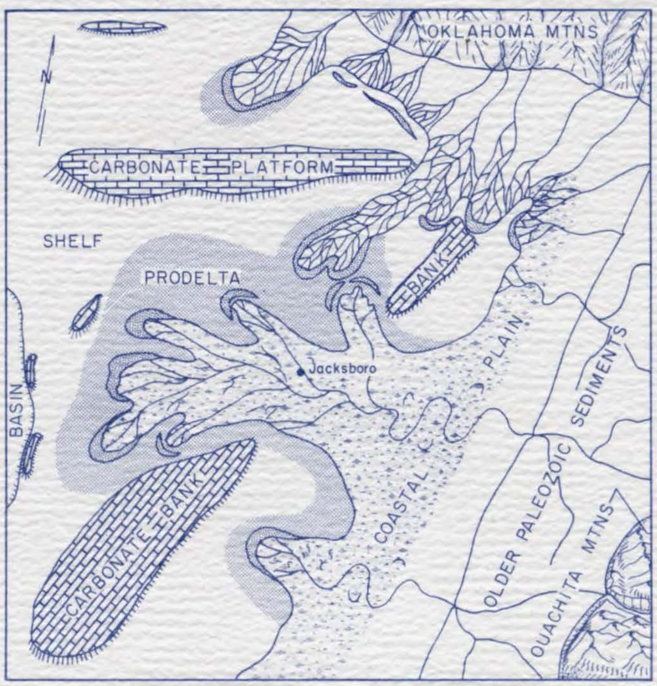
Report of Investigations-No. 82

Depositional Systems in Canyon Group (Pennsylvanian System), North-Central Texas

by Albert W. Erxleben



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by

Albert W. Erxleben[1]

ABSTRACT

The Canyon Group (Missourian Series) is a sequence of westward-dipping, genetically related carbonate and terrigenous clastic facies that crop out in a northeast-southwest belt across North-Central Texas. The section includes stratigraphic units between the base of the Palo Pinto Limestone and the top of the Home Creek Limestone.

Surface and subsurface studies within thirteen counties indicate that the terrigenous clastic rocks are principally component facies of high-constructive delta systems. The Perrin delta system repeatedly prograded westward and northwestward from source areas in the Ouachita foldbelt. Algal-crinoid banks flanked the Perrin delta system on the northeast and southwest. A typical vertical deltaic sequence includes (upward) (a) organic-rich prodelta mudstone, devoid of invertebrate fossils; (b) thin, distal delta-front sandstone and mudstone, displaying graded beds, sole marks, and flow rolls; (c) thicker proximal delta-front sandstone, exhibiting contorted beds, flow rolls, and contemporaneous faults; (d) locally contorted distributary-mouth bar sandstone; and (e) distributary channel sandstone, containing abundant trough cross-stratification and local clay-chip conglomerate. Thin, coal-bearing delta-plain deposits occur locally on top of deltaic sequences. All delta facies are rich in plant debris.

During delta abandonment and destruction, shallow bay-lagoon environments developed. Destructional facies include bioturbated sandy mudstone, burrowed sandstone, and thin, platy argillaceous limestone with abundant invertebrate fossils. Fossiliferous mudstone facies grade upward into transgressive shelf-carbonate facies commonly composed of phylloid algal-crinoid biomicrudite and local intraclastic biosparite shoal facies. Shelf carbonates include onlapping sheetlike deposits, thick, elongate bank deposits which stood above the sea floor with slight bathymetric relief, massive platform carbonate, and shelf-edge reef-bank accumulations.

The Henrietta fan-delta system, occurring exclusively in the subsurface of Montague, Clay, Wichita, Archer, and Baylor Counties, is composed of thick wedges of feldspathic sandstone and conglomerate that were deposited by high-gradient fluvial systems which built southwestward into northern Texas from source areas in the Wichita-Arbuckle Mountains of southern Oklahoma.

INTRODUCTION

The Canyon Group is a sequence of Upper Pennsylvanian (Missourian Series) limestone, sandstone, and shale facies comprising delta, fan-delta, and shelf-carbonate depositional systems. The group crops out in a northeast-southwest-trending belt across North-Central Texas and dips 40 to 50 feet per mile westward into the Midland Basin.

Deltas repeatedly prograded westward across the Eastern Shelf, supplied by rivers which originated in the Ouachita Mountains. At times, deltaic sedimentation was contemporaneous with nearby carbonate-bank growth. Abandoned delta lobes were transgressed by extensive shelf-carbonate facies. A variety of platform and shelf-edge carbonate units accumulated in the absence of significant terrigenous sediment input. Fan deltas built southwestward into Texas, supplied by high-gradient streams originating in the Wichita-Arbuckle Mountains of Oklahoma.

Facies analysis provides insight into the nature of depositional environments of the Canyon Group; delineation of depositional systems documents the Missourian paleogeography of North-Central Texas.

The area investigated (fig. 1) includes about 12,000 square miles of all or parts of Palo Pinto,

[1] Exxon Co., U. S. A., Houston, Texas

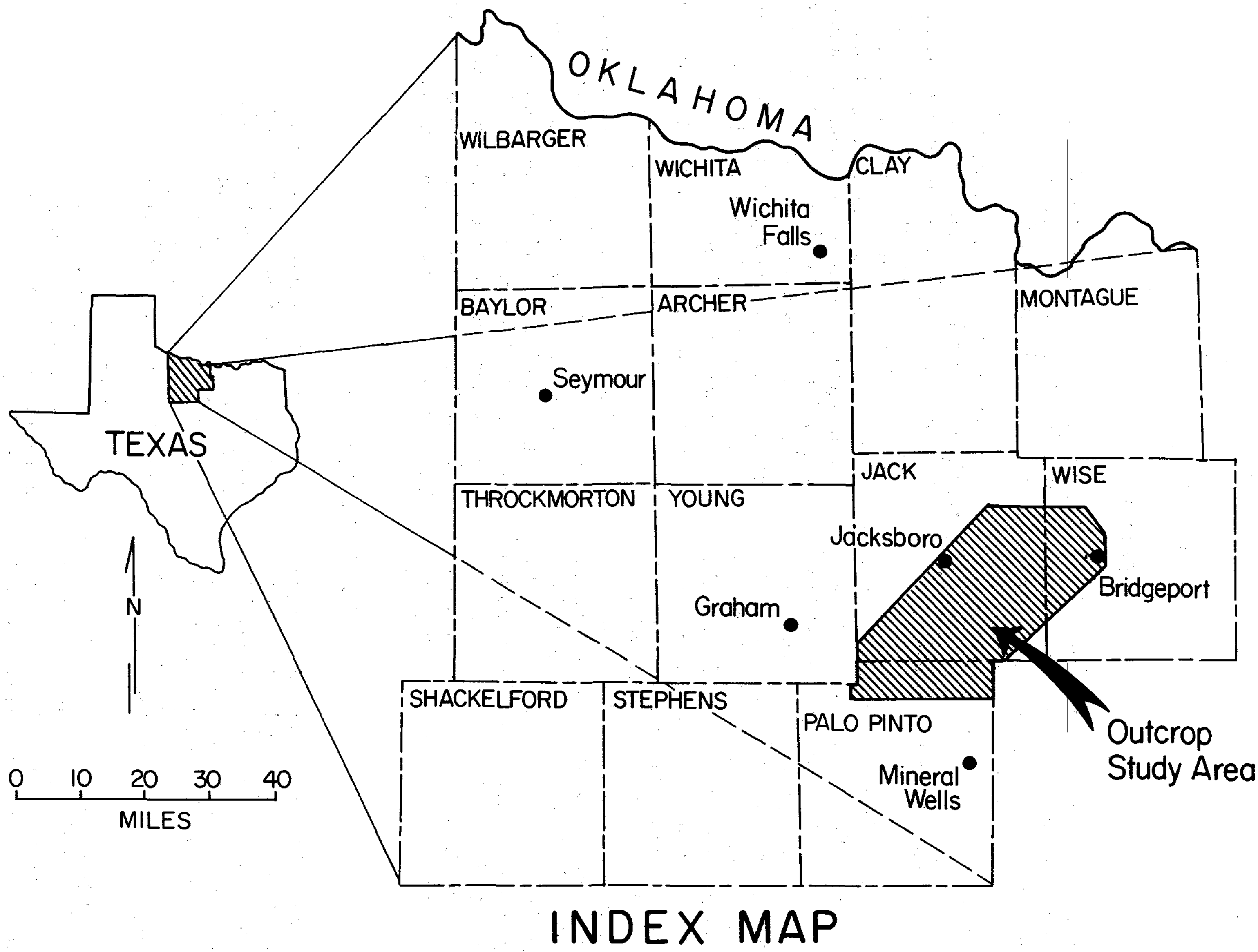

Figure 1. Location map showing study areas of both surface and subsurface Canyon Group in North-Central Texas.

Jack, Wise, Montague, Clay, Wichita, Archer, Young, Stephens, Shackelford, Throckmorton, Baylor, and Wilbarger Counties. Surface studies were concentrated in northern Palo Pinto, southeastern Jack, and western Wise Counties. Exposures of terrigenous clastic rocks were examined as far south as Rising Star in southern Eastland County.

The study was initiated to define, delineate, and explain the principal terrigenous clastic facies of the Canyon Group and to relate these systems to a variety of contemporaneous carbonate facies. The work was based on a rock-stratigraphic framework, and interpretations are lithogenetic.

The concept of *depositional systems* as defined by Fisher and others (1969, p. 10) comprises ". . . assemblages of process-related sedimentary facies. As such they are the stratigraphic equivalents to geomorphic or physiographic units." Depositional systems are informal rock-stratigraphic units characterized by assemblages of facies which are genetically linked by inferred depositional environments and associated processes. Recognition of depositional systems in ancient deposits is based firmly on Holocene analogues—applying what is known about modern depositional environments and processes to interpretation of the rock record.

METHODS OF STUDY

The outcrop mapping is based on stereographic aerial photographs with scale of 1:60,000 and extensive field checking. A geologic map (pl. I) was constructed using a county highway map base at a scale of 1:125,000. Forty-two sections were measured and described; critical outcrops were photographed and described in detail.

Subsurface studies involved use of 1,570 electric and sample logs in the construction of net-sandstone and net-limestone thickness maps for each of six Canyon Group formations. Net sandstone was interpreted and tabulated for the intervals between limestone marker units. Gross limestone thickness totals were obtained from the logs, and interbedded mudstone was subtracted to give net limestone. Thickness maps were prepared at a scale of 1 inch equals 16,000 feet and were later reduced to half-scale for reproduction. Eight subsurface cross sections were constructed from electric and sample logs. Two cores through the Chico Ridge Limestone in northwestern Wise County (cores and descriptions are from Erxleben (1974) and are on open file at the Bureau of Economic Geology) were described to provide a continuous sequence of unweathered carbonate facies.

ACKNOWLEDGMENTS

Many people made this study possible. L. F. Brown, Jr., Bureau of Economic Geology, The University of Texas at Austin, suggested the project and provided guidance throughout the investigation. J. H. McGowen and E. G. Wermund, Bureau of Economic Geology, Earle F. McBride and Arthur Cleaves, Department of Geological Sciences, The University of Texas at Austin, and B. H. Wilkinson, University of Michigan at Ann Arbor, provided criticism and advice. Land owners of Jack, Wise, and Palo Pinto Counties generously provided access to private property.

Barbara K. Hartmann and Roy Ferguson drafted several illustrations. J. W. Macon, Cartographer, Bureau of Economic Geology, supervised final preparation of illustrations. Karen White edited the manuscript; Fannie Sellingsloh and Dawn Weiler handled composition for the report. Thanks are extended to my parents, Mr. and Mrs. A. W. Erxleben, and especially to my wife, Charlotte.

PREVIOUS INVESTIGATIONS AND STRATIGRAPHIC TERMINOLOGY

Pennsylvanian strata in North-Central Texas were first studied by Tarr (1890), Cummins (1891), Dumble (1892), and Drake (1893) in investigations of the coalfields of the Colorado and Brazos River valleys. Cummins (1891) applied the names Bend, Millsap, Strawn, Canyon, Cisco, and Albany divisions. The Canyon division was named for Canyon station on the Texas and Pacific Railway, approximately 4 miles west of the town of Strawn in Palo Pinto County. Cummins (1891) placed the base of the Canyon division at the base of the first prominent limestone and the top of the division at the top of the uppermost prominent limestone in the Brazos River valley.

Plummer and Moore (1921) assigned lithostratigraphic names, including, in ascending order, Palo Pinto Limestone, Wolf Mountain Shale, Winchell Limestone, Placid Shale, Ranger Limestone, Colony Creek Shale, and Home Creek Limestone (fig. 2). The Canyon division of Cummins was replaced by Canyon Group, retaining the original rock-stratigraphic definition used by Cummins. The base of the Canyon Group was defined as the base of the Palo Pinto Limestone; the top of the Home Creek Limestone marks the top of the Canyon Group (Plummer and Moore, 1921). Thick limestone units and interstratified clastic facies of the Canyon Group are underlain and overlain by thick, predominantly clastic rocks of the Strawn and Cisco Groups.

Scott and Armstrong (1932) proposed new stratigraphic names for the Canyon Group of Wise County in the northern Trinity River valley (fig. 2). Plummer and Hornberger (1935) described the geology of Palo Pinto County and included a map of the rock units of the Canyon Group. Lee and others (1938) published significant stratigraphic and paleontologic studies of Pennsylvanian and Permian rocks in North-Central Texas, including a section on stratigraphy and paleontology of the Canyon Group.

Cheney (1940, 1945, 1947) proposed a time-stratigraphic classification for North-Central Texas Pennsylvanian rocks in which he equated the Strawn, Canyon, and Cisco Groups with the Desmoinesian, Missourian, and Virgilian Series of the midcontinent area. Group boundaries were adjusted up or down to coincide with faunally inferred time boundaries; many of these boundaries were not mappable (Brown, 1959). The base of the Missourian Series did not correspond to the defined rock-stratigraphic base of the Canyon Group, but was established by the first occurrence of Missourian fossils including fusulinids of the genus *Triticites*. Based on the first occurrence of Virgilian fusulinids, Cheney accepted the Home Creek Limestone as the top of the Missourian Series.

Guidebooks and articles by the Abilene Geological Society (1954), North Texas Geological Society (1940, 1956, 1958), and West Texas Geological Society (1951) have contributed to the knowledge of Canyon stratigraphy. Recent studies include those of Eargle (1960), Terriere (1960), Laury (1962), Feray and Brooks (1966), Brooks and Bretsky (1966), Feray and Jenkins (1953), and Bretsky (1966). Perkins (1964) mapped the Canyon Group of south-central Jack County; Raish (1964) described and interpreted the petrology of the Chico Ridge Limestone in western Wise County; and Pollard (1970) investigated the Winchell Limestone near Lake Possum Kingdom (northwestern Palo Pinto County) placing emphasis on the role of phylloid algae in carbonate-bank evolution. Heuer (1973) studied paleoecologic relationships in the Wolf Mountain Shale of the Lake Possum Kingdom area. Significant lithofacies studies of the Canyon Group were completed by Wermund (1966, 1969), Wermund and Jenkins (1968, 1969, 1970), and Brown and Goodson (1972).

TECTONIC SETTING

During Missourian time (fig. 3) prominent mountainous uplands of the region included the Ouachita foldbelt on the east and the Amarillo-Wichita-Arbuckle Mountains to the north. To the south, the Llano uplift may have stood as a group of intermittently emergent islands of modest relief. The Matador Arch - Red River uplift - Muenster Arch system extended across North Texas in a series of local, structurally high areas underlain by buried granitic basement. The Red River uplift of northern Clay, northern Wichita, and central Wilbarger Counties was the site of a stable carbonate platform during Missourian time; this east-west arch system persisted primarily as a result of stability and nonsubsidence of its granite core rather than of anticlinal uplift (Wilson, 1952).

The Bend Arch extended northward from the Llano uplift in the form of a broad, northward-plunging flexure. Cheney (1929) considered the Bend Arch to be a hinge between the Fort Worth and Midland Basins (fig. 3). During Late Mississippian and Early Pennsylvanian times, the Fort Worth Basin subsided as a foreland basin along the western margin of the Ouachita foldbelt. During Middle Pennsylvanian time, the eastern flank of the Fort Worth Basin began to rise, the Midland Basin began to subside more rapidly, and

SYSTEM	SERIES	GROUP	FORMATION	BRAZOS RIVER VALLEY	TRINITY RIVER VALLEY
PENNSYLVANIAN	VIRGILIAN	CISCO	GRAHAM	GONZALES LS. FINIS SH.	NOT STUDIED
	MISSOURIAN	CANYON	CADDO CREEK	HOME CREEK LS. COLONY CREEK SH.	JACKSBORO LS. HOG CREEK SH.
			BRAD	RANGER LS. PLACID SH.	RANGER LS. VENTIONER BEDS
			GRAFORD	WINCHELL LS. WOLF MOUNTAIN SH.	DEVIL'S DEN LS. / CHICO JASPER CREEK SH. / RIDGE ROCK HILL LS. / LS. LAKE BRIDGEPORT SH.
			PALO PINTO	WILES LS. POSIDEON SH. WYNN LS.	WILLOW POINT LS. HUDSON BRIDGE LS.
	MISSOURIAN DESMOINESIAN	STRAWN	MINERAL WELLS	KEECHI CREEK SH. TURKEY CREEK SS. DOG BEND LS. VILLAGE BEND LS.	NOT STUDIED

Figure 2. Correlation chart for the Canyon Group in the Brazos and Trinity River valleys of North-Central Texas. See discussion for pertinent references.

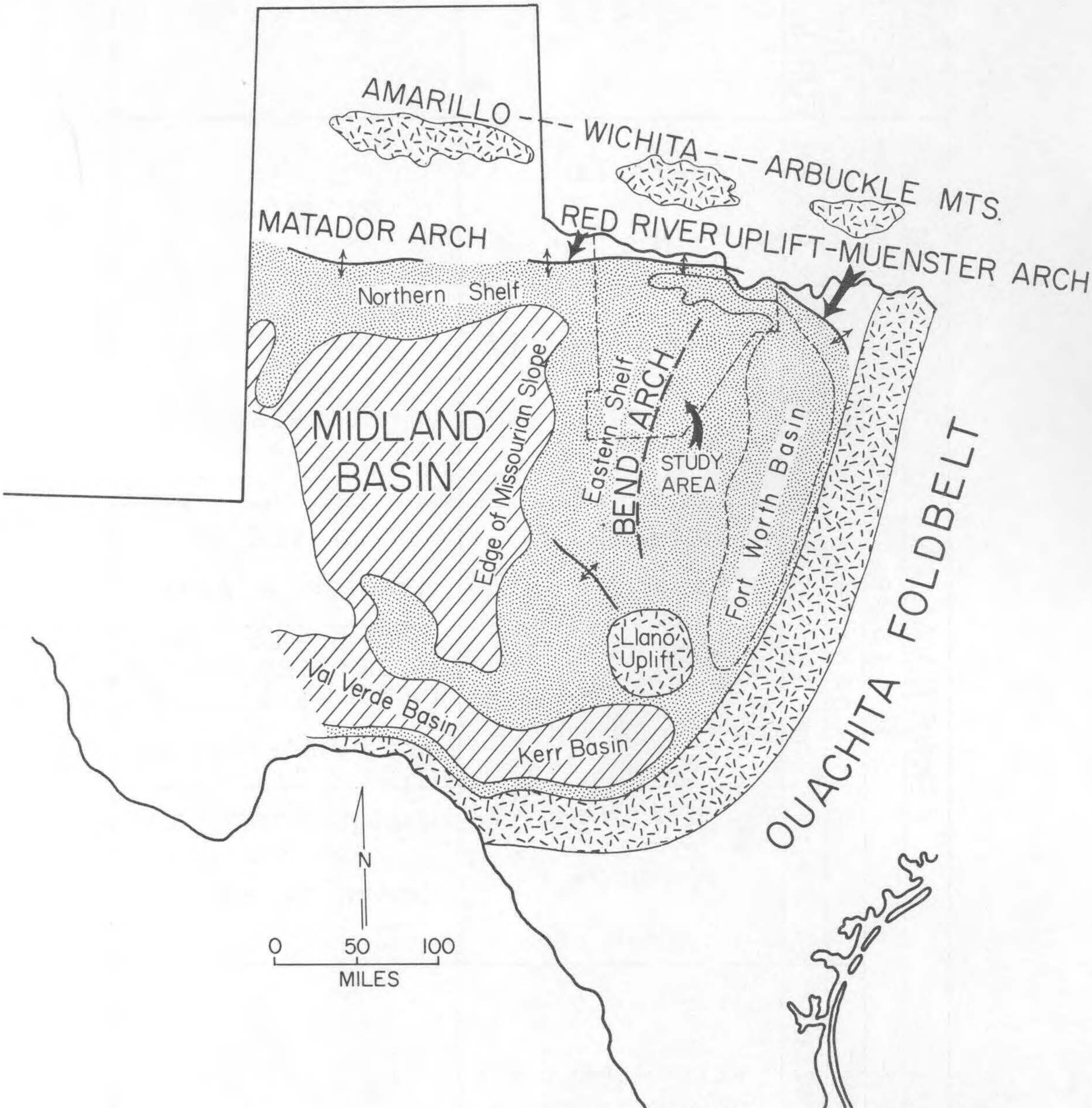

Figure 3. Tectonic setting for North-Central Texas during the Missourian Epoch; modified from Wermund and Jenkins (1969).

the Bend Arch originated as a hinge between the two depressed basin areas. Thick terrigenous clastic deposits of the Atoka and Strawn Groups essentially filled the Fort Worth Basin by the beginning of Missourian time, except for structurally low areas in northern Montague, northern Clay, and central Wichita Counties.

The Eastern Shelf, a Pennsylvanian-Permian physiographic feature on the structurally stable eastern flank of the Midland Basin, was a broad, relatively flat homocline which sloped gently to the west and northwest during Missourian and Virgilian times. The Eastern Shelf developed as a stable structural element on the older Concho Platform, a positive structural feature in North- and West-Central Texas during the early and middle Paleozoic (Cheney and Goss, 1952).

The term "Eastern Shelf," as used in this report, refers to the tectonically stable margin of the Midland Basin and is not synonymous with the term "Continental Shelf." The term "shelf," when used independently, refers to a zone extending from low waterline to the depth at which a marked increase in slope occurs, termed the "shelf edge" (Galloway, 1970). "Shelf deposition," as used herein, refers to deposition (such as carbonate accumulation) which was in equilibrium with existing shelf processes and conditions. As an example of this usage, a variety of sedimentary facies, including fluvial and deltaic sandstone and coal beds, were deposited on the physiographic, structurally stable Eastern Shelf, but only carbonate and mudstone units were deposited within the shelf depositional environments seaward of the deltaic systems.

Steep dips through Nolan, Taylor, Jones, Stonewall, and King Counties (fig. 4) mark a westward-facing Missourian shelf edge that flanked the deep Midland Basin.

The Ouachita foldbelt and the Wichita-Arbuckle Mountains supplied terrigenous clastic sediments to the northern part of the Eastern Shelf throughout most of Missourian time. In addition, uplifted clastic rocks of the Atoka and Strawn Groups along the eastern flank of the Fort Worth Basin probably served as a source of Canyon clastic sediments.

DEPOSITIONAL SYSTEMS

GENERAL RELATIONSHIPS

During deposition of the Canyon Group, a variety of depositional systems existed in North- and West-Central Texas (figs. 5, 6). Complexly interrelated sandstone, conglomerate, shale, and limestone facies record these distinctive depositional systems (pl. I).

Thick terrigenous clastic facies of the Canyon Group, which crop out in Jack and Wise Counties, have been referred to informally (Pollard, 1970) as the "Perrin delta complex," after the town of Perrin in southern Jack County. In this report, "Perrin delta system" is used to refer to the thick clastic facies that occur in outcrop and in the subsurface in that region. The Perrin system consists of terrigenous clastic rocks in the Wolf Mountain, Winchell, Placid, and Colony Creek Formations. Perrin delta lobes repeatedly prograded westward and northwestward across Jack, Young, Clay, Archer, Throckmorton, and Baylor Counties.

Thick wedges of feldspathic sandstone and conglomerate in northern Montague, northern and central Clay, southern Wichita, and northern Archer Counties define the Henrietta fan-delta system which built southward and southwestward into Texas, supplied by high-gradient fluvial systems that originated in the Wichita-Arbuckle Mountains of Oklahoma.

In addition to the terrigenous clastic systems, a variety of carbonate systems have been recognized. These include thick algal-crinoid carbonate-bank systems, such as the Winchell and Chico Ridge banks, which were elevated above the surrounding sea floor. As the Perrin delta was intermittently abandoned, subsidence permitted transgressive shelf systems composed of relatively thin shelf-mud and shelf-carbonate facies, such as the Ranger and Home Creek Limestones, to transgress the deltaic platforms.

Other Canyon carbonate systems include the Red River carbonate platform, composed of over 2,000 feet of limestone overlying the stable granitic mass of the Red River uplift. A shelf-edge

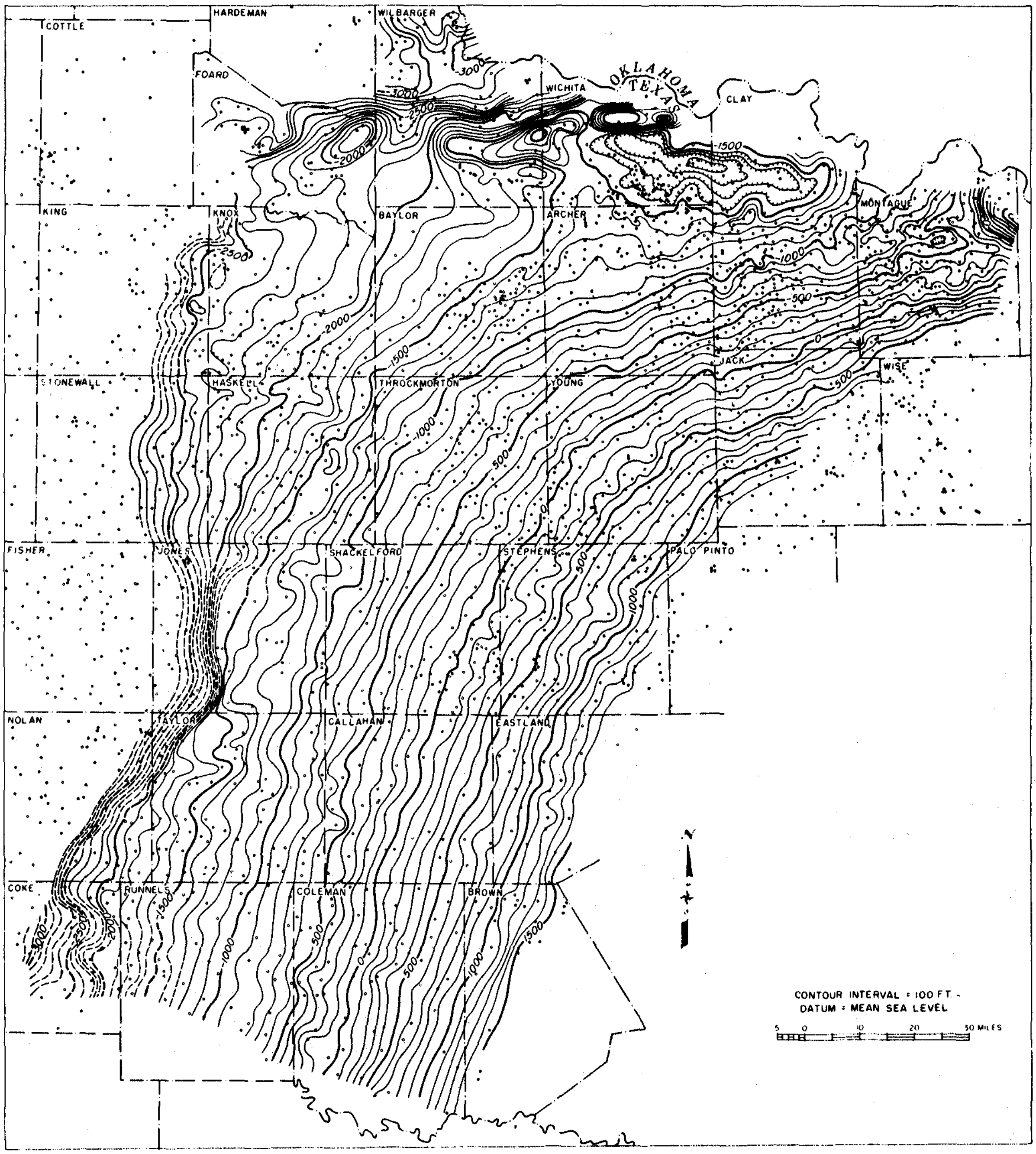

Figure 4. Structure contour map, top of Home Creek Limestone, North-Central Texas; adapted from Wermund and Jenkins (1969).

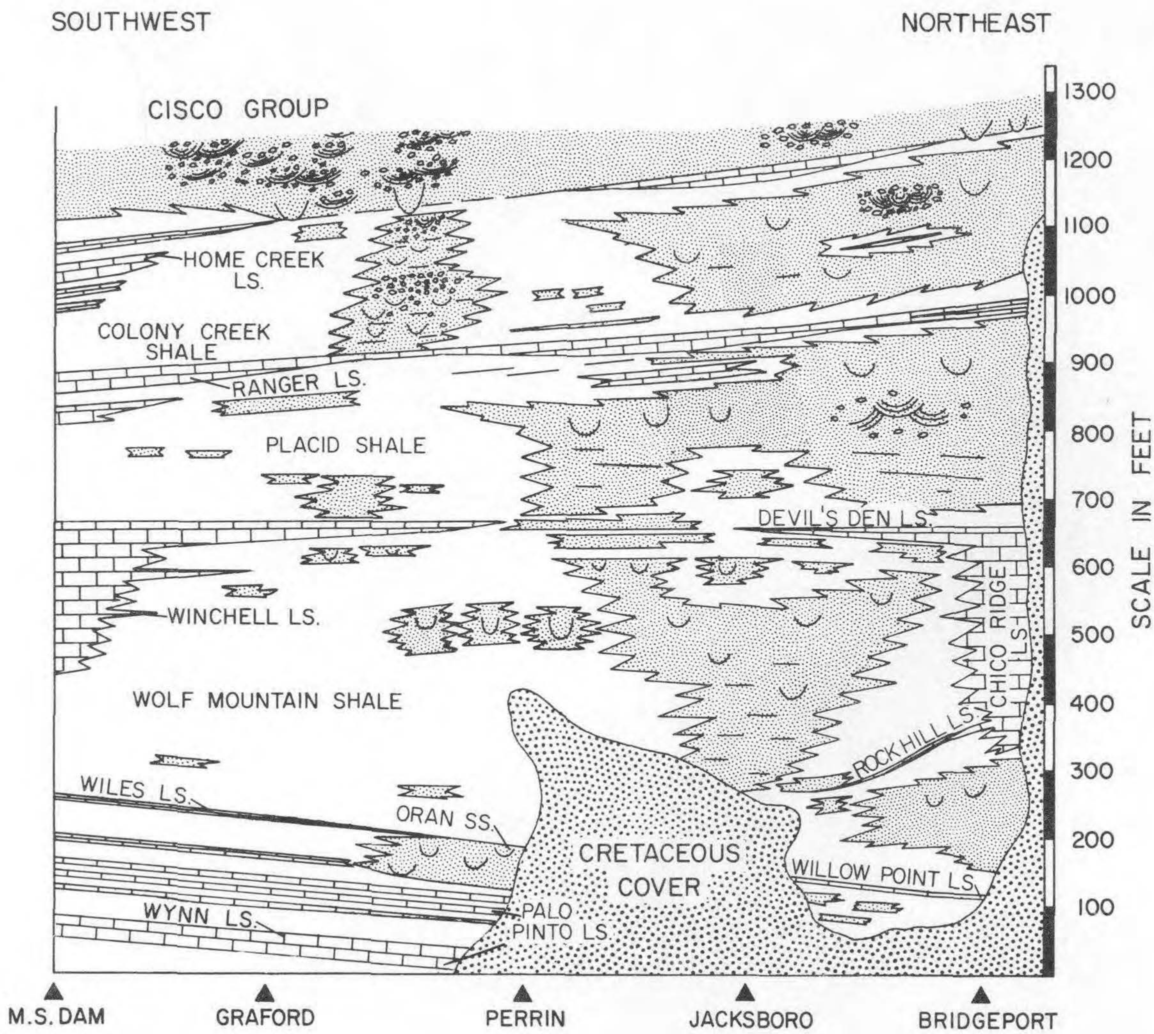

Figure 5. Schematic facies section along outcrop, Canyon Group, northern Palo Pinto, southeastern Jack, and western Wise Counties, Texas; based on 42 measured sections and lithofacies mapping.

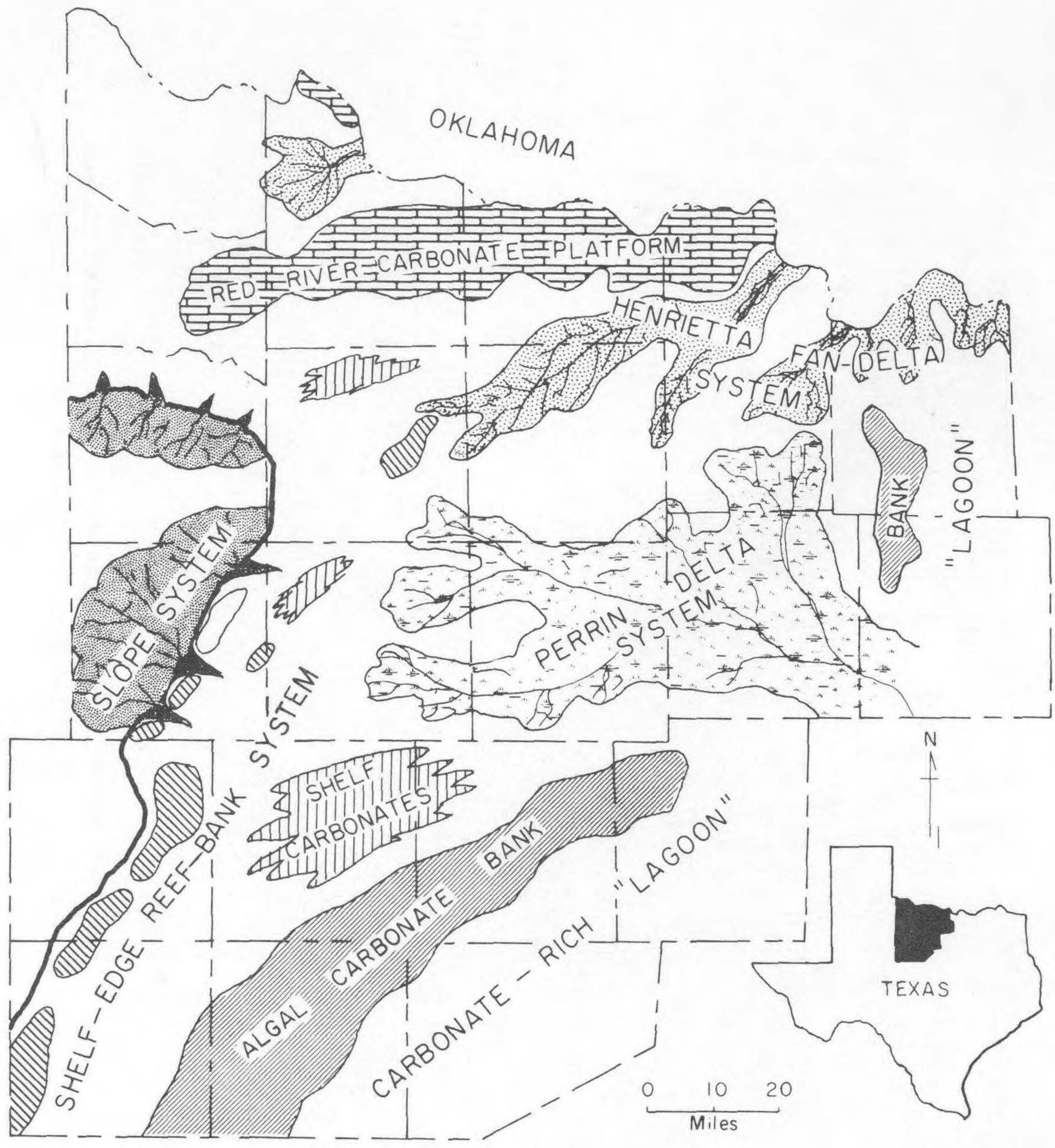

Figure 6. Generalized depositional systems during deposition of the Canyon Group, North-Central Texas.

reef-bank system developed along the Canyon shelf edge in Haskell, Jones, and Taylor Counties. Another thick carbonate accumulation, similar in geometry to the precipitous shelf-edge reef-bank accumulations of Haskell County, is located in east-central Baylor County. These shelf-edge and outer shelf reef-bank systems are thick (up to 1,500 feet), localized carbonate buildups which are generally not more than 15 miles in length and 8 miles in width.

E. G. Wermund (personal communications, 1973) recognized the presence of thick Canyon sandstone units basinward of the reef-bank system in western Haskell, eastern Stonewall, and northern Jones Counties. These sandstone accumulations are vertically persistent throughout the Canyon Group in that area, and probably represent slope-basin depositional systems similar to those described by Galloway and Brown (1972, 1973) for the overlying Cisco Group. The Perrin delta system and deltaic systems which prograded from the north supplied sediment to the slope-basin fans. These thick, relatively deep-water clastic deposits require further study before their exact geometry and relationships to other Canyon depositional systems can be determined.

PERRIN DELTA SYSTEM

The Perrin delta system persisted in eastern Jack and western Wise Counties during Missourian time. Deltaic progradation was interrupted periodically by one or more of the following: (1) decreased tectonism in the Ouachita foldbelt, (2) changing climatic conditions, (3) basinal or eustatic sea-level rises, or (4) shifts in the centers of deltaic progradation. Deltaic abandonment and destruction were followed by marine transgressions and deposition of sheetlike shelf carbonates. Three primary intervals of Perrin deltaic deposition include the Wolf Mountain and Winchell Formations, the Placid Formation, and the Colony Creek Formation. Surface and subsurface facies in each of these intervals are considered in sections to follow, but first a short discussion of some modern deltaic facies analogues is in order.

MODERN DELTAIC MODELS

Fisher (1968) classifies deltas on the basis of marine reservoir energy versus the progradational and aggradational influence of the river system. Deltas composed of a "... large proportion of fluvially influenced (constructive) facies are considered *high-constructive* systems; systems consisting predominantly of marine influenced (destructive) facies are *high-destructive* systems" (Fisher, 1968, p. 48). High-constructive deltas take two basic forms, high-constructive *elongate* deltas and high-constructive *lobate* deltas.

Elongate deltas include the modern Mississippi or bird's-foot delta and some small bayhead deltas in which the fluvial process dominates over the effects of marine waves, currents, and tides; elongate deltas build basinward rapidly by progradation of elongate bar fingers. Fisk (1961) describes the geometry, structures, and facies relationships associated with prograding bar fingers of the Holocene Mississippi delta (fig. 7). Bar-finger sand units are composed primarily of distributary-mouth bar facies. Bar fingers of the Mississippi delta comprise elongate sand lenses up to 5 miles in width. Bar-finger sand units may be up to 250 feet thick because of the highly compactible character of the underlying water-saturated prodelta mud, which allows distributary-mouth bar sands to stack vertically with virtually complete preservation.

As a distributary channel progrades basinward, its thick channel-mouth bar builds over prodelta clay and silty clay; a zone of delta-front sand, silt, and mud is deposited in front of and lateral to the channel. Prodelta mud, therefore, grades upward into silty sands and well-sorted coarser sands of the channel-mouth bar. The channel-mouth bar is transitional with overlying silty sand and mud of the natural levee deposits; organic-rich peaty clay, representing marsh deposits, may flank the natural levees. Bar-finger sand is fine to very fine grained and contains scattered plant material and thin layers of macerated plant debris. Sands are well laminated and sand and silt laminae are intercalated with laminae composed principally of plant fragments. Thin trough cross-stratification occurs throughout and a sparse fauna inhabits the environment.

Bar-finger deposits are interrupted by minor growth faults and contorted beds. Locally, sand and silt beds are contorted by upward movement of mud diapirs, caused by the excessive loading of water-saturated prodelta muds by thick channel-mouth bar sands. Distributary channels

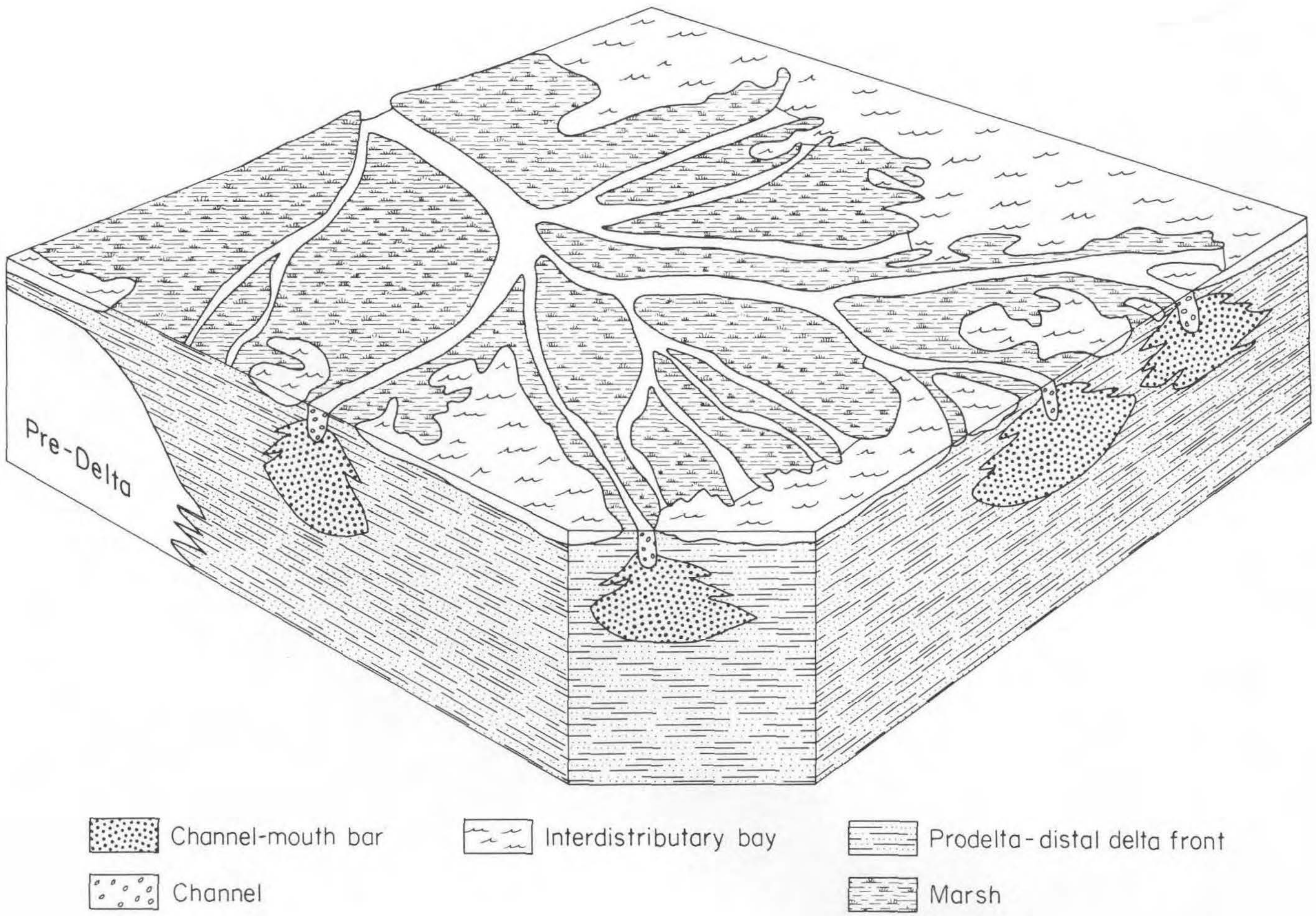

Figure 7. Block diagram of high-constructive elongate bird's-foot lobe, modern Mississippi delta; after Fisk and others (1961).

locally erode upper parts of bar-finger deposits. Distributary channel-fill deposits exhibit medium- to large-scale trough cross-stratification, plant debris, and some clay pebbles and chips; sands are fine grained and are generally well sorted.

Lobate deltas, such as the abandoned St. Bernard, Lafourche, and Teche lobes of the Holocene Mississippi delta, display fan-shaped to lobate geometry. Marine processes redistribute fluvial sands into sheetlike delta-front facies (fig. 8) with localized sand accumulations near distributary mouths (Frazier, 1967). Lobate deltas contain less mud than elongate deltas; consequently, with thinner prodelta facies, the foundering of abandoned deltaic lobes is relatively slow. Marine processes significantly rework and redistribute distal parts of lobate deltas (Fisher and others, 1969).

Prodelta mud units are laminated, whereas delta-front silty sands tend to display small-scale ripple cross-stratification. Delta-plain mud is organic-rich and may be root mottled and contain abundant wood fragments. Individual lobate delta lobes develop, according to Frazier (1967), in four basic steps. Distributaries begin their initial progradation into the marine environment, and as the system enlarges by further progradation, delta-front silty sands are worked laterally into sheetlike deposits, while delta-plain peat and inorganic mud of the natural levees accumulate. New distributaries form by crevassing, by avulsion of the main stream, and by bifurcation of preexisting distributaries. Distributary channels locally erode distributary-mouth bars during periods of high discharge. As distributaries are abandoned, delta-plain and delta-front sediments subside and may eventually be reworked by marine processes. Delta-margin islands form from reworked deltaic sand; oyster reefs may occupy newly formed lagoons and embayments. Old distributary courses may be reoccupied or new distributaries may form over the old subsided deltaic complex.

Deltaic lobes build seaward until they become overextended (Scruton, 1960). The river then shifts by avulsion to a shorter route to the sea; the old delta lobe is abandoned, and the sediment supply is shut off. Sand may be widely distributed over broad areas of the foundering deltaic lobe as thin, highly bioturbated sheet-sand facies.

Commonly preserved modern delta-plain facies include (Kolb and Van Lopik, 1966): (1) marsh deposits composed of peat, organic-rich mud and flood-borne silt and clay; (2) abandoned tidal channels filled with fine, well-sorted silt and clay containing some detrital organic matter; (3) lake deposits composed of fine clay and organic colloids showing no trace of bedding; (4) swamp deposits containing logs, in-place stumps and root systems, and plastic clay with local peat and layers of decayed wood. Natural levee deposits are composed of mud and sandy mud.

Elongate and lobate lobes of the Mississippi delta were and are deposited by high-constructive deltaic processes. The scale and relative proportions of sedimentary facies are different for every delta, whether modern or ancient. Facies relationships and sand geometry in the Perrin delta system, however, indicate high-constructive lobate and elongate delta deposition similar to the Holocene and modern Mississippi system.

PERRIN DELTA FACIES

Within the outcrop area (pl. I), stratigraphic and facies relationships exhibited by the delta system were determined from measured sections (pls. II, III; appendix 1). An idealized sequence of deltaic constructional and superposed destructional and open-shelf facies was recognized (fig. 9). Coarsening-upward constructional facies record a prograding delta lobe; marine-reworked destructional facies record delta abandonment, marine transgression caused largely by compaction of prodelta mud, and redistribution of deltaic sediments by marine processes. As subsidence progressed, fossiliferous open-shelf mud, overlapped by carbonate, transgressed abandoned delta lobes.

Prodelta facies.—Prodelta mudstone facies of the Perrin system are similar to Mississippi prodelta muds. For example, Perrin prodelta and superjacent distal delta-front facies commonly are well laminated with alternating silt and clay laminae and contain abundant reddish, ferrugenous (oxidized) clay-stone nodules and fine, macerated plant debris. Prodelta facies are generally dark gray to black, but local reddish to purplish zones are also present. Invertebrate fossils are rare to absent in most Perrin prodelta mudstones; distal prodelta facies may locally contain invertebrate fossils, especially mollusks. Distal prodelta mudstone units

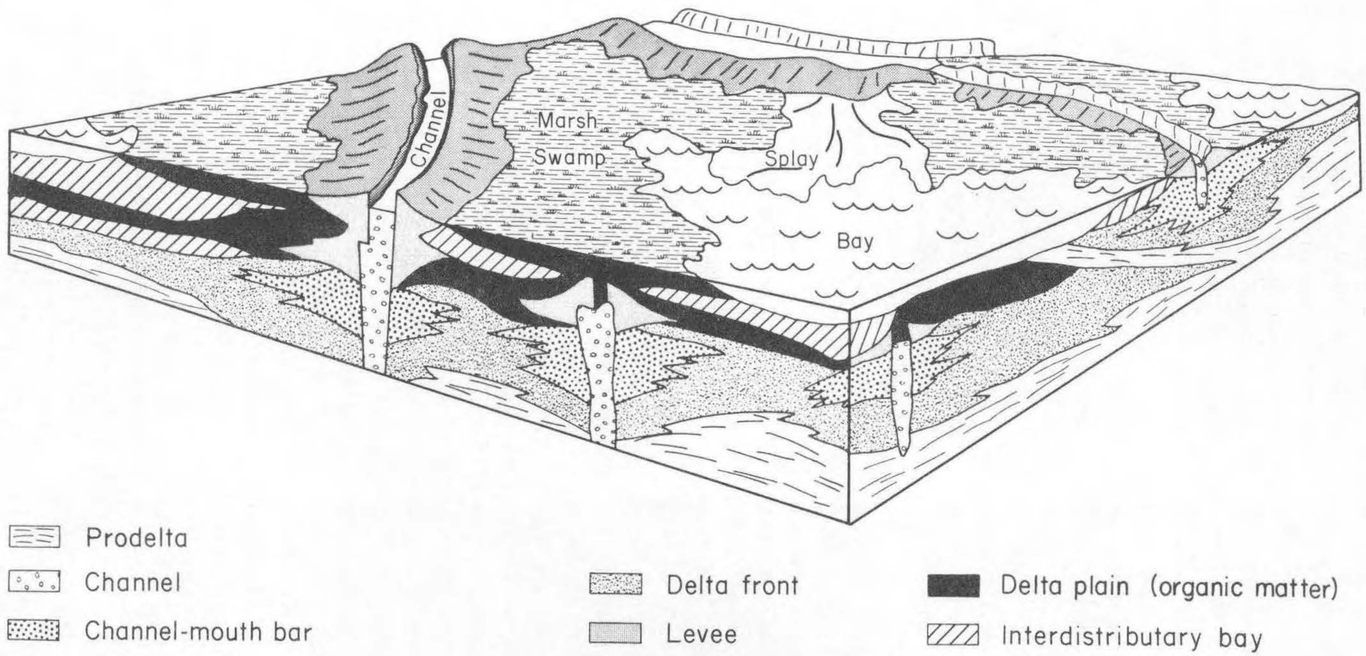

Figure 8. Block diagram of a high-constructive lobate delta, Lafourche lobe, Mississippi delta; after Frazier (1967).

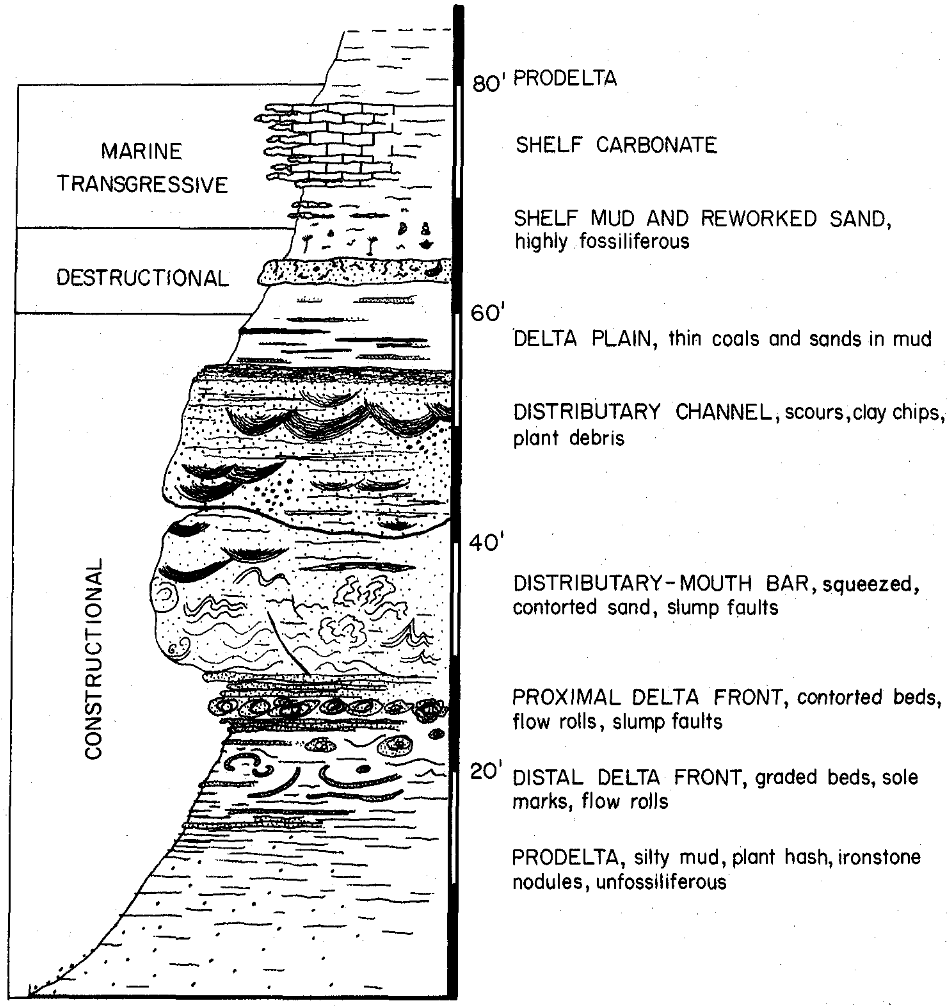

Figure 9. Idealized delta sequence, Canyon Group, North-Central Texas.

may also contain conularids. Prodelta facies were deposited by suspension deposition to give laminated siltstone and claystone; prodelta mud is locally bioturbated.

Prodelta facies, which were deposited by numerous lobes of the Perrin delta, may range in thickness from 3 to 4 feet in minor lobes up to 200 to 300 feet in major lobes of the Wolf Mountain Formation. In outcrop, prodelta facies underlie delta-front and distributary channel-fill sandstone facies and may overlie and grade laterally into highly fossiliferous open-shelf mudstone and carbonate units.

Distal delta-front facies.—Prodelta facies grade into very fine-grained sandstone and siltstone laminae of overlying distal delta-front facies. Thin, distal delta-front sandstone beds (generally less than 1 foot thick) are rich in fine, black plant debris and locally exhibit rippled bed forms on upper surfaces. Load casts, flute casts, and horizontal feeding trails are common on undersurfaces of thin, flaggy, distal delta-front sandstone beds. Sandstone beds are commonly graded and locally show small-scale trough cross-stratification. Horizontal laminae, however, are the most common sedimentary structures. Thin distal delta-front sandstone beds were probably deposited by local turbidity currents generated by high floodwaters debouching through distributaries. Flood surges eroded distributary-mouth bar and delta-front facies; resulting turbidity currents redeposited the sand in thin, distal delta-front sedimentation units. Sandstone beds commonly were rolled and contorted by contemporaneous slumping into water-saturated prodelta muds. Distal delta-front facies are virtually unfossiliferous because of the rapid influx of sediment and generally unstable nature of the sediment-water interface. These facies are from a few feet to a few tens of feet thick and are gradational with overlying and underlying sediments.

Proximal delta-front facies.—Proximal delta-front sandstone facies of the outcropping Perrin delta are fine- to very fine-grained, well-sorted quartzarenites. Commonly, the facies is thin to thick bedded and is gradational with underlying distal delta-front units. Sedimentary structures include abundant horizontal laminae and locally concentrated trough cross-stratification; locally, current-ripple bed forms are preserved on upper bedding surfaces (fig. 10). The sandstone beds are commonly contorted and rolled, especially near their bases, and may exhibit growth faults and a variety of load features. Proximal delta-front sandstone units normally contain abundant plant debris ranging from macerated "coffee grounds" to stems and leaves a foot or more in length. Bedding surfaces are normally covered with black flecks of fine plant fragments. Proximal delta-front sandstone units, which display a sheetlike distribution, can extend laterally for several miles and interfinger with shelf and interdistributary facies. Delta-front sandstone units of the Canyon Group range from a few feet to 100 feet thick.

Fine-grained, proximal delta-front sandstone beds in southeastern Jack and western Wise Counties (locality C) commonly weather to massive boulders which appear squeezed, contorted, and rolled. These sandstone beds are invariably rich in plant debris, including whole leaf impressions and *Calamites* pith casts. Concentrations of clay clasts and reddish ferrugenous claystone nodules are common. The sandstone beds may also contain abundant fine clay chips. Burrowing is generally restricted to the upper parts of proximal delta-front sandstone sequences and as local horizontal feeding trails on bedding surfaces.

Thick sandstone units of distributary-mouth bar origin may contain abundant trough cross-stratification, as well as a variety of sandstone lenses, growth faults, and load phenomena (fig. 10, 11). These relatively thick bar accumulations are normally contorted, especially near the bases, as a result of the rapid, local deposition of sand over highly compactible prodelta and distal delta-front mud. They may range from tens to hundreds of feet across and be from 10 to 200 feet thick.

Fine-grained sandstone units up to 100 feet thick are exposed within the Placid Formation 2.3 miles north of Wizard Wells, Texas (measured section 3). These sandstone units, which weather to contorted boulders the size of small houses and overlie coarsening-upward prodelta and distal delta-front facies, are interpreted to represent bar-finger facies of a high-constructive elongate lobe of the Perrin delta, which prograded through the area toward the northwest.

A massive, fine-grained distributary-mouth bar - distributary channel sandstone unit caps a hill 2.8 miles west of Perrin, Texas (measured section 23). The 40- to 50-foot-thick sandstone overlies a

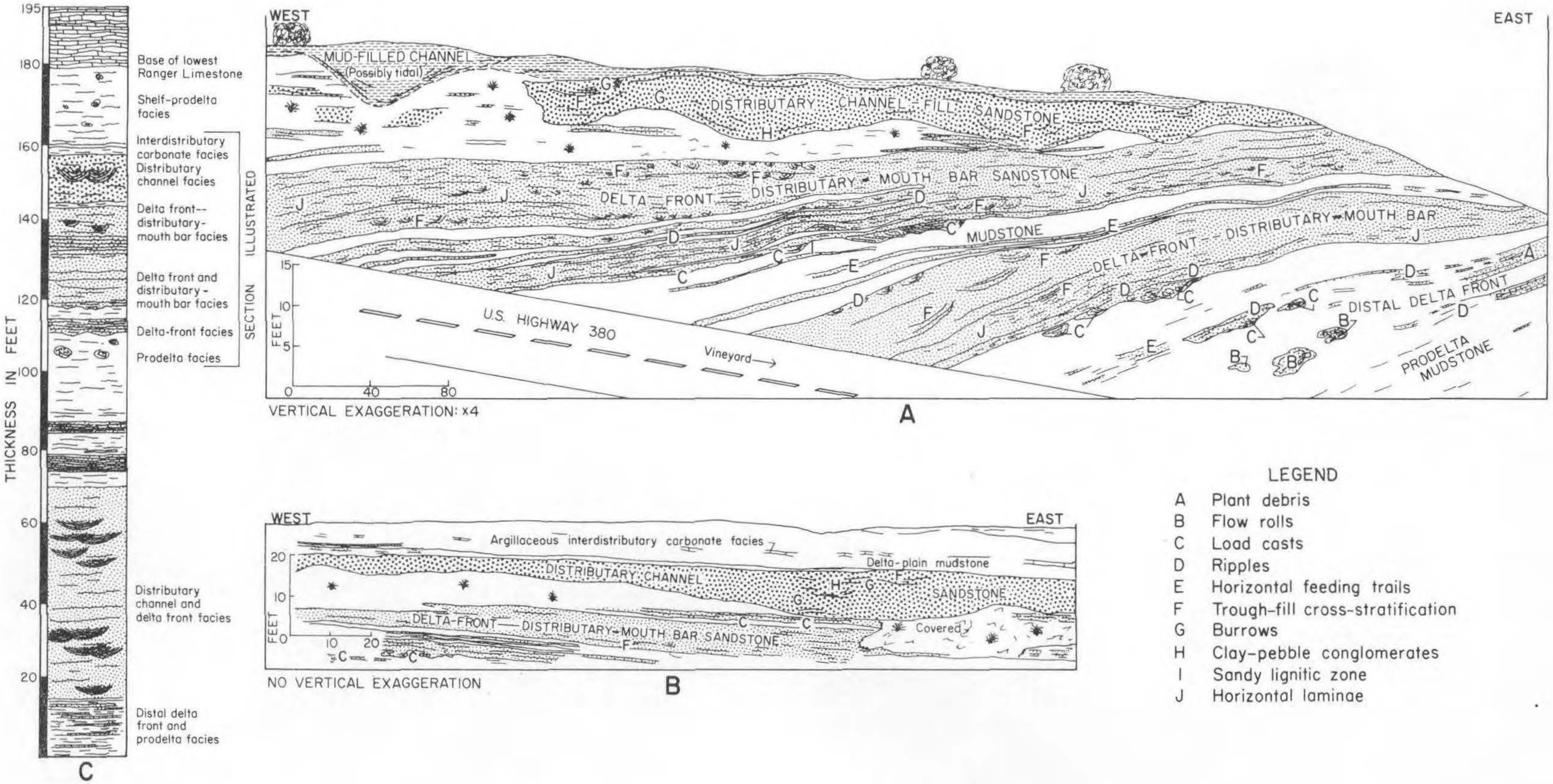

Figure 10. Delta-front and distributary channel facies, Placid Shale, along U. S. Highway 380, 2.5 miles west of Vineyard in eastern Jack County, Texas; measured section 1, plates I and III. (A) North side of road showing deltaic facies sequence of a Perrin delta lobe. (B) South side of road showing delta-front and superposed distributary channel-fill sandstones. (C) Measured section, upper part of Placid Formation exhibiting deltaic sequences and superposed transgressive facies.

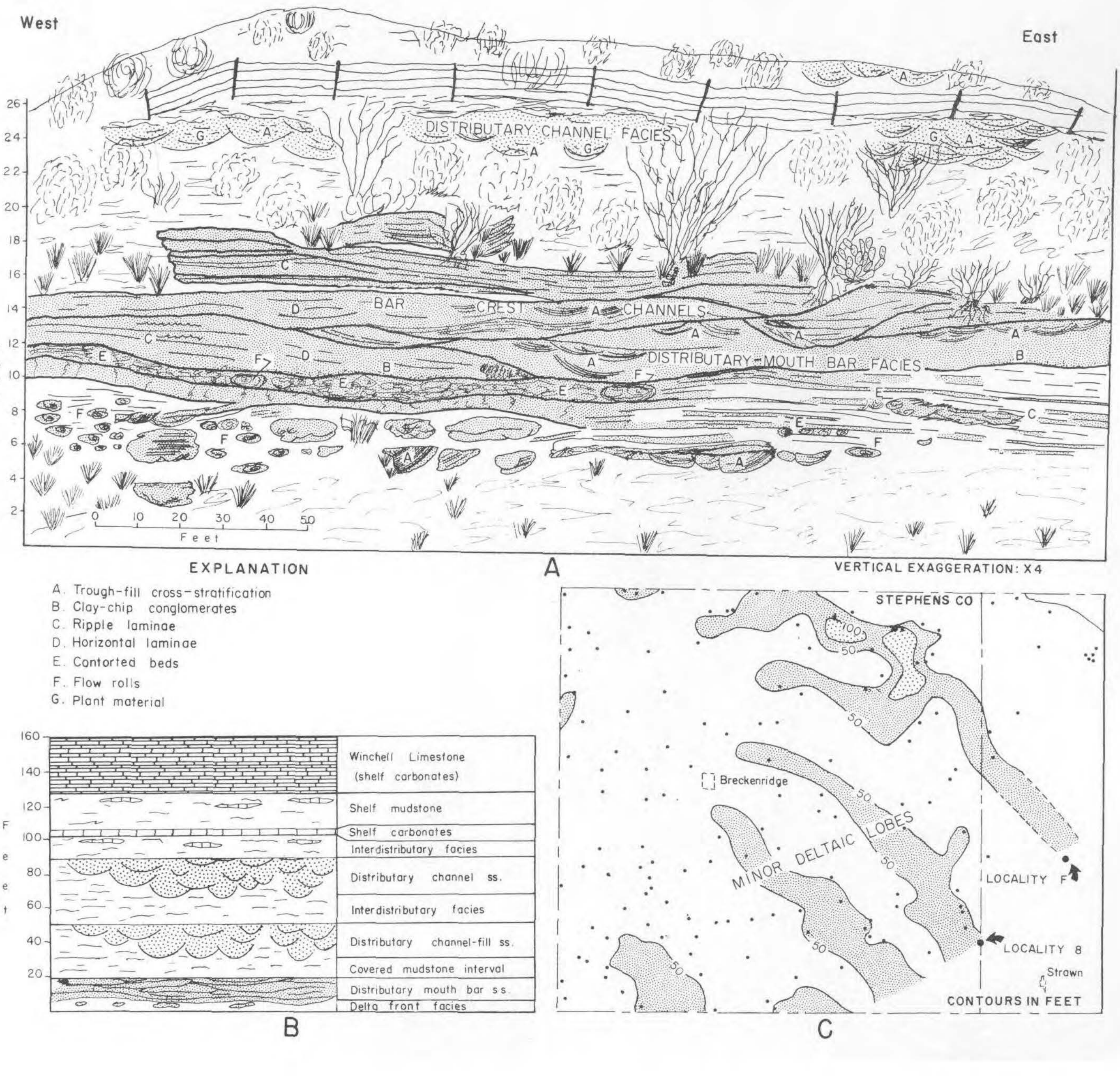

Figure 11. Deltaic sequence in a small delta lobe, upper Wolf Mountain Shale along Farm Road 207 at Palo Pinto - Stephens county line. (A) Channel-mouth bar facies with superposed distributary channel-fill deposits. (B) Measured section showing deltaic and overlying shelf-carbonate facies. (C) Net-sandstone thickness map for Wolf Mountain Formation in the area, showing extent of deltaic lobes.

60-foot section of sandy, prodelta mudstone. The bar-finger sandstone weathers into boulders, a few of which approach the size of small houses. The entire sandstone body apparently underwent post-depositional slumping; bedding surfaces within the sandstone body dip 20 to 30 degrees toward the south. A thinner sequence of delta-front sandstone beds, which slumped down into the underlying mudstone along a well-defined glide plane, is exposed along the highway near the base of the section. Penecontemporaneous and post-depositional slumping of proximal delta-front and distributary-mouth bar sandstone was common during Canyon deltaic deposition.

Strongly contorted, proximal delta-front sandstone in the lower part of Lake Bridgeport Shale is present in a roadcut along U. S. Highway 380, northwest of Bridgeport (locality E). Fine-grained delta-front sand (fig. 12) was injected into prodelta mud during slumping, resulting in unusually rolled and contorted structures. Sandstone beds slumped toward the east and northeast laterally to a northwestward-advancing distributary. Net-sandstone maps (discussed later) show that the Perrin delta lobes in the area prograded toward the west and northwest.

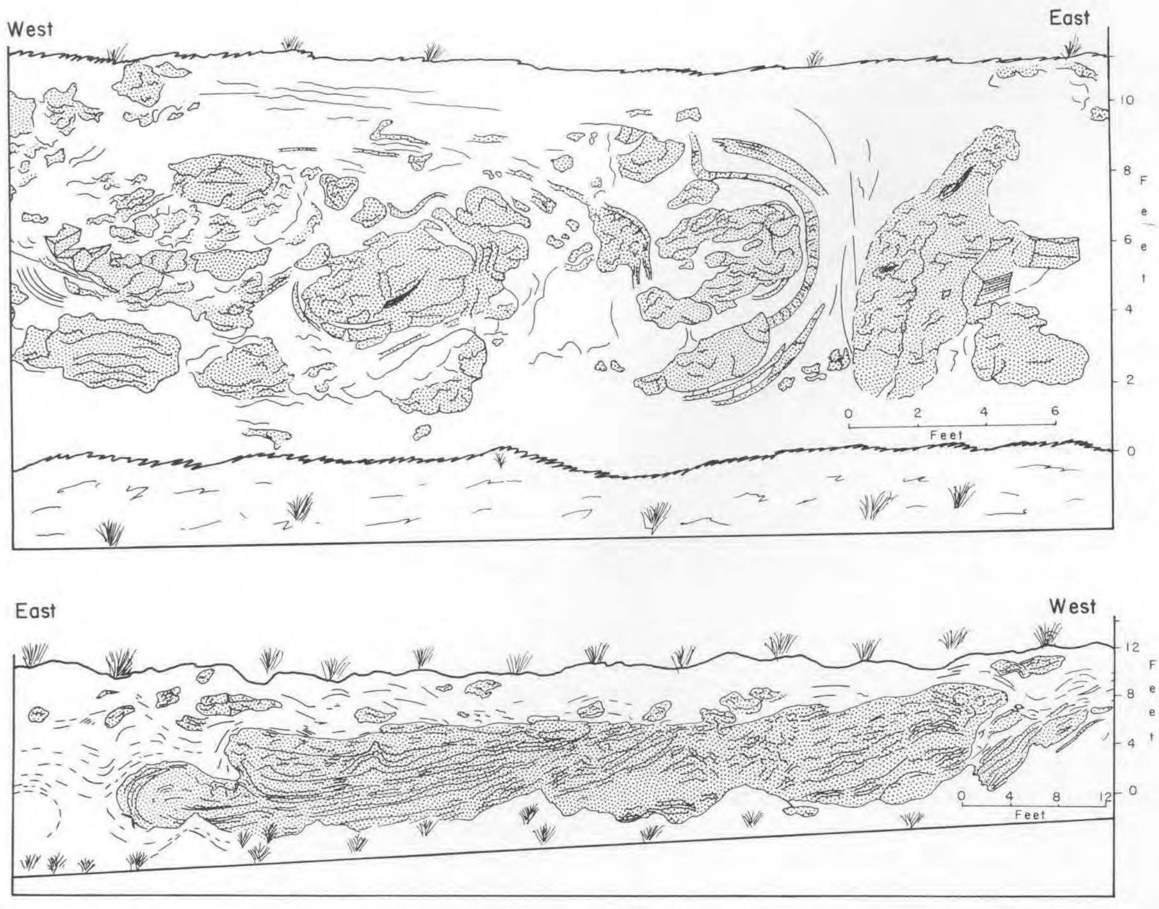

Figure 12. Slumped and contorted delta-front sandstones, Lake Bridgeport Shale (lower part of Wolf Mountain Formation), U. S. Highway 380 near Bridgeport, Texas; locality E, plate I. Top view, north side of highway; bottom view, south side of highway.

Distributary channel facies.—Fine- to medium-grained sandstone bodies of probable distributary channel-fill origin normally cut underlying delta-front sandstone and mudstone (fig. 10 and locality A). Distributary channel-fill sandstone facies are massive and homogeneous to strongly trough crossbedded and are commonly coarser grained than underlying delta-front facies. The channel fill may contain local clay-pebble conglomerate and concentrations of plant stems (particularly *Calamites)* and leaves up to 1 foot or more in length, as well as abundant fine plant debris. Distributary channel-fill facies are poorly sorted and contain a high percentage of clay particles. These "dirty" sandstone units generally contain more large plant stems and leaf impressions than do well-sorted quartzarenite varieties (fig. 11). In outcrop, distributary channel-fill deposits commonly are massive and appear to contain few sedimentary structures. Close examination of distributary channel sandstone units, however, reveals the presence of broad, low-angle trough cross-stratification. Although distributary channel-fill deposits may be up to 40 feet thick, they commonly are no more than 8 to 15 feet thick. Some massive distributary channel-fill facies contain small growth faults. Broad sandstone lenses must have stood up as depositionally high bar crests or middle-ground shoals (fig. 13).

Bases of distributary channel-fill units are sharp, erosional contacts. Distributary channels commonly overlie progradational, coarsening-upward sequences, but channels commonly eroded into subjacent interdistributary muds. In this latter instance, distributary channels must have shifted by avulsion and new channels eroded into older deltaic sediments.

Laminated fine-grained silt, clay, and coal locally fill channel-shaped scours in the upper parts of distributary channel sandstone units (fig. 14). These channel-fill mudstones and coals may represent later reoccupation of the channels and subsequent deposition of fine sediment from suspension after final abandonment. Some of these mud-filled channels also may have had a partial tidal origin.

Upper parts of distributary channel-fill and delta-front sandstone facies locally exhibit well-developed, straight-crested oscillation ripples and various interference-ripple bed forms on upper bedding surfaces. These bed forms probably resulted from marine reworking after delta abandonment. These same sandstone beds are locally burrowed, also indicating occupation of the abandoned delta front by marine organisms.

Delta-plain facies.—Facies interpreted to be of delta-plain origin are rare in outcropping Canyon rocks. Although Perrin deltaic sandstone facies generally contain abundant plant debris, carbonaceous clay and coal are rare. A possible explanation is that subsidence was slow on the tectonically stable Eastern Shelf and, therefore, thick delta-plain deposits did not develop as they have done within rapidly subsiding Mississippi River delta lobes. Marine waves, currents, and organisms also would have had ample opportunity to rework and destroy thin, highly organic Perrin delta-plain deposits after delta abandonment. Reworked deltaic sandstone beds overlain by highly fossiliferous shelf-mudstone facies commonly rest directly on abandoned distributary and delta-front facies.

A local coal (Dalton coal), approximately 8 feet thick, crops out in the Wolf Mountain Formation of northwestern Palo Pinto County, approximately 7.5 miles southwest of the town of Graford (pl. I). The coal is a loose, flaky, poorly indurated detrital deposit. The material does not appear to have been deposited in place, as no root systems or in-place stumps or stems have been observed. The coal rests directly on a 1-foot bed of well-sorted and well-indurated biosparite, which in turn overlies a mudstone that is rich in marine invertebrate fossils. Lateral to and overlying the Dalton coal are sandstone beds which are interpreted to be of delta-front and distributary channel-fill origin. The underlying biosparite bed may represent a well-winnowed beach, spit, or upper shoreface deposit within a shallow embayment, which formed over fossiliferous interdistributary bay-lagoon mud. Plant debris composing the coal was apparently transported and deposited at the head of a small bay or lagoon located between minor deltaic distributaries.

Another Canyon coal deposit (Bridgeport coal of western Wise and eastern Jack Counties) lies between members of the Palo Pinto Limestone. Scott and Armstrong (1932) report that the coal is 18 to 22 inches thick and is of good quality. It underlies a 55-foot-thick black shale which contains local sandstone bodies; the Willow Point Limestone, the uppermost Palo Pinto Limestone

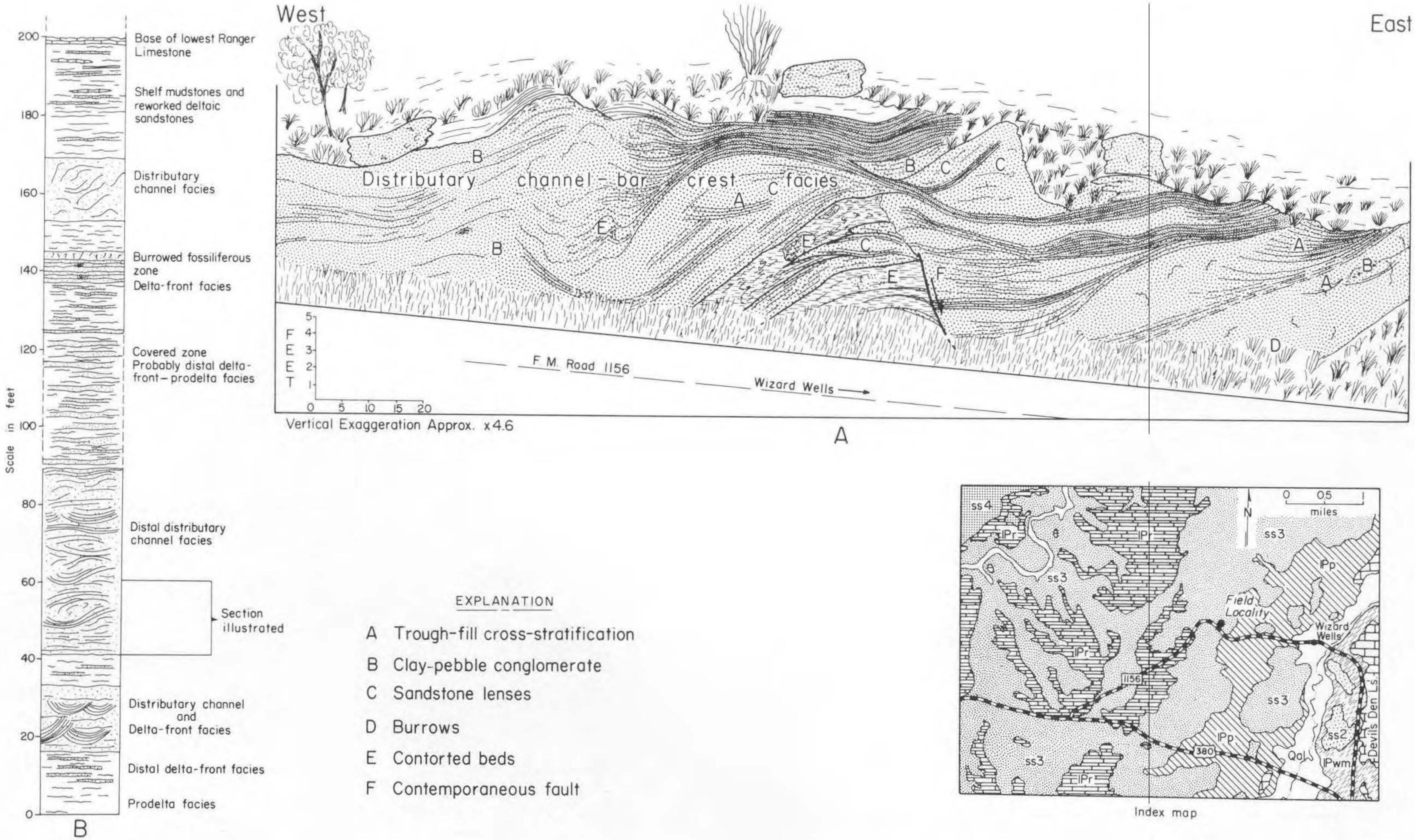

Figure 13. Distal distributary channel and bar-crest facies, upper Placid Shale, along Farm Road 1156, 1.4 miles west of Wizard Wells in eastern Jack County, Texas; measured section 2, plates I and III. (A) Complex distributary channel-fill deposits, displaying compactional features. (B) Measured section, upper Placid Formation showing Perrin facies overlain by shelf mudstones and carbonates.

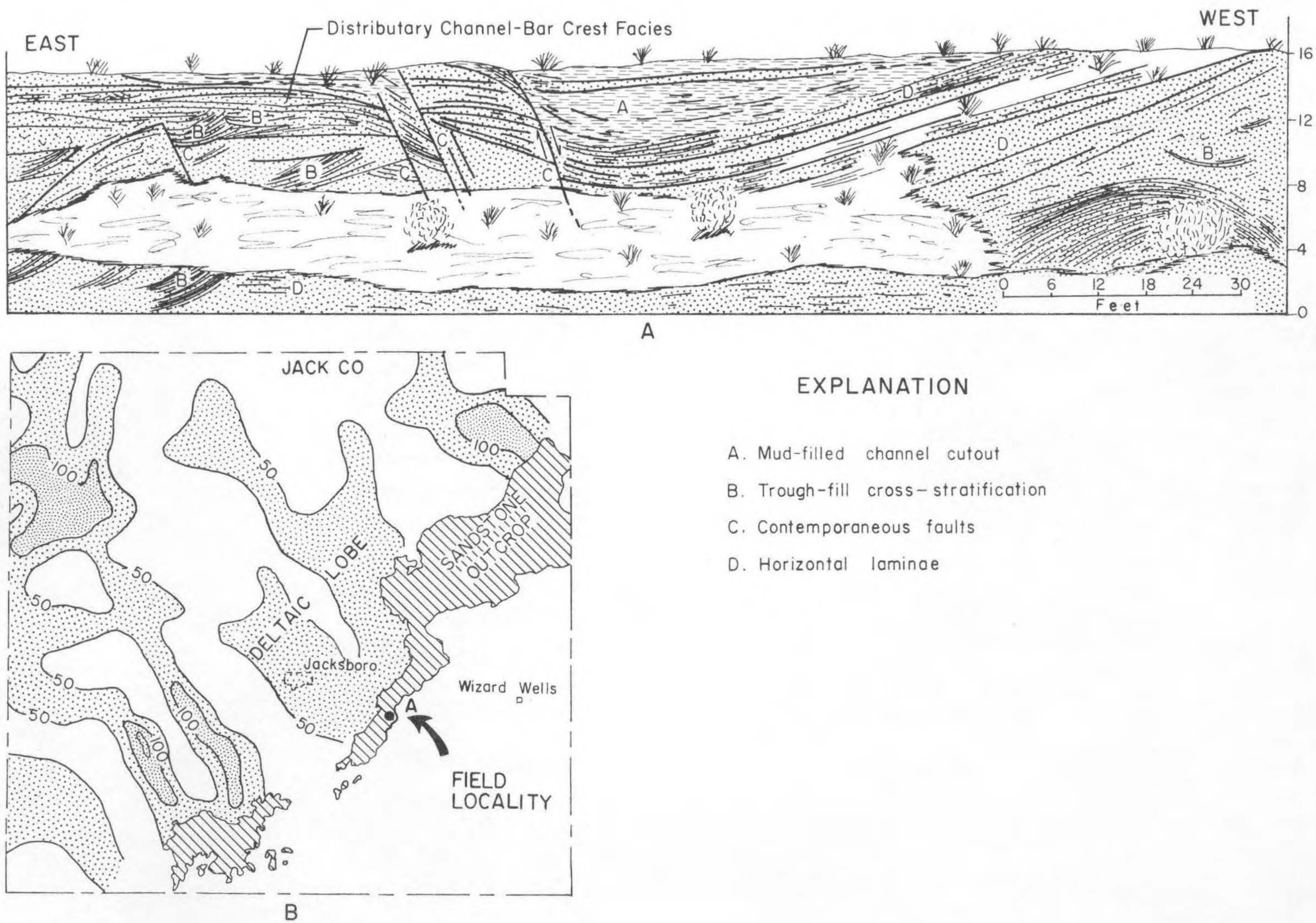

Figure 14. Distributary channel-fill facies, Colony Creek Formation, south side of U. S. Highway 380, east of Jacksboro, Texas; locality J, plate I. (A) Distributary channel-fill facies showing compactional features and mud-filled channel. (B) Net-sandstone map of Colony Creek Formation showing extent of deltaic lobes and location of roadcut.

member of western Wise County, overlies the black shale. Underlying the Bridgeport coal bed is a 20-foot section of blue to black clay that rests on a 12-foot coarse-grained sandstone which pinches out toward the southwest along strike. Scott and Armstrong state that plant fossils occur in the Bridgeport coal, but that they are rare. The Bridgeport coal extends southwestward to the vicinity of Perrin in southern Jack County (pl. I). The coal may be an in situ delta-plain deposit on a minor delta lobe which prograded westward through the area. The subbituminous nature of the Bridgeport coal contrasts with other detrital coals of the Canyon Group.

Thin, homogeneous mudstone sequences above and lateral to distributary channel-fill facies (fig. 10) are probably delta-plain accumulations in which very little organic material was preserved. These mudstone beds commonly are light gray to tan or brown, as opposed to thick prodelta mudstone facies which are normally gray to black. Plant roots may have destroyed the bedding within many of these inferred delta-plain facies.

Fluvial facies.—Fluvial channels filled with coarse clastic sediments locally eroded underlying Perrin deltaic facies. In the Placid Formation (near the vicinity of Big Creek; measured section 7) Local channels filled with coarse-grained sandstone and chert-pebble conglomerate replace underlying fine-grained deltaic sandstone and mudstone facies. These coarse-grained clastic units contain medium- to large-scale trough cross-stratification. Individual channel-fill bodies are 10 to 20 feet thick. Because the facies are poorly exposed, it is difficult to determine the precise nature of the fluvial system. The coarse-grained facies do not fine upward in grain size or display an upward decrease in scale of sedimentary structures. These facies may represent varieties of braided or perhaps coarse-grained meanderbelt systems.

In southern Jack County, north and west of Barton's Chapel (pl. I), deltaic sandstone and mudstone facies in the Colony Creek Formation (measured section 29) are overlain by extensive coarse-grained sandstone and chert-pebble conglomerate. These coarse channel-fill deposits represent component facies within a coarse-grained fluvial system. The system overrode and locally eroded the underlying, abandoned deltaic sediments.

Thick, widespread channels filled with coarse-grained sandstone and conglomerate locally eroded the Home Creek Limestone in southwestern Jack, southeastern Young, and northwestern Palo Pinto Counties (Lee and others, 1938). The lower part of the Cisco Group in this area consists of thick, coarse-grained sandstone, conglomerate, and shale facies; only local, thin carbonate stratigraphic marker beds occur within the thick clastic sequence. The area was a site of braided to coarse-grained meanderbelt fluvial deposition during a long segment of late Missourian and early Virgilian time.

At the outcrop, coarse-grained fluvial sandstone and chert-pebble conglomerate facies of the Perrin system are similar to coarse fluvial sediments of the underlying Strawn Group. These coarse terrigenous clastics in the Canyon Group may have been derived from Strawn and earlier rocks, which were uplifted and exposed along the western flank of the Ouachita Mountains during Missourian time. Coarse fluvial sandstone and conglomerate facies are not as common in Canyon rocks as they are in underlying Strawn and overlying Cisco Group rocks. The coarse-grained fluvial deposits account for less than 5 percent of the Canyon section exposed in the outcrop study area.

Interdistributary embayment facies.—Mudstone interpreted to be of interdistributary embayment origin was deposited between and locally on top of distributary channel-fill and delta-front sandstone. These mudstone units commonly contain abundant fossils of low-diversity consisting principally of a few species of pelecypods, gastropods, and some crinoids. Thin, argillaceous, fissile to platy limestone beds up to 4 feet thick are locally associated with the mudstone facies; these limestone units are poorly indurated and are generally tan to brown. Fossils include *Composita*-type brachiopods, echinoid spines and plates, and small gastropods. Platy to flaky algal mats and blades in this facies comprise a high percentage of the rock. Large amounts of fine-grained, terrigenous silt and clay deposited from overbanking floodwaters were mixed with the brackish-marine carbonate facies.

Destructional facies.—Highly bioturbated, fine-grained sandstone beds interpreted to be of delta-destructional, marine-transgressive origin commonly overlie Perrin deltaic facies and underlie shelf-carbonate facies (fig. 15). Destructional facies

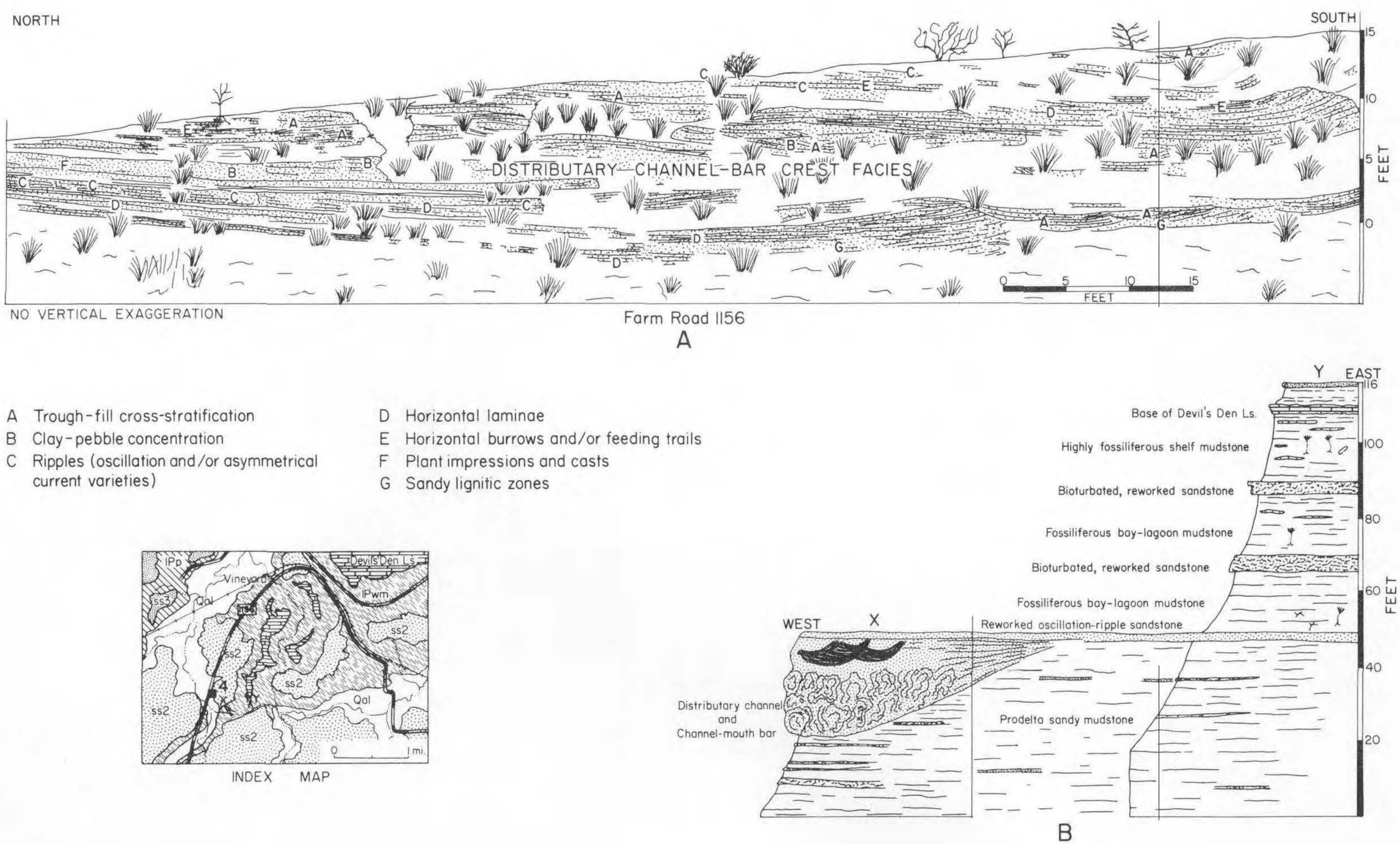

Figure 15. Deltaic, delta-destructional, and marine-transgressive facies, upper Wolf Mountain Formation along Farm Road 1156 south of Vineyard, eastern Jack County, Texas; locality H, plate I. (A) Distributary channel-bar-crest facies in east roadcut. (B) Measured sections X(14) and Y(13), Yates Ranch, east of roadcut (plate I) showing marine-destructional and marine-transgressive facies.

consist of well-sorted sand which was probably reworked by marine waves and currents after deltaic lobes were abandoned. Destructional sandstone beds are generally 2 to 6 feet thick and are commonly extensively burrowed by a variety of vertical, horizontal, and branching tubes up to 1 inch in diameter and several inches long (locality B). Disarticulated valves of the pelecypod *Myalina* also occur within the facies. Articulated, apparently in-place *Myalina* shells may occur in destructional sandstones, but they are rare. Destructional facies are normally vuggy or spongy as a result of intense bioturbation. Small-scale trough cross-stratification is abundant within the facies. The high porosity and permeability resulting from strong bioturbation, along with calcium carbonate derived from adjacent shelf-carbonate units, permitted extensive cementation of some destructional sandstones. This facies is commonly gradational between calcareous sandstone and sandy limestone.

Destructional sandstone beds are thin but extensive sheetlike units which may persist for several miles along outcrop. Deltaic facies of the Colony Creek Formation 5 miles east of Jacksboro (locality B) are overlain by a widespread, 3- to 5-foot-thick, highly burrowed, calcareous sandstone facies of delta-destructional origin (pl. I). For several miles along depositional strike, deltaic sandstone and mudstone below the Devil's Den Limestone (Winchell equivalent) of eastern Jack and western Wise Counties (measured sections 9, 10, 12) are also overlain by thin, reworked, destructional sandstone beds.

Destructional sandstone facies of the Perrin system are analogous in position, geometry, and sedimentary structures to the transgressive sheet sands and delta-destructional islands overlying the foundering Holocene St. Bernard delta lobe of the modern Mississippi delta.

Tidal channel facies.—Tidal channel-fill deposits are rare in outcrops of Canyon deltaic deposits; only two possible examples have been noted. First (fig. 10) is a symmetrical channel that was eroded into a massive distributary channel-fill sandstone unit of the Placid Formation. The maximum thickness of the symmetrical channel-fill deposit is 12 to 15 feet and consists of laminated fine siltstone and mudstone. No shell material, burrows, or cross-stratification have been observed in the channel-fill deposit; the feature may simply be a reoccupied channel in older distributary channel-fill sandstone, and not a tidal channel-fill deposit.

Half a mile east of Brad, Texas (along Highway 180), within the upper part of the Wolf Mountain Formation, a tidal channel eroded delta-plain deposits of a minor delta lobe that was abandoned and undergoing subsidence (fig. 16). Excellently exposed tidal channel-fill deposits are composed of calcite-cemented clay-stone pebbles, sand, and broken-shell debris up to 2 inches in diameter. The deposit contains abundant broken *Myalina* shells, crinoid debris, brachiopods, and various clasts, including ferrugenous clay-stone nodules; bedding is massive and sedimentary structures are not readily apparent. The upper 4 feet of channel-fill, which is finer than the underlying sediment, consists of well-sorted and well-indurated biosparite. Overlying the channel is about 15 feet of sandy mudstone of shallow-shelf origin; the Winchell shelf-carbonate facies overlies the entire sequence.

Shelf and interdeltaic facies.—Highly fossiliferous shelf and interdeltaic mudstone facies overlie and flank Perrin deltaic lobes; these mudstone units are, in turn, overlain by transgressive shelf-carbonate facies. The mudstone facies, which have been intensively bioturbated, are locally marly and contain local calcareous lenses and nodules. Invertebrate fossils include a variety of sponges; abundant crinoids and echinoid plates; brachiopods, including productids, chonetids, spirifers, rhynchonellids, and rostrospirifers; at least 12 genera of gastropods (the most common being *Straparolus*); scaphopods (*Dentalium*); several genera of pelecypods; cephalopods, including abundant orthocone nautiloids and several coiled nautiloids and goniatites; corals, the most abundant of which are *Lophophyllidium profundum* and species of *Caninia*; conularids; bryozoans of both encrusting and fenestrate forms; and small phosphatic (spiral) coprolites.

DISTRIBUTION OF THE PERRIN DELTA SYSTEM

The Perrin delta system was a persistent feature during most of Missourian time, as shown by thick terrigenous clastic facies in three consecutive Canyon stratigraphic intervals.

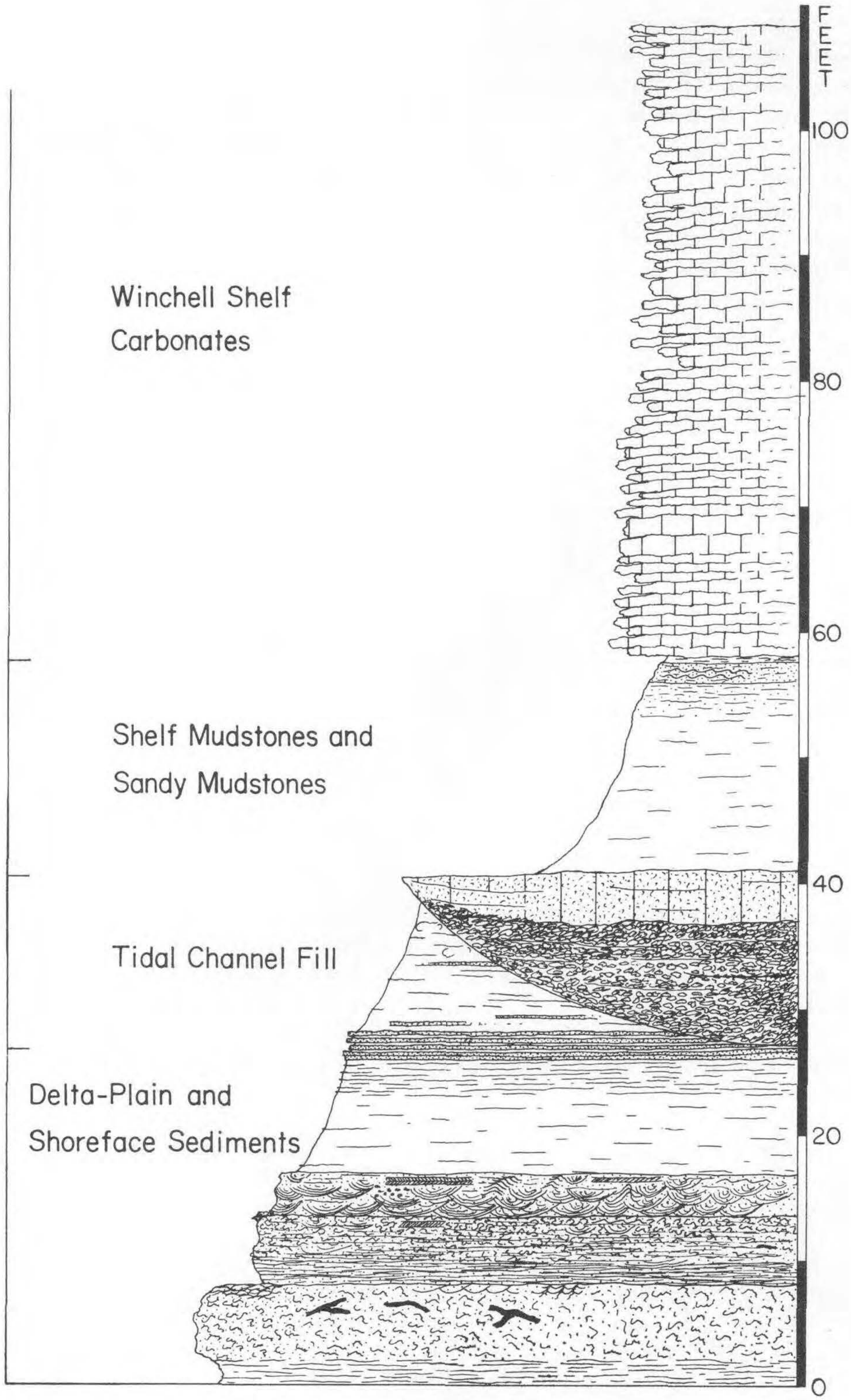

Figure 16. Measured section, upper Wolf Mountain Formation along U. S. Highway 180, 0.5 mile east of Brad, western Palo Pinto County, Texas, showing symmetrical tidal channel fill in delta-plain and shoreface sediments, covered by transgressive shelf facies.

Interval 1: Wolf Mountain - Winchell Formations.—During Canyon deposition, the Perrin delta system prograded west to northwest through Jack and Wise Counties (fig. 5), as evidenced by the orientation of thick deltaic facies in outcrop (pls. I, II). Thick carbonate-bank limestone facies of the Winchell Formation, which crop out in the Lake Possum Kingdom area of northwestern Palo Pinto County, interfinger to the north with fossiliferous, delta-flank mudstone and strike-fed sandstone units (fig. 5). From immediately southwest of Perrin in southern Jack County, northeastward to the vicinity of Bridgeport in western Wise County, thick deltaic sandstone and mudstone facies crop out along a northeast-southwest belt (pl. I). The Chico Ridge Limestone, a thick carbonate-bank sequence which flanks the Perrin delta system on the northeast, crops out in the Lake Bridgeport area (pl. I; fig. 5).

A net-sandstone thickness map (pl. IV) of the Wolf Mountain Formation displays dip-oriented, linear, and bifurcating sandstone trends interpreted to be framework sandstone facies of the Perrin delta system. Delta lobes extend for as much as 80 miles west and northwest into the subsurface from outcrops in Jack and Wise Counties. Maximum thickness of sandstone in the Perrin delta system occurs only 5 to 10 miles downdip from outcrop near Jacksboro in south-central Jack County. A series of Perrin lobes merged with Henrietta fan-delta lobes in southern Clay County. In western Jack County, Perrin delta lobes shifted to a westward orientation and prograded across Young and southern Archer Counties into Throckmorton and Baylor Counties. This shift in trend may have resulted from the influence of the contemporaneous Winchell carbonate bank, which exhibited slight depositional relief southwest of the Perrin delta system (pl. V). Areas containing only minor net-sandstone values probably represent interdistributary and interdeltaic embayments.

Thick accumulation of sandstone facies in northern Throckmorton County may have resulted from the influence of the Bend Arch, which trends generally north-south through western Young County (fig. 3). During deposition of the Wolf Mountain Formation, the arch possibly marked a break-in-slope, beyond which the water depth increased significantly. When prograding lobes of the Perrin delta system reached this break, the rate of progradation diminished and thicker deltaic sands were deposited in the deeper water. This process is analogous to what is now occurring with the bird's-foot lobe of the modern Mississippi delta, where distributaries have prograded into relatively deep water. In order for the Mississippi system to prograde basinward, thick sequences of deltaic sediments must accumulate.

Minor delta lobes prograded northwestward through Palo Pinto, Stephens, and Shackelford Counties (pl. IV). Progradation of these minor lobes was not contemporaneous with deposition of the northern part of the Perrin delta system, but rather preceded the major delta-building event. Sandstone units of one of these minor deltaic lobes crop out northwest of Strawn, Texas (fig. 11).

Progradation of the Perrin delta system during deposition of the Wolf Mountain Formation (fig. 17) was, in part, contemporaneous with deposition of the Chico Ridge carbonate-bank system to the northeast and the Winchell carbonate-bank system to the southwest. Bank deposition began as algal-crinoid mounds growing on abandoned deltaic and interdeltaic sediments in the lower part of the Wolf Mountain Formation. Lobes of the Perrin system prograded westward across the Eastern Shelf between these shoal-water carbonate banks. Electric logs clearly distinguish between the carbonate-bank and deltaic facies (fig. 18). In outcrop, carbonate-bank facies exhibit intercalated beds of terrigenous silty and sandy clay up to 3 feet thick. These terrigenous clastic units record periods of local influx from nearby deltaic lobes of the Perrin system. Shifting delta lobes introduced fine terrigenous clastics, which temporarily eliminated the carbonate-producing and carbonate-trapping organisms, restricting carbonate deposition to less turbid sites.

Winchell and Chico Ridge banks probably influenced the route of prograding Perrin delta lobes; deltaic lobes appear to have deflected around the banks (fig. 17). Near the end of Wolf Mountain deposition, the carbonate banks probably had little, if any, depositional relief. The banks, which likely originated with depositional relief, ended up as carbonate lagoons partially surrounded by deltaic lobes. Pollard (1970) believes that the Winchell Limestone near Lake Possum Kingdom exhibited only local depositional relief and was, for the most part, a flat carbonate biostrome. Raish (1964), on the other hand, recognizes peripheral sloping wedges of oolitic and bioclastic calcarenite, which he infers were shed

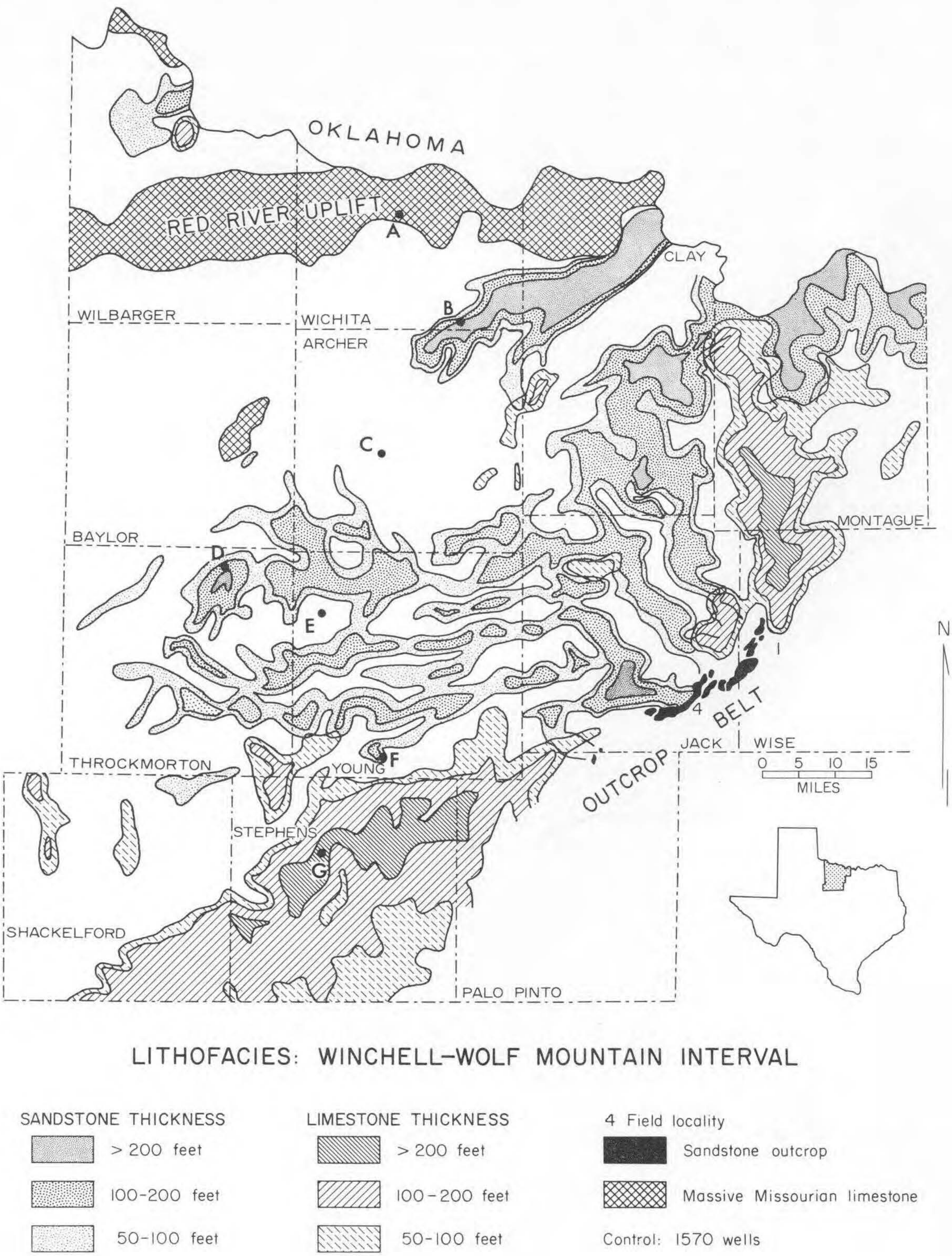

Figure 17. Net-limestone thickness map of the Winchell Limestone Formation superimposed upon net-sandstone thickness map of the Wolf Mountain Formation. Delatic lobes of the Perrin delta and Henrietta fan-delta systems prograded basinward contemporaneous with carbonate-bank accumulation. As the Perrin delta was abandoned, algal carbonates spread outward from the bank areas. Letters (A-G) refer to typical electric log patterns illustrated in figure 18.

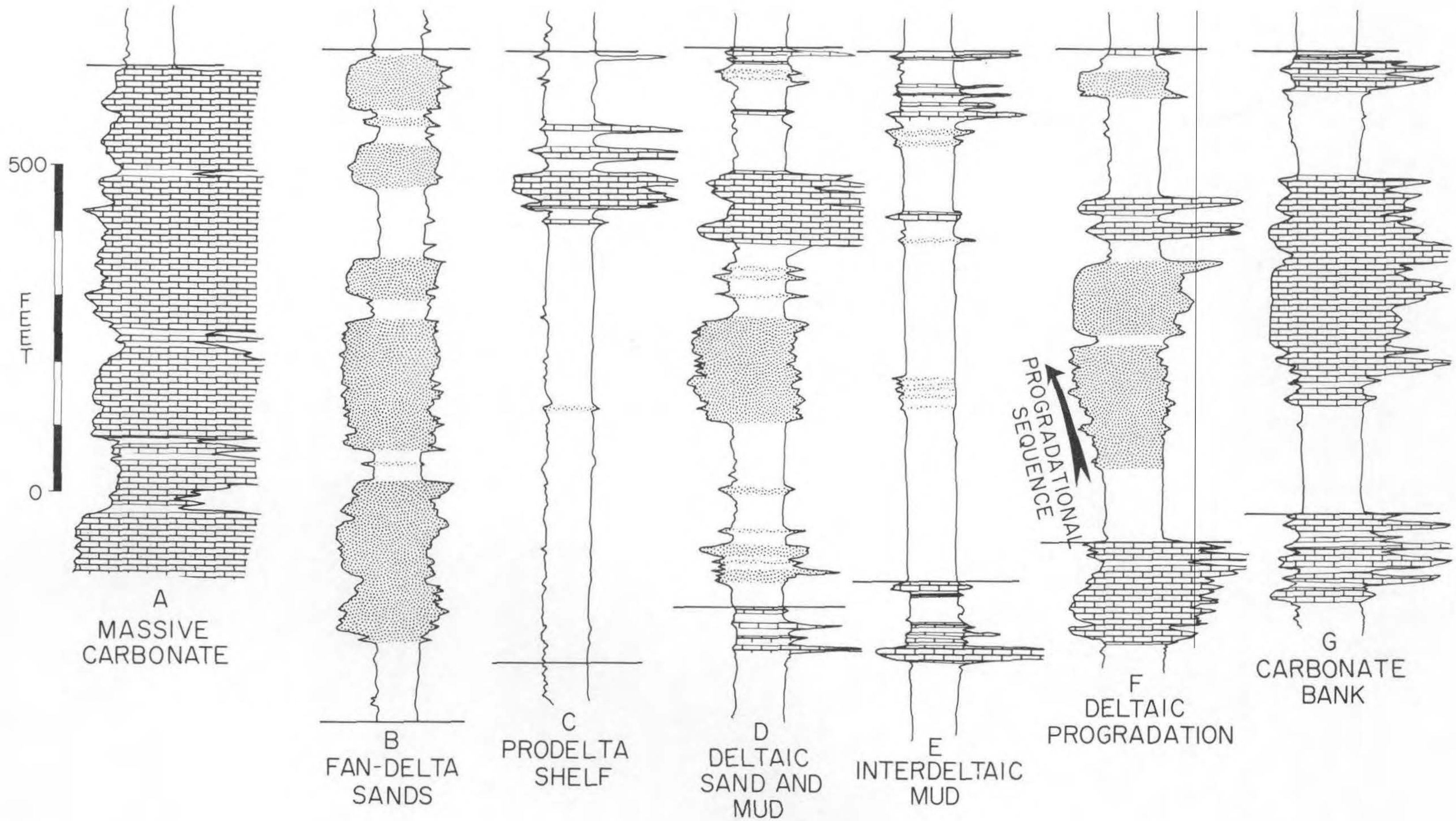

Figure 18. Typical electric log patterns of facies within Canyon depositional systems, North-Central Texas. See figure 17 for location of electric logs.

from the depositionally high Chico Ridge algal bank.

The Rock Hill Limestone (fig. 5; pl. I), a thin (less than 3 feet thick) intramicrudite and/or carbonate breccia deposit, was shed from the Chico Ridge bank early in its development. Angular limestone clasts up to 2 inches in diameter, molluskan debris, crinoid columnals, and corals are mixed within a fine-grained calcarenite and micrite matrix. The Rock Hill Limestone thins and pinches out away from the Chico Ridge carbonate bank over a distance of about 7 miles (pl. I). Angular clasts of micrite containing local crinoidal and algal debris must have been partially to completely lithified before they were swept from the bank and redeposited. It is evident, therefore, that the Chico Ridge carbonate bank underwent periods of subaerial exposure required for the lithification of lime mud.

With abandonment and subsidence of the Perrin delta, algal carbonate facies spread from adjacent carbonate banks and onlapped the edges of the foundering delta lobes, giving rise to the transgressive, sheetlike Winchell Limestone tongue of southern Jack County and the equivalent Devil's Den Limestone tongue of eastern Jack and western Wise Counties (fig. 5). Continued progradation of minor distributaries, as well as marine reworking of foundering Perrin delta lobes in southeastern Jack County, prevented complete overlap by Winchell - Devil's Den carbonate facies. In this region, therefore, deltaic clastics of the Placid Formation rest directly upon similar facies of the underlying Wolf Mountain Formation (fig. 5; pl. II).

The lateral and vertical relationships between terrigenous clastic and carbonate facies is shown by regional cross sections (figs. 19, 20, 21, 22). The predominance of carbonate and shelf-mudstone facies in Palo Pinto and Stephens Counties contrasts sharply with the thick deltaic, terrigenous clastic facies in Jack, Wise, and Montague Counties (Section E-E′, fig. 21).

Interval 2: Placid Formation.—From the Sparks Springs area of southern Jack County (pl. I) northeastward to the Cretaceous overlap, the outcropping Placid Formation is a complex facies association composed of laminated prodelta mudstone, delta-front and distributary channel-fill sandstone, reworked sandstone and siltstone, fossiliferous interdistributary mudstone, local contorted bar-finger sandstone, and local coarse-grained fluvial sandstone and conglomerate. From the vicinity of Sparks Springs Church (pl. I), outcropping delta facies thin and jnterfinger southwestward with interdeltaic embayment mudstone. Abandoned deltaic environments were ultimately overlapped during transgression by highly fossiliferous shelf mudstone and algal carbonate of the Ranger Limestone (pls. III, VII).

A net-sandstone map of the Placid Formation (pl. VI) shows that Perrin delta lobes in outcrop are part of a system which prograded to the northwest and west across northern Jack, northwestern Wise, and southern Clay and Montague Counties. Axes of thick sandstone facies in the subsurface north of Wizard Wells tie with outcropping Perrin deltaic sandstone units which are principally massive, contorted bar-finger sandstone units (pl. III). South of Wizard Wells, two thin delta lobes prograded westward; a small system, which prograded a short distance across southern Jack and northern Palo Pinto Counties, crops out in the Halsell Ranch area (pl. I; measured section 31). A large, bifurcating lobe prograded basinward across northern Stephens and southern Young Counties. Delta lobes located in the subsurface of southern and eastern Montague County lie beneath a thin cover of Cretaceous sediments.

In western Stephens and southeastern Shackelford Counties, mudstone and sandstone facies of the Placid Formation grade laterally into massive carbonate facies of the combined Winchell and Ranger Limestones (figs. 21, 22, 23, 24). Deltaic deposits in the Placid Formation in Jack, Wise, and northern Palo Pinto Counties are inferred to have been time-equivalent with carbonate-bank deposits in Stephens and Shackelford Counties.

In the subsurface of western and central Baylor County, extensive, thick sandstone facies apparently prograded from the northwest (fig. 25). Wermund and Jenkins (1970) show second-derivative trend surface maps that outline a large, inferred delta lobe, which extended southward across the Northern Shelf through Foard and Knox Counties and into western Baylor County during middle and late Missourian time.

In the vicinity of Highway 380 and FM Road 1156, west of Wizard Wells (fig. 5; pl. III), thin, ripple cross-stratified, laterally reworked quartz-sandstone beds lie between two principal

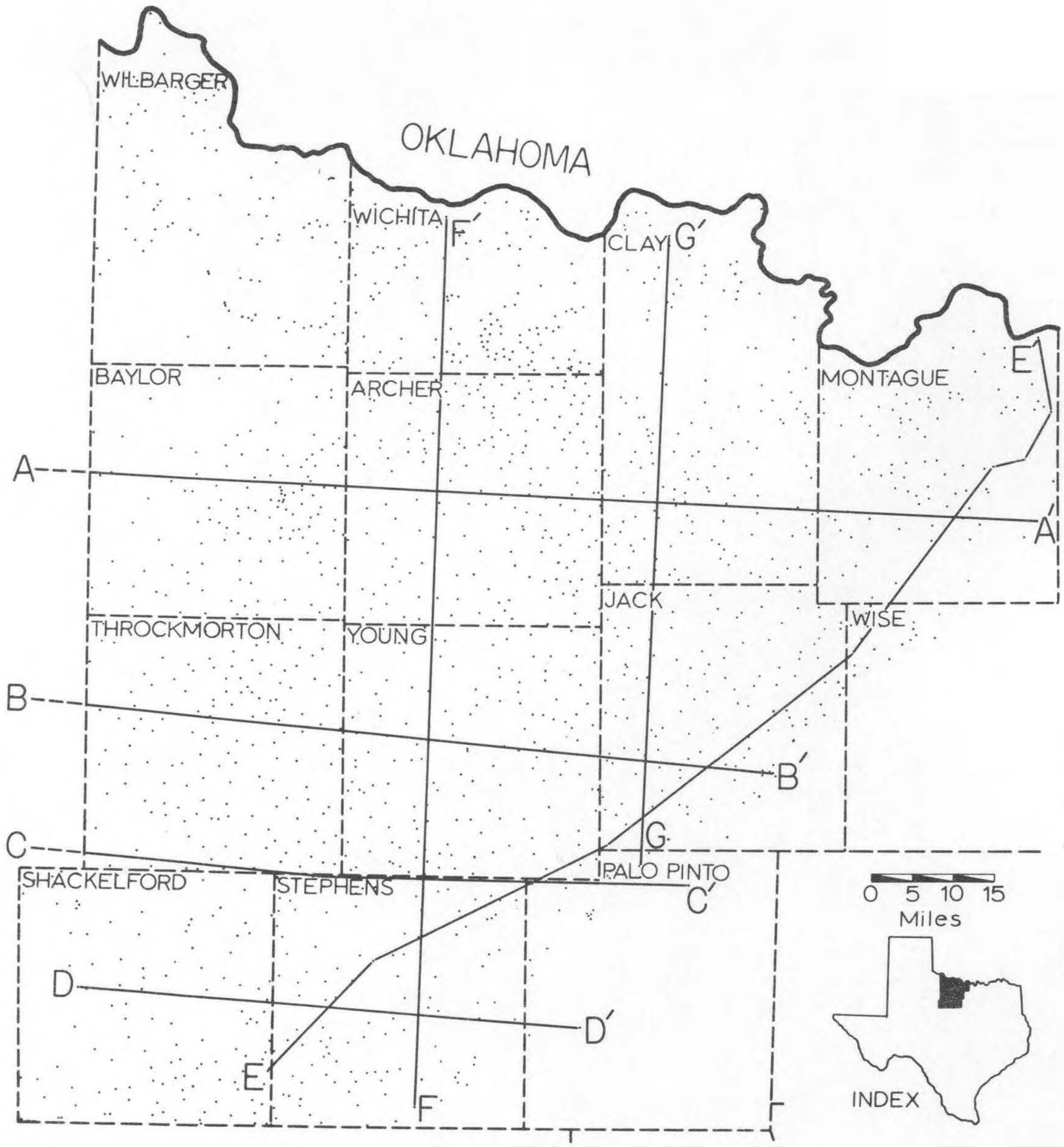

Figure 19. Index map showing positions of Canyon Group cross sections in North-Central Texas; all cross sections employ the top of the Home Creek Formation as the stratigraphic datum (well names and locations on open file, Bureau of Economic Geology, The University of Texas at Austin).

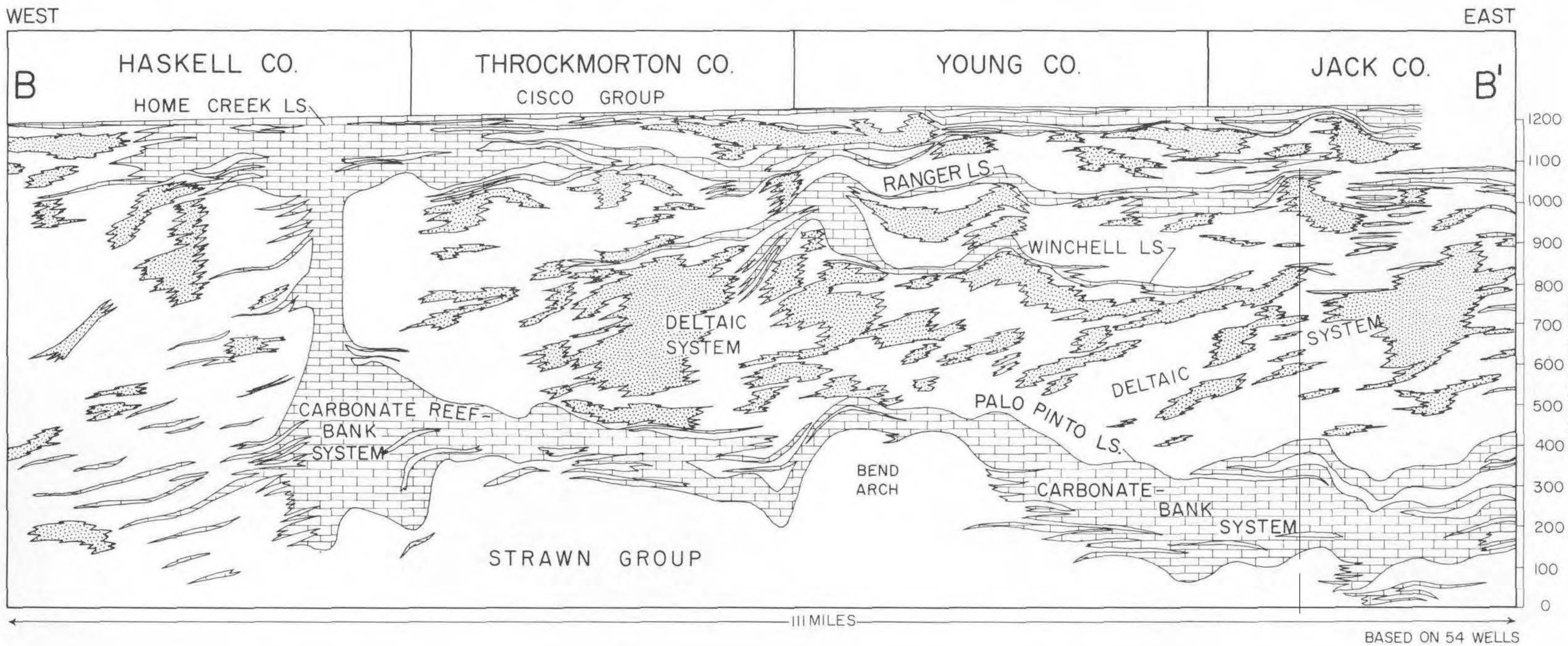

Figure 20. Subsurface cross section B-B′ (dip) from Jack County on the east to western Haskel County, Texas, on the west, showing deltaic and carbonate facies of the Canyon Group; based on 54 electric and sample logs. See figure 19 for line of section.

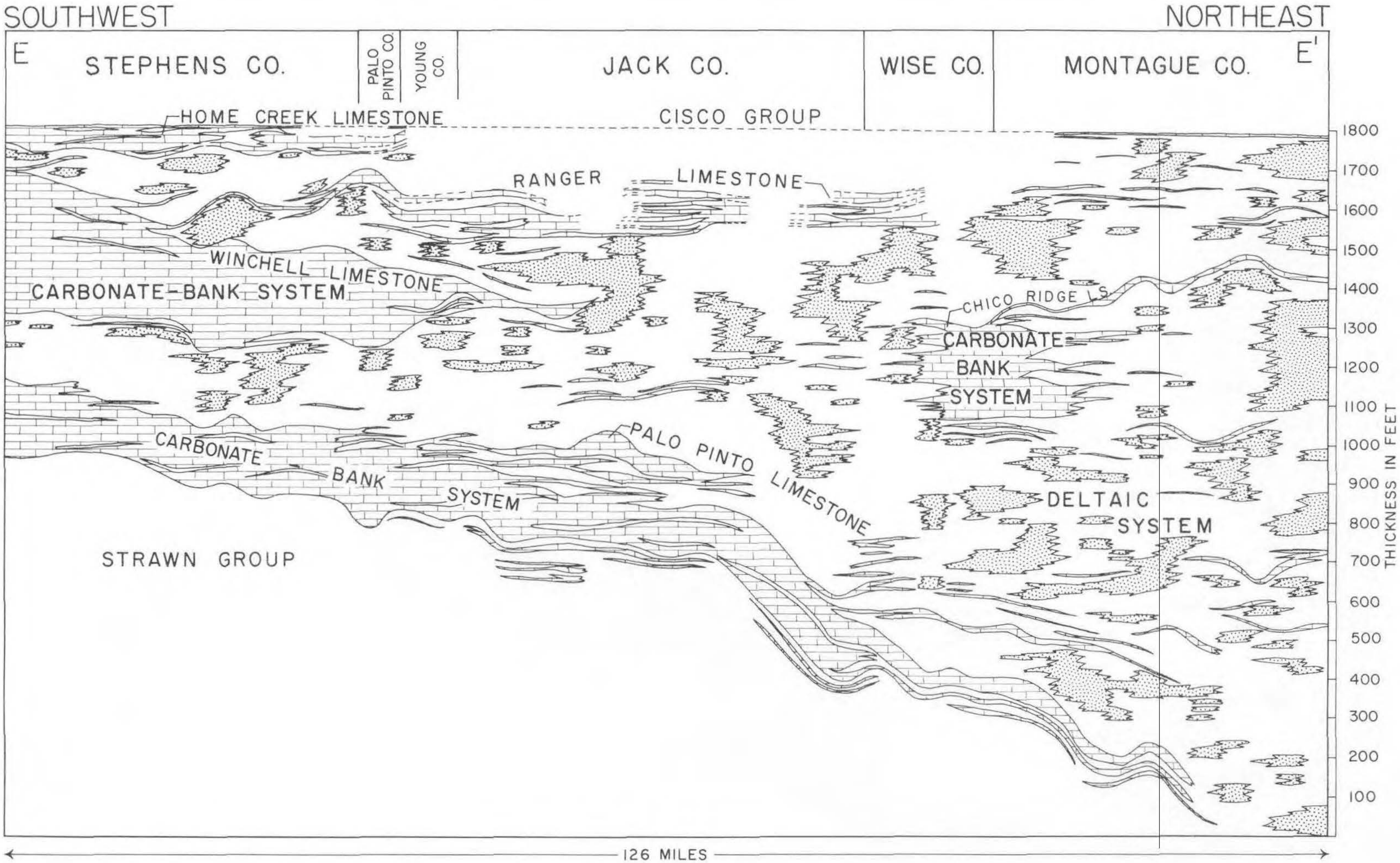

Figure 21. Shallow subsurface cross section E-E′ (strike) from Stephens to northern Montague Counties, Texas, showing facies of the Canyon Group; based on 48 electric and sample logs. See figure 19 for line of section.

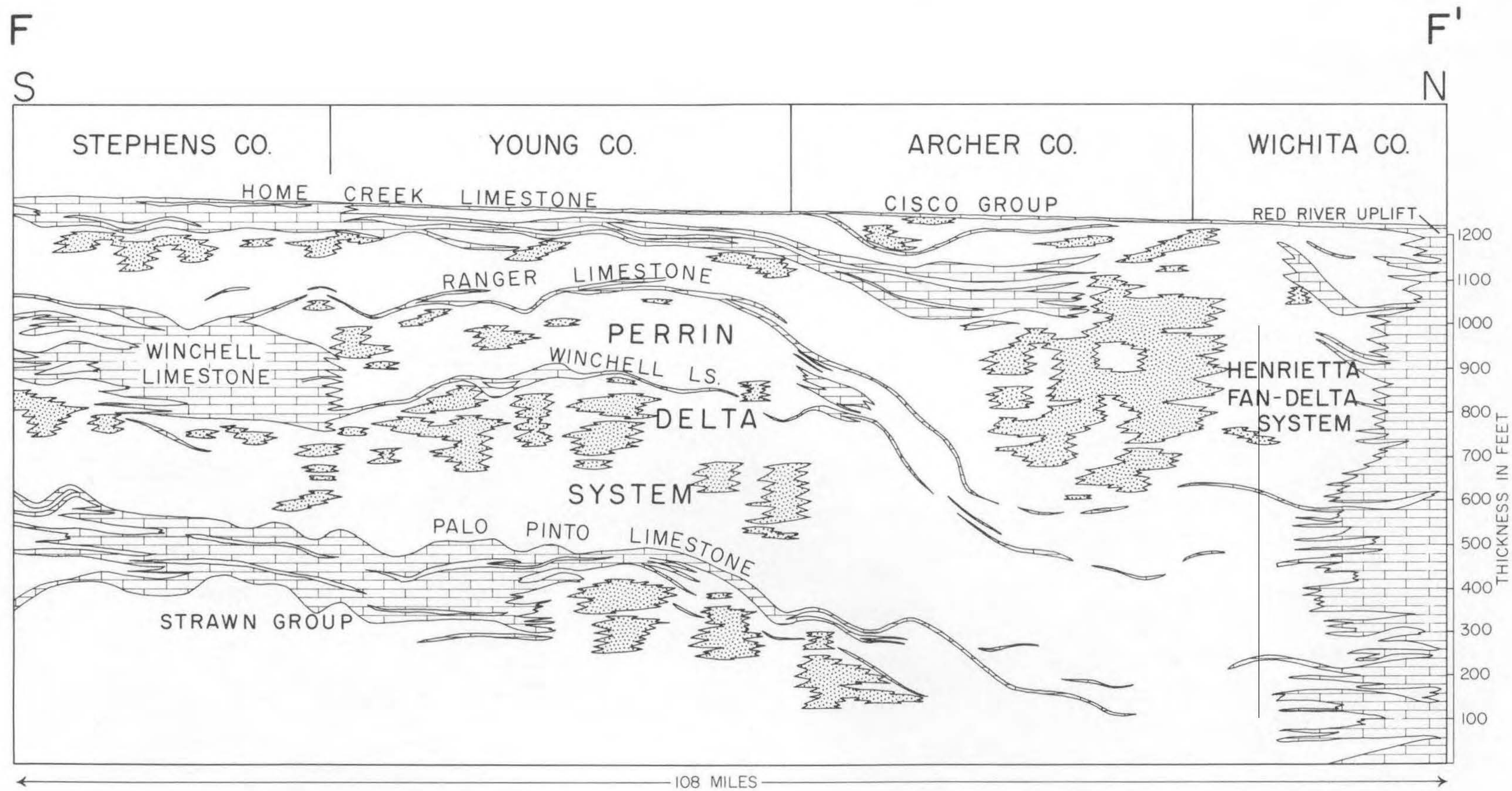

Figure 22. Subsurface cross section F-F′ from Stephens County northward to northern Wichita County, Texas, showing deltaic and carbonate facies of the Canyon Group; based on 45 electric and sample logs. See figure 19 for line of section.

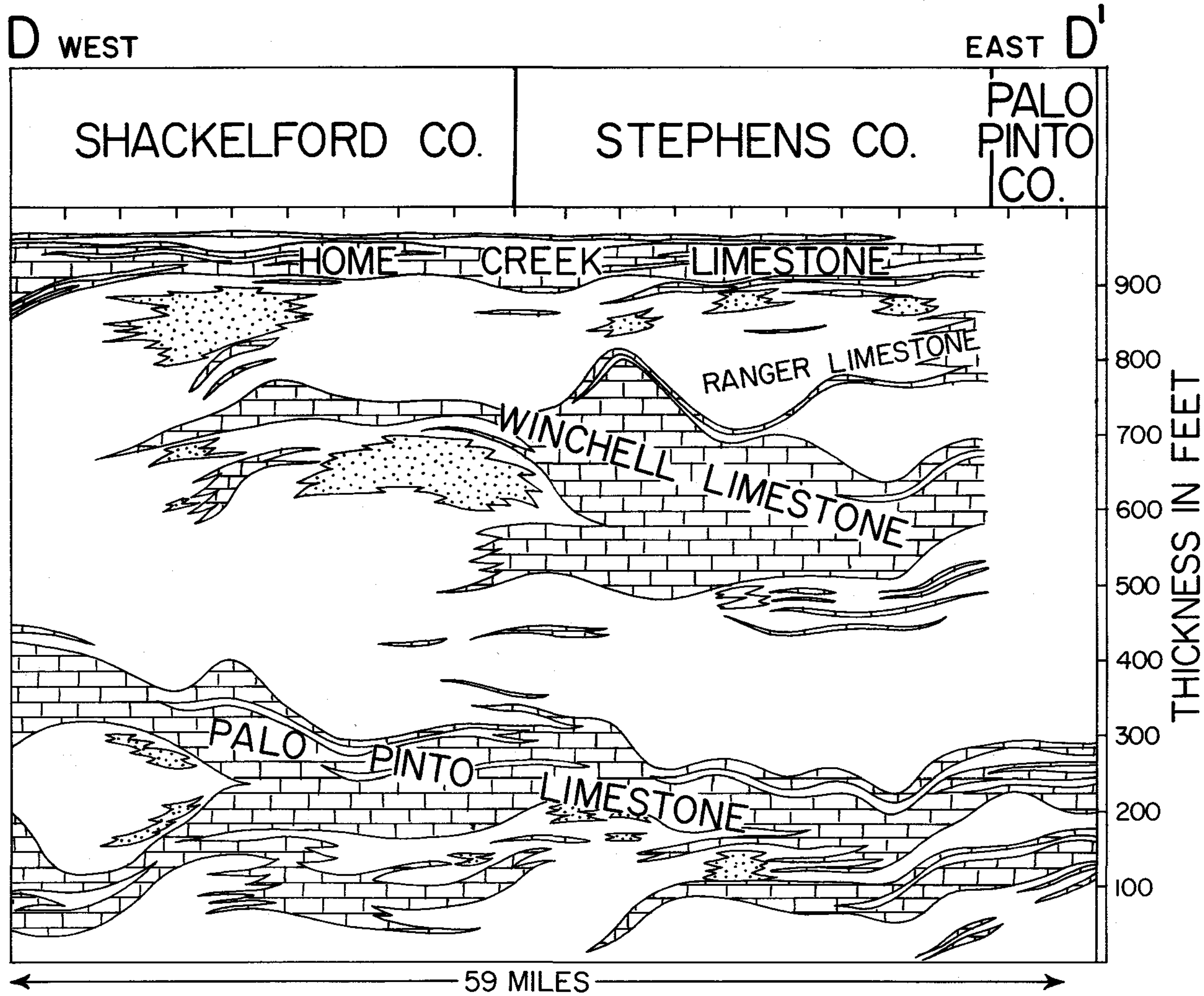

Figure 23. Subsurface cross section D-D′ from near outcrop in Palo Pinto County westward to western Shackelford County, Texas, showing carbonate and shelf-mudstone units and local deltaic sands of the Canyon Group; based on 20 electric and sample logs. See figure 19 for line of section.

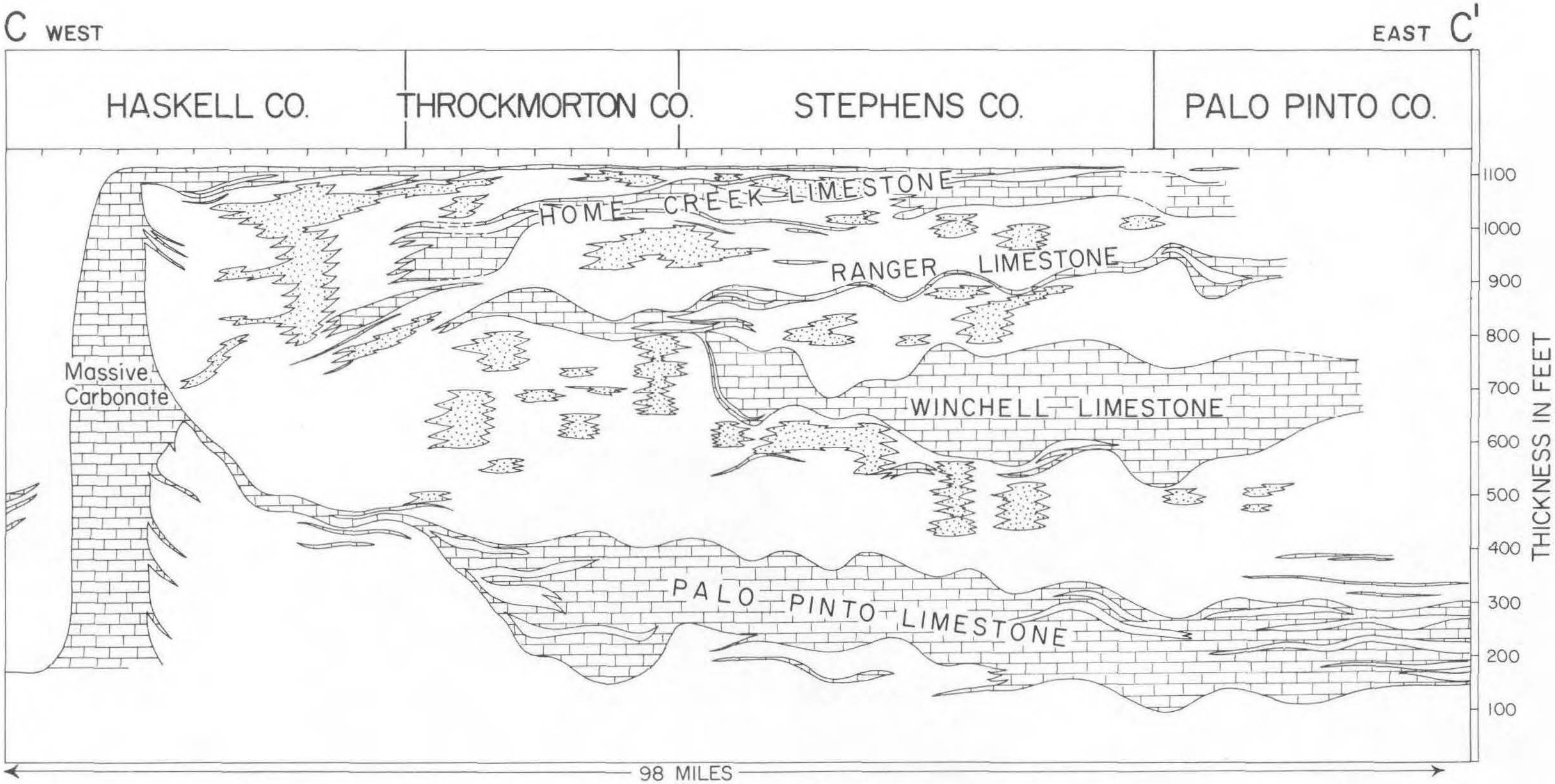

Figure 24. Subsurface cross section C-C′ from near outcrop in Palo Pinto County westward to western Haskell County, Texas, showing Canyon Group deltaic sandstone and mudstone units separated by shelf carbonates with a massive reef-bank carbonate buildup near the Missourian shelf edge; based on 39 electric and sample logs. See figure 19 for line of section.

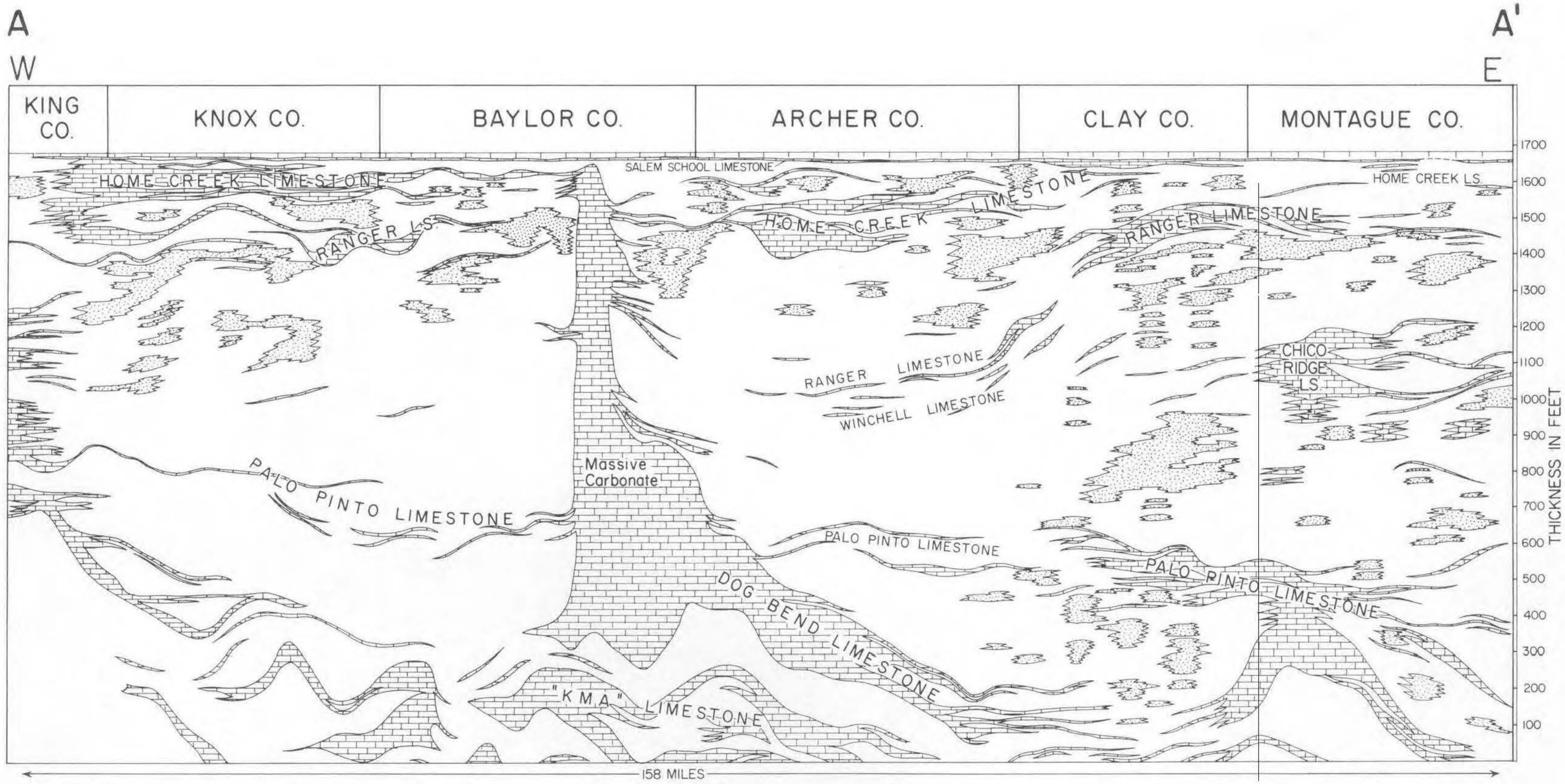

Figure 25. Subsurface cross section A-A′ from the shallow subsurface of eastern Montague County westward to eastern King County, Texas, showing deltaic and carbonate facies of the Canyon and upper Strawn Groups with a massive reef-bank carbonate buildup in eastern Baylor County; based on 59 electric and sample logs. See figure 19 for line of section.

limestone members of the Ranger Formation. Algal-crinoid carbonate of the lower Ranger Limestone Member was deposited contemporaneous with deltaic sediments a few miles to the southwest in the State Highway 199 - Beans Creek area (pl. I). As the delta lobes were gradually abandoned, marine processes reworked delta-front and distributary channel facies and spread the clastic sediments along strike, eventually overlapping the lower limestone member of the formation. Eventually, the upper member of the Ranger Limestone transgressed the entire Placid clastic sequence (fig. 5).

Interval 3: Colony Creek Formation.—With initiation of Colony Creek deposition, delta lobes prograded over updip Ranger shelf-carbonate facies. Elimination of Ranger Limestone deposition occurred at different times on various parts of the Eastern Shelf; for example, Ranger Limestone deposits in Stephens and Shackelford Counties may be time-equivalent with Perrin deltaic facies to the northeast within the Colony Creek Formation.

The distribution of lithofacies (pl. I; fig. 5) demonstrates that deltaic lobes prograded basinward through central Jack and Wise Counties during deposition of the Colony Creek interval. Composition, sedimentary structures, and stratigraphic relationships of Perrin sandstone and mudstone facies within the Colony Creek Formation resemble those in the underlying Wolf Mountain and Placid Formations. Plant-rich, fine-grained deltaic sandstone units overlie and flank sandy prodelta and interdeltaic mudstone facies. Within the Colony Creek Formation, fluvial channels, filled with coarse-grained sandstone and conglomerate, cut finer grained, subjacent deltaic sandstone and mudstone units; these channel-fill deposits crop out east and northeast of Jacksboro. The Cundiff Limestone, which occurs within the Colony Creek Formation south of the community of Cundiff in eastern Jack County (pl. I), is a thin, algal- and crinoid-rich facies that was probably deposited within a local bay-lagoon environment that formed following abandonment of an early Colony Creek deltaic lobe.

Principal Perrin fluvial-deltaic facies within the Colony Creek Formation (pl. VIII) extend basinward across western Jack, northeastern Young, southeastern Archer, and southwestern Clay Counties from outcrops north and west of Barton's Chapel (pl. I). At outcrop, these facies include thick, fluvial conglomerate units, which overlie and locally eroded finer-grained, subjacent deltaic facies. Two linear trends composed of 100 to 150 feet of net sandstone extend northwestward downdip from outcrop; thick narrow belts on the net-sandstone map may reflect the downdip limits of the coarse-grained fluvial facies.

Relatively thin, minor Perrin delta lobes trend westward across southeastern Young and central Stephens Counties; these may be observed at the outcrop in southern Jack, northwestern Palo Pinto, and eastern Stephens Counties. Thin, ripple cross-stratified, fine- to very fine-grained marine sandstone facies of strike-fed origin are common in the Colony Creek interval south of Lake Possum Kingdom (western Palo Pinto and eastern Stephens Counties). In northwestern Stephens, southwestern Young, southeastern Throckmorton, and northern Shackelford Counties, narrow trends with high net-sandstone values (pl. VIII) define northeast-southwest belts which may represent strike-fed barrier islands or strandplain sequences. These sands were derived from Perrin delta lobes to the northeast and Henrietta fan-delta lobes to the north. These strike-oriented linear sandstone trends appear to be isolated from principal dip-oriented net-sandstone trends of either the Perrin system or the Henrietta system. Individual strike-oriented sandstone units are 10 to 60 feet thick; electric log patterns of these facies exhibit blocky spontaneous potential and resistivity profiles with relatively sharp tops and bases. Well-developed, coarsening-upward sequences, common in deltaic facies, were not recognized on electric logs through these strike-oriented facies.

Locally, in the subsurface of south-central Shackelford County, the entire Colony Creek Formation is replaced by massive carbonate with thin, intercalated shaly beds (pl. VIII); the carbonate sequence terminates upward at the top of the Home Creek Limestone. Absence of terrigenous clastic progradation in this area permitted carbonate deposition to continue throughout most of Missourian time. Periodic influx of terrigenous sediment from prograding deltas to the north and east temporarily eliminated carbonate deposition in local areas. Nevertheless, algal-crinoid bank shoals and sheetlike biostromal deposits persisted in the southwest contemporaneous with deposition of deltaic lobes to the northeast (pl. VIII).

DEPOSITIONAL HISTORY OF THE PERRIN DELTA SYSTEM

The high-constructive Perrin delta was a persistent system composed of west- and northwest-trending lobes that prograded across the Eastern Shelf throughout most of Missourian time (fig. 26). Early delta development began during deposition of the lower part of the Wolf Mountain Formation of Wise, Montague, Palo Pinto, and Stephens Counties when relatively minor delta lobes prograded west and northwest supplied by sources in the Ouachita foldbelt. As these minor lobes were abandoned and began to subside, shoal-water algal-crinoid banks became established on the foundering deltaic platforms. The Winchell carbonate bank and the Chico Ridge carbonate bank remained depositionally high with respect to the surrounding sea floor. Brecciated-carbonate talus beds, such as the Rock Hill Limestone of western Wise County, were periodically shed from the elevated carbonate environments.

Following the establishment of the Winchell and Chico Ridge banks during middle Wolf Mountain deposition, major high-constructive Perrin deltas prograded westward across Jack County. The path of the prograding system may have been, in part, controlled by the presence of the carbonate banks to the north and south.

Longshore currents and waves reworked abandoned deltaic facies and transported terrigenous sediment along strike. Thin blankets of terrigenous silt and clay, which were intermittently deposited over lime mud and phylloid algae on the carbonate banks, caused local termination of carbonate deposition, marked by thin terrigenous clastic beds within the carbonate sequences. In this manner, strike-fed sand and mud from the Perrin delta system of Jack County interfingered to the southwest and northeast with carbonate-bank facies in the Lake Possum Kingdom and Lake Bridgeport areas, respectively.

During deposition of the Wolf Mountain Formation, and the lower and middle parts of the Winchell and Chico Ridge Limestones, the Perrin delta system prograded across Jack, Young, southern Clay, southern Archer, southeastern Baylor, and eastern Throckmorton Counties. Following abandonment and subsidence of the delta system, the Winchell Limestone of northern Palo Pinto and southern Jack Counties and the Devil's Den Limestone of Jack and Wise Counties spread laterally from the carbonate banks and onlapped the Perrin delta. Continued, but local progradation of minor deltaic lobes, as well as marine reworking of deltaic sand, prevented transgressive Winchell carbonates from completely overlapping the delta in southeastern Jack County.

Renewed deltaic progradation, which marked the beginning of Placid deposition, overwhelmed transgressive carbonate environments in Jack, Wise, Montague, Clay, Palo Pinto, and northern Stephens Counties, but an elevated carbonate-bank system persisted in western Stephens and southeastern Shackelford Counties. High-constructive deltaic lobes again built northwestward and westward, in part contemporaneous with lower Ranger carbonate deposition in the area east and southeast of Wizard Wells in eastern Jack County. With gradual abandonment of this phase of Perrin delta progradation, carbonate facies of the Ranger Limestone shelf overlapped the subsiding delta.

For a third and final time, transgressive shelf-carbonate environments (Ranger Limestone) were overridden by thick deltaic lobes and coarse-grained fluvial systems during Colony Creek deposition. Major Perrin delta lobes built northwestward across Jack, Wise, southwestern Montague, southern Clay, southeastern Archer, and northern Young Counties; whereas minor delta lobes built basinward across Stephens and southeastern Young Counties. Linear, strike-oriented sandstones were deposited in southeastern Throckmorton, southwestern Young, northwestern Stephens, and northeastern Shackelford Counties. These deposits probably represent reworked, strike-fed barrier island and strandplain facies that formed adjacent to the Perrin delta. Upon final abandonment of the Perrin delta system, the transgressive Home Creek Limestone locally covered deltaic sandstone and mudstone facies of the Colony Creek Formation.

Deltaic and fluvial systems prograded across the Eastern Shelf many times from sources in the Ouachita foldbelt. Brown (1969) states that from 10 to 15 repetitive fluvial-deltaic sequences exist in the Cisco Group. Cisco deltas seem to have followed a paleosurface controlled by underlying Home Creek Limestone deposits.

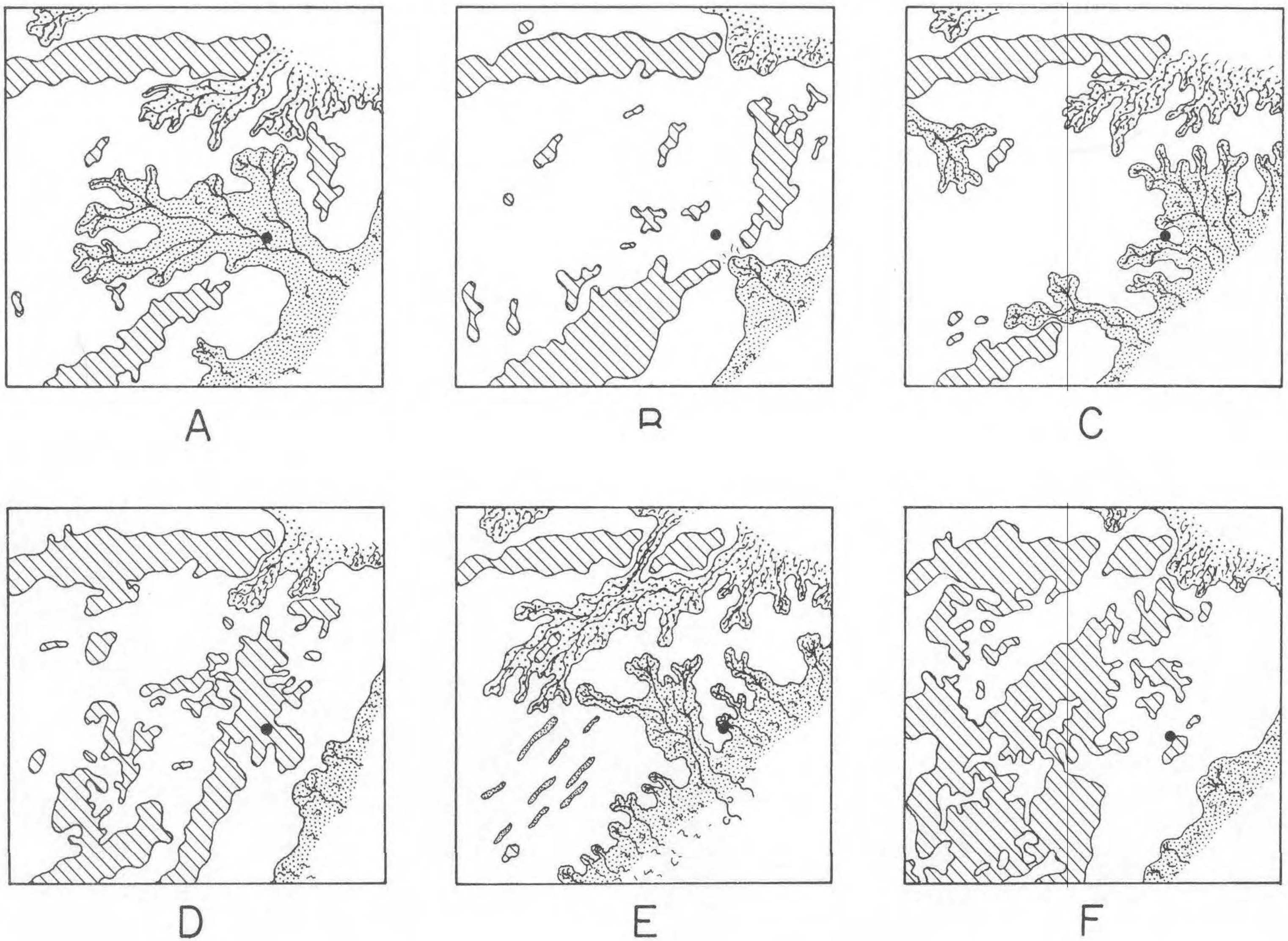

Figure 26. Evolution of paleogeography, Canyon depositional systems, North-Central Texas. Fine stipple indicates high-constructive elongate and lobate delta system; coarse stipple indicates fan-delta system; parallel lines indicate carbonate systems; and black dot marks position of Jacksboro, Texas. (A) Wolf Mountain time, (B) Winchell time, (C) Placid time, (D) Ranger time, (E) Colony Creek time, (F) Home Creek time.

PERRIN DELTA MODEL

A three-dimensional representation of a high-constructive Perrin delta lobe (fig. 27) indicates that laminated, essentially unfossiliferous prodelta mud was deposited in front of advancing distributaries. Thinly bedded, commonly graded, distal delta-front fine-grained sand and silty mud overrode the prodelta facies; thin organic-rich sandstone beds commonly slumped down the gently sloping face of the prodelta slope and became complexly contorted.

As delta distributaries prograded contemporaneously with nearby carbonate-bank accumulation, proximal delta-front and distributary-mouth bar sand was deposited on thin-bedded, distal sand and silt facies. Distributary channels scoured into underlying delta-front sand and interdistributary silt and mud. Locally, delta-plain mud and silty mud with thin peat beds were deposited on and laterally adjacent to distributary channel-fill deposits. Thin delta-plain deposits, which were reworked after delta abandonment, were rarely preserved. Thin, vuggy, bioturbated sandstone beds containing *Myalina* were commonly deposited on abandoned delta sequences. Following total delta abandonment and marine transgression, highly fossiliferous shelf mud, followed by superposed, open-shelf algal carbonate, was deposited over the abandoned delta sediments. Thick deltaic sequences were deposited rapidly compared with relatively thin, highly fossiliferous shelf-mudstone and open-shelf transgressive carbonate facies.

The Holocene Guadalupe delta at the head of San Antonio Bay, Texas (Donaldson and others, 1970) bears similarities to the Perrin delta system. Distributary channels of the Guadalupe delta have eroded underlying prodelta and bay deposits, a relationship common in the Perrin delta system. The Guadalupe delta progrades into shallow water, as did the Perrin delta. Donaldson and others (1970) suggest that this may account for the slight overlap and stacking of Guadalupe subdeltas and for the relatively thin prodelta sequences. Subsidence of the Guadalupe delta is relatively slow and generally results from slight compaction of thin prodelta and estuarine muds.

The Mississippi delta platform, on the other hand, significantly subsides within thick prodelta and delta-front facies. In the Gulf Coast Basin, many Tertiary and Quaternary delta facies are stacked vertically. Under relatively stable tectonic conditions, such as those afforded by the Pennsylvanian Eastern Shelf, however, deltaic lobes tend to prograde rapidly and spread extensively with little vertical stacking of facies (Brown, 1969). Delta-plain sediments deposited under these conditions are thin, and the slow subsidence rates allow ample time for marine destruction of thin delta-plain peats and peaty muds.

Somewhat similar delta models for Paleozoic rocks have been proposed by Pepper and others (1954), Moore (1959), Allen (1959), Friedman (1960), Pryor (1961), Potter (1963), Wanless and others (1963), Beerbower (1964), Swann (1964), Williams and others (1964), Donaldson (1966, 1969), Duff (1967), Wright (1967), Brown (1969), Wanless and others (1970), Galloway and Brown (1972), and Brown and others (1973).

HENRIETTA FAN-DELTA SYSTEM

FAN-DELTA PROCESSES AND FACIES

A fan delta is an alluvial fan that progrades into a body of water from an adjacent highland (McGowen, 1970). "Fan delta" was first used by Holmes (1965) in referring to a delta at Lynton and Lynmouth on the Bristol Channel, Devon, England. Friedman and Johnson (1966) propose the term "tectonic delta" for a delta composed chiefly of orogenic sandstone and conglomerate, contiguous to an active mountain front. Little difference exists between Friedman and Johnson's "tectonic delta" and a fan delta as defined by McGowen (1970). Although modern terrestrial-alluvial fans have received much attention by workers such as Blissenback (1954), Beaty (1963), Bull (1963), Denny (1964), Hooke (1967), and others, fan deltas have received relatively little study. McGowen (1970) presents what was probably the first complete study of the processes and sedimentary products of a small, active fan delta. Kidson (1953) describes a flood on the Lynmouth fan delta, which transported boulders up to 20 feet in diameter and deposited 50,000 cubic yards of sediment on the delta in 24 hours.

Fan deltas, like alluvial fans, have relatively small drainage areas and flashy runoff. McGowen (1970) states that during high flood stage, a sheetwash of small braided streams covers the entire surface of the Gum Hollow fan delta in Nueces Bay, Texas. As floodwaters subside, a

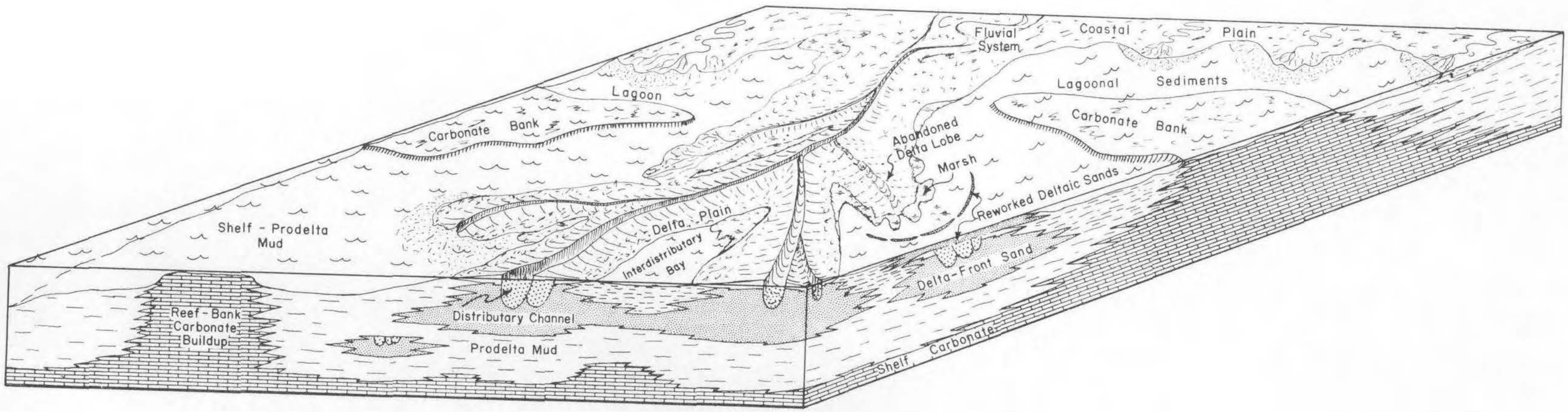

Figure 27. Block diagram model of a prograding high-constructive Perrin delta lobe showing gross facies framework and associated carbonate systems.

braided central channel is scoured down the axis of the delta. Gum Hollow delta aggrades only during periods of high runoff, such as during hurricanes and tropical storms.

Sedimentation on fan deltas is accomplished by the activity of relatively high-gradient braided streams. In as much as gradient is high and runoff is flashy, the ratio of coarse-grained to fine-grained sediments is much higher in fan deltas than in high-constructive lobate and elongate deltas. The braided fluvial system of a fan delta extends essentially all the way to the toe of the delta. Distributaries are generally short and braided. The system is choked with bed-load sediment which is transported only during peak runoff periods.

Thick, coarse-grained fan-delta wedges tend to stack in localized areas along actively rising mountain fronts. Stacked alluvial fan and fan-delta sediments are commonly bounded by a normal fault along a mountain front; the fault may move during deposition of the coarse facies. Maximum thickness of fan deposits occurs next to the source, adjacent to the bounding fault. Fan deltas, like alluvial fans, may be composed of feldspathic sand and gravel and sediments such as chert, limestone pebbles and cobbles, and poorly resistant rock fragments of various kinds. Preservation of non-resistant rock materials is possible because of the short transport distances.

DISTRIBUTION OF HENRIETTA FAN-DELTA LOBES

The Henrietta fan-delta system is named for the town of Henrietta, Texas, in north-central Clay County. It is used to refer to the thick system or wedge of coarse clastic facies deposited in this part of North-Central Texas during Middle and Late Pennsylvanian times. The Henrietta fan-delta system occurs entirely in the subsurface and, therefore, a detailed interpretation of facies relationships based on surface exposures cannot be made.

Wolf Mountain Formation.—Net-sandstone values of the Wolf Mountain Formation (pl. IV) reveal the presence of thick sandstone facies in northern Montague, northern and eastern Clay, southeastern Wichita, and northeastern Archer Counties, which extend southward from southern Oklahoma. The thick sequence in northern Montague County apparently prograded southward, while two thick lobes of sandstone in northern Clay County trend southwestward. The multistory nature of these massive, terrigenous clastic lobes is readily apparent from the magnitude and close spacing of the isolith lines along individual narrow trends. In northern Clay County, net-sandstone values for the Wolf Mountain Formation alone locally increase from about 25 feet to almost 500 feet in less than 3 miles. Nowhere does the Perrin delta system display such rapid changes in sand thickness.

The largest lobe of the Henrietta system prograded southwestward across northern Clay and into Wichita and Archer Counties during deposition of the Wolf Mountain Formation. The system bifurcated several times with smaller sublobes extending southward. The principal trend extends across Wichita County near Wichita Falls, and terminates in northern Archer County near the town of Holliday.

The thick Henrietta lobe in northern Clay County is contiguous with the eastern end of the Red River carbonate platform. In less than 2 miles, the Missourian section changes from massive, coarse clastic facies of the Henrietta system to massive platform-carbonate facies. The thick fan-delta lobe may rest in a "canyon" cut through the eastern end of the carbonate platform, or the clastic system may have simply built around the end of the platform, contemporaneous with carbonate deposition. Little interfingering of the massive clastic and carbonate facies occurs below the Ranger Limestone of northern Clay County (fig. 28, Section G-G′). The thick sandstone and conglomerate facies of the Henrietta system occupy virtually the entire Canyon (Missourian) interval.

The Henrietta lobe of eastern Clay County exhibits a well-defined, thick, narrow trend extending southwestward from the northwestern corner of Montague County. Southeast of the town of Henrietta, the narrow belt of clastic facies spreads into a broad fan. Northern lobes of the Perrin delta system interfingered with southern lobes of the fan-delta system in south-central Clay County. Sediments prograded into this area both from sources in the Ouachita foldbelt and from the mountains of southern Oklahoma.

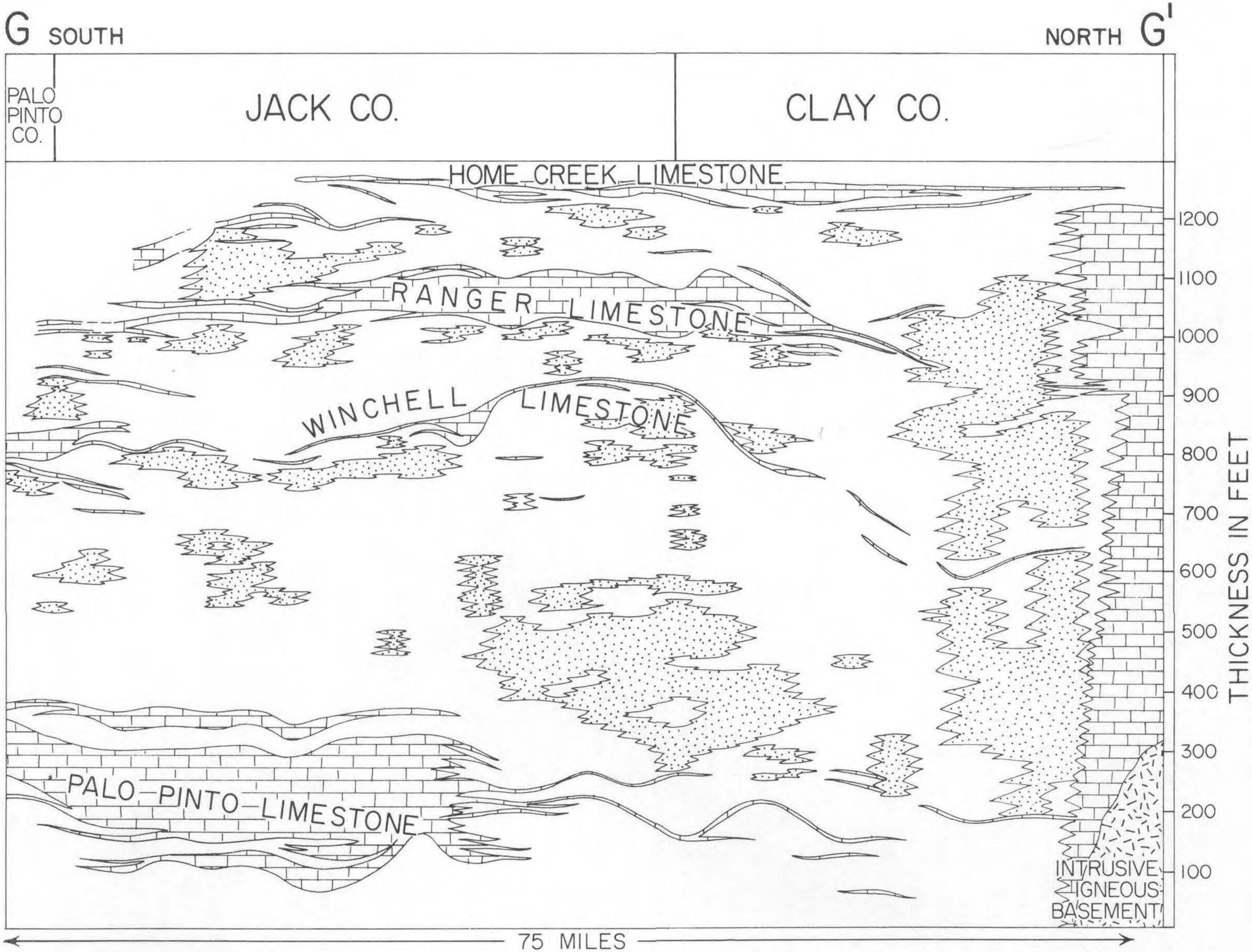

Figure 28. Subsurface cross section G-G′ (strike) from the shallow subsurface of Palo Pinto County northward to northern Clay County, Texas, showing deltaic and carbonate facies of the Canyon Group. Massive carbonate-platform facies cap igneous rocks of the Red River uplift in northern Clay County; based on 28 electric and sample logs. See figure 19 for line of section.

Limestone was rarely deposited across the main Henrietta lobe because of the virtually continuous influx of clastic sediments; minimal compaction of the coarse terrigenous clastics also provided for only little subsidence. Slight pauses in deposition occurred, however, since one thin limestone, approximately equivalent to the Winchell Limestone, extends most of the way across the lobe (fig. 28, Section G-G′).

Placid Formation.—During deposition of the Placid Formation (pl. VI), small fan-delta lobes continued to prograde into northern Montague County. The lobe in northeastern Clay County maintained its same general location, but was greatly reduced in size. The principal lobe persisted in northern Clay, southeastern Wichita, and northeastern Archer Counties; its areal distribution remained basically the same as that of the underlying Wolf Mountain Formation.

Colony Creek Formation.—During deposition of the Colony Creek Formation (pl. VIII), small fan-delta lobes persisted in northern Montague and northeastern Clay Counties at almost the same positions as in underlying formations. The principal lobe, however, prograded some 50 miles farther southwestward across the Eastern Shelf, where it encircled an outer shelf reef-bank buildup in west-central Baylor County. Several lobes developed in Baylor County, some of which extended southward into northern Throckmorton County. Net-sandstone values up to 435 feet occur in northwestern and north-central Archer County, as the system was rejuvenated by sediment input from late Missourian phases of the Arbuckle orogeny (Tomlinson and McBee, 1959).

Thick sandstone units of the Henrietta fan-delta system in northern Archer and southern Wichita Counties are confined principally to the Colony Creek Formation (fig. 22, Section F-F′). Massive carbonate facies of the Red River carbonate platform in northern Wichita County, unlike the massive carbonate facies of northern Clay County, interfinger with surrounding shales, indicating a contemporaneous depositional relationship.

As the Arbuckle orogeny progressed, stream gradients and sediment supplies increased. During deposition of the Colony Creek Formation, the Red River carbonate platform began to be dissected by southward-prograding fan-delta wedges; one lobe prograded through northeastern Wichita County between individual carbonate-platform areas (pl. VIII). North of the Red River uplift, in northern Wilbarger County, fan-delta lobes built southwestward into the eastern end of the Hardeman Basin during the Missourian Epoch (pls. IV, VI, VIII). Fan-delta lobes in the Hardeman Basin reached thicknesses of 100 to 150 feet during deposition of each of the three Canyon formations. During Virgilian time, the Red River platform was completely covered by southward-advancing, probably fan-delta deposits which originated in the southern Oklahoma mountains (as indicated by thick sandstones noted on well logs in the area).

LITHIC CHARACTERISTICS

Electrical logs of Henrietta fan-delta facies in northern Clay County (fig. 29) exhibit profiles that indicate massive sandstone facies. Coarsening-upward sequences are rare; most individual stratigraphic units display rather sharp bases and tops, characteristic of rapidly deposited clastic sediments largely in the form of braided stream deposits. Well samples contain feldspathic sandstone or arkose, or what is commonly referred to as "granite wash." Edwards (1959) studied thick Missourian coarse clastics on the north side of the Wichita Mountains along the southern edge of the Anadarko Basin and reports that "The term granite wash is applied to a coarse clastic sediment composed primarily of igneous rock fragments ranging in size from silt to boulders, with varying amounts of detrital carbonates and cherts" (p. 142). He further states that ". . . subordinate facies are arkosic sandstone, arenaceous, silty shales, and thin, argillaceous limestones" (p. 150). Composition of thick clastic sequences of the Henrietta fan-delta system is, for the most part, similar to that described by Edwards, based on available sample log descriptions.

HENRIETTA FAN-DELTA MODEL

Tomlinson (1929) describes the model of the Henrietta system when he interprets the sequence to be ". . . gravels, sands and silts of a piedmont alluvial plain bordering the Arbuckle-Wichita mountain system" (p. 73). As the Arbuckle and Wichita Mountain ranges were uplifted during the two basic phases of the

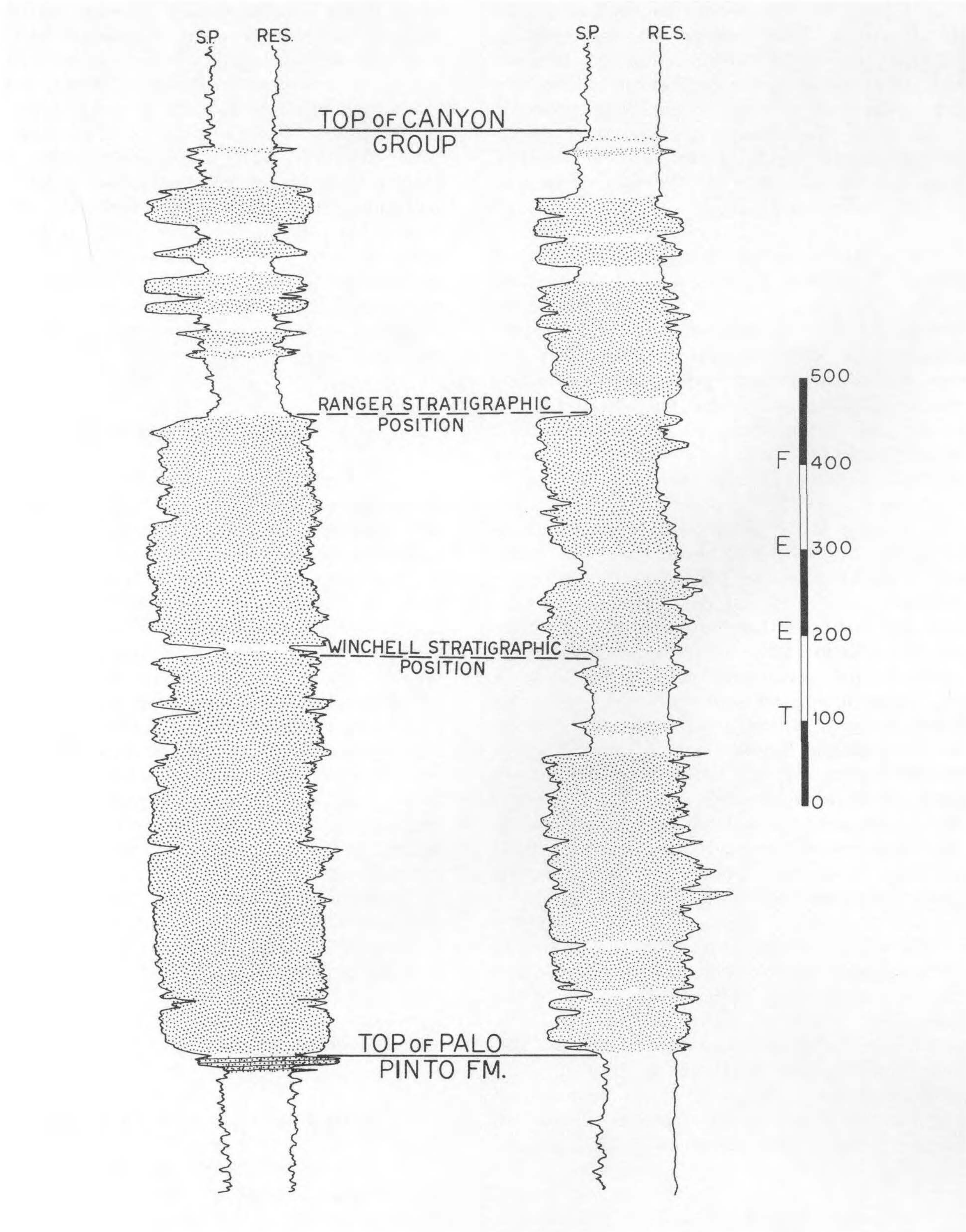

Figure 29. Typical electric log patterns (spontaneous potential and resistivity) of stacked coarse arkosic clastics of a massive Henrietta fan-delta lobe, Canyon Group, northern Clay County, Texas.

Arbuckle orogeny (late Desmoinesian and late Missourian through Virgilian), thick, coarse-grained alluvial fan and fan-delta aprons were shed both to the north and to the south (Tomlinson and McBee, 1959). Southward-advancing systems filled the relatively shallow Ardmore and Marietta Basins and, in Missourian time, built across the tectonically inactive Muenster Arch into North-Central Texas.

The basin immediately south of the Muenster Arch - Red River uplift was a northern remnant of the Fort Worth Basin. As sediments of the Henrietta system were introduced from the north, this fault-bounded basin subsided, allowing fan-delta wedges to stack to great thicknesses.

By contrast, the Perrin high-constructive delta system to the south prograded over a tectonically stable shelf composed of thick Desmoinesian sediments resting on massive carbonates of the Concho Platform. Subsidence was slow and clastic sequences did not stack to great thicknesses; rather, deltas prograded rapidly basinward as a series of relatively thin, shifting lobes. The Perrin delta system was fed by low-gradient streams, which crossed a broad coastal plain immediately west of the Ouachita Mountains. On the other hand, the Henrietta fan-delta system was fed by high-gradient (as evidenced by the coarse, poorly sorted load), probably braided streams which crossed a relatively narrow, fault-bounded coastal plain composed of stacked wedges of alluvial fan and fan-delta sediments.

The principal lobe of the Henrietta fan delta persisted throughout most of Missourian time. The trend of this system must certainly have been controlled by a zone of structural weakness and subsidence south of the Red River uplift. A structural, probably fault-bounded, low trend extends south westward from northern Clay County (fig. 4). This trough seems to have guided the path along which the principal Henrietta fan-delta lobe advanced.

Although distal fan-delta facies are subaqueous, much of the Henrietta system was a subaerial deltaic plain as evidenced by the fact that little carbonate has been recognized within the clastic lobes. In addition, thin coal deposits are associated with the principal Henrietta lobe in north-central Clay, eastern Wichita, northern Baylor, and north-central Throckmorton Counties.

The depositional framework of the Yallahs Basin area, southeast of Kingston, Jamaica (fig. 30), is structurally controlled, and the basin may be fault bounded (Burke, 1967). Two fan deltas, which are currently prograding into the subsiding basin from the adjacent Port Royal and Dallas Mountains, have built large subaqueous fans extending from the subaerial deltas to the basin floor. Gradients on the fans are high, and sediments include fragments of andesite and granodiorite with a clastic carbonate fraction averaging 30 percent by weight. Along the west side of the Yallahs Basin, a steep scarp supports the California Carbonate Bank and island shelf composed of carbonate detritus with local reefs. Submarine canyons locally cut through this detrital carbonate platform (Burke, 1967).

The Henrietta fan-delta system resembles the Yallahs Basin model in some respects. For example, thick wedges of coarse-grained, feldspathic sand were deposited in the northern remnant of the Fort Worth Basin, fed by nearby sources in the Arbuckle-Wichita Mountains. The Red River carbonate platform lay just to the west and north of the fan system. The Henrietta system, however, did not build across the Muenster Arch and spill over into a 1,200-meter-deep basin, as do the Yallahs fan deltas. The Henrietta deltas prograded into a relatively shallow, yet subsiding trough. Rates of subsidence in the shallow, tectonically unstable northern Fort Worth Basin kept pace with, or slightly lagged behind, clastic sediment input, as evidenced by the presence of thin coal beds.

Another example of a large-scale modern fan delta that progrades into a tectonically unstable basin occurs along the northwestern shores of the Gulf of California, with sediment sources in the mountains of Baja, California (Thompson, 1968). Examples of other ancient alluvial fan - fan-delta sequences have been described by Mallory (1958), Murray (1958), Allen (1965), Laming (1966), Meckel (1967), Allen and Friend (1968), Klein (1968), Nilsen (1968, 1969), Wilson (1970), and McGowen and Groat (1971).

CARBONATE SYSTEMS

The Canyon Group was originally defined as a group of thick carbonate units with interstratified shale and sandstone beds that crop out in

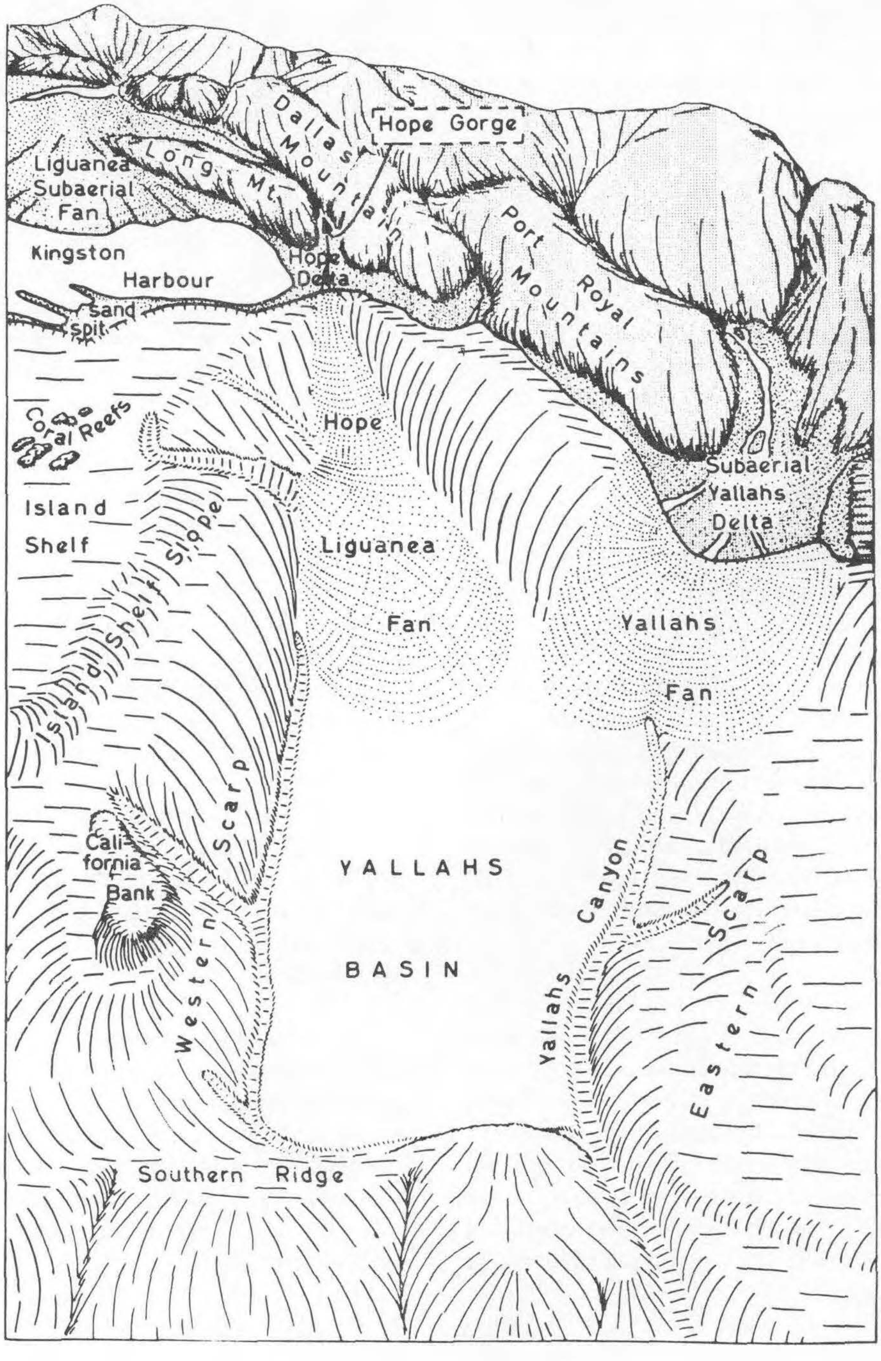

Figure 30. Depositional systems associated with the Yallahs Basin southeast of Kingston, Jamaica; adapted directly from the work of Burke (1967).

the Brazos and Colorado River valleys; the group was easily distinguished from the predominantly terrigenous clastic facies of the underlying Strawn and overlying Cisco Groups. Massive Canyon carbonate units crop out in the Brazos River valley and grade northeastward into deltaic sandstone and mudstone facies of the Trinity valley area. Sandstone facies of the Perrin delta system prograded westward, at times flanked by depositionally high carbonate banks. As deltaic lobes were abandoned, transgressive shelf-carbonate facies blanketed the subsiding deltaic sequences. Henrietta fan-delta lobes prograded southward and southwestward, generally in close association with the massive Red River carbonate-platform system. On the outer part of the Eastern Shelf, massive reef-bank systems persisted. What was the nature of these Canyon carbonate systems, and how did they relate to the contemporaneous terrigenous clastic systems?

CARBONATE-BANK SYSTEMS

Algal-crinoid carbonate banks developed at various times and in various places during deposition of the Palo Pinto, Winchell, Ranger, and Home Creek Limestones. A carbonate bank, as defined herein, refers to a skeletal limestone deposit which stood above the surrounding sea floor with depositional relief. Banks, unlike reefs, are constructed by nonframebuilding organisms, such as marine plants and crinoids. These organisms produce and trap lime mud and skeletal debris, thus building up depositional highs. Carbonate-bank sequences may contain local patch reefs of coral or bryozoans, but for the most part, bank systems are biostromes which interfinger with surrounding terrigenous clastic sediments. Carbonate banks of the Canyon Group formed on rather low-energy, shallow-shelf areas on older deltaic sands and muds. Based on comparisons with recent algal carbonates, Canyon carbonate facies probably accumulated in waters that generally did not exceed 10 to 15 feet in depth. Canyon banks are oriented essentially parallel with depositional strike (northeast-southwest); they commonly range from 100 to 300 feet thick.

According to Wermund (1966, 1969) and Pollard (1970), the Winchell Limestone is predominantly phylloid algal biomicrudite and biomicrite (terminology after Folk, 1959) with abundant fenestrate bryozoans and local crinoid concentrations. Pollard (1970) found that phylloid algae in the Winchell and other Canyon limestones comprise genera of green algae, including the codiaceans *Eugonophyllum, Anchicodium,* and *Ivanovia,* as well as the dasycladacean *Epimastopora.* Coralline red algae of the genus *Archeolithophyllum* are also locally present. Wermund (1969) states that encrusting algae, tentatively identified as *Osagia,* formed pellets which are common in sparry grainstone facies. Phylloid algae grew as erect plants on the sea bottom and trapped lime mud; a variety of other organisms thrived in association with the algae. These included gregarious crinoids, fenestrate and encrusting bryozoa, fusulinids, echinoids, local rugose corals of the genera *Lophophyllidium* and *Caninia,* colonial *Syringoporid* corals, sponges of the genus *Heliospongia,* brachiopods including the genera *Composita, Neospirifer, Echinoconchus,* and *Juresania,* gastropods of the genera *Bellerophon* and *Straparolus,* and pelecypods including the genera *Aviculopinna, Myalina,* and *Culunana* (Wermund, 1969; and observations by the writer). Fusulinids tend to be concentrated in zones up to a few feet thick within a micrite matrix.

Biolithites (true reef rock) are rare in outcropping Canyon carbonate units. Local *Syringopora* buildups occur in the Home Creek Limestone of Jack County and in the Winchell Limestone of the Possum Kingdom area. Perkins (1964) describes buildups of the solitary coral *Caninia* in the Home Creek Limestone of Jack County, but these are local biostromal zones and are not true biolithites. Raish (1964) describes local bryozoan biolithites in the Chico Ridge Limestone of western Wise County. Micrite and fossiliferous micrite are common in outcropping Canyon carbonate units, as are local, well-winnowed carbonate grainstones. This occurrence may be taken as evidence of localized higher energy in the form of waves and currents, possibly due to local shoaling.

Roepke (1970), in studying Canyon carbonates in Brown County, concludes that the abundance of biosparite beds (carbonate grainstone) seems to increase upward in some units, possibly indicative of the buildup of carbonate banks, climaxing with relatively high-energy shoal conditions. Along the Stephens - Palo Pinto county line northwest of Strawn, Texas, the Winchell Limestone is capped by a 6-inch zone of silicified shell debris and by local accumulations of *Myalina,* some of which have the valves intact and exhibit little evidence of transport (see appendix 1, Section Outside Mapped Area). This zone may represent a relatively high-energy, shoal-water accumulation of shell debris.

Outcropping carbonates of the Canyon Group display irregular and uneven beds generally less than 1 foot thick; locally, beds may be up to 3 feet thick. Dense, well-indurated limestone beds are intercalated with thin zones of terrigenous sandy mud derived from nearby deltas.

Wermund (1969) presents four conclusions concerning the origin and development of Canyon carbonate banks. These are as follows: (1) carbonate banks commonly originated on bathymetric highs on the sea floor, such as old deltaic platforms or previously existing carbonate banks or reefs; (2) the maximum and most rapid growth of carbonate banks occurred where phylloid algae and crinoids thrived, namely on shallow, well-lit, nonturbid bottoms; (3) production and entrapment of lime mud by living organisms and accumulation of skeletal debris allowed carbonate banks to build up; and (4) carbonate banks built up above the surrounding sea floor and stood as wave-resistant mounds.

Raish (1964) concludes that the Chico Ridge carbonate bank is composed of nine distinct limestone facies which include poorly fossiliferous calcilutite, algal calcilutite, crinoidal calcilutite, sponge calcilutite, bioclastic calcarenite, oolitic calcarenite, bioclastic calcirudite, fusulinid calcirudite, and bryozoan biolithite. Algal calcilutites and calcarenites are the principal facies. Calcarenites are concentrated in beds that dip up to 10 degrees and flank the inner bank calcilutites. The flanking calcarenites built up slightly higher than the interior bank facies and partially shielded the interior areas from wave and current activity. Based on heights of the steeply dipping flank beds, Raish estimates that the Chico Ridge bank stood 30 to 50 feet above the surrounding sea floor. He could find no evidence to support a reef origin for the Chico Ridge carbonate bank.

Tongues of coarse carbonate debris (i.e. Rock Hill Limestone) were periodically shed from the Chico Ridge carbonate bank. Zones of sharply angular to rounded carbonate debris are evident in cores of black mudstones lateral to the Chico Ridge system (cores and descriptions are from Erxleben (1974) and are on open file at the Bureau of Economic Geology). Mudstone units immediately below the carbonate-debris zones are locally swirled and contorted as if the debris had been rapidly deposited. J. H. McGowen (personal communication, 1973) has suggested the existence of carbonate turbidites or debris flows originating on the banks. Such flows could have been generated by storms which washed carbonate debris over bank edges into deeper water where terrigenous muds were accumulating under quieter water conditions.

Evidence for depositional relief of Canyon carbonate banks includes: (1) the peripheral sloping wedges of oolitic-bioclastic calcarenite described by Raish (1964) for the Chico Ridge Limestone; (2) the presence of surface and subsurface tongues of coarse, poorly sorted, poorly rounded intrasparudite and limestone breccia, such as the Rock Hill Limestone, which were shed as talus debris off the flanks of the shoal-water banks; (3) the presence of a high percentage of sparite and grainstone composing the thick, central banks, which indicates shoal-water, higher energy conditions (Wermund, 1966); (4) the fact that the final carbonate facies within a bank sequence is generally a grainstone (Wermund, 1966; Roepke, 1970), which indicates the higher energy effects of shoaling; and (5) the fact that granular bank facies in the Possum Kingdom area normally dip up to 10 degrees (Wermund, 1966), which suggests high-energy, perhaps migrating carbonate bars or sand waves. The depositional relief of carbonate banks was probably not due solely to lime mud and skeletal accumulation. Banks may have started forming initially on relatively high, abandoned deltaic platforms. These platforms furnished a stable, shallow, well-lighted substrate on which photosynthetic green algae thrived. The algae required shallow depths where light penetration was adequate. If the water over carbonate banks was intermittently turbid with suspended lime mud, then the depth at which green algae could have lived was severely restricted.

Two continuous cores through parts of the Chico Ridge Limestone of northwestern Wise County were examined (cores and descriptions are from Erxleben (1974) and are on open file at the Bureau of Economic Geology; see also pl. V: CH2, CH3). Both cores penetrated carbonates on the western (seaward) side of the bank. Core 2 is seaward from the bank proper, whereas Core 3 is nearer the center of the bank. Core 1 (CH1, pl. V), near the landward (eastern) side of the Chico Ridge Bank, is available but is not described. Both cores examined contain abundant phylloid algal biomicrudite and crinoid biomicrudite with numerous intercalated terrigenous mudstone beds. In both cores the carbonate sequences are capped by relatively thick biomicrudite facies; both cores also contain a single fusulinid zone within the upper biomicrudite units. Core 3, nearest to the bank proper, contains several zones of biosparite and intraclastic biosparudite; Core 2, which is seaward, contains no biosparite. Several coated-grain and oolite zones occur in Core 3; Core 2 shows none of these features. Wermund (1966) reports that the bank facies of the Winchell Limestone has a high percentage of sparite (grainstone) relative to the off-bank facies. This higher sparite percentage on elevated banks is probably a result of winnowing of lime mud and concentration of skeletal material by waves and currents on shoal-water areas. Local, shallow cross-bank channels filled with well-sorted biosparite have been noted within the Winchell bank carbonates of the Lake Possum Kingdom area.

Wermund (1969) notes that short tongues of bank facies interfinger laterally with mudstone units on the seaward (western) side of the banks; long tongues of limestone interfinger with mudstone units on the landward (eastern) side of the banks. This relationship occurs in the Chico Ridge Limestone (cross section A-A′, fig. 25). The banks probably restricted lagoonal areas on their landward sides; these protected, lower energy areas may have experienced more prolific algal-crinoid growth and buildup of lime mud and skeletal debris than the higher energy forebank zones. In addition, winds, which probably approached from the west (seaward), may have washed skeletal debris and lime mud off of the elevated banks and into the lagoonal areas to the rear in a process that is similar to the formation of washover fans on the lagoonal sides of present-day barrier islands. Some Canyon carbonate banks may have been intermittently emergent as evidenced by angular, at least partially prelithified, fossiliferous micrite clasts incorporated in flanking talus deposits.

Carbonate-bank systems of the Canyon Group seem to coincide with a structural trend which ran northeast-southwest through northwestern Palo Pinto, central Stephens, southeastern Shackelford, and northeastern Callahan Counties (Brown, 1969). This trend may have been a late Desmoinesian - early Missourian axis of tilting or perhaps simply a zone of slow subsidence and relative stability. The Palo Pinto Limestone bank became established along this trend, and later Winchell and Ranger carbonate banks formed on the stable area. Once formed along the stable structural zone, the carbonate bank influenced the position of later banks by offering a high, slowly subsiding foundation upon which to build. Carbonate banks (notably the Chico Ridge bank) formed on abandoned deltaic sediments.

Cores through the Chico Ridge Limestone contain zones of black plant debris formed by the accumulation of peaty material derived from shallow intertidal-dwelling Pennsylvanian plants that probably occupied ecologic niches similar to modern mangrove swamps of the Florida carbonate banks.

The Winchell and Chico Ridge banks flanked major lobes of the Perrin delta system (pl. V). Areal distribution of the banks is represented generally by thicknesses of limestone greater than 100 feet. Off-bank or transgressive shelf carbonates are generally delineated by limestone thicknesses less than 100 feet. Bank limestones are stratigraphically equivalent to Wolf Mountain Perrin delta facies, whereas transgressive shelf, off-bank carbonate tongues onlapped, and thus overlie, the Wolf Mountain Formation (figs. 5, 21).

The southern carbonate bank (Lake Possum Kingdom area, Palo Pinto County), which started forming during Winchell deposition, persisted as a bank during deposition of the Placid Formation and remained as a prominent Ranger Limestone bank (pl. VII). The Winchell and Ranger Limestones coalesce in west-central Stephens County, enclosing the Placid deltaic facies to the northeast in a carbonate envelope (figs. 21, 22). Thick Ranger Limestone bank facies developed in northern Shackelford and western Young Counties. The massive Ranger Limestone in western Young County (pl. VII) may have initially formed on the stable, slightly elevated Bend Arch. An elongate Ranger Limestone buildup in southeastern Archer County is a relatively small bank which developed on the distal delta-front facies of the abandoned Perrin delta. In northwestern Montague County, 90 feet of Ranger Limestone was deposited on minor lobes of the Henrietta fan-delta system.

The Home Creek Limestone is widespread and discontinuous (pl. IX). Upper Canyon banks developed in southern Shackelford County, and a thick, elongate carbonate trend parallels the major lobe of the Henrietta fan-delta system through Throckmorton and Archer Counties (figs. 22, 25). This thick carbonate trend may not have been an elevated bank system, but rather may have formed by carbonate accumulation in an embayment laterally to the principal Henrietta fan-delta, lobe. Home Creek carbonate deposition was contemporaneous with the last phases of Henrietta fan-delta deposition.

TRANSGRESSIVE SHELF-CARBONATE SYSTEMS

With abandonment of each of the three major episodes of deltaic progradation (Wolf Mountain, Placid, and Colony Creek), extensive carbonate facies of the Winchell, Ranger, and Home Creek Limestones, respectively, onlapped the subsiding delta lobes. In outcrop, these relatively thin carbonate facies are similar in composition to the carbonate banks. Phylloid algal biomicrudite predominates with local concentrations of biosparite and intraclast-rich zones distributed throughout. The widespread shelf-carbonate facies are generally 5 to 50 feet thick at outcrop and are irregularly and unevenly bedded. Individual beds average less than 1 foot thick and are separated by thin shale beds derived from nearby deltaic sources. In the subsurface, these limestone facies are relatively thin, widespread carbonate deposits (pls. V, VII, IX).

Transgressive shelf-carbonate facies of the Winchell Limestone extended outward from the carbonate-bank areas after abandonment of the Perrin delta. Winchell shelf-carbonate facies, which are up to 85 feet thick, average 50 to 60 feet thick and are distributed over the Perrin delta (Wolf Mountain Formation) in Jack, Young, and Throckmorton Counties. The Ranger Limestone, which is up to 70 feet thick but averages 40 to 50 feet thick, transgressed the Perrin delta system (Placid Formation) in Jack and southern Clay Counties. The Ranger Limestone is generally thickest where carbonate facies accumulated first in interdeltaic embayments; as deltaic subsidence progressed, the carbonate onlapped surrounding delta lobes.

Shelf carbonate of the Home Creek Limestone is also thickest in interdeltaic and on open-shelf areas (pl. IX). Limestone units are thin over most of the Perrin delta lobes of the Colony Creek Formation of Jack, southern Clay, southeastern Archer, and northeastern Young Counties. The Home Creek Limestone is 20 to 40 feet thick in those areas and it is thickest in interdeltaic areas and over the fringes of delta lobes (pls. VIII, IX).

Transgressive shelf facies of the Home Creek Limestone are thin over the principal Henrietta, fan-delta lobe (fig. 22). The Henrietta system remained as a slowly compacting, possibly subaerially exposed delta for a long period of time while Home Creek carbonate facies accumulated in adjacent flanking areas.

RED RIVER CARBONATE-PLATFORM SYSTEM

During deposition of the Canyon Group, the Red River uplift persisted as an east-west-trending structural high that supported deposition of a massive platform-carbonate sequence in northern Clay, northern Wichita, and central Wilbarger Counties (pls. V, VII, IX). Wells penetrating the Red River carbonate platform indicate that alternating massive limestone and shale sequences commonly reach thicknesses of 2,000 to 3,000 feet in low areas between granitic knobs. Where other wells encountered granite at relatively shallow depths, carbonate facies are commonly only a few hundred feet thick (figs. 22, 28). The Red River platform separated the Hardeman Basin of southern Oklahoma and North Texas from the Eastern Shelf and Midland Basin areas during Desmoinesian and Missourian times. On the platform, carbonate deposition probably remained near sea level throughout deposition of the Canyon Group; slow subsidence kept pace with limestone accumulation. Intermittently, the area may have been an emergent island or series of islands during Missourian time, but E. G. Wermund (personal communication, 1973) has stated that fusulinids of the genus *Triticites* have been found in the upper carbonate units, indicating carbonate accumulation during Missourian time.

During deposition of the Ranger and Home Creek Limestones, thick tongues of limestone spread north and south from the Red River platform in Wilbarger, Baylor, and Wichita Counties (pls. VII, IX). Massive Home Creek

Limestone tongues formed adjacent to upper parts of the principal Henrietta fan-delta lobe in Wichita and southern Wilbarger Counties (pl. IX). During deposition of the Colony Creek Formation, the eastern end of the Red River carbonate platform was beginning to separate into a series of individual, detached carbonate banks (pl. IX).

Carbonate deposition on the Red River platform ceased near the end of Missourian time. By late Missourian and early Virgilian times, basins just north of the Red River carbonate platform had been filled by southward-prograding feldspathic clastics from the rising Arbuckle and Wichita Mountains (Tomlinson and McBee, 1959). In early Virgilian time (lower part of Cisco Group), thick clastic facies from northern sources overlapped the Red River uplift in Wichita and Wilbarger Counties and spread southward into Texas (Wermund and Jenkins, 1970), probably as a series of fan deltas.

Rates of recent algal carbonate accumulation are slow compared to rates of delta progradation, and the entire Missourian Epoch on the Red River platform may be represented by only a few hundred (perhaps 400 to 500) feet of carbonate rock. The entire Paleozoic section on the uplift probably did not exceed 3,000 feet in thickness.

SHELF-EDGE REEF-BANK SYSTEMS

During late Desmoinesian (Strawn Group) and Missourian times, carbonate deposition persisted on the developing shelf edge. Similar carbonate deposition persisted locally in east-central Baylor County. In these areas, combinations of skeletal bank accumulation and reef growth produced local carbonate buildups which exceed 1,500 feet in thickness (figs. 20, 24, 25). Studies by E. G. Wermund and W. A. Jenkins (personal communication, 1973) and by numerous petroleum geologists (Conselman, 1960) have documented a trend of Canyon reef-bank carbonate buildups through eastern Haskell, eastern Jones, western Taylor, southeastern Nolan, northeastern Coke, and northwestern Runnels Counties just to the west of the present study area (fig. 6). Basinward of this line of carbonate buildups, the Canyon Group thins rapidly and consists primarily of shale with thin, relatively steeply dipping limestone beds (fig. 20). Sandstone units of the Canyon Group in western Haskell and eastern Stonewall Counties lie basinward of the massive reef-bank carbonate system (fig. 20) and may represent slope and basin-edge clastic wedges fed from the Perrin and Henrietta systems to the east. Wermund and Jenkins' (1970) second-derivative trend surface maps for the Canyon Group indicate that some of this slope-basin sandstone may have been derived from deltas which prograded southward across the Northern Shelf of the Midland Basin.

The massive shelf-edge carbonate accumulations are interpreted to be a system of banks and local reefs which persisted throughout deposition of deltaic and shelf-carbonate systems to the east. Some of the initial carbonate accumulation began in late Desmoinesian time (upper part of the Strawn Group) and persisted throughout Missourian time (fig. 25). The massive carbonate buildups are quite local with net limestone increasing from a few feet to over 1,200 feet over distances of 1 or 2 miles. Log characteristics commonly indicate porous, salt-water-saturated carbonate facies. These reef-bank buildups locally produce hydrocarbons (Conselman, 1960).

In five cores representing forebank, bank proper, and backbank areas, Toomey and Winland (1973) observed no framebuilding organisms in Desmoinesian shelf-edge limestones of the Nena Lucia Field (Nolan County). They stated that prolific growth of phylloid algae was responsible for the buildups. Six distinct carbonate facies were identified: (1) crinoidal debris facies on the outer and upper parts of the mound buildup, (2) pelletal-foraminiferal facies on the immediate front of the bank, (3) algal plate facies forming the massive, porous, hydrocarbon-productive core of the bank, (4) algal-interclast facies in areas beneath and immediately behind the bank core, (5) intraclastic facies interbedded with other facies, and (6) micrite facies in the lower part of the algal-intraclast facies. A facies cross section presented by Toomey and Winland (1973) indicates that the algal bank built upward and migrated toward the shelf through time.

Myers and others (1956) report that the late Paleozoic Horseshoe Atoll in the northern part of the Midland Basin is composed largely of fragments of crinoid columnals, bryozoan fronds, and brachiopod shells in a matrix of carbonate mud and sparry calcite. Little algal debris was noted and corals are a minor faunal constituent. Oolites are common in local, well-sorted calcarenites. Calcarenites (grainstones) are the most abundant textural facies present in the cores studied by Myers and others. Calcilutite and calcirudite, in that order, are the next most abundant facies.

These examples of Pennsylvanian carbonate facies can be used as comparative models for Canyon Group shelf-edge reef-bank systems. All of these systems are massive, abrupt, precipitous accumulations similar to modern coral and red-algae reefs but are composed almost entirely of phylloid algal, crinoidal, and other skeletal debris. Few framebuilding organisms are present.

The reef-bank system of the Canyon Group probably began to develop as late Desmoinesian and early Missourian algal and crinoid banks on a slightly developed shelf edge, where the break-in-slope was only minimal. The Midland Basin continued to subside as sediments accumulated on the Eastern Shelf. The shelf-edge break-in-slope subsequently became more pronounced, and carbonate growth was stimulated by upwelling, calcium-carbonate-charged waters from the deepening basin. Algal, crinoid, and other associated skeletal debris built up at rapid rates in the clear, freely circulating waters of the outer shelf and basin. Carbonate deposition may have persisted approximately at the prevailing wave base; thus, rigid framebuilding organisms were not required for the banks to remain as stable depositional highs. Only when carbonate accumulations reach and exceed prevailing wave base are rigid frame-builders required for stability. Organisms such as reefbuilding corals and red algae probably do not survive well below the prevailing wave base, a fact which may help to account for their sparsity in Pennsylvanian reef-bank system rocks.

Shelf-edge carbonate systems of the Canyon Group probably acted as partial sediment dams for outbuilding and upbuilding deltaic and shelf systems. By the end of Missourian time, the shelf edge exhibited a well-developed break-in-slope, largely due to the stabilizing and damming effects of the massive Canyon reef-bank system. Virgilian (Cisco, Wichita, and Albany Groups) clastic systems prograded to the edge of this well-defined shelf edge and spilled over sequences of thick slope wedges (Galloway and Brown, 1972).

Examples of other studies dealing with Pennsylvanian carbonate rocks include those of Harbaugh (1959, 1960) and of contributors to the Kansas Geological Society 27th Field Conference Guidebook (1962).

PALEOECOLOGY

Close relationships exist between various invertebrate faunas and specific sedimentary facies of the Canyon Group. Conclusions drawn here are based exclusively on field observations but are in general agreement with conclusions drawn by Heuer (1973) in his study of Wolf Mountain Shale faunas of the Lake Possum Kingdom area. Assemblages characteristic of each principal facies or group of associated facies are described and their general paleoecologic significance is evaluated.

PRODELTA - DISTAL DELTA-FRONT ENVIRONMENT

These environments were characterized by rapid, sporadic deposition of fine suspended sediments, which produced turbid water conditions, local turbidites, and soft, unstable bottom sediment conditions. Few marine organisms could live with such conditions; therefore, prodelta and distal delta-front mudstone and thin sandstone units are largely barren of macrofossils. These sediments commonly are laminated, indicating that even nonselective deposit feeders did not thrive. Thin sandstone beds, however, commonly exhibit horizontal feeding trails and tracks on lower and upper surfaces. One or two species of small pelecypods, gastropods, and conularids occur infrequently in prodelta mudstone units. Sparse coiled nautiloids and small crinoid columnals have been noted in distal prodelta and delta-front sequences, along with local inarticulate brachiopods of the genus *Orbiculoidea*. These environments commonly contain abundant fine carbonaceous plant debris which was transported from terrestrial environments.

DELTA-FRONT - DISTRIBUTARY CHANNEL ENVIRONMENT

Massive to highly contorted delta-front and distributary channel sandstone facies were deposited rapidly, normally under conditions of pronounced turbulence. As a result, the facies commonly are barren of marine macrofossils. Some burrowed zones are present, especially near the tops of these units, indicating periods of slack flow with little deposition or sediment transport. During such periods, burrowing organisms colonized the relatively stable sands. Thin, reworked zones may contain fusulinids, crinoid debris, mollusk fragments, orthocone nautiloids, and other organisms, but these zones are rare. Transported terrestrial plant debris is abundant and includes stem casts (notably *Calamites*) and leaves up to several inches long.

DELTA-PLAIN ENVIRONMENTS

Delta-plain mudstone and silty mudstone beds locally bear root mottles, but they commonly appear homogeneous. Thin, coaly zones commonly contain abundant plant impressions. Flattened *Calamites* pith casts and delicately lined impressions are very abundant in thin, delta-plain coal beds. No invertebrate fossils have been noted in what are interpreted to be delta-plain deposits. As previously stated, delta-plain deposits are rare, probably partly because of marine reworking of these originally thin facies after abandonment.

INTERDISTRIBUTARY BAY ENVIRONMENT

Shallow bay-lagoon facies between distributaries or overlying abandoned and foundered delta lobes commonly are thin, discontinuous, highly argillaceous limestone units that are platy or nodular. Phylloid algal blades and crinkled, ripped-up algal mat chips and flakes are abundant. The fauna includes crinoid debris, productid and *Composita*-type brachiopods, some *Myalina* valves, echinoid spines and plates, and a variety of pelecypods and gastropods. In addition, calcareous shale sequences containing abundant crinoids and other invertebrate macrofossils may locally represent shallow embayment deposits.

INTERDELTAIC ENVIRONMENT

The prolific and varied faunas of open-shelf mudstone facies (see later) may also be found in interdeltaic areas where detrital sediment influx was relatively limited. Where clastic detrital sediment influx was great, faunas were severely restricted to infaunal sediment ingestors and a few planktonic and nektonic species. Where detrital sedimentation was limited or virtually absent, faunas were prolific and varied, and numbers of individuals were great. Water depth probably was a secondary factor influencing faunal diversity.

DESTRUCTIONAL DELTAIC (MARINE) SANDSTONE ENVIRONMENT

Thin, highly burrowed, vuggy, reworked sandstone beds, which generally overlie deltaic sequences and underlie shelf-carbonate units, contain abundant vertical and horizontal branching burrows up to 1 inch in diameter. Large *Myalina* shells and brachiopods occur in some of the sandstone beds; rarely are both valves of *Myalina* intact. *Myalina* is commonly associated with reworked and redistributed facies, including tidal channels filled with both clastic and carbonate sediment. Reworked sandstone units may contain abundant fusulinids and brachiopod and molluskan shell debris.

OPEN-SHELF ENVIRONMENT

By far the most prolific and diverse invertebrate faunas are found in open-shelf mudstone deposited on abandoned delta facies and overlapped by shelf-carbonate units. Brachiopods of many varieties are abundant, gastropods are also abundant, and crinoid debris is common. Corals of the genus *Lophophyllidium,* fenestrate and encrusting bryozoa, fusulinids, orthocone nautiloids, coiled nautiloids and goniatites, sponges, echinoid spines and plates, scaphapods, and a few species of pelecypods are common faunal constituents within open-shelf mudstone facies. The dominance of filter-feeding brachiopods and crinoids may be indicative of relatively nonturbid water conditions, distant from terrigenous sediment sources. Fusulinids occur in great abundance in marly mudstone facies below shelf-carbonate units and within the carbonate sequences themselves. As previously mentioned, the prolific faunas of open-shelf environments also occur in the mudstones deposited in broad interdeltaic embayments away from centers of rapid clastic deposition.

Prolific sponge faunas occur immediately below many onlapping shelf-carbonate units and lateral to carbonate-bank facies. Several varieties of sponges thrived together. Crinoid debris is associated with the prolific sponge faunas, but corals are virtually absent from dominantly sponge communities. Sparse corals and sponges may occur together, but abundant sponges and corals rarely occur together. Competition may have existed between these groups for available firm larval-attachment sites.

CARBONATE ENVIRONMENTS

Faunal community structure in the various carbonate facies is complex and was probably influenced by a variety of factors, including water depth, energy, dominance of organisms (local phylloid algal thickets and crinoid thickets supported diverse assemblages), circulation, light penetration, frequency and amount of detrital influx, and many other interrelated variables.

Crinoids seem to have flourished in carbonate areas following periods of silty detrital influx. Crinoidal debris is most common in the silty beds between well-indurated limestone beds. Some of the more common carbonate faunal constituents already have been mentioned in discussions of the carbonate systems.

DEPOSITIONAL SYSTEMS AND ENERGY RESOURCES

Oil, gas, and coal have long been produced from Pennsylvanian rocks in North-Central Texas. The distribution of oil and gas accumulations is complexly related to primary depositional framework, regional and local structure, time of structural movement, sediment diagenesis, and proximity to outcrop. Coal deposits are related almost exclusively to primary depositional framework. Information dealing with locations of Canyon oil and gas fields comes from the work of E. G. Wermund, W. A. Jenkins, and H. Ohlen (personal communication, 1973). Information on subsurface distributions of Canyon coals is based on the work of Mapel (1967).

OIL AND GAS

Unlike the Strawn and Cisco Groups, the Canyon Group in the area studied is relatively nonproductive of oil and gas, especially from sandstone facies. Sandstone units of the Perrin delta system, even though well developed and associated with thick prodelta source beds, are nonproductive. One small field produces from deltaic sandstones within the Palo Pinto Limestone interval of southeastern Archer County (fig. 31).

The only significant hydrocarbon production from sandstone facies is in fields in southern Wichita and northern Archer Counties, along the northwestern flank of the principal Henrietta fan-delta lobe. The two Wichita County fields produce from thin channel sandstone reservoirs in the Wolf Mountain Formation, whereas northern Archer County production is from thicker sandstone reservoirs of the Henrietta system (Colony Creek Formation). A small field in northern Wilbarger County produces from thin sandstone reservoirs within the Home Creek Limestone. Small fields in northeastern Archer and southwestern Shackelford Counties produce from thin sandstone beds within the Palo Pinto Limestone.

Tomlinson and McBee (1959) report that Missourian feldspathic sandstone and conglomerate facies of southern Oklahoma are highly productive. Massive feldspathic facies of the Henrietta fan-delta system of North Texas may have further development potential.

Oil and gas production from carbonate systems of the Canyon Group is concentrated in massive limestone units of the Red River carbonate platform and the outer shelf and shelf-edge reef-bank systems. Two fields in central and eastern Wilbarger County produce from massive Missourian carbonate facies of the Red River uplift. Three small fields produce from Missourian carbonate reservoirs in and associated with the massive reef-bank accumulation of eastern Baylor County. One field in northwestern Shackelford County produces from carbonate beds of the Missourian shelf-edge reef-bank system, which trends northeast-southwest through that area. The only other hydrocarbons produced from the Canyon Group carbonate rocks come from small fields in northern Wilbarger County (eastern Hardeman Basin area).

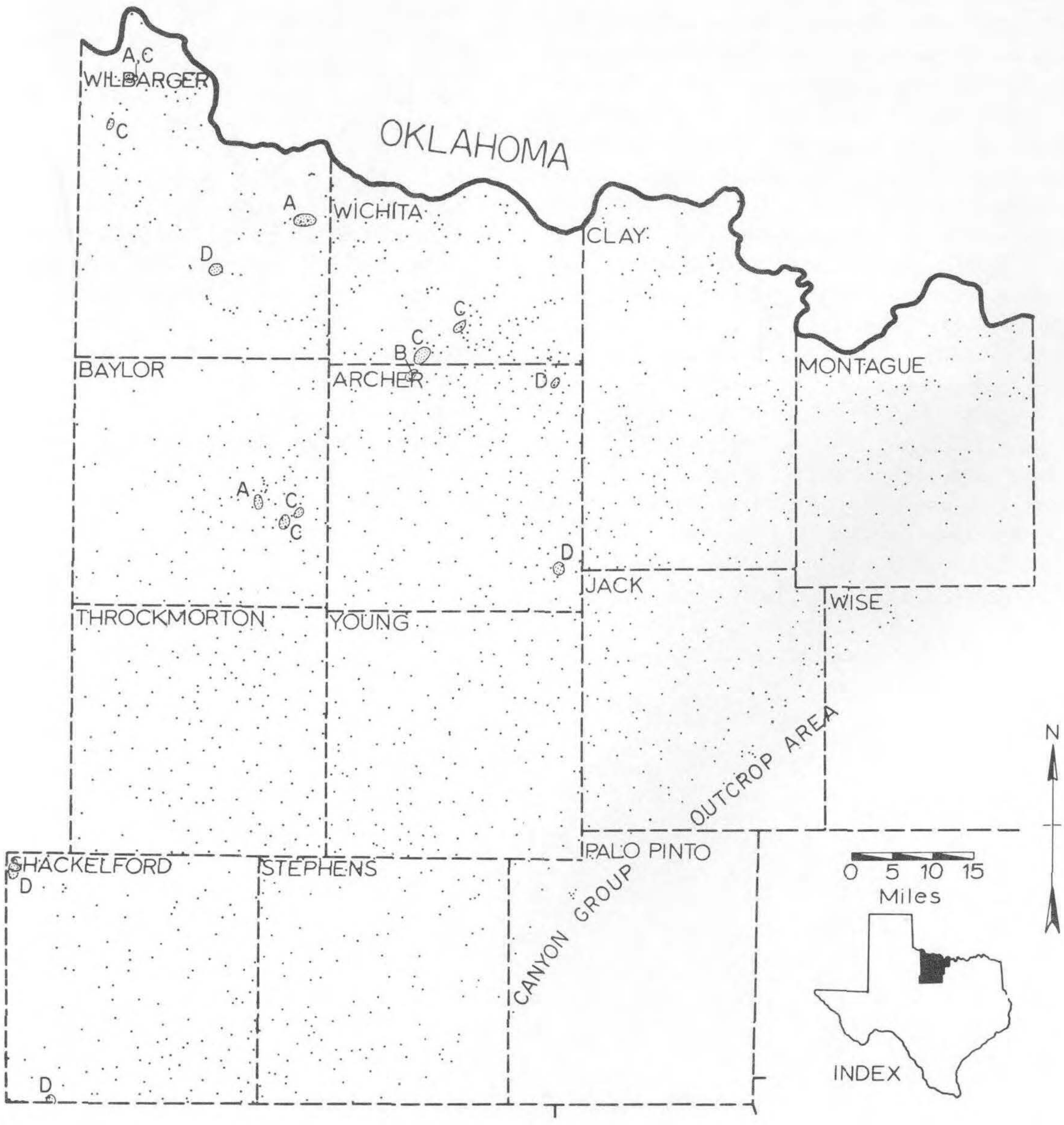

Figure 31. Distribution of hydrocarbon production from the Canyon Group, North-Central Texas. Adapted from unpublished studies by E. G. Wermund and W. A. Jenkins (personal communication); letters refer to Canyon interval from which production comes: (A) Home Creek Formation, (B) Colony Creek Formation, (C) Wolf Mountain Formation, (D) Palo Pinto Formation.

COAL

Outcropping coals of the Canyon Group are rare and are of local areal extent. Two examples of outcropping coals, the Bridgeport coal and the Dalton coal, have been discussed. Mapel (1967) mapped the subsurface distributions of coals using approximately 175 sample logs within the present study area. The major coal units lie immediately downdip from outcrops of the Perrin delta system in Jack, Wise, and Montague Counties, and on top of delta lobes in northwestern Jack, northeastern Young, southeastern Archer, and southern Clay Counties (fig. 32). Two areas of coal concentration are associated with the principal Henrietta fan-delta lobe in northern Clay and eastern Wichita Counties; coal in the northeastern corner of Montague County is associated with minor lobes of the Henrietta fan delta. Coals in northern Baylor and northern Throckmorton Counties are associated with relatively thin, distal sandstone facies of the Henrietta fan delta (Colony Creek Formation). Local coal beds of northwestern Young and northern Stephens Counties are associated with Perrin delta lobes. A coal bed in northwestern Stephens, northeastern Shackelford, and southeastern Throckmorton Counties is related to these same systems. Coal of southwestern Shackelford County may not be related to deltaic sandstone delineated in this study; however, a thin, strike-oriented sandstone body does lie in close association with these coals in the Placid Formation.

Coal units mapped by Mapel (1967) within the area of this study are the major Canyon coals mapped for the entire North-Central Texas region, except for coal zones in Hall and Motley Counties to the northwest. These northwestern coals are probably associated with feldspathic fan-delta sequences which prograded southward from the Wichita Mountains of southern Oklahoma. The only other coals of the Canyon Group in North-Central Texas are minor deposits in southern Callahan and northeastern Taylor Counties, southwest of the present study area; these coal beds may be associated with northwestward-trending minor delta lobes which prograded basinward through northern Brown County, as evidenced by outcropping deltaic sandstone facies in the Lake Brownwood area.

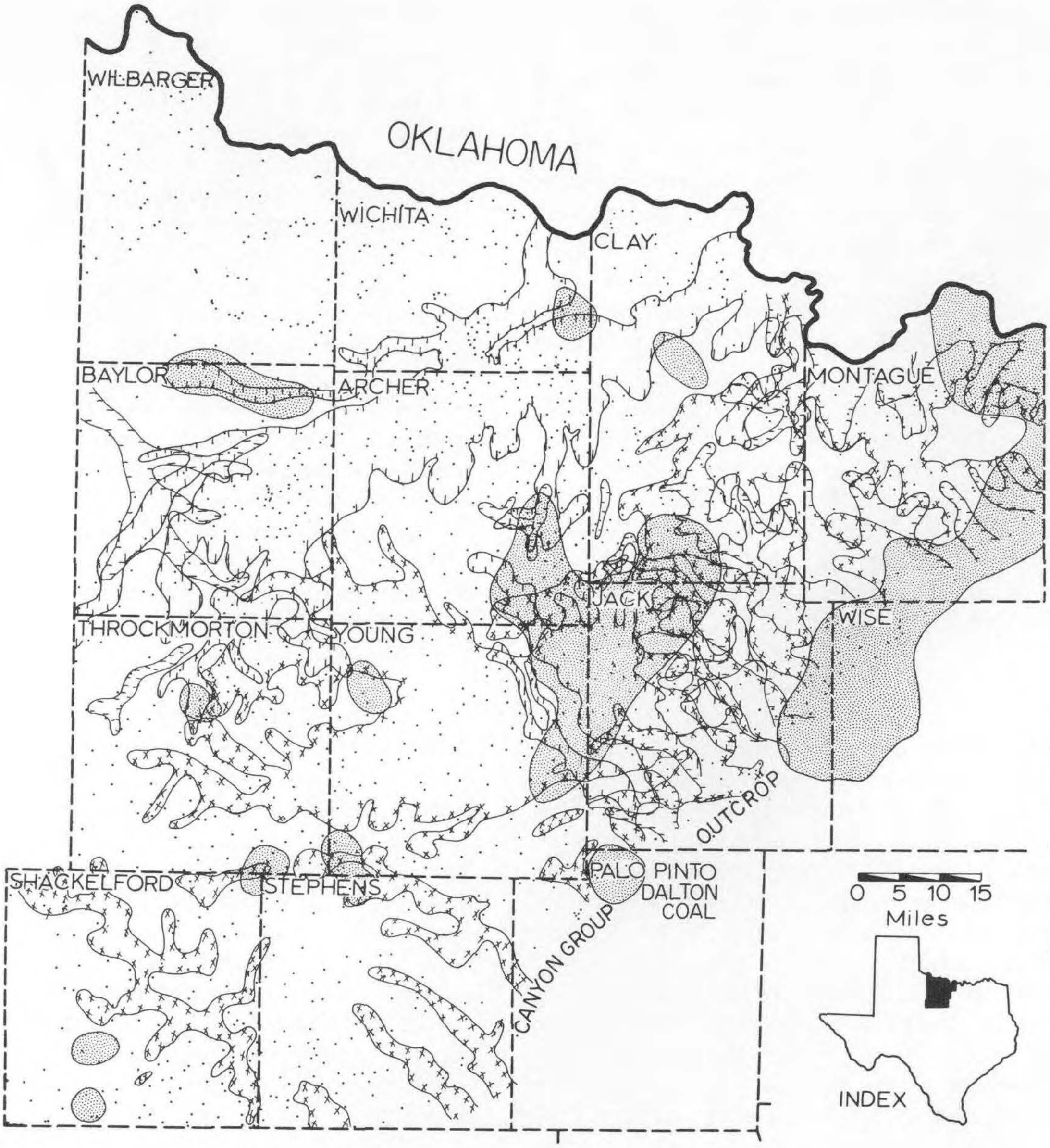

Figure 32. Distribution of Canyon Group coal from Mapel (1967) with Perrin and Henrietta system lobes superimposed to show the correlation between coal accumulation and deltaic deposition. Coals appear as stippled areas.

SUMMARY AND CONCLUSIONS

The Canyon Group of Missourian age is a sequence of westward-dipping carbonate and terrigenous clastic facies which crop out in a northeast-southwest-trending belt across North-Central Texas. At outcrop, thick algal bank and transgressive shelf-carbonate systems to the southwest interfinger with and overlie thick, deltaic sandstone and mudstone facies to the northeast in Jack and Wise Counties. The high-constructive Perrin delta system prograded westward and northwestward across the Eastern Shelf to deposit a series of thick, elongate, and bifurcating lobes which are preserved in Jack, Clay, Archer, Young, Baylor, and Throckmorton Counties. Sources of Perrin deltaic sediments lay in the Ouachita foldbelt to the east. Three major phases of deltaic progradation are present—Wolf Mountain, Placid, and Colony Creek Formations. After each major progradational phase, highly fossiliferous, open-shelf muds and superposed shelf-carbonate deposits onlapped the abandoned and subsiding delta lobes (fig. 33).

The initial Perrin delta system (Wolf Mountain Formation) prograded basinward between the Chico Ridge carbonate bank of Wise and Montague Counties and the Winchell carbonate bank of Palo Pinto, Stephens, and Shackelford Counties. These banks were constructed on top of minor delta lobes of the Perrin system by growth of phylloid algae and crinoids and other organisms entrapment of a carbonate mud matrix. Upon abandonment, shelf-carbonate tongues (Winchell and Devil's Den Limestones) spread outward from the carbonate banks and partially onlapped the foundered delta lobes. These transgressive carbonate facies, however, did not spread completely across southeastern Jack County because of continued minor deltaic progradation and reworking of older deltaic sediments in that area.

The Perrin delta system (Placid Formation) prograded toward the northwest and west over Winchell Limestone. Outcropping Perrin delta facies (Placid Formation) of eastern Jack and western Wise Counties include contorted bar-finger sandstone facies and well-developed distributary channel and delta-front sandstone units overlying thick, laminated prodelta and distal delta-front mudstone sequences. A carbonate-bank system persisted in Stephens and Shackelford Counties contemporaneous with deltaic progradation.

As the Perrin delta system was again abandoned, transgressive Ranger Limestone shelf facies spread northward from the carbonate bank and eastward from the open shelf, onlapping the subsiding delta lobes. Because interdeltaic and interdistributary areas were bathymetrically low and were inundated longest, shelf-carbonate units accumulated to greater thicknesses in those areas than on the prominent delta platforms.

Perrin delta lobes (Colony Creek Formation) eventually prograded over shelf-carbonate facies for the third time. Coarse-grained fluvial systems locally overrode and eroded finer grained delta sandstone and mudstone facies in southern Jack County. Strike-oriented barrier island or strandplain sandstone units up to 100 feet thick, which occur exclusively in the subsurface, are stratigraphically equivalent to the Perrin delta system of Throckmorton, Young, Stephens, and Shackelford Counties. Upon abandonment of the Perrin delta system, the Home Creek Limestone transgressed deltaic facies.

An idealized sequence of Perrin delta facies demonstrates a constructional and a destructional phase. The constructional sequence, in ascending order, includes: (1) laminated, largely unfossiliferous, prodelta mudstone containing abundant, fine organic debris and ferrugenous clay-stone nodules; (2) thin-bedded, graded, commonly contorted, fine-grained distal delta-front sandstone and siltstone within laminated shale; (3) fine-grained, plant-rich, massive, proximal delta-front sandstone which may be heavily contorted and contemporaneously faulted; (4) massive, fine- to medium-grained distributary channel-fill sandstone which contains trough cross-stratification, local clay-chip conglomerate, and abundant plant stems and leaves; and (5) thin, generally coaly, sandy mudstone delta-plain units which commonly appear homogenous and locally may be cut by symmetrical tidal channels. Destructional and transgressive marine facies, which developed on top of abandoned deltaic sequences, include: (1) highly burrowed, vuggy fine-grained sandstone beds up to 6 feet thick which locally contain *Myalina* shells; (2) heavily bioturbated, fossiliferous mudstone; (3) highly fossiliferous, open-shelf mudstone facies with abundant brachiopods, gastropods, sponges, crinoids, corals, and other organisms; and (4) algal shelf-carbonate facies.

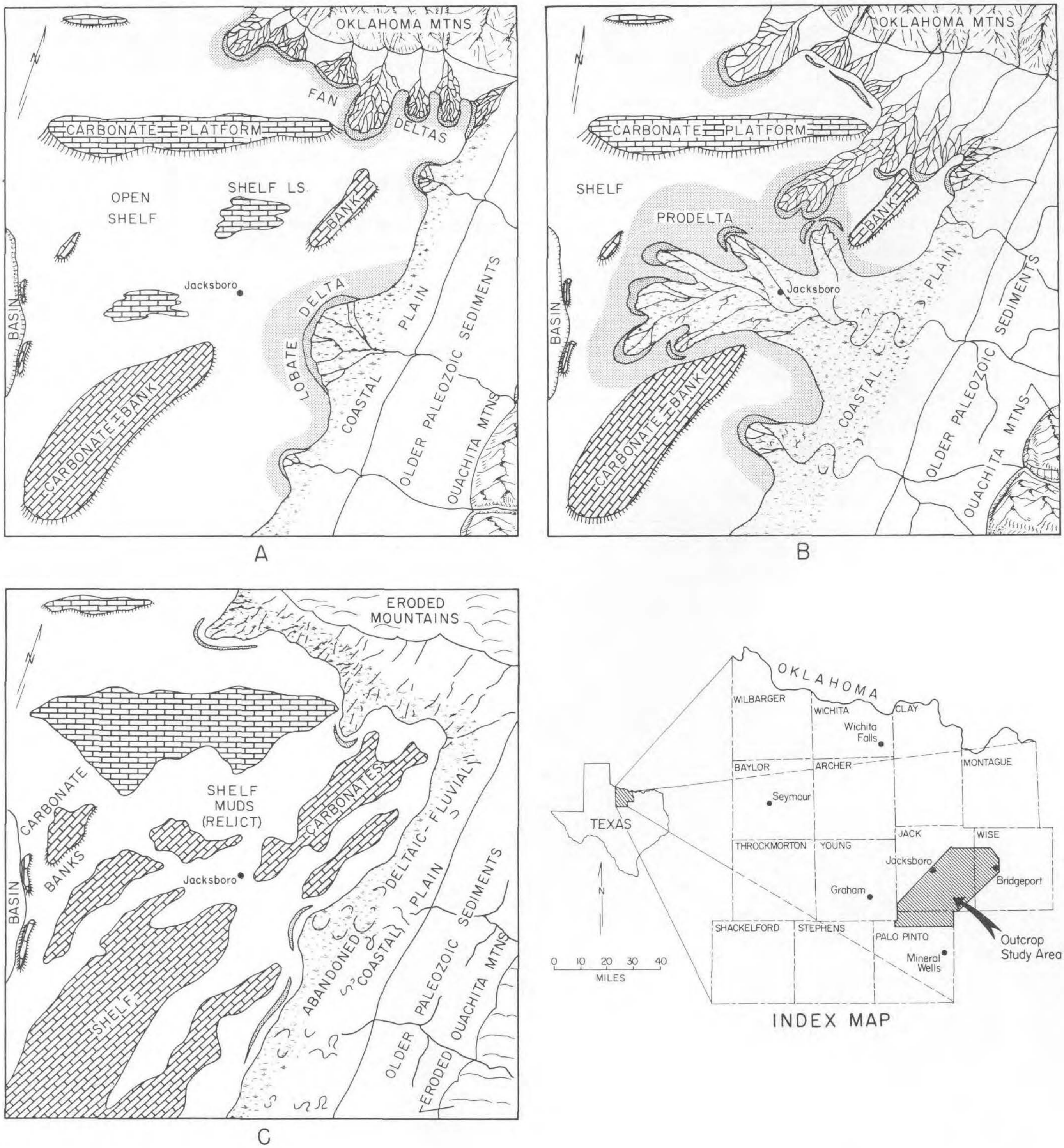

Figure 33. Evolution of Canyon Group paleogeography. (A) Early progradation of delta systems. (B) Maximum extent of delta development. (C) Transgression of abandoned deltaic lobes and deposition of blanket shelf carbonates. Based on three Canyon delta cycles.

The Henrietta fan-delta system comprises a series of coarse, feldspathic clastic lobes which prograded into North-Central Texas from sources in the Arbuckle-Wichita Mountains of southern Oklahoma. The principal Henrietta lobe prograded southwestward through Clay, Wichita, Archer, Baylor, and Throckmorton Counties. The Henrietta system prograded into a northern remnant of the Fort Worth Basin where coarse clastic sediments locally stacked to thickness of several hundred feet. The last progradational episode (Colony Creek Formation) resulted from renewed late Missourian phases of the Arbuckle orogeny. Coarse fan-delta sandstone facies deflected around a massive, outer shelf reef-bank limestone accumulation in eastern Baylor County. The contemporaneity of the Henrietta fan-delta and Perrin high-constructive delta systems is uncertain, but the deposits appear to be stratigraphically equivalent. The Henrietta system is restricted to the subsurface in Texas.

Carbonate systems of the Canyon Group include carbonate banks; a structurally controlled, massive carbonate platform (Red River uplift); outer shelf and shelf-edge reef-bank accumulations; and relatively thin, transgressive shelf-carbonate units which onlapped abandoned delta lobes and open-shelf mudstone facies. Carbonate facies are dominantly phylloid algal biomicrudite with abundant biosparite and intraclastic zones indicative of local shoaling. Tongues of angular carbonate breccia, such as the Rock Hill Limestone, were periodically shed from elevated carbonate banks.

Faunas of the Canyon Group are related to the depositional environments. The principal factor which governed the number and kinds of organisms in an area was probably the local rate of clastic-sediment input. Water depths and salinities were probably secondary factors.

Hydrocarbons are produced primarily from thin sandstone reservoirs that are peripheral to the principal Henrietta fan-delta lobe, and from carbonate systems which include the Red River carbonate-platform and outer shelf reef-bank systems.

Coals of the outcropping Canyon Group include local subbituminous deposits and transported, argillaceous, fissile coals deposited in bay-lagoon areas. Coals are associated with lobes of the Perrin delta and, to a lesser extent, with lobes of the Henrietta fan delta.

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APPENDIX 1
GENERALIZED MEASURED SECTION DESCRIPTIONS

Note: Detailed descriptions are to be found in the work of Erxleben (1974). Locations of measured sections are shown on the geologic map (pl. I).

Section 1: Measured from pond on south side of Hwy. 380, 3 miles west of Vineyard, Texas, westward up road to top of lowest Ranger Limestone Member (see fig. 10).

A 199-foot section, excellently exposed in a roadcut of the Placid Shale Formation, contains a thick Perrin prodelta mudstone and delta-front sandstone sequence that was ultimately overridden by a somewhat coarser grained distributary channel deposit. This classic deltaic sequence contains two stacked delta-front - distributary-mouth bar units which formed as a result of slight lateral shifts during deposition of the deltaic lobe. The entire sequence is overlain by argillaceous shallow-water embayment limestone and was ultimately capped by the lowest member of the shallow-shelf Ranger Limestone.

Section 2: Measured along Hwy. 1156, 2 miles west of Wizard Wells, Texas, from base of hill up winding curve to base of lowest Ranger Limestone Member at top of hill (see fig. 13).

A 241-foot section, well exposed in a roadcut of the Placid Shale Formation, contains prodelta mudstone overlain by contorted, deformed, and contemporaneously faulted distal distributary channel and bar-crest sandstone. The characteristics of rapid Perrin deltaic deposition and loading are excellently exposed in one segment of the roadcut. In the upper half of the section, breaks in deposition are marked by sandstone surfaces covered with shallow marine fossils. A later deltaic surge is recorded by massive, contorted delta-front and distributary channel sandstone near the top of the hill. The entire Perrin deltaic sequence was ultimately transgressed by the lowest member of the shallow-shelf Ranger Limestone. This section is roughly stratigraphically equivalent to section 1.

Section 3: Measured from creek level in Bear Hollow, eastward up boulder-strewn hillslope, continuing up knoll 0.4 mile to the north which is capped by Ranger Limestone float; 2.3 miles north of Wizard Wells, Texas.

A 212-foot section, relatively well exposed on a hillslope of the Placid Shale Formation, contains a prodelta - delta-front sandy mudstone sequence overlain by a 100±-foot-thick, loaded, squeezed, contorted, massive sandstone unit. The sandstone is interpreted to be a massive bar-finger component of a Perrin deltaic lobe that prograded to the north-northwest. Shallow marine shales and thin reworked sandstone units overlie the deltaic sequence. The immediate area in which this section lies contains the thickest exposed Perrin deltaic sequences observed within the Placid Shale Formation.

Section 4: Measured from road level along unpaved county road, northwestward to top of hill; 2.7 miles north of Wizard Wells, Texas.

A 190-foot section, exposed on a hillslope of the Placid Shale Formation, consists of two prodelta mudstone and delta-front - distributary channel sandstone sequences stacked one on top of the other. The prodelta sequence near the base of the hill is well exposed, is unfossiliferous, and contains ferrugenous nodules and sandy, silty laminae. This exposure of two stacked delta-lobe sequences typifies outcrops of Perrin delta facies in the Wizard Wells area.

Section 5: Measured westward up high-voltage line right-of-way from road level; off county road, 5.2 miles southeast of Cundiff, Texas.

A 167-foot section, exposed on a hillslope of the Placid Shale Formation, consists of two stacked prodelta mudstone and delta-front - distributary channel sandstone sequences. The lower of the two deltaic sequences is overlain by a 6-foot-thick coarse-grained sandstone and chert-pebble conglomerate, interpreted to be a fluvial channel that eroded into the underlying deltaic sediments. The entire exposure of stacked Perrin delta lobes is unconformably overlain by 10 feet of silica-cemented Cretaceous sandstone and conglomerate.

Section 6: Measured northwestward up county road from the level of Pecan Branch, through the lowest Ranger Limestone Member; 5.1 miles east-southeast of Cundiff, Texas.

A 124-foot section, relatively well exposed on a hillslope of the Placid Shale and Ranger Limestone Formations, consists of massive distributary channel and delta-front sandstone units near the base, overlain by prodelta and distal delta-front sandy mudstone units of a later delta lobe. A minor deltaic distributary channel sandstone near the top of the clastic sequence is capped by marly shallow-shelf mudstone and fossiliferous algal biosparudite of the transgressive shelf Ranger Limestone. This exposure typifies Perrin deltaic and shallow-shelf mudstone and limestone sequences in the area east of Cundiff.

Section 7: Measured southward up county road from 20 feet above the level of Big Creek; 1.4 miles south of refinery and 5.5 miles west of Chico, Texas.

A 74-foot section, relatively well exposed in a roadcut and on a hillslope of the Placid Shale Formation, consists of massive distributary channel and delta-front sandstone facies of the Perrin delta system, overlain by strongly trough cross-stratified conglomerate and coarse-grained sandstone of fluvial origin. This section illustrates well the relationships between fine- to medium-grained deltaic sandstones and the coarser channel fill of a fluvial system which scoured through the deltaic sediments.

Section 8: Measured northward up pipeline which crosses Highway 1658 running north-south and continues up and over Chico Ridge escarpment; 3 miles west-northwest of Bridgeport, Texas.

A 160-foot section, relatively poorly exposed on a hillslope of the Jasper Creek Shale (upper Wolf Mountain Shale Formation) and Devil's Den Limestone (Winchell Limestone), consists of prodelta mudstone overlain by thin delta-front and laterally distributed shallow marine deltaic sandstones. The top 55 feet of the section is represented by fossiliferous shallow-shelf mudstone with shallow-shelf crinoidal and algal biomicrudite on top. This section is generally above and slightly lateral to the area of major Wolf Mountain Perrin delta influx to the southwest, in western Wise and eastern Jack Counties.

Section 9: Measured from intersection with county road, up entrance road to Sid Richardson Scout Ranch; 3.7 miles east of Wizard Wells, Texas.

A 180-foot section, relatively well exposed on a hillslope of the Jasper Creek Shale (upper Wolf Mountain) and Devil's Den Limestone (Winchell), consists of basal prodelta mudstone which grades upward into silty, sandy distal delta-front facies. A massive fine-grained delta-front and distributary channel sandstone unit with a relatively sharp base overlies the distal delta-front facies, yielding a classic deltaic progradational sequence. Overlying the deltaic facies are prodelta-shelf mudstone beds, which become increasingly calcareous toward the top and grade upward into the shallow-shelf Devil's Den Limestone.

Section 10: Measured from head of small tributary creek northward up Devil's Den escarpment; 1.2 miles due east of Vineyard, Texas.

A 173-foot section, well exposed on a hillslope of the Jasper Creek Shale (upper Wolf Mountain Shale) and Devil's Den Limestone (Winchell), consists of prodelta-shelf mudstone beds which grade upward into a sequence of thin, burrowed shallow marine sandstone units interbedded with mudstones. This sequence is overlain by phylloid algal biomicrudite of the Devil's Den Limestone, a shallow-shelf transgressive tongue off the thick Chico Ridge bank to the northeast.

Section 11: Measured from base of Devil's Den outlier directly behind (southwest) the Yate's sale barn near the Yate's Ranch headquarters; 1 mile southeast of Vineyard, Texas.

A 161-foot section, rather poorly exposed on a hillslope of the Jasper Creek Shale (upper Wolf Mountain Shale) and Devil's Den Limestone (Winchell), consists of prodelta-shelf mudstone which grades upward into mudstone containing burrowed, *Myalina*-bearing, shallow marine-reworked sandstone units. The upper part of the section is marly to calcareous shallow-shelf mudstone capped by the transgressive shelf Devil's Den Limestone. Sections on the Yate's Ranch illustrate the characteristics of shallow marine-reworked sandstone units which are lateral to and overlie deltaic facies.

Section 12: Measured up northern end of southeasternmost Devil's Den Limestone outlier on the Yate's Ranch; 1.2 miles south of Vineyard, Texas.

A 131-foot section, well exposed on a hillslope of the Jasper Creek Shale (upper Wolf Mountain

Shale) and Devil's Den Limestone (Winchell), consists of sparsely fossiliferous prodelta-shelf mudstone units containing zones of rolled and contorted fine-grained, distal delta-front sandstone. This grades upward into well-laminated silty, sandy, laterally reworked delta-front facies overlain by burrowed, *Myalina*-bearing, shallow marine sandstone units in shale. The entire well-exposed sequence is capped by the shallow-shelf Devil's Den Limestone, which here consists of phylloid algal-crinoid biosparudite and biomicrudite in irregular and uneven beds.

Section 13: Measured from creek level at southernmost end of southern Devil's Den outlier on Yate's Ranch; 2 miles south-southwest of Vineyard, Texas (see fig. 15).

A 118-foot section, very well exposed on a hillslope of the Jasper Creek Shale (upper Wolf Mountain Shale) and Devil's Den Limestone (Winchell), consists of silty prodelta and interdistributary mudstone beds overlain by heavily burrowed, reworked shallow marine sandstone units, interbedded with fossiliferous shallow bay-lagoon mudstone facies. This is one of the best exposures of shallow marine, delta-destructional sandstone units in the entire Wolf Mountain Shale interval of Jack County. The destructional (transgressive marine) facies overlie and flank massive contorted delta-front and distributary channel facies, which are exposed a few hundred yards to the west. These deltaic facies are described in section 14 (see fig. 15). The shallow destructional marine facies grade upward into highly fossiliferous marly mudstone of a more open marine environment. Here, sponges, bryozoans, crinoids, and mollusks occur in profusion. The overlying Devil's Den Limestone is only 2.5 feet thick at this southernmost exposure of the unit.

Section 14: Measured from creek level, 0.3 mile west of the southern end of the southernmost Devil's Den outlier, on the Yate's Ranch; 2.2 miles south-southwest of Vineyard, Texas, and 0.2 mile east of Highway 1156 (see fig. 15).

A 67-foot section, moderately well exposed on a hillslope of the Jasper Creek Shale (upper Wolf Mountain Shale), consists of sandy, silty prodelta mudstone overlain by 25 to 30 feet of fine-grained, massive, squeezed and contorted sandstone of distributary channel and delta-front origin. The massive sandstone can be seen to pinch out laterally toward the west and is overlain by the shallow marine delta-destructional facies described in section 13. This local area is excellent for study of the relationships between constructional deltaic facies and destructional shallow marine units capped by carbonate (fig. 15).

Section 15: Measured from road level just west of Highway 1156, 2.3 miles south-southwest of Vineyard, Texas, on Roper Ranch Property, where strongly inclined sandstone beds are evident from the highway.

A 162-foot inclined section, moderately well exposed on a hillslope of the Wolf Mountain Shale Formation, consists of thick to massively bedded, fine- to medium-grained delta-front and distributary channel sandstone facies at the base, overlain by sandy mudstone, and burrowed sandstone units of shallow marine delta-destructional origin. The thick deltaic sandstone beds near the base of the hill are steeply inclined toward the south, probably due to post-depositional slumping of the units laterally down the prodelta slope. The sparsely fossiliferous overlying shallow marine beds show an increase of thin sandstone units upward and culminate in a fine-grained, trough crossbedded sandstone on top of the hill. This unit is likely of minor distributary channel origin.

Section 16: Measured up hillside west of Highway 1156, 2.8 miles south of Vineyard, Texas, on Roper Ranch, 0.3 mile west-southwest of abandoned house, on west side of highway.

A 72-foot section, well exposed on a hillslope of the Wolf Mountain Shale Formation, consists of highly fossiliferous shallow-shelf mudstone units which become increasingly sandy and silty toward the top of the section. Thin flaggy sandstone beds in the upper 12 feet of the section bear horizontal tracks and trails, horizontal laminae, local ripples and plant debris, and were probably deposited in a shallow interdistributary embayment which flanked minor deltaic distributaries.

Section 17: Measured up hillside from level of cow pond, on Roper Ranch, 0.6 mile west of Highway 1156; approximately 2.4 miles north-northwest of Joplin, Texas.

A 90-foot section, fairly well exposed on a hillslope of the Wolf Mountain Shale Formation, consists of sparsely fossiliferous shallow-shelf and prodelta sandy mudstone beds overlain by thin delta-front and lateral deltaic, fine-grained sandstone beds. The upper 15 feet of the section bears a small distributary channel unit, which is massive to squeezed and contorted in appearance, and shows local horizontal laminae.

Section 18: Measured up hillside on Roper Ranch; 0.7 mile west of Highway 1156 and 1.6 miles north of Highway 199, just west of Bean's Creek; 2.1 miles north-northwest of Joplin, Texas.

A 95-foot section, fairly well exposed on a hillslope of the Wolf Mountain Shale Formation, contains sandy, shallow-shelf and prodelta mudstone beds with abundant large ferrugenous nodules, overlain by a 6-foot-thick fine-grained distributary channel sandstone unit. The sandstone is locally contorted and trough crossbedded and contains plant debris throughout.

Section 19: Measured westward up unpaved road from old house and barn up to house at top of hillslope, 0.4 mile north of Highway 199; 1.2 miles northwest of Joplin, Texas.

A 56-foot section, well exposed on a hillslope and in shallow roadcut of the Wolf Mountain Shale Formation, consists of sandy prodelta-shelf mudstone and thin sandstone beds with local flute and load casts and horizontal laminae, overlain by flaggy sandstone units of probable delta-front and minor distributary origin. The section illustrates well the flaggy and well-laminated nature of a distal delta-constructional sequence.

Section 20: Measured up unpaved county road north of Highway 199; in two parts (see Geologic Map), begins at level of Bean's Creek and continues westward up road around first curve, second part of section begins westward of first part, at sharp right-hand curve in road, and proceeds northwestward to top of hill.

A 150-foot section, well exposed on a hillslope and in shallow roadcuts of the Placid Shale Formation, consists of sandy and silty prodelta and shallow-shelf mudstone beds with alternating thin flaggy sandstone beds, overlain by sandstone units of delta-front and distributary channel origin. The sequence is capped by an 11-foot, fine- to medium-grained sandstone unit, which is trough crossbedded and contains abundant fine clay chips and local clay galls. This interpreted distributary channel unit is locally contorted and bears local burrows up to 1 inch across.

Section 21: Measured up unpaved county road east of Highway 281 and southwest of Highway 199, in southeastern Jack County; measured from Bean's Creek tributary, northwestward up road to level of house on top of hill.

A 113-foot section, fairly well exposed on a hillslope and in shallow roadcuts of the Placid Shale Formation, consists of several feet of well-laminated prodelta mudstone and thin distal delta-front sandstone beds overlain by a light-gray to white, fine-grained sandstone, approximately 3 feet thick, which is interpreted to be a laterally distributed and reworked shallow-water delta-front sandstone facies. Three feet above this facies is a second clean, well-sorted sandstone about 5 feet thick, interpreted to be of a similar origin. Near the top of the section, massive trough crossbedded sandstone units, interpreted to be of distributary channel origin, were eroded into the underlying units. The clean, well-sorted, laterally distributed delta-front sandstone units within this section are somewhat unique in that similar units have not been observed elsewhere within the Placid Shale Formation. They are well exposed at this locality.

Section 22: Measured northward from base of hill, 0.4 mile east of East Fork of Keechi Creek in southeast Jack County; 3.3 miles northwest of Perrin, Texas.

A 78-foot section, fairly well exposed on a hillslope of the Wolf Mountain Shale Formation, consists of sandy shale and thin, flaggy sandstone beds of prodelta and delta-front origin, overlain by a trough crossbedded and contorted, 7-foot-thick sandstone of distributary channel-fill origin. Above this facies is a thin sandy shale sequence, overlain by a second 3-foot-thick trough crossbedded and locally contorted sandstone unit. The section is capped by 23 feet of sandy shale and thin sandstone beds which are largely covered.

Section 23: Measured northward up hill just north of Highway 2210, 2.8 miles due west of Perrin, Texas, and just east of the East Fork of Keechi Creek.

A 108±-foot section, well exposed in a roadcut and on a hillslope of the Wolf Mountain Shale Formation, consists of 63 feet of laminated and locally contorted mudstone and thin siltstone and sandstone beds of prodelta and distal delta-front origin. The eastern end of the roadcut exposes an 8-foot, thick-bedded, fine-grained delta-front sandstone unit which slumped down into the prodelta facies along a well-defined glide plane, penecontemporaneous with deposition. The hill above the roadcut is capped by a massive, fine-grained distributary channel sandstone unit that contains very large trough cross-stratification and may be up to 50 to 60 feet thick. The sandstone unit dips steeply toward the south due to post-depositional soft-sediment slumping into the underlying unstable prodelta mud. This section contains one of the best sequences of Perrin prodelta, delta-front, and distributary channel sandstone facies in the Wolf Mountain Shale Formation. In addition, the slumped sandstone units spectacularly illustrate the unstable nature of Perrin deltaic sandstone facies that prograded seaward over water-saturated prodelta mudstone units.

Section 24: Measured along Highway 2210 up Winchell Limestone escarpment, halfway between Perrin and Barton's Chapel, Texas, measured from north to west curve in road to top of hill; 6.3 miles due east of Barton's Chapel.

A 132-foot section, well exposed on a hillslope and in a roadcut of the Wolf Mountain Shale Formation and Winchell Limestone, consists of silty mudstone and rippled, thin sandstone beds of probable interdistributary embayment origin, overlain by a thin, poorly indurated limestone, which is 1.5 feet thick and is rich in invertebrate fossils. Above the muddy limestone unit, a silty, calcareous mudstone containing invertebrate fossils was cut into by an 18-foot-thick distributary channel-fill unit. The sandstone shows large-scale trough cross-stratification and is burrowed on top. Above the sandstone is a 51-foot-thick fossiliferous shallow-shelf mudstone with local rolled and contorted sandstone beds. The section is capped by 25 feet of very fossiliferous Winchell Limestone. This locality marks the northernmost extent of the Winchell Limestone proper. The unit pinches out just north of this roadcut and is replaced by terrigenous clastics of the Perrin delta system immediately to the northeast.

Section 25: Measured along county road from level of house on west side of road, up and around the north, to east curve to Sparks Spring Church; 4.7 miles northwest of Perrin and 6.1 miles east of Barton's Chapel.

An 89-foot section, poorly exposed on a hillslope and along a graded road in the Wolf Mountain Shale Formation, consists of laminated mudstone and thin, flaggy sandstone beds of prodelta and delta-front origin. The sandstone is trough cross-stratified and is only poorly exposed along the graded road. The section is capped by silty shales and thin sandstone beds, which appear unfossiliferous. The sediments exposed here represent constructional deltaic facies on the southern flank of the Perrin delta system.

Section 26: Measured northward up unpaved county road, as indicated on plate I, from just south of slight eastward bend in road up to flat break-in-slope; 5.3 miles northwest of Perrin, Texas.

A 42-foot section, fairly well exposed along a graded road in the Placid Shale Formation, begins with 30 feet of somewhat burrowed sandy siltstone laminae and thin beds of probable shallow-water, laterally spread, delta-flank origin. This sequence is covered by a firmly calcite-cemented sandstone bed 1.5 feet thick, which approaches a sandy limestone composition. Above that unit is 10 feet of poorly exposed thin-bedded sandstone and silty mudstone.

Section 27: Measured northward up unpaved county road, at location indicated on plate I, from 8 feet above level of pipeline crossing to VAMB Richards Tower on top of Ranger Limestone scarp; 5.8 miles northwest of Perrin, Texas. Section 27 lies above section 26, with an approximate 12-foot covered interval between.

A 107-foot section, fairly well exposed along a graded road in the Placid Shale Formation, consists of sandy siltstone, silty sandstone, and mudstone beds of probable delta-front to interdeltaic origin, overlain by a trough crossbedded, massive, fine-grained sandstone unit of distributary channel-fill origin. The massive 17-foot-thick sandstone is capped by 4 feet of thin- to medium-bedded, fine-grained sandstone. Overlying the sandstone are sparsely fossiliferous silty shallow marine mudstone beds and algal-crinoid limestone units of the Ranger Limestone.

Section 28: Measured along unpaved county road, at position indicated on plate I, from pond just south of county road, eastward to top of hill; 2.5 miles northeast of Oran, Texas.

A 62-foot section, well exposed on a hillslope and in a roadcut of the Oran Sandstone (upper part of the Palo Pinto Formation), consists of 37 feet of silty, sandy, unfossiliferous shale of probable prodelta or interdeltaic origin, overlain by 25 feet of fine-grained, highly cross-stratified sandstone which contains abundant plant debris and local clay pebbles. The sandstone may be of distributary channel or crevasse splay origin. This is the best exposure of the Oran Sandstone available for study at present.

Section 29: Measured eastward up southwest-facing slope of hill directly north of Barton's Chapel cemetery, on land owned by Charles Geer; 1.2 miles northeast of Barton's Chapel, Texas.

A 127-foot section, relatively poorly exposed on a hillslope of the Placid Shale Formation, Ranger Limestone Formation, and Colony Creek Shale Formation, begins with silty, calcareous shallow marine mudstone overlain by 6 feet of phylloid algal Ranger Limestone. Overlying the limestone is 24 feet of covered thin sandstone and mudstone beds of probable prodelta and delta-front origin, overlain by a 31-foot squeezed, contorted, and trough crossbedded distributary channel and proximal delta-front sandstone unit. A zone of thin silty shale and fine-grained sandstone beds above the channel unit was cut into by fluvial channels, which became filled with chert-pebble conglomerate and coarse sandstone bearing large-scale trough crossbeds throughout. This conglomerate unit is at least 26 feet thick and is of Colony Creek Shale (late Missourian) age. This area of southwestern Jack and southeastern Young Counties was an avenue for coarse-grained fluvial systems throughout late Missourian and early Virgilian times.

Section 30: Measured northward up unpaved county road to top of steep conglomeratic hillslope, from level of small tributary creek, just north of cow pond; 3.3 miles west of Barton's Chapel, Texas.

A 227-foot section, fairly well exposed on a hillslope and in shallow roadcuts of the upper part of the Colony Creek Shale, Home Creek Limestone, and Lower Cisco Group terrigenous clastics, consists of unfossiliferous, sandy, Colony Creek Shale, overlain by 2 feet of fissile, muddy coal, of delta-plain to shallow, marshy embayment origin. The coal is covered by thin-bedded, rippled sandstone and silty shale and thin conglomeratic limestone and biomicrudite, comprising the Home Creek Limestone. The overlying Cisco Group terrigenous clastics comprise the remainder of the section and consist of medium- to coarse-grained fluvial sandstones and conglomerates in a profusion of tabular to channel-shaped units. These terrigenous clastics are representative of the Lower Cisco fluvial system, which built westward through southwestern Jack and southeastern Young Counties during early Virgilian time.

Section 31: Measured up hill directly across unpaved county road from the Halsell Ranch headquarters in southwestern Jack County; 3.9 miles southwest of Barton's Chapel, Texas.

A 140-foot section, well exposed on a hillslope of the Placid Shale Formation and Ranger Limestone, consists of sandy shale of prodelta and delta-front origin, overlain by a fine-grained, trough cross-bedded and rippled delta-front sandstone, 14 feet thick. The sandstone holds up a prominent escarpment and is covered by a fossiliferous interdistributary embayment mudstone and a distributary channel - delta-front sandstone unit. The top 38 feet of the section is composed of fossiliferous shallow-shelf mudstone capped by algal Ranger Limestone units.

Section Outside Mapped Area: Measured just west of Stephens - Palo Pinto county line in Stephens County, beginning at large sandstone roadcut along Highway 207, approximately 8 miles northwest of Strawn, Texas, measured up through Winchell Limestone on top of hill (see fig. 11).

A 169-foot section, well exposed in a roadcut and on a hillslope of the Wolf Mountain Shale Formation and Winchell Limestone, consists of fine-grained delta-front and distributary-mouth bar facies excellently exposed in a long roadcut (see A, fig. 11), overlain by stacked, medium-grained distributary channel-fill deposits. The entire sequence is capped by shallow-shelf mudstone and carbonates of the Winchell Limestone. The terrigenous clastic rocks exposed here are part of a system of minor deltaic lobes that prograded toward the northwest through Stephens County.

APPENDIX 2
LOCALITIES AND EXPOSURES OF INTEREST
(See Geologic Map, Plate I, for Locations)

NOTE: Each of the measured sections described in appendix 1 contains fair to excellent exposures of deltaic, fluvial, and shallow-shelf facies. The short list of localities given here is intended only as a supplement to the more extensive listing of appendix 1.

A. Massive distributary channel-fill sandstone unit in upper part of Colony Creek Formation—A good exposure (roadcut at junction of Highway 59 and F.M. Road 1810) of an 8-foot-thick distributary channel, which scoured through underlying interdistributary mudstone. The sharp, erosional character of the basal contact and the massive and well-sorted nature of the sandstone is well characterized.

B. Strike-fed, delta-destructional sandstone unit in upper part of Colony Creek Formation—A relatively good exposure (4 feet thick) of highly burrowed, reworked, delta-destructional sandstone caps a shale bluff on the M. L. Steward Ranch (0.2 mile west of road). The sandstone is riddled with vertical and subvertical burrows up to 0.75 inch in diameter and several inches long, and contains impressions of mollusk fragments and brachiopod valves.

C. Massive, squeezed and contorted, delta-front and distributary channel-fill sandstone in middle to upper parts of the Placid Formation—The contorted and rolled nature of massive Perrin delta sandstone units can be seen in weathered boulders just west of the county road.

D. Distributary channel-fill and delta-front sandstone facies, and shallow-shelf carbonate tongues of the Chico Ridge carbonate bank—A 1-mile-long spillway for Lake Bridgeport exposes Perrin delta sandstone and mudstone units of the Jasper Creek Shale (upper Wolf Mountain Formation) overlain by carbonate tongues. The Chico Ridge carbonate bank is well developed (150 feet thick) 1 mile north-northeast of this spillway.

E. Wildly slumped and contorted delta-front sandstone beds (see fig. 12) in the lower part of the Lake Bridgeport Shale (lower Wolf Mountain Formation)—Delta-front sand units slumped into unstable, water-saturated prodelta muds of the Perrin delta, giving spectacular contorted and rolled structures. These features are exposed in a roadcut along Highway 380 on the northwest side of Bridgeport, Texas.

F. Limestone breccia and intramicrudite (Rock Hill Limestone) in the middle part of the Wolf Mountain Formation—The Rock Hill Limestone was shed as a partially to completely prelithified carbonate talus lateral to the early developing Chico Ridge bank to the northeast. The 2-foot-thick limestone is well exposed above fossiliferous shelf mudstone in a roadcut along Highway 380.

G. Massively bedded delta-front sandstone beds in lower Jasper Creek Shale (Wolf Mountain Formation)—Bedded delta-front sandstone beds of a minor Perrin delta lobe overlie sandy, silty prodelta facies and are fairly well exposed along a railroad cut of the Chicago, Rock Island and Pacific Railroad.

H. Distributary channel - bar-crest sandstone facies in upper part of Wolf Mountain Formation (see fig. 15)—Trough cross-stratified and horizontally laminated to rippled distributary and bar-crest facies of a Perrin delta lobe are exposed in a roadcut along F.M. Road 1156.

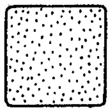
I. Unevenly bedded, shallow-shelf, algal carbonate facies (upper member, Ranger Limestone)—An excellent 15-foot-thick exposure of the shallow, transgressive shelf Ranger Limestone overlies rolled and contorted distal prodelta facies of a minor delta lobe.

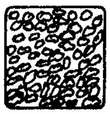
J. Distributary channel-fill facies (see fig. 14) in lower part of Colony Creek Formation—Massive to trough cross-stratified distributary channel sandstone is exposed in roadcuts along Highway 380. Excellent examples of contemporaneous soft-sediment faulting can be seen here, as well as a mudstone- and coal-filled abandoned channel cutout.

K. Distributary channel-fill facies in middle to upper part of Colony Creek Formation—A trough cross-stratified and somewhat slumped minor distributary channel sandstone unit is fairly well exposed in a roadcut west of the Halsell Ranch in southern Jack County.

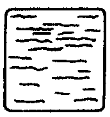
L. Shallow marine, transgressive shelf-carbonate facies (Ranger Limestone)—The shallow-shelf Ranger Limestone is well developed (40–50 feet thick) and is exposed in a roadcut along State Highway 16 in northwestern Palo Pinto County.

APPENDIX 3
Symbols Used In Measured Section Diagrams
(Refer to Plates II and III)

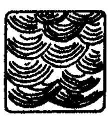
 Sandstone

 Conglomerate

 Limestone

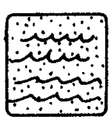
 Silty shale

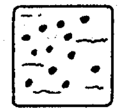
 Silty, sandy shale

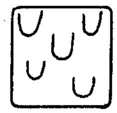
 Trough cross-stratification

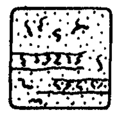
 Squeezed, contorted sandstone

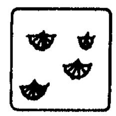
 Flow-roll structures

 Ripple bed forms

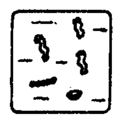
 Ferrugenous nodules

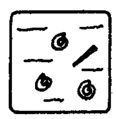
 Erosional channels

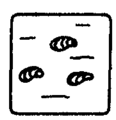
 Burrowed sandstone

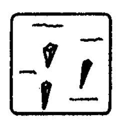
 Brachiopods

 Crinoids

 Sponges

 Nautiloids

 *Myalina* sp.

 Conularians

NOTE: The surface stratigraphic sections (pls. II, III) are based on measured sections at selected locations along strike in the Wolf Mountain and Placid Shale Formations respectively. Locations of measured sections are shown on the Geologic Map (pl. I) and are described in appendix 1. In each surface stratigraphic section (pls. II, III), the measured sections were projected perpendicularly into a line of section which parallels present day structural and inferred original depositional strike.