2, 3). Both the Allamoore and Hazel Formations are composed mostly of sedimentary rock with low susceptibility, and either could directly underlie the thrust fault from place to place without materially altering the interpretation of the magnetic anomalies.

Metamorphic rocks of the Carrizo Mountain Group exposed in the Eagle Mountains are identical to and on strike with some of the map units of that group in the Carrizo Mountains. The magnetic anomaly associated with the metamorphic rocks in the Eagle Mountains suggests that only a few hundred feet of Carrizo Mountain Group rock is present. This suggests that the Carrizo Mountain Group is in the upper plate of a thrust in the Eagle

Mountains, probably the Streeruwitz thrust fault. Thus, the minimum horizontal displacement along the Streeruwitz thrust fault is about 12 miles, the distance between the Eagle Mountains and exposures of the fault in the Millican Hills.

Northern Eagle Flat.—The largest and most continuous magnetic anomaly in the mapped area is a sinuous, high-amplitude magnetic maximum that trends northwest across northern Eagle Flat between the Carrizo Mountains and the southern Streeruwitz Hills. This anomaly, nowhere more than a mile wide, has an average closure of about 300 gammas and local maxima with 900 to 1,200 gammas closure. It seems to be associated with outcrops of amphibolite intruded into the Carrizo Mountain Group in both the Carrizo Mountains and the Streeruwitz Hills and probably indicates continuity of the amphibolite beneath a thin alluvial cover. This also suggests that the regional strike of the Carrizo Mountain Group changes from west-southwest in the western Carrizo Mountains to northwest beneath Eagle Flat. The abrupt right-lateral (northward looking west) offset of the anomaly about 3 miles west of Allamoore is not understood but may be related to younger (Cenozoic) faulting, to tear-faults associated with the Streeruwitz thrust fault, or to crumpling, folding, and imbrication in the upper plate of the thrust.

The Eagle Flat anomaly closely resembles that of a long, thin prism having a finite depth range. Assuming a susceptibility contrast between 0.002 and 0.003 c.g.s. units, a two-dimensional body whose upper end is 300 feet below the surface would have to be 2,000 to 3,000 feet wide and would have to have its base 4,000 to 6,000 feet below the surface, depending on location, in order to satisfy the observed anomaly. The depth to the top of the prism is arbitrary but is based on proximity to outcrops of the Carrizo Mountain Group and meager water well data. The width of the prism cannot be more than about half the width of the anomaly and the range given is, therefore, a maximum. The depth to the base of the prism is subject to errors, perhaps as large as 25 percent. This is because of inherent insensitivity of the magnetic method to the base of any regular parallelepiped. Ignoring possible effects of remnant magnetism and a poor knowledge of susceptibility contrasts as possible sources of error, and assuming that the anomaly originates entirely within the upper plate of the thrust fault, this anomaly also indicates that the upper plate is not more than about a mile thick beneath Eagle Flat.

Hillside Fault

Gravity and magnetic anomalies related to the Hillside fault (figs. 3, 4) range from 2 to 5 mgal and 200 to 400 gammas. The anomalies are discontinuous, difficult to delineate, and probably originate in part from the Streeruwitz thrust fault, along the 9-mile length of the known or inferred trace of the Hillside fault between Van Horn and Allamoore. Anomalies that suggest possible extensions of the Hillside fault can be recognized as far as 8 miles east of Van Horn but not west of Allamoore.

King (1965, p. 114) estimated more than 1,000 feet of northward downthrow along the Hillside fault near the Gifford-Hill quarry, 3 miles east of Allamoore (near control points 135 and 1123). The north end of gravity profile A-A′ (fig. 4) is normal to the N. 70° W. trend of the Hillside fault gravity anomaly about a mile east of Allamoore (anomaly A-A′-2). The anomaly is not long enough to completely satisfy the requirements for two-dimensional interpretation, but such an interpretation provides a reasonable estimate of displacement. Using a density contrast of 0.20 gm/cm^3, interpretation of anomaly A-A′-2 indicates about 2,000 feet of northward downthrow.

An east-trending, 6-mgal gravity anomaly a few miles east of Van Horn (control points 597-602) suggests a possible eastward continuation of the Hillside fault. The large magnetic anomaly associated with the Hillside fault in the Carrizo Mountains is missing and there is no obvious continuation between the two gravity anomalies. There is no compelling geologic evidence for a continuation of the Hillside fault, and, alternatively, the eastern anomaly could be interpreted as part of a larger closed anomaly associated with late Paleozoic east-plunging folds as suggested by King's paleogeological map (1965, fig. 2). Thus, the Hillside fault has, as King (1965, p. 115) remarked, ". . . been ascribed an inordinate role in the tectonics of the region by Moody and Hill (1956, pp. 1223-1224) . . . ," who interpreted it as a major element in their "Texas direction of wrench faulting." The Hillside fault is a part of a local zone of adjustment between tectonically active blocks; it has no regional or continental significance.

THE TEXAS LINEAMENT

The existence of the Texas lineament was suggested by R. T. Hill in 1902. Ransome (1915), Baker (1927, 1935), and Hill (1928) discussed and amplified the concept of a possible transcontinental zone of fracture between the Transverse Ranges of California and Trans-Pecos Texas.

In their discussions of the Texas lineament, Hill, Ransome, and Baker clearly were referring to a linear anomaly between alined structural and stratigraphic anomalies of regional significance that were detectable on the ground and on the small-scale regional geologic and topographic maps available to them. They variously called the Texas lineament a line of faulting, a linear zone of faulting or fracturing, and a linear zone between contrasting geologic provinces, but they never suggested or implied strike-slip movement as the origin of the lineament.

Albritton and Smith (1957), in a review of the subject, restated Baker's (1935) concept of the lineament as a broad band of faulting rather than a line and suggested that it might be a broad eastward continuation of the then recently discovered Murray fracture zone. Their illustrations show a 60- to 90-mile-wide zone extending eastward from the Transverse Ranges along the southern base of the Colorado Plateau to Trans-Pecos Texas as constituting the lineament. In addition, in accord with stratigraphic practice, they proposed a type locality for the lineament: ". . . the segment of about 55 miles in length which runs along the corridor of Eagle Flat." This topographic corridor extends from a point about 10 miles southwest of Van Horn, Texas, N. 60° W. through Sierra Blanca and for another 20 miles beyond toward El Paso. It separates two regions having strongly contrasting geologic history: the Diablo platform to the north and the Chihuahua trough to the south.

Along the north side of Eagle Flat, the Carrizo Mountain Group, in the upper plate of the Streeruwitz thrust fault, was thrust northward over the younger Allamoore and Hazel Formations, which were deformed and tectonically mixed during Late Precambrian deformation. The Diablo platform was defined along this old boundary late in Paleozoic time and again late in Mesozoic time. The southern borders of Eagle Flat and Hueco Bolson mark approximately the maximum northward extent of a Permian or older seaway (López-Ramos, (1969) and of thick Cretaceous sedimentation in the Chihuahua trough.

Thus, the topographic corridor of Eagle Flat, and probably the topographic corridor of Hueco Bolson as well, satisfies the definition of a lineament: alined structural or stratigraphic anomalies that produce topographic lines. Moreover, this zone of structural and stratigraphic discontinuity *is* the Texas lineament as originally proposed. The incontrovertible fact of the Texas lineament in Trans-Pecos Texas and the popular hypothesis of its origin by wrench faulting along the Texas direction of Moody and Hill (1956) or along any other direction must not be confused.

Moody and Hill (1956) included the Texas lineament in their world-wide system of wrench faults. They showed the Hillside fault as a short segment of a transcontinental left-lateral wrench fault of the Texas direction. Muehlberger (1965), on the basis of offset Precambrian isochrons, postulated 150 to 200 miles of right-lateral strike-slip movement along the Texas lineament and Hillside fault during late Paleozoic time.

In the Van Horn—Sierra Blanca region, neither geologic nor geophysical evidence supports wrench faulting. Two through-going fault trends are demonstrable, *viz.*, the north-trending (exposed) part of the Rim Rock fault and Salt Basin boundary faults and the northwest-trending segment of the Rim Rock fault. These are Cenozoic structural features that are more or less superposed on parts of the boundaries of the Diablo platform of Permian and Cretaceous time. There is no evidence for Cenozoic strike-slip motion along the lineament and much evidence that such movement, if any, is much older.

King (1965) has shown that strike-slip movement along the Hillside fault could not have occurred after the beginning of Permian time. Moreover, Permian reef complexes in the region are not offset in the vicinity of the lineament or in the vicinity of the aforementioned fault trends. Thus, it is most improbable that major strike-slip displacement occurred in West Texas after the beginning of Permian time. If the lineament has an old history of wrench faulting, the evidence necessary to demonstrate it must be in rocks older than Permian.

Much of this rock is missing in Trans-Pecos Texas, either because of nondeposition or erosion, and much of that remaining is covered. Lucia (1968), working with this meager data, was able to map marine, shoreline, and tidal flat facies in Lower Ordovician rocks in New Mexico and Trans-Pecos

Texas. The facies boundaries trend north to northwest. They define a 50- to 80-mile-wide shoreline facies that is not seemingly offset where it crosses the Texas lineament. If the origin of the lineament is related to strike-slip faulting, such movement must have occurred in Cambrian or Precambrian time. Denison and Hetherington (1969) did not suggest Precambrian wrench faulting in their synthesis of Precambrian terranes of the region which was based on isotopic age determinations and petrographic examination of core samples. They did not specifically exclude the possibility of wrench faulting, and it is not difficult to imagine wrench faults along some of their terrane boundaries.

The question of the origin of the Texas lineament is still an enigma. Nevertheless, the several more or less superposed tectonic disturbances in the region, ranging from Precambrian deformation and metamorphism to Cenozoic block faulting, not only suggest a fundamental crustal discontinuity but also tend to obscure evidence of its origin with structural complexity. With the presently available data, it is possible to state only that this lineament is a broad zone that trends about N. 60° W. across Trans-Pecos Texas, that the Van Horn—Sierra Blanca region lies athwart this zone, and that the length and remarkable straightness of the zone suggest wrench faulting.

CONCLUSION

Gravity data show that the Rim Rock fault follows the southern and western boundaries of the Paleozoic and Mesozoic Diablo platform and that it forms one boundary of Eagle Flat. Gravity and magnetic data show that the Hillside fault does not extend much east of Van Horn nor west of Allamoore. East of Van Horn, gravity anomalies trend in a northerly direction, and west of Allamoore they merge with or trend parallel to the Rim Rock fault anomaly. Magnetic and geologic data suggest that the maximum northward extent of Late Precambrian deformation is in or slightly north of Eagle Flat. Thus, the Texas lineament observed by Hill (1901, 1928), Ransome (1915), and Baker (1927, 1935) is a Cenozoic landform superposed on tectonic features dating from at least Late Precambrian to at least mid-Tertiary.

The Texas lineament is a broad zone of tectonic discontinuity that may reflect a zone of fundamental crustal weakness. Geological and geophysical evidence suggests that the lineament may have formed in Late Precambrian time. This evidence does not require that the lineament be associated with or indicate wrench faulting of transcontinental significance, but neither does it exclusively deny such an hypothesis. The distribution of Paleozoic and Mesozoic rocks in the region is incompatible with major wrench faulting since Late Cambrian or Ordovician time. Later, predominantly vertical movement along the lineament helped to define the boundaries of the Late Paleozoic and Late Mesozoic basins and platforms of Trans-Pecos Texas and northern Chihuahua.

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APPENDIX: GRAVITY AND MAGNETIC SURVEY

CONTROL POINTS AND BASES

The survey consists of 1,545 gravity and 1,683 magnetic control points ("stations") plus 21 gravity and 20 magnetic base, or reference, points. In most of the area, gravity and magnetic points are adjacent and have the same identifying number. It was necessary to move some magnetic stations away from the corresponding gravity location in order to avoid local magnetic interference; where practical, these points are shown on the map and are labeled with "M" as a prefix, e.g., magnetic station M872 corresponds to gravity station 872 but is about 1,100 feet to the south. Base stations are designated by capital letters, although some were first established as routine observation stations, given a number, then resurveyed as a base, and given dual letter and number nomenclature. For example, base L is also station 478. Stations were numbered consecutively as established or occupied by the gravimeter. It was not possible to keep station numbers in sequence by areas.

When the survey was begun in June 1966, 13 gravity base stations were set and tied together by the base-loop method described by Nettleton (1940, pp. 38-42). After a base-loop is closed, the differences in values around the loop are made to add to zero by small adjustments in each leg of the loop. Eventually, 21 gravity bases were set. Of these, bases K, AA, and AC were not tied into a loop and adjusted because of low meter drift rates and short distances between bases. Additionally, gravity bases P, AB, 804, and 1017 were not looped because they were intended as secondary reference points in lower accuracy reconnaissance lines and because of excessive travel time required to obtain a loop.

Four gravimeters were used in the survey: Worden Prospector model gravimeters number 64 and 152; LaCoste and Romberg number 96; and LaCoste and Romberg geodetic meter G-135. It would have been desirable to complete the entire survey with one gravimeter, but prior commitments for the various instruments made this impossible. The calibration of Worden-64, stated by the manufacturer as 0.08232 mgal per dial division, was used as a standard throughout the survey. All other instruments were recalibrated in the field to tie to Worden-64 by re-running base-loop B-C-E-D-B in eastern Eagle Flat. The largest difference in calibration constants determined was -0.00042 mgal per dial division for Worden-152.

Magnetic bases were set in the same manner as the gravity bases. Magnetic bases A, C, F, H, J, N, and P and supplementary magnetic bases 1045 and 1466 are not adjacent to gravity bases. There is no gravity base 1045 or 1466 and there is no magnetic base AA.

In addition to established (marked and numbered) gravity stations, magnetometer readings were made at 142 locations to obtain better detail in areas of steep magnetic gradient. Most of these are not shown on the map but were honored in contouring the data. Where shown, these are indicated by the number of a nearby established station and a suffix, e.g., 1466G.

Two Sharpe Instruments vertical component fluxgate magnetometers were used in the survey. Six bases and 139 stations were also read with a Ruska vertical component (Schmidt balance type) magnetometer. About 150 stations and three bases were read with Sharpe magnetometer number 510167 in August 1966. All bases were reset and more than 95 percent of the stations were read with Sharpe number 704281 in 1968. The Sharpe magnetometers read directly in gammas and can usually be read to ±2 gammas on the most sensitive scale if magnetic intensity changes at rates less than about 500 gammas per mile and wind velocity is below 15 miles per hour.

ELEVATION AND LOCATION

The geographic position of 1,732 control points was established by reference to landmarks on topographic maps, by automobile odometer along roads or trails, by plane-table surveying, and by pace-and-compass traverse. The elevation of 1,573 of these was established by benchmarks, plane-table survey, reference to large-scale topographic maps, and aneroid altimeter.

The location and elevation of 1,417 stations were determined from preliminary, field-checked editions of 16 new U. S. Geological Survey 1:24,000-scale topographic maps. Thirteen of these maps were contoured at 10-foot or smaller intervals, two were contoured at a 20-foot interval, and one was at a 40-foot interval. The field-established elevation of many landmarks, such as fence corners, road junctions, and arroyo crossings, is shown on these maps to the nearest foot. Stations were established on 529 of these "useful elevations" and on 172 benchmarks. The elevation of 94 stations was established by plane table and alidade. The location of 53 of these was also established by plane table, but the remaining 41 were located by reference to landmarks on 1:48,000-scale planimetric geologic maps. An American Paulin System surveying altimeter, calibrated in 2-foot intervals, was used to establish the elevation of 23 stations whose location was established by reference to landmarks on 1:63,360 planimetric maps. The remaining 760 stations were located by reference to landmarks and by automobile odometer; their elevations were established by reference to contours on the large-scale topographic maps. Elevations were not determined at 159 stations that were occupied only by the magnetometer. Table 4 shows probable accuracy of elevation control and the probable effect on the gravity survey.

FIELD PROCEDURE

Field procedure consisted of first reading the gravimeter or magnetometer at a convenient base, reading at several stations, and finally returning to a base. Except in rare instances when it was wholly impractical, the instruments were returned to a base every two hours. By so doing, earth tides and instrumental drift can be treated together and adjusted out of the gravity data. This procedure also minimizes the possibility of reading the magnetometer during a reversal in diurnal drift. As an additional check for abnormal drift, about 20 percent of all stations were re-read to check drift and repeatability. Because most of the survey was conducted by automobile or jeep along roads and trails, 10 to 20 new stations and 2 to 4 check stations were occupied in a two-hour traverse between bases.

DATA ADJUSTMENT AND REDUCTION

Drift Corrections

As used here, drift is the difference between readings at bases at the beginning and at the end of two-hour or shorter intervals of observing gravity or magnetic values. The largest part of gravimeter drift is instrumental and is induced by temperature changes, slack in the reading dial gear-train, and nonlinearity of the instrument (when not otherwise accounted for). The gravity effect of earth-tides is small in a two-hour interval and is included as instrumental drift. Magnetometer drift is caused mostly by diurnal variations in magnetic intensity, but some instrumental drift is induced by sudden and large changes in ambient temperature and by vibration during transport. Drift was corrected on a linear time scale between observations at bases. For example, for gravity, 0.01 mgal per minute was added to the observed readings to correct for a 1.00 mgal downward drift in 100 minutes. Magnetometer drift was corrected in the same manner.

Reduction of Gravity Data

Adjusted observed gravity data were reduced to Bouguer gravity anomaly by four adjustments or corrections: (1) free air correction; (2) Bouguer correction; (3) terrain correction; and (4) adjustment for theoretical gravity. The free-air and Bouguer corrections were combined into a single correction because both are dependent on altitude above (or beneath) an arbitrary datum, usually mean sea-level. In this survey, the combined correction was 0.06 mgal per foot altitude above

TABLE 4. *Probable accuracy of elevation control.*

Type of elevation control	Maximum error *(feet)*	Probable maximum error in gravity survey *(feet)*	Probable effect on gravity data *(mgal)*
Topographic maps—			
40 ft. C.I.	±20	±10	±0.60
20 ft. C.I.	±10	± 7.5	±0.45
10 ft. C.I.	± 5	± 4	±0.24
5 ft. C.I.	± 2.5	± 2	±0.12
Benchmarks	± 0.1	± 0.1	±0.0006
"Useful elevations"	± 1.0	± 1.0	±0.06
Plane-table surveys	± 1.0	± 1.0	±0.06
Altimeter	± 5.0(?)	± 5.0(?)	±0.30(?)

mean sea-level. This corresponds to an average density of surficial rock, the "Bouguer density," of 2.67 gm/cm^3. Although this density assignment is open to some question, many noncommercial surveys in the Western Hemisphere are reduced with this value. By using this possibly high value for Bouguer reduction, this present survey may be tied to and compared with the extant government work in the region.

Theoretical gravity accounts for the increase of gravity from equator to pole. One method of making corrections for theoretical gravity is to contour the northward increase of gravity on the base map on which the control points are plotted. It is then a simple and satisfactorily precise procedure to interpolate between the contours and to determine the correction for each station. Nettleton (1940, pp. 51-53) described the method and (pp. 137-143) provided tables of theoretical gravity from which these contours may be plotted.

The Bouguer and free-air corrections both assume that the ground surface at an observation point is flat. If, on a 1,300-foot radius surrounding the station, the average surface elevation differs more than about 100 feet from the station elevation, terrain correction is necessary. Approximately 70 percent of the gravity stations in this survey were corrected for terrain irregularity through zone J (4.1 miles = 6.6 km) by the chart and overlay methods of Hammer (1939). This was a slow and tedious process but quite necessary and worthwhile because some corrections amounted to more than 2.0 mgal and many were in the range 0.5 to 1.0 mgal. The first four zones (zones B-E) were completed in the field when the station was occupied. The elevation differences of the outer zones were determined from the large-scale topographic maps or from enlargements of the small-scale topographic maps.

The final Bouguer gravity anomaly, g_z, is found by

$$g_z = g_o + E - g_t + T$$

where g_o is adjusted observed gravity, E is the elevation correction (combined Bouguer and free-air corrections), g_t is theoretical gravity, and T is terrain correction. Note that T is always positive (*see* Nettleton, 1940, pp. 56-57) and g_t is always subtracted.

The survey was tied to 15 benchmark-gravity stations of the U. S. Coast and Geodetic Survey and Air Force Chart and Information Center. The final tie was accomplished by linear adjustment of the entire survey to obtain a best fit of the 15 prime stations.

Reduction of Magnetic Data

Observed vertical magnetic intensity data are adjusted for drift in much the same way as described for gravity data. Drift rates ranged from zero to more than 100 gammas per hour. When the drift rate exceeded 30 gammas per hour, all affected stations were re-run unless corrections could be made using check stations.

Regional magnetic intensity changes from place to place in broad trends. Deel and Howe (1948) published charts showing the regional variation of vertical intensity for 1945. This variation is susceptible to contouring and treatment in the same manner as theoretical gravity. Various procedures for determining the regional gradient of magnetic intensity have been used by other workers in recent years, for example, the departure of the observed magnetic intensity "surface" from a fitted "nth" order mathematical surface. This procedure is useful in some surveys, but the data of this present survey do not warrant such sophisticated treatment. In this survey, the interpolated value from the chart of Deel and Howe (1948) was subtracted from the adjusted observed magnetic intensity at each station in order to produce a map value above or below an arbitrary datum. Station elevation has no significant effect on ground magnetometer data, and terrain effects, if any, can be neglected (Grant and West, 1965, pp. 306-308).

Precision and Accuracy

Gravity and magnetometer readings have the range of precision to which they are repeatable. During the course of the survey, 248 (16 percent) of the 1,556 nonbase gravity stations were routinely re-read as check stations. In the magnetometer survey, 392 (23 percent) of the 1,703 nonbase stations were re-read as check stations, and an additional 158 stations (9.3 percent) were re-run because of excessive drift or for other reasons. The average repeatability of the gravity survey is within ±0.04 mgal, close to the 0.01 mgal resolving power of the Worden gravimeter (on a given scale). Similar results were obtained with the LaCoste and Romberg gravimeters. The extreme range of gravity repeatability is +0.16 to -0.13 mgal, and only 23 stations (9.3 percent of those repeated or 1.5 percent of all stations) failed to repeat within ±0.06 mgal.

The repeatability of the magnetometer survey is about 11.5 gammas but the range and spread are large, ranging from +35 to -37 gammas. About

20 percent of the stations repeated failed to repeat by ±20 gammas. The repeatability is about 2.6 percent of the 300 scale, the magnetometer scale most frequently used.

The accuracy of the survey describes how truthfully it represents the actual distribution of the gravity and magnetic anomalies. This is inherently difficult to test and evaluate but, empirically, if the data are contourable and if the contours seem reasonable in view of the surface geology, the survey must be assumed to be reasonably accurate. Assuming the aforementioned precision of reading, the accuracy of the survey depends on the precision of geographic location, choice of regional gradient, if any, and faithfulness of the contours to the data. The accuracy of the gravity survey also depends on the accuracy of the elevations, terrain corrections, and the choice of the Bouguer density.

The precision of horizontal positioning is about ±200 feet throughout the survey. Elevations were determined with an average precision of ±5.0 feet or less. The choice of Bouguer density equal to 2.67 gm/cm^3 is necessary in order to tie the survey to earlier work by federal agencies and others. Using ±5.0 feet for elevation precision, 1.14 mgal per mile for the average south-to-north gradient of gravity (Nettleton, 1940), and reading precision of ±0.04 mgal, the gravity survey is accurate to about ±0.40 mgal excluding terrain corrections. The accuracy of terrain corrections is difficult, if not impossible, to assess. Considering the amount of data that is incorporated into them, the terrain corrections probably are not in error by more than 15 percent; the average error probably is about 5 to 10 percent.

The accuracy of the magnetometer survey depends on the precision of reading, horizontal positioning, and contouring of the resulting map values. Assuming that the error of location does not exceed ±200 feet, the accuracy of the uncontoured data is dependent solely on the reading precision (as stated earlier, about ±11.5 gammas, or about ±2 percent of the maximum range of the survey).