BUREAU OF ECONOMIC GEOLOGY
The University of Texas
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Peter T. Flawn, Director

Report of Investigations — No. 55

Heavy Minerals in the Wellborn Formation, Lee and Burleson Counties, Texas

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LEE AND BURLESON COUNTIES, TEXAS

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ABSTRACT

At five places along the outcrop of the Wellborn Formation in Lee and Burleson counties, Texas, anomalously high gamma radiation is associated with concentrations of heavy minerals. The most abundant heavy minerals are ilmenite, magnetite, and zircon. The radiation is emitted by some radioactive element in zircon. The intensity of the radiation and the areal extent of the radiation anomalies were measured by a scintillation counter.

The Wellborn Formation, composed of sediments deposited in near-shore environments, is characterized by cross-bedded sandstone lentils interbedded with montmorillonitic, lignitic shale and lignite. Heavy minerals in the lower part of the Wellborn are concentrated in thin sheets and wedges along cross-beds and in local patches and streaks.

There are about 4 million tons of heavy mineral-bearing sandstone with an average of about 2 percent heavy minerals, or 2-1/2 million tons with an average of almost 3 percent heavy minerals. Locally, ilmenite, magnetite, and zircon make up as much as 25 percent of the sandstone, although concentrations are too small to be considered as commercial deposits under present economic conditions.

INTRODUCTION

Geologic Setting

The Wellborn Formation (Eocene), a topographically prominent unit of the Texas Coastal Plain, is made up of sandstone, shale, and a small amount of lignite. It conformably overlies the montmorillonitic clays and sands of the Caddell Formation and is overlain (with local disconformities) by the Manning Formation.

The Wellborn Formation strikes northeast through the eastern part of Lee and Burleson counties and forms a low, northwest-facing cuesta covered with post-oak. The formation dips east-southeast at about 90 feet per mile. The Wellborn cuesta, the dominant topographic feature of the area, is cut by eastward-trending Yegua Creek; south of Yegua Creek the cuesta is only slightly dissected. North of Yegua Creek the formation is thinner, the dip is less, and the outcrop belt is several times as wide north of the creek as it is south of the creek. Where Birch Creek and smaller tributaries have dissected the cuesta, the underlying Caddell Formation is exposed, and the upper part of the Wellborn Formation forms outliers of low sand hills heavily wooded with post-oak.

The characteristic topography on the Caddell Formation is the deep V-shaped gullies (Pl. III, A) that are cut into the distinctive light gray or white sandy clays. The Caddell is poorly exposed south of Yegua Creek.

Yegua Creek, which flows eastward into the Brazos River, forms the southeastern boundary of Burleson County, separating it from Lee and Washington counties to the south and southeast. The two principal tributaries of Yegua Creek in this area are Nails Creek in Lee County and Birch Creek in Burleson County. Nails Creek is controlled largely by the Wellborn cuesta. It follows the face of the Wellborn cuesta, flows northeast, and enters the Yegua a short distance upstream from the Wellborn outcrop. Birch Creek cuts through the Wellborn cuesta and joins the Yegua a short distance downstream from the Wellborn outcrop.

Accessibility

The area is accessible by unpaved, but graded, county roads and unimproved farm and ranch roads. The principal towns near the area are located on railroads. The Gulf, Colorado and Santa Fe Railroad passes through Lyons and Somerville, 8 miles north of the area. Giddings, about 16 miles to the southwest, and Burton, about 9 miles to the southeast, are on the Southern Pacific Railroad.

The area south of Yegua Creek is connecte with Giddings and Burton by paved roads. The most recently paved segment, Farm Road 1697, is not shown on the map (Pl. I) but follows the general route of the east-west road south of Flag Pond. All of the roads connecting the northern part of the area with the railroad at Lyons and Somerville are unpaved one-lane county roads which are inadequate for heavy vehicles in the best of weather and are impassable when wet. Two bridges cross Yegua Creek; neither can support heavy vehicles.

Previous Work

The earliest studies of the Tertiary rocks of the Coastal Plain were by E. T. Dumble, R. A. F, Penrose, Jr., and W. Kennedy.

Penrose (1890) reported on investigations which he and Dumble carried out along the Colorado River between Austin and La Grange, along the Brazos River between Waco and Hempstead, and along the Rio Grande between Eagle Pass and Reynosa. Kennedy's (1893) report on the geology of Grimes, Brazos, and Robertson counties is the first published reference to the "Wellborn beds."

The first comprehensive study of the Texas Coastal Plain was by Deussen (1924), who studied the area west of the Brazos River and mapped gross lithologic units. His work served as the basis for more detailed recent work.

Ellisor (1933) studied the rocks of the Coastal Plain and correlated rocks in Texas with those of Louisiana, Mississippi, and Alabama. She used subsurface methods and made projections back to the outcrop. The consequences of one such projection are discussed by Renick (1936, p. 24).

Harris (1941) described several sections of the Wellborn Formation in a report on the geology of Lee County. Russell (1955) measured one section in the Yegua Creek area and mapped (1957) the northernmost part of the area of this present study. More recent work by Eargle (1959) deals with rocks in the Karnes County area. Most of the detailed surface mapping has been in Grimes, Brazos, and Karnes counties. The area between, which includes the area of this investigation, has been studied mainly by reconnaissance methods.

Acknowledgments

The writer expresses appreciation to P. T. Flawn, who made the initial examination of the Lee and Burleson County heavy mineral properties and supervised this project in all phases. Property owners B. F. Blackburn, John Branch, Shelly Branch, Beulah Carter, L. V. Colvin, Spencer O. Falkenberg (for the T. W. Falkenberg Estate), Col. John E. Weiler, and Oliver Whitener allowed free access to the land. Howard Dodd, Jr., donated the use of his home as a permanent field camp. James M. Pegg assisted in the field. L. E. Garner provided X-ray data on some of the clays. The Pan American Petroleum Foundation provided a grant for thin sections and polished sections. Faculty members of The University of Texas Department of Geology and staff members of the Bureau of Economic Geology who assisted in a variety of ways are W. L. Fisher, P. U. Rodda, J. A. Wilson, W. C. Bell, Alan Scott, J. W. Macon, D. F. Scranton, B. M. Harris, R. M. Wheeler, and D. A. Schofield. Jay Callahan, of Trans-Tex Exploration Company, Inc., supplied the results of trial beneficiation tests.

Present Study

During 1954 and 1955 uranium prospectors were active along the southwestern outcrop of formations from the Yegua to the Oakville. Many radiation anomalies were discovered; some are strong and associated with uranium minerals and others are weak and associated with concentrations of heavy minerals, including ilmenite, magnetite, and zircon.

During the spring and summer of 1956, P. T, Flawn made a study of weakly radioactive localities in the Wellborn Formation in the area of this report (Flawn, 1956), The writer and J. M, Pegg spent six weeks making plane-table geologic maps and scintillometer surveys of radiation anomalies on the Falkenberg, Blackburn, and Colvin properties (Pl. I). Two more radiation anomalies were discovered, one on the Carter-Branch property and one on the Weiler property (Pl. I), Trans-Tex Exploration Company, Inc., dug test trenches on parts of the Falkenberg, Blackburn, and Colvin properties, and channel samples were taken from the walls of these trenches.

Radiation readings were taken with a scintillometer on grid patterns at intervals of 200, 100, and 50 feet. The radiation values were plotted on a map (1 inch = 100 feet) and contoured at an interval of 0. 01 milliroentgens per hour.

In 1959 and 1960, the writer mapped the rocks in which the heavy mineral deposits occur and located the boundaries of the formal stratigraphic units.

STRATIGRAPHY

Renick (1936) discussed the nomenclatural history of the Jackson Group and mapped the following formations: Whitsett, Manning, Wellborn, Caddell. He divided the Wellborn into an upper sandstone member (Carlos), a lower sandstone member (Bedias), and a middle member, which he did not name, consisting largely of sandstone, clay shale, mudstone, lignite, and lignitic shale.

Renick (1936, p. 26) described the Bedias as follows:

"The Bedias sandstone consisting of an upper hard layer with soft sand below is present over much of the area shown in Plate II [including Lee and Burleson counties].... The sandstone is almost continuous across Grimes and Brazos counties, but in Burleson County between the Gulf Coast and Santa Fe Railroad and Brazos River it is poorly developed or absent. It may be traced almost continuously across Lee County with the exception of the divide area in the vicinity of the Southern Pacific Railroad, where it is covered with gravel.... Throughout the area shown on Plate II the Bedias sandstone is gray, medium grained, and contains ashy material throughout. The topmost massive beds where present break with a conchoidal fracture and vary from hard sandstone to quartzite. Small black specks probably representing ferro-magnesian minerals are a characteristic of this phase...."

Renick (1936, pp. 31–32) described the Carlos as follows:

"... This sandstone is gray to white and more argillaceous than the Bedias sandstone. On the weathered surface it contains a mass of pipes, oriented in all directions, which resemble impressions of fossilized vegetable matter which may represent stems of sea weeds.... The fresh exposures of the rock contain fragments of disseminated lignitized wood and the individual pipes generally contain wood impressions. On the whole the Carlos sandstone is not as hard as the Bedias sandstone and generally breaks with a splintery fracture instead of the conchoidal fracture which is characteristic of the Bedias sandstone. However, at some places, notably along the outcrop in parts of Fayette County, the top of the Carlos sandstone is harder and semiquartzitic so that it resembles certain phases of the Bedias sandstone.... No logs or lignitic material other than stem impressions are present in this sandstone. The cross-bedded character locally suggests current action of some type, perhaps from waves."

Renick did not consider the Bedias to be a continuous lithic unit; he noted several localities where it is "poorly developed or absent."

According to Renick, the main differences between the upper and lower parts of the Bedias and the upper hard part and the lower soft part of the Carlos or, for that matter, the only differences between the Bedias and the Carlos, are hardness, fracture, and the allegations that the Bedias contains "black specks" and that the Carlos is more argillaceous than the Bedias.

In his correlation table, Renick (1936, Pl. IV) presented three measured sections which are close to or within the area of this present study. One of these is not correctly located. It is said to be in the southwest corner of the Claiborne Lawrence survey, Lee County, but this places the section more than 2 miles west of the Wellborn outcrop.

On the James Craft survey in Burleson County there is an outcrop that Renick identified as Bedias (locality 9). (For location of numbered localities, see Appendix, p. 17). This prominent sandstone can be traced with reasonable certainty as far as Yegua Creek, but south of Yegua Creek there are several sandstone beds low in the Wellborn, and it is not clear which, if any, of these is Bedias. South of measured section 5, even these sandstone units cannot be traced with any certainty. Northeast, along the outcrop on the James Craft survey, the rock Renick designated as Bedias thins and disappears.

The only one of these three measured sections that shows an extensive sequence of the Wellborn is described as being in the west corner of the H. Best survey in northeast Lee County. This probably refers to the exposure on the Colvin property described herein as measured section 7 (p. 26). The section as measured and described by Renick (1936, p. 30) follows:

Section measured along the road through the center of the R. Carter 181-acre tract, H. Best survey, northeast Lee County. Instrument work by R. C. Briggs, September 9, 1931.

	Thickness (Feet)
Carlos sandstone:	
Massive irregularly weathered hard sandstone; top of Carlos member	3
Middle Wellborn:	
Soft gray sand interbedded with tan sand and gray shales, the latter containing thin flaggy sandstone; some poorly preserved fossil casts in the flags	12
Hard cross-bedded semiquartzitic sandstone	1
Cross-bedded, gray and tan sandstone grading into soft sand in the lower part	7
Soft gray and tan sand without flags; lower part fractured	8
Total measured	31
Chocolate-colored shales.	

Renick did not designate any of the lower sandstone beds as Bedias, although one of them forms a prominent cuesta and contains concretions of heavy minerals. But, though he may have had reservations about identifying the Bedias, he had no such reservations about the Carlos. He identified it positively and implied ("the top of Carlos member") that part of it is missing.

Because the sandstone beds in the Wellborn are so similar, both megascopically and in thin section; because cementation (and therefore hardness and, to some extent, fracture) throughout the Wellborn appears to be capricious and without apparent stratigraphic control; and because the rocks of the Wellborn are characteristically lenticular, the writer is unable to distinguish these units in the field. Rather than map as Carlos any sandstone at the top of the Wellborn cuesta and as Bedias any quartzitic sandstone at the base of the Wellborn, these members are dropped from further consideration.

Caddell Formation

Lithology. --The upper part of the Caddell, in Lee and Burleson counties, is mainly sandy, montmorillonitic clay; sand increases upward, and the formation grades into the clayey sandstone of the Wellborn Formation. In southern Lee County, the formation is about 45 feet thick (Harris, 1941). Like the Wellborn, the upper part of the Caddell contains a large amount of chocolate-colored, lignitic shale and resistant, lenticular sandstone beds from 1 to 3 inches thick. The sandstone beds of the Caddell are fine to very fine grained, angular to subangular, well sorted, and contain disseminated glauconite grains.

The Caddell Formation contains a large amount of silicified wood, including agatized and opalized palm wood. The sides of the gullies are littered with fragments of silicified wood including a few logs and stumps. Several silicified logs were found north of Birch Creek (locality 7) in beds that are transitional between the Caddell and Wellborn. These beds are prominently cross-bedded with dips of 10 to 20 degrees in various directions. Limonite nodules 1 to 3 inches in diameter occur in the upper part of the Caddell and irregularly throughout the Wellborn Formation. Dark gray to yellowish-brown glauconitic nodules 5 to 8 inches in diameter and containing fragments of white montmorillonitic claystone and pelecypod imprints occur sparsely in the upper part of the Caddell in the gullied area between the Falkenberg and Blackburn properties and the northwest-southeast road. At the southwest end of the map area, about 2,500 feet northwest of Post Oak School (locality 8), several brecciated boulders of pumice 6 to 12 inches in diameter are exposed in silty clay. The outer half inch to 1 inch of each boulder is stained with limonite. The material is partly devitrified glass showing very fine pumiceous texture. The index of refraction of the pumice is within the range given for rhyolite glass (George, 1924).

Boundary between Caddell and Wellborn. --No distinct break in lithology occurs between the Caddell and the Wellborn. The sandstone and shale of the upper part of the Caddell grade into the sandstone and shale in the Wellborn. Locally, the boundary between the formations is drawn at the base of the lowest prominent ledge-forming sandstone or sequence of flagstones (Pls. III, B; IV, A, B; fig. 1). Isolated sandstone lenses lower in the section are considered to be in the Caddell Formation. Regionally, there is no single through-going bed at the base of the Wellborn to serve as the boundary between the Caddell and Wellborn. In the absence of such a bed, the boundary is drawn at the base of approximately contiguous sandstone lentils. In covered areas and breaks between lentils, the boundary can be located only approximately (Pl. II).

Wellborn Formation

Lithology and bedding. --The Wellborn Formation is a sequence of lenticular beds of fine-grained to very fine-grained sandstone, mudstone, and claystone. In the mapped area, it has a thickness from 14 to 70 feet. Flagstone beds range from half an inch to 3 inches thick, massive soft sandstone beds range from 2 to 6 feet thick, and hard sandstone beds range from 6 inches to 2-1/2 feet thick. Platy clay shale, lignitic shale, and shaly mudstone are from 2 inches to 3 feet thick.

Besides being lenticular, the beds pinch and swell along strike; massive sandstone beds grade laterally into flagstones or lens out completely. Even closely adjacent sections are difficult to match, and correlation of individual beds between widely separated outcrops is unreliable.

The Wellborn Formation differs from the Manning and Caddell by the absence of megascopic volcanic debris (except montmorillonitic clay) and the scarcity of leaf impressions. The lower part of the Manning is marked in several places by thin tuff lentils. In the Caddell (locality 8) there are several brecciated boulders of pumice. No material of this kind was found in the Wellborn. Leaf imprints and leaf debris are abundant in the Manning and scarce in the Wellborn.

One of the more abundant rock types in the upper part of the Wellborn is shaly mudstone. It is interbedded with tan clay shale that weathers very light gray. Where present, abundant chips of shaly mudstone litter the outcrop and can be used as an aid in mapping.

The lower part of the Wellborn in many places contains lignitic shale. The best exposures in this area are on the Colvin property.

Renick (1936, p. 18) reported limonite concretions in the Caddell but not in the Wellborn. Harris (1941, p. 27) reported them in the Wellborn. In the north part of the Weiler and Whitener properties (locality 9), limonite concretions 1 to 3 inches in diameter are well exposed in the upper few feet of the Caddell and the lower few feet of the Wellborn.

Bedding surfaces are irregular and show many local reversals of dip. They are best exposed on dip slopes of hard sandstone lentils. A dip of 10 degrees occurs on the Colvin property (locality 4) (Pl. V, A). North of Birch Creek, on the Whitener property (locality 5), there is a doubly plunging anticline in the basal sandstone of the Wellborn. High-angle dips do not extend more than a few yards, but low-angle reversals of dip cause the Wellborn beds to converge and diverge over distances on the order of a few thousand feet. East of the Falkenberg and Blackburn properties, two

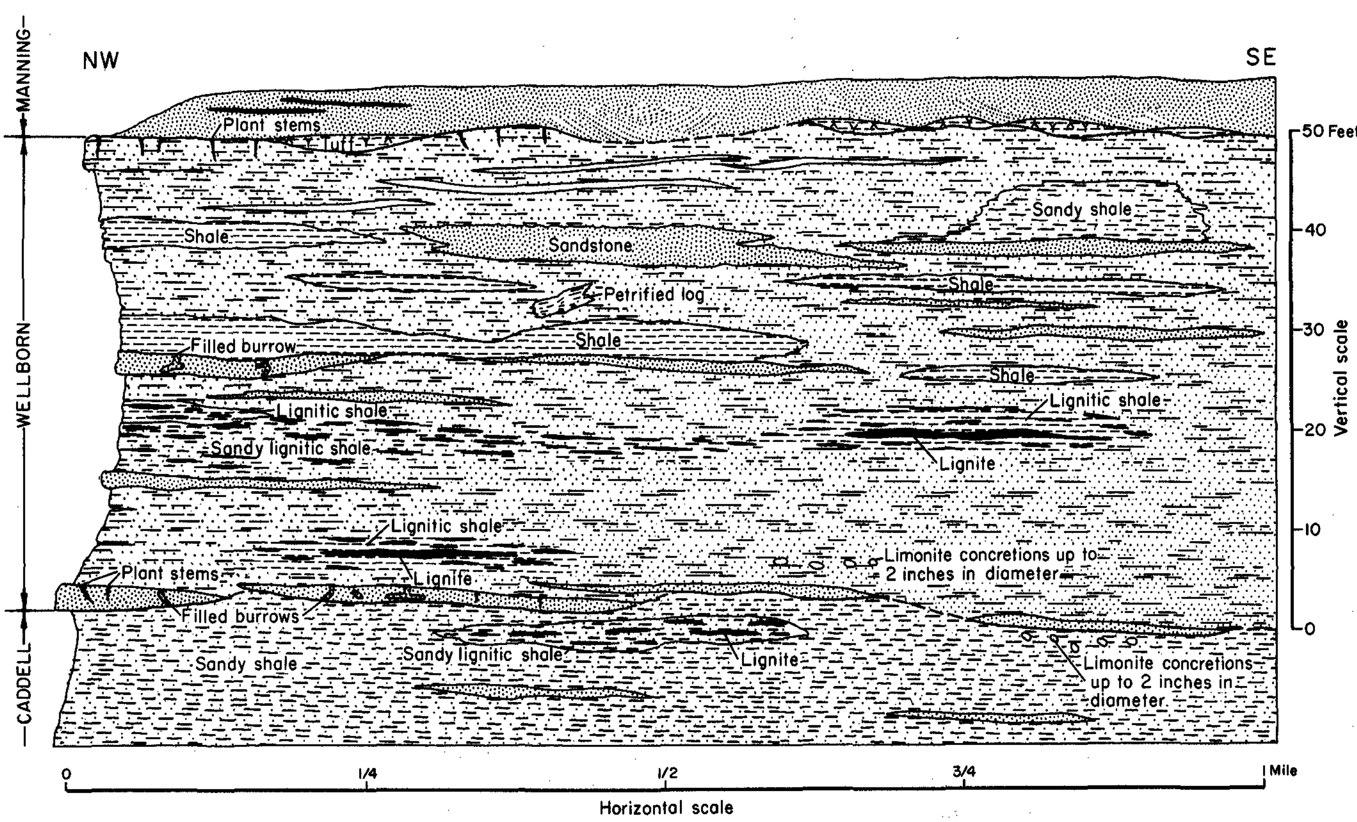

FIG. 1. Schematic section of the Wellborn Formation as described in this report.

resistant sandstone beds are continuously exposed through measured sections 8, 9, 10, and 11, a total distance of about 4, 000 feet. The vertical separation of these two beds at the four measured sections is 40, 50, 4.5, and 8 feet, respectively.

Boundary between Wellborn and Manning. --The lower beds of the Manning are montmorillonitic claystone, mudstone, shale (some of which contains abundant fossil leaves and leaf debris), fine- to medium-grained cross-bedded sandstone (Pls. V, B; VI, A), and tuff lentils 1 to 3 inches thick at or near the base of the formation. The boundary was drawn along the base of the lowest tuff lentil (or the lowest medium-grained sandstone, or the lowest shale with leaf impressions) immediately overlying rocks of Wellborn lithology.

Some of the lower claystone and mudstone beds of the Manning are so similar to Wellborn rocks that, in the absence of the more distinctive Manning rocks, they can be distinguished in the field only by over-all stratigraphic sequence and lithic continuity. Some Manning shales are easily mistaken for Caddell shales.

The Manning rests unconformably on the Wellborn with no indication of erosion or a break in deposition except on the Colvin property (locality 7) where Manning sandstone fills channels and irregularities in the upper surface of the Wellborn. The Manning sandstone (medium grained to coarse grained and moderately sorted to poorly sorted) contrasts sharply with the underlying very fine-grained bluish-gray Wellborn quartzite (locality 20) (Pl. VI, B). In the northern part of the area, most of the lower beds of the Manning are shale with leaf impressions.

Sedimentary structures. --Both the Wellborn and the Manning characteristically are cross-bedded mostly at low angles. Many sandstone beds are tabular sets of foreset laminae with low-angle cross-stratification, which results in long, even to undulant surfaces. Many of the wavy flagstones were formed by separation of sandstone along low-angle cross-beds. Cementation tends to follow cross-beds. Many lentils are bounded by surfaces which cut across some cross-beds and follow others.

South of the Colvin property (locality 19) (Pl. VII, A), plant drag marks (McKee, 1954) (Pl. VII, B), wave ripple marks (Pl. VIII, A), and clusters of mudballs 2 to 5 mm in diameter are well exhibited. Current ripple marks, which strike from N. 30° E. to N. 70° E. (Pl. VIII, B), are abundant in the area mapped south of Yegua Creek. The wave-length is about 3 inches, and the amplitude is about a quarter of an inch. Most are nearly symmetrical. The asymmetrical ripple marks indicate a current direction toward the southeast. One set of ripple marks strikes N. 60° W. and indicates current direction toward the southwest. The under sides of some flagstones show flow casts.

Disconformities are abundant in the Wellborn. Some are marked by fossil grass stems and tree stumps in growth position and by small-scale features such as ripple marks, flow grooves, plant drag marks, and small-scale local channels and scours. The upper surfaces of some beds are littered with plant fossils oriented along local drainage lines. Grass stems in growth position are common both high and low in the Wellborn. Fossil burrows of shallow-water marine organisms are prominent low in the formation. The only extensive channeling is on the upper surface of the Wellborn on the Colvin property and environs where there is a change from fine-grained sand of the Wellborn to medium-grained sand of the Manning--a change that is in sharp contrast to the discontinuities lower in the Wellborn, many of which mark a change from fine-grained sand deposition to clay deposition or mark a break in deposition between two bodies of identical fine-grained sand.

Cementation.--The principal cementing agents in the Wellborn rocks are opal and chalcedony with minor amounts of microcrystalline quartz and limonite. The silica is probably derived from decomposition of volcanic ash in the Manning, Whitsett, and Catahoula (Folk, 1957, p. M-12).

The cement is not evenly distributed. Although some lentils are cemented strongly, immediately adjacent ones are uncemented; some are cemented strongly in part and otherwise weakly cemented or uncemented. In some rocks, cement follows one cross-bed unit through part of its extent, then abruptly changes directions to follow an abutting cross-bed unit. In this way, a sequence of cross-bedded sandstone and shale is a network of cemented units interspersed with uncemented or only slightly cemented units (fig. 2).

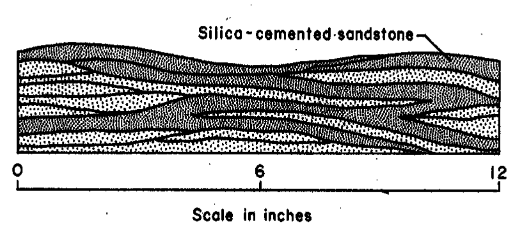

FIG. 2. Cementation along cross-beds, upper part of the Wellborn Formation, near measured section 2, west of Post Oak School (Lee County).

Some lentils that are not prominently cross-bedded contain quartzitic masses which locally have transitional boundaries. In many such rocks silica appears to have entered the rock along a fossil plant stem; only the rock in the vicinity of the stem is cemented. However, not all plant stems are silicified. Some joint blocks appear to have been silicified along their margins,

Within the same sand body, patchy cementation produces strikingly different rocks. Along the top of the Wellborn cuesta in several localities there are two rock types which are similar to the upper hard and lower soft lithologies discussed by Renick (1936, p. 32). A quartzite, which forms a low ridge across the south part of the Colvin property (locality 21) (Pl. IX, A) is in abrupt lateral contact with a light gray, soft, argillaceous sandstone which weathers dark gray (Pl. IX, B). The upper surface of this soft sandstone is weathered into saucer-shaped depressions from 1 to 3 feet in diameter and 1 to 3 inches deep (Pl. X, A). The rim of each of these is raised a few inches higher than the surrounding rock so that it stands in bold relief.

In the cross-bedded and thinly bedded units the solution obviously moved along certain beds in preference to others. In partially cemented massive beds the liquid seems to have moved along porosity or capillarity gradients, thus accounting for the lateral changes from soft to hard rock (fig. 3).

clay-free silicified rocks. Limonite stains give some of the quartzite and quartzitic sandstone a brownish-gray to lavender-gray color. This is more common in the northeastern part of the area in Burleson County than in Lee County.

The tan montmorillonitic clay in the Wellborn is similar to clay in the Caddell and the Manning. The tan color is caused by minute particles of lignite along bedding planes. Where the concentration of lignitic debris is higher, the clay is chocolate brown.

Fossils. --The most abundant fossils in the Wellborn are plant stems and wood fragments; large fragments, logs, and leaf impressions were found. Harris (1941, p. 26) mentioned leaf imprints in the Wellborn. In this respect, the contrast between the Wellborn and the Manning is marked. Some of the Manning shale beds are composed almost totally of leaf debris.

Some of the hard sandstone and quartzitic sandstone, particularly in the upper part of the formation, contains fossilized grass stems which are similar to eel grass (Renick, 1936, p. 32).

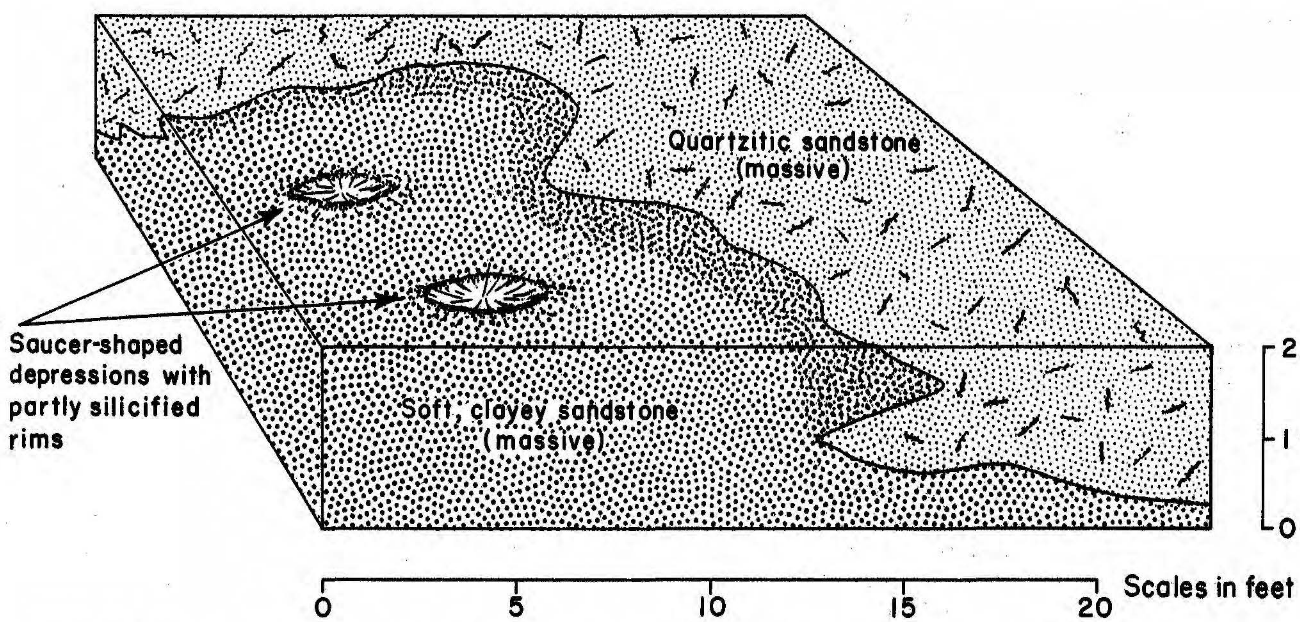

FIG. 3. Cementation controlled by porosity and permeability. Upper part of the Wellborn Formation on the southern part of the Colvin property, Lee County, near locality 4. Schematic.

Color. --The sandstone beds of the Wellborn Formation are predominantly light gray to buff. (For precise color designations, see petrographic descriptions in the Appendix, p. 17.) Pervasive coloring by limonite is rare, though the rocks are commonly stained yellowish brown in streaks and spots. In the heavy-mineral-bearing sandstone bodies, the concentrations of black grains form dark gray streaks and patches. Quartzite on the Colvin property (locality 2) is bluish gray. This color occurs locally and sporadically in the

These stems are oriented perpendicular to the bedding plane. Lower in the formation, the upper surface of many resistant sandstone bodies is strewn with plant stems and stem casts the size of a pencil (locality 6).

A few petrified logs were found. On the Whitener property (locality 7) in rocks transitional between Caddell and Wellborn, there are several petrified logs within a few yards of each other. Near this spot an agatized palm stump and the petrified root buttresses of a tree were found on the basal sandstone of the Wellborn. Both fossils are in growth position.

Poorly preserved pelecypod molds, about an inch wide, were found at a few places.

Branching fossil burrows, like those made by shallow-water marine organisms such as Callianassa (mud shrimp), were found in a few places in slightly glauconitic sand. The horizontal branches, 1 to 1-1/2 inches thick, join at the base of a vertical burrow about 4 to 6 inches tall and about 3 inches thick (Pl. X, B; XI, A). One of those shown in Plate XI, A, was truncated by the overlying bed. The burrows are filled with fine-grained sand that is lighter gray than the surrounding sand and is more strongly cemented. Because of the difference in cementation, burrows have been exposed by weathering and erosion. Well-preserved burrows have a pelleted surface, which has prompted some geologists to use the term "corncob burrows." They are similar to the "pipes" figured by Stenzel (1939, pp. 68, 69).

A piece of petrified wood from the Colvin property is riddled with burrows similar to those made by shipworms (Teredo). The burrows are 3 to 4 mm in diameter. The bedrock is medium hard, fine-grained sandstone with spotty cementation. The burrows are filled with sand like the sand in the surrounding rock, but the sand in the burrows is cemented with opal.

Environment of deposition. --The lower part of the Wellborn Formation is characterized by slightly glauconitic sandstone with claystone and siltstone interbeds. The sand is commonly thick-bedded and contains burrows like those made by shallow-water marine organisms. Grass stems (some in growth position), plant detritus, plant drag marks, rill-wash channels, and ripple marks indicate deposition in very shallow water, possibly on tidal flats. Truncated burrows indicate disconformities that may be related to numerous minor advances and retreats of the shore line or to storms. The non-fossiliferous claystone and siltstone are probably lagoonal.

The upper part of the Wellborn is composed predominantly of lignitic shale and sandstone interbeds with abundant plant detritus and grass stems in growth position; other fossils are scarce. These lignitic sediments were probably deposited in lagoons or marshes.

Many sedimentary features, especially on the Colvin property, probably indicate deposition under a fluvial régime (Pl. XI, B).

STRUCTURE

The predominant structure of the Wellborn Formation is a gentle homocline. Deformation is local and includes only faults and joints. Three N. 70° E. normal faults were mapped in the Wellborn. North of Birch Creek (localities 12 and 13) two faults are downthrown to the northwest with dips of 35 and 30 degrees, respectively, on the fault plane. A fault east of the Falkenberg and Blackburn properties (locality 14) is downthrown to the southeast and the fault plane dips 55 degrees. Displacement is only a few feet. These faults can be traced 20 to 50 yards. Russell (1957) mapped three parallel faults of low displacement trending northeast-southwest on the Whitener and Weiler properties; his map indicates by dashed lines that these faults are a mile or more in extent. They were not seen during the present study. On the Colvin property (locality 2) a large block of bluish-gray quartzite dips steeply toward the north; its structural relationship is not clear.

Flagstones and the massive resistant sandstone beds in the Wellborn are extensively jointed (Pl. VIII, B). In the flagstones, the joints are 2 to 6 inches apart; in the more massive rocks, they are 1 to 2 feet apart. The joints are approximately vertical. Two strong sets strike from N. 55° E. to N. 85° E. and intersect at angles of 10 to 20 degrees. Locally, a weak cross set is roughly at right angles to the strong sets. There is a distinct joint anomaly on the Whitener property (locality 11). Here the strong sets strike N. 55° W. to N. 80° W. with a weak cross set.

PETROGRAPHY

The sandstones in the Wellborn, as seen in twenty-one thin sections (see Appendix, p. 17) have almost the same composition (fig. 4). They range from sandy siltstone to fine sandstone; all are subarkoses. Most are well sorted in the sand fraction; many are clayey. Most contain glauconite, zircon, opaque minerals, tourmaline, chert, volcanic rock fragments, and plagioclase. The plagioclase composition ranges from oligoclase to andesine. Besides plagioclase, the rocks contain lesser amounts of orthoclase and microcline. All feldspar grains are fresh. Mica and metamorphic rock fragments are rare. Most of the quartz grains are subequant, but about 10 to 20 percent are flat and platy. In thin section, in certain orientations, these look like long slivers.

Three thin sections from the Manning indicate a wider variety of sandstone types and a wider range of grain size in the Manning than in the Wellborn. In composition, they are an orthoquartzite, a subgraywacke, and an arkose. The arkose contains 20 percent volcanic rock fragments, whereas volcanic rock fragments are rare in the other two samples. They range in grain size from very fine sandy siltstone to silty medium sandstone.

Cement. --The principal cementing agents are silica (in the form of opal, chalcedony, and microcrystalline quartz) and limonite (limonite is more commonly a stain than a cement). Three types of cementation were observed: (1) In some rocks the pore spaces are filled with silica so that there is no clay or any other matrix except silica cement. This is characteristic of the hardest rocks in the section. (2) Several thin sections of tough to partly friable rocks have a clay and silt matrix with irregularly distributed silica cement which forms a resistant framework within what would otherwise be a very soft rock. (3) In some rocks the matrix and the cement cannot easily be distinguished. Most of these appear to have a clay matrix which has been silicified and in some cases limonitized, the latter especially along cross-bed surfaces and near weathered surfaces.

Cementation paragenesis in the Wellborn is well defined in only a few thin sections (fig. 5). As shown below, thin sections 3, 7, and 20 show only two stages of cementation; thin sections 10 and 11 show three stages of cementation.

In rocks in which opal cement occurs, it is the first formed. In clayey rocks in which opal cement occurs in streaks and spots, some of the opal is mixed with clay and is soft. Rocks which are completely cemented with relatively pure opal are quartzites.

A possible source for the opaline silica is near at hand. The Jackson and Catahoula are made up in large part of volcanic ash, much of it altered to montmorillonite. The cementing silica probably is derived from the decomposition of volcanic ash and deposited as opal.

Thin section	Cement	Time (Early)		Time (Late)
3	Limonitic chalcedony	x		
	Microcrystalline quartz			x
7	Limonitic chalcedony	x		
	Microcrystalline quartz			x
10	Opal	x		
	Limonite		x	
	Microcrystalline quartz			x
11	Opal	x		
	Limonitic chalcedony		x	
	Microcrystalline quartz			x
20	Opal	x		
	Limonite			x

The second stage of cementation in thin sections 3 and 10 is characterized by limonite. In the other thin sections the second stage is chalcedony slightly stained with limonite. Limonite is a minor cementing agent, whereas chalcedony is a major cementing agent. The persistence of limonite in this stage suggests oxidizing conditions possibly at or near the surface where subaerial conditions of alternating wetting and drying could bring about its introduction and oxidation (Moorhouse, 1959, p. 352). Perhaps this second stage of cementation occurred after the erosion of some of the overlying rocks.

The third stage of cementation is characterized by microcrystalline quartz with no limonite stain. Microcrystalline quartz occurs only as a final filling of some of the pore spaces. It may be a continuation of stage two under slightly different conditions.

Quartz overgrowths on quartz grains are rare.

Silicification in the Wellborn is uneven and spotty. In many places it follows cross-beds, and in others it reflects the original porosity and permeability of the rock which permitted the flow of silica-rich liquids and the deposition of silica. Because of this, there are many occurrences of very hard rock, locally, where only part of a bed has been cemented. For example, the quartzite on the Colvin property is in sharp lateral contact with soft, clayey sandstone in the same bed.

Most of the quartzitic rocks have a border of limonitic stain on weathered surfaces. The limonite invaded not only the margin of the rock but moved through zones of porosity along some cross-beds or zones of incomplete cementation.

Origin of sediments. --The minerals in the Wellborn Formation are derived from sources including (1) high-rank metamorphic rocks of the southern Appalachians, (2) volcanic eruptions in

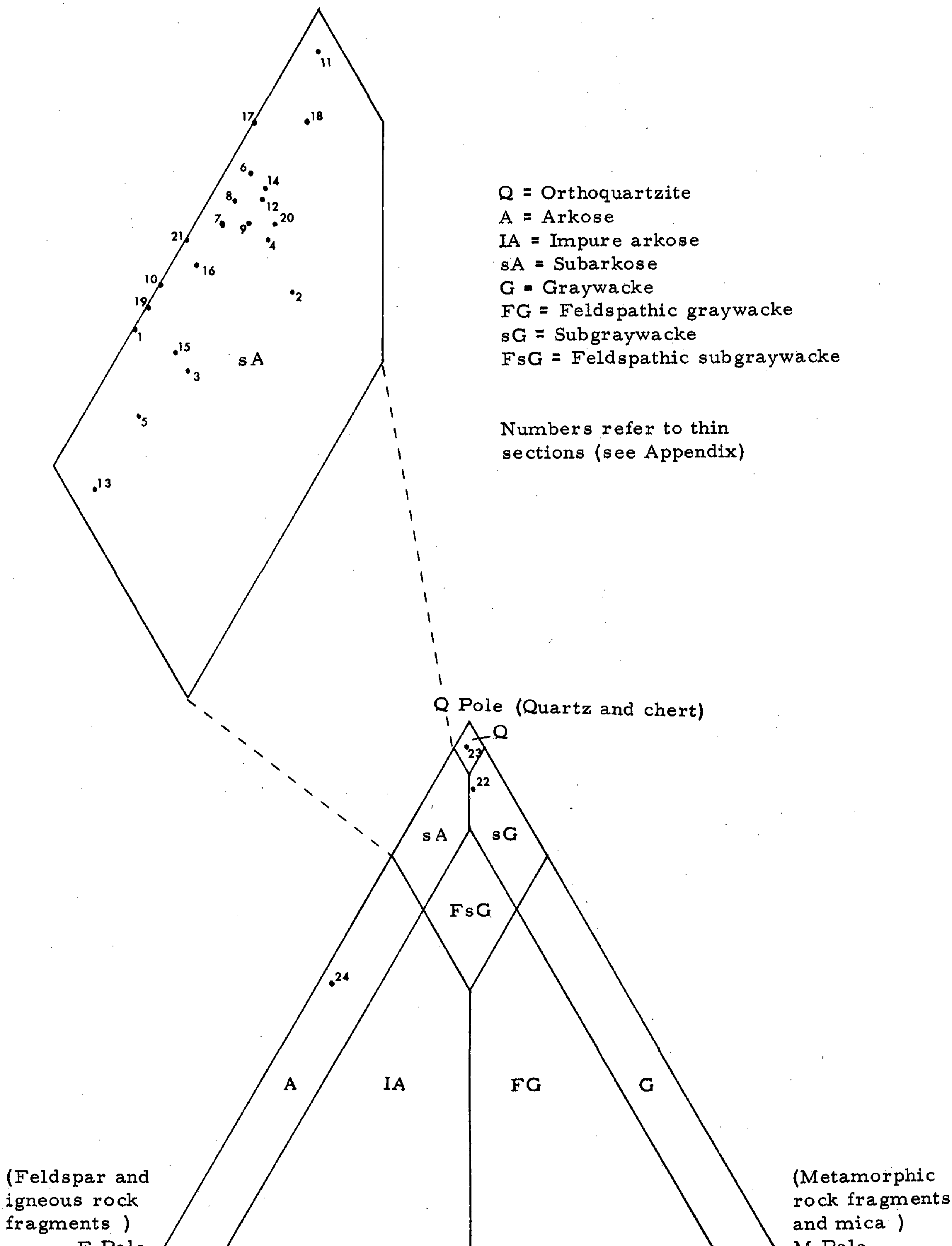

FIG. 4. Petrographic nomenclature according to Folk (1957).

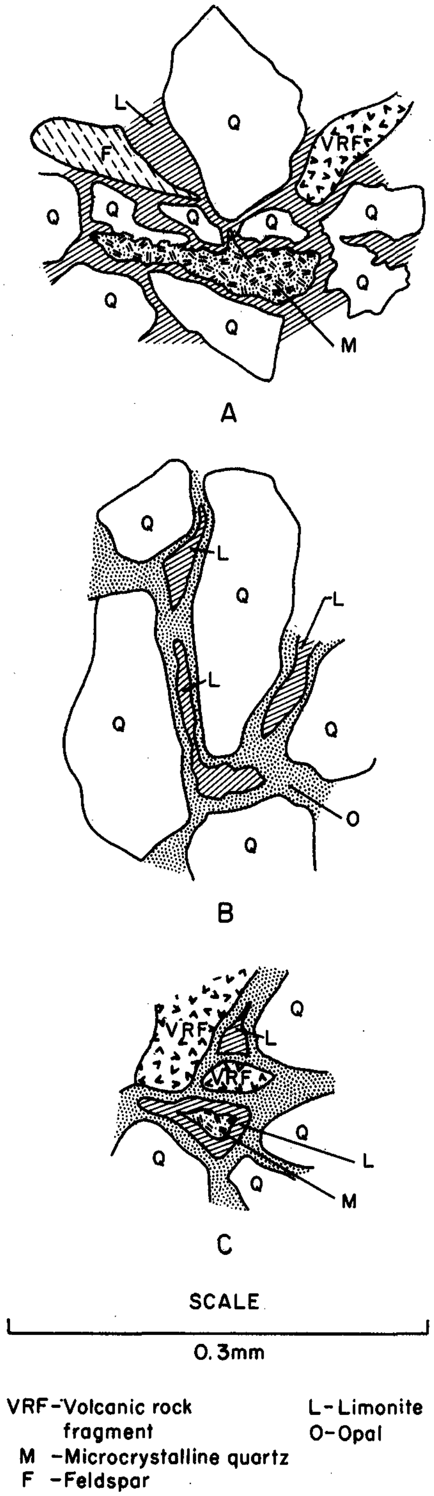

FIG. 5. Cementation paragenesis in the Wellborn Formation as seen in thin sections. A, Thin sections. Two stages of cementation: (1)limonitic chalcedony and (2) microcrystalline quartz. B, Thin section 20. Two stages of cementation: (1) opal and (2) limonite. C, Thin section 10. Three stages of cementation: (1) opal, (2) limonite, and (3) microcrystalline quartz.

the western part of North America, and (3) older sedimentary rocks.

Minerals diagnostic of a source in high-rank metamorphic rocks are staurolite and kyanite. According to Todd and Folk (1957, p. 2564), in a study of the Carrizo Formation and Newby Member of the Reklaw Formation (Middle Eocene) in Bastrop County, Texas, the abundance of kyanite and staurolite in the heavy mineral suite demonstrates that the Carrizo and Newby belong to the southern Appalachian detrital province. The staurolite and kyanite came from the same metamorphic source as the Eocene and Recent sediments in Mississippi and Alabama. In central Texas, kyanite and staurolite were deposited in decreasing abundance through Miocene time.

Besides staurolite and kyanite, other minerals in the Wellborn which are found also in the southern Appalachians include ilmenite, magnetite, corundum, and tourmaline.

As pointed out by Folk (1954, p. 16), the deposition of the Yegua through Catahoula sediments coincided with widespread volcanism in much of western North America. Several minerals in the Wellborn indicate a volcanic source. The most abundant of these is montmorillonite, which was derived from decomposition of volcanic ash. Also present are volcanic rock fragments, volcanic glass, and traces of volcanic quartz. Concerning the source of some detrital plagioclase, Folk (1957, p. M-14) said, "...if a formation contains more plagioclase than K-feldspar, suspect a volcanic source--especially if the plagioclase crystals are zoned." Although plagioclase is more abundant than K-feldspar in some of the Wellborn rocks, it is not zoned. Therefore, the only indications that it is volcanic are its relative abundance and its association with volcanic rock fragments and minerals. The presence of abundant idiomorphic zircon crystals is a further indication of a volcanic source (Callender and Folk, 1958).

A source in older sedimentary rocks is evidenced by the amount of chert in most of the Wellborn sandstones. Folk (1957, p. M-12) said, ". . .reworked chert forms 1–4% of the terrigenous fraction of sediments. It is always diagnostic of an older sedimentary source...." In addition to chert, the rounded zircon and rounded tourmaline, because of their hardness and resistance to chemical attack, also are probably reworked from older sedimentary rocks.

All of the feldspar in the Wellborn is fresh and angular. According to Folk (1957, p. P-5), this indicates either (1) a cold source area, (2) an arid or semi-arid source area, or (3) conditions of rapid erosion, deposition, and burial with no time for abrasion and chemical attack. Abundance of plant fossils in Wellborn and adjacent formations possibly indicates humid local conditions, but the Wellborn probably has not been subjected to weathering and abrasion under humid conditions for any prolonged period.

HEAVY MINERALS

Distribution and abundance. --In a few places the rocks in the lower part of the Wellborn Formation form a cuesta covered by sandy soil. All five radiation anomalies and their associated heavy mineral concentrations are on this lower cuesta. Distribution of the heavy minerals is very irregular (table 1). There is no single heavy-mineral-bearing sandstone; many small lentils and sets of cross-beds are rich in heavy minerals.

On the Falkenberg and Blackburn properties (table 1) trenches dug across the most radioactive areas show considerable horizontal and vertical variation in the amount of heavy minerals. For example, the soil has a range from almost 3 to almost 18 percent heavy minerals. A clay below the soil contains from about 1 to about 10 percent heavy minerals. Below this, a sandstone contains heavy minerals ranging from a trace to about 35 percent.

Within any heavy-mineral-bearing sandstone the heavy minerals are concentrated along some cross-bed surfaces, in irregular streaks and patches, in wedge-shaped bodies where an entire cross-bed unit is made up predominantly of heavy minerals, and disseminated through the rock.

The heavy mineral suite in all five localities is the same. The most abundant heavy minerals are ilmenite and magnetite which together range from 50 to 87 percent of the heavy mineral fraction (tables 2 and 3). Because they cannot be distinguished accurately enough to be counted separately, they are here referred to as ilmenite-magnetite. The ilmenite-magnetite grains are slightly rounded. Based on chemical analysis of a composite sample taken by Jay Callahan from the Blackburn and Falkenberg properties, ilmenite makes up nearly all of the ilmenite-magnetite fraction.

Zircon ranges from 4 to 23 percent. Four species (colors) of zircon were noted: white, yellow, lavender, and gray. Zircon shapes range from short, stubby crystals to elongate ones. Except for a small percentage of well-rounded grains, the zircon is euhedral and shows no rounding. Some crystals have only the most elemental crystal faces, whereas others have fully developed secondary faces.

Leucoxene is white to yellowish brown and ranges from 2 to 14 percent.

Tourmaline in rod-like fragments and well-rounded grains ranges up to about 4 percent. Most grains are amber to brownish gray, but a few are dichroic in pink and green.

Other heavy minerals occurring in minor amounts are staurolite, kyanite, spinel, corundum, garnet, rutile, limonite, biotite, apatite, titanite, monazite, and fluorite.

The only minerals in the Wellborn Formation in this area which carry radioactive elements are monazite and zircon. Monazite is present only as a trace mineral. Zircon, which always contains traces of hafnium and also commonly contains thorium and uranium (Ford, 1932, p. 611), is the source of radiation.

Polished sections. --The study of polished sections was undertaken to answer three questions: (1) Is the ilmenite in surface samples significantly different from the ilmenite in the trench samples? (2) Does the ilmenite differ from one locality to the next? (3) Are the ilmenite grains intergrown with magnetite? This last is an important consideration if percentages of ilmenite taken from grain counts are to be used in estimating the titanium dioxide content of the deposits.

Magnetite and ilmenite cannot be distinguished with certainty on the basis of reflectivity in these sections. A few grains can be identified as magnetite by a pattern of hematite alteration which apparently follows octahedral planes. On the other hand, many grains containing closely spaced parallel blebs of hematite can be identified as ilmenite. These hematite blebs probably originated through alteration of magnetite which exsolved along basal planes in the ilmenite. Many other ilmenite grains can be readily identified because they are partly altered to leucoxene.

By far the commonest alteration product is hematite, or possibly a mixture of iron and titanium oxides, which occurs along cracks and in the cores of grains. Many of the grains have a thin surface coating of similar material which gives them (unpolished grains) a brassy luster. A few grains, most noticeable in the polished section from the Blackburn trench, are deeply altered to leucoxene on the surface but contain hematite in the cracks and cores. Also prominent in both the Blackburn and Falkenberg trenches are grains in which alteration to leucoxene has proceeded so far that they consist of remnants of ilmenite within leucoxene grains.

There is no apparent difference between the ilmenite-magnetite on the surface and that taken from the trenches. Likewise, there is no appreciable variation from one locality to another except that the ilmenite-magnetite from the surface of the Weiler property shows less alteration inside the grains than that from any of the other localities.

Table 1. Heavy mineral samples.

Location[1]	Sample No.[2]	Nature of sample	Depth (feet)	Percent heavy minerals[3]	Weighted av. h. m. /ft.
		FALKENBERG-BLACKBURN PROPERTIES			
Channel sample, 12 feet from south end of trench T0	HM 32	Sandy soil	0.0 - 1.4	2.76	
	HM 33	Sandy clay	1.4 - 4.4	4.13	5.7
	HM 34	Sandstone	4.4 - 5.4	14.45	
Channel sample, west end of trench T5	HM 35	Sandy soil	0.0 - 1.3	9.44	20.2
	HM 36	Sandstone	1.3 - 2.3	34.60	
Channel sample, 30 feet from west end of trench T5	HM 37	Sandy soil	0.0 - 1.1	17.87	
	HM 38	Sandy clay	1.1 - 2.5	9.54	18.1
	HM 39	Sandstone	2.5 - 4.2	35.14	
	HM 40	Sandstone	4.2 - 5.2	1.62	
Channel sample, 3 feet from east end of trench T5	HM 41	Sandy soil	0.0 - 1.0	12.59	
	HM 42	Sandy clay	1.0 - 3.0	10.23	18.2
	HM 43	Sandstone	3.0 - 4.7	30.82	
Channel sample, 18 feet from east end of trench T6	HM 44	Sandy soil	0.0 - 1.6	8.03	
	HM 45	Sandy clay	1.6 - 2.6	4.16	4.5
	HM 46	Sandstone	2.6 - 3.6	2.51	
	HM 47	Sandstone	3.6 - 4.9	1.85	
Channel sample, middle of trench T3	HM 48	Sandy soil	0.0 - 1.1	4.09	
	HM 49	Sandy clay	1.1 - 3.1	1.19	1.3
	HM 50	Clayey sandstone	3.1 - 5.4	0.13	
Weighted average heavy minerals per foot, all trenches, Falkenberg-Blackburn--10.2					
		COLVIN PROPERTY			
South trench. Material predominantly sandstone.					
Zone I[4]	HM 22		0.0 - 1.0	10.99	
Zone II	HM 23		1.0 - 2.5	17.75	35.1
Zone III	HM 24		2.5 - 5.0	55.36	
Zone III, subdivided	HM 25		2.5 - 3.0	57.38	
	HM 26		3.0 - 3.5	34.40	
	HM 27		3.5 - 4.0	45.04	55.0
	HM 28		4.0 - 4.5	69.15	
	HM 29		4.5 - 5.0	68.62	
		WEILER PROPERTY			
Surface sand over anomaly	HM 20			24.07	
	HM 21			27.16	
		CARTER-BRANCH PROPERTY			
Surface, point of highest radiation	HM 51			46.00	

1/ See inset no. 2, Plate I.

2/ Sample numbers refer to heavy mineral concentrates. See Appendix, p. 22.

3/ Sample determinations based on bromoform separations made by R. M. Wheeler and D. A. Schofield.

4/ Zone is an interval sampled as a whole and also as subdivisions.

Because the grains studied herein show alteration to either leucoxene or hematite, or to both leucoxene and hematite, or to what appears to be a mixture of oxides of titanium and iron, it is believed that they are composed of both magnetite and ilmenite in a fine intergrowth.

Descriptions of polished sections are given in the Appendix (p. 22).

Concentration of heavy minerals. --According to a study of heavy minerals from Recent beaches along the coast of Mississippi (Foxworth et al., 1962, pp. 31–41), heavy minerals are carried along the shore by longshore currents and swell waves. They are deposited by the incoming wind waves and become concentrated by the back rush of water which returns most of the lightweight quartz sand to the sea but maroons the heavy minerals on the forebeach. Squalls move the heavy minerals higher up on the beach and build up a succession of berms, one on top of the other. A trench across one of these berms shows converging laminae of heavy minerals. Commonly, after a build-up of this sort, a tidal flat forms behind the berm, so that higher waves slosh over the top and pave the tidal-flat side of the berm with a thin sheet of heavy minerals. In addition, heavy minerals are concentrated in all parts of the shore area by winnowing action of rains and winds. The distribution of the heavy minerals in the Wellborn sandstone beds strongly suggests an origin comparable to that described by Foxworth.

Foxworth made no mention of heavy minerals in shale, but many of the shale beds in the Wellborn are rich in heavy minerals, Gillson (1949) said that waves washing over an offshore bar cause concentrations of heavy minerals by bringing large quantities of sand into lagoonal basins while depositing the heavy minerals on the bar. Stronger waves would carry heavy minerals over into the lagoon. A lagoonal basin of this sort acted upon by storms with intervening periods of quiescence could explain the presence of heavy minerals in clay and mudstone, and it could also explain the lignite and lignitic debris in the shale.

Table 2. Wilfley table concentrate[1/] from 400-pound composite sample from Blackburn and Falkenberg properties. Grain counts by Dean Callender (Flawn, 1956).

Mineral	Frequency	Percentage
Magnetite and ilmenite	275	50.45
Zircon	97	17.79
Brown leucoxene-earthy rutile	27	4.96
Leucoxene	23	4.22
Rutile	3	0.55
Monazite	2	0.37
Garnet	2	0.37
Pyrite	3	0.55
Staurolite	2	0.37
Limonite	7	1.28
Other	4	0.73
Quartz	100	18.36
Totals	545	100.00

[1/] This concentrate is a table cleaning of the combined concentrate and middlings from a spiral concentrator product that was cleaned once. The concentrate is 70.4 percent of the table head. It assays 43.1 percent TiO_2.

Reserves. --On the basis of the radiometric surveys of the Falkenberg, Blackburn, and Colvin properties and the sampling Of the trenches and test pits, Flawn (1956) estimated the total amount of sandstone containing heavy mineral concentrations at less than 500, 000 tons.

In 1958 the U. S. Bureau of Mines conducted a drilling program (Hahn et al., 1961) which included all five properties plus a sixth locality northeast of the Falkenberg property on land owned by Oliver Whitener. This property was examined by the writer but was not radioactive; the Bureau of Mines also concluded that the property contains no appreciable concentrations of heavy minerals. Their findings are based on samples taken from auger holes 6 to 73 feet deep.

The Bureau of Mines estimated that there are slightly more than 4 million tons of heavy-mineral-bearing sandstone with an average of 2.05 percent heavy minerals, or 2-1/2 million tons with an average of 2.82 percent heavy minerals.

Commercial possibilities. --The heavy mineral concentrations in this study probably are not of commercial interest under present conditions. Locally, concentrations are high, but they are scattered over a distance of several miles along strike, and the reserves are low. In some places, mining would be difficult; hard rock would have to be blasted. Disaggregation of the ore probably would be expensive, because the material ranges from clay and hard shale to sandstone (soft to hard). The ore contains abundant lignite fibers and roots. Ilmenite-zircon-bearing heavy mineral deposits now being mined in this country carry other valuable minerals and are characterized by large reserves and low mining costs. For example, at Trail Ridge, Florida, E. I. du Pont de Nemours & Company, with a large-scale dredge operation, works low-grade ore (2 to 4 per cent heavy minerals) from enormous reserves. The ore is processed cheaply through Humphreys spirals. Production from the Lee and Burleson County deposits would involve higher mining costs, low volume, and limited reserves.

Table 3. Grain counts (in percent) of heavy mineral concentrates from selected samples.

Sample No.	HM 22	HM 1	HM 51	HM 4	HM 39	HM 32	HM 34	HM 21
Ilmenite-magnetite	66	88	78	71	65	68	72	76
Zircon	23	7	5	4	7	16	7	12
Leucoxene	8	4	9	14	2	7	14	6
Tourmaline	1	1	2	4	1	1	1	1
Staurolite	1	Tr	1	4	1	Tr	1	1
Kyanite	Tr	--	--	Tr	1	1	Tr	2
Spinel	Tr	--	--	--	--	Tr	--	Tr
Corundum	Tr	--	--	1	--	Tr	--	Tr
Garnet	--	--	--	--	Tr	--	--	--
Rutile	Tr	--	--	--	1	1	Tr	Tr
Limonite	1	--	--	Tr	--	--	1	Tr
Biotite	Tr	--	--	--	--	1	Tr	--
Apatite	--	--	--	--	--	--	--	Tr
Titanite	--	--	--	--	--	--	--	Tr
Fluorite	--	--	1	--	--	--	1	--
Other	Tr	Tr	4	2	22	5	3	2
Total	100	100	100	100	100	100	100	100

HM 22, Colvin property, surface.
HM 1, Colvin property, trench.
HM 51, Carter-Branch property, surface.
HM 4, Blackburn property, surface.
HM 39, Blackburn property, trench.
HM 32, Falkenberg property, surface.
HM 34, Falkenberg property, trench.
HM 21, Weiler property, surface.

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APPENDIX

Location (Approximate) of Numbered Localities
(See Pl. I)

Locality 1. Burleson County, north of Yegua Creek, on the Somerville road near junction with road that runs northwest-southeast.

Locality 2. Lee County, south of Yegua Creek, on the Colvin and Carter-Branch heavy mineral property, at the top of measured section 7.

Locality 3. Lee County, south of Yegua Creek, on northeast-southwest road about 2,000 feet southwest of St. Mary Church.

Locality 4. Lee County, south of Yegua Creek, on the Colvin and Carter-Branch heavy mineral property between measured section 6 and measured section 7.

Locality 5. Burleson County, north of Birch Creek, between the Weiler and Whitener heavy mineral property and Sweet Home Church, about 1, 000 feet southeast of measured section 17.

Locality 6. Burleson County, north of Yegua Creek, near the east side of the Falkenberg and Blackburn heavy mineral property, at the base of measured section 11.

Locality 7. Burleson County, north of Birch Creek, 2,000 feet east of the Weiler and Whitener heavy mineral property, about 1,000 feet north of measured section 17.

Locality 8. Lee County, extreme southwest end of the map area, about 2,500 feet northwest of Post Oak School.

Locality 9. Burleson County, northeast end of the map area, about 1,500 feet northeast of the northeast corner of the Weiler and Whitener heavy mineral property.

Locality 10. Lee County, south of Yegua Creek, on the Colvin and Carter-Branch heavy mineral property, between measured section 6 and measured section 7.

Locality 11. Burleson County, north of Birch Creek, 1,400 feet east of the Weiler and Whitener heavy mineral property, 1,000 feet west of measured section 17.

Locality 12. Burleson County, north of Birch Creek, 2,000 feet northwest of Sweet Home Church, 800 feet northwest of measured section 18.

Locality 13. Burleson County, north of Birch Creek, 2,500 feet southeast of the Weiler and Whitener heavy mineral property, 1,000 feet south of measured section 17.

Locality 14. Burleson County, north of Yegua Creek, 2,000 feet east of the Falkenberg and Blackburn heavy mineral property, 1,200 feet east of the top of measured section 10.

Locality 15. Burleson County, north of Yegua Creek, on the northwest-southeast road, about 1,500 feet north of measured section 11.

Locality 16. Burleson County, northeast end of the map area at the road junction.

Locality 17. Burleson County, northeast end of the map area, about 3,500 feet northwest of the Somerville road.

Locality 18. Burleson County, Weiler and Whitener heavy mineral property.

Locality 19. Lee County, south of Yegua Creek, on the road west of St. Mary Church, in measured section 5.

Locality 20. Lee County, south of Yegua Creek, on the Colvin and Carter-Branch heavy mineral property, about 400 feet south of the top of measured section 7.

Locality 21. Lee County, south of Yegua Creek, on northeast-southwest road, about 2,500 feet northeast of St. Mary Church.

Locality 22. Burleson County, north of Yegua Creek, about 2,000 feet northeast of the northeast corner of the Falkenberg and Blackburn heavy mineral property.

Petrographic Descriptions

Thin Sections

No. 1. Wellborn Formation (MS 5, unit k). Lee County, south of Yegua Creek on old road west of St. Mary Church.

Megascopic description. --Rock is a very light gray (N8),[1] well-sorted, angular to subangular, hard, very fine-grained sandstone; yellowish-brown ferruginous stains as bands 1 to 3 mm wide and 2 to 3 mm apart occur along cross-beds. A few quartz grains are round and some are platy. The fracture is sharp. Very low-angle cross-beds are marked by limonite stains (above) and concentrations of dark minerals.

Petrographic description. --Rock is composed of quartz (54%); microcline, fresh (6%); chert (5%); orthoclase, fresh (4%); plagioclase (oligoclase), fresh (4%); tourmaline (tr); muscovite (tr); metamorphic rock fragments (tr);and zircon (tr). Matrix (27%) is opal cement.

[1] Color designations based on Rock-Color Chart distributed by The Geological Society of America (reprinted 1963).

Rock. --Very fine sandstone; opaline, mature, chert-bearing subarkose.

No. 2. Wellborn Formation (MS 5, unit 1). Lee County, south of Yegua Creek on old road west of St. Mary Church.

Megascopic description. --Rock is a very light gray (N8), well-sorted, hard, clayey, very fine-grained sandstone. Grains are angular to subangular, well rounded in part. Most grains are subequant with a few flat, platy grains. Joints are stained with limonite. Rock has abundant white claylike grains and a trace of dark minerals. It is flaggy; the slabs are 1-1/2 inches thick.

Petrographic description. --Rock is composed of quartz (52%); plagioclase (oligoclase), fresh (3%); microcline, fresh (2%); stretched metaquartzite (2%); orthoclase, fresh (1%); volcanic rock fragments [2] (tr); metamorphic rock fragments (tr); muscovite (tr); biotite (tr); and zircon (tr). Matrix (38%) is montmorillonite clay cemented with chalcedony. A trace of microcrystalline quartz is present as a second stage of cementation.

Rock. --Clayey, very fine sandstone; siliceous, immature subarkose.

No. 3. Wellborn Formation (MS 4, unit o). Lee County, south of Yegua Creek on old road west of St. Mary Church.

Megascopic description. --Rock is a very light gray (N8) to pale yellowish-brown (10 YR 6/2), well-sorted, angular to subangular, medium soft, slightly friable, slightly porous, muddy, very fine-grained sandstone. Quartz is predominantly subequant with a few flat, platy grains. Fracture is irregular. Rock contains brown, lignitic plant stems and a trace of dark minerals.

Petrographic description. --Rock is composed of quartz (50%); chert (6%); volcanic rock fragments (6%); plagioclase (oligoclase), fresh (3%); volcanic glass, partly devitrified (2%); fossil plant material (2%); stretched metaquartzite (1%); orthoclase, fresh(1%); biotite(tr); muscovite (tr); metamorphic rock fragments (tr); glauconite (tr); zircon (tr); and opaque minerals (tr). Matrix (29%) is montmorillonitic clay stained with limonite. A trace of microcrystalline quartz is present as a second stage of cementation.

[2] As used in these descriptions, the term volcanic rock fragments refers to pieces of "felty" or microcrystalline groundmass from volcanic rocks.

Rock. --Muddy, very fine sandstone; immature, chert-bearing, volcanite subarkose.

No. 4. Wellborn Formation (MS 5, unit p). Lee County, south of Yegua Creek on old road west of St. Mary Church.

Megascopic description. --Rock is a light gray (N7), well-sorted, angular to subround, very hard, quartzitic fine-grained sandstone. It contains fossil plant stems and a trace of dark minerals. Cross-beds are outlined by limonite stains which occur also around plant stems.

Petrographic description. --Rock is composed of quartz (51%); orthoclase, fresh (7%); chert (2%); stretched metaquartzite (2%); microcline, fresh (tr); hornblende (tr); plagioclase, fresh (tr); rutile (tr); zircon (tr)jand opaque minerals (tr). Matrix (38%) is opal cement.

Rock. —Fine sandstone; opaline, mature subarkose.

No. 5. Wellborn Formation (MS 3, unit b). Lee County, south of Yegua Creek one-half mile north of Post Oak School.

Megascopic description. --Rock is a very light gray (N8), well-sorted, angular to subangular, fine-to very fine-grained sandstone; rock is hard except where stained with limonite along cross-beds. Limonitic areas are slightly porous and slightly friable. Most quartz grains are subequant; some are platy.

Petrographic description. --Rock is composed of quartz (62%); volcanic rock fragments (5%); chert (3%); orthoclase, fresh (1%); microcline, fresh (1%); plagioclase, fresh (tr); metamorphic rock fragments (tr); stretched metaquartzite (tr); volcanic quartz (embayed phenocrysts) (tr); opaque minerals (tr); and zircon (tr). Matrix (28%) is opal cement.

Rock. --Fine to very fine sandstone; opaline, mature, chert-bearing volcanite subarkose.

No. 6. Wellborn Formation (MS 3, unit i). Lee County, south of Yegua Creek one-half mile north of Post Oak School.

Megascopic description. --Rock is a very light gray (N8), well-sorted, angular to subangular, fine-to very fine-grained sandstone; rock is hard except where stained with limonite along cross-beds. Limonitic areas are slightly porous and slightly friable. Most quartz grains are subequant; some are platy.

Petrographic description. --Rock is composed of quartz (62%); volcanic rock fragments (5%);

chert (3%); orthoclase, fresh (1%); microcline, fresh (1%); plagioclase, fresh (tr); metamorphic rock fragments (tr); stretched metaquartzite (tr); volcanic quartz (embayed phenocrysts) (tr); opaque minerals (tr); and zircon (tr). Matrix (28%) is opal cement.

Rock. --Fine to very fine sandstone; opaline, mature, chert-bearing, volcanite subarkose.

No. 7. Wellborn Formation (MS 3, unit j). Lee County, south of Yegua Creek one-half mile north of Post Oak School.

Megascopic description. --Rock is a light gray (N7) to pale yellowish-brown (10 YR 6/2), well-sorted, angular to subangular, unevenly cemented, tough, porous, very fine-grained sandstone containing plant stems; weathers brownish gray.

Petrographic description. --Rock is composed of quartz (43%); plagioclase (oligoclase), fresh (3%); oligoclase, fresh (2%); microcline, fresh (2%); chert (2%); stretched metaquartzite (tr); muscovlte (tr); fossil wood (tr); zircon (tr); and opaque minerals (tr). Pore space is 15% of the rock. Matrix (33%) shows two stages of cementation: (1) limonitic chalcedony and (2) microcrystalline quartz (tr), some units of which are in optical continuity with chalcedony.

Rock. --Very fine sandstone; siliceous, limonitic, mature subarkose.

No. 8. Wellborn Formation (MS 7, unit b). Lee County, Colvin property (Pl. I, inset 3).

Megascopic description. --Rock is a light gray (N8), moderately sorted, angular to subangular, hard, fine-grained sandstone; has limonitic streaks that are soft and slightly porous; contains plant stems; rock is quartzitic in streaks along cross-beds and locally around plant stems.

Petrographic description. --Rock is composed of quartz (46%); orthoclase, fresh (4%); chert (3%); glauconite (2%); microcline, fresh (1%); plagioclase (andesine), fresh (1%); volcanic rock fragments (1%); muscovite (tr); and metamorphic rock fragments (tr). Pore space is 10% of the rock. Matrix (32%) is opal cement which is locally limonitic.

Rock.—Fine sandstone) opaline, submature, chert-bearing, glauconitic subarkose.

No. 9. Wellborn Formation (MS 7, unit d). Lee County, Colvin property (Pl. I, inset 3).

Megascopic description. --Rock is a light gray (N7), well-sorted, angular to round, medium hard, clayey, very fine-grained sandstone; contains fossil plant stems; cross-bedding is outlined by concretions of dark minerals and clayey limonitic streaks.

Petrographic description. --Rock is composed of quartz (52%); chert (6%); microcline, fresh (2%); volcanic rock fragments (2%); orthoclase, fresh (1%); plagioclase (andesine), fresh (1%); volcanic glass (1%); opaque minerals (1%); muscovite (tr); metamorphic rock fragments (tr); stretched metaquartzite (tr); zircon (tr); and glauconite (tr). Pore space is 11% of the rock. Matrix (23%) is opal cement with a small amount of montmorillonitic clay.

Rock. --Clayey, very fine sandstone; opaline, immature, chert-bearing, volcanite-bearlng subarkose.

No. 10. Wellborn Formation (MS 7, unit 1). Lee County, Colvin property (Pl. I, inset 3).

Megascopic description. --Rock is a light gray (N7) to dark yellowish-orange (10 YR 6/6), well-sorted, subangular to subround, very hard, quartzitic, very fine-grained sandstone. Fracture is sharp and conchoidal. Rock has limonitic stains near weathered surfaces and along cross-beds.

Petrographic description. --Rock is composed of quartz (56%); orthoclase, fresh (4%); volcanic rock fragments (3%); microcline, fresh (3%); chert (1%); plagioclase (oligoclase), fresh (1%); muscovite (tr); metamorphic rock fragments (tr); opaque minerals (tr); glauconite (tr); and zircon (tr). Pore space is 5% of the rock. Matrix (27%) shows three stages of cementation: (1) opal, (2) limonite (minor), (3) microcrystalline quartz (tr).

Rock. --Very fine sandstone; opaline, limonitic, mature, volcanite-bearing subarkose.

No. 11. Wellborn Formation (MS 18, unit b). Burleson County, north of Birch Creek near Sweet Home Church.

Megascopic description. --Rock is a light gray (N7), well-sorted, angular to subround, medium soft, tough, clayey, fine-grained sandstone. Closely spaced parallel limonitic stains occur along lamination planes.

Petrographic description. --Rock is composed of quartz (51%); chert (3%); volcanic rock fragments (2%); microcline, fresh (1%); plagioclase (oligoclase), fresh (1%); glauconite (1%); clay grains (1%); muscovite (tr); opaque minerals (tr); zircon (tr); and fossil wood (tr). Matrix (40%) is montmorillonitic clay cemented locally by opal and a trace of microcrystalline quartz.

Rock. --Clayey, fine sandstone; immature, chert-bearing, volcanite-bearing subarkose.

No. 12. Wellborn Formation (MS 18, unit k). Burleson County, north of Birch Creek near Sweet Home Church.

Megascopic description. --Rock is a pinkish-gray (5 YR 8/1), moderately sorted, angular to subangular, medium hard, porous, silty, very fine-grained sandstone; contains abundant platy quartz grains; rock is flaggy; joints and bedding planes are stained by limonite.

Petrographic description. --Rock is composed of quartz (55%); volcanic rock fragments (4%); chert (3%); plagioclase (oligoclase), fresh (2%); glauconite(1%); metamorphic rock fragments (1%); orthoclase, fresh (tr); microcline, fresh (tr); muscovite (tr); opaque minerals (tr); and zircon (tr). Pore space is 3% of the rock. Matrix (31%) is opal cement with a small amount of montmorillonitic clay.

Rock. --Silty, very fine sandstone; opaline, immature, chert-bearing, volcanite subarkose.

No. 13. Wellborn Formation (MS 18, unit 1). Burleson County, north of Birch Creek near Sweet Home Church.

Megascopic description. --Rock is a very light gray (N8), well-sorted, angular to subround, medium hard, clayey, very fine-grained sandstone; limonitic stains occur around plant stems and along some cross-beds; cross-bedding is not distinct.

Petrographic description. --Rock is composed of quartz (52%); volcanic rock fragments (6%); plagioclase (oligoclase), fresh (4%); orthoclase, fresh (4%); microcline, fresh (3%); chert (2%); metamorphic rock fragments (1%); glauconite (1%); muscovite (tr); opaque minerals (tr); zircon (tr); rutile (tr); and plant fossils (tr). Matrix (27%) is clay, partly chalcedonized.

Rock. --Clayey, very fine sandstone; immature, volcanite-bearing subarkose.

No. 14. Wellborn Formation. Locality 12, Burleson County, north of Birch Creek about 800 feet northwest of measured section 18.

Megascopic description. --Rock is a yellowish-gray (5 Y 8/1), well-sorted, angular to subangular, medium hard, muddy, fine-grained sandstone. Rock is porous except in streaks of montmorillonitic clay. Limonitic stains follow some cross-beds; cross-bedding is not distinct.

Petrographic description. --Rock is composed of quartz (58%); volcanic rock fragments (4%); chert (2%); microcline, fresh (1%); plagioclase, fresh (1%); orthoclase, fresh (tr); muscovite (tr); metamorphic rock fragments (tr); stretched metaquartzite (tr); glauconite (tr); plant fossils (tr); and epidote (tr). Pore space is 17% of the rock. Matrix (17%) is montmorillonitic clay cemented locally, in two stages, by (1) chalcedony and (2) a trace of microcrystalline quartz.

Rock. --Muddy, fine sandstone; chalcedonic, immature, volcanlte subarkose.

No. 15. Wellborn Formation (MS 17, unit i). Burleson County, north of Birch Creek, half a mile east of inset 1, Plate I.

Megascopic description. --Rock is a very light gray (N8), moderately sorted, angular to subangular, soft, weakly cemented, very fine-grained sandstone containing fossil plant stems.

Petrographic description. --Rock is composed of quartz (61%); volcanic rock fragments (9%); microcline, fresh (3%); plagioclase (oligoclase), fresh (2%); shale fragments (2%); chert (tr); muscovite (tr); stretched metaquartzite (tr); volcanic glass (tr); opaque minerals (tr); glauconite (tr); zircon (tr); volcanic quartz (embayed phenocrysts) (tr); and plant fossils (tr). Pore space is 9% of the rock. Matrix (14%) is opal cement with a trace of montmorillonitic clay.

Rock. --Very fine sandstone; opaline, mature, volcanite subarkose.

No. 16. Wellborn Formation (MS 9, unit f). Burleson County, north of Yegua Creek near southern boundary of inset 2, Plate I.

Megascopic description. --Rock is a light gray (N7), moderately sorted, angular to subangular, very hard, fine-grained sandstone containing fossil plant stems; rock has irregular limonitic stains.

Petrographic description. --Rock is composed of quartz (50%); chert (3%); microcline, fresh (3%); plagioclase, fresh (3%); volcanic rock fragments (3%); muscovite (tr); glauconite (tr); and plant fossils (tr). Pore space is 6% of the rock. Matrix (32%) is opal cement.

Rock. --Fine sandstone; opaline, submature, chert-bearing, volcanite-bearing subarkose.

No. 17. Wellborn Formation. Locality 15, Burleson County, north of Yegua Creek on northwest-southeast road, about 1,500 feet north of measured section 11.

Megascopic description. --Rock is a yellowish-gray (5 Y 8/1), well-sorted, angular to subangular, medium hard, clayey, very fine-grained sandstone; it is unevenly cemented, slightly porous, and slightly montmorillonitic. Rock contains fossil plant stems and abundant platy quartz grains.

Petrographic description. --Rock is composed of quartz (49%); clay grains (5%); chert (2%); plagioclase, fresh (2%); volcanic rock fragments (2%); plant fossils (2%); microcline, fresh (1%); glauconite (1%); volcanic quartz (embayed phenocrysts) (tr); muscovite (tr); and zircon (tr). Pore space is 6% of the rock. Matrix (30%) is montmorillonitic clay, in part opalized and in part chalcedonized. A trace of microcrystalline quartz occurs as a second stage of cementation as follows: (1) chalceony, (2) microcrystalline quartz.

Rock. --Clayey, very fine sandstone; chalcedonic, immature, chert-bearing subarkose.

No. 18. Wellborn Formation. Locality 16, Burleson County, northeast end of map area at road junction.

Megascopic description. --Rock is a light gray (N7), well-sorted, angular to subangular, hard, quartzitic, very fine-grained sandstone. It contains fossil plant stems bordered with limonite. Some of the quartz grains are platy.

Petrographic description. --Rock is composed of quartz (60%); chert (5%); plagioclase (oligoclase), fresh (4%); volcanic rock fragments (2%); clay grains (2%); glauconite (1%); shale fragments (1%); muscovite (tr); metamorphic rock fragments (tr); opaque minerals (tr); zircon (tr); volcanic quartz (embayed phenocrysts) (tr); plant fossils (tr); and tourmaline (tr). Matrix (25%) is opal cement with a trace of limonite,

Rock. --Very fine sandstone; opaline, mature, chert-bearing subarkose.

No. 19. Wellborn Formation. Locality 17, Burleson County, northeast end of map area (Pl. I) about 3, 500 feet northwest of Somerville road.

Megascopic description. --Rock is a very light gray (N8) to light brownish-gray (5 YR 6/1), well-sorted, angular to subangular, clayey, very fine-grained sandstone. It is weakly cemented in general but strongly cemented locally; it has limonitic streaks; some of the quartz is platy.

Petrographic description. --Rock is composed of quartz (45%); plant fossils (5%); volcanic glass (5%); volcanic rock fragments (4%); chert (2%); plagioclase (oligoclase), fresh (2%); glauconite (2%); microcline (tr); opaque minerals (tr); and zircon (tr). Matrix (35%) is opal cement interspersed with montmorillonitic clay. One microcline overgrowth was noted.

Rock. --Clayey, very fine sandstone; opaline, chert-bearing, glauconitic, volcanite subarkose.

No. 20. Wellborn Formation. Locality 9, Burleson County, northeast end of map area (Pl. I) about 1, 500 feet northeast of area of inset 1.

Megascopic description. --Rock is a yellowish-gray (5 Y8/1), well-sorted, angular to subround, very fine-grained sandstone. Cementation is irregular, with quartzitic areas interspersed with poorly cemented, slightly porous areas. Rock contains fossil plant stems. Limonitic stains border the plant stems and also the quartzitic areas.

Petrographic description. --Rock is composed of quartz (61%); volcanic rock fragments (4%); plagioclase (andesine), fresh (3%); chert (2%); metamorphic rock fragments (2%); opaque minerals (1%); tourmaline (tr); muscovite (tr); glaucophane (tr); and epidote (tr). Pore space is 14% of the rock. Matrix (13%) is opal cement with a small amount of clay.

Rock. --Very fine sandstone; opaline, mature, chert-bearing volcanite subarkose.

No. 21. Wellborn Formation. Locality 18, Burleson County, Weiler and Whitener heavy mineral property.

Megascopic description. --Rock is a yellowish-gray (5Y7/2), well-sorted, angular to subangular, medium hard, muddy, very fine-grained sandstone. Rock has irregular limonitic stains. It contains fossil plant stems and irregular bodies of chocolate-colored montrnorillonitic clay.

Petrographic description. --Rock is composed of quartz (53%); volcanic rock fragments (6%); chert (3%); plagioclase, fresh (3%); plant fossils (3%); shale fragments (3%); microcline, fresh (1%); glauconite (1%); tourmaline (tr); muscovite (tr); volcanic glass (tr); stretched metaquartzite (tr); and opaque minerals (tr). Matrix (28%) is montmorillonitic clay with a small amount of opal cement and a trace of limonite cement.

Rock. —Muddy, very fine sandstone; opaline, immature, chert-bearing volcanite subarkose.

No. 22. Manning Formation. Washington County, 2 miles southeast of Colvin property on Burton road.

Megascopic description.--Rock is a yellowish-gray (5 Y 8/1), moderately sorted, angular to subangular, hard, glauconitic, sandy (very fine-grained) siltstone. Has conchoidal fracture.

Petrographic description. --Rock is composed of quartz (51%); glauconite (8%); chert (4%); metamorphic rock fragments (3%); orthoclase, fresh

(1%); plagioclase, fresh (1%); microcline, fresh (tr); volcanic rock fragments (tr); biotite (tr); muscovite (tr); stretched metaquartzite (tr); opaque minerals (tr); zircon (tr); and clay grains (tr). Matrix (32%) is opal cement with a trace of chlorite; a few grains are cemented by quartz overgrowths. One orthoclase overgrowth was noted.

Rock. --Very fine sandy siltstone; opaline, submature, chert-bearing, glauconite-bearing subgraywacke.

No. 23. Manning Formation. Burleson County, quarry 2 miles southwest of center of Somerville on road to Yegua Creek.

Megascopic description. --Rock is a yellowish-gray (5 Y 8/1), well-sorted, angular to subangular, hard, silty, very fine-grained sandstone. Pale yellowish-brown (10 YR 6/2) montmorillonitic clay occurs as streaks and as burrow fillings. Clay streaks have conchoidal fracture.

Petrographic description. --Rock is composed of quartz (59%); chert (3%); glauconite (2%); plagioclase, fresh (1%); plant fossils (tr); metamorphic rock fragments (tr); microcline, fresh (tr); volcanic rock fragments (tr); muscovite (tr); and stretched metaquartzite (tr). Matrix (35%) is about half opal and half chalcedony (not in paragenetic sequence). The rock is cemented locally by either opal or chalcedony but not by both in any one locality. The boundary between opal and chalcedony is sharp; some grains are bounded on one side by opal and on the other side by chalcedony.

Rock. --Silty, very fine sandstone; chalcedonic and opaline, mature, chert-bearing, glauconite-bearing orthoquartzite.

No. 24. Manning Formation. Locality 29, Lee County, south of Yegua Creek, 400 feet south of the top of measured section 7.

Megascopic description. --Rock is a yellowish-gray (5 Y 8/1), well-sorted, subangular to round, porous, weakly cemented, muddy, medium-grained sandstone. Rock is irregularly stained by limonite; clay is montmorillonitic.

Petrographic description. --Rock is composed of quartz (27%); volcanic rock fragments (14%); chert (8%); orthoclase, fresh (7%); microcline (partly altered to sericite) (6%); plagioclase (andesine), fresh (5%); clay grains (2%); and stretched metaquartzite (1%). Pore space is 10% of the rock. Matrix (20%) is montmorillonitic clay with spots of chalcedony cement and opal cement. A few quartz grains show (1) percussion marks, (2) quartz-cemented fractures in quartz grains, and (3) quartz overgrowths.

Rock. --Muddy, medium sandstone; chalcedonic and opaline, immature, chert-bearing, volcanite-bearing arkose.

Polished Sections

HM 1 [3/] Colvin, south trench. Most of the ilmenite-magnetite grains are rimmed by what is probably a mixture of oxides of iron and titanium. The grains are extensively altered to hematite along cracks and planes of parting. The cores of many grains have been altered to hematite. Less than 10 percent of the grains have very fine, closely spaced parallel blebs of hematite which is probably an alteration product of exsolved magnetite. Less than 10 percent of the grains have been altered extensively to leucoxene.

HM 4 Blackburn, surface. Same as HM 1.

HM 22 Colvin, surface. Same as HM1. Hematite alteration along cracks and in the cores of grains is slightly more extensive than in HM 1 and HM 4.

HM 21 Weiler, surface. Same as HM 1. Hematite alteration along cracks and in the cores of grains is slightly more extensive than in HM 1 and HM 4. Also, about half of the grains have thin alteration on the surface but no internal alteration at all.

HM 39 Blackburn, trench. Most grains have thin alteration on grain boundaries as in HM 1, but hematite alteration along cracks and in the cores of grains is more extensive than HM 1 (comparable to HM21 and HM22). No more than 2 or 3 percent of the grains have fine, closely spaced exsolution textures, as described in HM 1. Alteration to leucoxene is more extensive than in HM 1. About 5 percent of the grain boundaries are altered to leucoxene sufficiently to give strong internal reflections, while the cracks and cores of these same grains are altered to hematite and give considerably darker internal reflections. Several grains have been altered almost entirely to leucoxene, leaving small remnants of unaltered ilmenite inside the grain.

HM 34 Falkenberg, trench. Same as HM 39.

In all of the polished sections there are a few grains that appear to be 100 percent leucoxene. These are slightly more abundant in HM 39 and HM 34.

Although pure ilmenite has distinctly lower reflectivity than pure magnetite, in these sections

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[3/] Designations HM 1, HM 4, etc., refer to heavy mineral concentrates. (See also tables 1 and 3.)

this distinction in reflectivity cannot be made. The only remaining criteria for distinguishing ilmenite and magnetite are (1) the presence or absence of leucoxene and (2) the pattern of alteration (along basal planes in ilmenite and octahedral planes in magnetite). A few grains are altered extensively to both hematite and leucoxene. Much of the alteration both on the surface of the grains and inside the grains shows colors and internal reflections that are intermediate between leucoxene and hematite and suggests that the material may be a mixture of oxides of iron and titanium.

Measured Sections
(Pl. II)

MS 1. Road cut on road west from Ben Pietsch property, 3.4 miles southwest of Post Oak School, Lee County; outside area of Plate I.

	Thickness (feet)
Top of cuesta	
Wellborn Formation--	
(k) Massive, light gray, slightly porous, moderately hard, clayey, fine-grained sandstone; contains hard, clayey, concretionary bodies up to a foot or more in diameter; has quartzitic streaks in upper 2 or 3 feet	11.0
(j) Massive, light gray, soft, friable, lignitic, very fine- to fine-grained sandstone; contains a trace of dark minerals	13.5
(i) Light gray, poorly cemented, tough, very fine- to fine-grained sandstone with yellowish-brown streaks and spots; forms a rough semi-resistant ledge; upper weathered surface is very rough because of abundant plant stems	1.0
(h) Light gray to yellowish-brown, soft, lignitic, clayey, very fine-grained sandstone; has irregular cracks filled with lignitic debris; weathered surface is scoured between the cracks leaving lignitized cracks as slightly resistant ridges standing in high relief	6.5
(g) Light gray to yellowish-brown, soft, clayey, lignitic, silty, very fine-grained sandstone; grades upward into (h) . . .	1.0
(f) Light brown to dark brown lignitic clay shale; grades upward into (g)	11.5
(e) Light gray, moderately hard, clayey, lignitic, fine-grained sandstone; has yellowish-brown streaks and spots; contains trace of dark minerals . . .	1.0
(d) Light brown to dark brown lignitic clay shale	3.7
(c) Light gray to yellowish-gray, soft, very fine-grained sandy siltstone in layers 1 to 2 inches thick interlayered with yellowish-brown to light brown lignitic clay shale in layers 1 to 2 inches thick	5.7
(b) Lavender-gray, soft, clayey, silty, very fine- to fine-grained sandstone; hardened by silicification on exposed surfaces; contains a trace of dark minerals	2.5
(a) Light gray, soft, lignitic, clayey, silty, very fine- to fine-grained sandstone; has yellowish-brown spots and chocolate-colored plant stems; contains a trace of dark minerals; forms a low, sloping outcrop	3.7
Total thickness exposed	61.1

MS 2. Lee County.[4]

	Thickness (feet)
Top of cuesta	
Wellborn Formation--	
(j) Soft, finely banded, clayey, fine-grained sandstone with alternating light gray and yellowish-brown bands; cross-bedded	1.0
(i) Light gray, weakly cemented, fine sandstone; contains a few pelecypod molds with few details preserved; gradation to (h)	2.5

4/ Locations of measured sections 2-18 are shown on Plate I.

		Thickness (feet)
(h)	Light gray, soft, friable, fine-grained sandstone; contains a trace of dark minerals; cross-bed surfaces marked by lignitic debris; cross-beds dip southwest to west-southwest . . .	7.0
(g)	Light gray, moderately hard, clayey, very fine-grained sandstone	0.5
(f)	Light gray, soft, clayey, very fine-grained sandstone; finely banded with limonitic streaks parallel to the cross-beds; contains a trace of dark minerals; cross-beds dip west to northwest	3.0
Caddell Formation--		
(e)	Tan, lignitic, clay shale . .	3.0
(d)	Chocolate-colored, lignitic clay shale; lower 3 inches is high-grade lignite with no appreciable amount of clay .	1.0
(c)	Tan clay shale; light gray on dry surface	7.0
(b)	Chocolate-colored lignitic shale; pinches and swells within a thickness range from 1/2 foot to 2 feet for a distance of 50 feet along the outcrop	2.0
(a)	Tan clay shale; light gray on dry surface	2.0
Total thickness exposed		35.5

MS 3. Lee County.

		Thickness (feet)
Top of cuesta		
Wellborn Formation--		
(j)	Light gray to buff, soft, fine- to very fine-grained sandstone; weathers in saucer-shaped depressions 2 to 3 feet in diameter and 3 to 6 inches deep (thin section 7)	5.0
	Covered	5.0
(i)	Massive, blocky, fine-grained, sandstone; in part buff colored and soft with bluish-gray quartzite in irregular patches and along some cross-beds (thin section 6)	2.0
(h)	Light gray, soft, fine-grained sandstone	2.0
	Covered	2.0
(g)	Chocolate-colored, soft, lignitic clay shale; petrified log	1.0
(f)	Tan, soft, clay shale	0.3
(e)	Light gray, soft, fine-grained sandstone	0.6
(d)	Light gray, hard, flaggy, fine-grained sandstone	0.2
(c)	Light gray, soft, fine-grained sandstone with lignitic debris along cross-bed surfaces; contains a trace of dark minerals	2.0
(b)	Light gray, moderately hard, very fine-grained sandstone, finely banded limonitic streaks along cross-bed surfaces; contains a trace of dark minerals	0.5
(a)	Tan, soft, sandy clay shale .	2.0
Total thickness exposed		25.6

MS 4. Lee County.

		Thickness (feet)
Top of cuesta		
Wellborn Formation--		
(d)	Light gray to buff, soft, fine-grained sandstone; weathers in saucer-shaped depressions 2 to 3 feet in diameter and 3 to 6 inches deep; contains clayey nodules about 1/2 foot in diameter	2.0
(c)	(Poorly exposed) soft, light gray to buff fine-grained sandstone; ripple-marked; has very low-angle cross-beds 1/8 to 1/4 inch thick, some of which are bluish gray and are quartzitic as a result of silicification along certain cross-beds . .	1.0
	Covered	7.0
(b)	(Very poorly exposed) light gray to buff, moderately hard, very fine-grained sandstone with bluish-gray quartzitic cross-beds; has deeply weathered ripple marks	1.0
	Covered	30.0
(a)	Light gray to tan, hard, very fine-grained sandstone with limonitic streaks, plant stems, filled borings, and a trace of dark minerals; poorly exposed, outcrop littered with float; measured thickness only approximate	1.0
Total thickness exposed		42.0

MS 5. Lee County.

		Thickness (feet)
Top of cuesta		

	Thickness (feet)
Wellborn Formation--	
(p) Light gray to medium gray, quartzitic, very fine- to fine-grained sandstone; contains a trace of dark minerals and abundant silicified plant stems; has conchoidal fracture; rings when struck with a hammer; in layers 2 inches to 1 foot thick; locally, has closely spaced yellowish-brown streaks that follow cross-beds (thin section 4)	3.0
(o) Light gray to yellowish gray, soft, clayey, very fine-grained sandstone; contains a trace of dark minerals; slightly glauconitic; locally lignitic (including a petrified log at locality of measured section); weathered surface is rough and irregular (thin section 3)	11.0
(n) Light gray, siliceous, cross-bedded, very fine-grained sandy siltstone with yellowish-brown streaks, in layers 1/8 to 1/4 inch thick; interlayered with tan clay shale in layers 1/8 to 1/4 inch thick	1.0
(m) Medium gray to tan, soft, friable, silty, fine-grained sandstone; has cross-bedding and lignitic streaks; contains a trace of dark minerals . .	5.0
(l) Light gray, moderately hard, shaly, very fine-grained sandstone; splits into plates 1/8 to 1/2 inch thick; has yellowish-brown streaks; porous in part; lignitic; cross-bedded; interlayered with laminae of tan clay shale which weathers white and litters the outcrop (thin section 2)	6.0
(k) Bluish-gray, quartzitic, fine-grained sandstone (Pl. VII, A); has conchoidal fracture; has thin yellowish-brown streaks parallel to the bedding; contains a trace of dark minerals (thin section 1); surface of bed has ripple marks, plant drag marks, flattened mudballs 2 to 5 mm in diameter, and closely spaced joints (Pl. VIII, A, B); under side of some flagstones shows flow casts; shallow rill-wash channels are marked by oriented plant fragments; these channels transect the ripple marks at approximately a right angle	1.5
(j) Light gray to yellowish gray, soft, friable, fine-grained sandstone; has yellowish-brown streaks; splits into slabs 1 to 4 inches thick; has about 1 percent dark minerals; has a few imprints of small pelecypods	2.5
(i) Light gray, cross-bedded, soft, friable, fine-grained, slightly glauconitic sandstone; has yellowish-brown streaks; contains about 1 percent dark minerals; has branching fossil burrows like those made by littoral organisms such as <u>Callianassa</u> (mud shrimp) (Pls. X, B; XI, A)	11.5
(h) Light gray to yellowish-brown, moderately hard, platy, very fine-grained sandstone; splits into slabs 1/4 to 1 inch thick; very finely jointed; some of the joint blocks are hardened on exposed surfaces by silica and limonite; contains a trace of dark minerals	3.0
(g) Light gray to medium gray, soft, friable, lignitic, porous, fine- to very fine-grained sandstone; contains a trace of dark minerals; has irregular cracks (approximately 1 foot apart) filled with lignitic debris; sand has been scoured out in spaces between the cracks so that the lignitized cracks stand up as resistant ridges	7.5
(f) Light gray to yellowish-brown, hard, fine-grained sandstone; contains plant stems; has lavender-colored quartzitic streaks; contains a trace of dark minerals; occurs in layers 1 to 4 inches thick	1.0
(e) Chocolate-brown, soft, lignitic shale	1.0
(d) Greenish-brown to chocolate-brown, soft, lignitic, clayey, plastic to friable, very fine-grained sandstone	2.0
(c) Light gray, soft, friable, fine- to very fine-grained sandstone; has yellowish-brown spots and streaks; forms a slightly	

	Thickness (feet)
resistant ledge; contains a trace of dark minerals . . .	2.0
Covered	7.0
(b) Light gray, soft, lignitic, fine- to very fine-grained sandstone with a white clay matrix; yellowish-brown clay in spots and streaks; forms a poorly resistant outcrop with abundant plant stems and burrows that have been filled with sand	3.0
(a) Light gray, soft to moderately hard, fine-grained sandstone containing scattered flakes of light green mica, chocolate-colored fossil plant fragments, and a trace of dark minerals; layers are 4 inches to 1 foot thick and are interbedded with lenses of cross-bedded, soft, fine sandstone 1 to 4 inches thick; forms a resistant ledge	3.0
Total thickness exposed	70.5

MS 6. Lee County.

	Thickness (feet)
Top of cuesta	
Wellborn Formation--	
(k) Massive, light gray, quartzitic, fine-grained sandstone; contains fossil plant stems and a trace of dark minerals . .	6.0
(j) Light gray, hard, laminated, very fine-grained sandstone; splits into plates and slabs 1/4 inch to 1 inch thick	11.0
(i) Light bluish-gray, hard, quartzitic, fine-grained sandstone (Pl. VI, B); ripple marked	1.0
(h) Light gray, soft, fine-grained sandstone	13.0
Covered	5.0
(g) Brownish-gray, sandy, lignitic clay shale	6.0
(f) Light gray, moderately hard, clayey, fine-grained sandstone; contains a trace of dark minerals; forms a resistant ledge	1.5
(e) Light gray, soft, fine-grained sandstone	3.0
(d) Brownish-gray, slightly resistant, massive, lignitic, clayey, fine-grained sandstone; forms beds 6 inches to 1-1/2 feet thick	7.0
(c) Light gray, soft, fine-grained sandstone; contains a trace of dark minerals	2.0
(b) Very light gray, soft, fine-grained sandstone; contains a trace of dark minerals . . .	2.0
(a) Light gray, soft, fine-grained, massive sandstone	5.0
Total thickness exposed	61.5

MS 7. Lee County.

	Thickness (feet)
Top of cuesta	
Manning Formation (only the lowermost rocks described)--	
(m) Yellowish-gray, weakly cemented, clayey, silty, medium-grained sandstone with limonite stains in spots and streaks; locally quartzitic; contains wispy, white tuff lentils 1 to 2 inches thick in basal beds	2.0
Wellborn Formation--	
(l) Yellowish-gray, friable, clayey, fine- to very fine-grained sandstone; cross-bedded; cemented selectively along cross-beds; cross-beds in upper 1 to 2 feet are bluish-gray quartzitic sandstone (thin section 10) which intertongues with friable sandstone that weathers into saucer-shaped depressions (Pl. X, A) . . .	15.0
(k) Light gray, friable, fine-grained sandstone containing wispy lentils of soft, light gray, fine sandstone, cross-bedded	4.0
(j) Tan, moderately hard, clay shale	1.0
(i) Sandstone, same as (k) . . .	3.0
(h) Shale, same as (j)	1.0
(g) Sandstone, same as (k) . . .	2.0
(f) Chocolate-colored, soft, lignitic clay shale; yellow powdery mineral in cracks and along planes of parting is probably jarosite or copiapite	0.5
(e) Dark brown, soft, clayey lignite and lignitic clay	2.0
(d) Light gray, moderately hard, fine-grained sandstone; slightly glauconitic; cross-bedded at very low angle; splits into plates 1/8 inch thick (thin section 9)	2.0
(c) Light gray, soft, fine-grained	

	Thickness (feet)
sandstone; lignitic, cross-bedded; has a few very small channel conglomerates 4 or 5 inches thick with lateral extent not greater than 10 feet; contains a trace of dark minerals	10.0
(b) Light gray, moderately hard, fine-grained sandstone with quartzitic cross-beds and 1 to 2 percent dark minerals (thin section 8); slightly glauconitic; forms a cuesta; site of the heavy mineral concentrations on the Colvin property; contains petrified wood with filled borings like those made by shipworms (Teredo)	2.0
(a) Light gray, soft, friable, fine-grained sandstone; glauconitic in upper 1 to 2 feet; contains filled burrows averaging 1/2 inch in diameter	4.0
Total thickness exposed	48.5

MS 8. Burleson County.

	Thickness (feet)
Top of cuesta	
Wellborn Formation--	
(e) Gray to brownish-gray, hard, fine-grained sandstone; contains many white grains . . .	2.0
(d) Light gray, soft, fine-grained sandstone	3.0
Covered	35.0
(c) Dark brown, clayey lignite .	2.0
(b) Very pale bluish-gray, hard, very fine-grained sandstone; contains fossil plant stems and a trace of dark minerals . .	1.0
Caddell Formation--	
(a) Buff, soft, lignitic, clayey, fine-grained sandstone . . .	2.0
Total thickness exposed	45.0

MS 9. Burleson County.

	Thickness (feet)
Top of cuesta	
Wellborn Formation--	
(f) Gray to brownish-gray, hard, fine-grained sandstone; slightly glauconitic; contains many white grains (thin section 16).	1.5
(e) Light gray, soft, fine-grained sandstone	2.0
Covered	31.0
(d) Chocolate-colored, soft, lignitic, sandy mudstone	12.0
(c) Dark brown, lignitic clay . .	3.0
(b) Very pale bluish-gray, hard, very fine-grained sandstone; contains fossil plant stems and a trace of dark minerals . .	1.0
Caddell Formation--	
(a) Buff, soft, lignitic, clayey, fine-grained sandstone . . .	3.0
Total thickness exposed	53.5

MS 10. Burleson County.

	Thickness (feet)
Top of cuesta	
Wellborn Formation--	
(f) Brown, soft, lignitic clay shale	2.5
(e) Chocolate-colored, hard, very fine-grained sandstone containing abundant plant stems; cross-bedded at very low angle; cross-bed units are wavy, irregular slabs 2 to 4 inches thick that form shallow synclines	1.5
(d) Buff, cross-bedded, soft, very fine-grained sandstone .	2.5
(c) Chocolate-colored, cross-bedded, lignitic, very fine-grained sandstone	2.0
(b) Tan to light brown, medium hard, very fine-grained sandstone	1.5
Caddell Formation--	
(a) Buff, soft, lignitic, clayey, fine-grained sandstone . . .	10.0
Total thickness exposed	20.0

MS 11. Burleson County.

	Thickness (feet)
Side of hill	
Wellborn Formation--	
(g) Dark brown, lignitic shale . .	1.0
(f) Light gray to buff, hard, flaggy, very fine-grained sandstone; interbedded with lignitic shale	1.0
(e) Light gray to buff, soft, lignitic, very fine-grained sandstone	2.0
(d) Tan to chocolate-colored moderately hard, flaky, clay shale; weathers very light gray and litters the outcrop with	

	Thickness (feet)
flakes	1.0
(c) Same as (e)	5.0
(b) Buff, hard, very fine-grained sandstone with pale lavender, quartzitic masses (Pl. IV, B); contains abundant filled burrows averaging 1/2 inch in diameter; weathered upper surface covered by randomly oriented plant stems and stem casts	2.0
Caddell Formation--	
(a) Light gray to buff, lignitic, soft, clayey, very fine-grained sandstone; filled burrows averaging 1/2 inch in diameter	6.0
Total thickness exposed	18.0

MS 12. Burleson County.

	Thickness (feet)
Rim of gully	
Wellborn Formation--	
(i) Buff, slabby, moderately hard, lignitic, cross-bedded, very fine-grained sandstone; has limonitic streaks; burrows averaging 1/2 inch in diameter filled with sand and tan clay	0.5
(h) Light gray, soft, lignitic, very fine-grained sandstone; cross-bedded with limonitic streaks along cross-beds	1.0
(g) Buff, slabby, moderately hard, lignitic, cross-bedded, very fine-grained sandstone with limonitic streaks	0.5
(f) Light gray, soft, lignitic, fine- to very fine-grained sandstone; has limonitic streaks along cross-beds	2.5
(e) Dark brown, lignitic shale interbedded with tan clay shale; contains selenite crystals	1.0
(d) Light gray, soft, cross-bedded, very fine-grained sandstone	2.3
(c) Dark brown lignite	0.1
(b) Tan clay shale	0.2
(a) Same as (d)	1.3
Total thickness exposed	9.4

MS 13. Burleson County.

	Thickness (feet)
Top of cuesta, east side of road	
Wellborn Formation--	
(j) Light gray to medium gray, hard, very fine-grained sandstone; contains abundant plant stems and a trace of dark minerals	3.0
Caddell Formation--	
(i) Light gray, soft, very fine-grained sandstone with thin lentils of tan clay shale	3.3
(h) Dark brown lignite	0.1
(g) Same as (i)	3.0
(f) Same as (h)	0.1
(e) Light gray, soft, very fine-grained sandstone; lower 2 feet cross-bedded; contains lentils of tan clay shale	4.0
(d) Light gray, moderately hard, very fine-grained sandstone; lenticular	0.1
(c) Light gray, soft, very fine-grained sandstone; cross-bedded; contains wispy streaks of tan clay shale	1.0
(b) Light gray to buff, moderately soft, very fine-grained sandstone; fills channels and other irregularities in the upper surface of the underlying shale	0.5
(a) Tan, soft clay shale	0.5
Total thickness exposed	15.6

MS 14. Burleson County.

	Thickness (feet)
Side of gully	
Wellborn Formation--	
(e) Light gray, moderately hard, fine-grained sandstone	0.5
(d) Tan, soft, sandy clay shale	3.5
(c) Chocolate-colored, sandy, lignitic shale	2.5
(b) Light gray to buff, moderately hard, fine-grained sandstone in layers 4 to 6 inches thick; quartzitic locally	2.0
Caddell Formation--	
(a) Light gray, soft, clayey, fine-grained sandstone	8.0
Total thickness exposed	16.5

MS 15. Burleson County.

	Thickness (feet)
Side of gully	
Wellborn Formation--	
(e) Chocolate-colored, soft, lignitic shale	1.2

	Thickness (feet)
(d) Dark brown lignite	0.2
(c) Same as (e)	1.0
(b) Light gray, moderately hard, fine-grained sandstone; more than 2 percent dark minerals; glauconitic; quartzitic locally; has abundant lignitic debris along bedding planes; bed has very irregular rolling surface; in layers 4 to 6 inches thick .	2.0
Caddell Formation--	
(a) Tan, sandy clay shale; crudely interlaminated with soft, buff, clayey, fine- to very fine-grained sandstone	2.0
Total thickness exposed	6.4

MS 16. Burleson County.

	Thickness (feet)
Side of low hill	
Wellborn Formation--	
(c) Light gray, moderately hard, very fine-grained sandstone .	1.5
Covered	17.0
(b) Light gray to buff, hard, flaggy, fine- to very fine-grained sandstone	1.5
Caddell Formation--	
(a) Light gray to buff, soft, clayey, very fine-grained sandstone	6.0
Total thickness exposed	26.0

MS 17. Burleson County.

	Thickness (feet)
Side of gully	
Wellborn Formation--	
(j) Light gray, soft, fine- to very fine-grained sandstone interlaminated with tan to chocolate-colored clay shale . . .	5.0
(i) Light gray, moderately hard, flaggy, very fine-grained sandstone; slightly glauconitic; contains plant stems (thin section 15)	0.7
(h) Buff, soft, very fine- to fine-grained sandstone with wispy lentils of tan, soft clay shale	2.0
(g) Light gray to tan, clayey, moderately hard, shaly, fine- to very fine-grained sandstone; in slabs and plates 1/4 to 1/2 inch thick	0.8
(f) Same as (h)	1.0
(e) Buff, moderately soft, fine- to very fine-grained sandstone	0.5
(d) Buff to tan, soft, sandy clay shale	1.0
(c) Chocolate-colored, soft, clayey, fine- to very fine-grained sandstone	2.5
(b) Buff, hard, fine- to very fine-grained sandstone; contains plant stems and the petrified root buttresses of a tree in growth position	2.0
Caddell Formation--	
(a) Buff, soft, clayey, fine- to very fine-grained sandstone .	1.5
Total thickness exposed	17.0

MS 18. Burleson County.

	Thickness (feet)
Top of cuesta, road cut	
Wellborn Formation--	
(l) Light gray, moderately hard, very fine-grained sandstone; slightly glauconitic; splits into slabs 3 to 4 inches thick (thin section 13)	0.7
Covered	1.5
(k) Light gray, platy, sandy shale; slightly glauconitic; splits into plates 1/8 to 1/2 inch thick; plates litter the outcrop (thin section 12)	2.5
(j) Light gray to buff, soft, fine- to very fine-grained sandstone; cross-bedded; has lentils of light gray, soft, very fine-grained sandstone 1 to 3 inches thick near top	3.0
(i) Buff, soft, very fine-grained sandstone interspersed with tan, soft clay shale which splits into plates 1/8 to 1 inch thick; has abundant lignite laminae 1/8 inch thick . . .	4.0
(h) Tan clay shale interbedded with lentils of soft, light gray siltstone up to 1 inch thick . .	1.5
(g) Tan clay shale which weathers light gray; interbedded with lentils of light gray, soft siltstone up to 1 inch thick . . .	0.2
(f) Finely laminated light gray and chocolate-colored very fine-grained sandstone	0.3
(e) Tan clay shale which weathers light gray	0.1
(d) Buff, soft, very fine-grained	

	Thickness (feet)
sandstone	0.7
(c) Tan clay shale; weathers light gray.	2.0
Covered: light gray soil, 3 feet; dark brown soil, 4 feet .	7.0
(b) Very light bluish-gray, quartzitic, fine-grained sandstone; slightly glauconitic; has brown stains, plant stems, and a trace of dark minerals; in layers 4 to 6 inches thick (thin section 11)	2.0
Caddell Formation--	
(a) Light gray, soft, clayey, very fine-grained sandstone . . .	2.0
Total thickness exposed	27.5

PLATES III - XI

PLATE III

A. Characteristic topography on the Caddell Formation, Whitener property, Burleson County, Texas; locality 22.

B. Resistant basal sandstone of the Wellborn Formation underlain by soft, laminated, clayey sandstone of the Caddell Formation. Northwest corner of the Falkenberg heavy mineral property, Burleson County, Texas, looking east; locality 15.


A

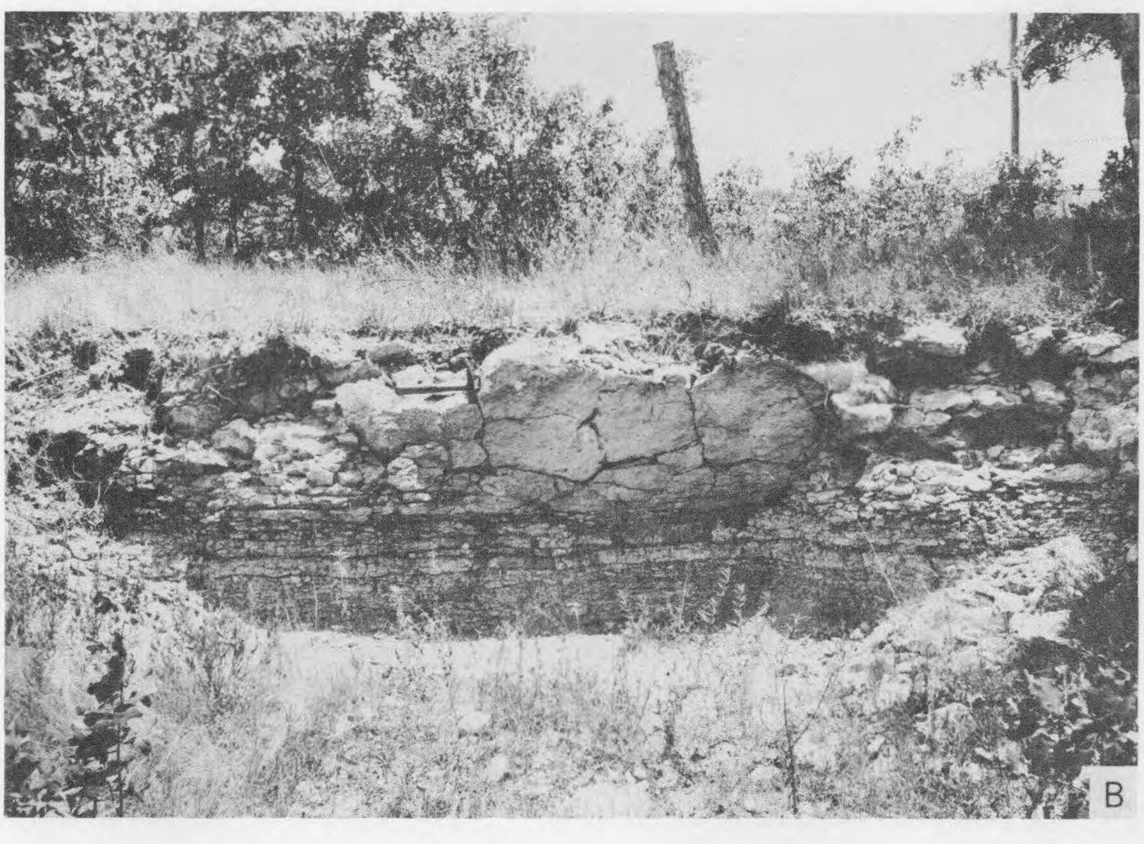
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PLATE IV

A. Cross-bedded basal sandstone of the Wellborn. Formation underlain by soft, clayey sandstone of the Caddell Formation. Flagstone surfaces follow cross-bedding. Southeastern part of Colvin property, Lee County, Texas, looking east; near locality 4.

B. Resistant basal sandstone of the Wellborn Formation underlain by soft, clayey sandstone of the Caddell Formation. East side of the Falkenberg heavy mineral property, Burleson County, Texas, looking northeast; locality 6.

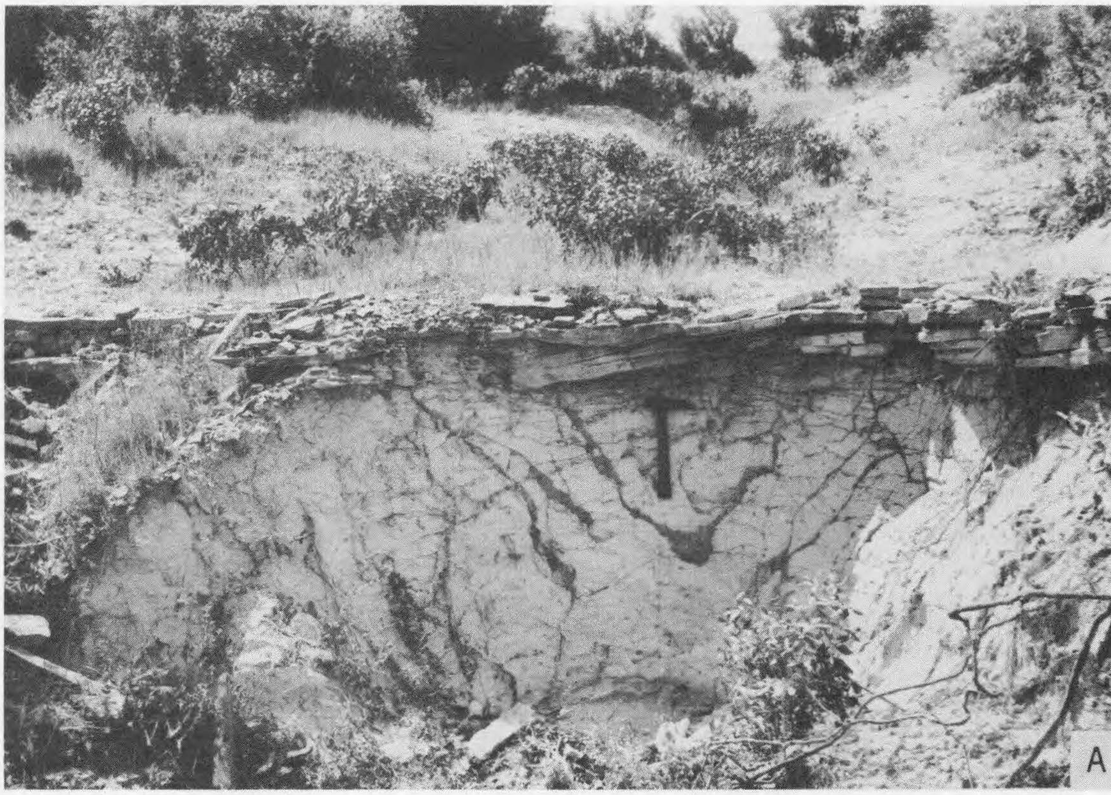
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PLATE V

A. Basal Wellborn sandstone showing local change in dip. On the southern part of the Colvin property, Lee County, Texas, looking east; near locality 4. Left: flat-lying beds. Right: beds dipping 10 degrees toward the lower right.

B. Cross-bedding in the Manning Formation. East of the Colvin property, Lee County, Texas, looking north; locality 20.

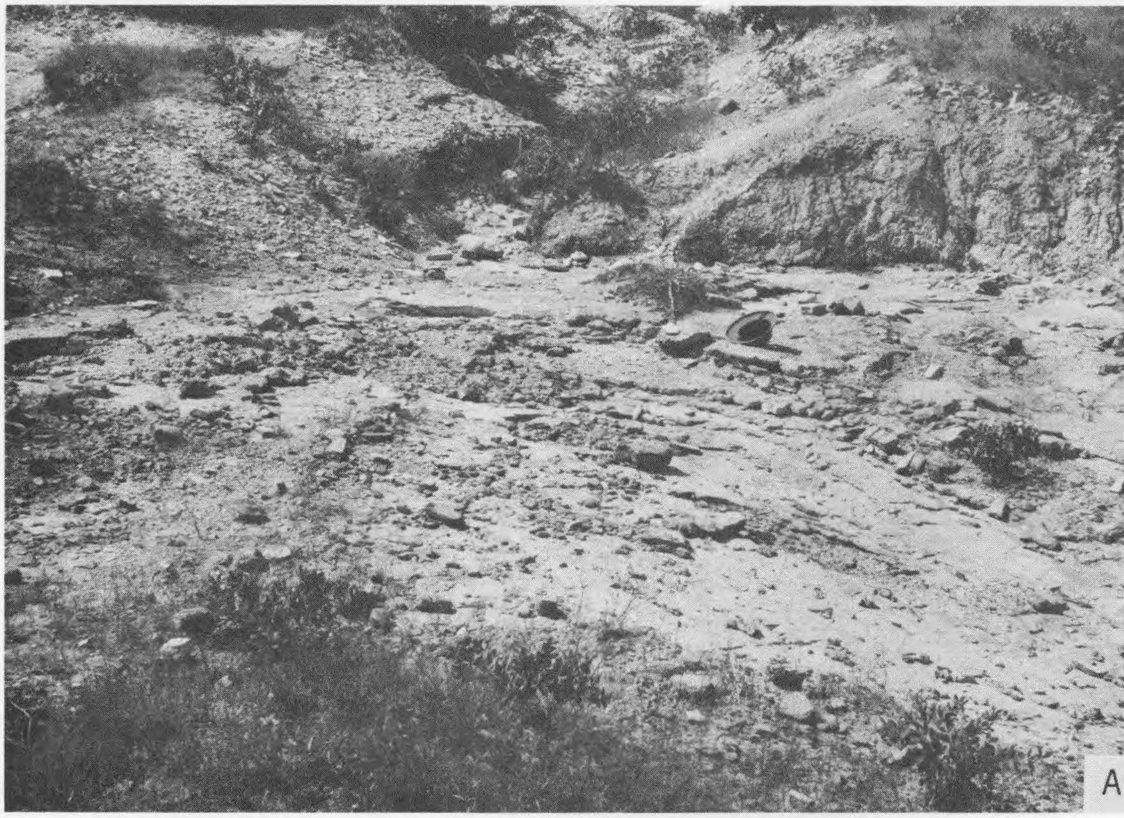
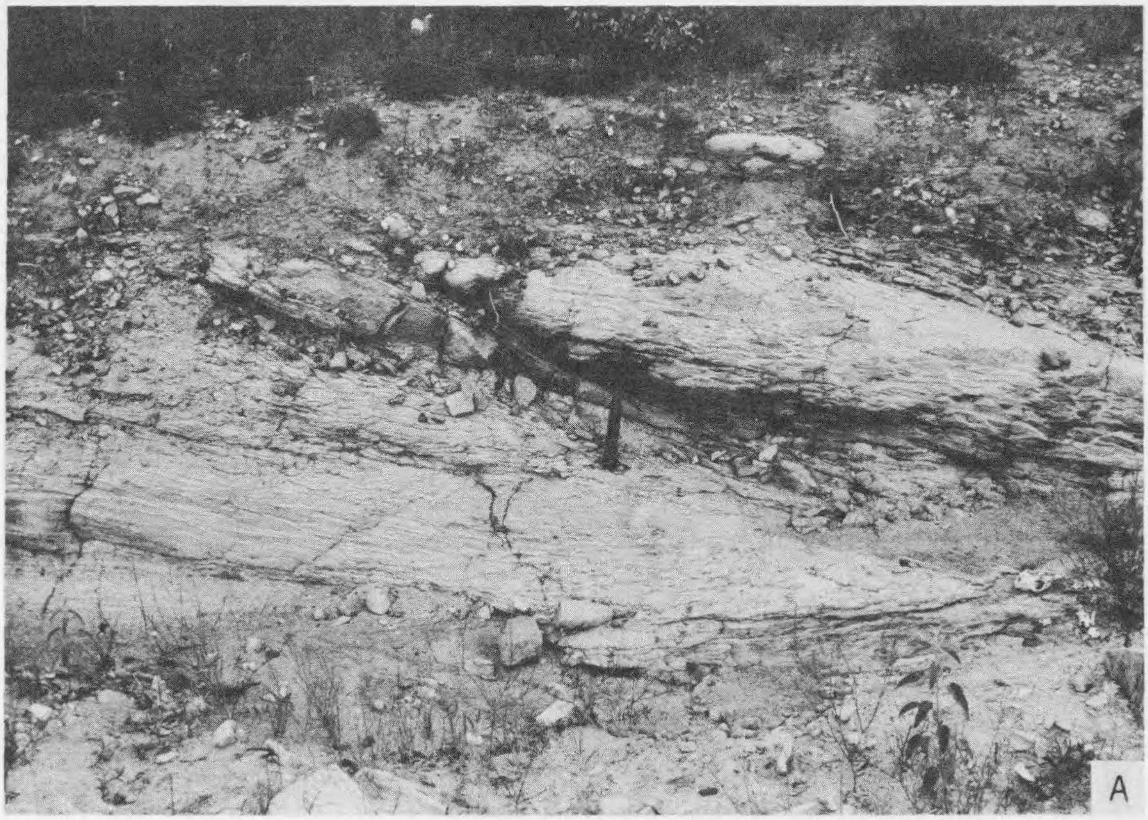


PLATE VI

A. Sandy clay (light gray streaks) along ripple laminae in medium-grained sandstone of Manning Formation. East of the Colvin property, Lee County, Texas, looking north; locality 20.

B. Manning sediments filling a channel in the upper part of the Wellborn Formation. East of the Colvin property, Lee County, Texas, looking northeast; locality 20. Fine-grained, bluish-gray, quartzitic subarkose (Wellborn), lower right, is in lateral contact with soft, silty, medium-grained arkose (Manning), upper left. Note cross-beds in the channel dipping toward the left.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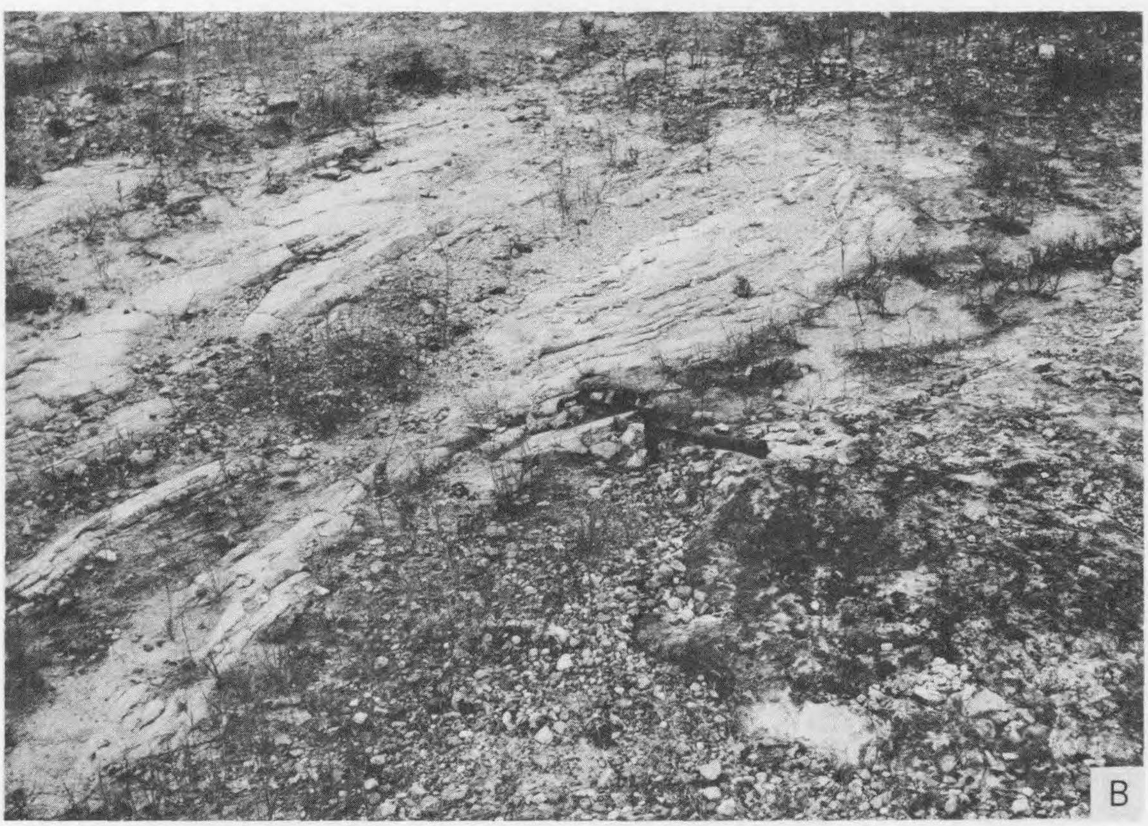
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PLATE VII

A. Sandstone in the Wellborn Formation (units (i), (j), and (k) of measured sections) on the old road west of St. Mary Church, Lee County, Texas, looking southwest; locality 19.

B. Plant drag marks, wave ripple marks, and joints in the Wellborn Formation (unit (k) of measured section 5).


k
j
i
A

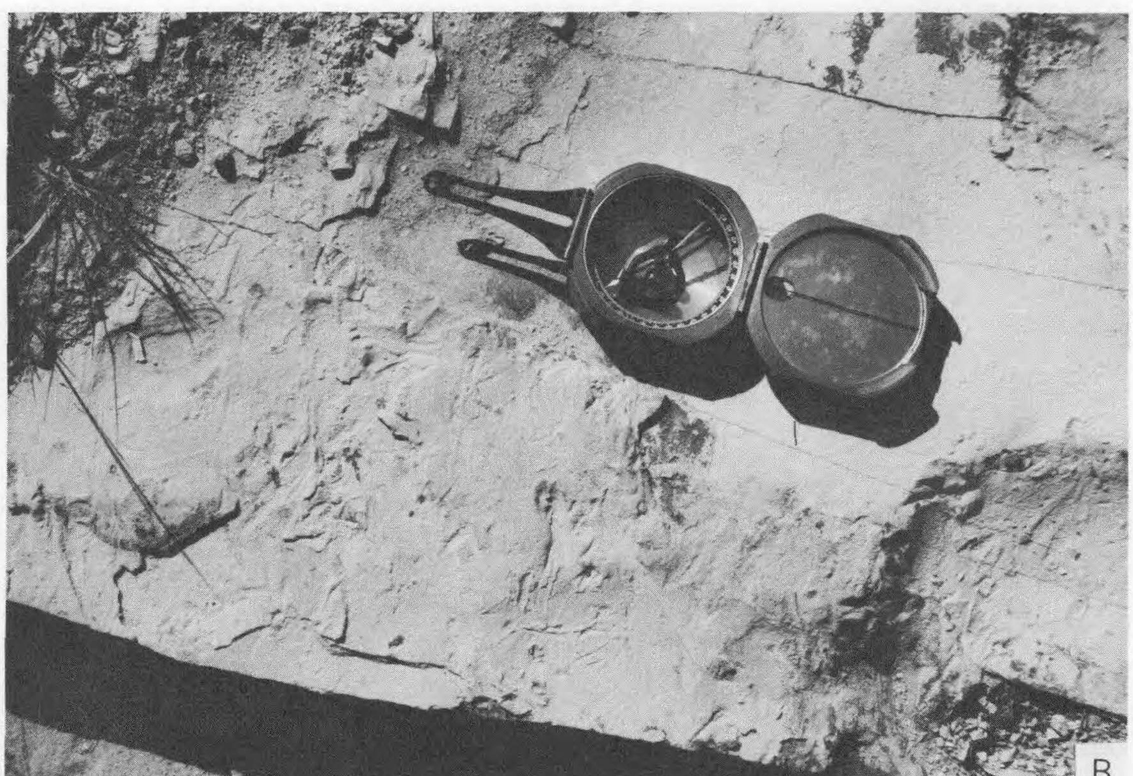
B

PLATE VIII

A. Wave ripple marks in the Wellborn Formation (unit (k) of measured section 5). See also Plate VII, A.

B. Current ripple marks with joints in the troughs of the ripples in the Wellborn Formation. Southwest part of the Colvin property, Lee County, Texas; near locality 4.

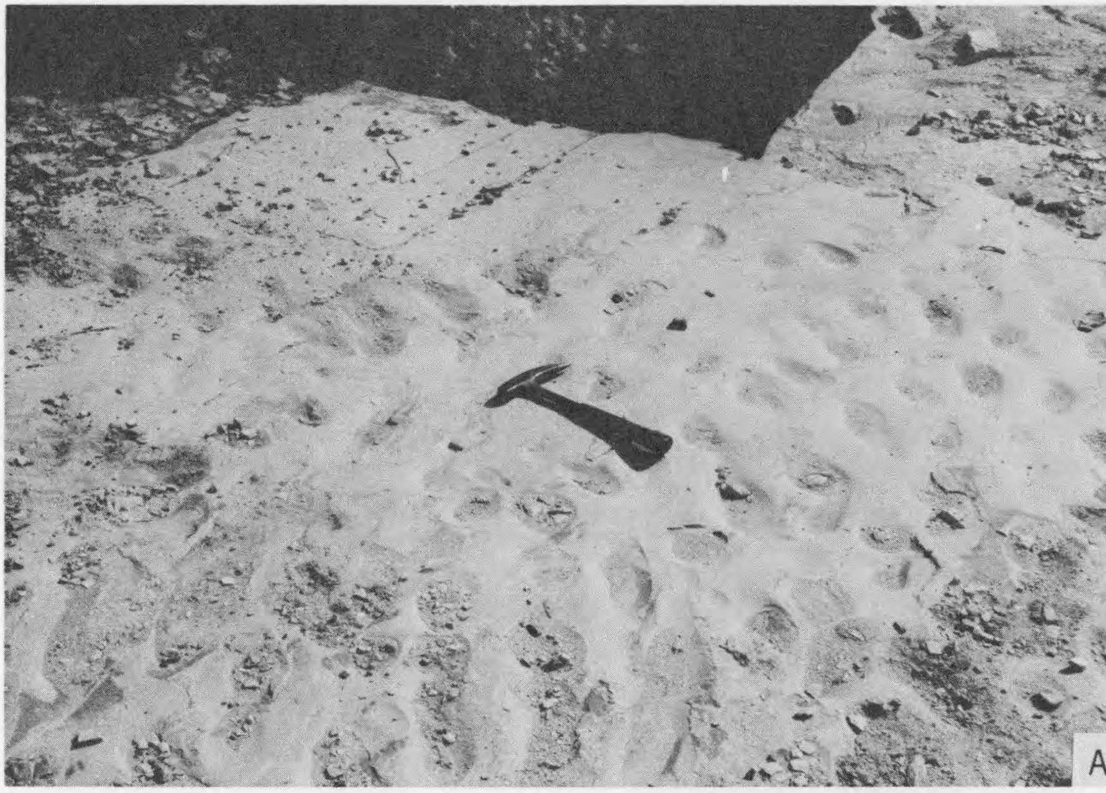
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PLATE IX

A. Quartzite in the upper part of the Wellborn Formation on the Colvin property, Lee County, Texas, looking southwest; locality 21.

B. Fine-grained Wellborn quartzite (right of hammer), traced along outcrop from locality of (A), in abrupt lateral contact with soft, clayey, fine-grained sandstone in the same bed (left of hammer) at locality 10 on the southern part of the Colvin property, Lee County, Texas, looking west.


A


B

PLATE X

A. Saucer-shaped weathering feature in soft sandstone on top of the Wellborn cuesta; near locality 10 on the southern part of the Colvin property, Lee County, Texas.

B. Filled burrow similar to that made by the mud shrimp Callianassa. Wellborn Formation (unit (i) of measured section 5), on the old road west of St. Mary Church, Lee County, Texas; locality 19.

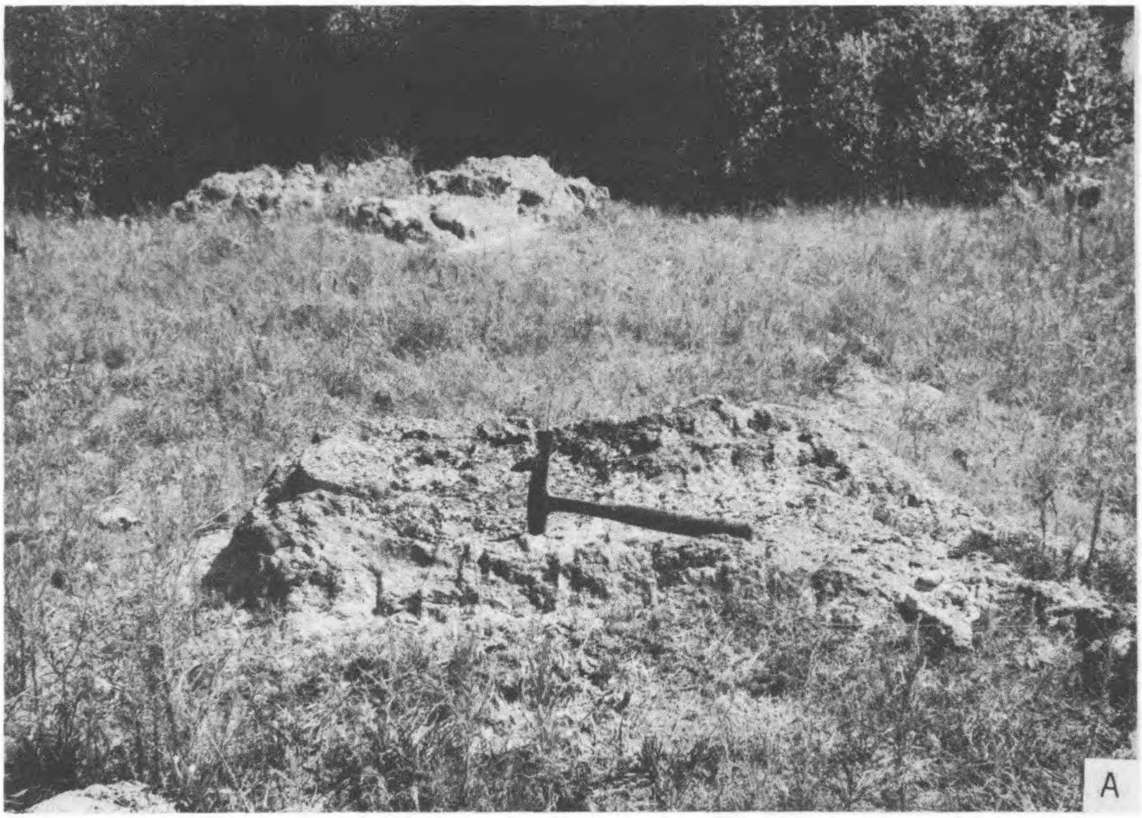
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PLATE XI

A. Filled burrows in the Wellborn Formation (unit (i) of measured section 5) on the old road west of St. Mary Church, Lee County, Texas; locality 19.

B. Fluvial bedding in the Wellborn Formation on the northern part of the Colvin property, Lee County, Texas, looking south. Near measured section 7, locality 2.


A


B

INDEX

*Entries marked by an asterisk are terms that appear many times in the petrographic descriptions (p. 17).