Geology of the Cross Plains Quadrangle, Brown, Callahan Coleman, and Eastland Counties Texas

GEOLOGICAL SURVEY BULLETIN 1096-B

Prepared in cooperation with the Bureau of Economic Geology, The University of Texas

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By PHILIP T. STAFFORD

PENNSYLVANIAN AND LOWER PERMIAN STRATIGRAPHY, BETWEEN THE BRAZOS AND COLORADO RIVERS, NORTH-CENTRAL TEXAS

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GEOLOGY OF THE CROSS PLAINS QUADRANGLE, BROWN, CALLAHAN, COLEMAN, AND EASTLAND COUNTIES, TEXAS

By Philip T. Stafford

ABSTRACT

The Cross Plains quadrangle lies in north-central Texas in parts of Brown, Callahan, Coleman, and Eastland Counties and covers an area of about 254 square miles. Studies were made of the lithologic characteristics, distribution, stratigraphic relations, thickness, and age of the rocks in the quadrangle. Rocks assigned to the Cisco group of the Pennsylvanian system and to the Wichita group of the Permian system underlie about one-third of the quadrangle, and the rocks assigned to the Trinity and Fredericksburg groups of the Cretaceous system underlie the remainder of the area. Quaternary alluvium and small amounts of terrace gravel of Pleistocene(?) and Recent age are present along the major streams.

About 75 percent of the Pennsylvanian and Permian rocks is gray and red shale; the rest is limestone, sandstone, siltstone, and conglomerate. All of the conglomerate, most of the sandstone, and some of the siltstone and shale fill channels which were cut by at least four periods of erosion during Permian time. No channel deposits of Pennsylvanian age were recognized in the quadrangle, although channel-fill rocks belonging to this system have been mapped a few miles to the south.

The Trinity group of the Lower Cretaceous (Comanche) series consists of about 90 percent sandstone and 10 percent conglomerate, siltstone, and shale. The Fredericksburg group, overlying the Trinity, consists of limestone and small amounts of interbedded shale.

About 3,100 wells had been drilled for petroleum in the quadrangle and several tens of millions of barrels of oil had been produced up to January 1, 1955. Most of the production has been from sandstone units of the Strawn, Canyon, and Cisco groups (Middle and Upper Pennsylvanian), although some has been from rocks of the Wolfcamp series (lower Permian), Bend group (Lower and Middle Pennsylvanian), and Ellenburger group (Ordovician). The oil-producing sandstone units are apparently correlative to channel-fill deposits which crop out in north-central Texas.

INTRODUCTION

LOCATION OF AREA

The Cross Plains quadrangle is located in north-central Texas in parts of Brown, Callahan, Coleman, and Eastland Counties (fig. 7). It constitutes an area of about 254 square miles, which is bounded by meridians 99°00′ and 99°15′ and by parallels 32°00′ and 32°15′. The quadrangle is in the south half of the northward-trending belt of exposed rocks of Pennsylvanian and Permian ages in Texas that extends from the Llano uplift northward to the Red River on the Oklahoma-Texas border. The Callahan Divide, a prominent topographic feature which separates drainage basins of the Brazos and Colorado Rivers (Fenneman, 1931, p. 57), crosses the quadrangle in a general northwest direction.

PURPOSE

In 1949, the U.S. Geological Survey, in cooperation with the Bureau of Economic Geology of The University of Texas, began a study of the rocks of Pennsylvanian and early Permian age in north- and west-central Texas as part of its oil and gas investigations. These studies have included lithologic characteristics, areal distribution, stratigraphic relations, thickness, age, structure, and petroleum accumulation. This report on the Cross Plains quadrangle is presented as one of several publications resulting from these investigations.

PREVIOUS GEOLOGIC STUDIES

Early workers (Tarr, 1890; Dumble, 1890; Cummins, 1891) named and described the large subdivisions of the Pennsylvanian and Permian systems in north-central Texas. Drake (1893) named most of the rock units which are now considered members, and in subsequent years Plummer and Moore (1921), Cheney (1929, 1940, 1948, 1949, and 1950), Sellards (1932), Lee and others (1938), Moore (1949), Cheney and Eargle (1951b), and Eargle (1960), revised, added to, and summarized the nomenclature. The Cross Plains quadrangle has been included as part of several geologic maps at various scales. Plummer and Moore (1921) in their publication on the Pennsylvanian of north-central Texas include a geologic map at the approximate scale of 1: 190,000. The Bureau of Economic Geology of The University of Texas, in cooperation with the American Association of Petroleum Geologists, compiled geologic maps of Callahan County (Plummer and Hornberger, 1932), Coleman County (Hudnall and Pirtle, 1929), Brown County (Hudnell and Pirtle, 1931), and Eastland County (Wender, 1929) from information contributed by oil companies and

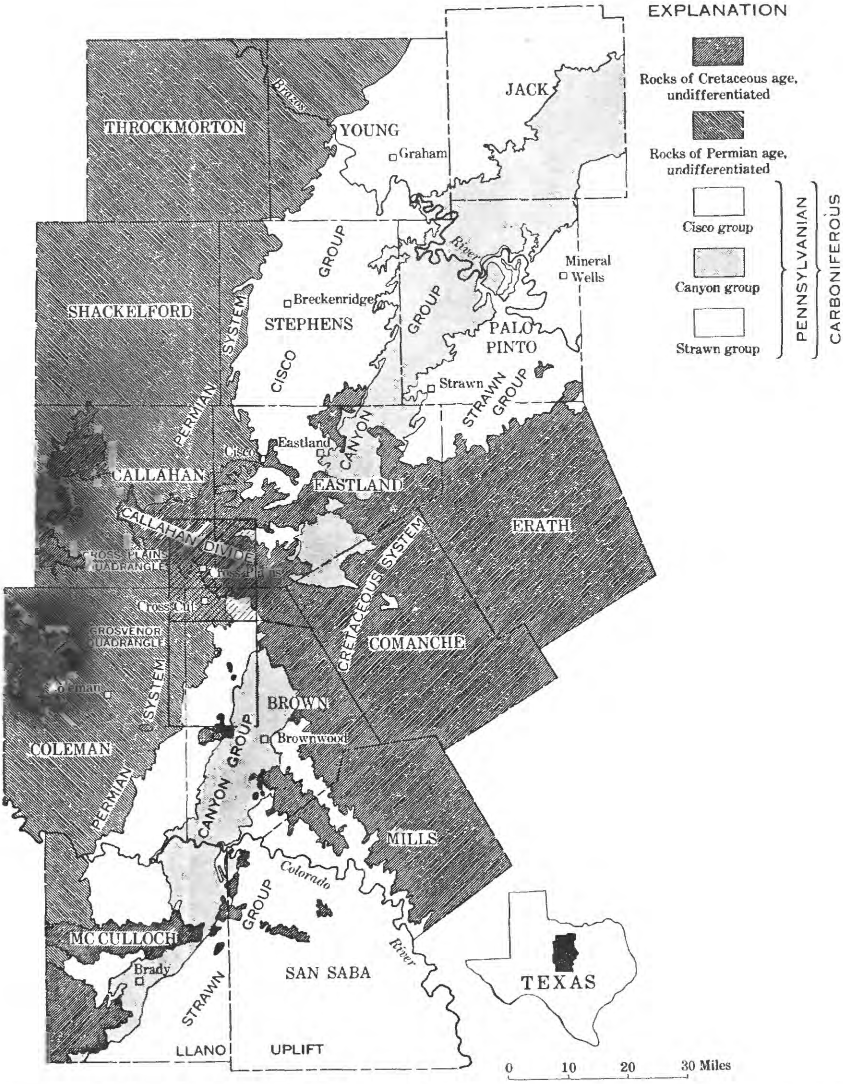

Figure 7.—Index map showing the location of the Cross Plains quadrangle and generalized geology of north-central Texas. (Geology modified after Darton and others, 1937.)

independent geologists and from the map of Plummer and Moore (1921). Cheney and Eargle (1951a) revised the geologic map of Brown County, which includes a part of the Cross Plains quadrangle.

ACKNOWLEDGMENTS

The writer is indebted to several members of the Geological Survey for their assistance in various phases of this investigation. Robert T. Terriere aided in mapping the southeastern part of the quadrangle.

D. Hoye Eargle introduced the writer to the regional geology and offered valuable advice on problems of regional geology. Donald A. Myers, by the use of fusulinids, assisted in the correlation of some limestone members of the Pennsylvanian and Permian between the outcrop in the southern part of the quadrangle (northern Brown County) and the northeastern part (Sabana River valley). Mackenzie Gordon, Jr., Helen Duncan, Norman F. Sohl, and Ellis Yochelson prepared faunal lists of selected fossil collections.

METHODS OF STUDY

MAPPING AND FIELDWORK

This report is based on fieldwork during the period 1952–55. The geologic mapping was done on aerial photographs at a scale of approximately 1:20,000 and transferred to the base map by means of a vertical projector and a low-order stereoscopic plotter. The base map was constructed from the aerial photographs by use of radial templates and a low-order stereoscopic plotter.

Three important mapping problems arose during fieldwork:

1. Early workers placed the upper limits of most formations of the Pennsylvanian and Permian at the top of limestone units. Although the limestone beds make the best stratigraphic markers (because of their topographic prominence, lateral continuity, and distinctive lithologic characteristics), their tops are poorly exposed and difficult to map accurately because they are deeply weathered on dip slopes of escarpments and are generally concealed by soil or alluvium (fig. 8). The bases of the limestone beds are generally well exposed and are

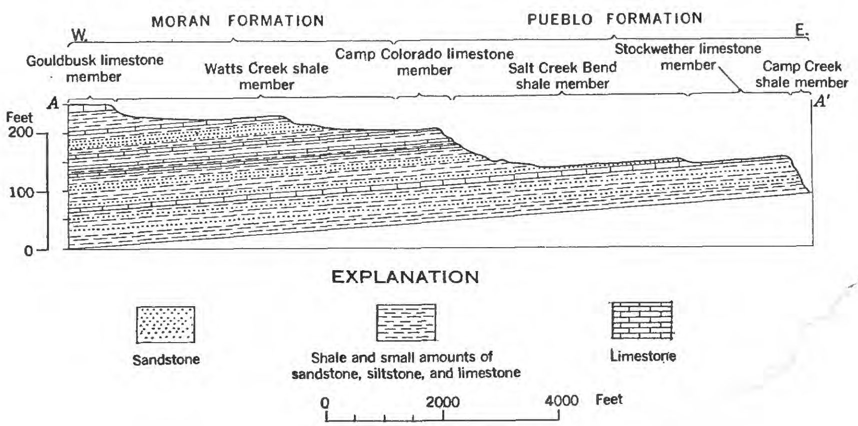

FIGURE 8.—Generalized cross section illustrating relation of stratigraphic nomenclature to lithologic characteristics and topographic expression of Permian rocks in the Cross Plains quadrangle. Line of section shown on plate 4.

the logical places to draw contacts of rock units in the field. Nevertheless, the tops of some limestone members were mapped where necessary to conform to recognized nomenclature (pl. 4).

2. Pennsylvanian and Permian channel-fill deposits of conglomerate, sandstone, siltstone, and shale are extensive. It is desirable to distinguish between channel-fill deposits and those that are not, inasmuch as their geographic and stratigraphic extent is important in interpreting the stratigraphy, geologic history, and economic geology. Because the channel-fill sediments have characteristic lithology and bedding, and give rise to distinct vegetation, the deposits are easily mapped. However, it is difficult or impossible to distinguish the fine-grained channel-fill shale and siltstone from the nonchannel shale and siltstone. For that reason, not all of the channel-fill rocks are shown on the geologic map (pl. 4).

3. The base of the Trinity group (Cretaceous) was mapped with considerable difficulty. At many places the boundary between the Paleozoic and overlapping Cretaceous rocks is obscured by loose sand weathered from friable sandstone in the lower part of the Trinity group, and the contact cannot be established closer than within several hundred feet.

DESCRIPTIVE TERMINOLOGY

The term "shale" is used for rocks of finer grain size than siltstone, regardless of the presence or absence of lamination or fissility.

In referring to the bedding of the rocks, the following terminology is used: massive, greater than 4 feet in thickness; thick bedded, 2–4 feet; medium bedded, 6 inches–2 feet; thin bedded, 2–6 inches; and very thin bedded, ½–2 inches. Platy refers to beds 1/16–½ inch thick, and fissile, less than 1/16 inch.

The limestone is classified according to grain size into three types, after Grabau as described by Pettijohn (1949, p. 300–307) : calcilutite, limestone composed mainly of particles of clay size (less than 1/16 mm in diameter; calcarenite, limestone composed mainly of particles of sand size (1/16–2 mm) ; and calcirudite, limestone composed mainly of particles greater than sand size (more than 2 mm).

In describing the relative abundance of fossils, and occasionally of rock types or other material, the following standard is used: very abundant, the fossils (or other constitutents) compose most of the rock or unit; abundant, make up a considerable part of the rock; plentiful, found with ease; common, found in most hand specimens of rocks; rare, usually difficult to find; and very rare, considerable searching is necessary.

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STRATIGRAPHY

About one-third of the Cross Plains quadrangle is underlain by sedimentary rocks belonging to the Cisco group of the Pennsylvanian system and the Wichita group of the Permian system. The rest of the quadrangle is underlain by sedimentary rocks of the Trinity and Fredericksburg groups of the Cretaceous system. Some alluvium and high terrace gravel of the Quaternary system are present along the major streams.

PENNSYLVANIAN AND PERMIAN SYSTEMS

The exposed rocks assigned to the Pennsylvanian and Permian systems are predominantly gray and red shale. Limestone constitutes about 10 percent of the rocks, sandstone about 7 percent, siltstone about 4 percent, and conglomerate less than 1 percent. Coal and hematite are very rare. The shale beds are persistent but poorly exposed. Most of the sandstone and all of the conglomerate are well-exposed, nonpersistent channel-fill deposits.

The thickness of the Pennsylvanian rocks averages about 260 feet and that of the Permian rocks about 610 feet. Erosion and channel cutting at the base of the Permian, however, locally thin the Pennsylvanian rocks to about 200 feet, and channel-fillings thicken the Permian rocks to about 670 feet.

Eargle (1960) discussed and revised the stratigraphic nomenclature and boundaries of the component formations, members, and beds in the Cisco group and the lower part of the Wichita group. His nomenclature is essentially followed in this paper. The nomenclature of Moore (1949) is used for those rocks of the Wichita group which were not discussed by Eargle.

CISCO GROUP

The Cisco group consists principally of gray and red shale and gray limestone (pl. 5). A small amount of sandstone and siltstone is present; some may be channel-fill deposits equivalent to the channel-fill sandstone and conglomerate of Cisco age in the Grosvenor quadrangle as mapped by Terriere (1960)

Eargle (1960) assigns two formations to the Cisco group; they are, in ascending order, the Graham and Thrifty. The total thickness of the group in this area, as given by Eargle, is about 385 feet. Only the upper 245 feet is exposed in the Cross Plains quadrangle.

GRAHAM FORMATION

The Graham formation overlies the Home Creek limestone member of the Caddo Creek formation of the Canyon group (Pennsylvanian), and is overlain by the Speck Mountain limestone member of the Thrifty formation of the Cisco group. Only the upper 135 feet of the Graham formation is exposed in the Cross Plains quadrangle. It includes five members, which are, in ascending order, the Bluff Creek shale member, Gunsight limestone member, Wayland shale member, Ivan limestone member, and an unnamed shale member.

BLUFF CREEK SHALE MEMBER

The Bluff Creek shale member crops out only in the extreme southeast, where about the uppermost 5 feet of the member is exposed. Southward, in the Grosvenor quadrangle, its total thickness is about 140 feet (Terriere, 1960). In the Cross Plains quadrangle the Bluff Creek consists of slightly fissile, noncalcareous, and nonfossiliferous very light-gray shale, mottled with purplish gray to pale red.

GUNSIGHT LIMESTONE MEMBER

The Gunsight limestone member, exposed only in the extreme southeast, consists of a single limestone bed 6 feet thick that forms a prominent bench for about half a mile along the sides of Lost Creek valley. Southward, the Gunsight consists of 2 limestone beds separated by 20–25 feet of shale. The upper limestone bed is absent in the Cross Plains quadrangle.

The Gunsight is light-gray to light-olive-gray calcilutite which weathers to pale-yellowish-brown blocks and slabs. It is very thin to medium bedded. At places it consists of brecciated limestone fragments with incrusting algae. The member, originally called the *Campophyllum* bed by Drake (1893), contains abundant horn corals. Bryozoans, crinoid stems, and brachiopods are rare.

WAYLAND SHALE MEMBER

The Wayland shale member consists of the beds between the underlying Gunsight limestone member and the overlying Ivan limestone member. It is approximately 80 feet thick; the basal 15 feet, however, is probably equivalent in age and stratigraphic position to the shale between the upper and lower beds of the Gunsight limestone member elsewhere.

The Wayland shale member is poorly exposed. At most places it consists of very light- to medium-light-gray silty shale, although a small amount of sandstone, siltstone, and mottled purple-and-red fissile shale is exposed in the upper part.

Terriere (1960) found channel-fill sandstone and conglomerate in the upper part of the Wayland in the Grosvenor quadrangle. These channel-fill deposits were correlated with the Avis sandstone of Plummer and Moore (1921) by Lee and others (1938, p. 123, 124). At many places in the Cross Plains quadrangle, the upper part of the section contains about 3 feet of very light-gray very fine grained sandstone which may correlate with the channel-fill deposits in the Grosvenor quadrangle.

No fossils were found in the Wayland in the Cross Plains quadrangle. A very large marine invertebrate fauna was collected from this member (Terriere, 1960) at a locality 1.3 miles south of the quadrangle boundary.

IVAN LIMESTONE MEMBER

The Ivan limestone member, consisting of 1 massive bed 5–7 feet thick, is very light-gray to medium-light-gray calcarenite, which weathers pale red in the middle part and brown in the upper and lower parts. The limestone is very sandy and on weathered surfaces resembles sandstone. Crinoid stems and unidentifiable fossil debris are common; fusulinids, gastropods, and brachiopods are rare. The Ivan caps a prominent escarpment, but generally only the lower foot or two is exposed.

UNNAMED SHALE MEMBER OVERLYING THE IVAN LIMESTONE MEMBER

The unnamed shale member between the Ivan limestone member of the Graham formation and the Speck Mountain limestone member of the Thrifty formation is 40 feet thick. It consists of about 90 percent shale and 10 percent sandstone (pl. 5).

The shale is, in part, light greenish gray and grayish red, and, in part, medium light gray to light gray. Some of it is silty and most of it is fissile. Carbonaceous plant remains are found along the bedding planes in the light- to medium-gray shale. In many places a bed of impure coal, as much as 6 inches thick, is exposed about 1 foot below the top of the member.

An apparently persistent 4-foot sandstone bed is present 20–24 feet above the base of the unit. This bed, which locally forms an indistinct bench, is light gray, very fine grained, very thin bedded, and, in places, slightly calcareous. A 1-foot nonpersistent sandstone bed is exposed near the base of the member at some places. A persistent zone of hematite nodules as much as 2 inches in diameter is present 25 feet above the base of the member.

THRIFTY FORMATION

The Thrifty formation is underlain by the Graham formation of the Cisco group and overlain by the Pueblo formation of the Wichita group (pl. 5). The thickness of the Thrifty formation in the Cross Plains quadrangle is about 100 feet, except where these rocks were removed by erosion during earliest Permian time.

The formation consists of five units, which are, in ascending order, the Speck Mountain limestone member, an unnamed shale member, the Breckenridge limestone member, an unnamed shale member, and the Chaffin limestone member. Eargle (1960) recognizes a sixth unit, the Parks Mountain sandstone member, which was not found in the Cross Plains quadrangle.

SPECK MOUNTAIN LIMESTONE MEMBER

The Speck Mountain limestone member is 5½–7 feet thick and consists of a lower very resistant limestone bed 3–4 feet thick, and an upper argillaceous limestone bed, 1½ feet thick. They are separated by 1–2 feet of medium-gray fissile shale containing an abundance of pelecypods and brachiopods having original shell material.

The lower bed is medium-gray to medium-light-gray calcilutite that weathers to various shades of light brown. It fractures subconchoidally and weathers to blocks which creep down the scarp beneath. Fusulinids, crinoid stems, and brachiopods are common to rare; unidentified fossil debris is common.

The upper bed, light-gray argillaceous calcilutite, appears to be present throughout the quadrangle, but it is covered at most places. It weathers to thin-bedded slabs and rubble which have an irregular fracture. Brachiopods, crinoid stems, and other fossils are common to rare.

UNNAMED SHALE MEMBER OVERLYING THE SPECK MOUNTAIN LIMESTONE MEMBER

The unnamed shale member, 35–40 feet thick, lying between the Speck Mountain limestone member and the Breckenridge limestone member, consists of fissile greenish-gray and red shale. It is nonfossiliferous in the Cross Plains quadrangle except for unidentified plant fragments which are common along the bedding planes. Terriere (1960) reports an abundant marine fauna from this member in the Grosvenor quadrangle.

BRECKENRIDGE LIMESTONE MEMBER

The Breckenridge limestone member ranges from 9–15 feet in thickness and averages about 12 feet. In northern Brown County it consists of a lower very resistant limestone bed generally 4 feet thick, a middle shale bed also about 4 feet thick, and an upper nonresistant argillaceous limestone bed about 1 foot thick. In the Sabana River valley in Eastland County, in the northeastern part of the quadrangle, the lower bed is 3½ feet thick, the middle bed 8 feet, and the upper bed 3½ feet.

In northern Brown County the lower limestone is light-gray to medium-light-gray calcilutite. Where deeply weathered, it is pinkish gray. The bed has characteristic wavy bedding planes and is very thin to thin bedded. It weathers to blocks about 4 feet thick and as much as 10 feet wide. Brachiopods are common, fusulinids are common to abundant, and unidentified organic material resembling algae is common. In the Sabana River valley this limestone bed is light yellowish gray to light brown and contains only a few crinoid stems and fusulinids. The wavy bedding planes present in northern Brown County are especially noticeable here.

The shale between the lower and upper limestone beds is light gray, greenish gray, and light olive gray mottled with pale red. It is nonresistant and is generally covered with soil.

In northern Brown County the upper limestone bed is light-greenish-gray to pale-red argillaceous calcilutite. It weathers to irregularly surfaced slabs 1 inch or less thick. Fusulinids are abundant; fenestellid bryozoans, crinoid stems, echinoid spines, and brachiopods are common. In the Sabana River valley in Eastland County this bed is light brownish to pinkish gray; the bedding, weathering, and fauna are similar to those of Brown County.

UNNAMED SHALE MEMBER OVERLYING THE BRECKENRIDGE LIMESTONE MEMBER

The rocks between the Breckenridge limestone member and the younger Chaffin limestone member are about 50 feet thick and consist of about 80 percent shale and 20 percent sandstone (pl. 5). The shale is light gray and pale to moderate red, mottled with greenish gray. It is noncalcareous, nonfossiliferous. and in part silty. The member contains a bed of persistent sandstone, 4–16 feet thick, whose top is 2 feet from the base of the Chaffin limestone member. This sandstone is very light gray, very fine to medium grained, and crossbedded. It resembles sandstone of the channel-fill deposits and may correlate with the channel-fill rocks in southeastern Coleman County to which the name Parks Mountain sandstone member was applied by Drake (1893). A 2-foot-thick poorly exposed sandstone bed is also present in the lower 15 feet of the shale.

In the southern part of the quadrangle, extensive conglomerate and sandstone deposits fill channels which were cut downward to within 6 feet of the Breckenridge. These channels were cut from above the Chaffin limestone member (fig. 9), and the deposits which fill them are part of the upper unit of the Waldrip shale member of the Pueblo formation of Permian age.

CHAFFIN LIMESTONE MEMBER

The Chaffin limestone member caps a very prominent scarp although it is only 1½–3½ feet thick. It is light- to medium-gray calcarenite

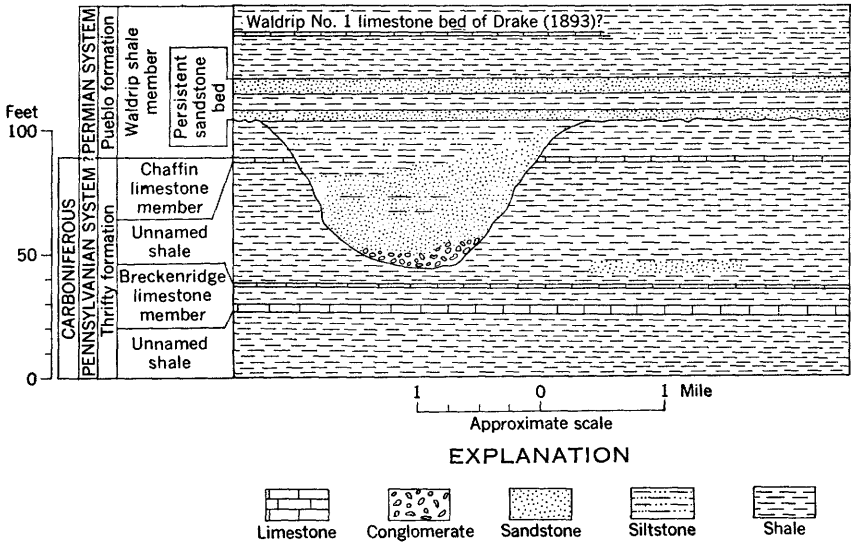

FIGURE 9.—Diagrammatic sketch showing stratigraphic relations of exposed rocks in the upper part of the Thrifty formation and lower part of the Pueblo formation in Brown County in the southern part of the Cross Plains quadrangle.

and calcilutite that weather pale red, light olive, and greenish gray. The limestone fractures subconchoidally and weathers to thin-bedded slabs and rubble. Fusulinids and crinoid stems are abundant to rare; brachiopods and corals are rare.

In the southernmost part of the quadrangle and in the Sabana River valley, the Chaffin was removed by erosion and its original position was occupied by channel-fill sandstone, siltstone, and shale of Permian age (fig. 9).

WICHITA GROUP

The Wichita group in the Cross Plains quadrangle includes all rocks from the base of the Waldrip shale member of the Pueblo formation to the top of the Coleman Junction limestone member of the Putnam formation. It includes all rocks of the Wolfcamp series of the Permian system. Elsewhere the group extends higher and includes about half the rocks assigned to the Leonard series of the Permian system. A composite columnar section by Moore (1949) shows the Wichita as being about 1,730 feet thick in Coleman, Concho, McCulloch, and Runnels Counties. In the Cross Plains quadrangle, however, only the lower 625 feet of rocks belonging to this group is present.

Of the 7 formations in the Wichita group, only the 3 lower ones—the Pueblo, Moran, and Putnam—crop out in the Cross Plains quadrangle. These rocks are principally alternating gray limestone and red and gray shale (pl. 5). Small amounts of conglomerate, sandstone, and siltstone are present, largely as channel-fill deposits, in the basal 300 feet. Except for these channel-fill deposits, the physical characteristics of the Cisco and Wichita groups in the Cross Plains quadrangle are generally indistinguishable. Paleontologically, the difference between the two groups is somewhat more noticeable, especially in the morphology of the fusulinids and ammonoids.

The Pennsylvanian-Permian boundary in central Texas has been the subject of much discussion and disagreement among geologists for several decades. Moore (1949) placed the boundary between Drake's (1893) No. 1 and No. 2 Waldrip limestone beds. Eargle (1960) extended the Waldrip shale member downward to include all beds of the Pennsylvanian and Permian transition zone of Moore's, but today the base of the Permian is considered to be at the base of the Waldrip for practical purposes. Terriere (1960) places it in the lower part of the Waldrip at the base of extensive channel-fill deposits. A persistent sandstone bed (pl. 4, fig. 9) mapped in the Cross Plains quadrangle is considered by Cheney and Eargle (1951a) to be "at or near the base of the Permian system." This sandstone is associated with the channel-fill deposits which Terriere considers to be the base of the Permian. In most of the area south of the Cross Plains quadrangle, however, the persistent sandstone bed and the channel deposits are generally absent. Division of the Waldrip into its component Pennsylvanian and Permian parts in that area is impracticable. Therefore, although the writer suspects that the base of the Permian in the area of the Cross Plains quadrangle may coincide with the base of the channel sandstone in the Waldrip shale member, he has placed the base of the Permian somewhere in the lower part of the Waldrip in a transitional zone. For practical purposes, the base of the Permian is shown at the base of the Waldrip shale member. Figure 9 diagrammatically illustrates the stratigraphic relations which involve this sandstone, the channel-fill deposits, and the presumed Pennsylvanian-Permian boundary in the Cross Plains quadrangle.

PUEBLO FORMATION

The Pueblo formation, about 310 feet thick, consists of 6 members which are, in ascending order, the Waldrip shale member, Saddle Creek limestone member, Camp Creek shale member, Stockwether limestone member, Salt Creek Bend shale member, and the Camp Colorado limestone member.

Eargle (1960) considers the Coon Mountain sandstone of Drake (1893) to be a seventh member of this formation. In this report, however, channel-fill deposits of sandstone and conglomerate, equivalent to part of the Coon Mountain sandstone member, are assigned to the Camp Creek shale member because the Camp Creek in places both overlies and underlies them (fig. 10).

The Pueblo formation is underlain by the Chaffin limestone member of the Thrifty formation, except where erosion during early Permian time has removed the Chaffin, and is overlain by the Watts Creek shale member of the Moran formation.

WALDRIP SHALE MEMBER

The Waldrip shale member, lying between the Chaffin limestone member of the Thrifty formation and the Saddle Creek limestone member of the Pueblo, consists largely of red and gray shale but also contains three thin limestone beds (fig. 11). Extensive deposits of channel-fill conglomerate, sandstone, siltstone, and gray shale are

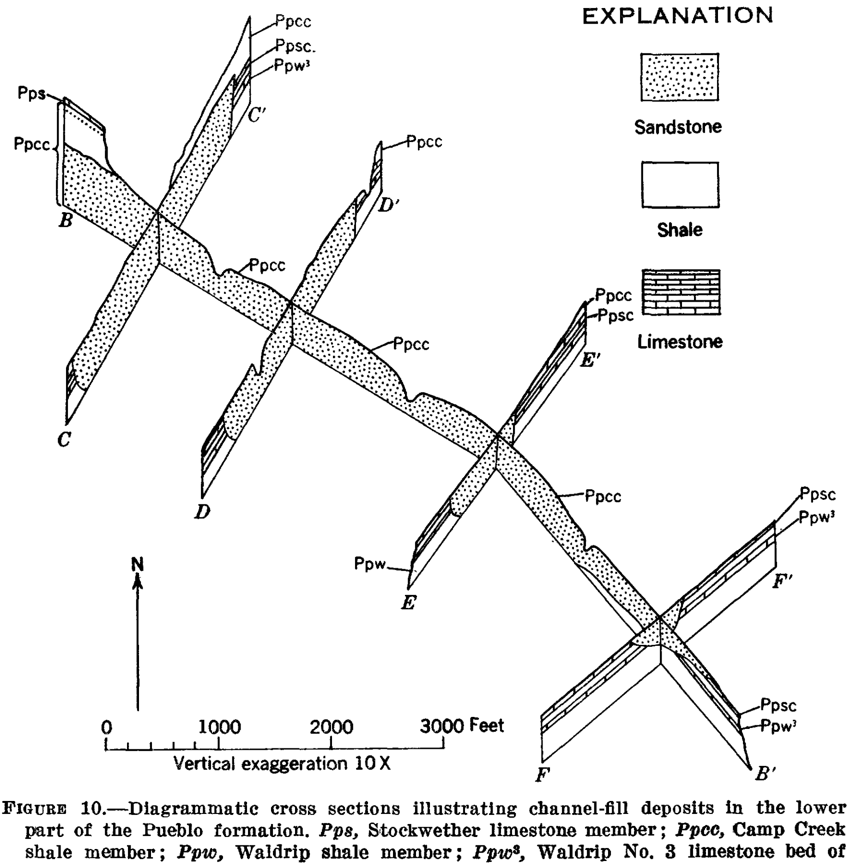

FIGURE 10.—Diagrammatic cross sections illustrating channel-fill deposits in the lower part of the Pueblo formation. *Pps*, Stockwether limestone member; *Ppcc*, Camp Creek shale member; *Ppw*, Waldrip shale member; *Ppw*³, Waldrip No. 3 limestone bed of Drake (1893). Lines of sections shown on plate 4.

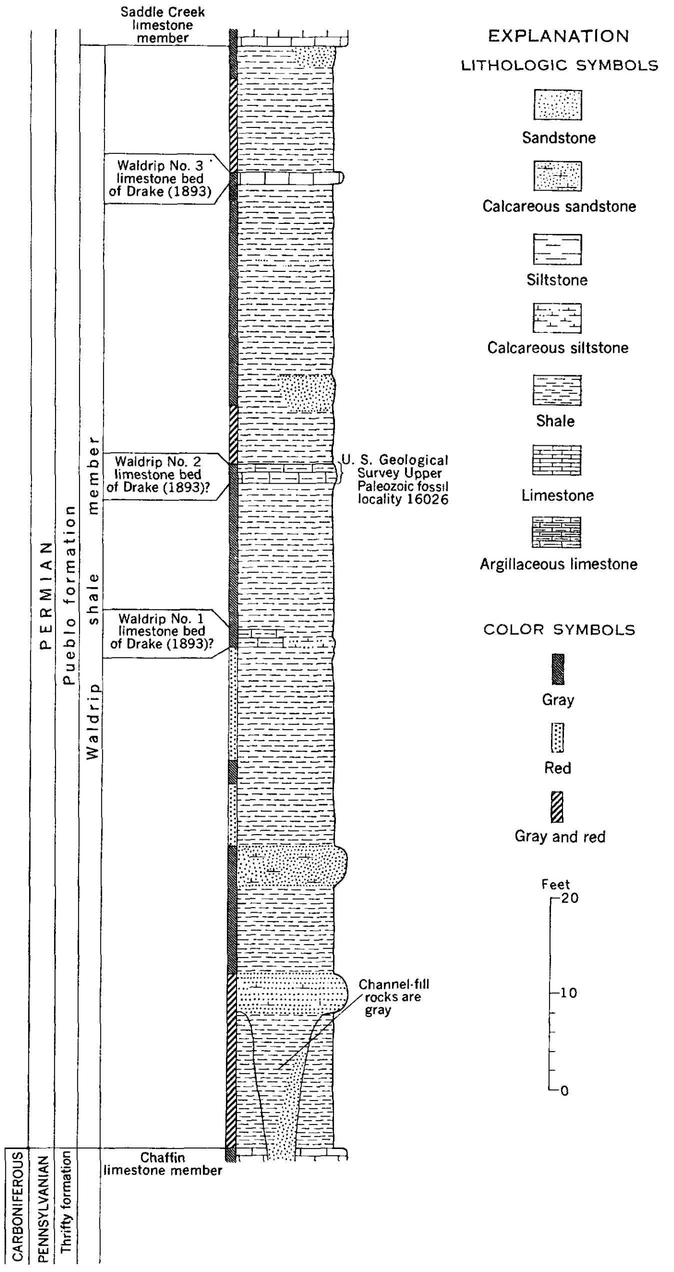

FIGURE 11.—Generalized columnar section showing color and lateral variation in lithologic characteristics of the Waldrip shale member of the Pueblo formation in the Cross Plains quadrangle in Brown, Coleman, and Eastland Counties.

present in the lower part. The member is about 115 feet thick, except where it fills channels and is as much as 175 feet thick (fig. 9).

The Waldrip has here been divided into a lower unit and an upper unit of Permian age (pl. 5). The Pennsylvanian-Permian boundary may lie within this lower unit, but, because the base of the Permian is actually indeterminable as it is transitional with the Pennsylvanian, the age of the Waldrip shale member is still considered to be Permian.

The lower unit is found throughout most of the quadrangle. In some places, however, it was removed by erosion. This poorly exposed unit, 13–20 feet thick, consists of fissile shale which is largely pale to grayish red but is, in part, light greenish gray.

Channel-fill conglomerate, sandstone, siltstone, and gray shale constitute the lower beds of the upper unit. The conglomerate, as much as 15 feet thick, consists largely of pebbles and granules of subrounded to well-rounded chert in a matrix of quartz and chert sand. The quartz sand is subangular and generally very fine to medium grained; the chert sand is subrounded to well rounded and is generally medium to coarse grained. The conglomerate is very resistant and caps prominent, extensive escarpments. Red shale, characteristic of the older rocks of the Waldrip, is absent in the channel-fill deposits.

A persistent mappable sandstone unit capping a prominent escarpment overlies the channel-fill deposits (fig. 11). Locally, this sandstone unit is the oldest rock overlying the shale of the lower unit (fig. 9). It is present throughout the southern part of the quadrangle, but it is covered by alluvium in the Sabana River valley. The sandstone unit consists of two sandstone beds separated by light- to moderate-greenish-gray shale. The lower sandstone bed is 1–8 feet thick, the upper sandstone bed 2–6 feet, and the shale parting 6–12 feet. The sandstone is generally medium to very light gray, but it is, in part, pale to moderate red and grayish red. It is generally calcareous and weathers to very thin to thin slabs.

The lowest 20 feet of rock overlying the persistent sandstone is largely red fissile shale which generally is noncalcareous and nonfossiliferous. Overlying the shale is a bed of argillaceous limestone and calcareous siltstone. This bed, 60 feet below the base of the Saddle Creek limestone member, is tentatively correlated with the Waldrip No. 1 limestone bed of Drake (1893). Although persistent, it is rarely exposed because it is nonresistant and generally covered with soil. In the southernmost part of the quadrangle, the bed is about 2 feet thick, very argillaceous, and light olive gray to yellowish gray. Crinoid stems, productids and other brachiopods, and fenestellid bryozoans are common; cephalopods are rare. Northward, near the Brown-Eastland County line, this bed is medium-gray very calcareous nonfossiliferous siltstone 1 foot thick.

About 15 feet above Drake's Waldrip No. 1 limestone bed is a 1½- to 3-foot-thick bed of argillaceous limestone that contains abundant invertebrate marine fossils. It is 35–45 feet below the base of the Saddle Creek limestone member and is tentatively correlated with the Waldrip No. 2 limestone bed of Drake (1893). It is distinctive light greenish gray, although locally it is pale red. This limestone forms an indistinct bench which is locally traceable for as much as 2 miles. It is well exposed in a road cut along an east-west gravel road (pl. 4), 0.7 miles south of Cross Cut and 0.5 miles west of State Highway 279. A collection from this locality (USGS Upper Paleozoic fossil locality 16026) that was identified by Mackenzie Gordon, Jr. (in consultation with Helen Duncan and Ellis Yochelson) contained the following fossils:

Lophophyllid corals
Dibunophyllum sp.
Fistuliporoid bryozoan
Fistulamina sp.
Polypora sp.
Rhomboporoid bryozoan
Streblotrypa? sp.
Crinoid columnals, plates, and spines
Derbyia crassa (Meek and Hayden)
Derbyia cymbula Hall and Clarke?
Chonetes puebloensis King
Marginifera wabashensis (Norwood and Pratten)
Dictyoclostus heucoensis King?
Linoproductus prattenianus (Norwood and Pratten)
Juresania nebrascensis (Owen)
Enteletes hemiplicatus (Hall)
Dielasma bovidens (Morton)
Punctospirifer kentuckensis (Shumard)
Neospirifer dunbari King
Neospirifer dunbari var. *alatus* Dunbar and Condra
Crurithyris planoconvexa (Shumard)
Composita subtilita (Hall)?
Allorisma terminale Hall
Allorisma sp.
Schizodus sp.
?Pleurotomariid steinkern
Bellerophon or *Knightites steinkern*
?Neritacean steinkern
Platyceras (*Orthonychia*) sp.
Trilobite pygidium

Fusulinids of Permian age are also present in this limestone.

A resistant limestone unit, which Eargle (1960) has correlated with the Waldrip No. 3 limestone bed of Drake (1893), is present 7–15 feet below the base of the Saddle Creek limestone member (fig. 11). This bed, ¾ to 2¾ feet thick, is medium light gray to medium dark gray and locally light olive to greenish gray. It weathers to slabs, except at some places where the upper part weathers to rubble. This limestone is very resistant, but it forms a relatively indistinct bench and is difficult to map throughout most of the area. Fusulinids, brachiopods, and crinoid stems are common to rare.

The rocks between the Waldrip No. 2 and No. 3 limestone beds generally are fissile shale that is mostly medium to light gray but in the lowest quarter is commonly pale to grayish red. Unidentified plant fragments are common along bedding planes. Very light-gray very fine grained sandstone, as much as 3 feet thick, is present locally in this part of the Waldrip.

Hematite nodules as much as 1 inch in diameter generally are present in the basal 10 feet of shale between the No. 2 and No. 3 limestone beds.

In a small area 2 miles northeast of Cross Cut, channels were cut during Permian time from above the Saddle Creek limestone member to at least 5 feet below the Waldrip No. 3 bed (pl. 4, fig. 10). The deposits in these channels are correlative with part of the Coon Mountain sandstone member of Eargle (1960) and Terriere (1960).

Coal has not been found in the Waldrip in this quadrangle, although it is common in the middle part of the member in most of the Brazos River drainage area and near the Colorado River.

SADDLE CREEK LIMESTONE MEMBER

The Saddle Creek limestone member, averaging about 10 feet in thickness, caps the top of a prominent escarpment. The lower half of this member is very resistant to erosion and is generally well exposed. A 1-foot limestone bed at its base is composed of medium-light-gray to medium-gray very thin bedded to thin-bedded calcilutite that has an irregular fracture. It is overlain by 4 feet of light-gray very thin bedded calcilutite which fractures subconchoidally and weathers to smooth-surfaced slabs. Calcitornellid-like Foraminifera, fusulinids, brachiopods, bryozoans, crinoid stems, corals, and algae(?) are common to rare.

The upper half of the Saddle Creek limestone member is light-gray to light-greenish-gray very thin bedded calcilutite and calcarenite interbedded with calcareous shale. It weathers to nodular slabs, is generally soil covered, and is nonfossiliferous except for rare fusulinids.

In an area 2 miles northeast of Cross Cut, erosion during the deposition of the Camp Creek shale member locally removed the Saddle Creek limestone member (pl. 4, fig. 10).

CAMP CREEK SHALE MEMBER

The Camp Creek shale member consists of 80 feet of fissile shale containing some sandstone and siltstone. The basal part is generally poorly exposed. The shale is largely medium to light gray, but in parts of the lowermost 20 feet and the uppermost 25, shades of red and greenish gray are common. Plant fragments are rare along bedding planes in the gray shale.

About 25 feet above the base of the Camp Creek is a poorly exposed 1-foot bed of very argillaceous limestone containing an abundance of brachiopods, pelecypods, gastropods, and bryozoans.

In the extreme southern part of the Cross Plains quadrangle, the position of the Camp Creek shale member is occupied by channel-fill sandstone, siltstone, and shale (pls. 4, 5). Two or more periods of erosion and channel filling are probably represented by these deposits. Additional study is needed to clarify and better understand the complex stratigraphic relations of the channel deposits in this part of the section.

Sandstone lentils, 2–10 feet thick, are widely present in the uppermost 25 feet of the Camp Creek. The sandstone beds appear to be fairly continuous, although their thickness changes considerably within short distances. They are very fine to fine grained, very light gray, and crossbedded. Some are calcareous and form prominent benches. These sandstone beds may represent northward extensions of the channel deposits which were mapped in the extreme southern part of the quadrangle (pl. 4).

STOCKWETHER LIMESTONE MEMBER

The Stockwether limestone member is 2–12½ feet thick and averages about 4 feet in thickness. It is very light-gray to light-gray calcilutite and calcarenite having a subconchoidal to irregular fracture. It is thin to medium bedded and generally weathers to smooth-surfaced slabs and blocks. About 15 percent of the rock is chert in irregular zones as much as 2 inches thick. Where fresh, the chert is pinkish gray to pale yellowish brown; where weathered, it is white. Northeast of Cross Cut, a shale parting 3 feet thick is generally present in the upper part of the limestone.

The basal part of the member is nonfossiliferous except for algal (?) remains. In the upper part, crinoid stems, algae (?), and unidentified organic fragments are common to abundant, and pelecypods, brachiopods, and bryozoans are rare.

In the extreme southern part of the quadrangle, the Stockwether member was removed by erosion during the deposition of the Salt Creek Bend shale member, and its position was occupied by sandstone, siltstone, and shale (pls. 4, 5).

SALT CREEK BEND SHALE MEMBER

The Salt Creek Bend shale member averages about 75 feet in thickness and consists of 80 percent shale, variegated in shades of gray, red, grayish green, and greenish gray, and 20 percent sandstone, siltstone, and limestone (pl. 5). The shale is noncalcareous, nonfossiliferous, and poorly fissile and generally weathers to chunky or tabular pieces.

Two persistent calcareous sandstone beds, each having a maximum thickness of 5 feet, crop out at about 25 and 15 feet below the top of the member. They are light gray and very fine to fine grained. Neither bed is easily mappable except where locally resistant. Brachiopods were observed at one exposure of the lower bed.

Lenticular calcareous siltstone beds, very light to medium light gray, were found throughout the section. These beds are generally 1–2 feet thick, but locally they are as much as 5 feet thick. At places they contain brachiopods and crinoid stems.

One persistent limestone bed, ½–2 feet thick, is exposed 11–15 feet below the top of the Salt Creek Bend shale member. In the southernmost part of the quadrangle, it forms a bench extending 3 miles along the west side of Greenbriar Creek. This thin-bedded limestone is light-gray to light-olive-gray calcarenite and weathers into irregular dark-surfaced slabs. Megafossil debris is abundant; algal-like material, oolites, crinoid stems, and whole brachiopods are common to rare. North and east of the area in which this limestone was mapped (pl. 4), the limestone becomes progressively argillaceous, grading into calcareous shale and siltstone.

Between this unnamed limestone bed and the overlying Camp Colorado limestone member is a ½ to 3-foot argillaceous light-gray to pale-red limestone bed. It is generally 6–10 feet below the top of the Salt Creek Bend shale member and 3–6 feet above the top of the unnamed limestone bed. This argillaceous limestone is nonresistant, generally soil or talus covered, and does not appear to be persistent. Locally, it contains abundant crinoid stems and megafossil fragments.

Some of the Salt Creek Bend shale member was removed during two periods of erosion. During the first period, channels were cut through the underlying Stockwether into the Camp Creek shale member; during a later period, channels were cut at least 20 feet into the Salt Creek Bend shale member (pl. 5) from within younger rocks of the Watts Creek shale member of the Moran formation.

CAMP COLORADO LIMESTONE MEMBER

The Camp Colorado limestone member consists of two limestone beds separated by shale. It is 20–30 feet thick and averages about 24 feet in thickness. The lower limestone bed, 1–4 feet thick, is a very light-gray to medium-gray calcilutite which fractures subconchoidally. At its northeasternmost exposure, this bed is reddish gray and fractures irregularly. It weathers into very thin to thin bedded slabs. Crinoid stems, brachiopods, fenestillid bryozoans, and fusulinids are rare.

The shale between the lower and upper limestone beds, 10–17 feet thick, is light gray to light greenish gray, fissile, and poorly exposed. Nonresistant argillaceous limestone, about one-half foot thick, is found 4–6 feet below the top of this shale bed at many places. Crinoid stems, brachiopods, bryozoans, and unidentified fossil debris are rare to abundant. In its northeasternmost exposure, the uppermost 3 feet of this shale unit contains as many as three 1-inch-thick argillaceous limestone layers with an abundance of crinoid stems and bryozoans.

The upper limestone bed, 6–11 feet thick, is variegated very light-yellowish-gray and light-olive-gray calcilutite and calcarenite which has a subconchoidal to irregular fracture. It weathers into slabs, plates, and rubble. Between the towns of Cross Cut and Cross Plains, this limestone is very thin bedded to thin bedded and contains some shale partings. Crinoid stems, algae(?), calcitornellid(?) Foraminifera, and unidentified fossil debris are common to abundant; brachiopods and gastropods are rare.

Erosion during the time of deposition of the Watts Creek shale member of the Moran formation locally removed the Camp Colorado limestone member. Sandstone and some conglomerate were deposited in the channels at the original position of the Camp Colorado (pls. 4, 5).

MORAN FORMATION

The Moran formation overlies the Pueblo formation and underlies the Putnam formation. It consists of about 195 feet of alternating shale and limestone containing some sandstone, siltstone, and coal. The formation has been divided into four members by Moore (1949). In ascending order, they are the Watts Creek shale member, Gouldbusk limestone member, Santa Anna shale member, and Sedwick limestone member.

WATTS CREEK SHALE MEMBER

The Watts Creek shale member, 75–120 feet thick, overlies the Camp Colorado limestone member of the Pueblo formation and underlies the Gouldbusk limestone member of the Moran formation. It is composed of about 80 percent poorly fissile shale—about half of which is pale red and the rest greenish gray and medium to very light gray—and about 20 percent limestone, sandstone, and siltstone.

Two persistent argillaceous limestone beds, each 1–2 feet thick, are present at about 5 and 10 feet above the base of the Watts Creek shale member (fig. 12). They are various shades of light greenish and reddish gray and generally weather to rubble or slabs.

A prominent scarp-forming limestone bed, the Ibex limestone of Cheney (1948), is present 35–60 feet below the top of the Watts Creek shale member and about 40–60 feet above its base (fig. 12). This bed, 4–6 feet thick, is calcilutite that is medium light gray to medium dark gray or bluish gray where freshly exposed and characteristically ferruginous stained, light brownish gray, light brown, or pale red where weathered. This sandy limestone has a subconchoidal fracture and weathers to blocks as much as 3 feet thick and 10 feet wide. Algae and fusulinids are rare.

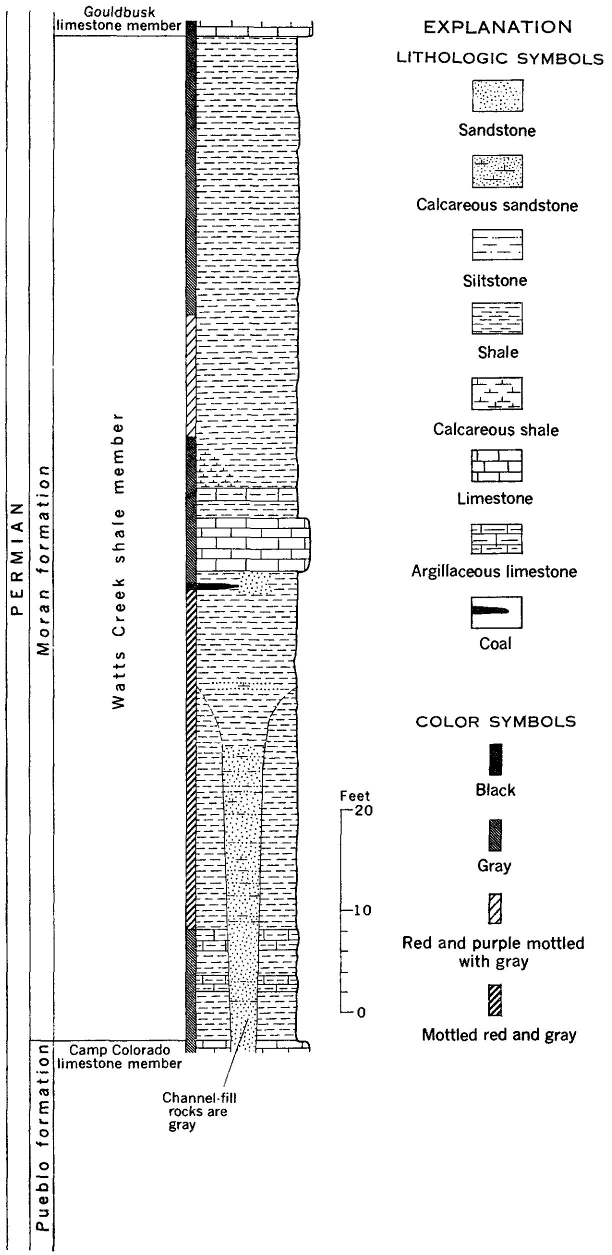

FIGURE 12.—Generalized columnar section showing color and lateral variation in lithologic characteristics of the Watts Creek shale member of the Moran formation in the Cross Plains quadrangle in Brown, Callahan, and Coleman Counties.

At many places much of the section between the base of the Moran formation and the Ibex limestone of Cheney (1948) is sandstone and siltstone. Most of the sandstone, and probably some of the siltstone, in this interval is channel-fill material.

About 1½ feet beneath the Ibex limestone of Cheney (1948) is a bed of impure coal or very carbonaceous shale about 2 inches thick. From 2–4 feet above the top of the Ibex limestone of Cheney (1948) is a very argillaceous limestone bed about 1 foot thick. It is very light gray calcarenite that is nonresistant to weathering, and that contains *Composita*, *Aviculopinna* (?), and fenestellid bryozoans at some places.

A very fossiliferous shale unit, 12 feet thick, is present 8–20 feet above the Ibex limestone of Cheney (1948). It is pale red to pale reddish purple, locally mottled yellowish gray and light greenish gray. Cephalopods, bryozoans, and brachiopods (*Composita* and productids) are common to plentiful.

In the extreme southeast corner of the quadrangle, 20–30 feet below the Gouldbusk limestone member, is a thin-bedded sandstone lentil as much as 8 feet thick. It is very fine to fine grained, light gray, and very calcareous and contains many megafossils having original shell material.

GOULDBUSK LIMESTONE MEMBER

The Gouldbusk limestone member is 10–17 feet thick and averages about 15 feet in thickness. This member was called the Horse Creek limestone by Drake (1893). Moore (1949) renamed the member Gouldbusk because Drake had also applied the name Horse Creek to beds in his Strawn division.

The Gouldbusk contains three distinct units. The basal unit, 5–6 feet thick, is very light-gray to medium-gray calcilutite which caps a prominent escarpment. It is very thin to thin bedded, fractures subconchoidally, and weathers into resistant smooth-surfaced slabs and blocks. This unit contains abundant algal (?) structures, clear calcite stringers which may be organic in origin, calcitornellidlike organic remains, and some unidentified megafossil fragments. Fusulinids, brachiopods, bryozoans, and crinoid stems are generally rare to absent, but locally are common.

The middle unit of the Gouldbusk, 1½–5 feet thick, is a poorly exposed nonresistant argillaceous limestone bed. One persistent layer of nodular limestone, ½–1 foot thick, contains an abundance of fusulinids.

The upper unit of the member, 5–7 feet thick, is also generally poorly exposed. It is medium-light-gray to medium-gray calcarenite and calcilutite containing an abundance of algal (?) material, calcitornellid(?) Foraminifera, and megafossil fragments; crinoid stems and complete brachiopods such as *Composita* are rare.

SANTA ANNA SHALE MEMBER

The Santa Anna shale member, 55–60 feet thick, consists mainly of interbedded silty shale and shaly siltstone. Sandstone constitutes about 5 percent of the member. The shale is light gray to medium dark gray; the siltstone is stained brown by limonite. Fossils are absent except for some sponges, which resemble *Talpaspongia*, and unidentified plant fragments along bedding planes.

Two sandstone beds, each about 2 feet thick, are found 30 feet and 5 feet below the top of the Santa Anna. The lower bed is persistent, the upper one, nonpersistent. Both beds are light gray, very fine grained, and calcareous.

SEDWICK LIMESTONE MEMBER

The Sedwick limestone member is generally poorly exposed. It is 20–25 feet thick and consists of three units—a lower and an upper limestone bed separated by shale. Rocks assigned to the Sedwick in the Cross Plains quadrangle may not include all of the units elsewhere considered to be Sedwick (Plummer and Moore, 1921; Moore, 1949). A 1-foot calcareous siltstone bed, which is apparently nonpersistent and rarely exposed, is here assigned to the overlying Santa Anna Branch shale member of the Putnam formation. This bed may correlate with Plummer and Moore's upper limestone bed of the Sedwick in the Brazos River drainage area. Additional detailed mapping in the Brazos River area at the type section of the Sedwick is necessary before exact correlation can be made.

The lower limestone bed, 1½–2 feet thick, is iron-stained calcilutite. Where weathered, its color is pale red, light yellowish gray, light brown, grayish orange pink, and dark yellowish orange. In fresh exposures, which are rare, it is light to medium gray. The limestone has a subconchoidal fracture, is thin to medium bedded, and generally weathers to rubble and rounded, smooth-surfaced boulders. Gastropods, cephalopods, brachiopods, and pelecypods are rare.

The middle unit, 15–17 feet thick, is about 90 percent light-gray to medium-light-gray shale. Locally, a nodular argillaceous limestone layer, as much as 2 feet thick, is present in the lower 5 feet. This limestone is light gray and contains crinoid stems. A unit of medium-light-gray to light-gray, calcareous nonfossiliferous sandstone and siltstone, as much as 2 feet thick, is also locally present in the basal 5 feet.

The upper limestone bed, 2½–4½ feet thick, is very argillaceous yellowish-gray calcilutite. It has an irregular fracture and weathers to slabs of very thin to medium thickness. Cephalopods and brachiopods are rare to absent.

PUTNAM FORMATION

The Putnam formation, about 120 feet thick, consists of two members—the Santa Anna Branch shale member at the base and the Coleman Junction limestone member at the top. This formation forms the most prominent escarpment of the Pennsylvanian and Permian rocks found in the quadrangle.

SANTA ANNA BRANCH SHALE MEMBER

The Santa Anna Branch shale member, about 115 feet thick, is about 90 percent shale, the remainder being limestone and siltstone. The uppermost 60 feet is generally better exposed than most shale beds. The basal 55 feet is very poorly exposed and generally forms soil-covered lowlands.

About half the shale in the upper 60 feet of the member is pale red; the other half is either mottled or has alternate shades of red and gray (fig. 13). The shale of the basal 55 feet of the member is generally light gray to medium light gray. About 15 feet of the mottled pale-red and light-gray calcareous shale near the middle of the member is very fossiliferous. A fossil collection was made from this shale in a cut along an east-west gravel road, about 500 feet west of the Cross Plains quadrangle, Callahan County, 2.3 miles west of State Highway 206, and 6.5 miles S. 75° W. from the center of Cross Plains. The collection from this locality (USGS Upper Paleozoic fossil locality 16028) was identified by Mackenzie Gordon, Jr. (in consultation with Helen Duncan and Ellis Yochelson), and contained the following fossils:

Polypora sp.
Orbiculoidea sp.
Nuculana sp.
Aviculopecten spp.
Schizodus sp.
Sphenotus sp.
Euphemites sp.
Donaldina sp.
Stegocoelia sp.
Cavellina sp.
Hollinella sp.

Crinoid stems were associated with the above fauna. Most of the shale of the Salt Creek Bend shale member of the Pueblo formation also contained unidentified plant fragments.

Three limestone beds are present locally in the Santa Anna Branch shale member. The lowest of these, about 50 feet above the base, consists of about 3½ feet of interbedded shale and nonpersistent limestone (fig. 13). The limestone is medium-light-gray calcarenite in which cephalopods are rare.

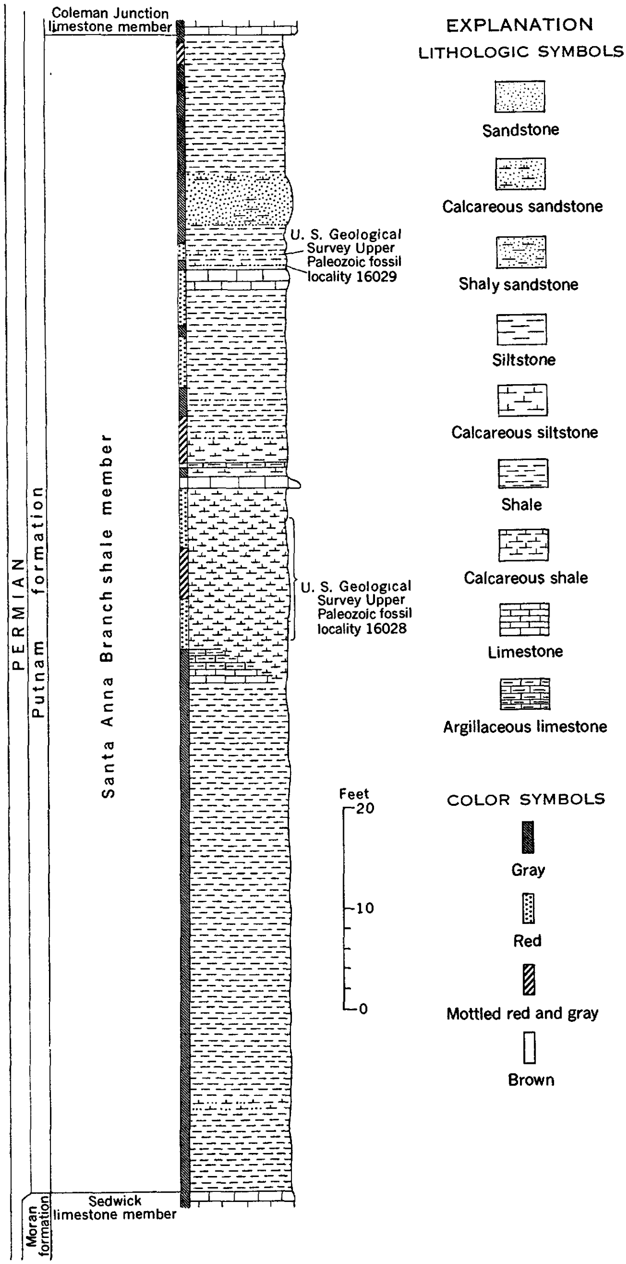

FIGURE 13.—Generalized columnar section showing color and lateral variation in lithologic characteristics of the Santa Anna Branch shale member of the Putnam formation in the Cross Plains quadrangle in Callahan and Coleman Counties.

The middle limestone bed, 70 feet above the base, is fairly resistant and locally well exposed; although persistent, it is not generally exposed. The bed consists of a basal 1 foot of moderate-yellowish-brown calcarenite in which brachiopods, crinoid stems, bryozoans, and cephalopods are common to rare. This basal bed is overlain by 1 foot of shale, which is turn is overlain by one-half foot of argillaceous nonresistant moderate-yellow-brown calcarenite containing many pelecypods, brachiopods, and crinoid stems.

The highest limestone bed, 90 feet above the base, appears to be persistent, but it is poorly exposed and has no noticeable topographic expression. It is nonfossiliferous moderate-red calcilutite to argillaceous calcarenite and about 2 feet thick.

Approximately 15 feet below the top of the Santa Anna Branch shale member is a persistent sandstone bed, 1–4 feet thick (fig. 13). Although the sandstone bed forms a noticeable bench locally its topographic expression is subordinate owing to the proximity of the very resistant Coleman Junction limestone member. The sandstone is fine grained, very light gray, and locally very calcareous and weathers as a single bed.

This sandstone is underlain by 5 feet of interbedded sandstone and shale containing abundant fossils and granule- and pebble-sized fragments of limestone in a cut along an east-west gravel road, approximately 1,100 feet west of the Cross Plains quadrangle and about 600 feet west along the road from the previously mentioned USGS Upper Paleozoic fossil locality 16028. A fossil collection from this place (USGS Upper Paleozoic fossil locality 16029), identified by Mackenzie Gordon, Jr. (in consultation with Helen Duncan and Ellis Yochelson), contained the following:

Rhomboporoid bryozoans	*Miltonella*? sp. juvenile valve
Strophomenid brachiopod, fragments	*Knightina*? sp.
Myalina sp.	*Roundyella* sp.
Aviculopecten sp.	Ostracode, genus indeterminate-sulcate
Cavellina sp.	Ostracode, genus indeterminate-Kirkbyidae
Bairdia sp., fragment	

About 8 feet above the base of the Santa Anna Branch shale member, there is a nonpersistent calcareous siltstone bed which may possibly be part of the Sedwick limestone member of the Moran formation in the Brazos River drainage area.

COLEMAN JUNCTION LIMESTONE MEMBER

The youngest rocks of Permian age that are exposed in the quadrangle belong to the Coleman Junction limestone member. This member is exposed only along the extreme west edge of the quadrangle, where it consists of about 5 feet of very resistant limestone capping a prominent escarpment. To the west it may be a few feet thicker.

The Coleman Junction consists of three units. At the base is 3½–4½ feet of limestone which is very light-gray to medium-gray calcilutite. It generally weathers to various shades of light brown and yellowish brown. Light-brownish-gray shale overlies the basal limestone and it, in turn, is overlain by half a foot of limestone similar to the basal limestone. The limestone weathers to slabs and blocks of thin- and medium-bedded thickness, has an irregular fracture. Fossil fragments are present, but no identifiable remains were observed.

CRETACEOUS SYSTEM

The Cretaceous rocks belong to the Trinity and Fredericksburg groups of the Comanche series (Lower Cretaceous). They range from 330–480 feet in thickness and average about 405 feet. These rocks consist of sandstone and limestone and minor amounts of conglomerate, siltstone, and shale (pl. 5). An angular unconformity having a relief of about 150 feet separates the Cretaceous and the Paleozoic rocks.

TRINITY GROUP

The Trinity group, 200–350 feet thick and averaging about 275 feet, is present in almost two-thirds of the quadrangle. It consists of about 90 percent sandstone and 10 percent conglomerate, siltstone, and shale.

The lowest third of the group is very poorly exposed and weathers to loose sand which obscures the underlying contact between the Cretaceous and Paleozoic. The upper two-thirds of the Trinity is somewhat better exposed, mainly because it forms a prominent escarpment which is extensively gullied.

The Trinity group is not subdivided in the Cross Plains quadrangle because its units generally are not lithologically or topographically distinctive. Some persistent calcareous siltstone beds, 1–15 feet thick, can be traced for short distances and may be equivalent in part to the Glen Rose limestone (middle formation of the Trinity), which is exposed to the southeast. Inasmuch as these beds are covered with soil and are stratigraphically and geographically very close to the Fredericksburg group, they are not shown on the geologic map (pl. 4).

Conglomerate, interbedded with sandstone, is usually present in the basal 5–35 feet of the Trinity group (pl. 5). At many localities it consists entirely of well-rounded quartz and quartzite granules and pebbles in a matrix of very fine to very coarse sand cemented with calcium carbonate. Rounded pebbles and cobbles of Pennsylvanian and Permian rocks, principally limestone, are common in a few places. At one locality in the southeastern part of the quadrangle, however, about two-thirds of the conglomerate consists of reworked chert granules and pebbles from channel-fill deposits of the Permian.

In some of the topographically lower areas of the pre-Cretaceous surface, as much as 35 feet of sandstone, siltstone, and shale of the Trinity lies between the basal conglomerate and the Paleozoic rocks. The shale is nonfossiliferous, calcareous to noncalcareous, and usually silty and rarely has visible bedding; it is light reddish brown, light greenish gray, light reddish gray, and light gray. Some of the shale contains well-rounded quartz or quartzite pebbles. The sandstone is very light greenish gray and light pinkish gray, very fine to coarse grained, nonfossiliferous, and in part silty, calcareous, and well cemented.

Conglomerate, 2–10 feet thick and consisting largely of subrounded to well-rounded pebbles and cobbles of limestone from the Pennsylvanian and Permian units, is present about 50 feet above the base of the Cretaceous in the southeastern part of the area.

That part of the Trinity that overlies the basal 50 feet consists largely of sandstone that is very fine to coarse grained, very light gray to white, friable, noncalcareous, nonfossiliferous, nonresistant, and well sorted and is composed almost entirely of quartz grains. A minor amount of the sandstone is pale red to reddish brown and calcareous.

Four calcareous siltstone beds—three of which appear to be persistent—are present in the upper part of the Trinity (pl. 5). They are nonfossiliferous and dark yellowish orange, pale red, and pale reddish brown. Where extensively weathered, they appear honeycombed. Gray, green, red, and brown shale is associated with these siltstone beds.

FREDERICKSBURG GROUP

The Fredericksburg group, elsewhere consisting of three formations, is underlain by the Trinity group and overlain by the Washita group (Comanche series). Only the two lower formations—the Walnut clay and Comanche Peak limestone—are exposed in the Cross Plains quadrangle. The youngest formation, the Edwards limestone, caps a prominent escarpment only 50 feet north of the quadrangle boundary. The Fredericksburg consists of limestone and a minor amount of interbedded shale (pl. 5). It is 145 feet thick where its top is exposed; however, only the lower 130 feet is present in the Cross Plains quadrangle.

WALNUT CLAY

The nonresistant Walnut clay, 5–17 feet thick and averaging about 10 feet, overlies the Trinity group and underlies the Comanche Peak limestone. This formation generally forms a soil- and talus-covered bench near the top of an escarpment capped by the more resistant

Comanche Peak. The Walnut consists of about two-thirds calcareous shale and one-third argillaceous limestone. The limestone is generally light- to very light-gray calcarenite and calcilutite, but locally it is light brownish gray to light pinkish gray. It weathers to rubble and slabs as much as 5 feet wide and 2 inches thick.

Gastropods and pelecypods (especially *Gryphaea marcoui* and *Exogyra texana*) are common to abundant in both the limestone and shale. Oolites and algal-like structures are abundant in the limestone.

COMANCHE PEAK LIMESTONE

The Comanche Peak limestone is underlain by the Walnut clay and overlain by the Edwards limestone (pl. 5). It has a total thickness of 135 feet, although only the lower 120 feet is present in the quadrangle. The formation can be divided into three units—lithologically similar lower and upper limestone units separated by a characteristic fossil bed (pl. 5). The lower unit is about 30–45 feet thick, the upper unit about 80 feet thick (only the lower 65 feet is exposed in the quadrangle), and the middle unit 10–15 feet thick.

The lower and upper units consist of very light- to light-gray calcarenite and calcilutite. Where the limestone is deeply weathered, it is pinkish, yellowish, and light brownish gray. It is very thin to thin bedded and weathers to slabs and rubble. In the lower unit, algal- or oolite-like structures are abundant, organic debris is common, and pelecypods and gastropods are rare. In the upper unit, fossils other than unidentified organic fragments are very rare to absent.

The middle unit, the base of which was mapped (pl. 4), has a basal argillaceous limestone bed, 1 foot thick, which contains abundant cephalopods, including *Oxytropidoceras*, gastropods, and pelecypods (*Gryphaea* and *Exogyra*). Overlying the basal part is a bed of coquina, 5 feet thick, consisting almost entirely of *Gryphaea*. Overlying the coquina is argillaceous limestone, 4–9 feet thick, containing an abundance of echinoids, gastropods, and pelecypods.

The Comanche Peak limestone forms 3 benches and 3 escarpments (fig. 14) which are especially conspicuous on aerial photographs. The base of the lower unit generally caps a prominent escarpment, and the rest of the unit forms a bench; the middle unit and the lower 20 feet of the upper unit form another escarpment, and the next 10 feet of the upper unit forms another prominent bench; and the upper 50 feet of the formation forms a third escarpment which is generally capped by Edwards limestone, although in the mapped area the Edwards and some of the Comanche Peak have been removed by erosion.

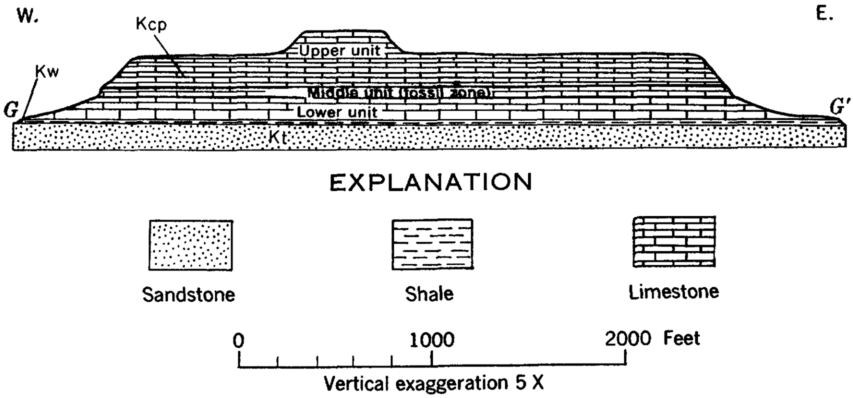

FIGURE 14.—Cross section showing characteristic benches and escarpments formed by the Fredericksburg group in the Cross Plains quadrangle in Callahan County. *Kcp*, Comanche Peak limestone; *Kw*, Walnut Clay; *Kt*, Trinity group. Line of section shown on plate 4.

QUATERNARY SYSTEM

HIGH TERRACE GRAVEL

Two high terrace gravel deposits are present in the quadrangle. One, about 15 feet thick, is at the extreme south edge of the quadrangle, about 100–115 feet above Pecan Bayou, and is probably of Pleistocene age. The other, about 3 feet thick, is at the extreme east edge, about 15 feet above the Sabana River, and is probably Recent. The gravel is predominantly unconsolidated pebbles and cobbles of reworked Pennsylvanian, Permian, and Cretaceous limestone and conglomerate. A small amount of finer material (clay to granule size) is also present. Fresh-water molluscan shells are found at some localities in these gravel deposits.

ALLUVIUM

Alluvium in the Cross Plains quadrangle consists of gravel, sand, silt, and clay. Along Pecan Bayou these unconsolidated deposits are as much as 15 feet thick; elsewhere, they are no more than 10 feet thick.

In the part of the quadrangle that is covered predominantly by Cretaceous rocks, all important areas of alluvium were mapped, as well as several narrow belts along small streams (pl. 4). Where the Pennsylvanian and Permian rocks predominate as bedrock, generally only the large deposits were mapped as it was difficult to differentiate small insignificant deposits of alluvium from colluvium and soil in that area.

STRUCTURE

The Cross Plains quadrangle is located along the Bend arch, a structural feature extending from north of the Llano uplift to just south of Wichita Falls. The Pennsylvanian and Permian rocks have a regional west-northwest dip of about 45 feet per mile, or ½°. Locally, minor structural features cause variation in direction and amount of dip. Many of these features appear to be the result of differential compaction over lenticular channel-fill sandstone and conglomerate deposits, and because commercial quantities of oil have accumulated in many of these minor structural features, further detailed study of the geologic structure of the upper Paleozoic rocks in the area may result in locating additional oil fields.

The Cretaceous rocks appear to have been little deformed. The attitude of the evenly bedded limestone beds of the Fredericksburg group ranges from horizontal to a northeast dip of approximately 20 feet per mile.

The basal part of the Trinity group lies on an uneven pre-Cretaceous surface having a maximum relief of about 150 feet. Thus, any structure-contour map of this boundary would largely reflect this old surface rather than any minor deformation. Because of the generally poor exposures and lack of traceable beds, the dip of the younger Trinity rocks is difficult to determine. Presumably, they have approximately the same amount and direction of dip as those of the Fredericksburg.

No faults or major folds were noted in any of the rocks in the Cross Plains quadrangle.

ECONOMIC GEOLOGY

PETROLEUM

As of January 1, 1955, about 3,100 wells had been drilled for petroleum, and several oil and gas fields were located in the Cross Plains quadrangle. Most of the fields have no recognized official name, though a few fields, such as the Baum, McKinney, and Ruwaldt, are officially listed by the Railroad Commission of Texas (1955). The other fields in the quadrangle are included in the Brown County Regular field, Callahan County Regular field, Coleman County Regular field, and Eastland County Regular field, as listed by the Railroad Commission of Texas (1955). Some names have been unofficially applied by the petroleum industry to fields and producing areas in the quadrangle: the Cross Cut-Blake district (also known as two separate fields—the Cross Cut and the Blake) in northern Brown County, the Cross Plains field in southeastern Callahan County, and the Pioneer field in southwestern Eastland and southeastern Callahan

Counties. However, because records for the fields are maintained on a geographic basis, no estimate of the present or cumulative production of oil can be readily made for the quadrangle, although production consisted of several tens of millions of barrels through January 1, 1955. Klinger (1941, p. 548) in a study of the Cross Cut-Blake district, which is largely in the Cross Plains quadrangle, notes that "this district had produced more than 6,300,000 barrels of oil through 1940 and 95,000 barrels during that year."

Most fields discovered before 1930 were found on the basis of surface geology. More recent discoveries, however, have been based largely on subsurface geology. The wells are generally a few hundred to 3,500 feet in depth, and most are pumped. The gravity of the produced oil ranges from about 35° to 45° API. The initial potential of the oil wells is generally 10–200 barrels per day, although some have shown considerable greater potentials and some less.

Most production has been from sandstone units belonging to the Strawn, Canyon, and Cisco groups, although some oil has been produced from the Wolfcamp series. A relatively small amount of the production has been from limestone units in the lower part of the Strawn group, the Bend group (Lower and Middle Pennsylvanian), and the Ellenburger group (Ordovician). Most producing sandstone units apparently are channel-fill deposits correlative or similar to those shown on the geologic map (pl. 4). Therefore, detailed geologic mapping and study of the channel deposits, both on the surface and in the subsurface, could aid in locating new oil and gas accumulations. A detailed presentation of the subsurface geology, however, is beyond the scope of this report.

CONSTRUCTION MATERIALS

ROAD MATERIAL

A small amount of road material has been produced in the quadrangle. Limestone from a small quarry in the Comanche Peak limestone, conglomerate and residual gravel from the lower part of the Trinity group, and stream gravel from alluvium have been used locally for highway construction and for surfacing secondary roads. The thick Permian limestone beds, the conglomerate of the Trinity group, and the Comanche Peak limestone are potential sources of road material for highway construction or improvement.

SAND AND GRAVEL

The sand and gravel deposits in the alluvium are generally poorly sorted, and any screening and washing operations might be impeded by large cobbles and boulders.

Sandstone is mined for the manufacture of glass from the Trinity group, several miles southwest of the quadrangle at Santa Anna in Coleman County (fig. 7). This sandstone bed, tentatively correlated with the Paluxy sand of the Trinity group, is also present in a large area in the northwestern part of the quadrangle, where it may be of commercial value.

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