Geology of the Eastern Part of the Marathon Basin, Texas

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by PHILIP B. KING

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GEOLOGY OF THE EASTERN PART OF THE MARATHON BASIN, TEXAS

By PHILIP B. KING

ABSTRACT

This report covers the Paleozoic rocks in the eastern part of the Marathon Basin, west Texas, and in the eastern end of the Glass Mountains to the north, as well as the Cretaceous rocks which lie unconformably on them to the northeast, east, and southeast. The geologic map accompanying the text amplifies ground surveys made between 1927 and 1931, and is based on recent topographic maps, and on photogeology derived from the later air photographs. The accompanying text summarizes the results of the earlier ground surveys, and subsequent observations made by other geologists.

The Marathon Basin exposes pre-Permian Paleozoic rocks. Within the report area these are largely of Carboniferous (Mississippian and Pennsylvanian) age; older Paleozoic rocks are exposed mainly west of the report area. The Carboniferous consists of the Tesnus Formation, the Dimple Limestone, the Haymond Formation, and the Gaptank Formation. The first three are thick, sparsely fossiliferous flysch deposits, of Chesterian, Morrowan, and Atokan ages. The fourth is an abundantly fossiliferous shallow-water marine deposit of Des Moinesian, Missourian, and Virgilian ages.

The Tesnus and Haymond Formations are largely sandstone and shale; the Dimple is largely limestone, but contains flysch features similar to the other two. Striking features of the Haymond Formation are boulder-beds, or wildflysch, which contain heterogeneous cobbles and boulders, including great slabs of carbonate rocks as long as 130 feet across. The overlying Gaptank Formation is mainly sandstone and shale, but contains interbedded conglomerate layers in the lower part, and thick limestone layers in the upper part. The conglomerates indicate that important deformation was taking place in the older rocks not far to the south.

The succeeding Permian rocks of the eastern Glass Mountains are largely of Wolfcampian age, and consist of the thin Neal Ranch Formation and the thick overlying Hess Limestone. The Hess lies with conspicuous angular unconformity on the Neal Ranch and Gaptank Formations.

The Lower Cretaceous Comanchean Series is divided on the map into the Trinity, Fredericksburg, and Washita Groups. It is mostly limestone and interbedded marly limestone, but the Maxon Sandstone forms a persistent layer at the top of the Trinity Group. A few small bodies of intrusive igneous rocks of Tertiary age occur in the Carboniferous rocks in the southwest part of the report area.

Extensive areas of lower ground within the area are covered by thin deposits of gravel of Quaternary age. The deposits are of several Pleistocene and Holocene ages, the older of which are unrelated to modern topography. The most extensive deposits form broad gravel plains, which toward the south are dissected so that younger alluvial deposits lie below them along the present drainage.

The structures of the area are of several ages, the oldest being more complex than the younger. The oldest are in the pre-Permian rocks, which are strongly folded and faulted. These deformed pre-Permian surface rocks are shown by deep drilling to lie with marked discontinuity along a great thrust fault (Dugout Creek overthrust) on another sequence of pre-Permian rocks like those in the cratonic area north of the Marathon (Ouachita) orogenic belt.

The Permian rocks in the Glass Mountains to the north are younger than the deformation of the older rocks, and are at most gently tilted to the north, but they are nevertheless unconformable below the Cretaceous. The Cretaceous rocks slope at low angles northeast, east, and southeast away from the Marathon dome, but structure contours indicate that they are warped into broad, east-plunging arches and troughs.

INTRODUCTION

The Marathon Basin is a topographic feature in western Texas, formed by the removal of the Cretaceous strata that originally covered the Marathon dome, and subsequent excavation of the relatively weaker, strongly deformed pre-Permian rocks beneath. The Glass Mountains to the north are formed of stronger Permian rocks, mainly carbonate, from which the Cretaceous rocks have also been largely stripped. The Cretaceous strata along the edges of the Marathon dome stand above the deformed pre-Permian rocks of the Marathon Basin in prominent escarpments, many of which show clearly the angular unconformity between the pre-Permian rocks and the Cretaceous (fig. 1). The Cretaceous rocks extend outward toward the east, north, and south into the plateaus and mesas that are characteristic of this part of Texas.

This report covers the eastern part of the Marathon Basin, east of the 103°5′ meridian (pl. 1; fig. 2), as well as the eastern end of the Glass Mountains and part of the surrounding Cretaceous plateaus. The northern part lies in Pecos County, the southern part in Brewster County. It is traversed across the center by the Sunset Route of the Southern Pacific Railroad and by U.S. Highway 90. U.S. Highway 385, from Marathon to Fort Stockton, extends across the north part of the area.

All the area of this report was mapped geologically between 1927 and 1931, as a part of a comprehensive survey of the Marathon Region (King, 1930, 1937). Surveys west of the 103° meridian were made in detail on topographic maps, but no topographic maps were available at the time for the area to the east, which covers about a quarter of the Marathon Basin, so that mapping was by reconnaissance surveys of greater or less accuracy.

Since 1968, topographic maps of the eastern part of

FIGURE 1.—Angular unconformity between Paleozoic rocks of Marathon Basin and Cretaceous cover rocks. Southwest face of Housetop Mountains 18 miles east of Marathon at eastern rim of Marathon Basin. Tilted Tesnus Formation (Carboniferous) overlain by flat-lying Glen Rose Limestone (Lower Cretaceous).

the basin, east of the 103° meridian, have been published on the 1:24,000 scale, and two sets of air photographs on different scales have also become available. The topographic maps form the Marathon Gap, Reininger Draw, Dimple Hills, Caprock Butte, Housetop Mountains, Tesnus NE, Tesnus, and Tesnus SE 7½-minute quadrangles (fig. 3). The writer has had these eight quadrangles reduced photographically to make two 15-minute quadrangles on the 1:62,500 scale, in order to match the already available 15-minute quadrangles to the west.

The present report includes the results from a photogeologic survey of the area of the eight 7½-minute quadrangles, based on examination of air photographs, the 1:24,000 topographic maps, and available ground surveys made in 1927 to 1931 (pl. 1). The resulting mapping in the north is mainly a refinement of the original surveys, with more precision as to form and location. The mapping in the south, especially south of the line of the Southern Pacific Railroad, is in an area that was covered only cursorily before and adds many geological details; however, because these details have not been verified by additional ground surveys, considerable uncertainty of interpretation exists. For orientation purposes, a 5-minute strip of the area west of the 103° meridian is also included. The northern part of the strip is taken without modification from the previously published maps. Farther south, greater or lesser modifications have been made on the basis of the photogeologic survey.

The ensuing text describes the bedrock and surficial formations of the area, based in part on the original

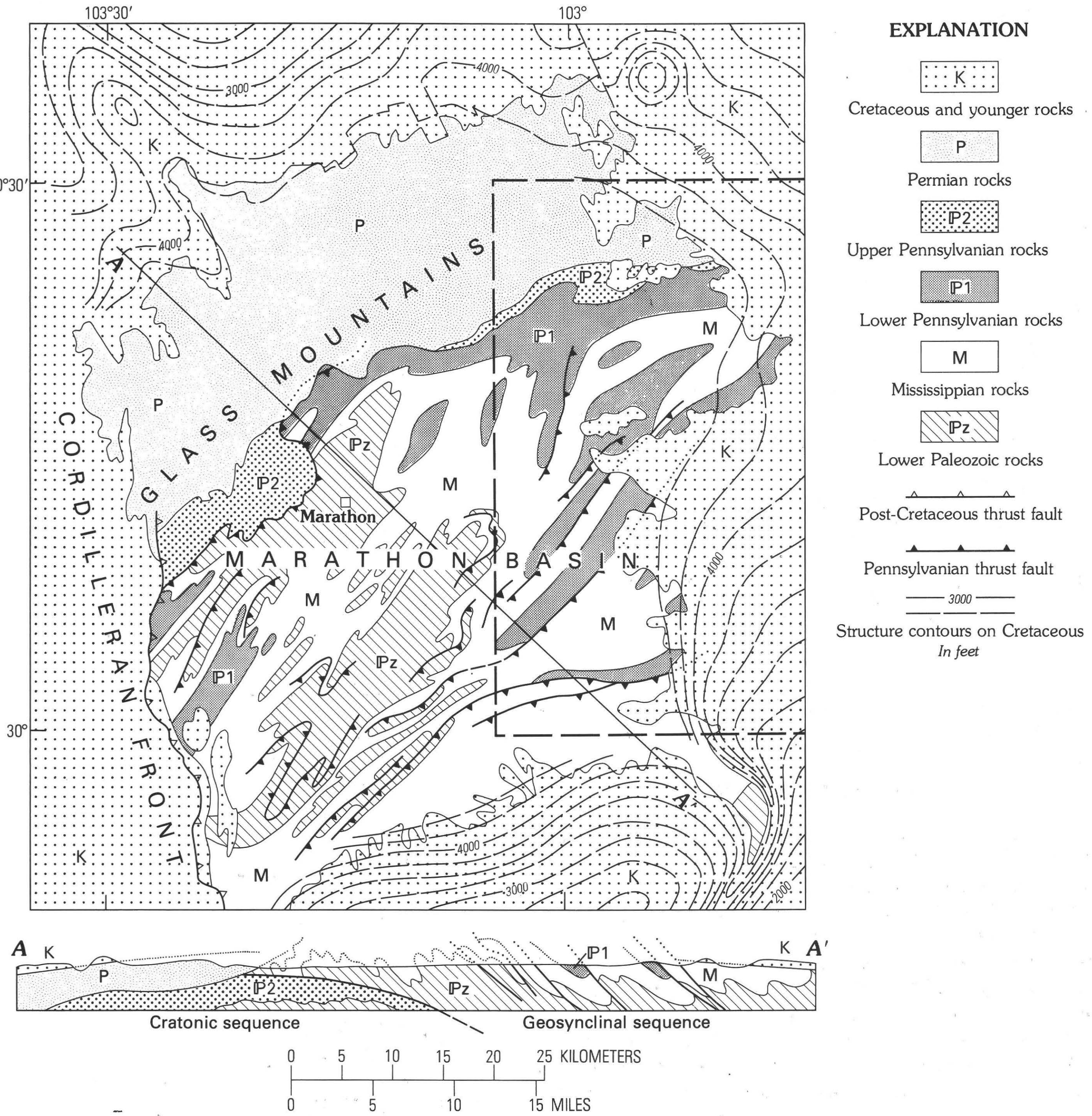


FIGURE 2.—Map of the Marathon Basin, western Texas, showing area covered by this report. Report area outlined by dashed line.

work of 1927 to 1931, but with many additions resulting from subsequent developments, including the results of investigations by others.

STRATIGRAPHY

The bedrock of the area reported on is of Ordovician, Devonian, Mississippian, Pennsylvanian, Permian, and Cretaceous ages (fig. 4). The older, pre-Mississippian rocks emerge in the Marathon Basin farther west, and only a few outcrops extend into the western edge of the report area. A few intrusive igneous rocks of Tertiary age occur in the southwestern part of the area. Extensive areas are covered by deposits of Quaternary gravels, of which several ages can be differentiated.

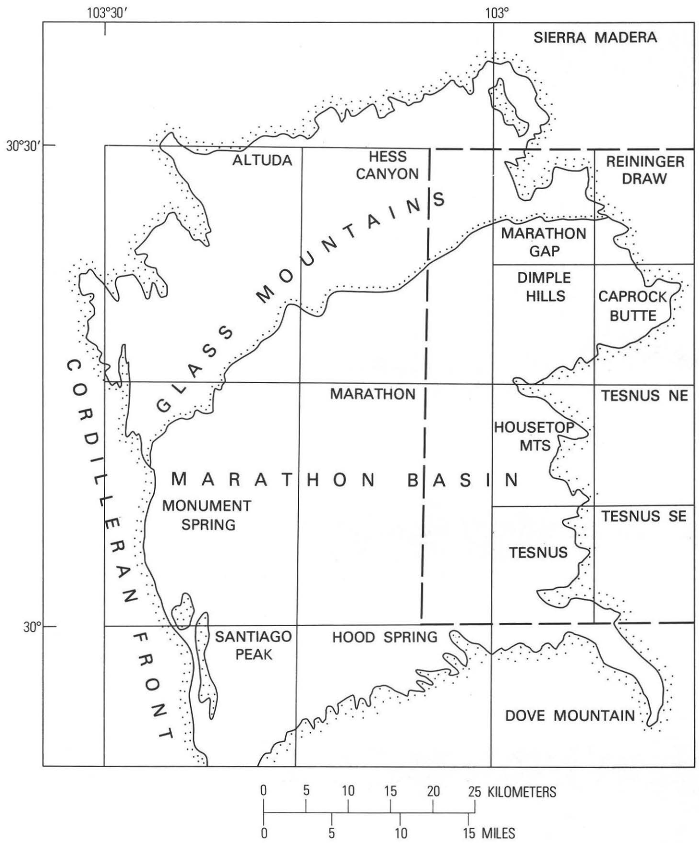


FIGURE 3.—Map of the Marathon Region showing topographic quadrangle maps referred to in text. Area of report outlined by dashed line.

PRE-MISSISSIPPIAN ROCKS

Pre-Mississippian rocks are exposed in the Warwick Hills at the western edge of the report area, and in the Lighting Hills and Horse Mountain a few miles west of the area farther south. They are the eastern edge of a large area of pre-Carboniferous rocks, principally in the large Dagger Flat anticlinorium. These rocks have been strongly folded, and in part are repeated in a series of thrust slices, and they plunge eastward beneath the Mississippian and overlying Carboniferous.

The nearest outcrops consist of the Caballos Novaculite (Dc), of Devonian and early Mississippian age, and the Marvillas Chert (Om) of Late Ordovician age. These siliceous formations are resistant to erosion, and in the Warwick and Lightning Hills stand in low strike ridges, but they rise farther south into Horse Mountain, altitude 5,010 feet, the highest point in the Marathon Basin.

CARBONIFEROUS ROCKS

This thick sequence of strata between the Devonian below and the Permian above is partly of Mississippian and partly of Pennsylvanian age, with a rather uncertain boundary between them. Hence, they will be referred to herein as Carboniferous.

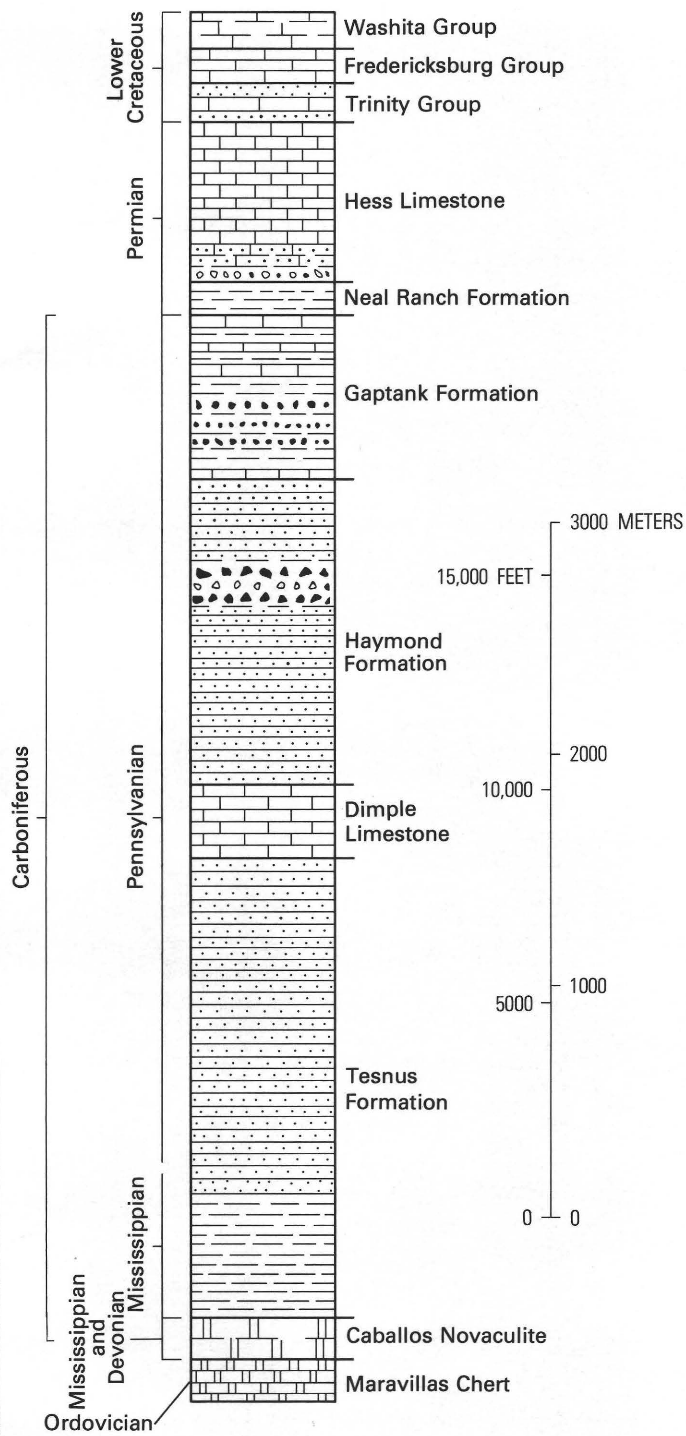


FIGURE 4.—Columnar section showing geological formations that occur in the report area.

TESNUS FORMATION

The lowest Carboniferous strata in the report area belong to the Tesnus Formation (Ct), named for Tesnus

Station[1] on the Southern Pacific Railroad within the report area (Baker and Bowman, 1917, p. 101–102). The Tesnus consists of flysch composed of sandstone and shale, interbedded in units a few feet to several hundred feet thick. It is less resistant to erosion than the underlying Caballos Novaculite or the overlying Dimple Limestone, and hence forms low ground within the Marathon Basin. To the north, it is extensively masked by Quaternary gravel deposits, but in the southeast part of the basin (as in the south part of the report area), it projects in a confusion of low, rough ridges, which are known by such titles as Hells Half Acre and Devils Backbone.

The Tesnus has a variable thickness that increases southeastward, In the northwestern part of the Marathon Basin it is no more than 300 feet thick. In the area south of the town of Marathon, a section 1,619 feet thick was measured. Farther east, in the west part of the report area, a section between the Haymond Mountains and Peña Blanca Spring to the west totaled 6,520 feet. No surface sections of the Tesnus Formation are available farther east and southeast, but in the south part of the report area the thickness must be greater than any of these figures, as the formation crops out over wide areas and dips at high angles, although with unknown duplications by folding and thrusting.

Deep drilling in the northern part of the report area has provided some additional data on the thickness of the Tesnus Formation. In the Continental-Allison well east of Gap Tank, the Tesnus is reported to be 4,210 feet thick. The Mobil-Cox well 6 miles to the south apparently passed through three sequences of Tesnus, repeated by thrusting, which were 3,690 feet, 2,490 feet, and 1,960 feet thick, respectively. Farther southwest, immediately west of the report area, the Exxon-Law well passed through 5,070 feet of Tesnus. These thicknesses are not definitive, because no data are available as to the steepness of dip of the strata in these wells, or details of the structure.

The lower part of the Tesnus Formation is dominantly shale, but sandstone beds dominate in the upper part. The lower shaly part was originally termed the Rough Creek Shale Member (Baker and Bowman, 1917, p. 101) after an anticlinal area on Rough Creek immediately south of the report area, but this name is preoccupied by another stratigraphic unit in central Texas. Moreover, there is no assurance that these lower shaly beds are at the same stratigraphic level in all parts of the Marathon Basin; nevertheless, the general shaliness of the lower part of the formation is genuine. Shales dominate the lower 2,000 feet of the 6,510-foot section between the Haymond Mountains and Peña Blanca Spring, and the lower 1,189 feet of the 1,620-foot section south of Marathon. Most of the 300-foot section in the northwestern part of the Marathon Basin is shale. In the eastern part of the Marathon Basin, the upper 300 to 400 feet of the Tesnus is again black shale, which contains thin limestone beds in the upper part that are gradational into the Dimple Limestone.

The general stratigraphy and lithology of the Tesnus Formation were described in the earlier reports (King, 1930, p. 31–36; 1937, p. 55–62). Within the last few decades its petrography and sedimentary structures have been investigated by various geologists (Johnson, 1962; McBride and Thomson, 1965; Cotera, 1969; Thomson, 1969; Flores, 1977; McBride, 1978, p. 131–136).

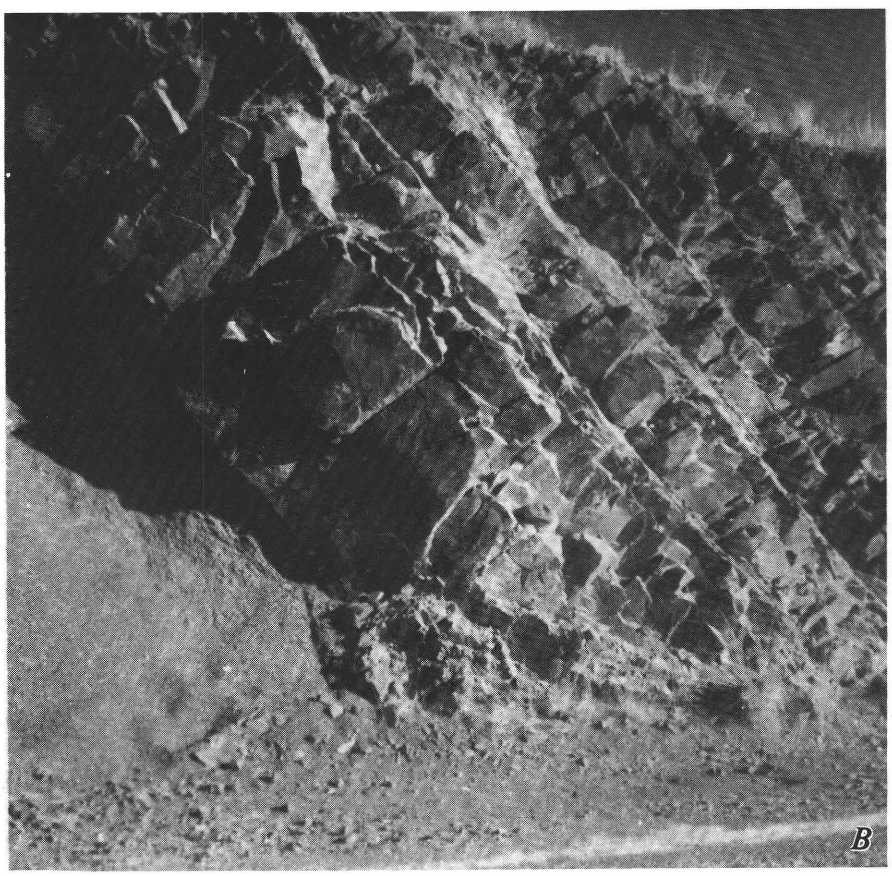
The lower shales are dominantly illite; higher up they are chlorite and illite, with some montmorillonite. Many of the lower shales are black or blue-black, but there are some interbedded greener layers, and these dominate in the higher strata.

The sandstones form layers a few inches to several feet thick, which frequently occur in groups or bundles (fig. 5), separated by shaly units of somewhat lesser thickness. This characteristic distinguishes the Tesnus from the otherwise very similar Haymond Formation, in which the layering is much thinner and more regular. Some thick, massive sandstone beds occur; such ledge-making sandstones are particularly prominent in the eastern part of the Marathon Basin, just above the lower shales, and are well shown on the air photographs. The sandstones are commonly fine grained and weather rusty brown; on fresh surfaces they have a greenish tinge, due to chlorite in the matrix.

Quartz grains form somewhat over half of the sandstones; the remainder are grains of other minerals and of rock fragments. The sandstones may be classed as quartz wackes, or immature subgraywackes. According to Cotera (1969) the middle part of the upper sandstones in the eastern part of the Marathon Basin contains more feldspar than the parts above or below, which contain more metamorphic rock fragments. Accessory heavy mineral grains include abundant garnet in the lower part, and also significant amounts of apatite. Other accessory minerals include zircon, magnetite, tourmaline, and hornblende.

In the southeastern part of the Marathon Basin, in the southern part of the report area, are layers of massive white quartzite (q), enclosed in the more usual sandstones and shales. These are probably only two or three in number, but they are much repeated by folding and thrusting. They form especially prominent,

[1]Tesnus is on the line of the Sunset Route of the Southern Pacific Railroad, and the name is simply the word "Sunset" spelled backwards.



light-colored, sharp-edged ridges that stand out on the air photographs.

Thin layers of chert-pebble conglomerate occur in places near the base, and are also reported at a few places in the upper part in the southeastern part of the Marathon Basin. The fragments are black, green, brown, and white chert, mostly derived from the underlying Caballos Novaculite. The pebbles are commonly cemented by chalcedony.

Sedimentary structures in the Tesnus sandstones have been described by various geologists (Johnson, 1962; McBride and Thomson, 1965; Thomson, 1969). Graded bedding is not prominent, owing to the general fine grain of the sandstones, but bases of each bed are generally sharply marked, whereas their upper contacts are less prominent. The basal contacts are frequently marked by flute casts and groove casts. In some beds these are crossed at right angles by soft-sediment faults with displacements of less than an inch or two. In some layers there are well-marked slump structures that produce warped, folded, and disrupted sandstone beds. Commonly these are associated with sandstone dikes.

Paleocurrent measurements from beds of sandstone in the Tesnus Formation in all parts of the Marathon Basin show an invariable movement from southeast to northwest (Johnson, 1962, p. 790–791). Opinions have varied through the years as to the conditions of origin of the Tesnus Formation, but it is now generally believed that it was deposited in a trough of considerable depth, into which the sandstones, at least, were transported by turbidity currents. They have the characteristics of submarine fan deposits (McBride, 1978, p. 135; T. H. Nilsen, written commun., 1978).

Fossils are not abundant in the Tesnus Formation. The most common are plant fragments, mostly worn and comminuted. Larger plant fragments, including sizeable logs, occur at a few places, especially in the upper part, as at a locality south of Marathon. According to David White (King, 1937, p. 61) these are of Early Pennsylvanian (Pottsville) age. From shale samples near the top of the formation, Bruce Harlton has obtained Foraminifera said to be of Early Pennsylvanian age (King, 1930, p. 36). However, conodonts from shales near the base of the Tesnus are Mississippian (Ellison, 1962). Radiolarians (Baker, 1963) and a crustacean (Brooks, 1955) are also reported.

The Tesnus Formation therefore includes strata of Mississippian and Early Pennsylvanian age. It is probably equivalent to the similar but thicker Stanley and Jackfork Formations of the Ouachita Mountains, which are of Meramecian, Chesterian, and Morrowan age.

DIMPLE LIMESTONE

The Dimple Limestone (Cd) is named for the Dimple Hills (Baker and Bowman, 1917, p. 105), a synclinal mass in the north part of the present report area, which rises 750 feet above W B Flats. The hills are so-named for the dimpled appearance of their dissected slopes. The Dimple projects from the low ground of the Marathon Basin in prominent ridges, only a little lower than those of the Caballos Novaculite. Within the report area, the Dimple is repeated in many ridges, from the Dimple Hills and W B Flats southward nearly to Shely Peaks (Tres Hermanas).[2] In the south part of the area, the ridges curve about in synclinal hooks, each enclosing Haymond Formation in their centers. In the north part of the area, the outcrops are much more interrupted by the cover of Quaternary gravels, but the fragments of outcrop clearly show the same orderly pattern (fig. 16).

In the Dimple Hills the writer (King, 1930, p. 36–38) measured a thickness of 1,160 feet of the formation, which, however, includes 66 feet of transition beds below and over 200 feet of transition beds above, which are dominantly shaly, with only a few thin interbedded limestone layers. Thomson and Thomasson (1964) report 905 feet on the ridge west of Frog Creek about 6 miles southwest of the Dimple Hills. These are apparently maximum thicknesses of the formation. Measurements by the writer and Thomson and Thomasson along the north and northwestern edges of the Marathon Basin yield thicknesses of 380 to 400 feet. In the buttes 7 miles east-southeast of Gap Tank, Thomson and Thomasson report a thickness of 435 feet. The formation also thins southeastward from the maximum. Measurements by the writer (1937, p. 62–63) and Thomson and Thomasson indicate a thickness of about 500 feet in the Haymond area, and in the southeastern part of the Marathon Basin near Panther Peaks, Thomson and Thomasson report 250 to 400 feet.

The sedimentology of the Dimple Limestone has been studied by Thomson and Thomasson (1964; 1969a, b), who distinguish three facies. Along the north edge of the Marathon Basin is a shelf facies, presumably formed in fairly shallow water, composed

◀ FIGURE 5.—Thick-bedded sandstones of upper part of Tesnus Formation, with interbedded shale. *A*, On San Francisco Creek 16 miles southeast of Marathon. *B*, Cut on U.S. Highway 90 east of Lemons Gap 19 miles east of Marathon; stratigraphic top to the right.

[2] On the older maps, the group of peaks on the promontory of Cretaceous rocks in the southeast part of the report area were designated as Tres Hermanas. On the recently published Tesnus 1:24,000 topographic sheet they are designated as Shely Peaks, but the earlier name is perpetuated by the name of the triangulation point on the western peak. In the present text, both names are indicated.

of grainstones in beds several feet thick, crossbedded in part, but not graded; they are interbedded with lenticular layers of chert-pebble and chert-cobble conglomerate. Southeast of this, in a belt about 4 miles wide, is a slope facies, transitional from the shelf facies into a basin facies; it includes the exposures in the Dimple Hills. The remainder of the Dimple farther southeast, including the part in the report area, is a basin facies. Beds are mostly thinner than in the shelf facies, and more regular. The rock is fine-grained, and all beds are graded, their lower parts being lime packstones, their upper parts spicular lime mudstones, passing into shales and spicular cherts. Upper parts of some of the layers are prominently convoluted, the convolutions being emphasised by silicification of the laminae (figs. 6 and 7). The basin facies is a calcareous flysch. The distinguishing features of the shelf and basin facies are very evident in the field. They were apparent to the writer during his earlier field work in the area, although without realization of their meaning.

Directional structures, such as groove casts, crossbedding, overturning of convolute laminae, and aligned sponge spicules, all show paleocurrents directed southeastward, except in the southeasternmost belt near Panther Peaks, where a few determinations show northwestward-directed paleocurrents.

Fossils are fairly common in the Dimple Limestone, but most of them are fragmented shells, so that it is difficult to obtain identifiable material. From various localities in the Marathon Basin, the writer has col-

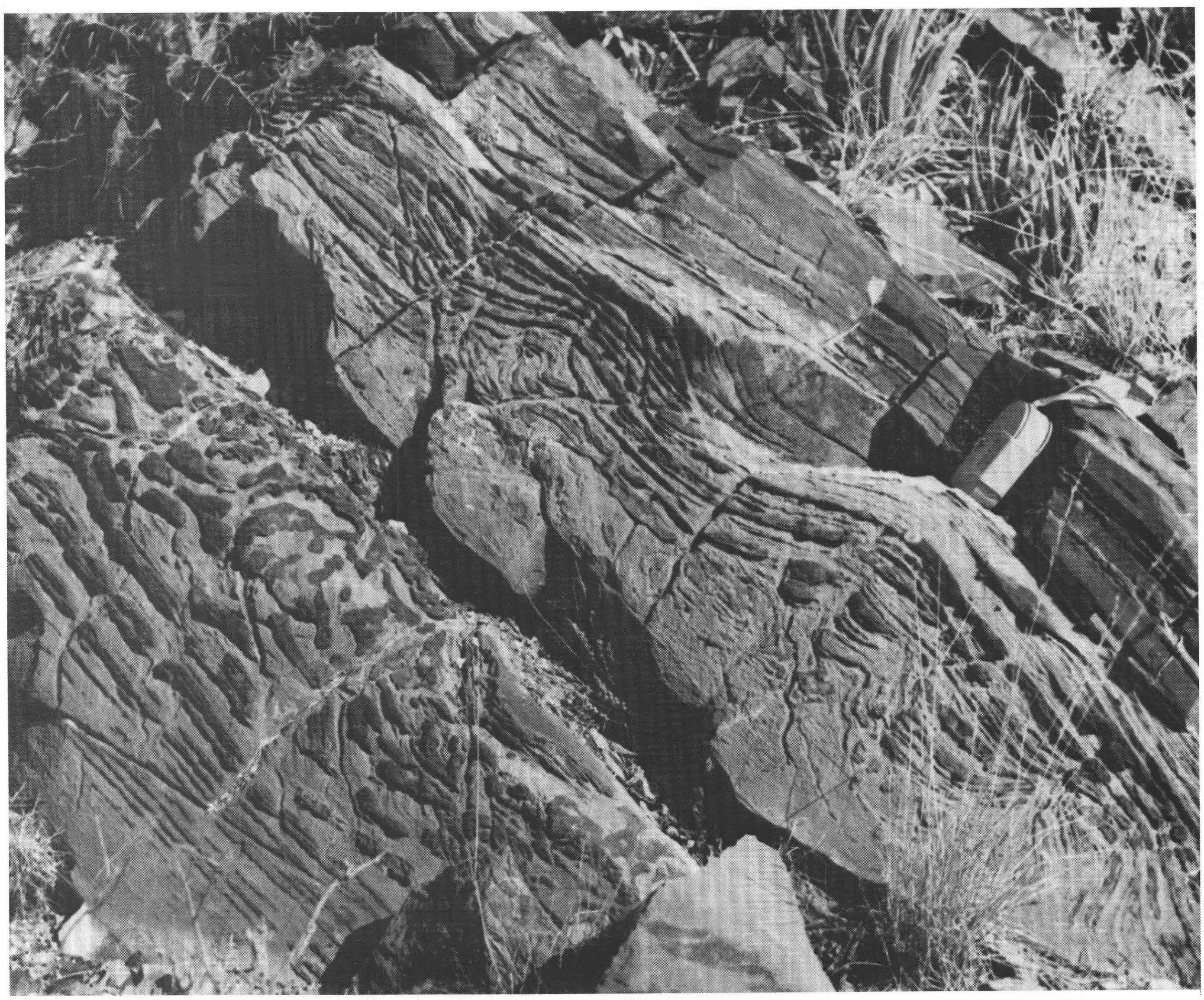


FIGURE 6.—Dimple Limestone east of Haymond Station 15 miles east-southeast of Marathon. Inverted beds of resedimented carbonate, with convolute layers outlined by silicified bands.

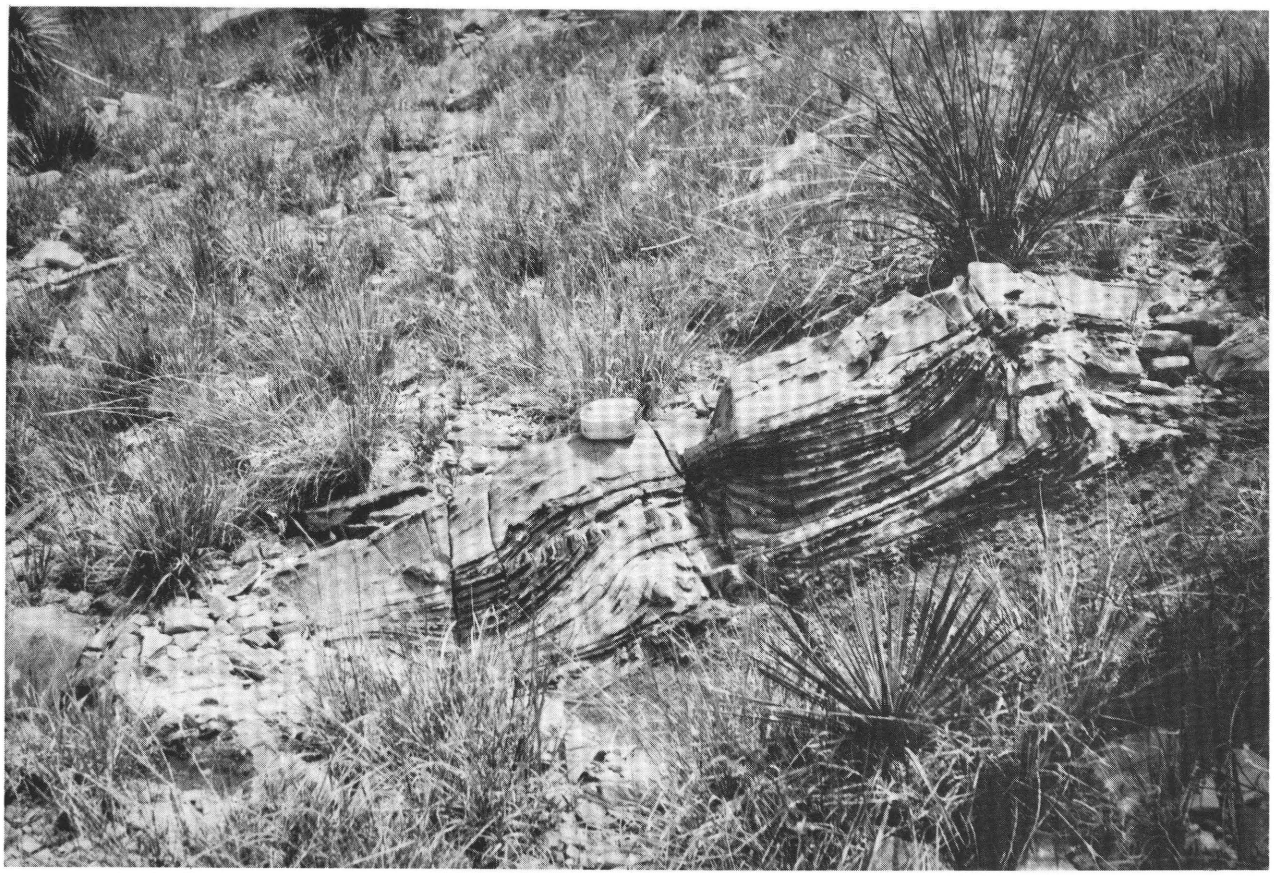


FIGURE 7.—Structures in Dimple Limestone similar to those in figure 6, originally described (King, 1930, pl. II) as "dome-like structures outlined by chert bands." On ridge west of Frog Creek, 15 miles east of Marathon.

lected corals, brachiopods, and a few poorly preserved ammonoids (probably *Gastrioceras*). These were considered by G. H. Girty to be of Pottsville (Early Pennsylvanian) age (King, 1937, p. 64). Bruce Harlton has collected Foraminifera from shales interbedded in the Dimple which are believed to be of Marble Falls or Wapanucka age (King, 1930, p. 39). Ellison and Graves (1941) identified species of conodonts considered to be of Morrowan age.

Sanderson and W. E. King (1964) have obtained fusulinids from the Dimple Limestone at many localities in the Marathon Basin, and recognize three zones—the oldest containing *Millerella*, the next highest *Profusulinella* and *Eoschubertella*, and the highest *Fusulinella*. They consider the oldest to be of Morrowan age and the two higher ones Atokan. The *Millerellas* occur at localities all over the Marathon Basin, the two higher zones being more restricted, the last occurring only at a few localities in the northwestern part of the basin.

In summary, all the fossils in the Dimple Limestone indicate an early Pennsylvanian age (Pottsville of Girty). Most of them indicate a Morrowan (Marble Falls or Wapanucka) age, but some of the fusulinids are evidently Atokan.

HAYMOND FORMATION

The Haymond Formation (Ch) is named for Haymond Station on the Southern Pacific Railroad in the eastern part of the Marathon Basin, in the report area (Baker and Bowman, 1917, p. 107), where it is exposed in two synclines east and west of the station. The formation is a clastic, sandy and shaly flysch deposit somewhat like the Tesnus Formation, and like it forms low ground in the Marathon Basin. Its extent is more restricted than the Tesnus, however, as it is confined to synclinal remnants, and it is further masked by Quaternary deposits. The most extensive areas of the Haymond Formation in the Marathon Basin are in the report area, those elsewhere in the basin being smaller and preserving a smaller thickness of beds.

In the north part of the Marathon Basin, the cover of Quaternary deposits is especially extensive, the largest areas of exposure being along the bases of Cretaceous mesas southeast of Gap Tank. Outcrops are more continuous farther south, especially in the two synclinal areas east and west of Haymond Station. A little-known area of Haymond Formation occurs in the southeastern part of the Marathon Basin south of Tesnus Staton, south of an outcrop band of Dimple Limestone that extends eastward from Panther Peaks.

No complete sections of the Haymond Formation from base to top are exposed. In most of the synclinal remnants the top is not preserved, and only the upper part, in downward sequence below the Gaptank Formation, is preserved southeast of Gap Tank. In the syncline east of Haymond Station, the writer estimated a thickness of 3,600 feet of strata above the Dimple Limestone; McBride (1966, pl. 1) gives 4,200 feet in the same area. Southeast of Gap Tank, both the writer and McBride found about 2,000 feet of strata below the Gaptank Formation. A possible tie between the two sequences is the occurrence in both of boulder-beds. The Haymond Formation is at least 5,000 feet thick, and might be thicker.

The Haymond Formation was described at length by the writer (1937), p. 64–73) and by others during the 1930's. Within the last few decades it has been given extensive sedimentological study (McBride, 1964a, 1966, 1969, 1970, 1978, p. 141–146; Dean and Anderson, 1966; Flores and Ferm, 1970; Flores, 1972, 1974, 1975; among others). Most of these recent studies have been made on outcrops within the report area.

The most abundant rock type in the Haymond is thin-bedded sandstone and shale, in alternating layers a few inches thick (fig. 8). This particular facies seldom occurs in the Tesnus Formation and is a good field guide for distinguishing these otherwise similar sandy

FIGURE 8.—Lower part of Haymond Formation in cut on U.S. Highway 90 east of Lemons Gap 18 miles east of Marathon. Height of cut about 10 feet. Thin-bedded flysch composed of interbedded sandstone and shale; bending of strata at top of cut results from soil creep. Compare with sandstone beds of Tesnus Formation in figure 5*B*, which is faulted against the Haymond to the east.

and shaly flysch formations. The facies forms all the lower part of the sequence in the synclines near Haymond Station, but only a small part of the section southeast of Gap Tank. The sandstone layers are commonly a few inches thick, and are mainly fine grained, verging on coarse siltstone; a few coarser sandstone beds are a foot or more thick. The shale beds have the same general thickness as the sandstone beds. McBride estimates that there may be more than 15,000 alternating sandstone and shale layers in the synclines near Haymond. By statistical analysis, Dean and Anderson (1966) propose a correlation of layers of the sandstone and shale between exposures on U.S. Highway 90 and on the Southern Pacific Railroad 7 miles to the south, thus implying a great persistence of individual layers. McBride (1966, p. 18–22) records various small-scale sedimentary structures in the sandstone and shale beds. Graded bedding occurs in many layers, but is obscure. Many of the layers are finely laminated, and the upper parts are crossbedded or even convolute-laminated. Many of the lower bedding surfaces are marked by groove casts or flute casts. Some of the bedding surfaces contain plant fragments.

Coarse sandstone beds are minor constituents in the sequences to the south, but are much thicker and more prominent in the sequence southeast of Gap Tank to the north. They were termed "arkose" by the writer (1930, p. 42; 1937, p. 66), but McBride (1966, p. 23) states that they contain no more feldspar than the other sandstones of the Haymond, although they contain less fine-grained matrix. Nevertheless, the coarse sandstones differ from these in their lighter colors, greater friability, and thicker, structureless layers. Individual beds may be as thick as 5 feet, but southeast of Gap Tank bundles of the sandstone beds exceed 50 feet in thickness.

Limestone layers are uncommon in the Haymond Formation. The only exceptions are two thin layers of brown sandy and pebbly limestone in the synclinal area 3 miles south of the Dimple Hills that contain fusulininds (Skinner and Wilde, 1954) (fig. 9). They are interbedded in the prevailing thin-bedded sandstones and shales, and McBride (1966, p. 15) believes that they are turbidites like the enclosing strata.

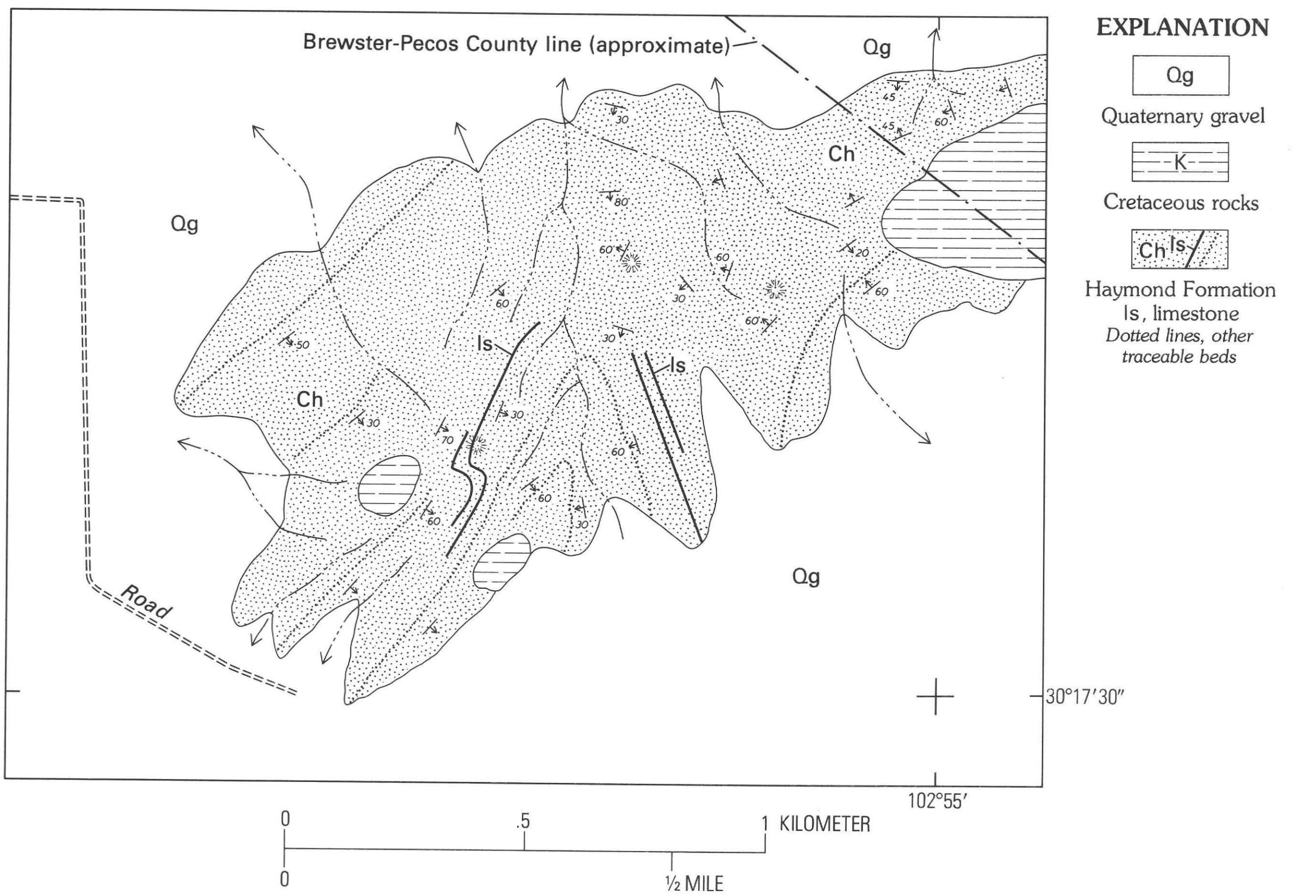


FIGURE 9.—Field sketch made in 1930 of outcrop area of Haymond Formation 3 miles (5 km) south of Dimple Hills, showing outcrops and structure of fusulinid-bearing limestone layers.

BOULDER-BEDS

The most spectacular rocks in the Haymond Formation are the boulder-beds (Chb), which have aroused much interest and study since their discovery by the writer in 1930. They occur in two areas—in the syncline east of Haymond Station below Housetop Mountains[3] where they crop out for a distance of about 8 miles, and in the area of Haymond Formation southeast of Gap Tank where they crop out for a distance of about 4 miles. The boulder-beds in the two areas are of somewhat different character, although they probably occur at nearly the same stratigraphic level.

The boulder-beds below Housetop Mountains are about 1,800 feet above the base of the formation, and form a lenticular complex a few hundred feet to more than 900 feet thick. The assemblage includes boulder-bearing mudstone, interbedded coarse sandstone, contorted thin-bedded flysch, and chert conglomerate. The boulder-bearing mudstones attain their greatest thickness and greatest concentration of boulders in an area west of the summit of Housetop Mountains, and lens out and interfinger with other clastic rocks northeast and southwest along the strike.

The most impressive feature of the boulder-beds in this area is the large size of some of the individual blocks (figs. 10 and 11). The largest blocks are of limestone, mainly a fossiliferous Pennsylvanian limestone, but including one block of Dimple Limestone 130 feet across at a locality south of the Southern Pacific Railroad. The fossiliferous limestone is unlike any formation in the Marathon Basin, or in any nearby regions, but its fauna is of Early Pennsylvanian age, hence approximately the age of the Dimple Limestone. Somewhat smaller fragments are from older formations of the Marathon Basin sequence, especially of the Caballos Novaculite (fig. 12), but there are a few others from the Tesnus Formation and the Maravillas Chert. Besides these, are numerous well-rounded cobbles of crystalline rocks—rhyolite, schist, aplite, syenite, vein quartz, and the like; they have yielded radiometric ages by Rb/Sr methods of 370 to 410 m.y. (Silurian and Devonian) (Denison and others, 1969, p. 249).

Many, perhaps most of the boulders of Caballos Novaculite are brecciated. The writer (1937, p. 91) compared the brecciation of the novaculite in the boulders to that seen at the bases of thrust sheets elsewhere in the Marathon Basin, and interpreted the brecciation as having been produced tectonically, before emplacement in the boulder-bed. However, Folk (1973, p. 718) has observed novaculite breccias in outcrops of the Caballos which he believes formed penecontemporaneously with the sedimentation. The tectonic origin of the brecciation of the novaculite in the boulders is therefore questionable.

The following data on the larger boulders from the Housetop Mountains area have been compiled from the author's detailed map of the area (King, 1937, plate 10):

Formation	Number and diameter of boulders 3–10 ft	10–50 ft	50+ ft	Total
Fossiliferous Pennsylvanian limestone	24	24	7	55
Dimple Limestone	1	1	1	3
Tesnus Formation	5	6	----	11
Caballos Novaculite	73	15	----	88
Maravillas Chert	1	----	----	1

The boulder-beds southeast of Gap Tank are about 400 feet below the base of the Gaptank Formation and lie in a sequence of prevailingly coarse, thick-bedded sandstone. The boulder-beds are each no more than 10 to 25 feet thick. McBridge (1966, p. 28) and Flores (1972) record two or more layers, separated by as much as 150 feet of other strata. The exotic fragments are cobbles and boulders as much as 3 feet in diameter, with one block 7 feet long. Most of the fragments are of Caballos Novaculite, but there are also many of Maravillas chert and limestone; a very few are sandstone from the Tesnus, fossiliferous Pennsylvanian limestone, and rhyolite. The composition of the fragments thus differs from those in the Housetop Mountains area to the south, and it contrasts notably with fragments in the conglomerates of the Gaptank Formation nearby and higher in the section.

FOSSILS AND AGE

Indigenous fossils are rather rare in the Haymond formation. Plant fragments are fairly common, but most of them are small and clearly reworked. Larger identifiable material has been found at a few places. In a layer southeast of Gap Tank, about 1,200 feet below

[3]On older maps, small groups of mountain peaks have been indicated by the singular word "Mountain," and this has been used on older maps for the peaks of Cretaceous rocks at this place. Within the last few decades the U.S. Geological Survey has used the plural form for these features, hence "Housetop Mountain" of older usage becomes "Housetop Mountains" on the Housetop Mountains 1:24,000 topographic map.

FIGURE 10.—Boulder-beds of Haymond Formation at an area of greatest concentration of large boulders, at west foot of Housetop Mountains 19 miles east-southeast of Marathon. *A*, General view, looking northwest. The small knobs are mainly giant blocks or slabs of fossiliferous Pennsylvanian shelf limestone. Lower half of Haymond Formation and Dimple Limestone in middle distance; scarps of Lower Cretaceous on skyline. *B*, Nearer view of one of the exotic limestone blocks at same locality, with mudstone matrix of boulder-bed in foreground.

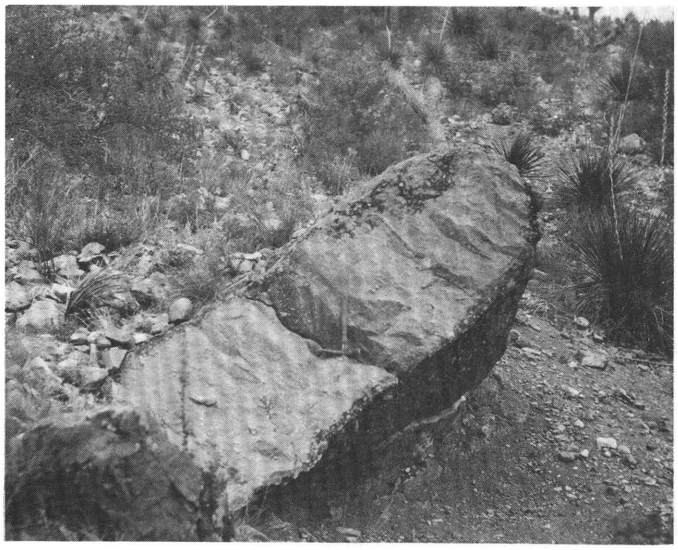


FIGURE 11.—Medium-sized slablike boulder of Pennsylvanian limestone at a locality not far to the north, projecting from mudstone matrix.

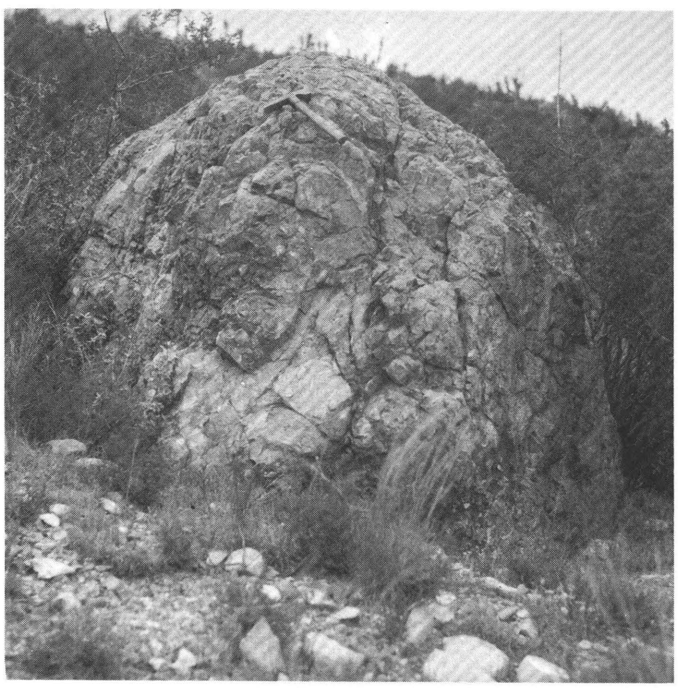


FIGURE 12.—Large rounded boulder of brecciated Caballos Novaculite in boulder-bed at a locality near figures 10 and 11.

the boulder-bed, David White and the writer collected plant remains considered by White to be of Pottsville age. The thin limestone beds in the middle of the Haymond south of the Dimple Hills contain fusulinids identified by Skinner and Wilde (1954, p. 803) as *Fusulinella haymondensis* n. sp., considered to be of Atokan age. The Haymond Formation seems to be approximately equivalent to the Atoka Formation of Oklahoma and Arkansas.

The blocks of fossiliferous Pennsylvanian limestone in the Haymond Formation of the Housetop Mountains area contain a large fauna of invertebrates, which were thoroughly collected by J. Brookes Knight in 1931 (King, 1937, p. 72–73). G. H. Girty states that these are of Early Pennsylvanian age and mentions their resemblance to various Morrowan faunas. This suggests that the limestones in the blocks are of nearly the same age as the Dimple Limestone, although they are of a very different facies.

ORIGIN

The Haymond Formation, like the Tesnus, is a flysch deposit, composed largely of interbedded sandstone and shale; however, the details of its character, and thus the conditions of its formation, are considerably different. Most of it was deposited in water of much depth, and the thin-bedded sandstones and shales, at least, are clearly turbidite deposits, but they are basin-plain deposits rather than submarine fan deposits as in the Tesnus (McBride, 1978, p. 143–144; T. H. Nilsen, written commun., 1978). Paleocurrent observations by McBride (1966, p. 54–55) show a dominant sediment transport toward the northwest, but with a minor turning of the currents westward down the axis of the trough.

More uncertainty attends the origin of the coarse sandstone beds, especially those of the upper part of the formation southeast of Gap Tank. McBride (1966, p. 53) proposes that they were probably deep-water deposits like the thin-bedded sandstones and shales, although with some doubt, whereas Flores (1972, p. 3424) interprets them as delta-front and delta-plain deposits, thus implying a shallow water origin. They also have many characters of deeper water submarine fan deposits (E. T. McBride, written commun., 1978).

Many ideas have been expressed through the years as to the origin of the boulder-beds. Notions that they were glacial deposits (Baker, 1932; Carney, 1935), beach deposits (Flores and Ferm, 1970), a tectonic moraine (Van der Gracht, 1931), or the crests of broken folds (Hall, 1957) have little merit.

The writer has always believed, from the time of their first discovery, that the boulder-beds were somehow intimately related to the tectonic evolution of the region. Later, in line with developing concepts of sedimentology, he (1958, p. 1734) proposed that the boulder-beds "were subaqueous deposits, laid down in a deep, rapidly subsiding trough, with tectonically unstable, probably faulted margins. Into the trough, probably from both sides, the blocks, boulders, well-rounded cobbles, and muds were carried from the unstable shelves, in subaqueous landslips which developed proximally into turbid flows." The boulder-beds are thus an exaggeration of the more usual sedimentation, or a wildflysch. McBride (1966, p. 49–52) has elaborated on the same scheme.

McBride, however, on the basis of paleocurrent data from the enclosing more usual flysch strata, concludes that the boulders were all carried into the sedimentary trough from the southeast. A southeastern source is plausible for many of the fragments—those of the older Paleozoic Tesnus, Caballos, and Maravillas Formations, as well as the rounded cobbles of crystalline rocks. The Paleozoic radiometric ages obtained from the latter and incompatible with those of the basement of the craton to the north, and they must have come from a backland that was being orogenically deformed during early Paleozoic time. The well-rounded character of the crystalline cobbles indicates that they had been first laid down on beaches before they slumped and slid into their present positions.

Nevertheless, the great limestone blocks and slabs could not have had a southeastern source, and the writer believes that they were derived from an unstable shelf to the northwest. The slab of Dimple Limestone is of shelf, or northwestern facies, and the more numerous slabs of fossiliferous Pennsylvanian limestone probably had a similar source, from the craton to the northwest. The rocks of the boulder-bed thus appear to have had a composite source, from unstable margins on both the southeastern and the northwestern sides of the depositional trough.

GAPTANK FORMATION

The Gaptank Formation (Cg) is named for Gap Tank (Udden, 1917, p. 38) at the edge of the Glass Mountains in the north part of the report area. The Gaptank Formation forms the top of the Pennsylvanian in the Marathon Basin sequence and is exposed along the north edge of the basin, at the bases of the Glass Mountains escarpments. The main area of exposure is in the foothills south of Gap Tank in the northwestern part of the report area. Smaller exposures of the Gaptank occur farther east in the north part of the report area. From the Gap Tank area, the upper part of the formation is exposed along the base of the Glass Mountains escarpment westward from the report area for 3 miles to the Wolf camp Hills. Still farther west are other outcrops south of the Glass Mountains of rocks of Late Pennsylvanian, or Gaptank age, but they are of another facies, lie in a different structural setting, and will not be considered further here.

AREA NEAR GAP TANK

In the area south of Gap Tank, the Gaptank Formation is folded into an east-plunging anticline, steepest on the south flank, but dipping more gently on the north flank beneath the Permian rocks of the Glass Mountains (fig. 13). In this area, the writer estimated a thickness of the formation of about 1,800 feet between the underlying Haymond Formation and the overlying Wolfcampian strata. On the geologic map, the formation in this area is divided into a lower (Cgl) and an upper (Cgu) part.

At its base, resting on shales and sandstones of the Haymond Formation, is the *Chaetetes* limestone, about 50 feet thick. This is followed by 150 feet of shale and sandstone. In the next 750 feet of section the sandstone and shale contains five conglomerate layers 15 to 40 feet thick, which are thickest to the south, and thin rapidly on the north flank of the anticline. The upper 750 feet of the formation (Cgu) containes five limestone layers 50 to 75 feet thick, separated by sandstone and shale, the thickest limestone layers being at the top.

The conglomerate beds of the lower part of the formation contain well-rounded limestone cobbles as much as a foot in diameter, mostly from the Dimple Limestone, but including a significant number from the *Chaetetes* limestone at the base of the formation (fig. 14); minor fragments of chert from the lower formations of the Marathon Basin have also been reported. The rapid northward thinning of the conglomerate beds indicates that their cobbles were derived from an area undergoing deformation not far to the south (King, 1930, p. 110–112). However, the succession of the lower beds in the Gap Tank area itself is to all appearances conformable.

Nevertheless, Ross (1967, p. 372) places a major unconformity beneath the lowest conglomerate bed, and reassigns the beds beneath, including the *Chaetetes* limestone, to the upper part of the Haymond Formation. This interpretation is very questionable; unconformities (and pseudo-unconformities) are a "dime-a-dozen" in this part of the sequence, and assigning a major role to any of them is highly subjective. Ross's supposed time gap between the *Chaetetes* limestone and the conglomerates is not convincing, as the faunas below and above are of Desmoinesian and Missourian age, respectively, with a considerable thickness of unfossiliferous beds between. The greatest change in sedimentation in the sequence is between the siliciclastic Haymond beds and the succeeding *Chaetetes* limestone, hence I continue to place the base of the Gaptank Formation where it was originally described.

To the north, at Gap Tank, the Gaptank Formation is overlain by about 100 feet of the Neal Ranch Formation of early Wolfcampian age (Ross, 1965, p. 81, section 41), but this unit pinches out a short distance to the west. Both the Gaptank and the Neal Ranch are overlain with moderate angular unconformity by the

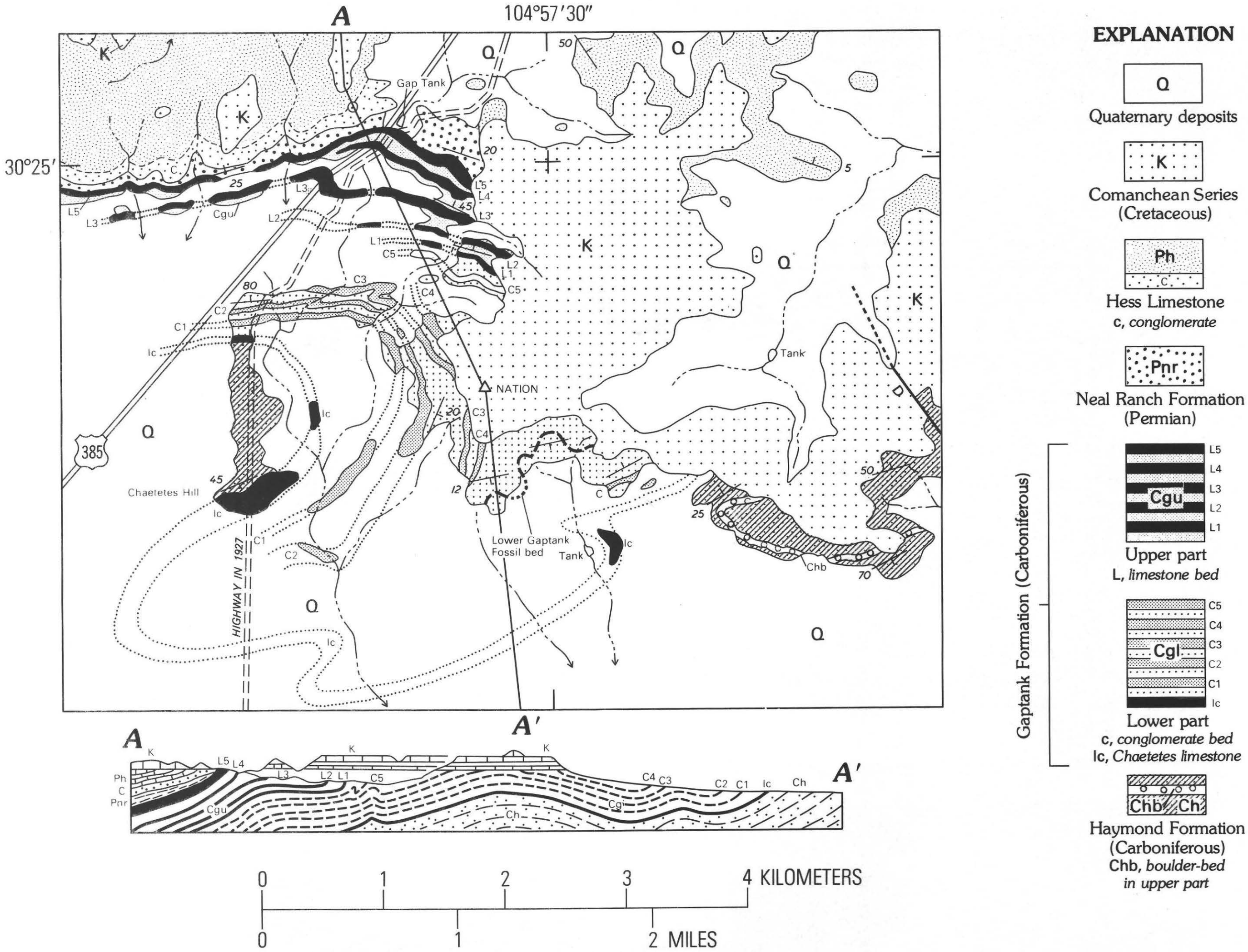


FIGURE 13—Geologic map of the Gap Tank area showing details of sub-divisions of the Gaptank Formation, based on surveys made in 1927 (King, 1930, fig. 15), which are difficult to reconcile in detail with the modern topographic data.

basal conglomerate of the Hess Limestone of upper Wolfcampian age. The strata below the unconformity are considerably truncated by it. Ross (1967, p. 373) suggests that as much as 400 to 500 feet of upper Gaptank beds, mainly limestone, may wedge in below the unconformity between Gap Tank and the Wolfcamp Hills.

Fossils occur at many levels in the Gaptank Formation in its type area, and indicate that the formation embraces all of the late Pennsylvanian (Des Moinesian, Missourian, and Virgilian), in contrast to the rather limited age range of the vastly thicker and Late Mississippian and Pennsylvanian flysch deposits (Chesterian, Morrowan, and Atokan).

The *Chaetetes* limestone at the base contains *Chaetetes milleporaceus,* cup corals, brachiopods, and the fusulinids *Fusulina attenuata, F. haworthi,* and *Wedekindelina euthisepta,* which are of Des Moinesian age. Fossils next appear between the second and third conglomerate beds, but the most prolific lower Gaptank fossils are in shales between the fourth and fifth conglomerate beds, at a locality originally discovered by J. A. Udden (1917, p. 38–39) and Emil Böse (1917, p. 17–18), at the south foot of the Cretaceous mesas, 2 miles southeast of Gap Tank. The bed contains corals, bryozoans, pelecypods, gastropods, a cephalopod (*Schistoceras smithi*), a large assemblage of brachiopods, and a large number of small *Triticites* re-

FIGURE 14.—Roundstone cobbles in lowest conglomerate member of the Gaptank Formation south of Gap Tank and 20 miles northeast of Marathon. The clasts are mainly from the Dimple Limestone, but include a few from the *Chaetetes* limestone at the base of the Gaptank, one of which (C) appears below the hammer in *B*. ▶


c

lated to *T. irregularis*. This fauna is of Missourian age.

Fossils are less abundant in the higher limestones and associated beds of the Gap Tank section, but a few brachiopods and other forms occur at different levels. From the lower part of the interval Ross (1965, p. 11) has identified *Triticites ohioensis, T. burgessae,* and *T. joensis* of Missourian age, and from the upper part of the interval *T. compactus, T. beedei, T. primarus,* and *T. cullomensis* of Virgilian age.

Conodonts have been recovered at a few places in the Gap Tank section (Ellison, 1964). Many conodonts have been obtained from the *Chaetetes* limestone at the base which are of Des Moinesian age, and a collection from the lower part of the upper limestone sequence has yielded conodonts of Missourian age.

EXPOSURES EAST OF GAP TANK

East of Gap Tank, the Gaptank Formation is exposed at only a few places. The first exposure is 3½ miles south of the Allison Ranch.[4] Here, Ross (1965, p. 82, section 42) records 155 feet of the formation, mainly limestone and shale, overlain by conglomerate of the Hess Limestone, with the Neal Ranch Formation missing. The base of the formation was not observed, but the Haymond Formation is exposed nearby to the south.

A much larger exposure occurs 7 miles east of Gap Tank, which is the easternmost occurrence of the Gaptank Formation in the Marathon Basin. It was visited by the writer in 1930, and has not since been reported on; it much deserves further study. At the time the following section was recorded (fig. 15).

Stratigraphic section of Gaptank Formation and associated beds 7 miles east of Gap Tank

Cretaceous limestone (Trinity Group) at top, unconformable on beds beneath.

Paleozoic rocks:	*Feet*
(15) Slabby and crossbedded sandstone	100
(14) Brown limestone, with some conglomerate	10
(13) Lower and upper part of interval not exposed; beds of gray sandstone near middle, locally quartzitic	120
(12) Brown limestone	5
(11) Covered	100
(10) Massive gray limestone, with marls at base containing various brachiopods, and *Triticites irregularis*	25
(9) Brown sandstone, with interbedded shale that is mostly covered	250
(8) Conglomeratic limestone, containing large blocks of Dimple Limestone	10
(7) Sandstone and shale	20
(6) Brown massive sandstone	10
(5) Sandstone and shale	30
(4) Brown limestone	4
(3) Ferruginous brown and red sandstone	40
(2) Brown limestone	5
(1) Ferruginous brown and red sandstone at base; base not exposed, but Haymond Formation is exposed nearby	

[4]The name is omitted from the Marathon Gap 1:24,000 topographic sheet, although the group of buildings at the ranch is shown.

Without more critical study, many features of this sequence are enigmatic. The lower beds of the section dip 30° or more to the north, but the dip gradually flattens northward to 10° or 15°, yet there are no evident breaks or unconformities in the sequence. The only certain indication of age is the identified *Triticites* in bed 10, which is of Missourian age. Beds 14 and 15 at the top may represent the base of the Hess Limestone, as they seem to be continuous with the Hess to the north, but there is no indication of the intervening Neal Ranch Formation. The strata below bed 10 somewhat resemble the lower part of the Gaptank Formation of the Gap Tank area, but conglomerate beds are subordinate here.

ORIGIN

As a whole, it is evident that the Gaptank Formation was deposited in much shallower water than the flysch that preceded it, although McBride (1964b, p. 43–44) has recorded some turbidite structures and soft-sediment deformation in the shales and sandstones of the lower part. Ross (1967, p. 373–379) interprets the upper limestone units as having been deposited on shallow banks, passing into somewhat deeper water nearby. The conglomerate beds in the lower part of the Gaptank Formation afford clear evidence of important deformation in the older rocks of the Marathon Basin to the south, and may indicate a major orogeny of Des Moinesian age in that area, to which most of the Gaptank Formation is postorogenic. The Gaptank Formation was probably laid down only along the northern fringes of the deformed belt, and not farther south. The formation has sometimes been compared with molasse, although this is not entirely apt, as the original Molasse of Switzerland is mainly a continental and fresh-water deposit, whereas this formation is entirely marine.

PERMIAN ROCKS

NEAL RANCH FORMATION

The Neal Ranch Formation (Pnr) corresponds to the original Wolfcamp Formation of Udden (1917) and Böse (1917), whose type area is the 400- to 500-foot sequence in the Wolfcamp Hills 3 to 5 miles west of the report area. The formation was given its present name by Ross (1959, p. 299–301; 1965, p. 20), as a lower subdivision of the expanded Wolfcampian Series. After the original work by Udden and Böse, the Neal Ranch Formation of present usage was restudied in more detail by the writer (1930), p. 52–57), and later by Ross

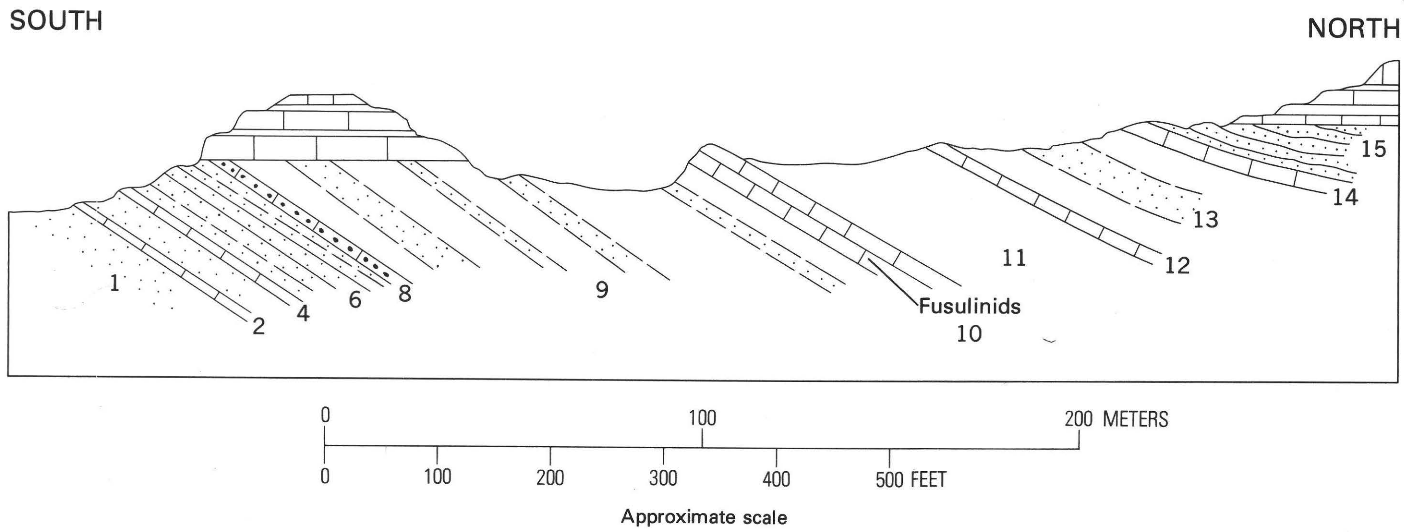


FIGURE 15.—Profile of Gaptank Formation and associated beds 7 miles east of Gap Tank. From a field sketch made in 1930. Numbers refer to units described in text.

(1965) and by Cooper and Grant (1972, p. 30–44).

The writer mapped the formation as a continuous band of outcrop from the Wolfcamp Hills eastward as far as Gap Tank, mainly because of the inclusion at the base of the *Uddenites*-bearing shales which were later excluded. Later observers have concluded that for much of this distance it has been cut out by pre-Hess erosion, so that the basal Hess conglomerates lie directly on various limestone layers in the upper part of the Gaptank Formation.

A small remnant of the Neal Ranch Formation reappears, however, immediately south and southeast of Gap Tank within the report area, where Ross (1965, p. 81–82, section 4) records about 100 feet of shale and calcarenite, with a little limestone-pebble conglomerate at the base, lying on the upper limestone bed of the Gaptank Formation. The Neal Ranch here contains the fusulinids *Pseudoschwagerina uddeni, P. beedei, Schwagerina compacta, S. gracilitatis, Paraschwagerina acuminata, Triticites koschmani,* and other species; Cooper and Grant (1972, p. 37) found very few other fossils.

The Neal Ranch Formation records the same type of shallow-water, irregular deposition as the upper part of the Gaptank Formation, and is essentially an upward continuation of Gaptank sedimentation. In fact, the precise position of the Gaptank-Neal Ranch boundary has fluctuated through the years, and from observer to observer. This problem mainly concerns the beds in the more complete sections west of the report area, and will not be dealt with here.

HESS LIMESTONE

The Hess Limestone (Ph) forms much of the bulk of the pre-Cretaceous rocks of the Glass Mountains from the report area westward for about 12 miles, and crowns the southern escarpment of the mountains, that overlooks this part of the Marathon Basin.

The formation has undergone various changes in classification since it was named by Udden (1917, p. 43). Originally, it was conceived of as a separate formation, or time-stratigraphic entity, between the Wolfcamp and Leonard Formations (Udden, 1917; King, 1930). Later (King, 1932) it was interpreted as a lateral facies of the lower part of the Leonard Formation of the western part of the Glass Mountains, from which it was separated by a reef barrier. Still later, when the concept of an expanded Wolfcampian Series was adopted, it was found that many characteristic Wolfcampian fusulinids occurred in the lower part of the Hess. Ross (1965) therefore transferred this lower part, comprising 200 to 400 feet of beds to his Lenox Hills Formation, named in the western part of the Glass Mountains, and he supposed that it was separated from the overlying Hess by an unconformity. Cooper and Grant (1972, p. 60) failed to find evidence for this supposed unconformity and retained the whole unit in the Hess Formation. However, they consider that the whole of the Hess, including its upper or Taylor Ranch Member, to be of Wolfcampian age.

The basal unit of the Hess is a conglomerate of limestone and chert pebbles and cobbles. Ross (1965, p. 30) notes considerable variation in the thickness of the conglomerate—from more than 200 feet to 50 feet or less, and even disappearing in places—suggesting deposition over an eroded topography of mild relief. It lies with angular unconformity on the Neal Ranch and Gaptank beds beneath. This unconformity is, in fact, the only well-marked structural break between the rocks of the Marathon Basin and the Permian rocks of the Glass Mountains to the north; structural breaks lower in the sequence have been claimed, but are either less well-marked, or dubious. In the eastern Glass Mountains the unconformity is only moderate, although well-marked everywhere. In the northwestern part of the Marathon Basin, farwest of the report area, the beds above lie with right-angled unconformity on orogenically deformed beds beneath. The unconformity was long supposed to be at the top of the Wolfcamp Formation, but according to modern concepts of the Wolfcampian Series, it lies between its lower and upper parts.

Within the report area, the Hess Limestone forms most of the exposures of Permian rocks of the eastern end of the Glass Mountains, but its outcrops are much interrupted by Cretaceous outliers, and it finally passes beneath the Cretaceous about 6 miles east of Gap Tank, and is not exposed again in the northeastern part of the report area. In the report area (as elsewhere) the Hess is separated from the Cretaceous by an angular unconformity, but the divergence is slight, as the formation dips low to the north, generally at an angle of 5° or less.

No sections of the Hess have been measured within the report area. Above the Wolfcamp Hills, 4 to 6 miles to the west, the writer measured 1,839 feet (1930, p. 61, section 24), but above the Montgomery Ranch at the west edge of the report area, he obtained 2,128 feet (1930, p. 145–146, section 27); a similar considerable thickness must exist farther east, judging from the very wide outcrop belt of the formation.

The overlying main body of the Hess, in its typical development from the Wolfcamp Hills eastward, is a thick, monotonous mass of thin-bedded limestones, mostly containing few fossils other than poorly preserved fusulinids. In the lower part, especially in the equivalent of the Lenox Hills Formation, is much interbedded red and green shale with thin beds of sandstone, which become more prominent eastward. Marker beds are few. The most persistent is a layer of silicified fossils 200 to 400 feet below the top, which Cooper and Grant (1972, p. 56) have termed the Taylor Ranch Member (*tr*). It contains numerous branchiopods, rare ammonoids (*Perrinites*), and notable numbers of sponges (*Heterocoelia*). From the lower part of the Hess Limestone (Lenox Hills equivalent) Ross (1965, p. 32) records various species of *Pseudoschwagerina, Schwagerina,* and other fusulinids characteristic of the Wolfcampian. Near the middle, below the Taylor Ranch Member, is a zone of *Schwagerina crassitectoria* and *S. gumblei,* The upper part, above the Taylor Ranch Member, contains various species of *Parafusulina,* which are similar to those of the Leonardian.

The Hess Limestone is clearly a backreef deposit, like the other backreef deposits higher in the Permian sequences in the Glass Mountains, Guadalupe Mountains, and elsewhere in west Texas. The writer's (1932) interpretation that the Hess Limestone in the eastern Glass Mountains is equivalent to ledge-making limestones and interbedded shales in the western Glass Mountains has been verified in modified form by Cooper and Grant (1972, p. 44–52), who interpret the Hess above the Lenox Hills equivalent as correlative with their Skinner Ranch Formation in the western part of the mountains, which they divide on the basis of thick limestone units and interbedded shale units into the Decie Ranch, Poplar Tank, and Sullivan Peak Members.

PERMIAN ROCKS ABOVE THE HESS LIMESTONE

The northwestern corner of the report area contains a small segment of the bands of outcrop of the higher Permian rocks of the Glass Mountains sequence—the originally mapped as Leonard Formation (Pl) (now the Cathedral Mountain Formation of the Leonardian Series), the Word Formation (Pw), and the Vidrio and Gilliam Limestones (Pv, Pg). The latter three units form the Guadalupian Series. The outcrops of these formations within the report area are small and not distinctive, and they will nol be considered further here.

LOWER CRETACEOUS (COMANCHEAN) SERIES

A large part of the report area, especially in the northeastern and southeastern parts, is occupied by the Comanchean Series, which lies with prominent angular unconformity on the Paleozoic rocks. On the map, the Comanchean Series is divided into the Trinity, Fredericksburg, and Washita Groups; more detailed subdivision is not feasible without further field examination.

TRINITY GROUP

The Trinity Group (Kt) crops out mainly south of the latitude of Gap Tank, and consists largely of the Glen Rose Limestone. It also includes the persistent Maxon Sandstone at the top, which serves to divide the Glen Rose from the overlying limestones of the Fredericksburg Group.

GLEN ROSE LIMESTONE

The Glen Rose makes it appearance in the mesas southeast of Gap Tank, where it is about 50 feet thick. It wedges out by overlap to the north, and is missing at the base of the Cretaceous west of the tank. It thickens progressively to the south. A thickness of 312 feet was measured on the west face of Housetop Mountains (see section below), and the topographic map suggests that it is 800 feet or so thick on Shely Peaks (Tres Hermanas) at the south edge of the report area. However, Graves (1954, p. 16–19) measured 475 feet in the Hood Spring Quadrangle to the southwest, on the south rim of the Marathon Basin. In the Gap Tank area the Glen Rose consists of buff marls, in part sandy, with interbedded ledges of white marly limestone. Farther south, the limestone beds increase in prominence, but interbedded marls and sandy marls continue south of the latitude of Housetop Mountains. On Shely Peaks in the south part of the area, air photographs indicate that the Glen Rose is largely limestone, with four or five ledges more prominent than the rest, and in places with an exceptionally prominent cliff-making unit at the base.

The following section of the Glen Rose Limestone and overlying Cretaceous beds was measured in 1931 on the west face of Housetop Mountains.

Section of Glen Rose Limestone and overlying Cretaceous strata on the west face of Housetop Mountains. By P. B. King, 1931

	Feet
Edwards Limestone:	
(22) Limestone, light gray, massive, in part somewhat cherty, forming a sheer cliff on the face of the mountain	122
Comanche Peak and Walnut equivalent:	
(21) Marl, passing into white marly limestone toward the top	50
Maxon Sandstone:	
(20) Sandstone, medium-grained and sugary, pale brown or buff on fresh surfaces, dark brown on weathered surfaces. Forms thin to thick beds, many of which are crossbedded at low to steep angles. Some layers are honeycombed. In places forms a sheet cliff, but rock is more or less loosened along joints, and thus breaks out into great angular blocks	102
Glen Rose Limestone:	
(19) Marl, sandy, with some nodular limestone layers	16
(18) Sandstone, calcareous, forming a ledge	5
(17) Marl, buff and sandy, with thin nodular limestone	8
(16) Sandstone, crossbedded and sugary	4
(15) Marl, brown and sandy	16
(14) Limestone, massive, gray-brown	19
(13) Marl, not well exposed	21
(12) Limestone, gray, in 3-foot to 8-foot ledges	38
(11) Marl, white and buff, and white thin-bedded nodular limestone	32
(10) Limestone, massive, forming a single ledge, with thinner bedded limestones below and above. Top part is full of oyster shells. Forms second massive ledge in the Glen Rose	16
(9) Marl, brown and buff, and marly limestone	37
(8) Limestone, gray and massive, in 3-foot to 4-foot ledges. Forms first main ledge of the Glen Rose	32
(7) Limestone, white, with some interbedded marl	24
(6) Limestone, white to pale buff, in thick ledges	13
(5) Marl, white and buff	4
(4) Limestone, massive, white	2
(3) Limestone, white, soft, and platy	5
(2) Limestone, buff, mottled, nodular, with oyster fragments	7
(1) Marl, nodular, sandy, containing numerous fragments of oysters and some whole shells, probably *Exogyra quitmanensis*	13

Unconformity; bed lies on upturned and truncated strata beneath. *Tesnus Formation* at base of section.

The Glen Rose Limestone contains many oysters and rudistids. Near Housetop Mountains an oyster, probably *Exogyra quitmanensis,* is abundant in the basal layers. Higher up, the foraminifer *Orbitolina texana* is common at some levels; near Housetop Mountains and Tesnus it forms a zone about 100 feet below the top.

MAXON SANDSTONE

The Glen Rose Limestone is separated from the overlying Fredericksburg Group by the Maxon Sandstone, named for Maxon, a former station on the Southern Pacific Railroad where it leaves the Marathon Basin in the southeastern part of the report area (King, 1930, p. 92); its ledges are prominent on the escarpment east of the railroad at this locality. The Maxon has the same stratigraphic position and habit as the Paluxy Sand of north-central Texas, but a separate name is used because of the wide geographic separation of the two areas.

The Maxon is a brown, well-indurated, coarse- to medium-grained, crossbedded sandstone, which forms one or more conspicuous ledges that are cut by vertical joints that cause it to break out into great cubical blocks. In the mesas immediately southeast of Gap Tank it is 90 feet thick, but like the underlying Glen Rose it thins abruptly northwestward, so that it is absent at the base of the Cretaceous west of Gap Tank. Several miles to the east, however, it is traceable northward, past the point of disappearance of the Glen Rose, to merge with the Basement Sands of King (1930, p. 93) of the north part of the report area. South of Gap Tank the Maxon thickens somewhat; 102 feet was measured on Housetop Mountains (see section above), and it may be somewhat thicker farther south. Graves (1954, p. 18) reports 115 to 157 feet of the Maxon on the south rim of the Marathon Basin in the Hood Spring Quadrangle, but here the formation is losing its character and is grading into sandy shale and marl.

The Maxon Sandstone was studied for master's theses at the University of Texas at Austin by Donald A. Butterworth (1970) and Marvin G. Thompson (1977), who have added details of its petrography and sedimentology. They found that the sandstone is well-sorted, rounded, fine- to medium-grained, made up mainly of quartz with very minor amounts of feldspar and heavy minerals, and with a clacite-hematite-clay matrix, the dominant clay being kaolinite. Sediment transport was to the south, and it was deposited in a fluvial-deltaic environment.

The Maxon Sandstone is generally recognizable on air photographs as a prominent dark ledge, which is most evident along the escarpments at the edge of the Marathon Basin, but is less conspicuous on the lower mesa slopes farther east. The top was used as the Trinity-Fredericksburg boundary in constructing the geologic map of the area.

The writer has observed no fossils in the Maxon Sandstone, but Graves (1954, p. 21) lists a small assemblage of pelecypods and gastropods (including *Actaeonella*) in the Hood Spring Quadrangle. Whether the Maxon should be assigned to the Trinity or the Fredericksburg Group is somewhat uncertain, but the general preference has been to place it in the Trinity.

BASEMENT SANDS

In the north part of the report area a thin basal sand lies on the Permian rocks, and has been termed the "Basement Sands" (King, 1930, p. 93). It corresponds to the "Basal Cretaceous Sandstone" of Adkins (1927, p. 31) in the Fort Stockton area to the north; the same unit was termed the Antlers Sand on the Pecos Sheet of the Geologic Atlas of Texas (Bureau of Economic Geology, 1976), this name being derived from localities much farther northeast in southern Oklahoma. In the north part of the report area the formation varies from a featheredge to as much as 75 feet. It consists of coarse, brown, crossbedded sandstone much like the Maxon Sandstone, with which it is laterally continuous east of Gap Tank. On the geologic map, it is included with the Trinity Group for convenience, although Adkins (1927, p. 33) found *Exogyra weatherfordensis* near the top in the Fort Stockton area, which is a characteristic fossil of the Fredericksburg Group. The Basement Sands are probably a transgressive deposit, mainly of Trinity age in the south, but becoming younger farther north.

FREDERICKSBURG GROUP

Within the report area the Fredericksburg Group (Kf) is mainly thick-bedded limestone that was termed Edwards Limestone in the earlier reports (King, 1930, p. 95). At the base, however, is about 50 feet of more shaly or marly beds that may be equivalent to the Walnut Clay and Comanche Peak Limestone of central Texas, and at the top in the north part of the area is a persistent layer of marly clay that is equivalent to the Kiamichi Formation of farther east in Texas. Within the last few decades a different terminology for the Fredericksburg Group has been used for areas south of the Marathon Region, notably in the Big Bend area (Maxwell and others, 1967, p. 35, 36, 40; St. John, 1966). The softer beds below are termed the Telephone Canyon Formation, the thick-bedded medial limestones the Del Carmen Limestone, and the softer beds above the Sue Peaks Formation. The applicability of these terms to the present report area is dubious, as the sequence in the south is a thicker, more dominantly carbonate facies.

Within the report area the group is 190 to 220 feet thick in the Glass Mountains to the north, and of about the same thickness in the Fort Stockton area still farther north (Adkins, 1927, p. 37), but it thickens southward. Graves (1954, p. 21–26) records about 400 feet on the south rim of the Marathon Basin in the Hood Spring Quadrangle, and the group is apparently of about the same thickness in the southeastern part of the report area.

In the Glass Mountains to the north the group includes prominent ledges as thick as 10 feet of light-gray, dense or finely crystalline limestone, containing rudistids and much concretionary brown chert. Between the limestone ledges are softer, more marly strata. The limestones fade out farther north, and in the Fort Stockton area the group consists of marly limestones below, a medial fossiliferous calcareous clay, and a few thin limestone ledges at the top, just below the Kiamichi horizon (Adkins, 1927, p. 37–41).

The Kiamichi equivalent at the top of the Fredericksburg Group is prominent only in the north part of the report area, where it forms a white or yellowish slope between limestone ledges below and above. In this area, it forms a conspicuous light band that can be traced on the air photographs for long distances. The Kiamichi equivalent is not as evident farther south on the photographs, but Graves (1954, p. 25–26) recognized it in the Hood Spring Quadrangle as a poorly resistant layer about 50 feet thick, separating limestone ledges below and above. The Kiamichi equivalent is generally quite fossiliferous, and contains among other forms the characteristic oyster *Gryphea navia*.

WASHITA GROUP

The Washita Group (Kw) is scantily represented in most of the report area, except in the extreme southeastern corner, where it covers most of the surface; elsewhere it is preserved only as remnants on the tops of the ridges of the older Cretaceous strata. The part of the group preserved in the report area was termed the Georgetown Limestone in previous reports (King, 1930, p. 96–97). In the Big Bend region its equivalent is the Santa Elena Limestone (Maxwell and others, 1967, p. 47), but this is a much thicker more massive phase, and the applicability of this name to the report area is questionable. Higher parts of the Washita Group, the Del Rio Clay and Buda Limestone, are not preserved in the report area.

A rather complete section of the Georgetown about 200 feet thick occurs in the north part of the report area, east of the Marathon-Fort Stockton highway. Here, it consists mainly of marly limestone, but it contains two prominent ledges of rudistid limestone near the middle and top, which correspond to the Middle and Upper Caprocks of the Fort Stockton district, that Adkins (1927, p. 46–48) correlated with the Denton and Main Street Formations of north-central Texas.

Farther south, the marly intervals in the limestone disappear. In this region the position of the Washita beds was located in places during the field surveys, and seems to correspond on the air photographs with prominent light-colored beds on the tops of the ridges. These light-colored beds were assumed to be Washita, in the absense of additional ground inspection, and were used in marking the Washita Group on the geologic map. Graves (1954, p. 27–28) reports 380 feet of Washita beds on the south rim of the Marathon Basin in the Hood Spring Quadrangle, again with the top eroded and the Del Rio and Buda missing at the top. They are probably as thick or thicker in the southeastern part of the report area. In this area, various ledge-making units are evident on the photographs that are higher than the layer selected as the base of the Washita in mapping, but no data are available as to their character; much yet remains to be learned about the Cretaceous stratigraphy in this part of the area that would only be possible from additional ground surveys.

CONDITIONS OF DEPOSITION OF LOWER CRETACEOUS ROCKS

A long pause in deposition intervened between the formation of the Permian rocks and those of the Lower Cretaceous. During this interval, the report area and all the surrounding region was subjected to erosion, and was reduced to a nearly level plain, which has been called the Wichita paleoplain.

The Cretaceous deposits overlapped this paleoplain from south to north, and formed in a shallow-water marine environment rich in lime. As a result of this northward overlap, the Trinity deposits only extend into the northern part of the report area, where they wedged out against a low scarp on the paleoplain produced by the Permian carbonate rocks on the site of the present Glass Mountains; farther north, Fredericksburg beds form the basal deposits. The basal deposits in the north are the Basement Sands, formed of sands eroded from regions farther north, which probably became slightly younger northward. Farther south, beyond the edge of the wedge of Trinity deposits, a sheet of sands of about the same age, the Maxon Sandstone, extends across the reprt area over the older Cretaceous deposits.

The northward overlap is also reflected by a change in facies—from thick, massive limestones in the south, as in the Big Bend area, through a mixed assemblage in the report area of interbedded limestones and more marly and shaly strata, into a thinner sequence in the north, as in the Fort Stockton area, of dominant marl and clay, with only rare, persistent limestone interbeds. This change in facias is reflected in the faunas. Among the pelecypods, for example, the rudistids, a sessile, reef-building group, are common in the dominant limestones in the south, whereas oysters such as *Gryphea* abound in the dominant marls and clays in the north. Even in the north, however, rudistids made occasional incursions, and built the prominent "caprocks" of the Washita Group in that area.

TERTIARY IGNEOUS ROCKS

A few bodies of intrusive igneous rocks (Ti) occur in the southwest part of the report area, and were mapped by the writer during his survey of the Marathon Quadrangle in 1930 (King, 1937, p. 117–118). The largest bodies are on Twin Peaks, where two thick dikes a mile in length cut the Tesnus Formation. The dikes dip 70° southeast, whereas the enclosing strata dip at a lower angle. According to C. S. Ross (King, 1937), the rock is a porphyritic quartz diorite, with very alkalic feldspar and ferromagnesian minerals. A mile south of Twin Peaks, a series of narrower dikes follows the trace of the Hells Half Acre fault for nearly 2 miles. Megascopically, these rocks resemble those on Twin Peaks. The intrusive rocks in this area are probably of Tertiary age, like the others in surrounding parts of the Marathon Region.

QUATERNARY DEPOSITS

More than a quarter of the report area is covered by a thin blanket of gravel deposits of Quaternary age; this cover is most extensive in the north part of the area. It is also more extensive in the eastern part of the area than had been indicated on previously published maps, as all the valleys draining eastward and northeastward from the Marathon Basin through the Cretaceous mesas are floored by gravel deposits a mile or so wide. The Quaternary gravel deposits are of Pleistocene and Holocene ages, the younger being the most extensive.

Possibly the oldest Quaternary deposit forms a belt about 3 miles long at an altitude of 3,400 feet on top of the divide south of Alamo Creek in the southeast part of the report area (Qgo), in an outcrop area of the Washita Group. Air photographs indicate that its gravels break off in dissected scarps along its edges, and that they have no evident relation to modern drainage or topography. The gravels must have been deposited when drainage and topography were very different from those of today. It is probably equivalent to the upland gravel deposits described previously

(King, 1937, p. 10) from localities east of the Marathon Region. The deposit has not been examined on the ground, and it would probably repay examination.

Another, more extensive gravel deposit (also mapped as Qgo), perhaps nearly as old, forms a plain several square miles in extent, which slopes northwestward from an altitude of more than 3,900 feet to 3,800 feet near Copeland Trap, where it meets the younger Quaternary deposits along the Southern Pacific Railroad west of Tesnus. Its broad, smooth surface conceals the steeply dipping Carboniferous rocks and like the first deposit mentioned, its surface breaks off in erosion scarps along its edges.

The other Quaternary deposits are considerably younger. In the west-central part of the area, and farther west in the Marathon Basin, in areas drained southward by San Francisco Creek and its tributaries, two levels are represented—older deposits (Qg) that stand 100 feet or more above modern drainage and are preserved in large and small remnants on the low hilltops of tilted Carboniferous rocks, and alluvial deposits (Qa) along the present streams. These distinctions fade out in the north part of the report area, in which drainage flows eastward and northeastward, and has not been subjected to renewed dissection. Here, broad alluvial plains (mapped as Qg) extend over many square miles, from W B Flats between Gap Tank and the Dimple Hills, eastward to the edge of the report area. These plains conceal large parts of the deformed Carboniferous, although ridges of Tesnus, Dimple, and Haymond Formations project here and there, and furnish clues as to the general bedrock pattern.

Interesting features of the east-central part of the report area are the eastward-draining "dry valleys," such as those followed by U.S. Highway 90 and the Southern Pacific Railroad in their courses eastward from the Marathon Basin. These appear to have been beheaded by drainage of San Francisco and Maxon Creeks rather late in Quaternary time. This appearance is particularly striking in the southern valley followed by the Southern Pacific Railroad. Where this valley leaves the Marathon Basin it is drained by Maxon Creek, but about 3 miles to the east, Maxon Creek abruptly leaves the valley, and drains southeastward through a canyon cut in the Cretaceous limestones, although a broad valley continues east-northeastward. For about 4 miles east of the Maxon Creek turnoff, the valley is drained by westward-flowing Cox Creek with east-directed barbed tributaries, but beyond this the valley slopes eastward with no evident drainage lines, past Rosenfeld siding. The flow of Cox Creek has clearly been reversed from east to west into Maxon Creek.

Along the Cretaceous escarpments facing southward toward W B Flats in the north part of the report area are many patches of landslide debris (Ql) that partly obscure the Carboniferous rocks along the bases of the escarpments. Some of the masses consist of large coherent blocks of Cretaceous rocks which at first sight appear to be in place. The landslides were formed by undermining of the Cretaceous strata by the weaker Carboniferous rocks beneath. The time of undercutting and landsliding was probably considerably before the present. Similar landslide masses are rather common farther west, along the south-facing escarpment of the Glass Mountains.

TECTONICS

The rocks of the report area are partitioned into several groups, each separated by angular unconformities and structural discontinuities, and each having its own distinctive set of structures. The oldest group of rocks is that of the pre-Permian Paleozoic age exposed in the Marathon Basin, and their structures exhibit the most complex deformation. Moreover, deep drilling in the basin discloses that these rocks lie on a major discontinuity, or great overthrust fault, beneath which are a different set of pre-Permian rocks and structures. The next group of rocks is that of Permian age in the Glass Mountains to the north, which are tilted northward at low angles, rather than folded. Finally, above both groups of Paleozoic rocks, are those of Cretaceous age, which are much less deformed, but which slope gently eastward and northeastward off the flanks of the Marathon dome.

SURFACE STRUCTURE OF THE PRE-PERMIAN ROCKS

The pre-Permian rocks of the report area are a small part of the Marathon segment of the Ouachita orogenic belt that is exposed in the Marathon Basin, which consists of strongly deformed rocks of Cambrian to Pennsylvanian age. Exposed parts of the orogenic belt extend for about 30 miles west of the report area, but their extensions eastward and westward from the basin are concealed by the Cretaceous cover. Clearly, the belt must extend for long distances beyond beneath this cover, and this is confirmed by well penetrations, especially toward the east (Flawn and others, 1961).

Within the report area, the surface rocks of the deformed belt are mostly of Carboniferous age; the pre-Carboniferous components emerge only up the plunge of the folds farther west (fig. 2). Except in the southern part, the Carboniferous rocks are deformed into broad folds, broken on their flanks by thrust faults, that trend northeastward to eastward. In the extreme south part of the area, folding and thrust faulting are more complex. The structural pattern of the pre-Permian rocks can be reconstructed from their outcrops, even where they are partly concealed by the cover of Cretaceous strata and Quaternary deposits (fig. 16).

South of W B Flats the next conspicuous feature in the Carboniferous rocks is the Dimple Hills, which are a compact, semicircular mass of Dimple Limestone of synclinal structure. The limestones dip rather regularly at angles of 10° to 45° toward the center of the hills from all sides, and they are apparently surrounded on all sides by outcrops of Tesnus Formation. The syncline of Dimple in the hills is, however, a wrinkle on the crest of an anticlinorium, whose extent is well exposed southwestward, where it is bordered on both the northwestern and southeastern sides by belts of Dimple Limestone, but whose extension eastward is mostly concealed by the Quaternary deposits of W B Flats.

Southwest of the Dimple Hills, the northwestern flank of the anticlinorium is broken by a fault, termed the Frog Creek thrust, which dips 20° east at a locality where it is well exposed. It carries Dimple Limestone on the border of the anticlinorium over Haymond Formation to the west. West of the area of Haymond Formation, and west of Frog Creek, is a prominent hook-shaped ridge of Dimple Limestone, which is folded with a northeastward plunge. Air photographs show that the ledges of the Tesnus Formation enclosed within the hook have a much more complex pattern than the simple hook in the overlying Dimple, suggesting considerable disharmonic folding.

The southward extension of the structures of this area is concealed by the broad expanse of Quaternary deposits of W B Flats, beyond which only older Carboniferous rocks come to the surface. The Gaptank and Haymond Formations are not preserved here, yet in the last exposures on the north the strata dip toward the south, so that there must be a reversal of the structure beneath the flat. An eastward extension of the structures south of the flat occurs on its north side in an area 7 miles southeast of Gap Tank, where the Dimple Limestone dips steeply northward beneath the Haymond Formation. Between these north-facing strata and the south-facing strata near Clark Butte is a gap of about a mile concealed by Quaternary deposits. It does not seem possible to reconcile the structures on the two sides of the gap by any system of folding, so there must be faulting between of undetermined character. The reconstruction proposed by Flores (1972, p. 3417) is much too simple.

The northernmost structures of the system are those near and south of Gap Tank, where the Gaptank Formation and the underlying Haymond Formation are folded into a broad, east-plunging anticline, steeper on the south flank than the north, where the upper Gaptank strata pass beneath the Permian rocks of the Glass Mountains with dips of 15° or less (fig. 13).

Another fold is exposed along the edges of the Cretaceous mesas 3 to 6 miles southeast of Gap Tank, as far as Clark Butte. Here, the rocks are all Haymond Formation, whose boulder-bed layer in the upper part is exposed discontinuously along the edge of W B Flats for a distance of 4 miles and dips 15° to 80° to the south. The dip reverses in the underlying sandstones of the formation to the north, defining an anticline whose north flank dips gently toward the north; within the limits of exposure, the boulder-bed layer does not reappear on this flank. At the western end of the outcrop of the boulder-bed, its dip also reverses to the northeast, indicating that the anticline plunges westward beneath the nearest exposures of Gaptank Formation. The western extension of this anticline must lie beneath the Quaternary deposits of W B Flats, south of the anticline of the Gap Tank area.

Southeast of this anticlinorium, between Gap Tank and the Dimple Hills and a long westward extension of the Cretaceous mesas 4 miles to the south, Carboniferous rocks emerge from the Quaternary deposits only in small discontinuous areas, but enough are exposed to define broadly the structural pattern (fig. 16). The Dimple Limestone projects here and there in occasional ridges, which outline a synclinal area of Haymond Formation south of the hills (including the area shown in fig. 9) and an anticlinal area of Tesnus beyond it. The Dimple Limestone is exposed in a few places south of this anticlinal area of Tesnus, the easternmost being on a ridge just northeast of the Skevington (formerly Purington) Ranch at the eastern edge of the report area—the easternmost outcrop of Paleozoic rocks in the Marathon Basin.

The structures in the Carboniferous rocks are better revealed in exposures south of the long westward extension of Cretaceous mesas that ends in Spencer Mountain.[5] The poorly exposed structures north of the mesas can be correlated across the Cretaceous cover with the structures to the south (fig. 16).

To the south, the most conspicuous features are the two synclinal, northeast-plunging belts east and west of Haymond Station, bordered by long ridges of Dimple Limestone that end southwestward up the plunge in synclinal hooks, and which preserve Haymond Formation along their axes. The southeastern syncline is the larger and deeper, and preserves nearly 4,000 feet of Haymond Formation west of Housetop Mountains, including the boulder-beds in the upper part. Between each syncline, and to the northwest, are narrower and

[5]Termed Cedar Mountain on older maps. The present term is indicated on the Housetop Mountains 1:24,000 topographic sheet.

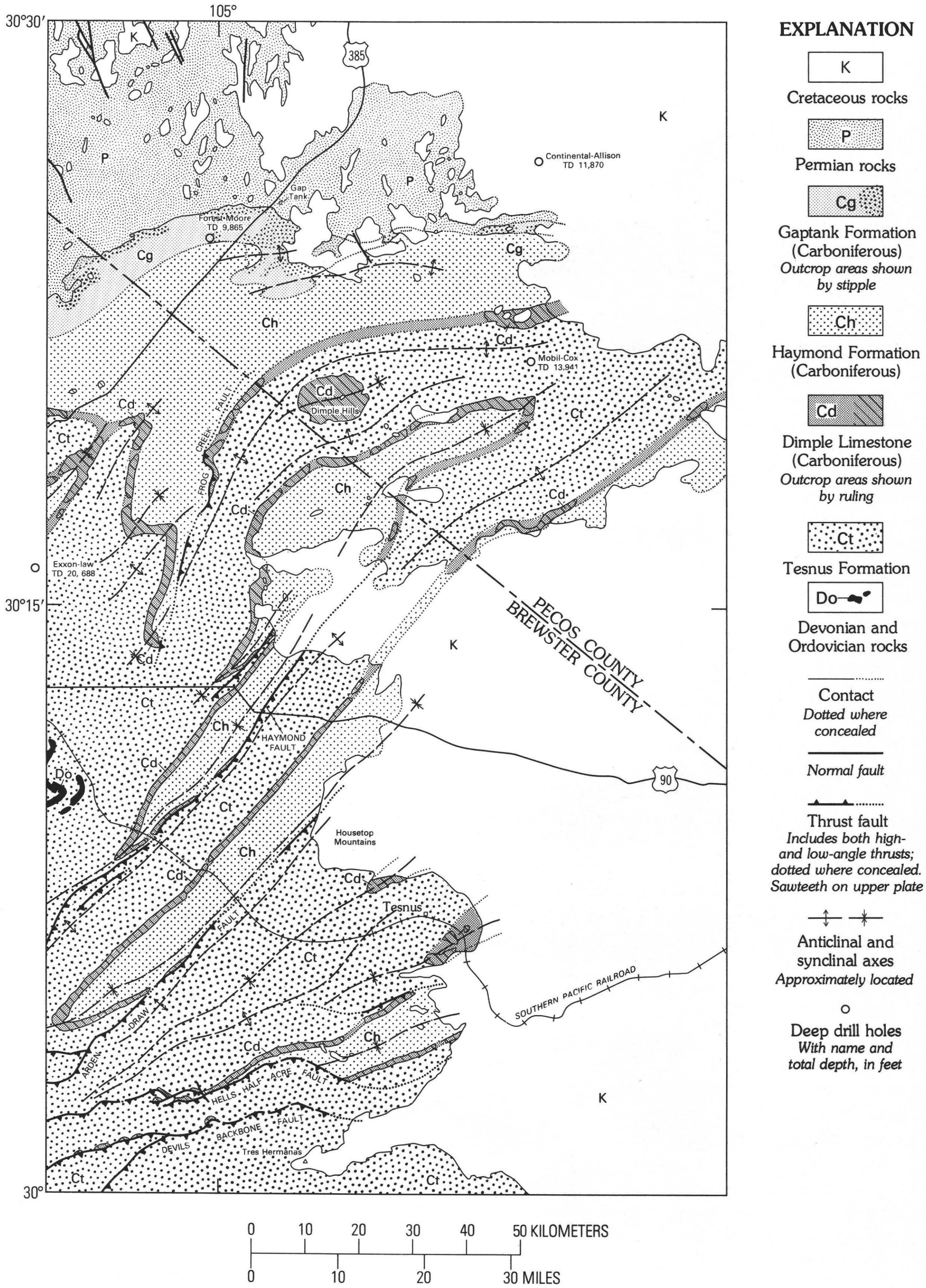


FIGURE 16.—Map of report area showing inferred structural pattern of the Paleozoic rocks.

steeper anticlines of Tesnus Formation, with the lower shale unit in their cores. Each syncline is faulted on its southeastern flank, so that the Dimple of each synclinal hook is terminated northeastward, beyond which Tesnus is in fault contact with Haymond. The two faults have been termed the Haymond and Arden Draw[6] thrust faults (King, 1930, p. 106). A few poor exposures of the faults show dips of 60° to 80° southeast. They evidently formed by simple breaking of the flanks of the folds.

Southeast of the two synclines just described, toward Tesnus Station, is a broad area of Tesnus Formation. The trends of the Tesnus ledges, as indicated on the air photographs, show that the same broad folding continues in this direction. The ledges outline two additional northeast-plunging synclines that are structurally higher than those just described, so that only Tesnus is preserved with its lower shale unit on the flanks. Down the plunge to the northeast in each of these two synclines, small areas of Dimple Limestone are preserved, northwest and southwest of Tesnus Station, before the whole deformed complex disappears beneath the Cretaceous.

South of this area of open folds, in the southeast part of the report area, a change in structure of the Carboniferous rocks is clearly revealed on the air photographs. The trends of the ledges change from open bends around the folds into a much more consistent east-northeast trend. During the writer's mapping of the southeastern corner of the Marathon Quadrangle, west of the 103° meridian, in 1930, he recognized at this change in structure a major, probably low-angle, thrust fault termed the Hells Half Acre overthrust (King, 1937, p. 130). West of San Francisco Creek, the trace of this fault is followed by narrow slivers of Caballos Novaculite and Maravillas Chert, and by dikes of Tertiary porphyry. East of San Francisco Creek are slivers and broader wedges of Dimple Limestone. Lack of time and of adequate base maps prevented the tracing of this fault east of the 103° meridian. The air photographs indicate that the wedges of Dimple Limestone coalesce in this direction into a continuous east-northeast-striking belt that extends eastward until it passes beneath the Cretaceous south of Tesnus Station.

Where the Hells Half Acre overthrust extends east of the 103° meridian is conjectural. There must be a fault north of the belt of Dimple Limestone, because it is quite discordant with the openly folded Tesnus to the north, but this may be a subsidiary feature. Toward the east end of the belt of Dimple, Haymond Formation is preserved south of it; Haymond was sketched here during the writer's brief reconnaissance in 1930, and McBride (1964a, fig. 7, p. 39) has recorded sedimentological observations on it. Complications are introduced, however, because the air photographs reveal another belt of Dimple Limestone 2 miles south of the first one. Does this second belt dip to the south also, in another thrust slice, or does it form the southeastern flank of the area of Haymond, which would have a synclinal structure? Very tentatively, the second alternative is accepted on the geologic map, and the Hells Half Acre fault is projected south of it. It is assumed that the Hells Half Acre fault is such a fundamental feature that it would hardly preserve on its upper plate any areas of Haymond Formation, or any extensive areas of Dimple Limestone.

The area south of the Hells Half Acre fault, in the south part of the report area, is primarily a domain of the Tesnus Formation, which is strongly deformed, and probably thicker than elsewhere in the Marathon Basin. The formation contains two or more layers of white quartzite, that project in sharp ridges, such as Devils Backbone, and are plainly visible on the air photographs. Sharp folds, broken by thrust faults, were mapped on Devils Backbone; one of these, termed the Devils Backbone thrust, preserves small wedges of Dimple Limestone on its downthrown side, but its extent farther east and west has not been traced. Some folds in the white quartzite layers are also visible farther east on the air photographs, but on the whole the ledges strike nearly east and west. The general structure is enigmatic, and could only be worked out by additional ground surveys. During the writer's fieldwork in 1930 (1937, p. 130) he was impressed with the effects of much greater deformation of the rocks in this area than farther north. There are numerous shear zones and veinlets of quartz and calcite in the massive sandstone beds, and the shaly layers show the effects of incipient metamorphism and the development of secondary mica.

SUBSURFACE STRUCTURE OF THE PRE-PERMIAN ROCKS

The structures just described only extend to depths of 2 miles or so, at least in the north half of the report area, as indicated by deep drilling by oil companies which has been done in the last few decades; at greater depths are quite different structures and formations. Most wells drilled earlier in the Marathon Basin were only carried to depths of 3,000 feet or less, and penetrated the usual Marathon Basin formations and structures (King, 1930, p. 129). The later wells, by contrast, have been extended to depths as great as 20,000 feet. All are wildcat tests, put down in hopes of obtaining new petroleum deposits. The early wells were drilled to test the Marathon Basin formations; the later wells

[6]Named for the valley draining southwestward into San Francisco Creek southeast of the Haymond Mountains. This was marked as "Arden Draw" on earlier editions of the Marathon 1:62,500 topographic sheet, but on later editions the name is changed to "China Draw."

were drilled to test the possibilities of the deeper-lying formations. Small showings of oil or gas have been reported in some of the wells, but none have encountered any commercial production.

The locations of the deep drill holes are shown in the accompanying figure 17, and the drill records are illustrated graphically in figure 18. They are also summarized verbally in the section "Wall Data."

The deep drilling discloses that the familiar surface formations of the Marathon Basin lie on a major surface of discontinuity, below which are formations characteristic of the cratonic area north of the orogenic belt—Pennsylvanian above, with older Paleozoic beneath, including the Middle Ordovician Simpson Group and the Lower Ordovocian Ellenburger Limestone. This discontinuity emerges in a small area in the northwestern part of the Marathon Basin, where it is a nearly flat-lying thrust fault that the writer named the Dugout Creek overthrust (King, 1930, p. 108–110).

Along its outcrop in the northwestern part of the Marathon Basin, the Dugout Creek thrust is seen to truncate the bases of all the folds in the Marathon Basin rocks, so that it is a shear that has cut through structures that had previously been deformed. In this area, it is also seen to be truncated above by the unconformity at the base of the upper Wolfcampian Lenox Hills Formation, yet Wolfcampian fusulinids have been reported at several localities in the folded complex beneath it (which is mainly Upper Pennsylvanian Gaptank equivalent). These lower Wolfcampian fusulinids indicate that the Neal Ranch equivalent was involved in the thrusting; hence, the time of thrusting was in the middle of the Wolfcampian Epoch. Extending these data eastward, the Gaptank and Neal Ranch Formations of the eastern Glass Mountains must be allochthonous to the thrusting, even though they are synorogenic to postorogenic to the Des Moinesian and Missourian orogeny in that area. The angular unconformity at the base of the Hess Limestone, although seemingly modest in this area, must mark the time of emplacement of the thrust sheet.

The eastward extension of the leading edge of the Dugout Creek thrust is concealed by the unconformably overlying Permian rocks of the Glass Mountains, but its existence farther east (as in the north part of the report area) is proved by the subsurface penetration of the thrust in drill holes in the northeastern part of the Marathon Basin. Here, the buried trace of its leading edge must lie beneath the Permian rocks of the eastern Glass Mountains north of Gap Tank.

For the most part, the drill records indicate that the thrust surface slopes fairly regularly southeastward from its leading edge, but there are some exceptions in the western part of the Marathon Basin. Two wells drilled near Marathon, the Mobil-Adams and the Gulf-Combs, although located only 3 miles apart, show a difference in depth of the thrust of more than 4,000 feet. Also the record of the Turner, Combs well 16 miles south of Marathon, if correctly interpreted, indicates the thrust at a depth of only 1,600 feet, whereas it lies much deeper farther north. The reasons for these discrepancies are at present unknown, due to incompleteness of data. Either the surface of the thrust was originally irregular in these areas, or it has been warped or even folded.

The southeastward extent of the thrust beneath the Marathon Basin rocks is unknown. It is reported that seismic profiles extend it far southeastward from the last well penetrations, so it may underlie all the deformed surface formations in the Marathon Basin.

STRUCTURE OF THE PERMIAN ROCKS

The Permian rocks (Hess Limestone and younger) all occur in the Glass Mountains, whose eastern end extends into the northwestern part of the report area. Unlike the older Paleozoic rocks, the Permian rocks are little deformed, and dip northwestward or northward at angles of 15° or less. Their inclination is, however, steeper than that of the Cretaceous rocks which overlie them unconformably. In the western and central Glass Mountains the Permian rocks and the overlying Cretaceous are broken by a system of nearly vertical northwest-trending normal faults, with displacements as great as several hundred feet, and variable directions of downthrow, which were imposed on the rocks after the other structures in the Glass Mountains were created. These faults decrease in numbers eastward, and very few of them appear in the eastern part of the Glass Mountains, including the report area.

Within the report area the Permian strata, mainly the Hess Limestone, have the same gentle northwestward dip as the Permian rocks farther west in the Glass Mountains, and have a moderate discordance with the overlying Cretaceous. Dips recorded in the Hess are all less than 12°, and most are 5° or less. In the easternmost exposures of the Hess, about 5 miles east of Gap Tank, the recorded observations include some dips to the northeast, and a few to the south, which indicate a minor warping of the Permian rocks, whose extent cannot be traced.

STRUCTURE OF THE CRETACEOUS ROCKS

Within the map area, the Cretaceous rocks slope northeast, east, and southeast off the eastern side of the Marathon dome. In the north part of the area, the slope is less than 100 feet to the mile and is barely

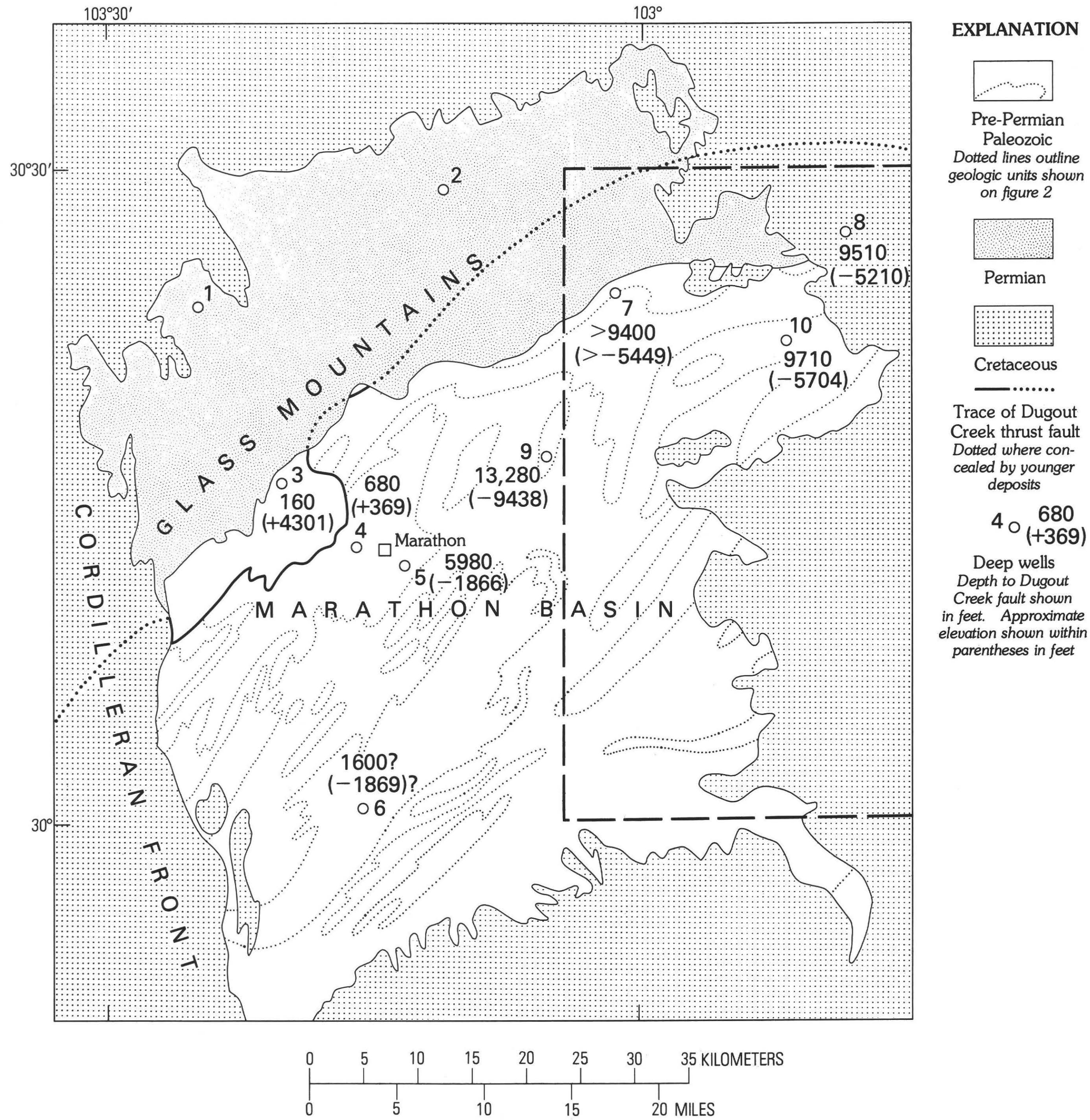


FIGURE 17.—Map of the Marathon Region showing locations of deep drill holes in the Marathon Basin and Glass Mountains and the depth of penetration to the great thrust fault (Dugout Creek overthrust). Report area outlined by dashed line. Wells are as follows: 1, Gulf-Lippit; 2, Mobil-Sibley; 3, Slick-Urschell-Decie; 4, Mobil-Adams; 5, Gulf-Combs; 6, Turner-Combs; 7, Forrest-Moore; 8, Continental-Allison; 9, Exxon-Law; 10, Mobil-Cox.

perceptible to the eye. In parts of the extreme southern part of the area the slope steepens to more than 800 feet to the mile.

The structure of the Cretaceous rocks is illustrated by the accompanying map (fig. 19). Elevations of contacts from which the contours were made were obtained from their positions on the contours of the topographic maps. Structure contours on two horizons are shown: on the top of the Trinity Group, and on the base of the Washita Group; as the intervening Fredericksburg Group thickens southward, it was not feasible to reduce all the contours to a common datum. Because

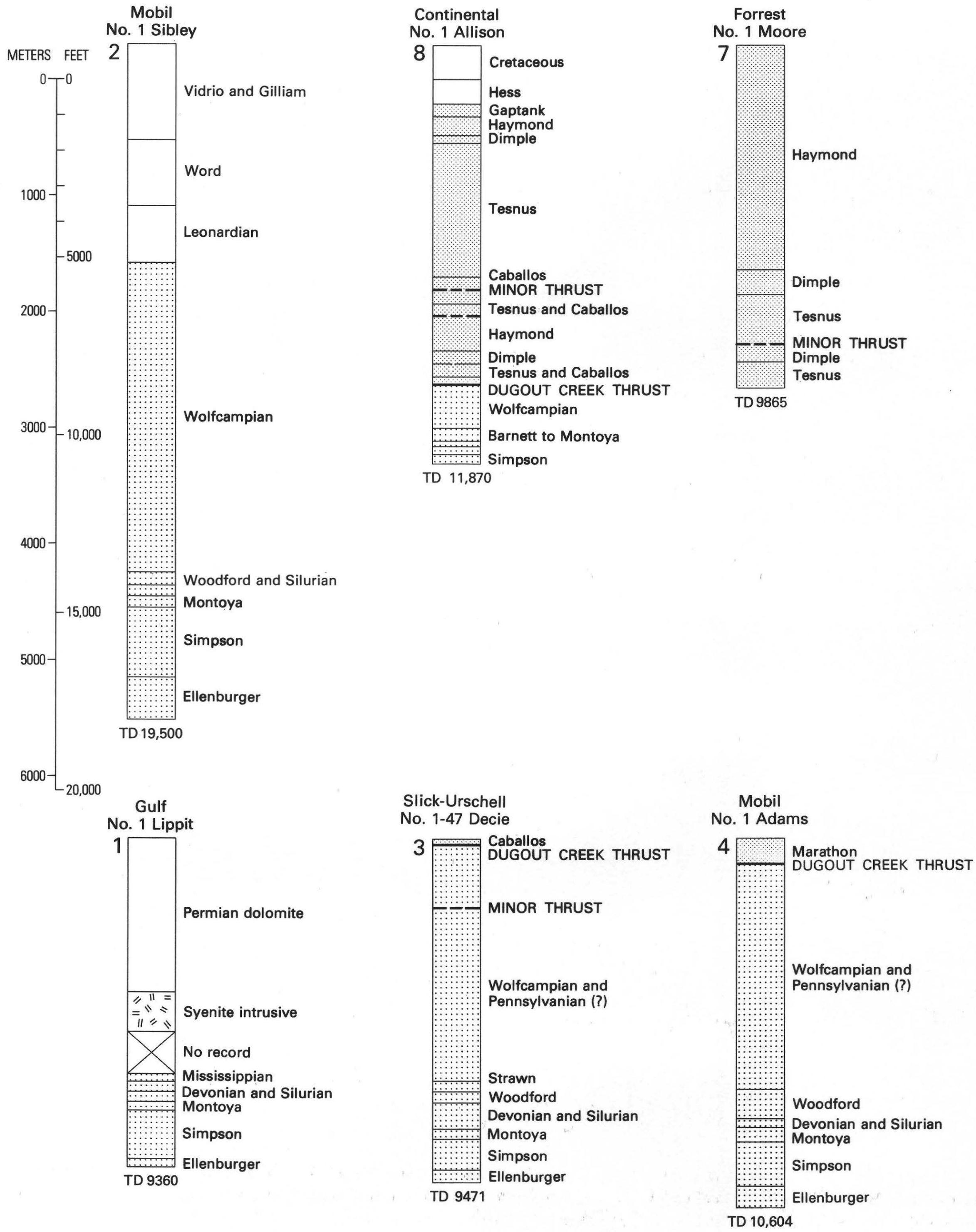


FIGURE 18.—Graphic representation of records of deep drill holes in the Marathon Region. Upper sections in the eastern part of the region; lower section in the western part.

of the gross nature of the source data, it was not possible to reproduce minor wrinkles in the structure; hence, the contours are generalized to show only the regional structure.

The contours show a broad, easterly-plunging arch in the north part of the area, with northeastward dips in the north in the Glass Mountains, and southeastward dips in the south toward U.S. Highway 90. This arch is accentuated in an anomalously high area 6 miles southeast of the Dimple Hills, where the Maxon Sandstone at the top of the Trinity Group stands higher on the escarpment than to the east or west; it is

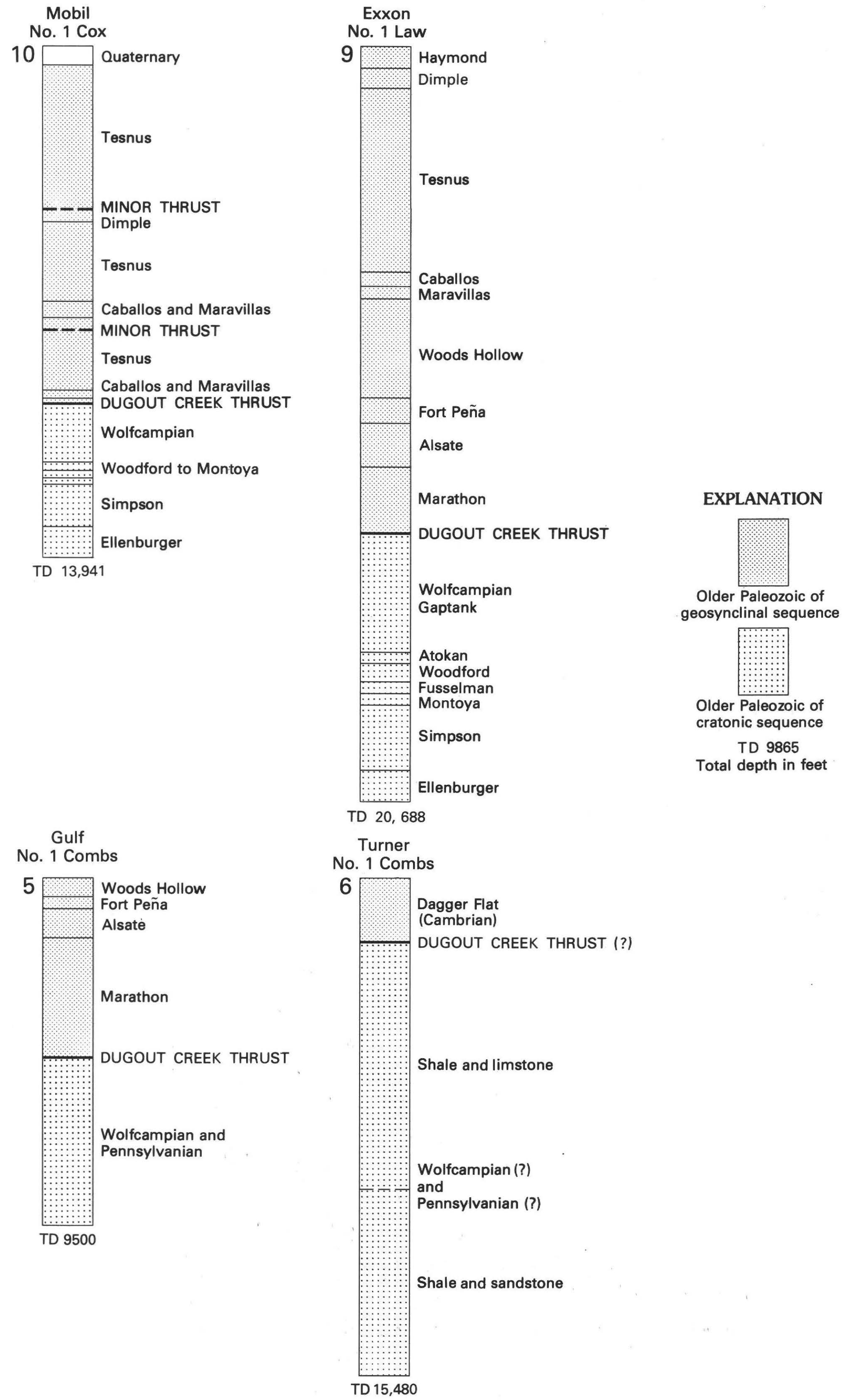


FIGURE 18.—Continued.

provided for on the contour map by a closed 4,600-foot contour.

In the southeast corner of the report area, south of the Southern Pacific Railroad, is a southeast-plunging

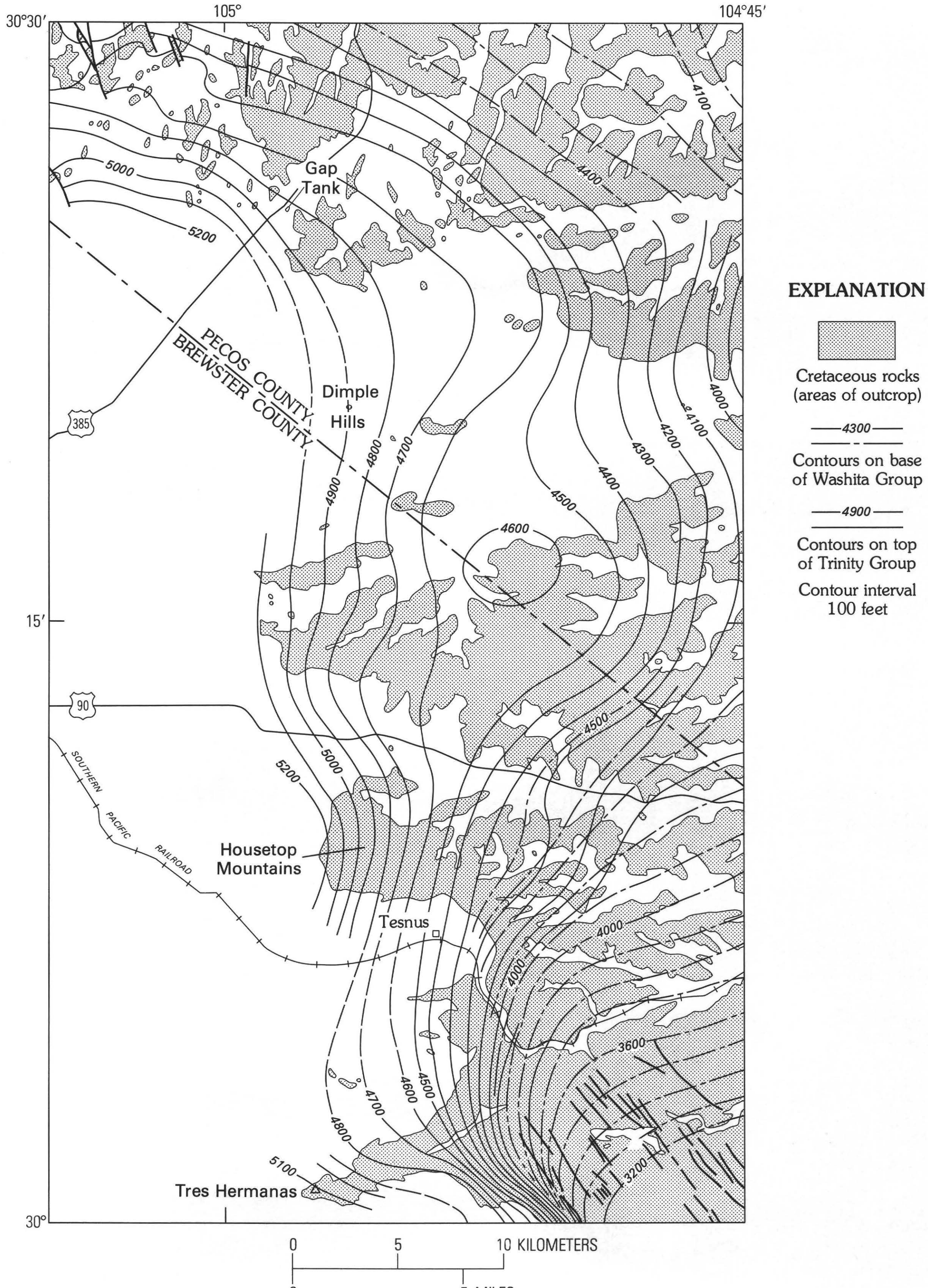


FIGURE 19.—Map of report area showing outcrops of the Cretaceous rocks and structure contours on two horizons in the Cretaceous.

trough, expressed on the geologic map by a nearly unbroken expanse of Washita Group. West of this, in the direction of Shely Peaks (Tres Hermanas), is a northeast-dipping homocline, with the steepest tilting of the Cretaceous rocks in the map area (more than 800 feet per mile); it is a small segment of the northeastern flank of a southeast-plunging anticline which is prominent near the Jones Ranch, in the Dove Mountain Quadrangle to the south.

In the southeastern corner of the report area the Washita beds and the underlying Cretaceous rocks are traversed by prominent, closely spaced, northwest-trending linear features. Some, perhaps many of these are faults of moderate displacement, and offsets of the formation contacts have been detected on some of them on the air photographs. These linears are at the northwestern end of a system of fractures and faults that are more prominent southeast of the report area. Two or three of them cross the Rio Grande in this direction, with west-northwest trend and scarps that face southwest.

What is the relation of the Cretaceous structure to the salients and recesses on the eastern side of the Marathon Basin—to the broad flats exposing Carboniferous rocks, partly covered by Quaternary gravels that project eastward, and the intervening areas of westward-projecting Cretaceous mesas? The most striking salient is that in the north, along W B Flats and eastward into Big Canyon, which extends entirely across the map area. A lesser salient occurs near Tesnus, between the west-projecting Cretaceous mesas of Housetop Mountains and Shely Peaks, which is drained in part by Maxon Creek; this extend about halfway across the map area.

It can be assumed that the original consequent drainage off the eastern side of the Marathon dome consisted of streams that followed the Cretaceous structure; these streams would have taken their courses in the eastward-plunging downwarps, leaving the upwarps on the interfluves. The relation of drainage to structure cannot be verified in detail, because most of the Cretaceous rocks in the salients have been eroded, so that contour control is lacking. It is clear, however, that the drainage pattern is not related to the Cretaceous structure in the manner outlined. The great salient in the north part of the report area, eastward from W B Flats, broadly follows the crest of the eastward-plunging arch. The salient to the south, near Tesnus, has no clear relation to the Cretaceous structure, so far as data are available. Clearly, therefore, much erosional adjustment has occurred since the time when the consequent drainage was first established on the Cretaceous surface.

TECTONIC HISTORY OF THE MARATHON REGION

The rocks and structures within the report area have been described. It is now worthwhile to summarize the tectonic history of these rocks and structures. The writer's interpretations of this history have been set forth at length in various previous publications (King, in Flawn and others, 1961, p. 176–190; King, 1977, 1978) and will be summarized here, based partly on data from within the report area, but also including that from a larger region.

The pre-Permian rocks of the Marathon Region accumulated in a segment of the Ouachita geosyncline, which lay on the southern border of the North American continent, extending from east of the present Ouachita Mountains of Oklahoma and Arkansas, southwestward to western Texas (including the Marathon Region), and possibly beyond into Mexico. The rocks of the geosyncline and the orogenic belt which formed from it are only exposed for 280 miles of this distance, in the large segment in the Ouachita Mountains, and in smaller segments in the Marathon Region and elsewhere in west Texas (fig. 20). Many data on the intervening segments are afforded by drill records. In all these areas, however, only the marginal parts of the geosynclinal rocks and their structures are revealed; the inner parts are beyond the reach of the drill and are deeply covered by younger sediments.

In all the segments, the rocks of the Ouachita geosyncline are remarkably alike, and contrast strongly with those of the cratonic area to the north; they also differ in many particulars with the character and tectonic history of those in the Appalachian orogenic belt to the east and northeast. In the Marathon Region and the Ouachita Mountains, the Ouachita rocks are characterized by a relatively thin sequence of lower Paleozoic leptogeosynclinal or starved basin deposits (Cambrian through Devonian into Early Mississippian), followed by a vastly thicker flysch sequence of Carboniferous age (Late Mississippian, Morrowan, and Atokan).

During early Paleozoic time, the shelf break at the margin of the continental carbonate platform lay along the northwestern edge of the Ouachita geosyncline and orogenic belt, rather than within it, as in the Appalachian orogenic belt. Hence, the lower Paleozoic rocks were mainly shales and other fine-grained clastic deposits, with significant units of siliceous sediments (such as the Maravillas Chert and Caballos Novaculite of the report area and westward). Within the Ordovician of the Marathon Region (exposed west of the report area) there are many layers of bouldery debris of carbonate

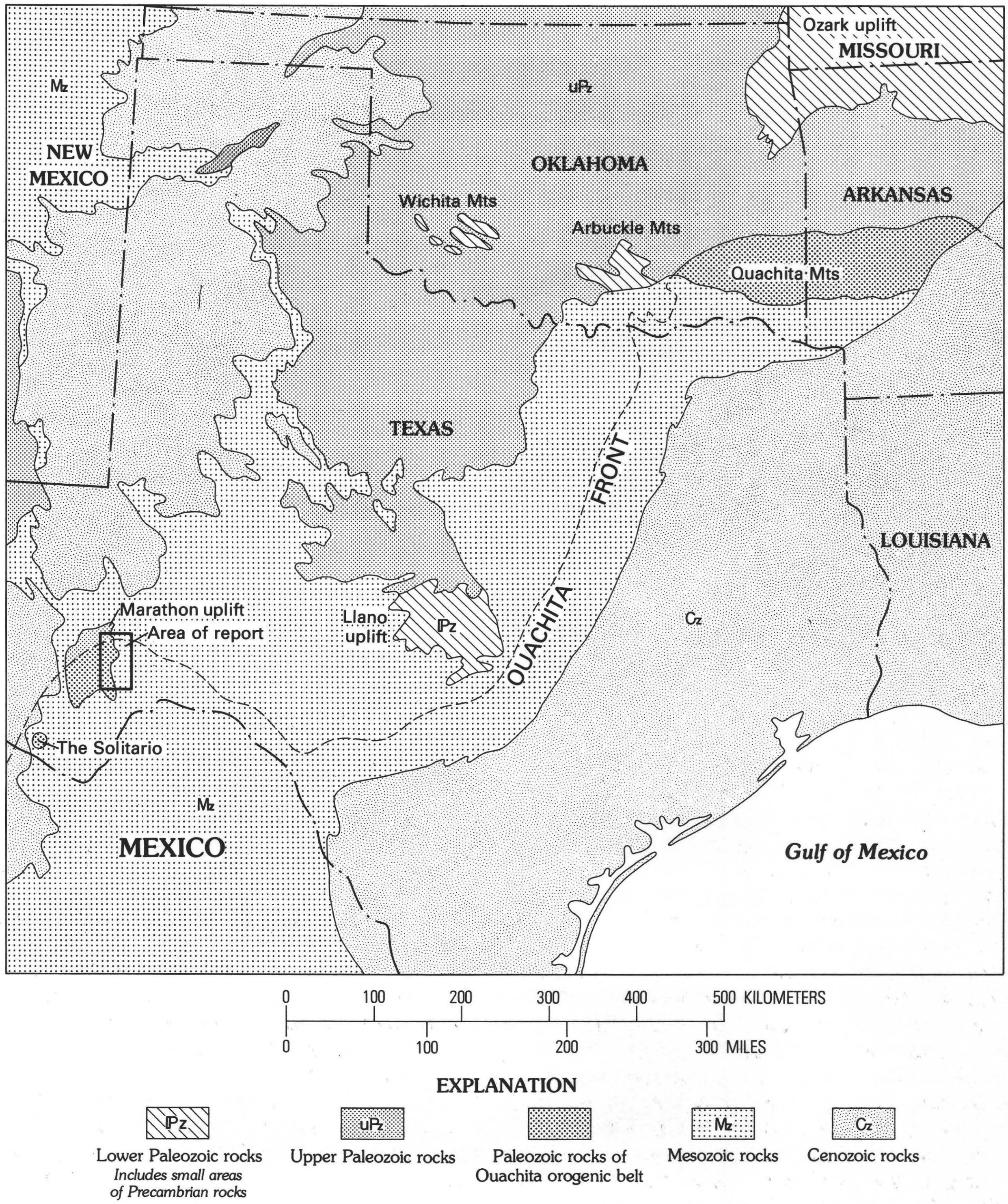


FIGURE 20.—Map of part of south-central United States, showing location of the Marathon Region and Ouachita Mountains. Report area is outlined.

rocks derived from the adjacent shelf, which slumped or slid into the deeper waters of the geosyncline.

The succeeding Carboniferous sequence (exposed in the report area and farther west in the Marathon Basin, is a vastly thicker flysch deposit, mainly sandstone and shale, laid down in a deeply subsiding area by turbid flows from adjacent lands, mainly southeast of the present outcrops. They accumulated on submarine deep-sea fans (as in parts of the Tesnus), or on basin plains beyond (as in parts of the Haymond). The northwestern border of the flysch trough lay not far northwest of the present exposures, as shown by the abrupt thinning of the Tesnus Formation in this direction (as in the northwestern part of the Marathon Basin), and by the shelf facies of the Dimple Limestone (along the northern edge of the basin). Late in the flysch cycle, deposition of the mainly fine-grained flysch sediments was punctuated by the deposition of boulder-beds, or wildflysch, in the Haymond Formation and comparable somewhat older deposits in the Ouachita Mountains. Their large clasts were derived in part from older geosynclinal rocks and other rocks farther southeast, and in part from the shelf to the northwest.

The geosynclinal rocks were deformed during an orogeny in Des Moinesian and Missourian time, when roundstone conglomerates derived from the deformed rocks of the fold complex were spread along its northwestern margin to form layers in the lower part of the Gaptank Formation. In contrast to the deep-water flysch deposits of the earlier Carboniferous, the Gaptank is a much thinner, shallower-water deposit.

The Gaptank and the succeeding early Wolfcampian Neal Ranch Formation are synorogenic or postorogenic to the Des Moinesian and Missourian orogeny, and were probably deposited only along the northern margin of the foldbelt. They are succeeded with angular unconformity by the later Wolfcampian Hess Limestone and by later Permian marine deposits that accumulated along the southern margin of the West Texas Permian basin. Before late Wolfcampian time, however, the Gaptank and Neal Ranch, as well as the earlier Paleozoic formations, were subjected to a new orogenic pulse, in Virgilian and early Wolfcampian time. During this pulse, the already deformed geosynclinal rocks were transported for many miles northwestward over their foreland along a frontal or Dugout Creek thrust, so that all the rocks exposed in the Marathon Basin are allochthonous, and so far as known lie with discontinuity at rather shallow depth on the cratonic rocks of their foreland. As a result of this orogeny, a new flysch trough, the Val Verde basin, developed along the northwestern front of the orogenic belt, which was thickly filled with Late Pennsylvanian and early Wolfcampian deposits. These are exposed beneath the Dugout Creek thrust in a small area in the northwestern part of the Marathon Basin, and have been penetrated beneath the thrust in deep wells farther east in the basin, where they lie on the older cratonic Paleozoic foreland rocks.

The deformed pre-Permian complex exposed in the Marathon Basin, and known elsewhere in the Ouchita orogenic belt, is merely the marginal part of the orogenic belt. The inner parts of the belt are little known, and are deeply covered by Mesozoic, mainly Cretaceous, deposits. A small area of schist, representing this inner belt, is exposed south of the Marathon Region on the Mexican side of the Rio Grande east of the village of Boquillas, and similar schists have been penetrated by drilling in places farther east. The relation of these schists to the marginal belt in the Marathon Basin and elsewhere is undetermined. It is also unknown how the marginal structures are related to probable plate convergence in the inner parts of the system.

The upper Wolfcampian and younger rocks of the Glass Mountains are postorogenic to the Paleozoic orogenies, and are tilted gently northward away from the orogenic belt toward the West Texas Permian basin. In their lower parts, however, (as in the basal Hess Limestone) they contain much debris eroded from the orogenic belt; they are otherwise fine grained and are mainly carbonate deposits.

After Permian time all the Paleozoic rocks—the orogenically deformed pre-Permian and the tilted Permian alike—were subjected to prolonged erosion, which leveled them into a nearly featureless surface, the Wichita paleoplain, before the Lower Cretaceous deposits were laid over them. The Cretaceous rocks overlapped northward from a basin farther south, as shown by the thickening of all the Lower Cretaceous formations from north to south, and by a regional change from solid massive limestones to the south (as in the Big Bend area) into clays and marls to the north (as in the Fort Stockton area). Within the report area, the northward overlap is manifested by the abrupt wedging out of the Trinity Group (Glen Rose Limestone and Maxon Sandstone) toward a low scarp in the paleoplain on the site of the front of the present Glass Mountains.

After Cretaceous time, early in the Tertiary, the west Texas region was subjected to various episodes of the Cordilleran deformation. This was more intense to the west, but along the orogenic front the Marathon dome was raised. Along its eastern side (as in the report area) the effects of the doming were only moderate, and resulted merely in a gentle slope of the Cretaceous rocks eastward, northeastward, and southeastward. These events were, however, associated with the intrusion of igneous rocks, a few small bodies of which occur in the southwestern part of the report area.

WELL DATA

Below are summaries of the records of ten deep drill holes that have been put down in the Marathon Basin and Glass Mountains since 1956. Their locations are shown on figure 17, and their records are illustrated graphically on figure 18. Other wells drilled earlier were only a few thousand feet deep, hence they are not of interest; some of them were listed in 1930 (King, 1930, p. 129). The records of later wells drilled in surrounding regions are given by Flawn, Goldstein, King, and Weaver (1961, p. 233–238). Logs of the wells are summarized below; they have been made by several commercial services in Midland, Tex. Where records are available that were made by several services they differ somewhat in detail; in the summaries given below, I have reconciled the differences to give the most probable version. Depths recorded in the wells were given in feet.

Abbreviations.—The following abbreviations are used in the records: G. C. & S. F. R.R., Gulf, Colorado and Santa Fe Railroad; G. H. & S. A. R.R., Galveston, Harrisburg, and San Antonio Railroad; T. C. R. R., Texas Central Railroad. FNL, FWL, FEL, and FSL, from north line, from west line, from east line, and from south line, respectively.

(1) *Gulf Oil Corporation, No. 1 Dora Lippit*

County: Brewster.

Location: Block 306, G.C. & S.F. R.R., 1,290 ft FNL, 600 ft FWL. Near Bisset Mountain, about 6 miles northeast of Altuda.

Elevation: 4,750 ft. *Total depth:* 9,360 ft.

Completed: 1967.

Surface formation: Upper Permian dolomite.

Drill record:

Permian dolomite	550–4,460 ft
Syenite intrusive	4,600–5,560 ft
No record	5,560–6,680 ft
Mississippian	6,680–6,940 ft
Woodford	6,940–7,130 ft
Devonian	7,130–7,440 ft
Fusselman	7,440–7,460 ft
Montoya	7,460–7,770 ft
Simpson Group	7,770–9,200 ft
Ellenburger	9,200–9,360 ft TD

Comments.—Below the Permian rocks this well penetrated a normal middle and lower Paleozoic cratonic sequence. The syenite intrusive is related to the doming of Bissett Mountain.

(2) *Mobil Oil Company, No. 1 D. J. Sibley*

County: Pecos.

Location: Block 331, section 82, 4,330 ft FNL, 2,304 ft FWL. In northern part of Glass Mountains, about a mile east of the Pecos-Brewster County line.

Elevation: 4,700 ft from topographic map; original record gives 2,596 ft. *Total depth:* 19,500 ft.

Completed: 1969.

Surface formation: Gilliam Limestone (Upper Permian).

Drill record:

Permian limestone	1,490–2,900 ft
Word Formation, with *Parafusulina*	2,900–4,620 ft
Leonardian, with *Parafusulina, Boultonia, Staffella,* and *Schubertella*	4,620–6,410 ft
Wolfcampian, with *Schwagerina, Pseudofusulina,* and *Triticites*	6,410–15,170 ft
Middle Paleozoic (Barnett, Kinderhookian, Woodford, and Devonian cherty dolomite)	15,170–15,820 ft
Fusselman Limestone	15,829–15,990 ft
Montoya Limestone	16,825–16,285 ft
Simpson Group	16,825–18,350 ft
Ellenburger Limestone	18,350–19,500 ft TD

Comments.—The 8,760 feet assigned to the Wolfcampian is part of the Val Verde basin sequence. The middle and lower Paleozoic rocks beneath are a normal cratonic sequence.

(3) *Slick-Urschell Oil Company (Woods Oil & Gas Company), No. 1–47 Mary Decie and others.*

County: Brewster.

Location: Block 4, G.C. & S.F. R.R., section 47, 660 ft FEL, 330 ft FWL of NE ¼ of section. Six miles northwest of Marathon, at foot of Glass Mountains escarpment, in northwestern part of Marathon Basin.

Elevation: 4,661 ft. *Total depth:* 9,471 ft.

Completed: 1956.

Surface formation: Caballos Novaculite, in klippe of overthrust.

Drill record:

Caballos Novaculite	0–160 ft
Dugout Creek thrust plane	160 ft
Wolfcampian and Pennsylvanian (?), with *Triticites* and *Schwagerina;* thrust fault at 1,600 ft	160–6,820 ft
Strawn Group, with *Fusulina* and *Fusulinella*	6,820–6,980 ft
Woodford	6,980–7,270 ft
Silurian and Devonian	7,270–8,070 ft
Montoya Limestone	8,070–8,250 ft
Simpson Group	8,250–9,637 ft
Ellenburger Limestone	9,637–9,471 ft TD

Comments.—This well drilled through a klippe of Caballos Novaculite into 6,660 of upper Paleozoic rocks, generally called Wolfcampian (but probably including Upper Pennsylvanian Gaptank

Formation, which is exposed in surrounding areas). Below is a normal cratonic sequence, proving that the Dugout Creek thrust carries Marathon Basin rocks over equivalent rocks of their foreland.

(4) *Mobil Oil Company, No. 1 Adams*

County: Brewster.

Location: Block 4, G.C. & S.F. R.R., section 25, 1,320 ft FSL, 1,320 ft FWL. About 1 mile west of Marathon.

Elevation: 4,049 ft. Total depth: 10,604 ft.

Drilled: in 1960's.

Surface formation: Marathon Limestone.

Drill record:

Marathon Limestone	0–680 ft
Dugout Creek thrust	680 ft
Wolfcampian and Pennsylvanian? clastic rocks	680–7,720 ft
Woodford	7,720–8,106 ft
Silurian and Devonian	8,106–8,436 ft
Fusselman Limestone	8,436–8,520 ft
Montoya Limestone	8,529–8,730 ft
Simpson Group	8,730–10,000 ft
Ellenburger Limestone	10,020–10,604 ft TD

Comments:—See well 5, below.

(5) *Gulf Oil Corporation, No. 1 D. S. C. Combs*

County: Brewster.

Location: Block 4, G.C. & S.F. R.R., section 16,660 ft FSL, 1,980 ft FEL. About 1½ miles southeast of Marathon.

Elevation: 4,114 ft. *Total depth:* 9,500 ft.

Completed: 1956.

Surface formation: Woods Hollow Shale.

Drill record:

Lower Paleozoic formations of Marathon sequence, from surface down to 4,850 ft, or to 5,860–6,100 ft. Different records make different formation assignments; cherts from 320 to below 700 ft are variously assigned to the Fort Peña Formation, or Caballos Novaculite and Maravillas Chert. The rocks below 700 ft are partitioned accordingly, but all agree that the lower part is Marathon Limestone. Andesitic intrusions recorded between 3,870 and 3,990 ft

Dugout Creek thrust, variously placed at 4,850 ft and 5,980–6,100 ft.

Beneath to total depth at 9,500 ft is light gray, fine-grained sandstone of Wolfcampian or Late Pennsylvanian age, with a few fusulinids.

Comments:—This well, and the Mobile, Adams well about 3 miles to the northwest, drilled through the Dugout Creek thrust into a foreland sequence. Note, however, that the Adams well passed through the thrust at a depth more than 4,000 ft shallower than the Combs well, and reached formations older than those penetrated in the Combs well.

(6) *Fred Turner, Jr., No. 1 D. S. C. Combs*

County: Brewster.

Location: Block 21, (G.H.S.A. R.R.), section 37, 433 ft FSL, 2,406 ft FWL. About 16 miles south of Marathon, near middle of Dagger Flat anticlinorium.

Elevation: 3,469 ft. *Total depth:* 13,980 ft.

Completed: 1957.

Surface formation: Dagger Flat Sandstone.

Drill record:

Interbedded shale and sandstone, probably Dagger Flat	0–1,600 ft
Change in formation, possibly Dugout Creek thrust	1,600 ft
Interbedded shale, limestone, and sandstone. In the upper part shale and limestone dominate, below 8,400 ft, mostly shale and sandstone. Chert occurs from 2,180–3,300 ft; fragments of spines and shells, 2,730–2,740 ft; no other fossils recorded	1,600–13,980 ft TD

Comments:—The whole sequence penetrated in this well consists of deformed shaly and sandy rocks, but in the absence of determinable fossils, interpretaton is engimatic. The change in formation at 1,600 ft may indicate that the well passed from Cambrian clastics into Pennsylvanian clastics, with the Dugout Creek thrust between, but this would place the thrust at a higher level than most of the other penetrations in the Marathon Basin.

(7) *Forrest Oil Company (Lone Star Producing Company), No. 1 Jo Ann Moore.*

County: Pecos.

Location: Block 1, G.C. & S.F. R.R., section 7, 660 ft FSL and 1,320 ft FEL. About 1½ miles southwest of Gap Tank in the flat south of the Glass Mountains escarpment.

Elevation: 4,416 ft. *Total depth:* 9,865 ft.

Completed: 1961.

Surface formation: Haymond Formation.

Drill record:

Haymond Formation, with *Triticites* at 150–180 ft	60–6,360 ft
Dimple Limestone, with *Millerella, Paramillerella,* and *Pseudostaffella* at 6,500–7,730 ft	6,360–7,000 ft

Tesnus Formation ------ 7,000–8,480 ft
Dimple Limestone (repeated), with *Paramillerella, Millerella,* and *Endothyra* at 8,456–8,960 ft ------ 8,480–8,800 ft
Tesnus Formation ------ 8,800–9,865 ft TD

Comments.—This well failed to reach the Dugout Creek thrust at total depth. The recorded repetition of Dimple Limestone, probably by thrust slicing, indicates greater structural complexity at depth than the rather open folding in the surface formations.

(8) *Continental Oil Company, No. 1 J. E. Allison et al*

County: Pecos.

Location: Block 2, T.C. R.R., section 10, 2,180 ft FSL, 1,320 ft FEL. In valley between Cretaceous mesas, 8 miles east of Gap Tank.

Elevation: 4,300 ft (approximately, from topographic map), *Total depth:* 11,870 ft.

Completed: 1974.

Surface formation: Lower Cretaceous.

Drill record:

Cretaceous	0– 663 ft
Hess Limestone	663–1,242 ft
Gaptank Formation	1,242–1,612 ft
Haymond Formation	1,612–2,342 ft
Dimple Limestone	2,342–2,500 ft
Tesnus Formation	2,500–6,710 ft
Caballos Novaculite	6,710–6,870 ft
Fault	6,870 ft
Tesnus Formation	6,870–7,070 ft
Caballos Novaculite	7,070–7,500 ft
Fault	7,500 ft
Haymond Formation	7,500–8,742 ft
Dimple Limestone	8,742–8,900 ft
Tesnus Formation	8,900–9,158 ft
Caballos Novaculite	9,158–9,510 ft
Sole fault (Dugout Creek thrust)	9,510 ft
Wolfcampian and Pennsylvanian	9,510–10,730 ft
Barnett Shale	10,730–11,022 ft
Woodford and Devonian	11,022–11,182 ft
Fusselman Limestone	11,182–11,220 ft
Montoya Limestone	11,220–11,812 ft
Simpson Group	11,812–11,870 ft TD

Comments:—This well lies several miles south of the projected subsurface trace of the leading edge of the Dugout Creek thrust, or sole fault of the Marathon orogenic belt. The repetition of the Carboniferous formations above it indicates much thrust slicing of the rocks of the upper plate. Beneath the sole fault is a normal sequence of the Paleozoic cratonic formations, ending in the Simpson Group at total depth.

(9) *Exxon Company (Humble Oil & Refining Company), No. 1 Virginia Law*

County: Brewster.

Location: Block 2 G.C. & S.F. R.R., section 91, 1,980 ft FNL and FEL. At south end of a synclinal trough of Dimple and Haymond Formations west of Frog Creek, and 10 miles east of Marathon.

Elevation 4,832 ft. *Total depth:* 20,688 ft.

Completed: 1972.

Surface formation: Haymond Formation.

Drill record:

Haymond Formation	70–400 ft
Dimple Limestone	400–1,000 ft
Tesnus Formation	1,000–6,070 ft
Caballos Novaculite	6,070–6,500 ft
Maravillas Chert	6,500–6,830 ft
Woods Hollow Shale	6,830–9,850 ft
Fort Peña Formation	9,850–10,230 ft
Alsate Shale	10,230–11,506 ft
Marathon Limestone	11,506–13,280 ft
Sole fault (Dugout Creek overthrust)	13,280 ft
Wolfcampian and Gaptank; limestone in upper part, clastics below	13,280–16,760 ft
Atokan	16,760–16,870 ft
Woodford and Devonian	16,870–17,470 ft
Fusselman Limestone and other Silurian	17,470–17,620 ft
Montoya Limestone	17,620–18,020 ft
Simpson Group	18,020–19,550 ft
Ellenburger Limestone	19,550–20,688 ft TD

Comments.—This is currently the deepest well that has been drilled in the Marathon Basin, and has the deepest penetration of the sole fault. The formations beneath are of the normal cratonic sequence.

(10) *Mobil Oil Company, No. 1 Cox*

County: Pecos.

Location: Thomas J. Hall survey, section 100, 1,980 ft FNL and FEL. In the middle of W B Flats, about 6 miles east of the Dimple Hills.

Elevation: 4,006 ft. *Total depth:* 13,941 ft. *Completed* in 1960's.

Drill record:

Valley fill	0–292 ft
Tesnus Formation	292–4,205 ft
Fault	4,205 ft

Dimple Limestone	4,205–4,385 ft
Tesnus Formation	4,385–6,875 ft
Caballos Novaculite	6,875–7,167 ft
Maravillas Chert	7,167–7,516 ft
Fault	7,516 ft
Tesnus Formation	7,526–9,477 ft
Caballos Novaculite	9,477–9,568 ft
Maravillas Chert	9,568–9,710 ft
Sole fault (Dugout Creek overthrust)	9,710 ft
Wolfcampian (and upper Pennsylvanian?)	9,710–11,350 ft
Woodford	11,350–11,368 ft
Fusselman Limestone and other Silurian	11,368–11,510 ft
Montoya Limestone	11,510–11,870 ft
Simpson Group	11,870–13,053 ft
Ellenburger Limestone	13,053–13,941 ft TD

Comments.—The sole fault was penetrated in this well at an elevation only a little deeper than in the Continental-Allison well 6 miles to the north. Of interest is the considerable duplication by thrust slicing of the Marathon Basin rocks above it. The formations beneath the thrust are part of the normal cratonic sequence.

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