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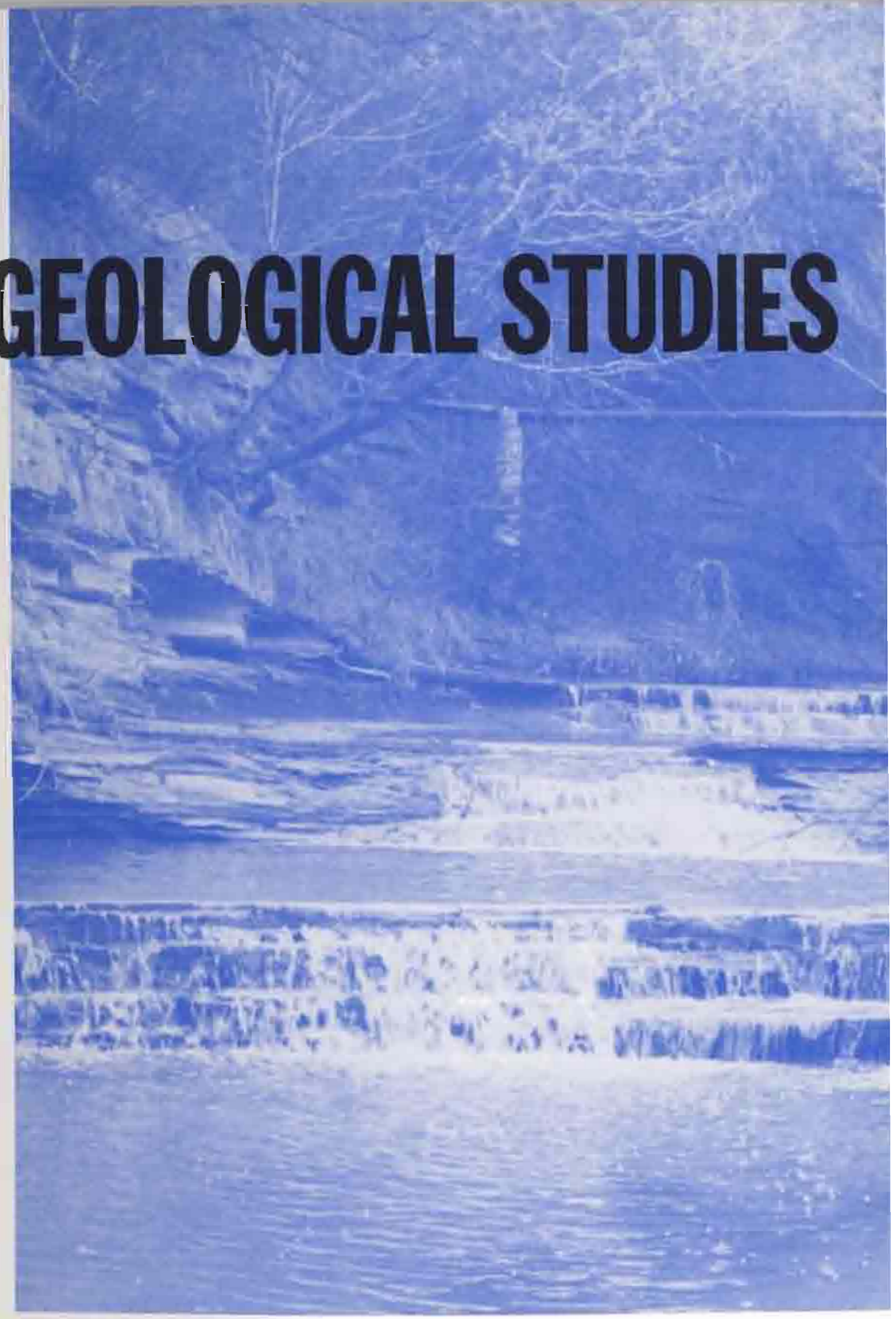

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Stratigraphy of the Eagle Ford Group (Upper Cretaceous) and Its Source-Rock Potential in the East Texas Basin

MILTON A. SURLES, JR.

"Creative thinking is more important than elaborate equipment--"

Frank Carney, Ph.D.
Professor of Geology
Baylor University
1929-1934

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Cover: Limestone beds near the top of the Lake Waco Formation.

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Stratigraphy of the Eagle Ford Group (Upper Cretaceous) and Its Source-Rock Potential in the East Texas Basin

Milton A. Surles, Jr.

BAYLOR UNIVERSITY
Department of Geology
Waco, Texas
Spring 1987

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Stratigraphy of the Eagle Ford Group (Upper Cretaceous) and Its Source-Rock Potential in the East Texas Basin

Milton A. Surles, Jr.

ABSTRACT

The Eagle Ford Group, of the upper Cretaceous Gulfian Series, is one of the most stratigraphically complex clastic-dominated units in the East Texas basin. At the type locality in Dallas County, Texas, the Eagle Ford consists of bluish-black, carbonaceous sediments exceeding 400 feet in thickness. In this area, the Eagle Ford includes the Tarrant (15 to 20 feet of brownish-gray calcareous sandstone), the Britton (250 to 300 feet of interbedded brown calcareous mudstone), and the Arcadia Park Formations (100 to 200 feet of dark gray calcareous mudstone).

Eastward into the basin, the Eagle Ford thickens to 900 feet as the upper Eagle Ford acquires another unit of terrigenous clastics on top of the Arcadia Park, called the Sub-Clarksville Sands. Southward out of the basin, the Eagle Ford thins by truncation and changes lithologic character; consequently the previously named subdivisions are no longer recognizable. Near Waco, the lower Eagle Ford consists of mostly montmorillonitic clays with disseminated calcium carbonate, called the Lake Waco Formation, and the upper Eagle Ford consists of dark gray, blocky shales, named the South Bosque Formation.

Geochemical analysis of Eagle Ford rocks throughout the East Texas basin indicates that the Eagle Ford Shales are organically rich enough to be considered superior source-rocks for some of the petroleum found in Austin, Eagle Ford, Woodbine, and Buda aged reservoirs. Within the petroleum generative province of East Texas, the Eagle Ford could have generated approximately 400 billion barrels of oil.

Significant petroleum reserves have been produced from rocks of Eagle Ford age in the East Texas basin. However, exploration for petroleum within Eagle Ford strata is at best very difficult. With the application of modified delta models, reservoir quality rocks can be mapped in order to define exploration fairways for the individual units of the Eagle Ford. When all of these fairways are compiled on the same map, two areas of major interest for Eagle Ford exploration become apparent.

INTRODUCTION

PURPOSE

The upper Cretaceous System in the East Texas basin is dominated by terrigenous clastic deposits. Of these rock units, one of the most complex is the Eagle Ford Group, which exists throughout most of the East Texas basin and represents a long and complicated period in Cretaceous deposition. Various stratigraphic studies based on local areas have described and attempted to interpret the Eagle Ford section, but few agree on major aspects of Eagle Ford deposition. No study examines Eagle Ford rocks throughout the East Texas basin, yet to properly interpret this major sequence a basin-wide study is necessary.

Some Eagle Ford facies have produced petroleum within the East Texas basin, while others have been recognized as probable source-rocks associated with some of the largest oil fields in East Texas. However, the Eagle Ford Group has been relatively ignored by petroleum explorationists.

Therefore, the purposes of this investigation were: 1) to describe the Eagle Ford Group throughout the East Texas basin; 2) to develop a depositional history of Eagle Ford rocks in east Texas; and 3) to relate this character and history of the Eagle Ford to its source-rock and petroleum potential.

LOCATION

The area of interest is within the structural province of the East Texas basin (Fig. 1). Rocks of the Eagle Ford Group crop out on the western and northern margins of the basin, marking the boundaries of the study area in these directions. The eastern margin of the basin is defined by the Sabine uplift, which was a positive structural feature during Eagle Ford time (Granata, 1963, p. 66). The southern extent of the study area is marked by the Angelina-Caldwell flexure which apparently was the shelf margin during Eagle Ford time. Beyond the flexure, the upper Cretaceous strata dip steeply into the Gulf Coastal basin.

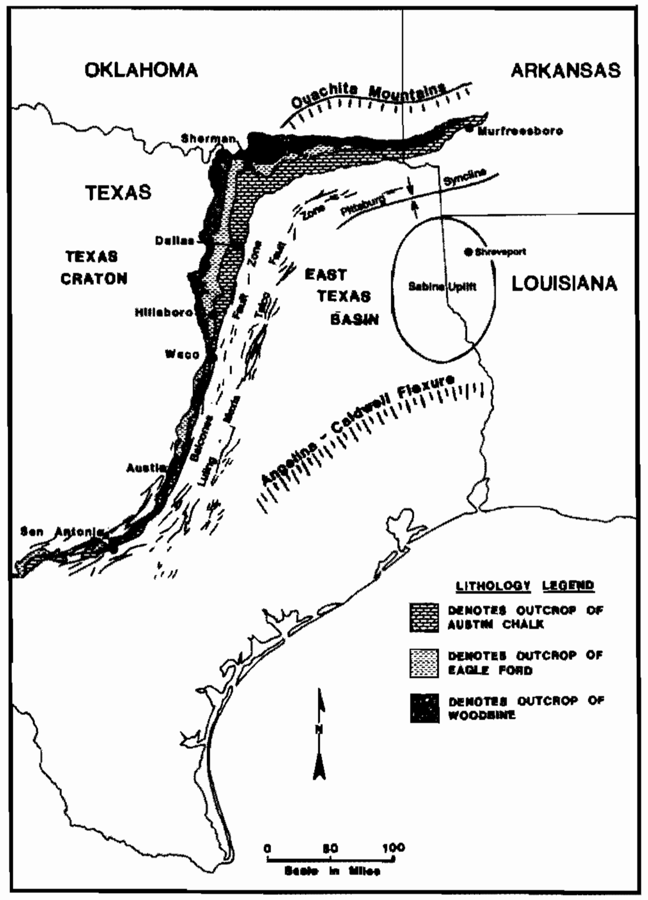


Fig. 1: Index map of the East Texas basin. The basin is bounded on the north and west by the outcrop belt of Eagle Ford rocks, on the east by the Sabine uplift, and on the south by the Angelina-Caldwell flexure.

Stratigraphically, rocks of the Eagle Ford Group are of upper Cretaceous Gulfian Series (Fig. 2). The age of Eagle Ford rocks ranges from middle-late Cenoman-

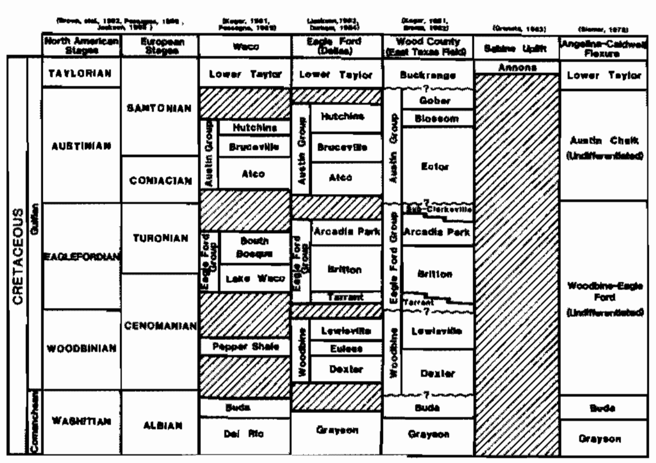


Fig. 2: Stratigraphic column for the upper Cretaceous Eagle Ford Group and surrounding strata. Note the terminology and stratigraphic differences exhibited by the Eagle Ford throughout the East Texas basin.

ian to late Turonian. Throughout most of the basin, the Eagle Ford and Woodbine are often undifferentiated and rest unconformably on the Buda Limestone. The Austin Chalk overlies the Eagle Ford throughout the basin and the contact between the two is generally unconformable along the updip margins of the basin.

METHODS

The methods used in this investigation included a field reconnaissance, an examination of electric logs, laboratory analysis of cuttings from wells drilled in the basin and outcrop exposures, and a review of the literature.

Outcrop localities were examined for lithology, fauna, sedimentary structures, and stratigraphic relationships as indicators of depositional models for the group. Representative sections were described for the different formations. These sections were used to correlate Eagle Ford rocks along the outcrop with electric log profiles.

Well logs were used to establish thickness and character of the units within the Eagle Ford. This information was used to generate isopach maps, sand isolith maps, and stratigraphic cross-sections which aid in understanding correlation and distribution of the Eagle Ford.

Laboratory analysis consisted of organic carbon analysis of samples by use of a Leco Automatic Carbon Determinator in combination with a Leco Induction Furnace. This information provided data to generate an isopleth map of organic carbon for the Eagle Ford group. This map, combined with distribution of producing fields, was used to draw conclusions about the source-rock potential of Eagle Ford rocks.

The literature review included all works pertaining to Eagle Ford rocks of the East Texas basin, selected works on organic geochemistry, and references on structure, oil production, sedimentation, and deposition of organic muds and anoxic shales.

PREVIOUS WORKS

In the progress of this study an extensive review of previous works was undertaken, dealing with (1) the Eagle Ford Group and associated rocks, (2) the structural development of the East Texas basin, (3) occurrence, distribution and significance of dark organic shales, (4) more general references on depositional environments, oil generation and migration in the East Texas basin, and (5) techniques of organic analysis of Eagle Ford and associated rocks.

To enhance readibility, this section of about fifty manuscript pages included in the original thesis, has been excluded from this published version of the report. If you wish a copy of this summary of previous works, simply write the Department of Geology, Baylor University, Waco, Texas 76798, or call (817) 755-2361.

ACKNOWLEDGMENTS

I cannot begin to acknowledge all those who contributed in some way to the preparation of this thesis. However, my deepest appreciation is extended to O. T. Hayward, Baylor University, whose advice and persistent encouragement was a fundamental factor in completion of not only this work, but also my academic career thus far. Thanks are also extended to Robert C. Grayson, Jr., and James L. McAtee, Baylor University, for their technical advice and help in editing of this work. Others who offered helpful suggestions include Fred L. Stricklin, Jr., Cenomanian Corp.; and Peter Allen, Joe C. Yelderman, and Rena Bonem, Baylor University.

Sincere gratitude is expressed to the American Association of Petroleum Geologist Research Committee and the equivalent committee of the Southwest Section of that organization for Grants-in-Aid which helped fund the study. Thanks are extended to Paul Doliver and Diane Barnes of Geomap Inc., for providing well data, Jackie Reed and Kurt Ritch with Arco Corp., for technical support and use of laboratory equipment, and to Mobil Oil Corp., for donation of geochemical supplies. Finally, special thanks are extended to my parents, Mr. and Mrs. Milton A. Surles, for their love, devotion, and support, without which none of this would have been possible.

DESCRIPTIVE GEOLOGY

The Eagle Ford Group and its temporal equivalents are complex litho-stratigraphic units representing a significant portion of the upper Cretaceous (Gulfian) section of North America. The complexity of the section is reflected by the numerous changes in lithology, character, and stratigraphic nomenclature existing not only within the East Texas basin, but also between North American Cretaceous basins. To understand Eagle Ford rocks, it is necessary to consider both regional and local aspects of Eagle Ford deposition. Therefore, the purpose of this section is to describe rocks of Eagle Ford age in North America, and then to describe in greater detail the nature and distribution of Eagle Ford rocks in the East Texas basin.

REGIONAL STRATIGRAPHY

As a starting point, the East Texas basin is briefly described first. The Eagle Ford sediments are then traced eastward out of Texas into the Eastern Gulf Coastal basin, then southward out of east Texas into south Texas, Mexico, and west Texas. Finally a comparison is made with the upper Cretaceous equivalents of the Western Interior region.

East Texas

Eagle Ford rocks in east Texas are dominated by dark bluish-gray shale which varies in thickness from 200 to 900 feet. It is thickest near the center of the basin and thins towards the southern and eastern margins of the basin. The Eagle Ford also thins eastward along the northern outcrop and southward along the western outcrop towards the boundaries of the basin. While the dominant lithology is shale, the section contains interbeds of sandstone, limestone, and bentonite. Generally, the Eagle Ford decreases in carbonates up section and increases in terrigenous clastics in the same direction.

Eastern Gulf Coastal Basin

Eastward out of the East Texas basin, Eagle Ford rocks pinch out both on the outcrop and in the subsurface, apparently as a result of erosion and nondeposition related to the Sabine uplift (Granata, 1963, p. 65). However, a narrow band of Eagle Ford rocks up to 100 feet in thickness occurs both in the sub-surface and as a narrow outcrop belt in southwestern Arkansas, known as the Pittsburg syncline (Stehi et al., 1972, p. 39). A change in character of the Eagle Ford in this area, from dark laminated shales of the East Texas basin to blue calcareous shale with abundant red clay, probably indicates proximity to a source of terrigenous clastics (Stehi et al., 1972, p. 46).

Eastward, in northwestern Louisiana, the Eagle Ford thins to less than 80 feet, and consists of dark fossiliferous shales interbedded with greenish, tuffaceous, chloritic sands and greenish bentonitic shales (Hazzard, 1939, p. 137). Continuing eastward, the lower-most unconformity of the upper Cretaceous section in the Eastern Gulf region is along the contact of the Tuscaloosa (equivalent to Woodbine rocks) and overlying Eutaw Formations (possibly equivalent to lower Austin rocks) (Fig. 3) (Stephenson and Monroe, 1938, p. 1641). Thus, rocks of Eagle Ford age are generally missing from the Eastern Gulf Coast.

Significant to the history of Eagle Ford deposition are volcanic centers near Murfreesboro, Arkansas, which were active during early Gulfian time (Ross et al., 1929, p. 175). These centers have been suggested as possible

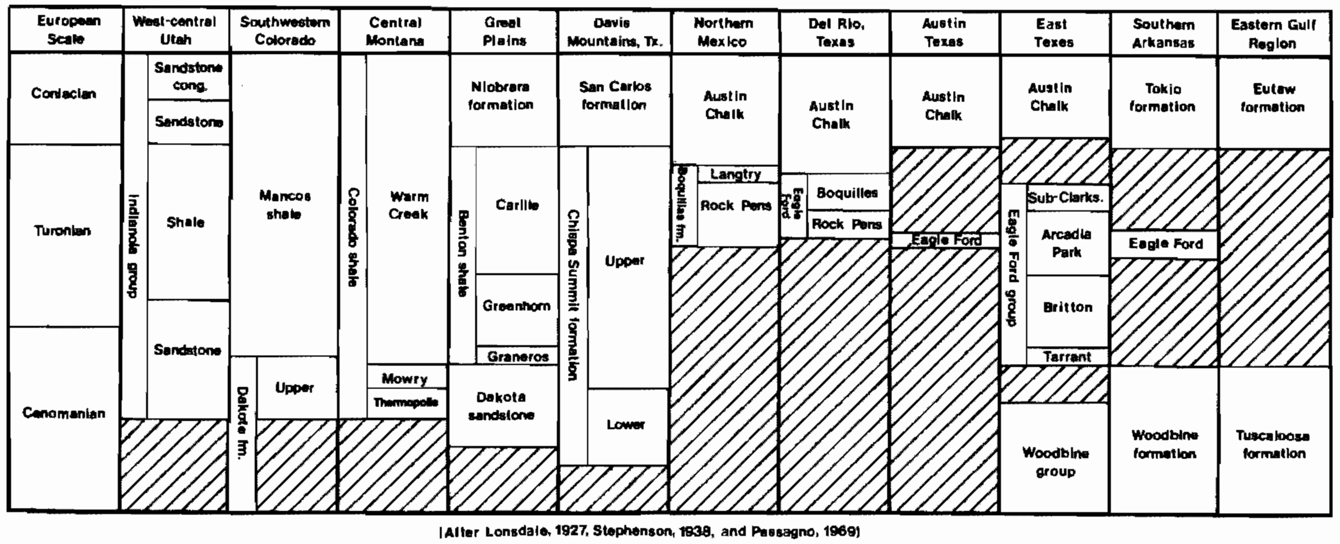


Fig. 3: Stratigraphic correlation chart of the Eagle Ford equivalents in North America (after Lonsdale, 1927, Stephenson, 1938, and Pessagno, 1969). Eagle Ford rocks of east Texas are equivalent to several rock units in North America including: the Boquillas Formation, the Chispa Summit Formation, the Benton Shale, the Colorado Shale, the Mancos Shale, and the Indianola Group. Note the unconformity which exists in the Eastern Gulf region representing Eagle Ford time.

sources of the volcanic ash, now represented by bentonite seams in the Eagle Ford of east Texas (Miser and Ross, 1925, p. 123).

Southwest Texas, Mexico, and West Texas

The Eagle Ford rocks thin southward from Dallas to Austin, apparently because of non-deposition of lower units and truncation of upper beds (Brown and Pierce, 1962, p. 2144), possibly as a result of concurrent uplift in the Llano area (Stephenson, 1928, p. 487). At Austin, Eagle Ford thickness is under 42 feet, and consists of thin bedded buff marls and chalks, unconformably resting on Buda Limestone and unconformably overlain by the Austin Chalk (Pessagno, 1969, p. 63).

Southward beyond Austin, the section again thickens to 112 feet near Del Rio, where it consists of black shales subdivided into a lower Rock Pens Member, and an upper Boquillas Formation. The contact between the Boquillas and Austin Chalk is conformable and gradational (Pessagno, 1969, p. 62). Serpentized rocks occur as masses in the Eagle Ford from this area (Lonsdale, 1927, p. 45), and these have been suggested as sources for bentonites in the Eagle Ford of southeast Texas.

Westward into Mexico, the Eagle Ford equivalents thicken to 188 feet and are termed Boquillas Formation. Disconformably overlying the Buda Limestone, the Boquillas is divided into: 1) the lower Rock Pens Member, consisting of 150 feet of gray calcareous siltstones, mudstones, and limestone flags; and 2) the upper Langtry Member, consisting of 38 feet of buff calcareous marlstones, marls, and thin-bedded chalky limestones. The Austin Chalk conformably overlies the Boquillas in this area (Pessagno, 1969, p. 61).

Westward into the Davis Mountains of west Texas, rocks of Eagle Ford age are termed the Chispa Summit Formation, consisting of 2000 feet of strata subdivided into two units: 1) a lower 500 feet of thin-bedded buff to gray calcareous muds, calcareous silts, marls, and chalks; and 2) an upper 1500 feet of dark gray calcareous mudstone with occasional limestone concretions and nodules. The Chispa Summit Formation rests disconformably on the Buda Limestone and is conformably overlain by the San Carlos Formation of Austin age. The most complete section of Eagle Ford age rocks is that present in this area, ranging from late Cenomanian through late Turonian age without any detectable hiatus.

Western Interior

The Eagle Ford Shale of the East Texas basin correlates well with several units of the Western Interior United States (Fig. 3). Among these, the Benton Shale is perhaps the nearest correlation. Other groups from the Western Interior that also correlate with Eagle Ford sediments include: the Indianola Group of west-central Utah; the Mancos Shale of southwestern Colorado; and the Colorado Shale of central Montana (Moreman, 1942, p. 195).

Summary

Following a late Woodbine erosional period, Eaglefordian seas inundated several areas of the continental United States. In east Texas the sediments deposited from these seas consisted of 200 to 900 feet of dark bluish-gray shale interbedded with sandstone, limestone, and bentonite. The Eagle Ford is generally absent in the Eastern Gulf Coast, where Eagle Ford time is represented by a major unconformity. In the East Texas basin, Eagle Ford rocks thin southward to the latitude of Austin, then thicken toward Del Rio. Thickening continues westward into Mexico, and west into the Davis Mountains, where it reaches a maximum thickness of 2000 feet.

Eagle Ford sediments of the East Texas basin correlate with Western Interior equivalents including the Benton Shale, Indianola Group, Mancos Shale, and Colorado Shale.

EAGLE FORD GROUP

The Eagle Ford Group of the East Texas basin consists of as much as 400 feet of bluish-black laminated clay distributed throughout the basin. The type locality for Eagle Ford rocks is at the townsite of Eagle Ford, approximately 7 miles west of Dallas, in Dallas County, Texas (Sellards et al., 1932, p. 422), where it is subdivided into the Tarrant Sandy Clay, the Britton Clay, and the Arcadia Park Shale (Fig. 2) (Sellards et al., 1932, p. 425). Eastward into the basin, the upper Eagle Ford expands by the addition of the Sub-Clarksville Sand (McNulty, 1966, p. 379). Because these subdivisions are the most complete, they form the framework of the description for this section. Each unit is described in terms of lithologies, stratigraphic contacts, and thickness and distribution.

Lithology

Eagle Ford rocks of east Texas are dark bituminous laminated clays (Shuler, 1918, p. 15). On the outcrop near Dallas, the lower two-thirds of the formation consists mostly of blue and black laminated shale which grades upward into a brown weathered section of ferrigenous glauconitic sand interlaminated with clay. Eagle Ford rocks are not normally fossiliferous, though fossiliferous beds do occur in certain outcrops (Gordon, 1911, p. 17-19). North and south of Dallas, the clay in the Eagle Ford becomes less sandy as the outcrop belt narrows in both directions (Stephenson, 1927, p. 6; Stephenson, 1928, p. 488). Northward from Dallas, the Eagle Ford continues as dominantly black laminated clay. Eastward, near Sherman, sandstone stringers become more common and increase in thickness and number (McNulty, 1966, p. 375). Southward from Dallas, the Eagle Ford thins as upper beds are truncated (Brown and Pierce, 1962, p. 2144). The silts and sands typical of the northern basin are conspicuously absent, and carbonate-rich rocks dominate the lower Eagle Ford near Waco (Brown and Pierce, 1962, p. 2137).

Within the basin, the Eagle Ford is recognized on electric logs by a drastic decrease in both spontaneous potential (Sp) and resistivity in relation to the overlying and underlying rocks (Fig. 4). The contact between Woodbine and lower-most Eagle Ford rocks is normally drawn at the base of the first shale section above the upper-most sand of the Woodbine. The upper contact between the Eagle Ford and Austin is drawn at the top of the last shale section below the lowest known limestone member of the Austin group. Occasional peaks in both Sp and resistivity occur in the Eagle Ford section throughout most of the basin, representing small carbonate and sand bodies in the dominantly shale section.

Stratigraphic Contacts

Eagle Ford rocks unconformably overlie Woodbine strata along the margins of the East Texas basin.

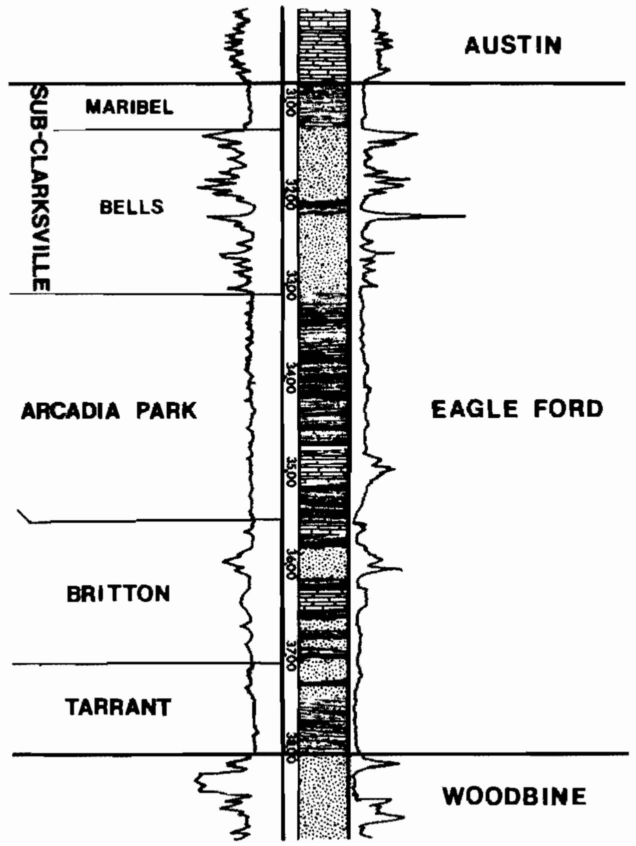


Fig. 4: Well 23, Bend Oil Corp. #1 Albowitch. The Eagle Ford can be subdivided into four formations in this well: the Tarrant, the Britton, the Arcadia Park, and the Sub-Clarksville which can be further subdivided into the Bells and Maribel Members. Note the lithologic interpretations of the log signatures including sand, limestone, and shale.

However, in the southwestern portion, beyond the pinchout of Woodbine rocks, the Eagle Ford rests directly on Buda Limestone, and the contact marks the Comanchean-Gulfian unconformity. The Eagle Ford Group is overlain by the Austin Group in all portions of the basin. Throughout the basin, this contact is believed to be unconformable, with rocks of upper Turonian and lower Coniacian age missing through non-deposition and truncation.

Distribution and Thickness

An isopach map of the Eagle Ford Group shows a thick sequence of Eagle Ford rocks in the northcentral portion of the basin, near area A (Fig. 5). The Eagle Ford gradually thins southward, due not only to the absence of the Tarrant and Sub-Clarksville Formations, but also as a product of gradual thinning of the Britton and Arcadia Park Formations (Fig. 6). Thinning along the Belton high is reflected at area B, possibly indicating positive expression of this feature during Eagle Ford time. The Eagle Ford thins rapidly eastward out of the basin and is not present over the Sabine uplift, area C. Another thickening of the Eagle Ford occurs south of the Sabine, where the strata plunge into the Gulf Coast basin.

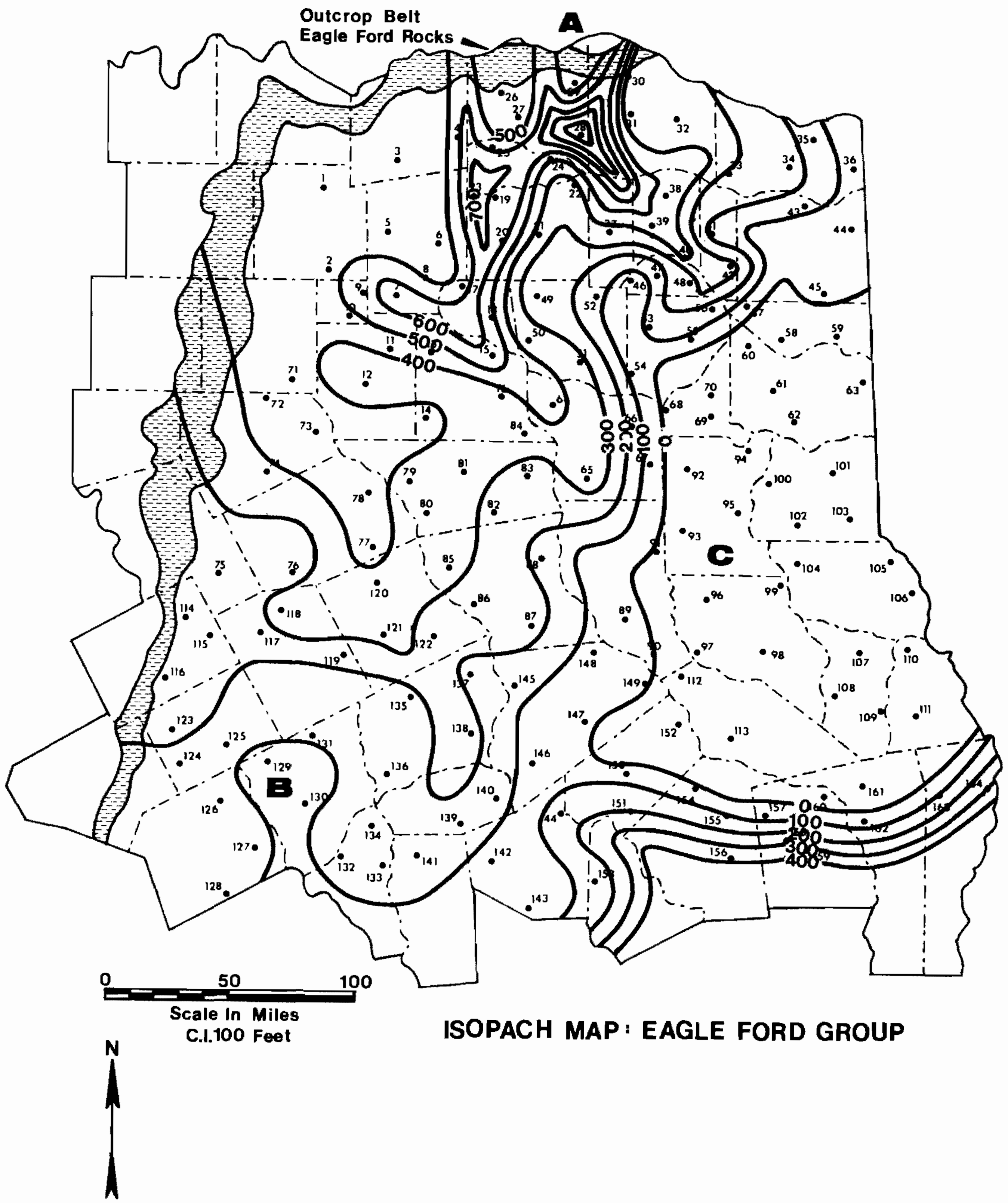


Fig. 5: Isopach map of the Eagle Ford Group. The Eagle Ford thickens in the northern portion of the basin near area A, and thins southward accompanied by thinning along the Belton high, area B. The Eagle Ford is absent over the Sabine uplift, area C, apparently due to erosional removal after deposition.

The northward thickening is associated with the northern portion of the central East Texas basin, probably indicating more rapid sedimentation possibly accompanied by salt withdrawal and subsidence. The greatest thickness of sediment is also coincident with an increase in sands in the Eagle Ford, while the southern thinning is accompanied by an increase in carbonates, suggesting that clastic influx was occurring from the north during Eagle Ford time. This northern influx increased the overall thickness of the group and preferentially excluded carbonates in the northern portions of the basin.

Tarrant Sandy Clay

Lithology

The lower-most unit of the Eagle Ford, the Tarrant Sandy Clay, consists of 15 to 20 feet of gray to brownish-gray calcareous sandstone interbedded with brown siltstone, brownish limestone, and shale. The base of the Tarrant characteristically has a zone of reworked mudstone pebbles, siderite, alunite, borings, glauconite, and black phosphate nodules (Brown and Pierce, 1962, p. 2135). Throughout Johnson and Hill counties, the basal Tarrant contains "water worn" sandstone pebbles, which are as much as two inches wide in their longest dimension (Sellards et al., 1932, p. 423).

On electric logs the Tarrant formation is represented by a sandy shale section above the sand-dominated Woodbine signatures and below the shale-dominated signatures of the lower Britton (Fig. 4). The contact between the Woodbine and Tarrant is drawn at the base of the sandy shale signature above the last true sand of the Woodbine. The contact between Tarrant and Britton is indicated by the abrupt transition from sandy shale to shale signatures. Occasional carbonates occur near the Tarrant-Britton contact, usually in lower Britton strata.

The sandy shale log signature of the Tarrant reflects varying permeability caused by small sand stringers throughout the section (Cross Sections A - A′ and D - D′). Carbonates are generally restricted to the western and southwestern portions of the basin, probably reflecting reduced clastic sedimentation farther from the deltas (Cross Sections B - B′ and F - F′).

Stratigraphic Contacts

At the Eagle Ford type locality near Dallas, the contact between the Woodbine Group and Tarrant formation is unconformable, indicated by a sharp lithologic change and the presence of reworked material in the base of the Tarrant, often marked by white alunite nodules (Stephenson, 1929, p. 1327; Stephenson, 1946, p. 1764). It is not known to what extent the unconformity extends into the sub-surface. The Tarrant is overlapped from the south by the Britton Clay (Brown and Pierce, 1962, p. 2144). The contact between the two is considered to be conformable, showing both gradational and abrupt lithologic changes (Figs. 6 and 7).

Distribution and Thickness

The Tarrant thickens basinward to over 200 feet in the northcentral portion of the basin, near Area A (Fig. 8). The isopach also shows the Tarrant pinching out southward and eastward, which appears to be due to a combination of thinning and facies change (Figs. 6 and 7). Thinning occurs in the northwestern portion of the basin in area B, probably a product of slower sedimentation rates.

Individual Tarrant sands average less than 10 feet in thickness. On a sand isolith, areas of thick sand accumulations reflect stacking of sands rather than thickening of individual sand bodies (Fig. 9). Two buildups of sand occur in the Tarrant, one originating in the north, near area A, and one from the west, near area B, indicating two sources of clastic influx during Tarrant time, and also that the shoreline was very near the present outcrop line. Tarrant sand accumulations reach a maximum combined thickness of 40 feet where Tarrant sediments are more than 200 feet thick and the shale-to-sand ratio is 5:1. Thus even during the deposition of the Tarrant rocks containing the most sand, the dominant sediment was mud.

The distribution of the sands in area C resembles sand distribution from a bird foot delta complex, indicative of low destructive energy. The relationship between the accumulations of sand in areas A and C is best explained by the transgressive nature of the lower Eagle Ford. Distributary pathways in area C were established early in Tarrant time. As the Eaglefordian seas transgressed into the East Texas basin, the distributary pathways retreated to area A. The thicker sequence of sand at area A is probably a function of a longer period of delta stabilization.

The restriction of Tarrant carbonates to the northwestern portions of the basin corresponds with generally less sand in these areas, suggesting development of marginal embayments between the sand distributaries.

Britton Clay

Lithology

On the outcrop near Dallas, the Britton Clay consists of 250 to 300 feet of dark brown laminar calcareous mudstone interbedded with thin impure beds of limestone and siltstone. Southward, the Britton thins and its upper beds are truncated (Brown and Pierce, 1962, p. 2144). South of Hill County, the Britton assumes the name Lake Waco (Pessagno, 1969, Pl. 9). The Lake Waco is subdivided into the Bluebonnet Member, the Cloice Member, and the Bouldin Member. Generally, the Lake Waco consists of mostly montmorillonitic clays with considerable disseminated calcium carbonate, numerous limestone beds near the base and top, minor seams of bentonite, and rare kaolinitic clays (Burkett, 1965, p. 28). Bentonites are concentrated in the Britton where at least 34 bentonite seams have been reported within 70 feet of strata (Brown and Pierce, 1962, p. 2135).

On electric logs the Britton is recognizable by a distinctive signature indicative of shale (Fig. 4). The upper contact of the Britton with the lower-most Arcadia Park was recognized by a rapid decrease in carbonate in upper Britton to a shale-dominated lower Arcadia Park. This decrease was marked by a negative kick in

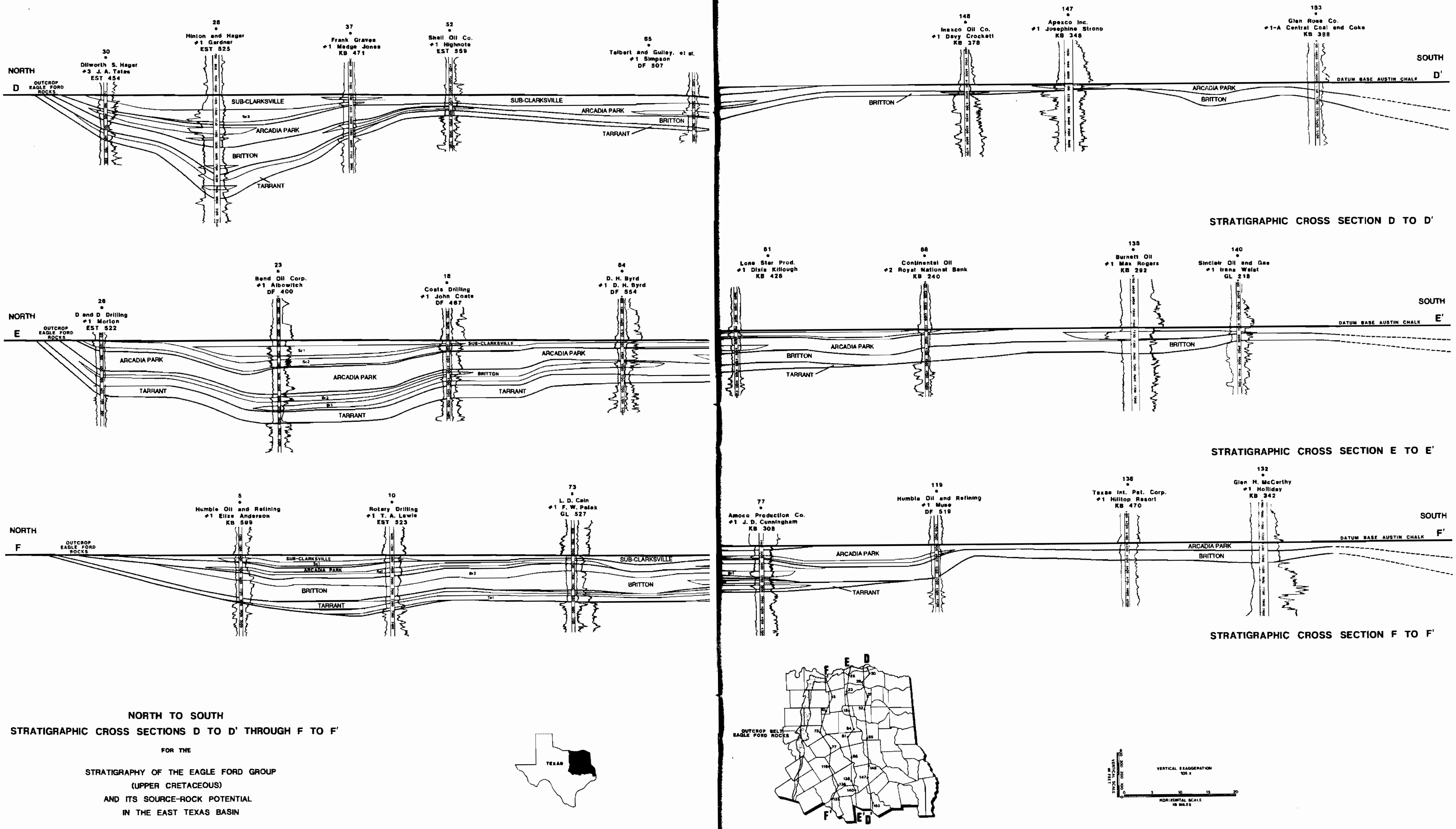
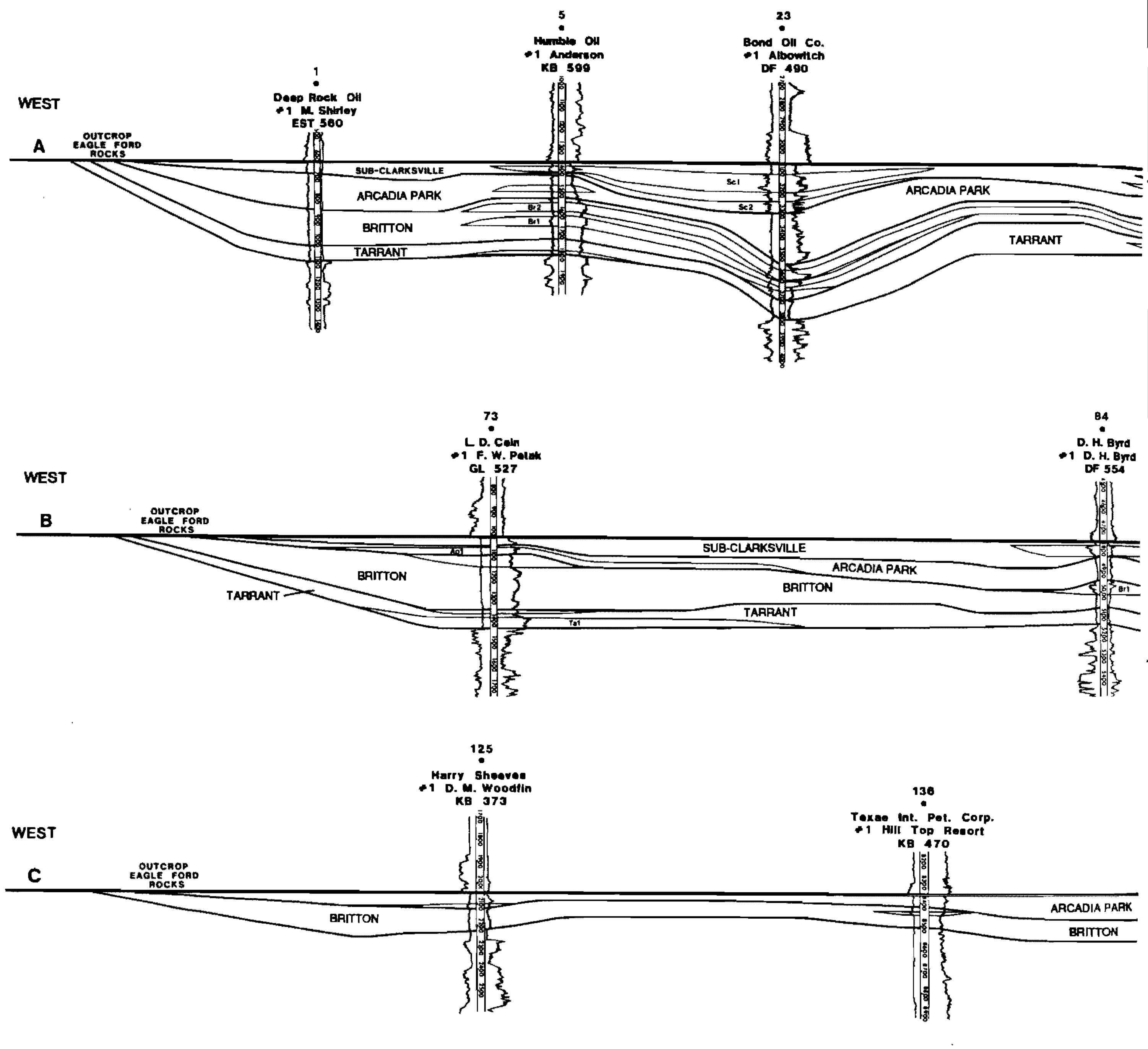
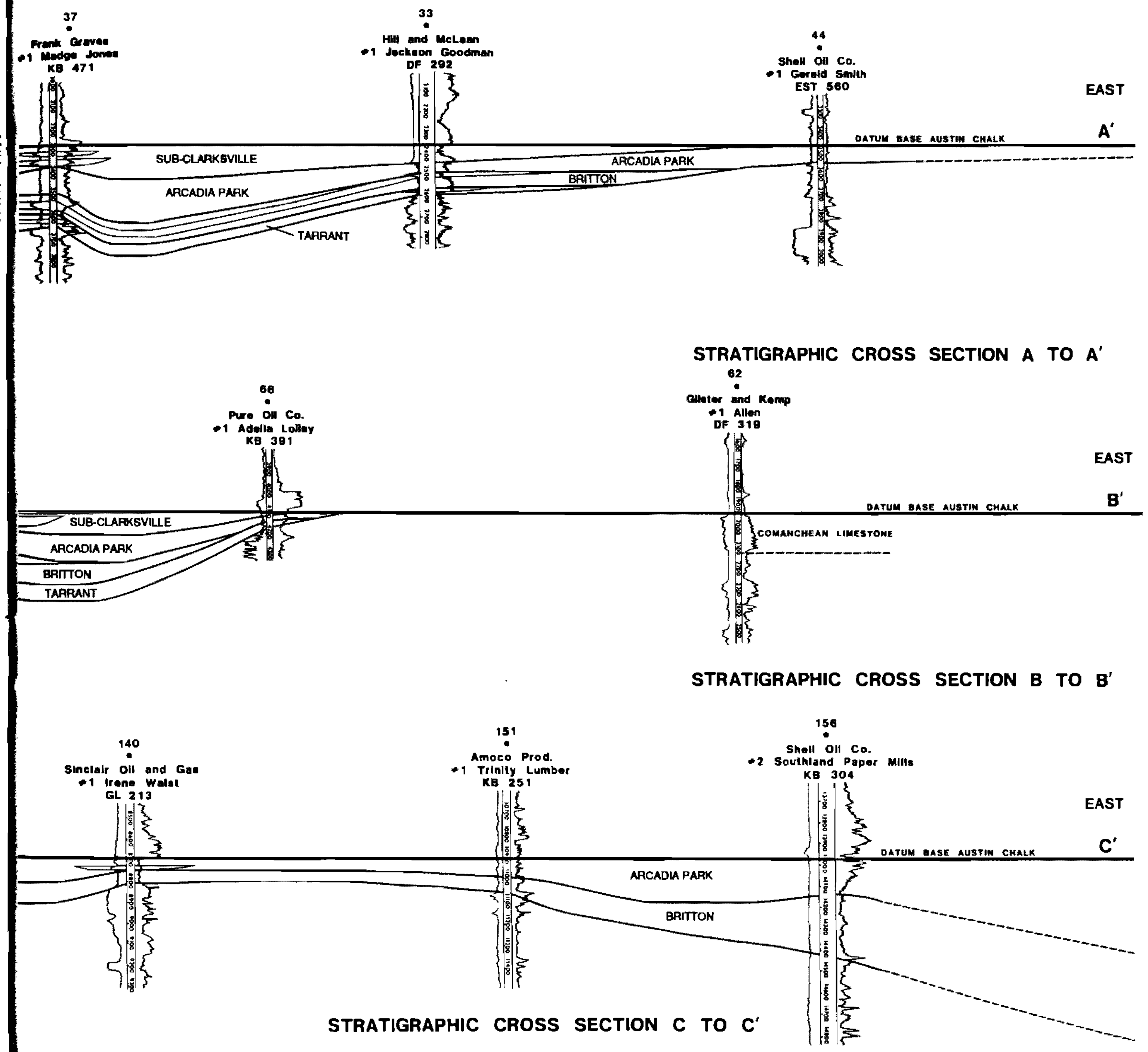


Fig. 6: North to South Stratigraphic Cross Sections D to D' Through F to F'.





WEST TO EAST

STRATIGRAPHIC CROSS SECTIONS A TO A' THROUGH C TO C'

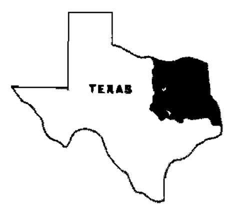
FOR THE

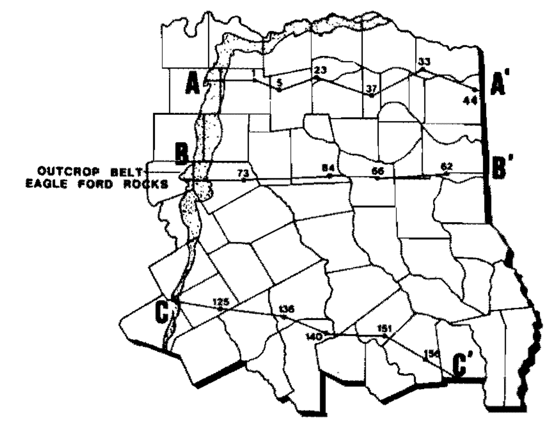
STRATIGRAPHY OF THE EAGLE FORD GROUP

(UPPER CRETACEOUS)

AND ITS SOURCE-ROCK POTENTIAL

IN THE EAST TEXAS BASIN





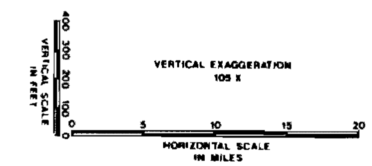


Fig. 7: West to East Stratigraphic Cross Sections A to A' Through C to C'.

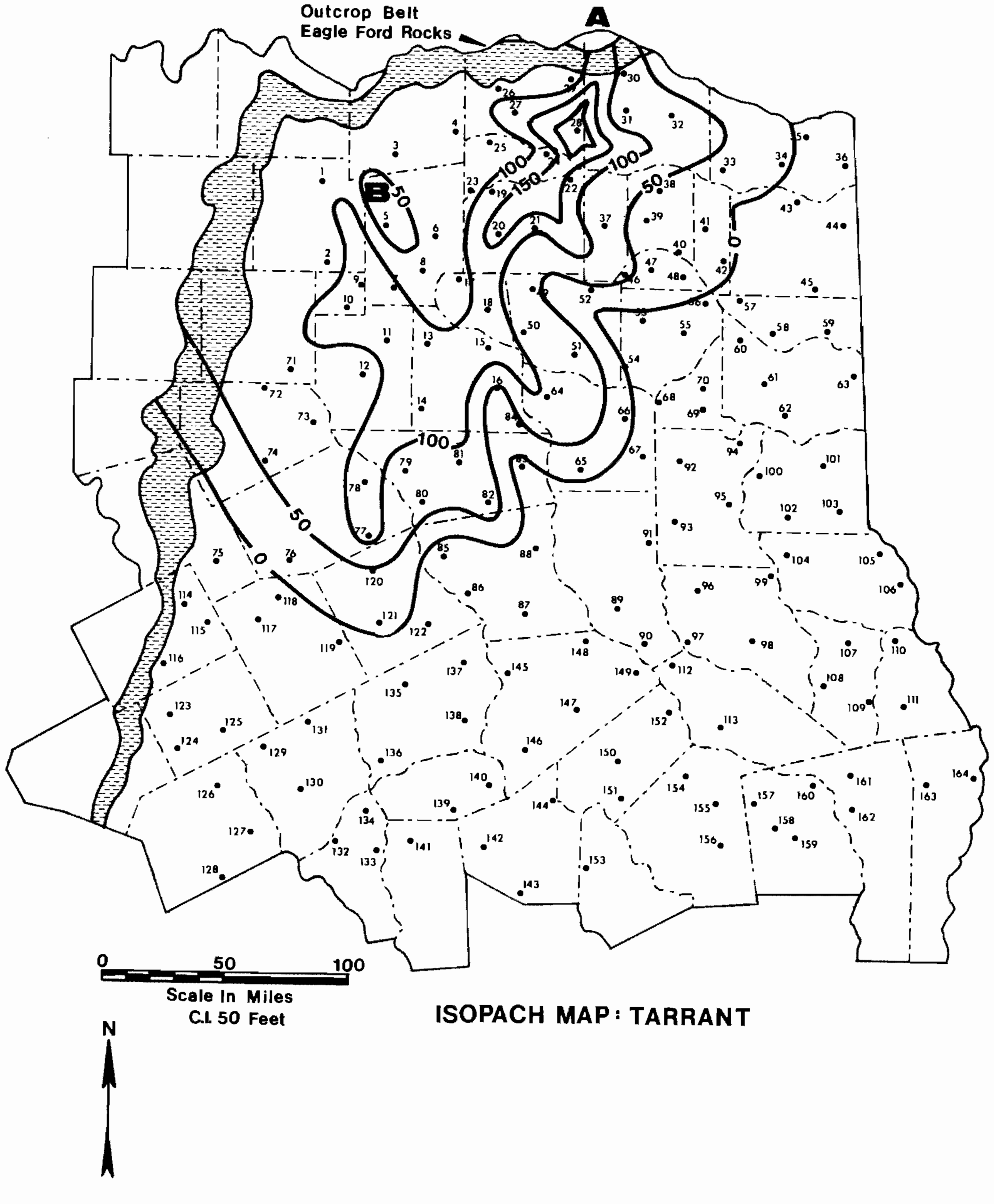


Fig. 8: Isopach map of the Tarrant Sandy Clay. Tarrant rocks thicken in the northcentral portion of the basin, near area A. Note the thinning of the Tarrant in area B, and the southward and eastward limit of the unit, apparently a product of thinning and facies change.

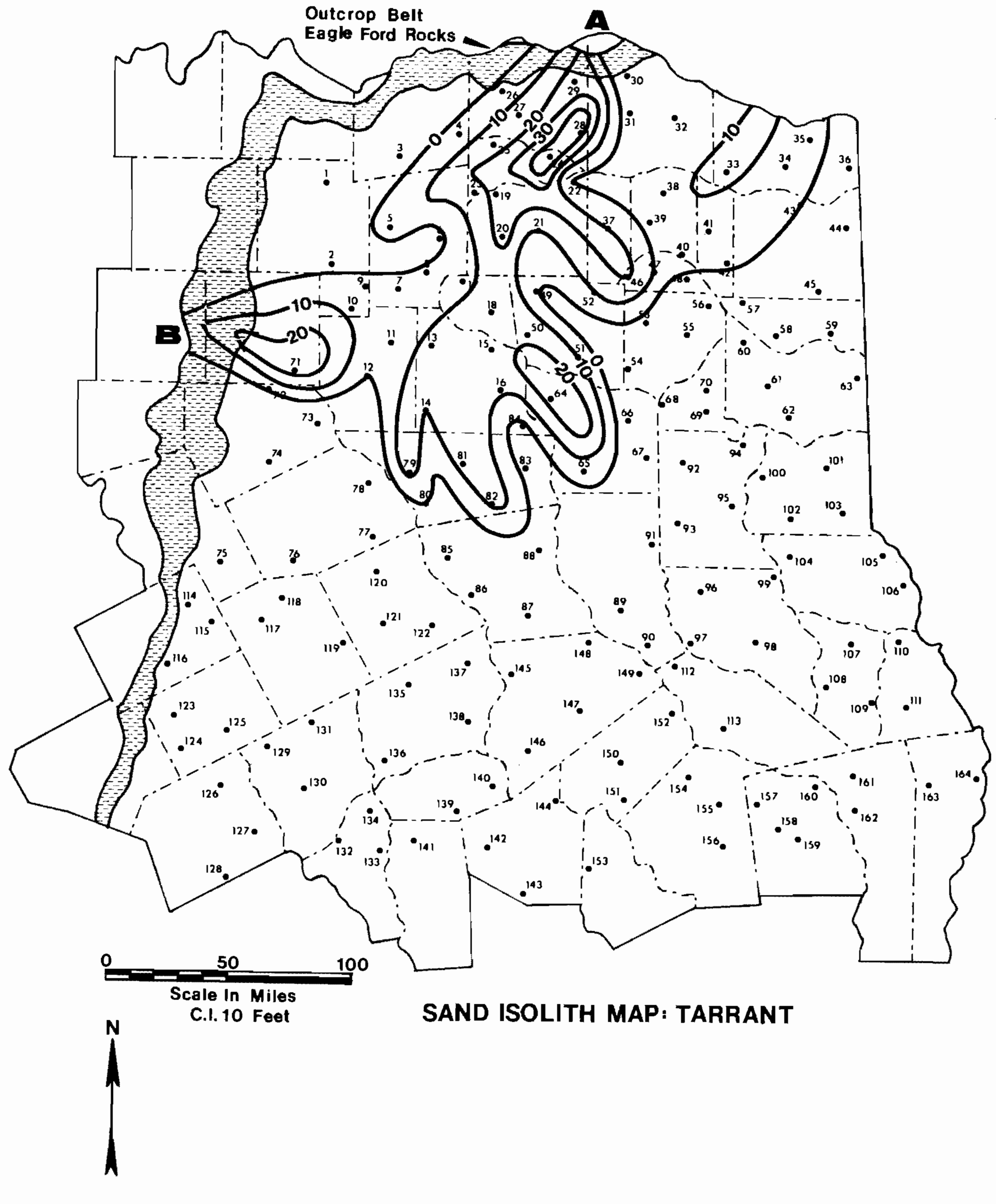


Fig. 9: Sand isolith of the Tarrant. Moderate sand buildups occur in two areas within the basin, one originating in the north near area A, and one in the west near area B. Note the sand distribution pattern in area C resembles a bird foot delta complex.

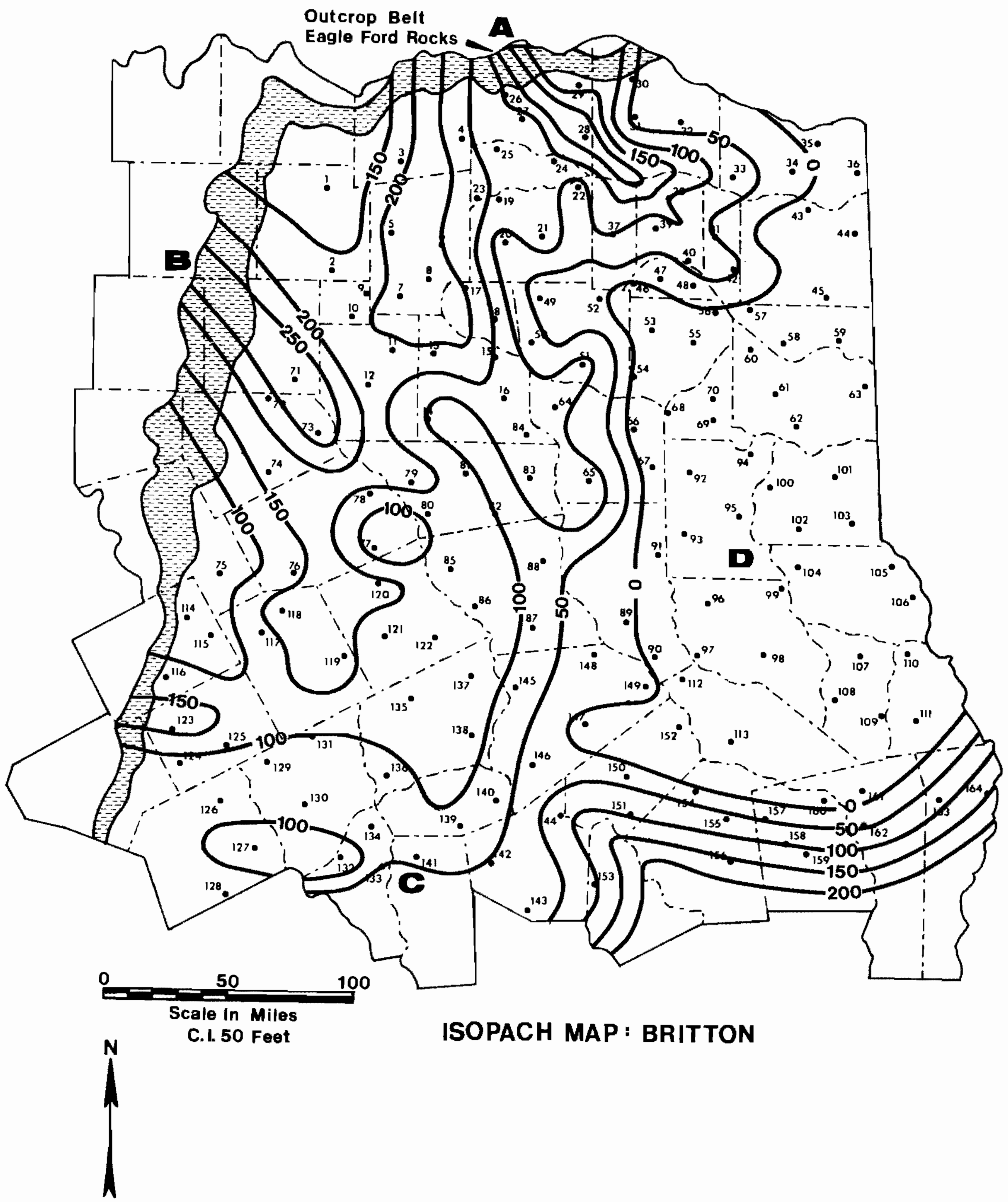


Fig. 10: Isopach map of the Britton Clay. Three areas of thickening of Britton strata occur in the north near areas A and B. Southward thinning of Britton rocks to less than 50 feet occurs at the Angelina-Caldwell flexure, area C. Note the absence of Britton strata over the Sabine uplift, area D, apparently due to erosional removal after deposition.

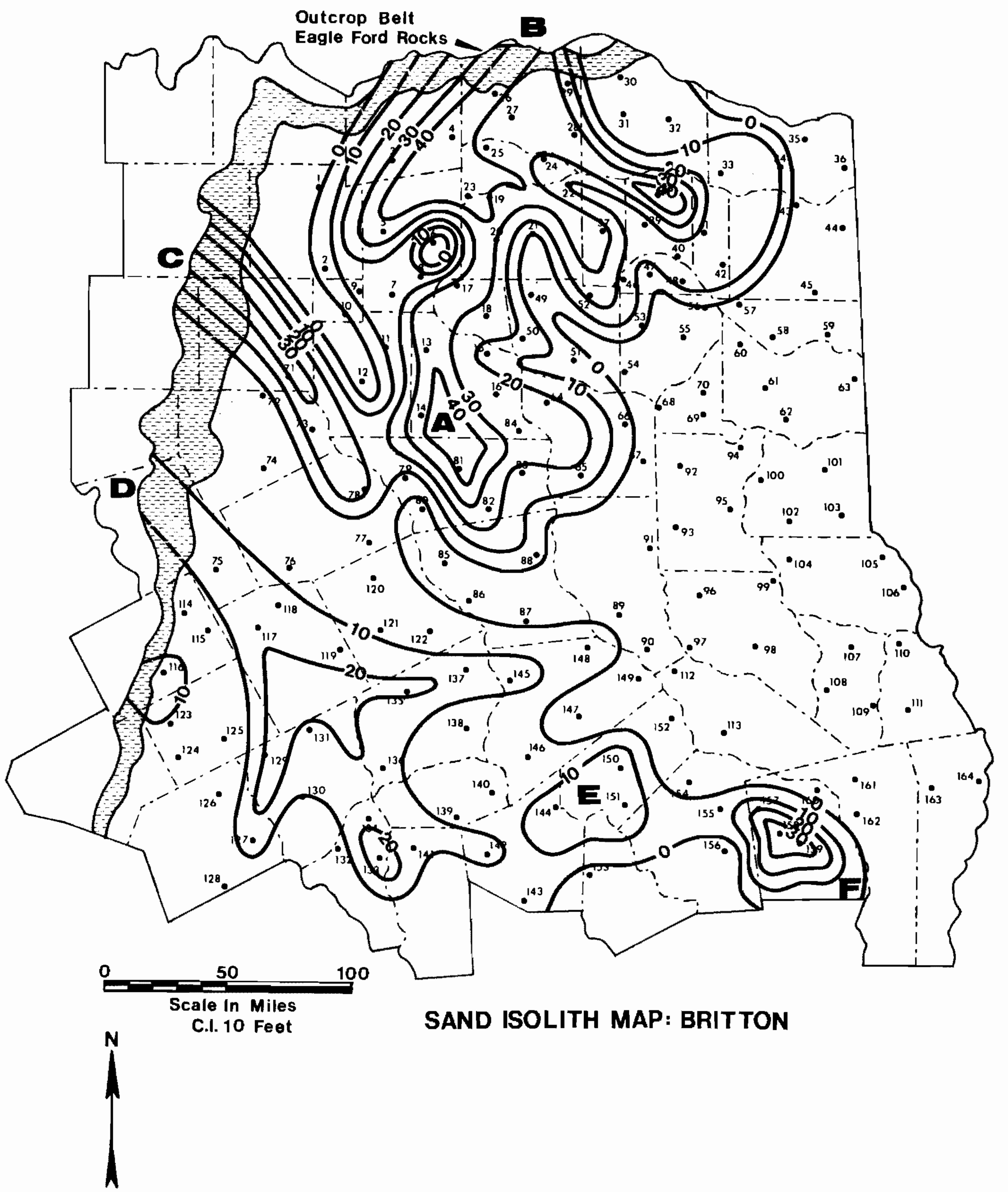


Fig. 11: Sand isolith of the Britton Clay. Six areas of major sand accumulation are visible, A, B, C, D, E, and F. Of these, a highly complex sand body originates in area B and extends to area A. The elongate distribution of sand in area C could be due to paucity of data. Sand distribution near area D resembles a bird foot delta complex. Sand accumulations at areas E and F are not related to any major points of clastic influx and are apparently the result of turbidity transport related to the Angelina-Caldwell flexure.

the resistivity on the electric logs, which is the top of the Britton.

The increase in resistivity on electric logs reflects the increased limestones and disseminated carbonates present both on the outcrop and in the sub-surface. Several limestone beds are laterally extensive (Cross Sections A - A′ and E - E′). Carbonate body Br1 (Cross Section E - E′) suggests a progradation of the carbonate environment into the basin. However, carbonate body Br2 occurs at approximately the same position in each well, indicating that an areally extensive carbonate environment existed towards the end of Britton time. Small sand channels (Cross Sections C - C′, D - D′, and F - F′) are present, and range to 40 feet in thickness.

The wide distribution of both calcareous and terrigenous sediments, often overlapping, suggests interfingering of carbonate and sand depositional environments during Britton time. Carbonate bodies include calcareous mudstones, calcareous bioclastic mudstones, packstones, and bioclastic grainstones, all of which indicate wide varieties of carbonate depositional environments (Charvat, 1985, p. 33, 37). Carbonate body Br1 (Cross Sections A - A′ and E - E′) apparently represents an interdistributary and marginal bay deposit, preserving mostly mud-dominated carbonates. Widespread carbonate deposits like Br2 (Cross Sections A - A′, E - E′, and F - F′) are indicative of periods of low clastic influx and widespread marine conditions, as indicated by extensive packstones and grainstones. Some of the grainstones with reworked shell material accumulated under higher energy environments.

While significant accumulations of both sand and carbonate occur in Britton strata, the dominant sediment is shale. This shale, which is usually dark and finely laminated, has been extensively studied by Chamness (1963), Silver (1963), Thomas (1980), and Charvat (1985), and is recognized as being highly organic, composed of calcium montmorillonite, with scattered kaolinite and calcite. These laminated organic-rich shales represent deposition in waters with anoxic bottom conditions. The laminar character of these rocks reflects the extremely calm water conditions that existed during their deposition. The increased organic content of these rocks also reflects sea floor conditions that enhanced organic preservation through exclusion of scavenging benthic organisms.

Stratigraphic Contacts

In the northern portions of the basin, the Britton formation conformably overlies the Tarrant. Southward beyond the pinchout of Tarrant rocks, the Britton Clay rests unconformably on the Woodbine. The stratigraphic hiatus represented by the Woodbine-Britton unconformity becomes more significant southward along the outcrop of the basin. From north to south, the Woodbine changes facies from sandstone to dark non-calcareous Pepper Shale. However, even here, where shale is on shale, the Woodbine-Britton contact is easily distinguished (Scott, 1926, p. 160). South of Belton, the Eagle Ford rests unconformably on the Buda Limestone. The Britton Clay is overlain by the Arcadia Park Shale. The contact between the two is unconformable along most of the margins of the basin, with portions of lower to middle Turonian rocks missing (Pessagno, 1969, p. 69). The stratigraphic hiatus of the Britton-Arcadia Park unconformity also increases southward along the outcrop.

Distribution and Thickness

The Britton Formation is present throughout most of the basin (Fig. 10). Three major areas of thickening occur; two in the north, near area A, which exceed 200 feet, and one on the western margin, near area B, which exceed 250 feet in thickness. The Britton Formation thins generally southward to less than 50 feet in area C. Variations in thickness correspond with sediment input points and probably reflect local differences in sedimentation rates. The eastern absence of Britton strata is apparently a function of erosional removal of the Britton during late Turonian uplift of the Sabine block (Granata, 1963, p. 66). The Britton Formation thickens south of the Sabine uplift as Eagle Ford rocks plunge into the Gulf Coast basin.

Britton Sand is distributed throughout most portions of the East Texas basin (Fig. 11). Most of the sands are thin, averaging less than 10 feet in thickness. Therefore, areas of thick sand accumulations usually reflect stacking of sands rather than thickening of individual sand bodies. Some Britton Sands attain thicknesses of 40 feet, making them the thickest Eagle Ford Sands in the lower Eagle Ford section. The shale-to-sand ratio for Britton strata rarely averages less than 5:1 for most of the basin, indicating that again the dominant sediment was mud.

Major sand accumulations originate from the north, area B, and extend southward to area A in a highly complex distribution pattern, probably caused by deltaic progradation across a shallow shelf in quiet water. Area C resembles a simple elongated deltaic lobe. However, the lack of typical deltaic configuration may be due to paucity of control.

The sand accumulation in area D shows close resemblance to a bird foot delta complex. Distribution of sand in this manner suggests both low wave energy and low tidal energy, even though this area was nearest the open ocean of the Gulf Coast basin. Accumulation of sand at area E probably represents offshore bar deposits. The southeastern accumulation of sand, in area F, extends past the Angelina-Caldwell flexure, and was probably deposited by currents fed by the offshore bars from area E (Siemers, 1978, p. 506).

Arcadia Park Shale

Lithology

On the outcrop near Dallas, the Arcadia Park consists of 100 to 200 feet of gray to dark gray, fissile, calcareous mudstone with thin laminae of siltstone, sandstone, and fragmental limestone. Southward, the Arcadia Park thins and assumes the name South Bosque Shale in the Waco area (Pessagno, 1969, p. 62). The South Bosque consists of dark gray to black, blocky shale with few bentonite seams. The upper 30 to 50 feet of the South Bosque is completely noncalcareous. The upper portions of the Arcadia Park contain Taff's (1891) "fishbeds." Two distinct "fishbeds" occur in the upper Eagle Ford, a sandstone "fishbed," terrigenous in origin showing fluvial aspects, and a limestone "fishbed," distinctly marine in origin suggesting a submarine platform (McNulty, 1965, p. 52, 53).

The most striking feature of the Arcadia Park is the numerous and varied concretions that occur within the section. These nodules, which vary widely in size, shape, and pattern, are apparently the result of diagenetic mineral deposition (Shuler, 1918, p. 17).

On electric logs the Arcadia Park is recognized by a distinctive blocky shale signature (Fig. 4). The upper contact of the Arcadia Park with lower-most Sub-Clarksville (or Austin in the southern basin) is recognized by an abrupt increase in sands or limestones.

The decrease in Sp and resistivity on electric logs reflect the dominance of fissile to blocky mudstone observed on the outcrop. Few carbonates exist in the Arcadia Park indicating that the environment in east Texas was not favorable for calcareous sedimentation. When carbonates are present in the Arcadia Park (Cross Sections A - A′, B - B′, and F - F′), they are usually thin and areally limited. Thin individual sand bodies are present in the Arcadia Park (Cross Section C - C′). However, thick sand accumulations increase in frequency and distribution, possibly reflecting an increase in clastic sedimentation during this time (Cross Sections D - D′ and E - E′).

Stratigraphic Contacts

In northern east Texas, the Arcadia Park is overlain by the Sub-Clarksville Formation of upper Eagle Ford strata. While the contact between the two is lithologically abrupt, it is conformable in nature. In the southern portions of the basin, the Arcadia Park is overlain by the Austin Group along an unconformable contact.

Distribution and Thickness

The Arcadia Park is present throughout most of the East Texas basin (Fig. 12). While variations in thickness occur throughout the basin, the Arcadia Park generally thickens in the northern portions of the basin, reaching more than 200 feet in thickness near area A. A significant thickening of the strata occurs in the central portions of the basin near area B, which exceeds 200 feet; this is possibly associated with minor thickening west of this area along the western margin of the basin. Thinning of Arcadia Park rocks near area C is indicative of slower sedimentation rates. The Arcadia Park sediments thin eastward and are not present over the Sabine uplift, area D. The eastward thinning and pinchout of Arcadia Park strata are a function of diminished deposition and eventual truncation due to westward progression of the Sabine uplift during late Turonian time (Granata, 1963, p. 75).

A moderate accumulation of Arcadia Park sediments occurs north of the Sabine, area E, termed the Pittsburg syncline (Stehi et al., 1972, p. 41). Arcadia Park sediments thicken southward away from the Sabine uplift as the Eagle Ford sediments plunge into the Gulf Coast basin.

Arcadia Park Sands are distributed throughout most of the East Texas basin (Fig. 13). The increase in thickness and distribution of large sand bodies in the Arcadia Park compared with older Eagle Ford Formations results in a lower shale-to-sand ratio beneath 2.5:1. Sand accumulations occur in six areas within the basin. Areas A and B are apparently the product of delta input from the north. Sand near area C appears to be related to delta input from central Texas. Shale-to-sand ratios for area C are greater than 10:1, indicating that the dominant sediment being deposited was mud. Sand accumulations at areas D and E appear to represent westwardly migrating channels off the Sabine. This is the first evidence of sand being derived from the Sabine uplift during Eagle Ford deposition, and suggests the tectonic uplift of that positive structural feature during this period. Shale-to-sand ratios for area E are less than 2.5:1, indicating high sand delivery off the Sabine. The sand at area F was deposited on the outer shelf of the basin (Siemers, 1978, p. 506). This sand, derived from the Sabine uplift, was apparently the product of turbidity transport across the Angelina-Caldwell Flexure (Siemers, 1978, p. 506).

The increase in thickness and distribution of sand bodies, the decrease in shale-to-sand ratios, the marked decrease in abundance and thickness of limestone, the lack of laminar clays, and the lesser abundance of organic matter suggest better circulation, more oxygenated waters, more abundant fauna, and a dominance of clastic over marine-derived sediments, probably as a result of vastly increased sediment supply.

Sub-Clarksville

Lithology

The Sub-Clarksville Sand is the upper-most unit of the Eagle Ford Group in the East Texas basin. Near Dallas, it is probably represented by the sandstone "fishbed" assigned to the upper Arcadia Park. It is not present along the western outcrop belt. Along the northern outcrop belt it expands from the single "fishbed" eastward to a thick sand accumulation of formational status (McNulty, 1966, p. 375). It is often termed the Lake Crockett along the northern outcrop belt, and is sub-divided into two members, a lower Bells Sandstone Member, and an upper Maribel Shale Member (McNulty, 1966, p. 377). The Bells Sandstone consists of gray to brown weathering quartz sandstone, typically fluvial in the north and marine near the southern margin of the unit. The Maribel Shale consists of medium to dark gray laminated shale with silty partings, and thins eastward along the northern outcrop as the Bells thickens. The Maribel grades upward into a 5 foot limestone bed that marks the top of the Eagle Ford Group (McNulty, 1966, p. 375).

The Sub-Clarksville is easily recognizable on electric logs by an increase in both Sp and resistivity signatures indicative of increasing sand (Fig. 4). The upper contact of the Sub-Clarksville with lower-most Austin is recognized by a rapid increase in carbonates of lower

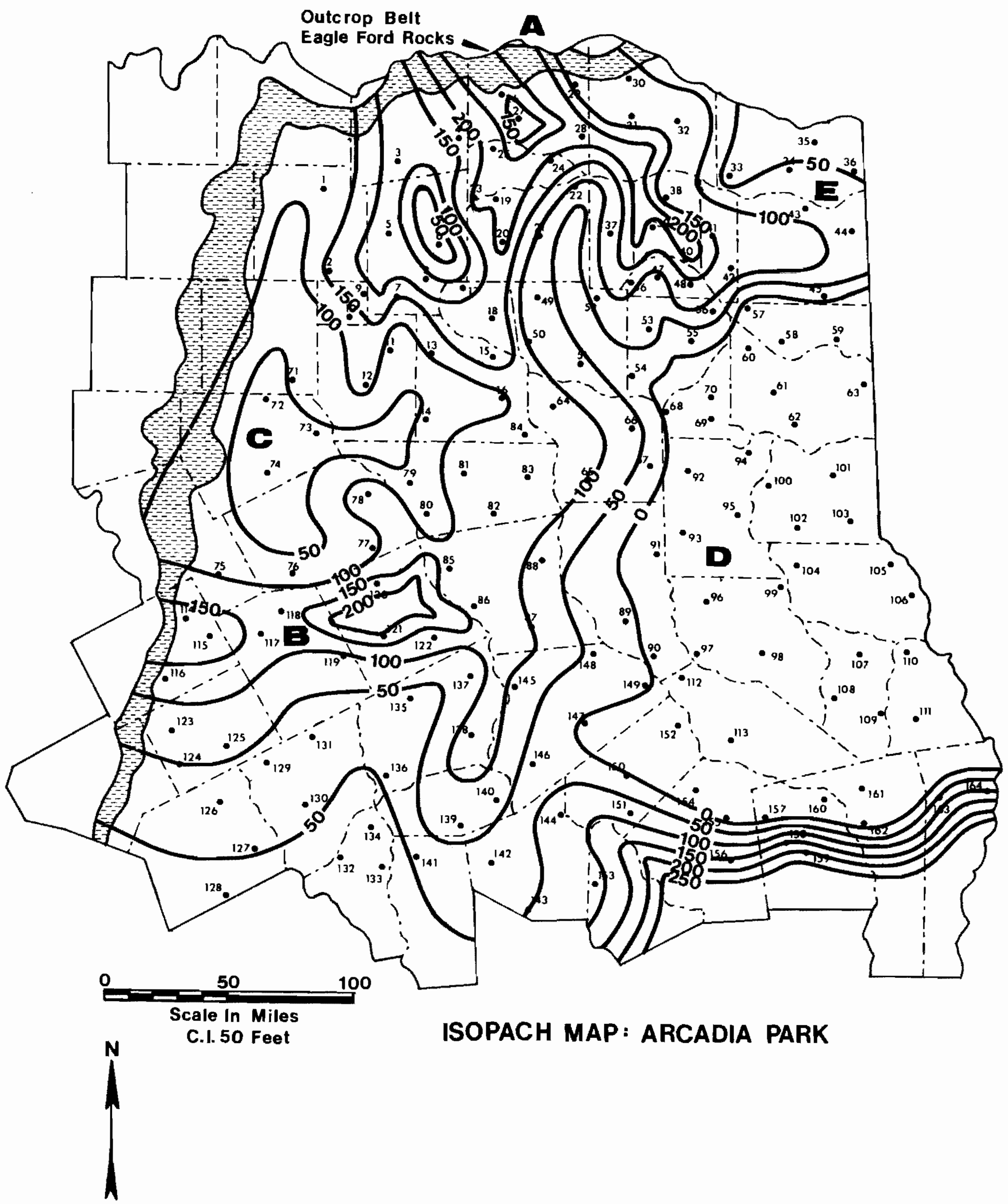


Fig. 12: Isopach map of the Arcadia Park Shale. Thickening of Arcadia Park occurs in areas A and B, apparently related to sediment influx. Thinning in area C, accompanied by an overall southward thinning appears to be related to slower sedimentation. Note the Arcadia Park is absent over the Sabine uplift, area D.

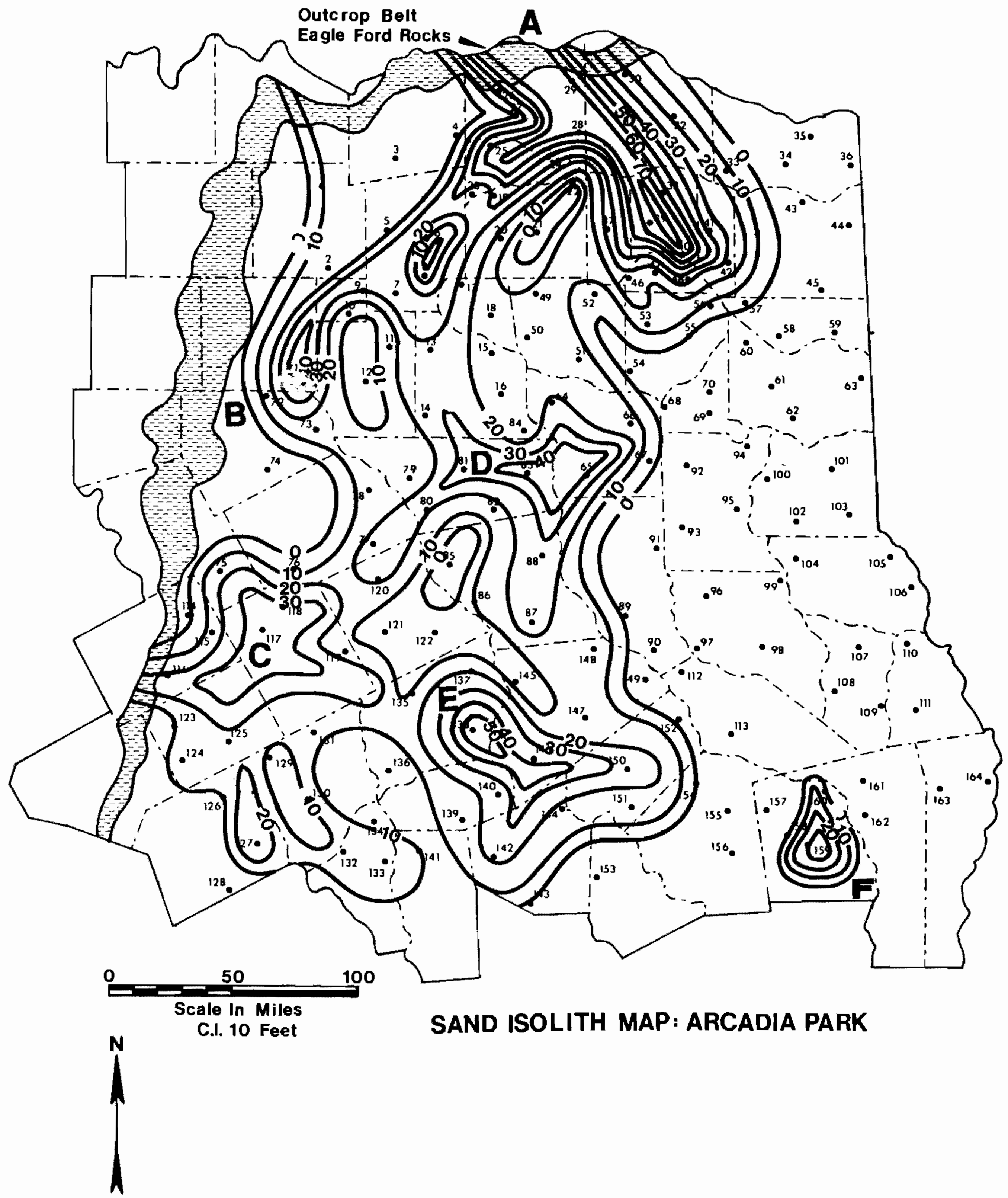


Fig. 13: Sand isolith of the Arcadia Park Shale. Six areas of major sand accumulations are visible, A, B, C, D, E, and F. Of these, A and B appear to be related to deltaic input from the north; C appears to be the product of deltaic input from central Texas; D, E, and F appear to be sand lobes, possibly associated with streams entering from the Sabine uplift on the east. Since F occurs beyond the Cretaceous continental margin, it may represent a turbidite sand deposit (Siemers, 1978, p. 506).

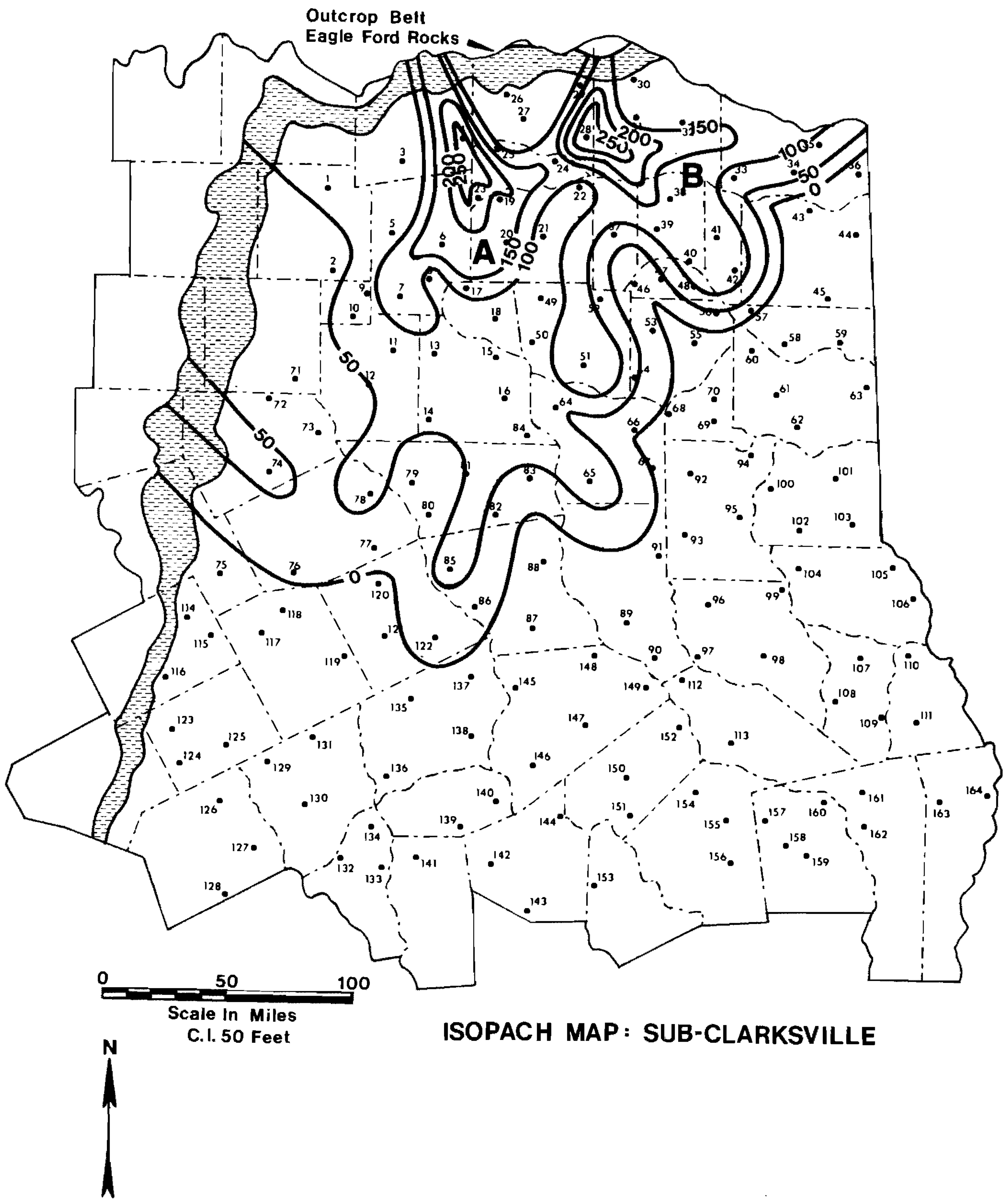


Fig. 14: Isopach map of the Sub-Clarksville Sand. Sub-Clarksville strata reaches 250 feet in thickness near areas A and B. Note the southern termination of the formation near the center of the basin.

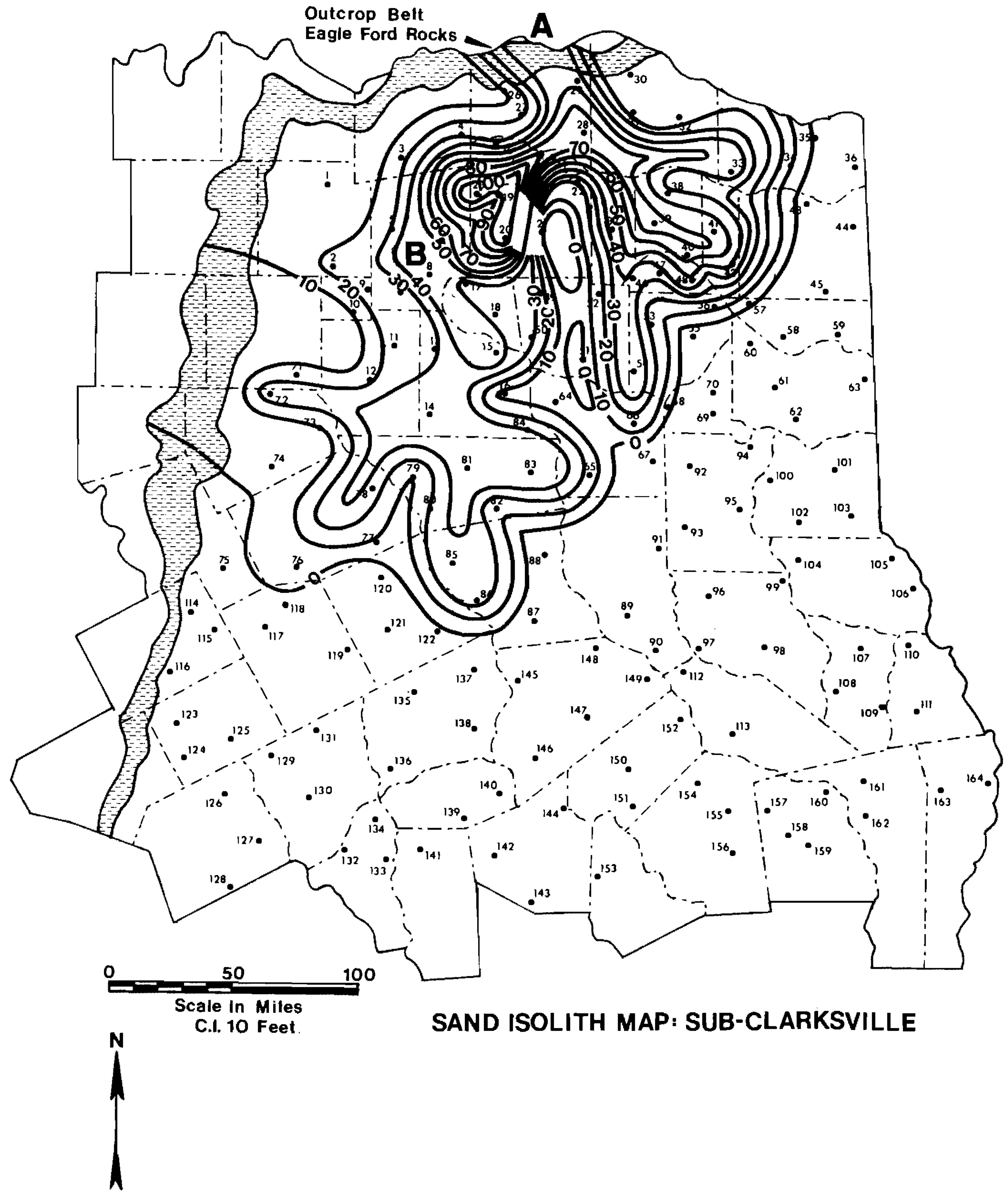


Fig. 15: Sand isolith of Sub-Clarksville rocks. Highly complex delta-like dispersal occurs in the northern East Texas basin, near area A, with lobes of sand extending southwest almost to the depositional pinchout of the unit. The thickest sand accumulations exceed 100 feet near area B, and are the thickest in the Eagle Ford section.

Austin. This increase is indicated by large kicks in both Sp and resistivity on electric logs.

The interbedding of the Maribel and Bells observed on the outcrop is reflected by the intermittent character on electric logs. Generally, the Sub-Clarksville contains more sand than any of the preceding Eagle Ford units, suggesting a dominance of clastic sedimentation during Sub-Clarksville deposition. Several of the sand units like Scl and Sc2 (Cross Sections A - A′, D - D′, and E - E′) are very thick and extensive, apparently the result of multiple stacking of smaller sand bodies. Very few calcareous sediments are observed in the Sub-Clarksville as is the usual case in clastic-dominated sedimentation.

Stratigraphic Contacts

On the outcrop, the contact between the upper Eagle Ford and lower Austin is usually considered unconformable, being recognized by the absence of the Sub-Clarksville Formation in the southern portion of the basin, the presence of a basal conglomerate in the Austin, and the presence of borings into the surface of the Eagle Ford filled with basal Austin Chalk (McNulty, 1964, p. 538). However, the nature of this unconformity in the sub-surface is not well known; the inferred hiatus associated with the Eagle Ford-Austin unconformity appears to diminish towards the north-central portions of the basin, and may disappear in the deeper portions of the basin.

Distribution and Thickness

Sub-Clarksville rocks occur only in the northern half of the basin (Fig. 14). The north to south thinning of Sub-Clarksville strata (Cross Sections D - D′ and F - F′) is apparently a product of sources on the north. Correlations indicate that lateral thinning of Sub-Clarksville (Cross Section E - E′) was the product of erosional truncation along the southern margin of the unit. Sub-Clarksville rocks reach a maximum thickness of 250 feet in the northern East Texas basin, near areas A and B.

A sand isolith of Sub-Clarksville rocks shows highly complex delta-like dispersal of sand in the northern portion of the basin, with lobes of thick sand extending southward almost to the depositional limit of the unit (Fig. 15). The thickest sand accumulations exceed 100 feet and are the thickest in the Eagle Ford section. The shale-to-sand ratio is 1.5:1, the lowest of any Eagle Ford unit. Clearly the source of Sub-Clarksville sediments was from the north, apparently delta input from area A, with a complex distributary system. The input point for Sub-Clarksville Sands is essentially the same as that for all coarse clastics throughout Eagle Ford time, indicating a major river source sustained for a very long period. The abrupt increase in sand during Sub-Clarksville time suggests a major change in provenance, perhaps a product of tectonic uplift.

SUMMARY

Eagle Ford rocks of the East Texas basin consist of the Tarrant, Britton, Arcadia Park, and Sub-Clarksville Formations which have several common characteristics. These formations are mud-dominated with an increasing sand content upward in the section. All of these formations were supplied with sediment from the north and northwest except for late in Eagle Ford time when sediments also originated from the east off the Sabine uplift. Eagle Ford rocks become more marine southward and are typically referred to as laminate deposits of anoxic bottom waters. However, only the bottom two-thirds of the group have this bituminous laminated nature.

DEPOSITIONAL MODEL

Because of the highly organic nature, the abundance of laminites, and the absence of benthic foraminifera, models for Eagle Ford deposition have generally involved deep water environments. However, laminated organic-rich sediments without benthic fauna are not water depth indicators. The only conclusions that can be made from organic-rich laminites is that: 1) organic sedimentation was high; 2) clastic sedimentation was low; 3) organic preservation was high, suggesting anoxia beneath the sediment-water interface; 4) bioturbation was lacking, due to the lack of benthic organisms, suggesting anoxic bottom waters; 5) current and wave activity were minimal; and 6) cyclical variations in sediment delivery were occurring. These conditions could indicate either shallow epicontinental or deeper pelagic waters.

Beyond this, Eagle Ford rocks of east Texas contain numerous and varied features indicative of shallow water deposition, including: 1) marked unconformities of uncertain origin at the base and top of the Eagle Ford Group, and within the group as formation boundaries; 2) rapid alteration in sediment type, from anoxic to oxygenated, suggesting rapid changes in sediment and bottom water chemistry; 3) progradational sediment dispersal patterns suggesting shallow water deltaic depositional systems; and 4) intraformational phosphatic conglomerates on unconformity surfaces. All of these factors combine to indicate that Eagle Ford rocks of the East Texas basin were products of generally shallow water sedimentation, with water depths ranging from as shallow as a few feet to as deep as one to two hundred feet.

PRE-EAGLE FORD TIME

With the termination of Woodbine deposition, marginal parts of the basin were subjected to long periods of non-deposition and erosion. Little is known about the Woodbine-Eagle Ford unconformity beyond the outcrop belt. The lack of recognition of upper Woodbine and lower Eagle Ford, as reported by Pessagno (1969, Pl. 9) may be a result of sediment starvation or condensation. There is no question that upper Woodbine strata have been eroded from the western flank of the Sabine. The lack of coarse sediments within the stratigraphic break suggests that the lands surrounding the East Texas basin were of low relief (Stephenson, 1929, p. 1324). While the details of the unconformity are uncertain, it is probable that the hiatus decreases basinward, and is no longer present in the central portions of the basin. However, the southward increase in stratigraphic hiatus along the outcrop suggests that the southwestern margin of the basin was subjected to greater erosion and/or longer periods of non-deposition than in the north.

TARRANT DEPOSITION

Differential regional subsidence, probably influenced by older structural trends in the basement, is believed to have formed the embayments and arches associated with the Gulf Coast (Bornhauser, 1958, p. 349). Towards the end of the Woodbine erosional period (late Cenomanian) basinal downwarping occurred in east Texas, apparently the result of sub-crustal movements possibly accompanied by salt withdrawal (Bornhauser, 1958, p. 367). Spasmodic downwarping allowed expansion of the Eaglefordian seas into east Texas, initiating Eagle Ford deposition (Coon, 1956, p. 87). The lower-most rocks of the Tarrant Formation of the Eagle Ford group record the initial expansion of the Eaglefordian seas and early development of Eagle Ford deposition (Fig. 16).

Early expansion of Eaglefordian seas were in a north to northwesterly direction. Reworked mudstone pebbles and small "water worn" sandstone pebbles at the base of the Tarrant, and the typical electric log signature of the Tarrant sections, suggest that the initial transgression of the Eaglefordian sea was probably only a spasmodic creeping of marine waters across the extremely flat

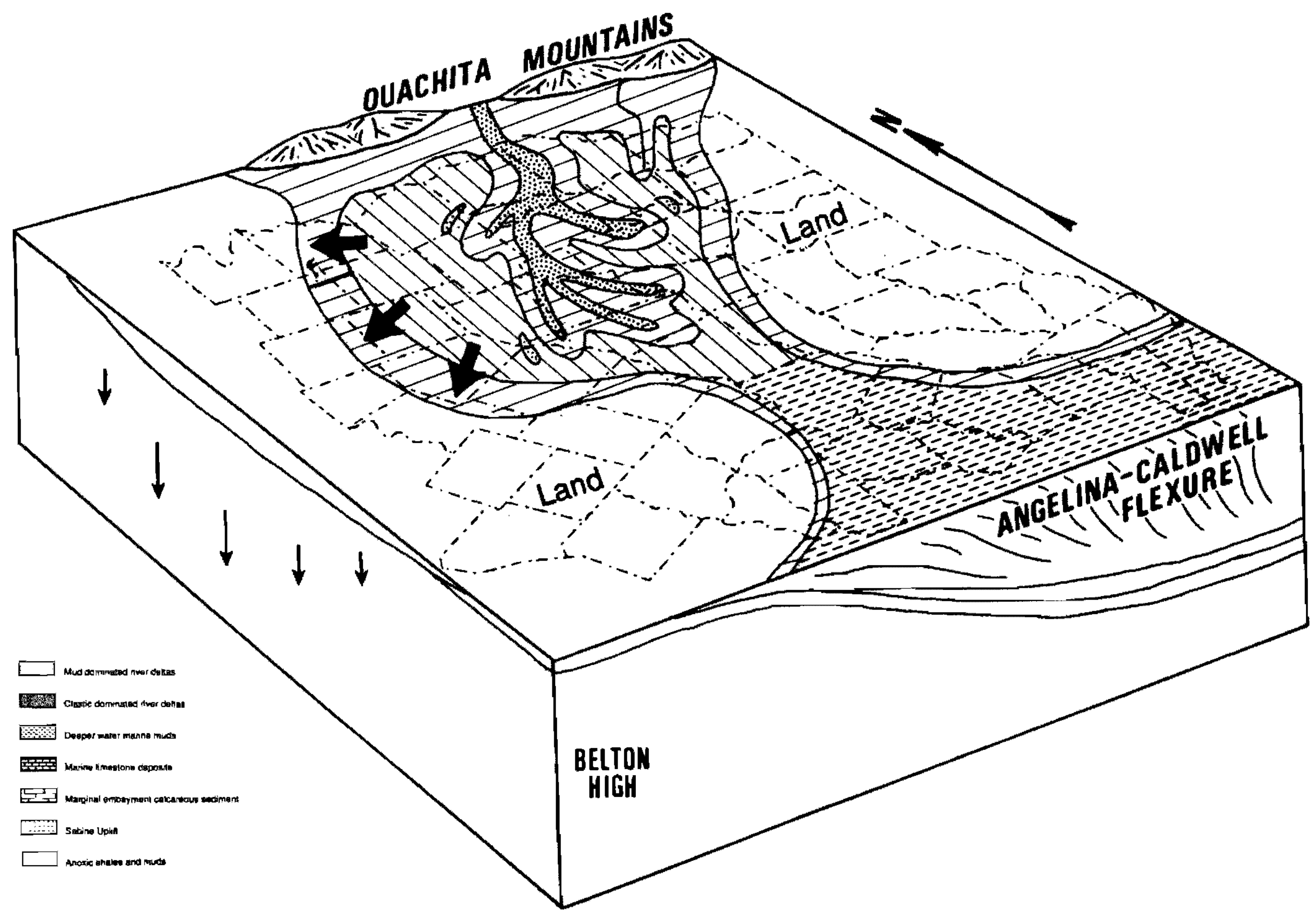


Fig. 16: Regional setting of the East Texas basin during Tarrant deposition. As Eaglefordian seas expanded north-northwesterly in east Texas, they reworked upper Woodbine sediments along the margins of the basin. Sediment influx began from the north rapidly establishing river deltas with mud-dominated sediments in the northcentral part of the basin. Finer sediments were deposited in more distant southern and western parts of the basin. Sedimentation in the deeper parts of the basin was occurring, but these sediments are indistinguishable from Britton strata.

expanse of east Texas. The southern extent of the beach facies on the western margin of the basin (Fig. 16) is not known, but probably corresponds with the southern termination of sand in Figure 9. The southwestern part of the basin apparently arched creating the Belton high, and formed a sub-marine platform subject to marine planation by waves and/or non-deposition. The same relationship occurs along the eastern margin of the basin, with no discernable beach facies south of the mapped sand termination in Figure 9.

With the invasion of Eaglefordian seas sediment influx began from the north near the Ouachita Mountains. This influx from the northern provenance was apparently in existence prior to Woodbine deposition and existed throughout much of Gulfian time, probably reflecting major continental drainage.

As distributaries fed into the East Texas basin, they rapidly formed deltaic complexes. The unusually high shale-to-sand ratios of these deltas suggest a provenance with low relief, and probably high rainfall. The thick accumulations of mud-dominated sediments around delta complexes suggest that rapid flocculation and sedimentation occurred as a result of high sediment influx and significant chemical variations between the runoff water and the water in the basin (Potter et al., 1980, p. 8). The net result was river deltas with mud-dominated sediments and few coarse clastic sediments, a condition that characterizes most of the Eagle Ford terrigenous deposits in east Texas.

Finer sediments were carried into more distant and deeper parts of the western and southern basin. In the northwestern part of the basin a marginal embayment existed to the west of the delta. Sedimentation rates in this area were slower than in the areas of active delta sedimentation. Sedimentation south of the mapped pinchout of the unit (Fig. 8) probably occurred in the deeper parts of the basin, but these sediments are indistinguishable from the overlying Britton strata and are included in that unit.

BRITTON DEPOSITION

Britton deposition marks the maximum extent of early

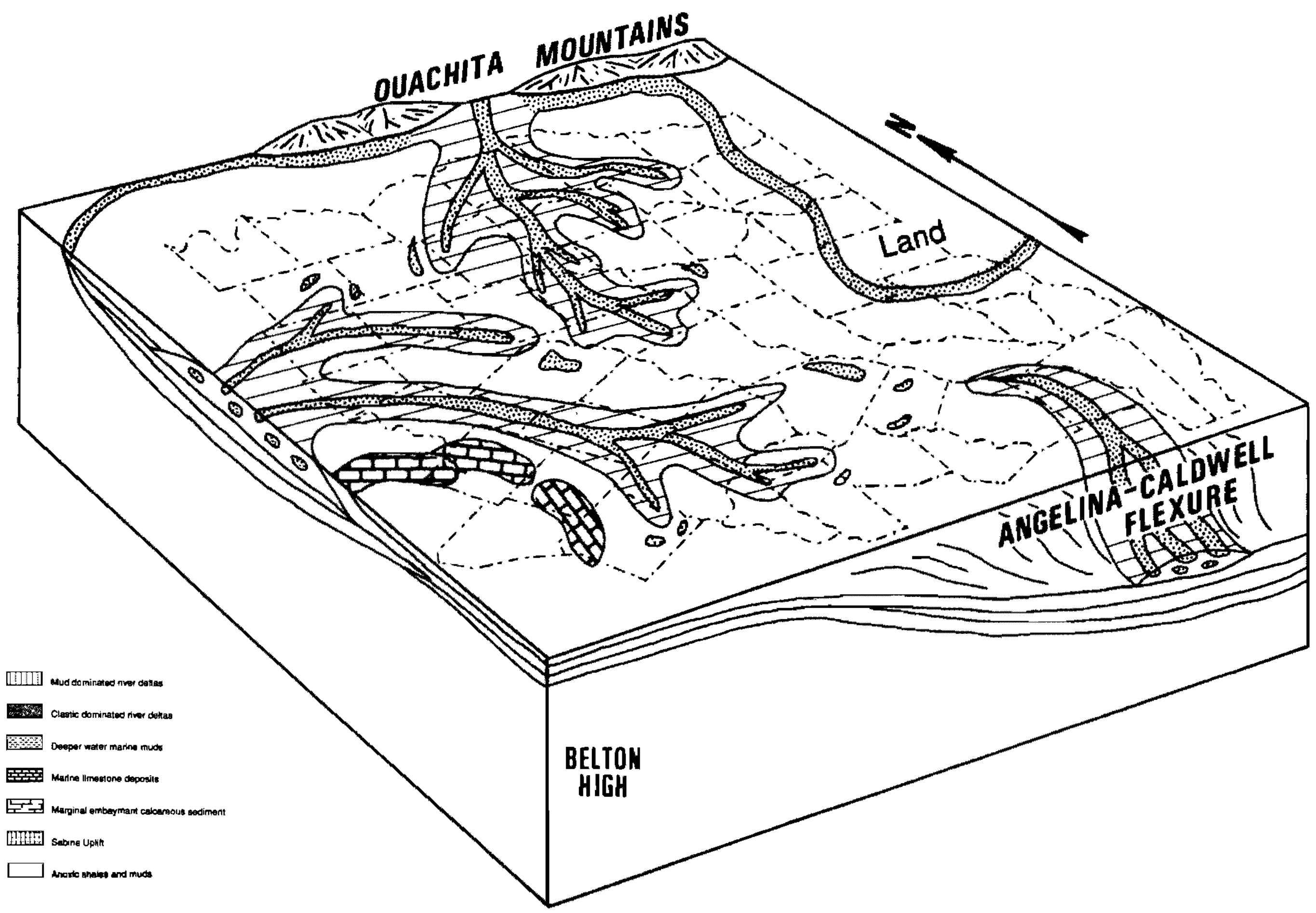


Fig. 17: Regional setting of the East Texas basin during Britton deposition. Eaglefordian seas reached their maximum extent into east Texas depositing laterally adjacent muds, sands, and limestones. Widespread marine conditions allowed extensive limestone deposits. Note that much of the Sabine uplift was receiving sediments during Britton time. Clastic influx created mud-dominated deltas which prograded across the shallow marine shelf. Some of the coarse sediment escaped down the Angelina-Caldwell flexure. Exceptional conditions made the east Texas area abnormally productive of organic rich sediments in the form of laminated anoxic shales.

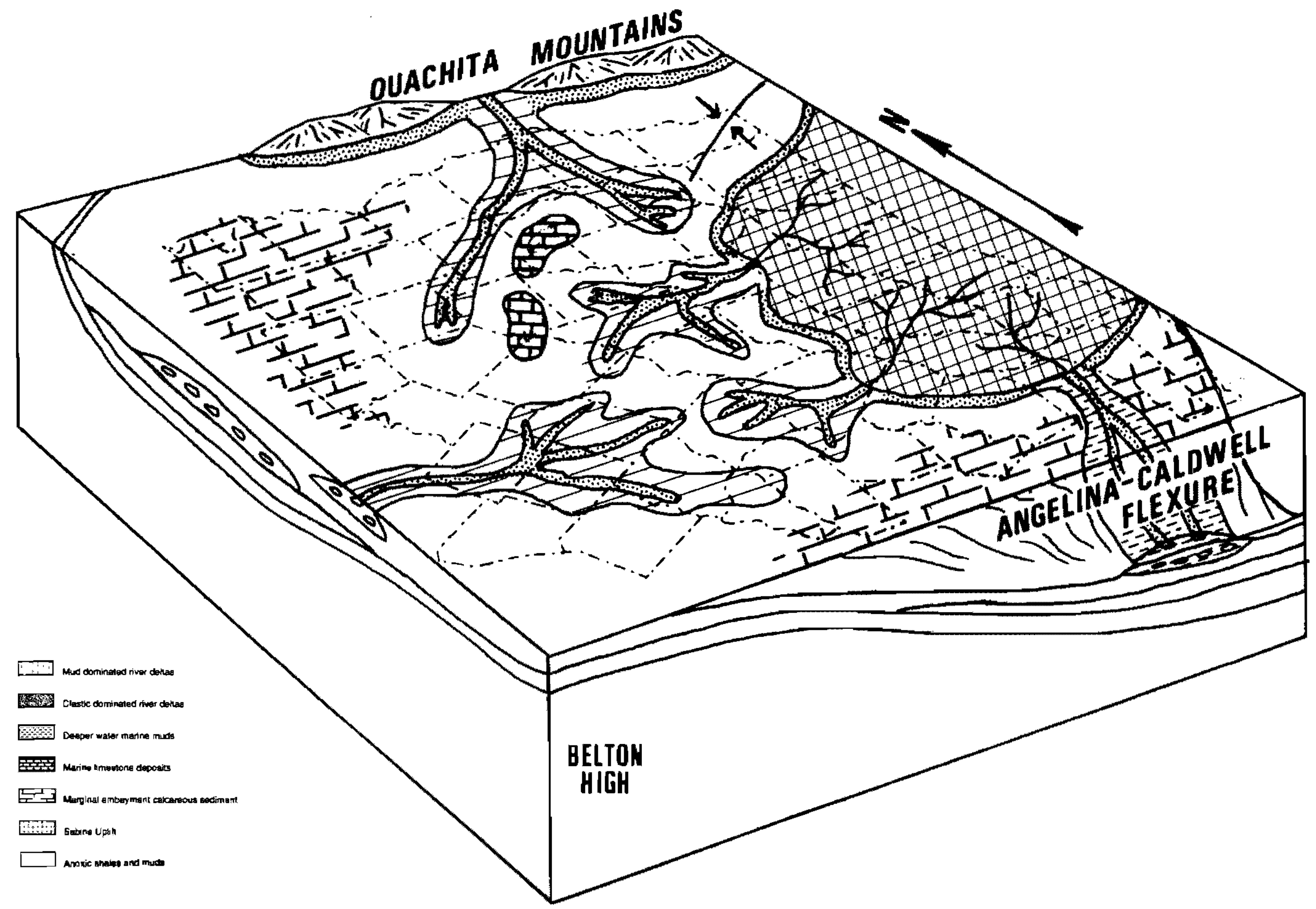


Fig. 18: Regional setting of the East Texas basin during Arcadia Park deposition. Following a brief unconformable period, Arcadia Park deposition began with re-establishment of clastic influx from the north and west, accompanied by drainage distributaries shed off the Sabine uplift. Note that these westwardly prograding deltas are the first evidence of Eaglefordian activity of this structural feature. Also note the downwarp called the Pittsburg syncline in the northeastern part of the basin. While mud from these deltas dominates east Texas, calcareous sediments were present in the marginal embayments.

Eaglefordian seas in east Texas (Fig. 17). The distribution of lower Eagle Ford sediments in and around the Sabine uplift, and the truncation of lower Eagle Ford sediments on the western margin of that uplift, suggest that the uplift received sediments during Britton time (Granata, 1963, p. 75). The presence, variety, and regional extent of Britton Limestones indicate widespread marine conditions and lower terrigenous input throughout east Texas. Early Turonian time was a carbonate-producing epoch indicating uniform climates world-wide during most of Britton deposition (Reeside, 1957, p. 522). The mud-deltas prograded across the shallow marine shelf of east Texas creating latterally co-existing sand, mud, and limestone depositional environments. Restricted limestone deposition existed in both the interdistributary areas of the deltas and as carbonate banks in marginal embayments around the deltas. The presence of abundant bentonite seams indicates that explosive volcanism occurred during Britton deposition, and that ash fell into unusually calm water where laminites indicate toxic bottom conditions. These conditions apparently existed throughout Britton deposition.

Clastic influx formed prograding deltas. The dominance of shale in the Britton section indicates that these deltas were mud-dominated. The distribution of sand can probably be attributed to progradation of the deltas across a shallow marine shelf with extremely quiet water (little or no destructive energy). Sand distribution in the southern basin, nearest the open ocean, reflects conditions of low tidal and low wave energy, indicating that the Gulf Coastal basin was also an area of little agitation.

The widespread laminated muds interbedded with more normal marine limestones suggest that geochemical environments were subject to rapid and major variations. Britton rivers apparently discharged large volumes of fresh water rich in both organic detritus and dissolved nutrients, making the East Texas basin abnormally productive in organic matter (Habib, 1982, p. 125). In areas of higher sedimentation rates, as in the delta facies, organic matter was rapidly buried and was relatively unaltered by diagenetic oxidative processes, creating some of the organic-rich sediments of the Eagle Ford (Habib, 1982, p. 123). Sediments in the marginal embayments were enriched in organic detritus over the deltaic sediments by photosynthetic productivity of plants of either marine or land origin (Waples, 1983, p. 970).

ARCADIA PARK DEPOSITION

Towards the end of Britton deposition, and continuing through early Arcadia Park deposition, conditions in the southwestern portions of the basin changed from periods of deposition to relatively long periods of non-deposition and possibly erosion. This stratigraphic hiatus, which marks the boundary between the Britton and Arcadia Park Formations, decreases northward along the outcrop, indicating that the northern basin was subjected to more complete periods of deposition. This unconformity probably diminishes basinward, though this is not known. Given the geologic setting of the Eagle Ford during this time, the Britton-Arcadia Park unconformity may reflect increased wave energy from the Gulf Coastal basin across the shallow platforms of southwestern east Texas.

During Arcadia Park deposition, clastic influx from the north continued (Fig. 18). Drainage of the Texas craton shifted southward, abandoning the earlier input points near Dallas and entering just north of the Belton high. The northwestern basin was the site of a marginal embayment with much slower sedimentation rates than in the deltas. Sand accumulations off the western margins of the Sabine uplift represent the first Eaglefordian activity of this structural feature. The older Britton, Tarrant, and Woodbine sediments which were once deposited on the western portion of the Sabine uplift, were then eroded, reworked, and redeposited as newly formed westwardly prograding deltas (Halbouty and Halbouty, 1982, p. 1051). Clastic sediments also shed southward off the Sabine and were transported by turbidity currents across the Angelina-Caldwell flexure into the deep Gulf Coastal basin (Siemers, 1978, p. 506).

The reactivation of the Sabine uplift created the downwarping of the Pittsburg syncline to the north. This shallow structural trough allowed the expansion of

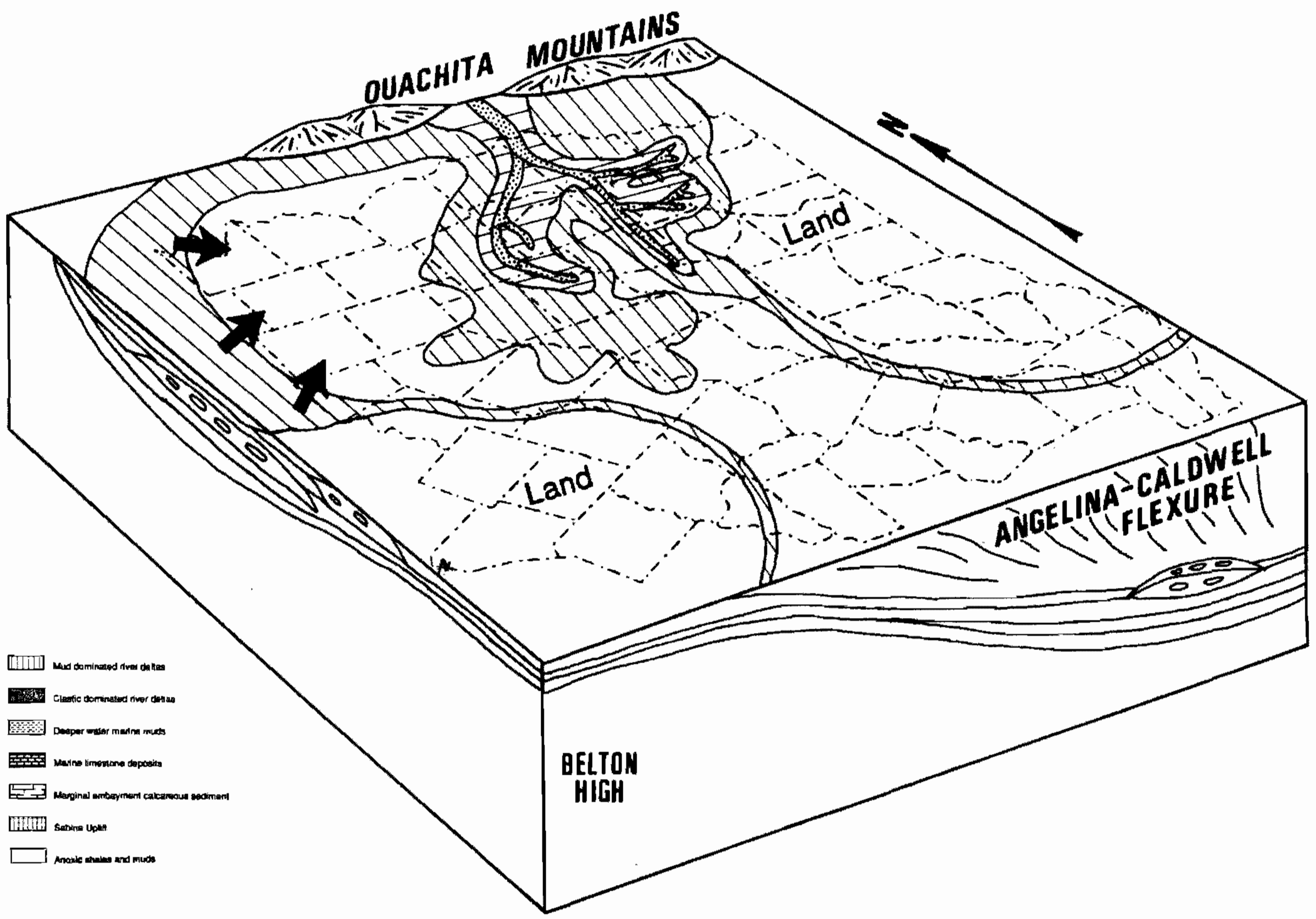


Fig. 19: Regional setting of the East Texas basin during Sub-Clarksville deposition. The dominant sediment type had shifted towards land-derived coarse clastics which formed an expanding delta that rapidly displaced the regressing Eaglefordian sea in east Texas. A marginal embayment in the northwestern portion of the basin preserved finer mud-dominated sediments. As the Eaglefordian sea regressed, the southwestern part of the basin was exposed to erosion which truncated upper Eagle Ford strata.

Eaglefordian seas into northwest Louisiana and southwest Arkansas (Granata, 1963, p. 53).

The decrease in limestones in Arcadia Park sediments, the increase in size and distribution of large sand bodies, and the lowering of shale-to-sand ratios reflect an increase in clastic sediment supply. Calcareous sediments were confined to interdistributary bays marginal to the deltas. Late Turonian sediments for other basins of the continental United States reflect this shift towards increased terrigenous deposition, indicating that large-scale environmental changes were responsible (Reeside, 1957, p. 522).

SUB-CLARKSVILLE DEPOSITION

Sub-Clarksville deposition marks the termination of Eagle Ford deposition by a shift toward land-derived coarse clastic sedimentation (Fig. 19). The input of clastic sediments from the north, as implied by the Bells Sand facies, created an expansive delta which occupied most of the northern portions of the basin. As the delta prograded southward, it gradually displaced the Eaglefordian sea in the East Texas basin. West of the Sub-Clarksville delta the Maribel accumulated in a large marginal embayment.

The regressing Eaglefordian sea exposed the southwestern portions of the East Texas basin to erosion, which removed and truncated upper Eagle Ford sediments. The depositional limit of the Sub-Clarksville is not known because of truncation near the southern margin of the formation. However, the Sub-Clarksville once extended south of the mapped pinchout, perhaps for a considerable distance.

SUMMARY

Eagle Ford deposition began following a late Woodbine erosional period and was characterized by river-dominated deltas that deposited mostly mud and prograded across the calm marine shelf of east Texas, supplying much of the sediments that comprise Eagle Ford rocks. Exceptional conditions early in Eagle Ford deposition created an abnormally productive basin which allowed sedimentation of carbon-rich laminated shales. Later during Eagle Ford deposition, the Sabine uplift became active as a provenance supplying clastic sediments to the east Texas area. The highly complex Sub-Clarksville delta displaced the Eaglefordian sea over a sizeable area, terminating Eagle Ford deposition.

SOURCE-ROCK POTENTIAL OF THE EAGLE FORD ROCKS IN THE EAST TEXAS BASIN

The Eagle Ford Group and adjacent Gulfian units have produced the greatest amount of petroleum in east Texas. The bituminous laminites in the Eagle Ford suggest that this unit could contain the organics that generated the Gulfian oil. Therefore, the purpose of this section is to evaluate the source-rock potential of the Eagle Ford Group in the East Texas basin, to examine reservoir trends of rocks that could be producing oil originating from the Eagle Ford, and to volumetrically estimate the organic carbon in the Eagle Ford of east Texas as an indicator of petroleum produced.

The method of investigation for this section entailed an evaluation of the total organic carbon content of the Eagle Ford as an indicator of source-rock potential. The organic carbon content (Appendix III) was used to produce a carbon isopleth map in order to delineate areas of high and low source-rock potential within the basin. The carbon isopleth map was compared with known petroleum production from Buda, Woodbine, Eagle Ford, and Austin reservoirs to identify production trends that might suggest that these reservoirs derived their oil from the Eagle Ford. The production information was used to define an Eagle Ford petroleum province (an area within the basin, defined by producing reservoirs that could have been provided with Eagle Ford oil). Finally, the above information was combined with an isopach map of Eagle Ford rocks to volumetrically estimate the organic carbon present as an indicator of petroleum generated from Eagle Ford rocks in the East Texas basin.

The Eagle Ford contains between 0.74% and 9.18% organic carbon at various locations throughout east Texas (Fig. 20). Three areas of anomalously high organic carbon were observed. Two readings, near areas A and B, occur in sediments representing marginal embayments. These high organic values reflect restricted environments with increased organic preservation of these embayments. The third anomalous reading, near area C, had coal or carbonized wood particles within the samples which biased the reading. However, the presence of these particles in this portion of the basin tends to support the delta model. The 1% isopleth roughly outlines the delta complex that supplied sediment from the north throughout Eagle Ford deposition. Readings in the central portion of the basin, where organic-rich sediments are deeply buried in a higher temperature regime, are considered to represent values that have been lowered by probable maturation of source-rocks and expulsion of oil, partially depleting the carbon content of the measured samples.

The lower Eagle Ford section is generally richer in organic carbon than the complete Eagle Ford section (Fig. 21). Late Eagle Ford time is marked by a shift to lower total organic carbon, generally less than 1% (Fig. 22). With the exception of the biased result in area C, the only portions of the basin with greater than 1% organic carbon were in the northwestern area where a marginal embayment existed throughout most of late Eagle Ford time (Figs. 16 and 17).

Rocks with greater than 0.5% organic carbon are

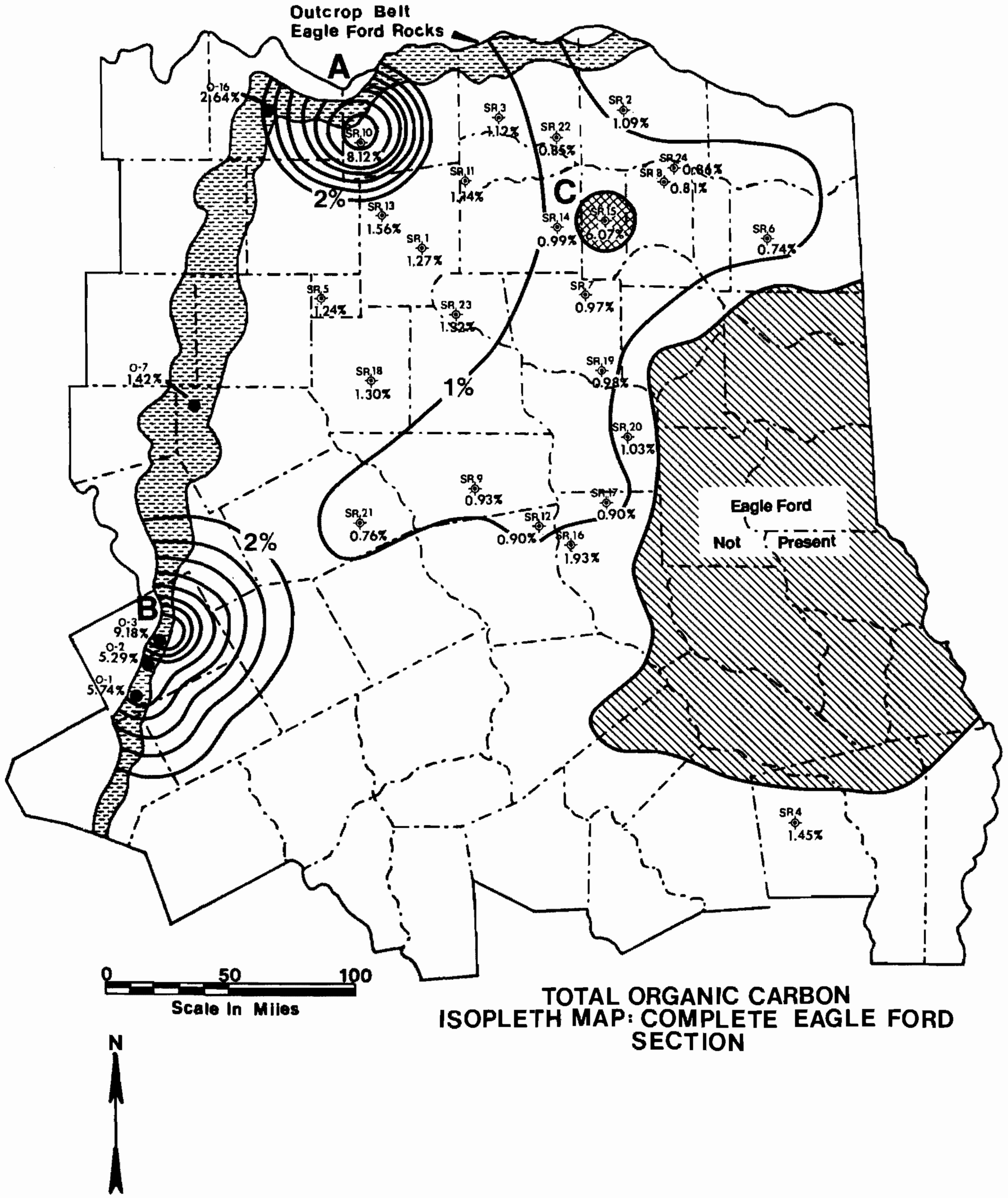


Fig. 20: Total organic carbon isopleth, Eagle Ford, East Texas basin. Organic carbon readings for the Eagle Ford range from 0.74% to 9.18%, generally averaging greater than 1%, which is unusually high for sedimentary rocks. Note the three anomalously high organic values in areas A, B, and C, which occur in marginal embayments that were enriched in organic sediments. Also note that readings in the central portions of the basin where sediments are deeply buried in a higher temperature regime probably represent values that have been lowered by maturation of organic material and expulsion of oil.

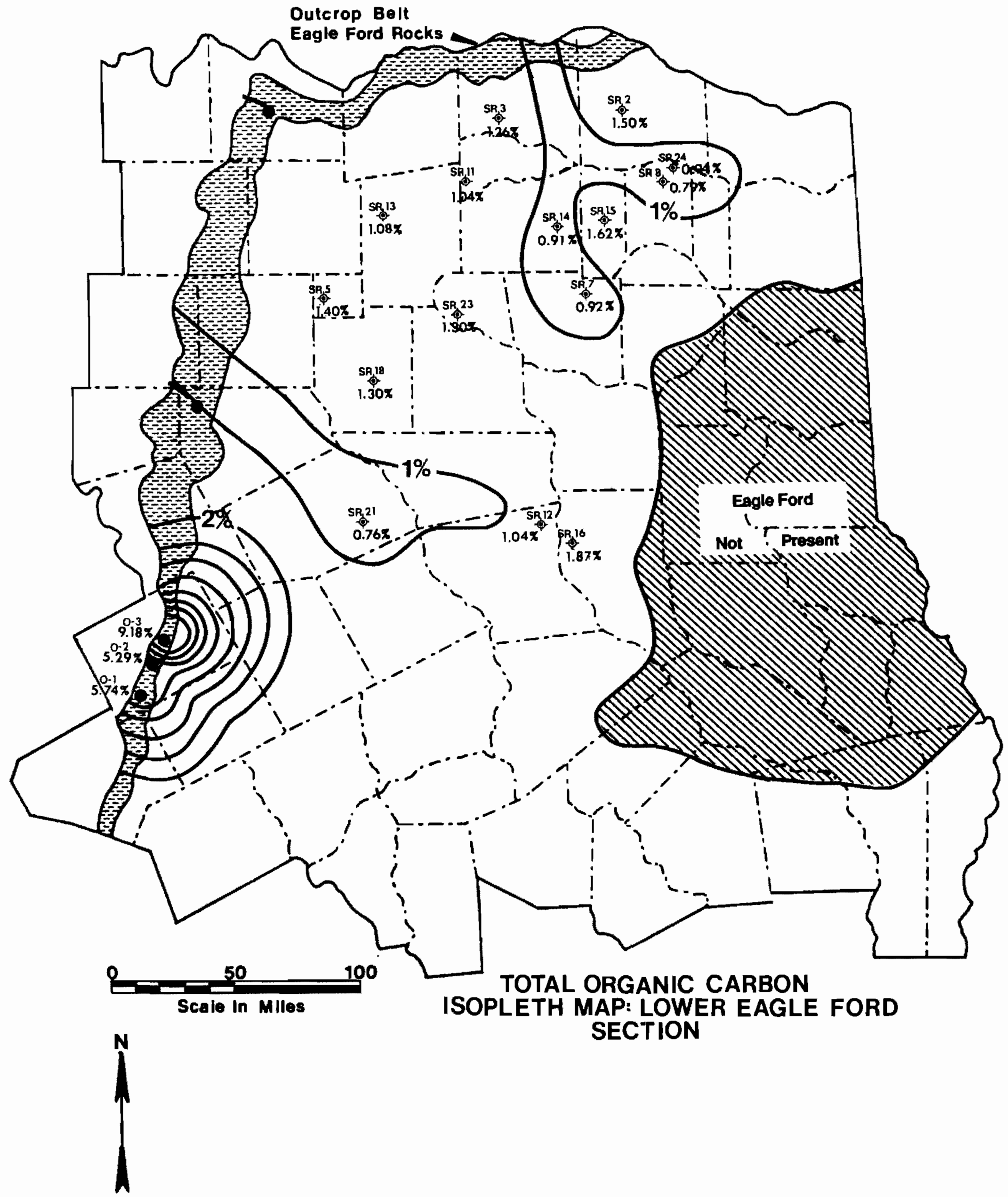


Fig. 21: Total organic carbon isopleth, lower Eagle Ford, East Texas basin. Few locations with organic carbon values lower than 1% occur, indicating an enrichment of the lower Eagle Ford section with respect to organic carbon.

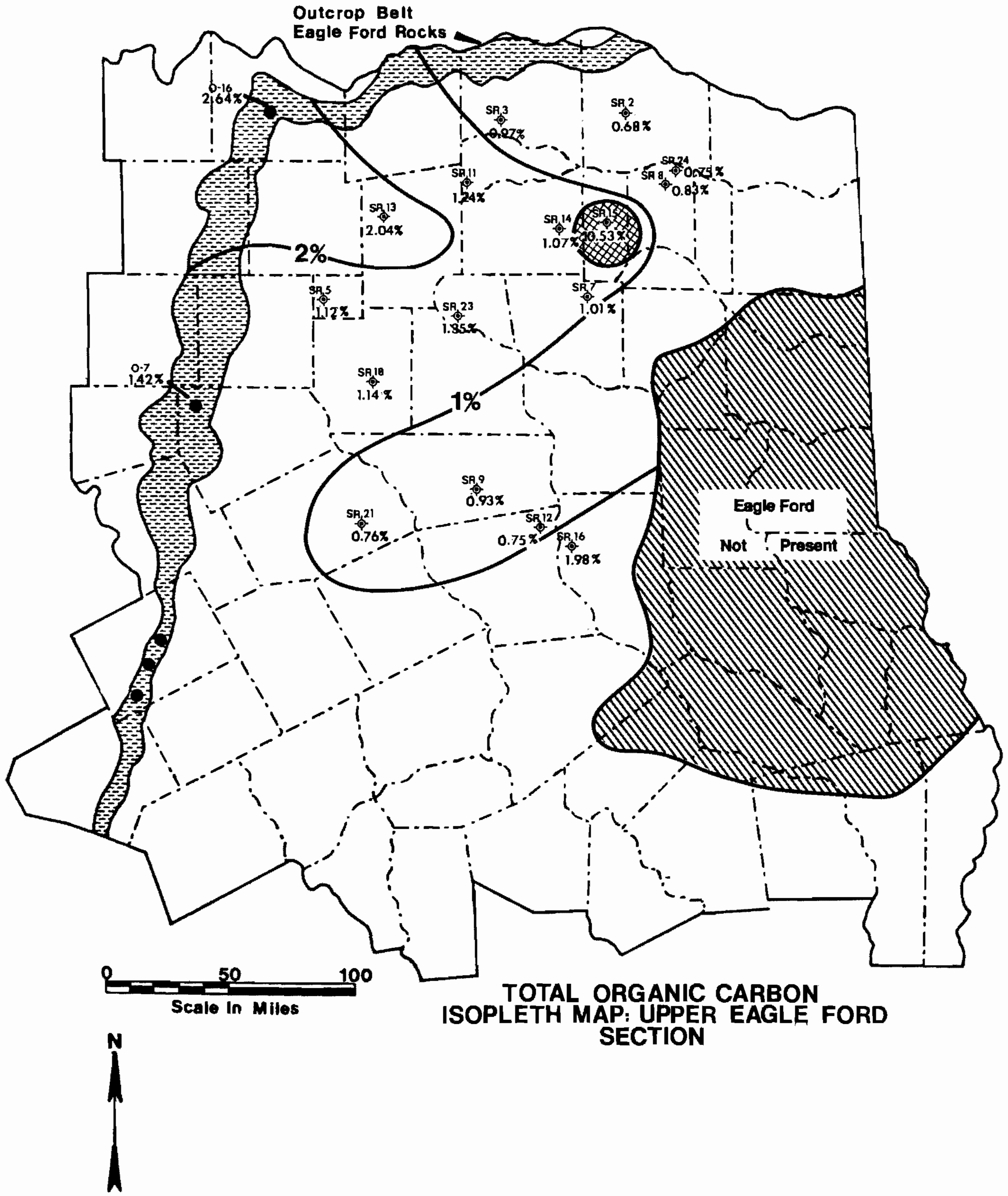


Fig. 22: Total organic carbon isopleth, upper Eagle Ford, East Texas basin. Upper Eagle Ford rocks generally have less organic carbon than those lower in the sequence, reflecting the clastic-dominated nature of these sediments.

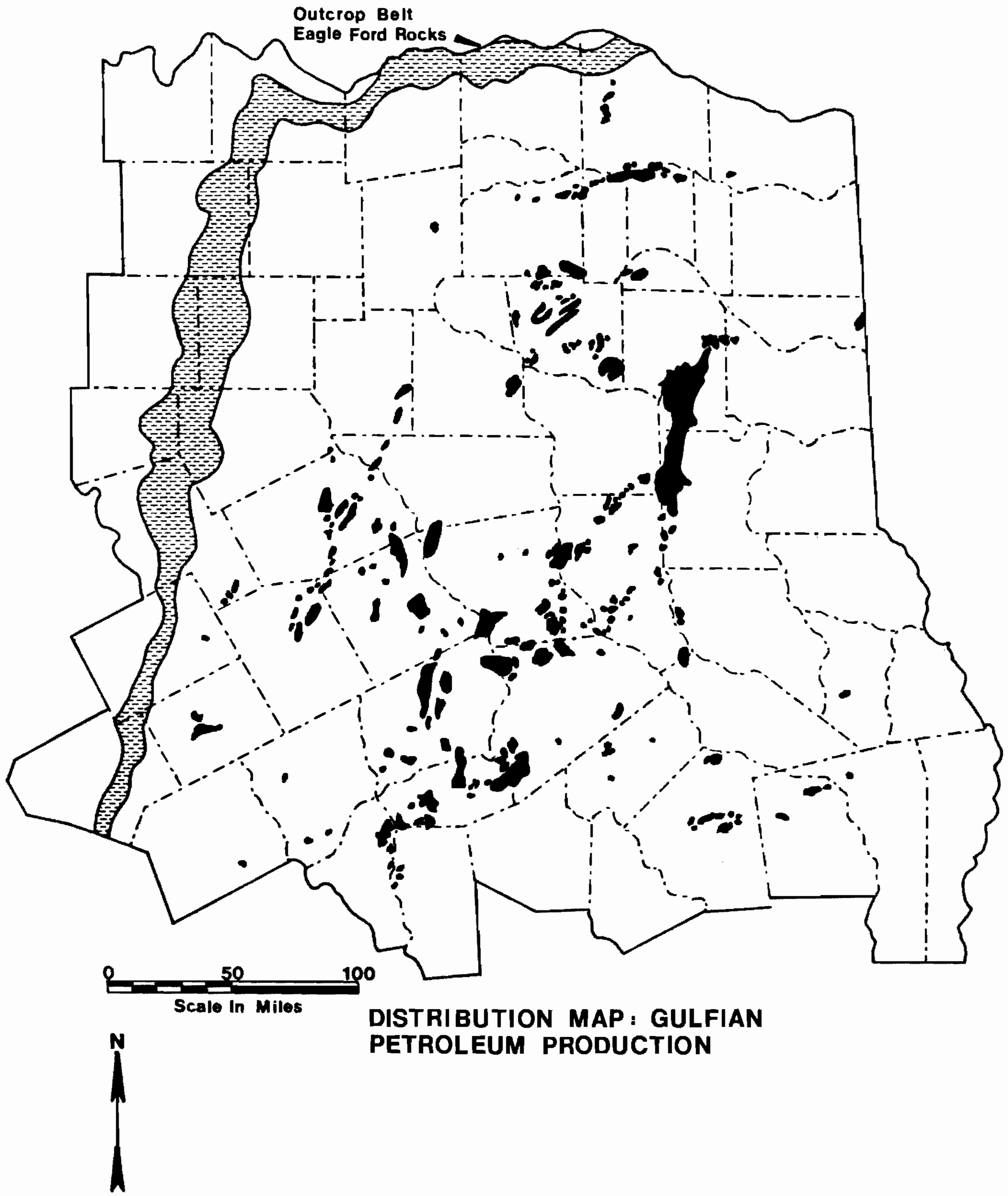


Fig. 23: Gulfian petroleum production in east Texas (Geomap, 1979, Pl. I). Most production is concentrated in the central portions of the basin where Eagle Ford rocks are rich enough to have provided the oil found in these reservoirs, possibly reflecting conditions of heat and pressure on the maturation of Eagle Ford organics.

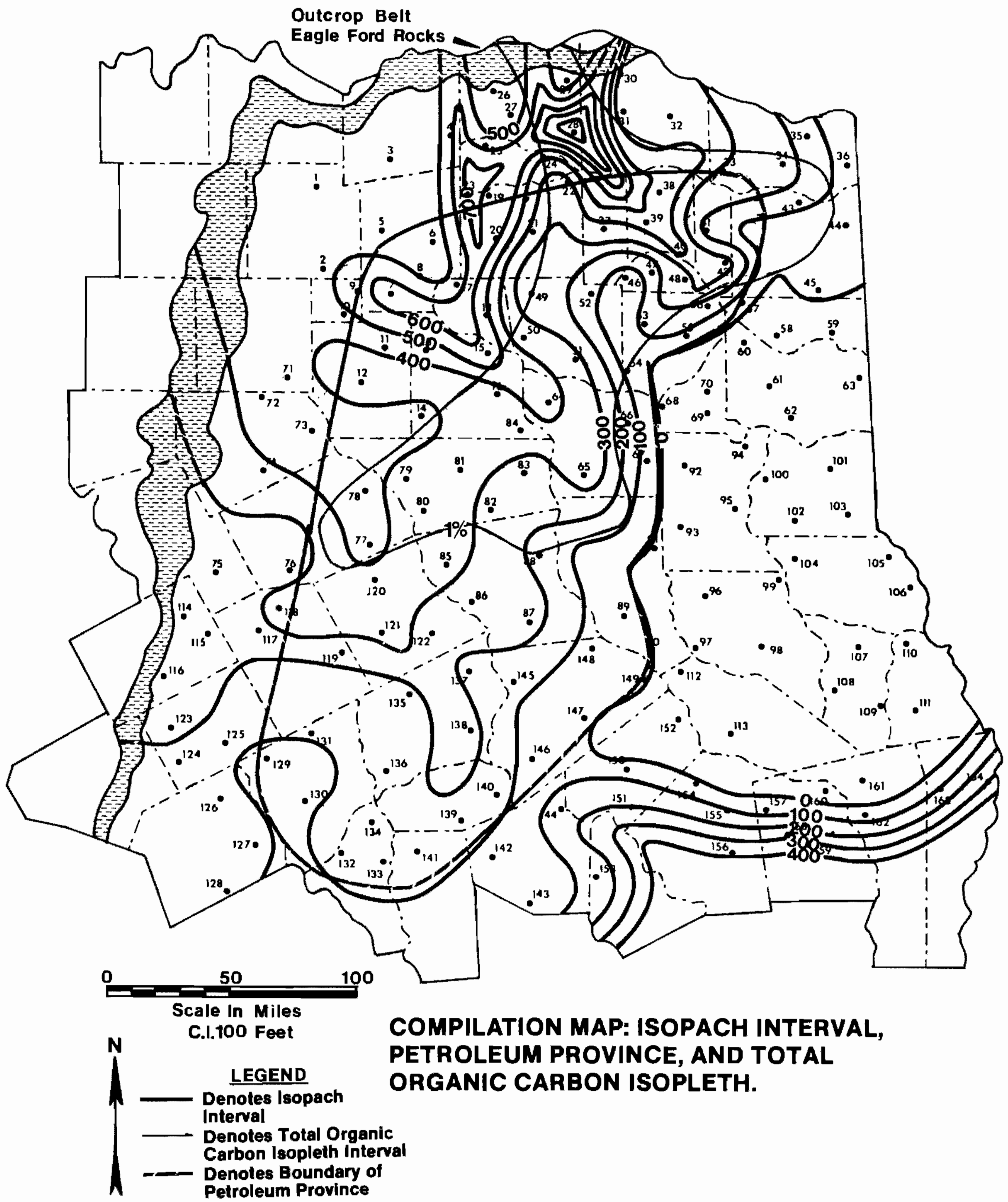


Fig. 24: Compilation map of isopach interval, petroleum generative province, and total organic carbon isopleth. By planimetering isopach intervals within the petroleum generative province, using an average organic carbon value of 1%, the potential oil generated by Eagle Ford rocks can be estimated as approximately 400 billion barrels.

generally considered potential source-rocks for petroleum (Barker, 1979; Waples, 1983). Shales with 0.4% organic carbon are possible sources of petroleum (Barker, 1979, p. 39). Therefore, Eagle Ford rocks, with organic carbon values averaging greater than 1%, may be considered superior sources of petroleum.

The map of Gulfian production shows that most production is restricted to the central portions of east Texas where the Eagle Ford organics may have been exposed to sufficient heat and pressure to generate and yield petroleum (Fig. 23). A few fields exist up-dip away from the major producing centers, probably representing unique petroleum conditions or longer distance migrations. The Eagle Ford in the central portions of the basin, nearest the major areas of Gulfian production, is clearly rich enough to have provided the oil found in these reservoirs. Therefore, individual reservoir units are considered in the following section.

Buda production is generally restricted to the central portions of the basin. Two areas of Buda production are up dip from the central portions of the basin, areas A and B. While Buda rocks in the basin are separated from organic-rich Eagle Ford clays by hundreds of feet of Woodbine strata, this may not have been an effective seal against migration of Eagle Ford oil. Buda production is most often associated with faulting or salt tectonism, either of which may have afforded migration pathways for Eagle Ford oil.

Woodbine production dominates most of the production of east Texas. Most Woodbine production occurs in the central part of the basin, although several large fields exist towards the western margin, near area A. The reservoir sands, which often dominate as much as 70% of the Woodbine section, are due to complex deltaic systems composed of land-derived clastics (Oliver, 1971, p. 1). Eagle Ford source-rocks in the center of the basin appear to have been rich enough to account for oil in Woodbine reservoirs.

Eagle Ford production is also restricted to the central part of the basin. Eagle Ford production does not extend as far west as the Woodbine and Buda fields, which may have been supplied with oil from Eagle Ford rocks. However, the western limit of Eagle Ford production may indicate either that Eagle Ford reservoirs are not present beyond this part of the basin, or that they have not been found.

Austin production is restricted to two general areas: 1) the northern and western margins where scattered small fields typically occur; and 2) along the southerly limit of the basin where major Austin accumulations occur. Economical Austin production occurs in zones of fractured porosity usually associated with localized faulting, deep-seated structures, or flexures related to lateral stress (Koger, 1981, p. 73). Oil found in Austin rocks has two appearances: 1) a golden brown high gravity crude oil found in the fracture zones; and 2) a black low gravity tar-like oil trapped in the primary matrix, which is uneconomical to produce (Hayward, oral communications, 1985). The high grade crude oil (uncharacteristic of authigenic Austin oil) associated with fractures (which could supply migration pathways) is indicative of oil derived from a different source than Austin rocks, possibly from the organic-rich Eagle Ford clays.

Potential volume of petroleum generated can be estimated on a local level by using total organic carbon, thickness of source-rocks, and areal distribution of the petroleum-generative province (Bishop et al., 1984, p. 44). The potential volume of oil generated by Eagle Ford organics can be derived by applying this technique regionally, using an average organic carbon value of 1%, planimetered thickness intervals (Fig. 24), and assuming that: 1) Eagle Ford organics are uniformly distributed in the section; 2) the organics in the center of the basin are residual in nature, and since they are substantially lower than organic carbon values in peripheral areas, maturation has occurred; and 3) the central area of the basin (defined by Gulfian production) is the petroleum generative province for Eagle Ford rocks. The potential volume of oil, therefore, equals approximately 400 billion barrels (Appendix IV).

PETROLEUM POTENTIAL OF EAGLE FORD ROCKS IN THE EAST TEXAS BASIN

Significant volumes of oil have been produced from Eagle Ford Sands of the East Texas basin. These sands have generally been related to the regressive delta facies of Sub-Clarksville time, even though reservoirs are present in the southern portions of the basin, beyond the mapped pinchout of the Sub-Clarksville Formation. This interpretation has not encouraged exploration beyond the Sub-Clarksville facies limits. However, with the application of a multiple delta model for the overall Eagle Ford sequence, the distribution of all Eagle Ford sands is better understood, and offers a refined approach and renewed incentive for future exploration. The purpose of this section is to define major fairways of reservoir rocks existent in the four formations herein recognized to compose the Eagle Ford.

The method of investigation for this section entailed use of the sand isoliths (already presented) to define areas with sand intervals thick enough to be considered possible reservoirs. Generally, a potential reservoir area was considered to be any area with cumulative sand thickness in excess of 10 feet. Areas up dip from Eagle Ford production were not considered to be optimum exploration areas.

TARRANT EXPLORATION FAIRWAY

The net sand map for the Tarrant Formation shows

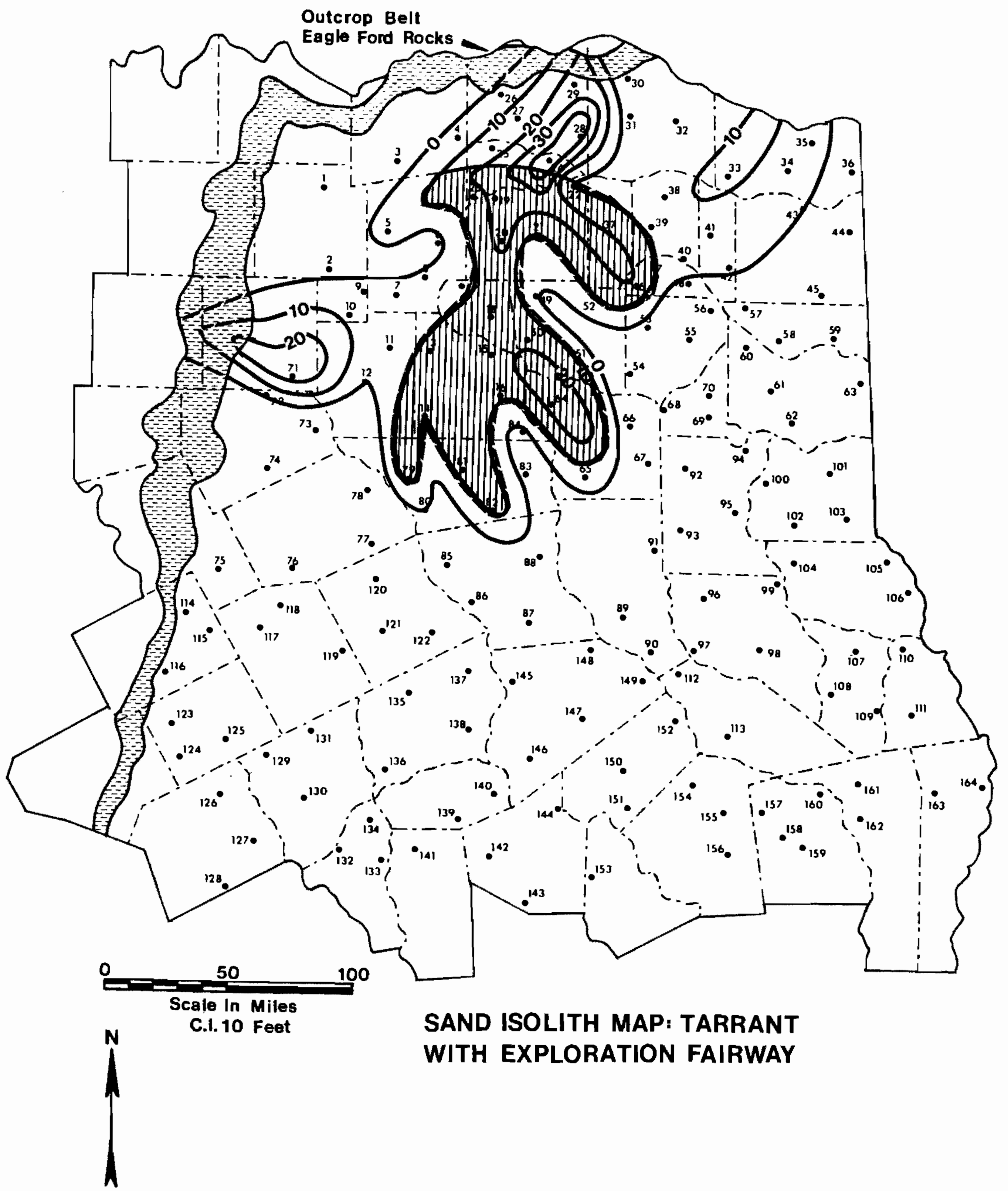


Figure 25: Sand isolith of the Tarrant with exploration fairway. The Tarrant exploration fairway covers parts of seven counties and consists of thin sands which can form significant reservoirs on low relief structures.

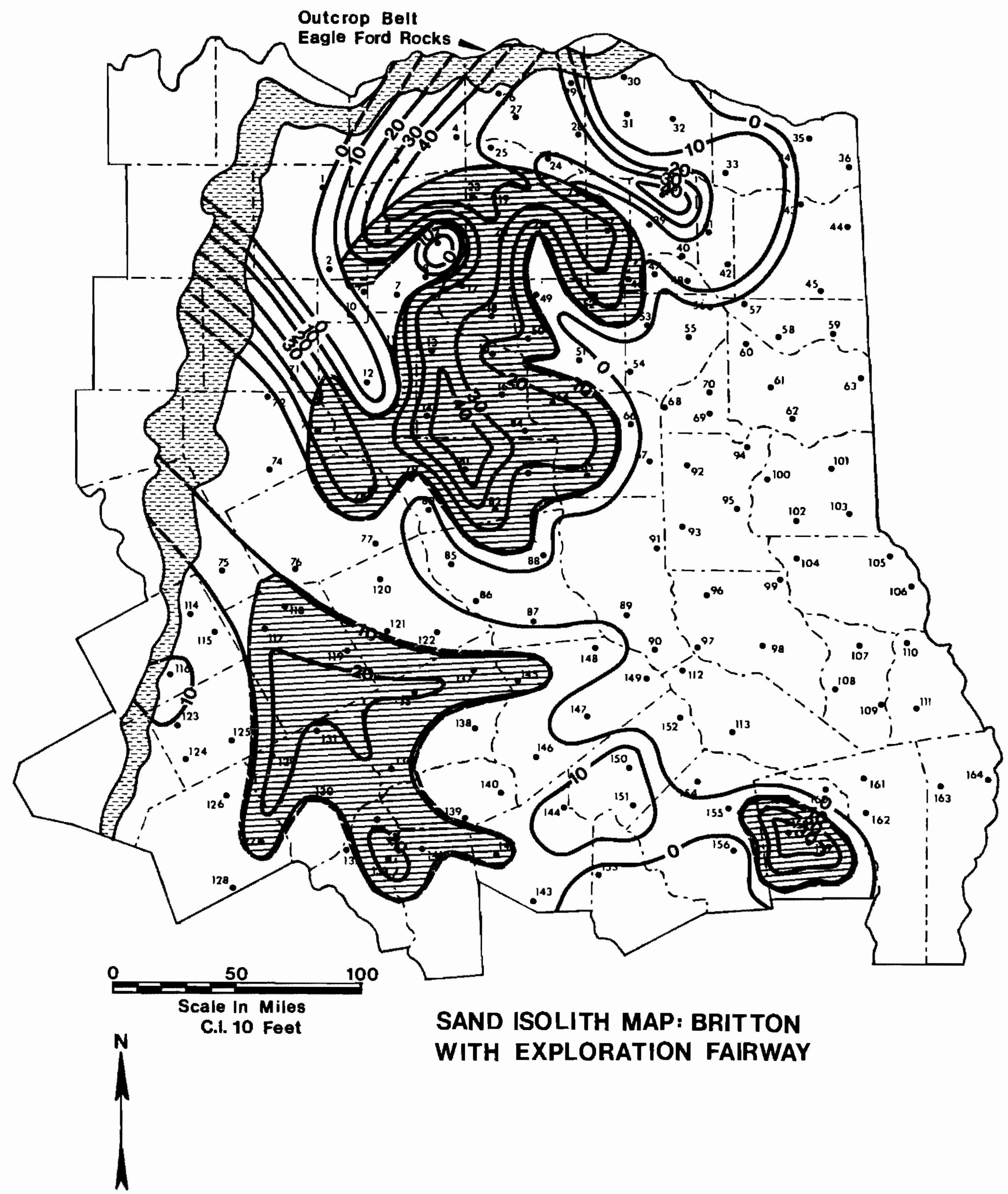


Fig. 26: Sand isolith of the Britton with exploration fairway. Britton fairways are distributed in three areas of east Texas. Of these, the northern fairway is the most attractive because of stacking of sands and thickening of sand units which may offer multiple pay horizons. Sands of the southwestern fairway are thinner and more widely separated, averaging between 10 and 15 feet in thickness. The southeastern fairway is composed of sands which probably represent turbidite fan facies that are thin and difficult to locate.

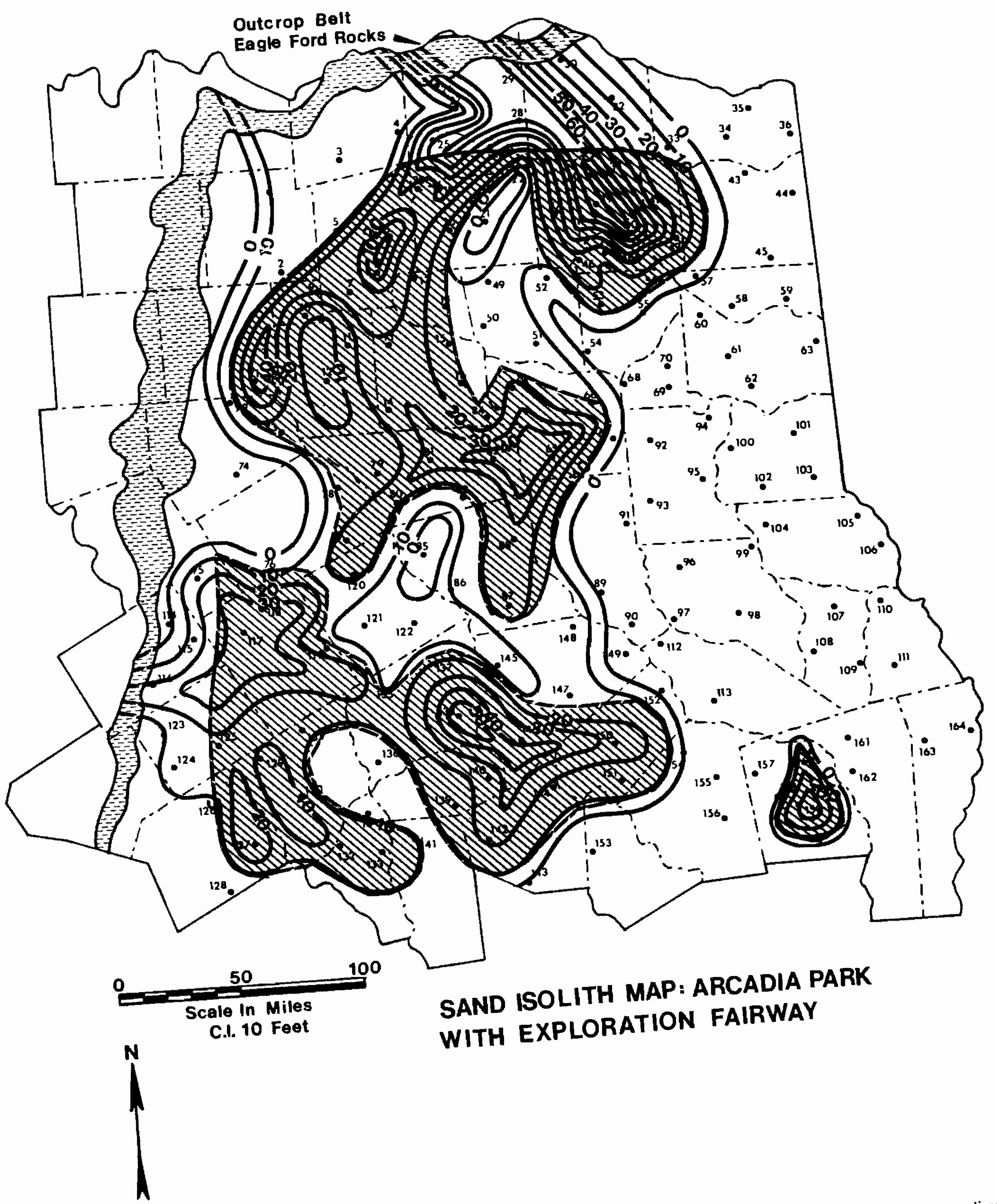


Fig. 27: Sand isolith of the Arcadia Park with exploration fairway. Three areas of potential exploration occur for Arcadia Park sediments. Of these the northern area is areally extensive and probably the most attractive, with total sand thickness of 90 feet, and individual sand thickness greater than 20 feet. While sands of the southwestern fairway are thin, cumulative reservoir thickness is highly attractive. Sands in the southeastern fairway are coincidental with Britton sands and are thin and difficult to predict.

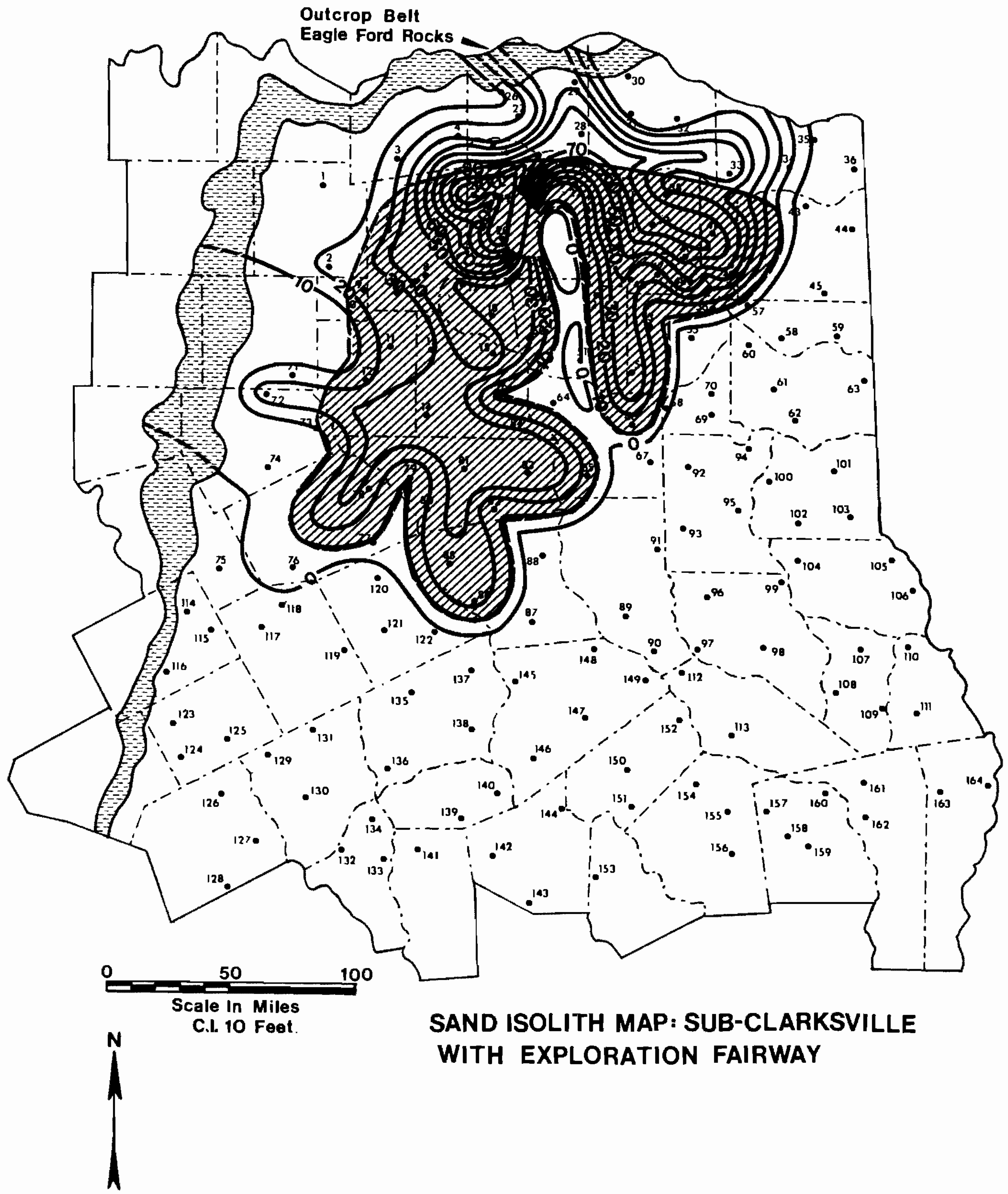


Fig. 28: Sand isolith of the Sub-Clarksville with exploration fairway. Petroleum production from this widely distributed fairway is limited to major structures. However, due to linear sands and local thinnings, stratigraphic pinchouts in conjunction with minor structural features may have created petroleum traps away from the narrow structural fairways.

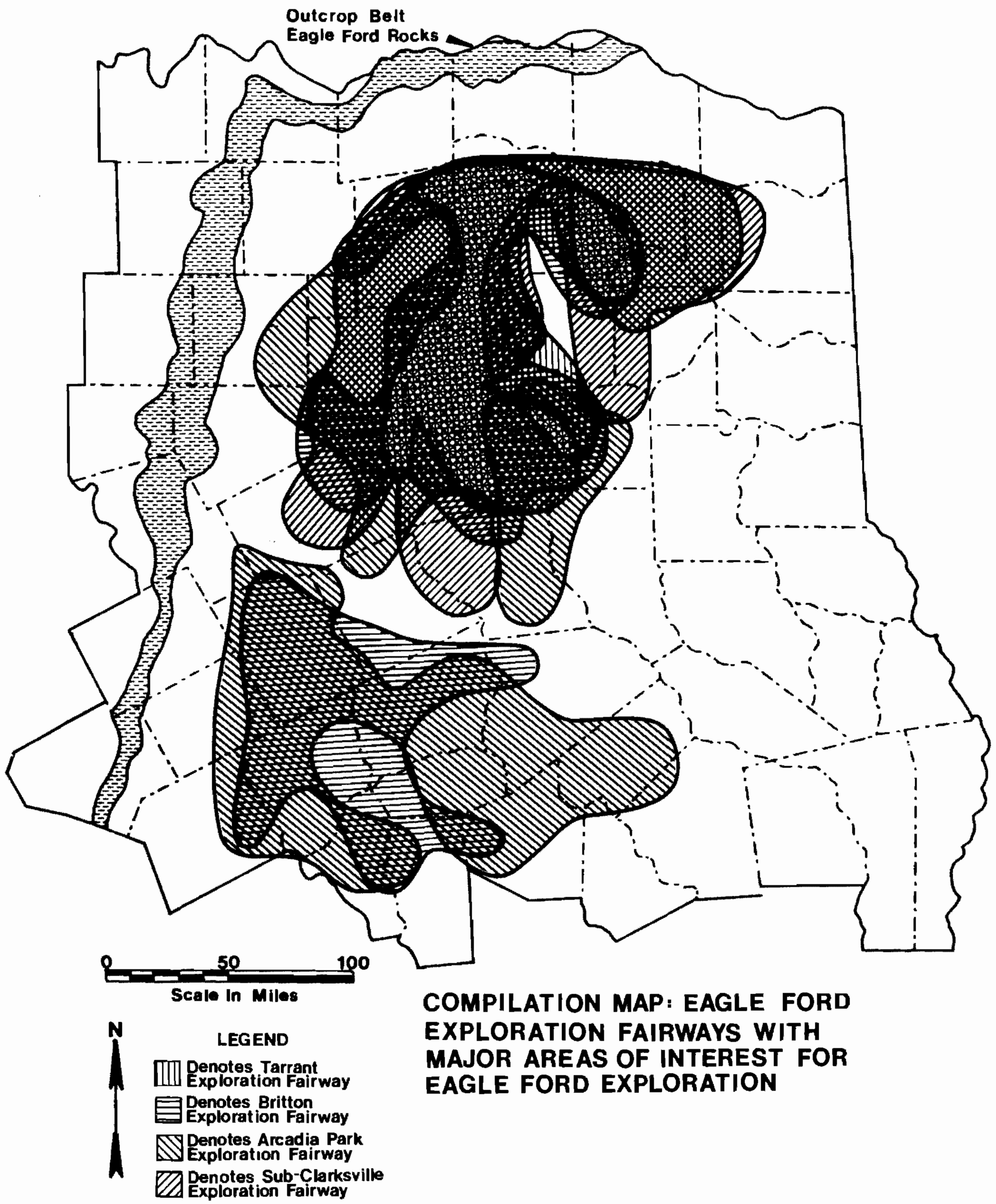


Fig. 29: Compilation map of the Eagle Ford exploration fairways. Two areas of major interest for Eagle Ford exploration occur. The northern area has sands from all four units stacked at depths from 3000 to 5000 feet. The southern area has sands from both the Britton and Arcadia Park stacked at depths from 2000 to 4000 feet.

potential reservoir sands in the northcentral portion of the basin, over parts of seven counties (Fig. 25). Discrete sands are in this area averaging 10 to 15 feet in thickness. Because these sands are thin, minor structural features such as low relief faults have the potential to produce effective traps. Drilling depths for Tarrant rocks in this area range from 3700 feet along the northern margins of the fairway down to 5100 feet at the southern boundary of the fairway.

BRITTON EXPLORATION FAIRWAY

The net sand map of the Britton Formation shows more widely distributed sands. Three areas of sand concentrations have reservoir potential (Fig. 26). The northcentral portion of the basin has high reservoir potential due to stacking of sands and thickening of individual sand units offering multiple pay possibilities. Britton Sands in this area range to 40 feet in thickness. Drilling depths for Britton rocks in the northern fairway range from 1700 feet along the northwestern margin of the fairway down to 5400 feet along the southern boundary.

The southwestern reservoir fairway extends over parts of eight counties. The reservoir sands in this area are thinner and more widely separated than those in the north, averaging between 10 and 15 feet in thickness. Drilling depths in this area range from 2000 feet along the western margin of the fairway down to 7500 feet along the southeastern margin.

The third potential fairway occurs in the extreme southeastern portion of the basin. These sands, which may represent turbidite fan facies, are thin and difficult targets. Drilling depths for this area range from 11,000 to 15,000 feet.

ARCADIA PARK EXPLORATION FAIRWAY

The net sands map for the Arcadia Park shows sands widely distributed throughout most portions of east Texas. Three fairways of potential Arcadia Park reservoirs show clearly (Fig. 27). The northern area, which is areally extensive, is probably the most attractive of the fairways. It covers most of northcentral east Texas to the updip limit of Eagle Ford production, and has total sand thickness of 90 feet with individual sand thicknesses averaging greater than 20 feet. Stacking of Arcadia Park Sands throughout most of this area leads to the potential for multiple pay horizons. Drilling depths for this area range from 1700 feet along the northwestern margin of the fairway down to 4700 feet along the southern boundary.

The sands of the southcentral fairway are thinner than the northern fairway. However, the cumulative reservoir thickness is still highly attractive. Individual sand thickness averages between 10 to 15 feet. Drilling depths range from 2000 feet along the western margin of the fairway down to 11,000 feet in the southeastern portion.

The third fairway for Arcadia Park exploration is in the extreme southeastern portion of the basin, coincidental with the Britton accumulation. Arcadia Park Sands are thin and difficult to predict, much like the Britton. Since the drilling depths range from 11,000 to 15,000 feet, this area is high risk for Eagle Ford exploration.

SUB-CLARKSVILLE EXPLORATION FAIRWAY

The net sands for the Sub-Clarksville are distributed throughout most of northcentral east Texas. Petroleum in these sands, which are generally thick and multiply stacked, is produced around major structures. In addition, due to the linear sands and local thinnings, stratigraphic pinch-outs probably occur in conjunction with minor structures, which may have created petroleum traps away from the major structural trends. Therefore, the Sub-Clarksville fairway has the potential for reservoir development throughout the area of deposition (Fig. 28). Drilling depths for this fairway extend from 1500 feet along the northern and western margin down to 5000 feet along the southern boundary of the fairway.

OPTIMAL EAGLE FORD EXPLORATION FAIRWAYS

When all of the fairways are plotted on the same base, the areas of major interest for Eagle Ford exploration show clearly (Fig. 29). Two areas are highly attractive because of the multiplicity of stacked reservoirs, the potential for productive traps even on subtle structures, and shallow drilling depths. The northern Eagle Ford fairway, which exists in a presently productive and relatively highly drilled portion of the basin, has the potential for undiscovered traps in reservoir sands from all four units at depths ranging from 3000 to 5000 feet. The less densely drilled southern Eagle Ford fairway has the potential for reservoir development in the Britton and Arcadia Park Formations at depths of 2000 to 4000 feet. Drilling penetrations of thin sands in both fairways should be reviewed for possible reservoirs that have been overlooked or disregarded as non-commercial at the time of drilling.

CONCLUSIONS

1. The Eagle Ford Group, one of the most complex clastic units of the upper Cretaceous Gulfian System, has been re-examined throughout the entire basin. Emphasis has been placed on regional relationships, local stratigraphic changes, subdivisions of the group, and mapping of sands and source-rocks in depositional subunits.

2. Eagle Ford sediments within the East Texas basin are confined by the outcrop on the western and northern margins, the Sabine uplift on the eastern margin, and the Angelina-Caldwell flexure along the southern margin.

3. Eagle Ford rocks of east Texas and their equivalents in other upper Cretaceous basins consist mostly of shale. Generally, the Eagle Ford thins southward out of east Texas over the San Marcos platform, and then thickens westward to the paleontologically complete section of the Chispa Summit Formation in the Davis Mountains. The Eagle Ford can be closely correlated with several groups from the Western Interior.

4. The Eagle Ford of east Texas is a shale-dominated sequence containing localized deltaic and fringing marine sands and consists predominantly of bluish-black bituminous laminated clays which are sub-divided into the Tarrant, Britton, Arcadia Park, and Sub-Clarksville Formations. The Tarrant consists of interbedded sandstone and shale, which records the initial transgression of the Eaglefordian seas. The Britton consists of finely laminated highly organic clays which characterize Eagle Ford rocks of east Texas. Arcadia Park sediments become more clastic-dominated and preserve the first evidence of the Sabine activity during late Eagle Ford deposition. The Sub-Clarksville is the sand-dominated unit of upper Eagle Ford strata in the northern portions of the East Texas basin.

5. Following a late Woodbine erosional period, crustal downwarping set the stage for transgression of Eaglefordian seas into east Texas. Tarrant deposition marks the initial formation of complex mud-dominated deltas. Britton deposition marks the maximum extent of Eaglefordian seas and deposition of the richest source-rocks in the form of carbon-rich anoxic muds on an embayed shallow marine shelf. Arcadia Park deposition began following a late Britton erosional period, and re-established most of the old deltas, accompanied by westwardly prograding deltas shed off the Sabine uplift. Sub-Clarksville deposition, which marks the termination of Eagle Ford deposition, was a product of a highly complex delta system which built seaward from previous deltas and displaced the Eaglefordian seas in east Texas.

6. The Eagle Ford Group of east Texas contains highly organic sediments which are sufficiently rich to have generated the oil produced from reservoirs of Buda, Woodbine, Eagle Ford, and Austin age rocks.

7. The recommended approach in exploring for Eagle Ford oil is usage of the expanded delta model to define exploration fairways for the individual units of the Eagle Ford. The stacking of these fairways delineates two optimum areas for Eagle Ford exploration.

APPENDIX I

OUTCROP LOCALITIES

LOCALITY

1: South Bosque (Arcadia Park)—15 foot exposure in Foster Creek by an unnamed gravel county road, 4.3 miles east-northeast of Moody, McLennan County, Texas. Blue gray fissile calcareous mudstone with thin laminae of siltstone, sandstone, and fragmental limestone.

2: South Bosque (Arcadia Park)—46 foot total exposure in unnamed tributary of South Bosque River, 5.2 miles south-southeast of McGregor Airport entrance on unnamed gravel road between Farm Roads 2416 and 2837, McLennan County, Texas. Blue gray fissile to blocky shale with thin micritic limestone beds near the base of the section.

3: Lake Waco (Britton), Cloice Member—56 feet total exposure in unnamed tributary of South Bosque River in Midway Park, Woodway, McLennan County, Texas. Laminated montmorillonitic clays with disseminated calcium carbonate, abundant bentonite, and limestone beds near the top of the section.

4: Lake Waco (Britton), Cloice Member—16 feet of section exposed along a bar ditch of unnamed county road, .5 miles south of Farm Road 2114. Intersection of unnamed road and Farm Road 2114 is 2.5 miles west of the town of West, McLennan County, Texas. Laminated blue gray shale interlaminated with bentonite.

5: Britton—8 foot section in Aquilla Creek at intersection with Farm Road 2114, McLennan County, Texas. Laminated blue gray to black shale.

6: Britton—8 foot exposure at the intersection of Highway 71 and Highway 81 behind the VFW hall, Hillsboro, Hill County, Texas. Interbedded laminated clay, bentonite, and thin limestones composed of reworked Inoceramus prisms.

7A: Arcadia Park—4 foot exposure at the intersection of Farm Road 67 and Cottonwood Creek, 5 miles north-northeast of Itasca, Hill County, Texas. Massive blocky shale which weathers to a tan orange.

7B: Arcadia Park—3 foot exposure 1.2 miles east of 7A, at the intersection of the eastern branch of Itasca Creek and unnamed gravel road towards Maypearl, Hill County, Texas. Bedded fissile shale which weathers to a buff color.

8: Tarrant—3 foot exposure at intersection of the north fork of Chambers Creek and Farm Road 1807, 1.5 miles southeast of Alvarado, Johnson County, Texas. Interbedded fossiliferous limestone, red-gray clay, and sandstone near base of Eagle Ford section.

9: Arcadia Park—4 foot exposure in the western branch of Bagby Creek, .4 miles south of Farm Road 1807, 1 mile west of intersection of Farm Road 1807 and 157, Johnson County, Texas. Fissile shale with concretions ranging up to 6 inches in diameter.

10: Arcadia Park—30 foot exposure along the west loop of Highway 67, .2 miles south of intersection with Highway 287, west of Midlothian, Ellis County, Texas. Blocky to fissile black shale with bedded calcite-pyrite concretions 20 feet beneath the Eagle Ford-Austin contact.

11: Britton—3 foot exposure in road cut on Highway 287, 2.5 miles northwest of Midlothian, Ellis County, Texas. Calcareous sandstone bed with scattered reworked fossils, borings, and small rounded quartz grains; has channel-like appearance.

12: Arcadia Park—20 foot exposure in road cut on Farm Road 1362, .75 miles west of Cedar Hill, Dallas County, Texas. Black fissile shale beneath the Eagle Ford-Austin contact.

13: Arcadia Park (type locality)—20 foot exposure in railroad cut at intersection of Highway 20 and unnamed railroad beneath White Rock escarpment. 6 miles southwest of Dallas, Dallas County, Texas. Black fissile shale.

14: Eagle Ford (type locality)—15 foot exposure in river cut on Trinity River, .3 miles east of intersection of Trinity River and Loop 12 (Highway 408), northern limits of the townsite of Eagle Ford, 7 miles west of Dallas, Dallas County, Texas. Black fissile calcareous shale.

15: Britton—4 foot exposure in Case Creek at intersection with Farm Road 902, 2 miles southeast of Ethel, Grayson County, Texas. Laminated shale interbedded with small micritic limestone ledges.

16: Britton—9 foot section in road cut of unnamed gravel road, .1 mile east of intersection with another unnamed gravel road, due east of Hagerman National Wildlife Refuge, .15 miles west of Hagerman Baptist Church, Grayson County, Texas. Tan brown massive silty shale.

17: Britton—6 foot section in Harris Creek at intersection with unnamed gravel road, 1.75 miles north of Highway 82, 2.8 miles west of Kersey Cemetery, Grayson County, Texas. Tan brown massive silty shale.

18: Arcadia Park—9 foot section in Iron Ore Creek at intersection with Farm Road 131, 3 miles southwest of Denison, Grayson County, Texas. Red silty clay with two mud diapirs. Inside diapirs, mud is mottled black and white.

19: Arcadia Park—18 foot section in drainage ditch just north of intersection of Farm Road 131 and Farm Road 691. Large section of dark black fissile shale.

20: Tarrant—8 foot section in road cut along Highway 82, just east of intersection with Mill Creek, 1.3 miles west of Bells, Grayson County, Texas. 4 feet of fissile gray shale overlain by a 2 foot resistant quartz sandstone bed which is overlain by more shale.

21: Sub-Clarksville—5 foot section in bar ditch on east side of Farm Road 1499, 1.4 miles south of intersection with Farm Road 197, Lamar County, Texas. White silty clay which weathers to red, consists of small quartz sand bound together in a white clay matrix. Limonite nodules are spread all over the ground.

22: Sub-Clarksville—5 foot section in road cut along Farm Road 2648, 3 miles east of intersection with Highway 271, Lamar County, Texas. Red silty clay which is white in fresh exposure. Consists of small quartz sand bound together in a white clay matrix.

APPENDIX II

WELL DATA

Well No.	County	Well Name	Log Date	Total Depth	Thickness: Tarrant	Thickness: Britton	Thickness: Arcadia Park	Thickness: Sub-Clarksville	Net Sands: Tarrant	Net Sands: Britton	Net Sands: Arcadia Park	Net Sands: Sub-Clarksville
1	Collin	Deep Rock 1-Shirley	8/21/52	8876	90	130	145	55	0	0	10	15
2	Collin	Manziel 1-Alexander	9/13/47	5667	71	174	170	45	0	8	14	22
3	Fannin	Lynn 1-Brown	3/11/52	5103	60	190	120	70	0	33	18	24
4	Fannin	Hawkins 1-Shelton	5/3/54	4153	85	175	165	250	8	40	18	40
5	Hunt	Humble 1-Anderson	Not Given	6271	35	225	105	62	8	32	18	30
6	Hunt	Cox 1-Hill	10/27/60	9482	75	210	40	155	0	0	0	55
7	Hunt	Pan Am 1-Cooksey	9/4/57	9501	125	210	150	128	5	18	32	28
8	Hunt	Humble 1-Graham	Not Given	5990	65	205	143	95	6	19	26	41
9	Rockwall	Farmer 1-Herndon	6/10/56	3955	145	160	160	80	4	12	32	28
10	Rockwall	Rotary 1-Lewis	3/21/65	7876	110	185	140	60	6	0	12	10
11	Kaufman	Hughes 1-Jones	11/16/74	10000	113	180	97	73	4	12	12	23
12	Kaufman	Gibson Drlg. 1-Lupe	4/8/57	3050	75	170	100	50	0	0	10	18
13	Van Zandt	Trinity Drilling 1-(No Name)	8/19/49	4488	105	200	120	60	18	34	24	26
14	Van Zandt	Cooper-Herring 1-Gibbs	10/9/52	4235	130	125	85	55	10	38	24	40
15	Van Zandt	Hootkins 1-Persons	7/24/60	6984	133	130	160	85	14	16	16	42
16	Van Zandt	Fair 1-Swinney	11/7/47	3718	50	137	64	97	12	26	10	4
17	Rains	Delta 1-Dowell	3/24/54	3921	90	205	140	100	10	32	26	37
18	Rains	Coats Drlg. 1-John Coats	2/1/53	6603	115	145	165	92	10	27	10	38
19	Hopkins	Amoco 1-Matherly	5/18/74	9925	105	135	215	155	22	40	46	91
20	Hopkins	Sunray 1-Seamon	12/29/63	12183	170	65	210	160	22	38	14	123
21	Hopkins	McAlester 1-Helm	11/25/62	11812	100	120	80	70	6	8	0	0
22	Hopkins	Grelling 1-Thompson	1/25/59	10449	110	95	90	60	10	18	0	20

Well No.	County	Well Name	Log Date	Total Depth		Tarrant	Britton	Arcadia Park	Sub-Clarksville
23	Delta	Bond 1-Albowitch	5/21/60	5893	Thickness	90	170	237	233
					Net Sands	15	66	32	122
24	Delta	Naylor 1-Young	12/13/59	7804	Thickness	100	110	160	125
					Net Sands	48	26	46	78
25	Delta	Kirkwood 1-Foster	7/9/49	3212	Thickness	95	145	200	75
					Net Sands	12	33	66	40
26	Lamar	D. and D. Drlg. 1-Morton	9/1/48	2935	Thickness	84	145	165	85
					Net Sands	5	45	45	20
27	Lamar	Stephens 1-Tidwell	4/11/80	2338	Thickness	110	140	130	70
					Net Sands	12	34	30	25
28	Lamar	Hagar 1-Gardner	5/12/51	5417	Thickness	220	240	200	255
					Net Sands	55	39	76	75
29	Lamar	Cosden 1-Adams	Not Given	3050	Thickness	95	125	140	110
					Net Sands	25	15	22	58
30	Red River	Hager 3-Tate	10/26/59	2716	Thickness	85	85	105	125
					Net Sands	8	5	20	25
31	Red River	Bowden 1-Welch	11/20/49	3087	Thickness	80	40	135	110
					Net Sands	6	4	50	36
32	Red River	Lee 1-Stiles	12/13/53	5008	Thickness	55	45	120	145
					Net Sands	5	5	18	28
33	Bowie	Hill and Mclean 1-Jackson	8/2/61	9591	Thickness	35	75	45	80
					Net Sands	14	18	12	55
34	Bowie	Coats 1-Sims	12/29/48	3853	Thickness	20	20	70	90
					Net Sands	5	10	0	10
35	Bowie	Pan Am 1-Bradham	10/21/66	6506	Thickness	0	0	43	75
					Net Sands	0	0	0	0
36	Bowie	Barnsdall 1-Greenwood	3/16/47	8188	Thickness	0	0	50	0
					Net Sands	0	0	0	0
37	Franklin	Graves 1-Jones	9/30/82	6684	Thickness	50	95	125	90
					Net Sands	19	32	32	43
38	Titus	Paxton, et al. 1-Burford-Al.	12/23/65	12133	Thickness	45	100	145	120
					Net Sands	8	43	69	51
39	Titus	Stephens 1-Driggers	1/6/62	7575	Thickness	45	90	170	145
					Net Sands	6	16	74	78
40	Titus	Hinton 1-Stephenson	3/14/50	4898	Thickness	47	88	195	115
					Net Sands	8	16	88	68
41	Morris	Humble 1-Wright	1/27/44	11810	Thickness	40	45	150	125
					Net Sands	6	14	30	65
42	Morris	Hunt 1-Robinson	11/10/45	8431	Thickness	25	50	120	130
					Net Sands	6	18	24	51
43	Cass	Phillips 1-Leonard	5/18/62	10725	Thickness	0	0	70	0
					Net Sands	0	0	0	0
44	Cass	Shell 1-Smith	Not Given	10801	Thickness	0	0	90	0
					Net Sands	0	0	0	0
45	Cass	Gilger 1-Davis et al.	Not Given	6043	Thickness	0	0	40	0
					Net Sands	0	0	0	0
46	Camp	Humble 1-Carpenter	9/4/70	12444	Thickness	50	55	115	40
					Net Sands	22	15	20	32
47	Camp	Humphrey 1-Nickerson	2/28/67	10725	Thickness	40	40	90	50
					Net Sands	8	10	22	35
48	Camp	Sun 1-Dyer	9/2/81	8872	Thickness	45	45	145	100
					Net Sands	0	18	32	48
49	Wood	Sohio 1-Morgan	Not Given	6579	Thickness	65	30	90	55
					Net Sands	0	4	16	20
50	Wood	Felder and Erwin 1-Hulsey	12/11/51	5815	Thickness	70	90	90	95
					Net Sands	12	14	14	29
51	Wood	Southland 1-Judge	10/5/56	9507	Thickness	68	105	80	120
					Net Sands	10	5	14	0
52	Wood	Shell 1-Highnote	12/28/52	5189	Thickness	52	32	60	70
					Net Sands	10	20	6	16
53	Upshur	McBee and Rudman 1-Ray	5/18/77	10768	Thickness	0	0	65	20
					Net Sands	0	0	16	20
54	Upshur	Edson 1-Payton	1/4/64	8127	Thickness	0	0	30	65
					Net Sands	0	0	0	36
55	Upshur	McBee and Rudman 1-Indian Ro.	11/17/72	12205	Thickness	0	0	33	0
					Net Sands	0	0	0	0
56	Upshur	Texaco 1-Newsome	1/17/67	11797	Thickness	0	0	85	60
					Net Sands	0	0	4	13
57	Marion	Magnolia 1-Hall	2/14/47	10014	Thickness	0	0	0	0
					Net Sands	0	0	0	0
58	Marion	Hollandsworth 1-Mathis	9/4/56	6204	Thickness	0	0	0	0
					Net Sands	0	0	0	0
59	Marion	Purnell 1-Deltic	2/13/60	6409	Thickness	0	0	0	0
					Net Sands	0	0	0	0
60	Harrison	Placid 1-Allen	5/20/47	8006	Thickness	0	0	0	0
					Net Sands	0	0	0	0
61	Harrison	Norton 1-Neal	4/6/58	7243	Thickness	0	0	0	0
					Net Sands	0	0	0	0
62	Harrison	Gilster and Kemp 1-Allen	8/23/54	7535	Thickness	0	0	0	0
					Net Sands	0	0	0	0
63	Harrison	Phillips 1-Valley	6/5/51	8358	Thickness	0	0	0	0
					Net Sands	0	0	0	0
64	Smith	Howard 1-Waters	12/13/54	5809	Thickness	90	105	140	65
					Net Sands	20	20	21	4
65	Smith	Talbert and Gulley 1-Simpson	5/18/57	5958	Thickness	45	105	110	60
					Net Sands	6	16	43	17
66	Smith	Pure Oil 1-Lolley	11/22/50	4325	Thickness	35	0	55	25
					Net Sands	0	0	17	12
67	Smith	Grelling and Oldham 1-Pope	8/31/55	4041	Thickness	0	0	23	0
					Net Sands	0	0	4	0
68	Gregg	Exxon 1-McCubbin	2/23/83	12017	Thickness	0	0	0	0
					Net Sands	0	0	0	0
69	Gregg	Key Prod. 4-Adkin-Ross	3/5/82	7806	Thickness	0	0	0	0
					Net Sands	0	0	0	0
70	Gregg	Ward Oil 2-Bodenheim Gas	5/5/66	11820	Thickness	0	0	0	0
					Net Sands	0	0	0	0
71	Dallas	South Texas Pet. 1-Stadden	8/9/72	2202	Thickness	75	250	70	45
					Net Sands	25	68	40	16
72	Ellis	Faulds Whitehead 1-Curtis Hill	1/15/60	3629	Thickness	90	235	45	40
					Net Sands	0	6	10	21
73	Ellis	Cain 1-Patak	5/26/53	3673	Thickness	80	255	45	30
					Net Sands	0	23	16	10
74	Ellis	Banks 1-Southard	3/6/71	17344	Thickness	70	165	32	58
					Net Sands	0	4	0	6
75	Hill	Dalton J. Woods 1-Estes	8/14/47	1258	Thickness	0	105	100	0
					Net Sands	0	14	18	0
76	Navarro	Falcon 1-Keitt	8/8/42	6455	Thickness	15	125	80	17
					Net Sands	0	6	6	2
77	Navarro	Amoco 1-Cunningham	4/27/80	10154	Thickness	105	90	90	20
					Net Sands	0	8	20	10
78	Navarro	Sundance 1-Arnett	12/12/78	7512	Thickness	145	138	102	60
					Net Sands	0	20	15	27
79	Henderson	Humphrey 1-Key	2/4/55	7638	Thickness	85	155	90	30
					Net Sands	16	6	18	10
80	Henderson	Delta 3A-Hustead	5/13/55	7535	Thickness	60	145	78	37
					Net Sands	0	0	25	20
81	Henderson	Lonestar 1-Dixie Killough	10/19/47	8216	Thickness	75	101	140	50
					Net Sands	14	47	37	35
82	Henderson	Windsor 1-Burkhart	11/23/53	5523	Thickness	90	60	125	23
					Net Sands	16	25	35	17
83	Henderson	British Am. 1-Anderson	7/17/66	10987	Thickness	0	110	145	45
					Net Sands	0	20	40	38
84	Van Zandt	Byrd 1-Byrd	1/5/52	7596	Thickness	49	125	105	65
					Net Sands	0	27	18	34
85	Anderson	TXO Prod. 1-Glenn	2/23/83	9537	Thickness	0	195	135	60
					Net Sands	0	0	0	25
86	Anderson	Continental 2-Royal Nat. Bank	3/14/52	9864	Thickness	0	128	110	25
					Net Sands	0	0	10	25
87	Anderson	Phoenix 1-Mathis	9/30/79	12503	Thickness	0	90	90	0
					Net Sands	0	0	29	0
88	Anderson	Herring 1-Carpenter	1/26/64	8426	Thickness	0	96	98	0
					Net Sands	0	5	25	0
89	Cherokee	Texaco 1-Whiteman	6/10/52	10150	Thickness	0	40	32	0
					Net Sands	0	0	0	0
90	Cherokee	Texaco 1-Dean	5/24/73	18120	Thickness	0	0	0	0
					Net Sands	0	0	0	0
91	Cherokee	Hansbro 1-Bolton	2/13/51	9094	Thickness	0	0	0	0
					Net Sands	0	0	0	0
92	Rusk	Hinton 1-Childress	4/18/42	10964	Thickness	0	0	0	0
					Net Sands	0	0	0	0
93	Rusk	Ft. Bend 1-Barron	3/31/72	8194	Thickness	0	0	0	0
					Net Sands	0	0	0	0
94	Rusk	J. C. Trahan 16-Tatum Crane	6/16/62	7068	Thickness	0	0	0	0
					Net Sands	0	0	0	0
95	Rusk	J. P. G. Oil 2-Troy Welch	1/18/66	7391	Thickness	0	0	0	0
					Net Sands	0	0	0	0
96	Nacogdoches	Palmer 1-Sitton McLain	10/23/82	9301	Thickness	0	0	0	0
					Net Sands	0	0	0	0
97	Nacogdoches	Tes. Gen. Pet. 1-Byrd	4/5/82	7944	Thickness	0	0	0	0
					Net Sands	0	0	0	0
98	Nacogdoches	Palmer 1-Simpson Adams	11/3/81	9689	Thickness	0	0	0	0
					Net Sands	0	0	0	0
99	Nacogdoches	Bancroft-Watson 1-Martindale	2/10/75	8137	Thickness	0	0	0	0
					Net Sands	0	0	0	0
100	Panola	Carter and Jones 1-Crawford	4/2/57	7133	Thickness	0	0	0	0
					Net Sands	0	0	0	0
101	Panola	Arkla 1-Cummings	9/10/44	4950	Thickness	0	0	0	0
					Net Sands	0	0	0	0
102	Panola	Arkla 2-Hardin	12/4/52	6125	Thickness	0	0	0	0
					Net Sands	0	0	0	0
103	Panola	Blalock and Walter 1-Sabine	11/17/54	6081	Thickness	0	0	0	0
					Net Sands	0	0	0	0
104	Shelby	Champlin 1-Langston	12/18/80	10286	Thickness	0	0	0	0
					Net Sands	0	0	0	0
105	Shelby	Carter-Jones 1-Pickering	4/8/58	7323	Thickness	0	0	0	0
					Net Sands	0	0	0	0
106	Shelby	Coats 1-Pickering	12/1/59	7000	Thickness	0	0	0	0
					Net Sands	0	0	0	0
107	San Augustine	Fairway 1-Matthews	4/23/63	9187	Thickness	0	0	0	0
					Net Sands	0	0	0	0
108	San Augustine	Carter-Jones 1-Long Bell	3/6/56	9154	Thickness	0	0	0	0
					Net Sands	0	0	0	0
109	San Augustine	Lester-Culbertson 1-Childers	8/28/53	10029	Thickness	0	0	0	0
					Net Sands	0	0	0	0
110	Sabine	Humble 1-Harvey	12/19/72	7073	Thickness	0	0	0	0
					Net Sands	0	0	0	0

Well No.	County	Thickness / Net Sands: Tarrant	Well Name / Britton	Arcadia Park	Log Date	Total Depth / Sub-Clarksville
111	Sabine		Millican 1A-Temple		10/28/72	8104
		0	0	0		0
		0	0	0		0
112	Angelina		Gulf 1-Angelina Lbr.		11/3/64	11310
		0	0	0		0
		0	0	0		0
113	Angelina		Southland Paper 1-Copes Hiers		12/27/63	10987
		0	0	0		0
		0	0	0		0
114	McLennan		J.L. Myers Sons 1-Elk City		1/21/64	2902
		0	65	163		0
		0	4	0		0
115	McLennan		Porter 1-Kophal		4/10/57	1405
		0	80	173		0
		0	6	15		0
116	McLennan		Chapel Hill 1-Waco Water Well		3/19/57	2091
		0	128	133		0
		0	10	24		0
117	Limestone		Hunt 1-Union Central Life		12/1/48	5195
		0	129	106		0
		0	14	30		0
118	Limestone		Wise and Windfohr 1-Collins		2/24/49	2299
		0	197	130		0
		0	12	38		0
119	Limestone		Humble 1-Muse		5/4/55	8223
		0	193	92		0
		0	16	17		0
120	Freestone		Lonestar 1-Miller		5/17/72	12122
		30	170	170		0
		0	10	24		0
121	Freestone		Wilson 1-Utsay		Not Given	8125
		30	110	222		0
		0	8	9		0
122	Freestone		Humble 3-RLGU		Not Given	9384
		0	160	105		15
		0	5	4		
123	Falls		Jenkins and Perkins 1-Porter		1/17/51	1102
		0	176	75		0
		0	8	10		0
124	Falls		Humble 1-Elanor Carroll		8/16/51	3718
		0	78	52		0
		0	6	12		0
125	Falls		Harry Sheaves 1-Woodfin		5/21/66	2709
		0	105	65		0
		0	8	16		0
126	Milam		Rim Rock Tidelands 1-Crawford		5/8/56	6995
		0	85	45		0
		0	4	10		0
127	Milam		D. H. Byrd 1-Green		5/23/53	8209
		0	113	50		0
		0	15	25		0
128	Milam		Gen. Crude 1-Coffield		3/15/60	6737
		0	89	56		0
		0	2	4		0
129	Robertson		Caraway 1-Yezak		7/28/66	9589
		0	50	33		0
		0	20	6		0
130	Robertson		Humble 1-Margie Michael		7/30/68	17260
		0	55	20		0
		0	10	12		0
131	Robertson		Hammon 1-Corn		9/12/73	12712
		0	100	42		0
		0	18	12		0
132	Brazos		McCarthy 1-Holliday		11/24/65	10975
		0	105	75		0
		0	6	8		0
133	Brazos		Cayuga Expl. 1-Wooten		3/27/78	12298
		0	50	95		0
		0	20	15		0
134	Brazos		Williams 1-Payne		Not Given	11345
		0	75	70		0
		0	14	8		0
135	Leon		Tenneco 1-Diehl		10/25/82	14643
		0	135	35		0
		0	20	10		0
136	Leon		Tipco 1-Hilltop		12/21/77	11542
		0	92	48		0
		0	14	8		0
137	Leon		Humble 1-Lester Foran		8/12/73	9720
		0	127	68		0
		0	10	22		0
138	Leon		Burnett 1-Max Rogers		1/28/71	8008
		0	120	105		0
		0	6	57		0
139	Madison		Anardarko 1-Hightower		11/4/74	12999
		0	95	55		0
		0	6	14		0
140	Madison		Sinclair 1-Irene Walst		3/13/65	11017
		0	55	55		0
		0	6	25		0
141	Grimes		Wainco 1-Davis		2/23/79	11435
		0	80	50		0
		0	15	10		0
142	Walker		Skelly Oil 1-Gibbs "A"		3/1/66	15969
		0	50	45		0
		0	14	20		0
143	Walker		Lonestar 1-Central Coal-Coke		12/16/72	16109
		0	40	50		0
		0	8	0		0
144	Walker		Union Prod. 1-Smither		8/11/56	11706
		0	80	80		0
		0	10	18		0
145	Houston		Wessely 1-Wilcox		10/3/80	11648
		0	87	65		0
		0	10	6		0
146	Houston		Marshall 1-Odom		2/8/83	10893
		0	45	20		0
		0	6	35		0
147	Houston		Apexco 1-Strong		2/16/78	12992
		0	0	0		0
		0	0	0		0
148	Houston		Inexco 1-Davy Crockett		3/10/76	11501
		0	42	48		0
		0	10	17		0
149	Houston		Kirby 1-Williams		7/31/74	11721
		0	15	0		0
		0	0	0		0
150	Trinity		Goldking 1-Joyce		2/10/80	11719
		0	47	35		0
		0	10	20		0
151	Trinity		Amoco 1-Trinity Lumber		8/1/80	11582
		0	65	80		0
		0	10	15		0
152	Trinity		Shell 1-Temple		6/19/71	18035
		0	0	0		0
		0	0	0		0
153	San Jacinto		Glen Rose 1-Central Coal-Coke		10/2/74	16468
		0	87	70		0
		0	0	—		0
154	Polk		Am. Libr. et al. 1-Cameron		9/14/54	12701
		0	35	0		0
		0	0	0		0
155	Polk		Wainoco 1-Carter Bros.		12/27/73	12274
		0	20	0		0
		0	5	0		0
156	Polk		Shell 1-Southland Paper		7/1/62	15150
		0	295	149		0
		0	0	0		0
157	Tyler		Amoco 1-Kirby Trust		6/17/72	11095
		0	20	0		0
		0	0	0		0
158	Tyler		Delta 1-Carter		3/2/74	17000
		0	100	183		0
		0	30	0		0
159	Tyler		La. Land and Exp. 1-Int. Paper		6/2/78	15138
		0	190	240		0
		0	32	50		0
160	Tyler		Kelly-Brock 2-Arco-Abbott		3/22/73	10277
		0	0	0		0
		0	0	0		0
161	Jasper		Kelly-Brock 1-Arco Huling		2/20/78	11222
		0	0	0		0
		0	0	0		0
162	Jasper		C.K. Pet. 1-Cameron Heirs		8/4/75	13158
		0	48	0		0
		0	0	0		0
163	Newton		Pan. Am. 1-Brown		11/2/62	14111
		0	65	70		0
		0	0	0		0
164	Newton		A.N.P. Prod. 1-Southern Pines		2/8/81	13717
		0	145	80		0
		0	0	0		0

APPENDIX III

SOURCE-ROCK DATA

LABORATORY PROCEDURE

The following laboratory procedure was modified from the Geochem Laboratories' Source-Rock Evaluation Manual (1980).

1. Rock samples were obtained from outcrops and cuttings from wells drilled in the East Texas basin.
2. Samples were ground until they fit through a 100 mesh screen.
3. Samples were measured in disposable crucibles. Sample weight varied between 0.2 and 1.8 grams.
4. Samples were treated with phosphoric acid (H_3PO_4), washed with distilled water, then dried in an oven set at 80° Celsius. (Liquid was leached through samples by a vacuum suction during treatment.)
5. Samples were run through a LECO automatic carbon determinator in conjunction with a LECO induction furnace at the Arco Research Laboratory in Plano, Texas. Iron chips and copper were added as accelerator.

Sample No.	Sample Local.	County / Sample Wt. (grams)	Well Name/Outcrop	Depth Interval / % Carbon
1	O-1	McLennan	Locality 1	—
		0.645		6.624
2	O-1	McLennan	Locality 1	—
		0.833		5.463
3	O-1	McLennan	Locality 1	—
		0.335		4.322
4	O-1	McLennan	Locality 1	—
		1.061		6.154
5	O-1	McLennan	Locality 1	—
		0.842		6.129
				O-1 Average = 5.74%
6	O-2	McLennan	Locality 2	—
		0.3975		5.701
7	O-2	McLennan	Locality 2	—
		0.681		5.292
8	O-2	McLennan	Locality 2	—
		1.111		5.352
9	O-2	McLennan	Locality 2	—
		0.983		4.369
10	O-2	McLennan	Locality 2	—
		1.114		5.785
				O-2 Average = 5.299%
11	O-3	McLennan	Locality 3	—
		0.215		8.314
12	O-3	McLennan	Locality 3	—
		0.454		9.825

Sample No.	Sample Local.	County	Sample Wt. (grams)	Well Name/Outcrop	Depth Interval	% Carbon
13	O-3	McLennan	0.726	Locality 3	—	9.598
14	O-3	McLennan	1.056	Locality 3	—	10.040
15	O-3	McLennan	0.354	Locality 3	—	8.145
						O-3 Average = 9.18%
16	O-7	Ellis	0.305	Locality 10	—	1.452
17	O-7	Ellis	0.604	Locality 10	—	1.402
18	O-7	Ellis	0.868	Locality 10	—	1.451
19	O-7	Ellis	1.080	Locality 10	—	1.113
20	O-7	Ellis	0.882	Locality 10	—	1.687
						O-7 Average = 1.421%
21	O-16	Grayson	0.307	Locality 17	—	2.611
22	O-16	Grayson	0.531	Locality 17	—	2.617
23	O-16	Grayson	0.841	Locality 17	—	2.684
24	O-16	Grayson	1.133	Locality 17	—	2.650
25	O-16	Grayson	0.900	Locality 17	—	2.658
						O-16 Average = 2.64%
26	SR-1	Hunt	0.397	Barnsdall 1-Hielbron	860-1000	1.451
27	SR-1	Hunt	0.757	Barnsdall 1-Hielbron	860-1000	1.518
28	SR-1	Hunt	1.065	Barnsdall 1-Hielbron	860-1000	1.305
29	SR-1	Hunt	1.299	Barnsdall 1-Hielbron	860-1000	0.823
						SR-1 Average = 1.27%
30	SR-2	Red River	0.417	Hinton 1-Pryor	566-721	0.659
31	SR-2	Red River	0.634	Hinton 1-Pryor	566-721	0.771
32	SR-2	Red River	0.931	Hinton 1-Pryor	566-721	0.683
33	SR-2	Red River	1.111	Hinton 1-Pryor	566-721	0.611
						SR-2 (upper) Average = 0.68%
34	SR-2	Red River	0.301	Hinton 1-Pryor	875-1000	2.452
35	SR-2	Red River	0.793	Hinton 1-Pryor	875-1000	1.081
36	SR-2	Red River	1.029	Hinton 1-Pryor	875-1000	0.888
37	SR-2	Red River	1.223	Hinton 1-Pryor	875-1000	1.567
						SR-2 (lower) Average = 1.49%
						SR-2 Average = 1.09%
38	SR-3	Lamar	0.387	Kamann 1-Bywater	855-880	1.047
39	SR-3	Lamar	0.557	Kamann 1-Bywater	855-880	0.968
40	SR-3	Lamar	1.060	Kamann 1-Bywater	855-880	0.918
						SR-3 (upper) Average = 0.977%
41	SR-3	Lamar	0.343	Kamann 1-Bywater	920-980	1.267
42	SR-3	Lamar	0.756	Kamann 1-Bywater	920-980	1.436
43	SR-3	Lamar		Kamann 1-Bywater	920-980	

Sample No.	Sample Local.	County	Sample Wt. (grams)	Well Name/Outcrop	Depth Interval	% Carbon
			1.183			1.052
						SR-3 (lower) Average = 1.255%
						SR-3 Average = 1.116%
44	SR-4	Tyler	0.452	Humble 1-Howell	14767	0.9353
45	SR-4	Tyler	0.685	Humble 1-Howell	14767	0.9303
46	SR-4	Tyler	1.162	Humble 1-Howell	14767	0.9108
						SR-4 (14767) Average = 0.925%
47	SR-4	Tyler	0.468	Humble 1-Howell	14803	1.373
48	SR-4	Tyler	0.709	Humble 1-Howell	14803	1.220
49	SR-4	Tyler	1.141	Humble 1-Howell	14803	1.342
						SR-4 (14803) Average = 1.31%
50	SR-4	Tyler	0.389	Humble 1-Howell	14816	1.976
51	SR-4	Tyler	0.723	Humble 1-Howell	14816	2.177
52	SR-4	Tyler	1.206	Humble 1-Howell	14816	2.227
						SR-4 (14816) Average = 2.127%
						SR-4 Average = 1.45%
53	SR-5	Rockwall	0.335	Riek 1-Whilden	1430	1.069
54	SR-5	Rockwall	0.681	Riek 1-Whilden	1430	1.188
55	SR-5	Rockwall	1.240	Riek 1-Whilden	1430	1.112
						SR-5 (upper) Average = 1.12%
56	SR-5	Rockwall	0.446	Riek 1-Whilden	1585	1.190
57	SR-5	Rockwall	0.799	Riek 1-Whilden	1585	1.132
58	SR-5	Rockwall	1.085	Riek 1-Whilden	1585	1.234
						SR-5 (middle) Average = 1.19%
59	SR-5	Rockwall	0.391	Riek 1-Whilden	1605	2.461
60	SR-5	Rockwall	0.791	Riek 1-Whilden	1605	0.6604
61	SR-5	Rockwall	1.500	Riek 1-Whilden	1605	1.070
						SR-5 (lower) Average = 1.397%
						SR-5 Average = 1.24%
62	SR-6	Cass	0.385	Arkansas 1-Duncan	3150-3330	0.7928
63	SR-6	Cass	0.7360	Arkansas 1-Duncan	3150-3330	0.7117
64	SR-6	Cass	1.169	Arkansas 1-Duncan	3150-3330	0.7143
						SR-6 Average = 0.7396%
65	SR-7	Wood	0.408	Ace 1-Winchester	4600-4650	1.081
66	SR-7	Wood	0.872	Ace 1-Winchester	4600-4650	0.9954
67	SR-7	Wood	1.170	Ace 1-Winchester	4600-4650	0.9555
						SR-7 (upper) Average = 1.011%
68	SR-7	Wood	0.456	Ace 1-Winchester	4700-4750	0.9983
69	SR-7	Wood	0.853	Ace 1-Winchester	4700-4750	1.005
70	SR-7	Wood	1.149	Ace 1-Winchester	4700-4750	0.9943
						SR-7 (middle) Average = 0.999%
71	SR-7	Wood		Ace 1-Winchester	4800-4850	

Sample No.	Sample Local.	County	Sample Wt. (grams)	Well Name/Outcrop	Depth Interval	% Carbon
			0.437			0.9557
72	SR-7	Wood	0.967	Ace 1-Winchester	4800-4850	0.8894
73	SR-7	Wood	1.353	Ace 1-Winchester	4800-4850	0.9026
						SR-7 (lower) Average = 0.9159%
						SR-7 Average = 0.97%
74	SR-8	Morris	0.376	Coats 1-Reese	2395-2485	0.8442
75	SR-8	Morris	0.770	Coats 1-Reese	2395-2485	0.8450
76	SR-8	Morris	1.155	Coats 1-Reese	2395-2485	0.8112
						SR-8 (upper) Average = 0.8335%
77	SR-8	Morris	0.375	Coats 1-Reese	2530-2605	0.8665
78	SR-8	Morris	0.772	Coats 1-Reese	2530-2605	0.7518
79	SR-8	Morris	1.112	Coats 1-Reese	2530-2605	0.753
						SR-8 (lower) Average = 0.79%
						SR-8 Average = 0.81%
80	SR-9	Henderson	0.426	Am. Liberty 1-Larve	5190-5250	1.009
81	SR-9	Henderson	0.898	Am. Liberty 1-Larve	5190-5250	0.9809
82	SR-9	Henderson	1.372	Am. Liberty 1-Larve	5190-5250	0.8070
						SR-9 Average = 0.93%
83	SR-10	Fannin	0.557	City of Trenton 1-W.W.	429-613	8.119%
84	SR-11	Delta	0.437	Freedman 1-Deering	1870-2020	0.9226
85	SR-11	Delta	0.853	Freedman 1-Deering	1870-2020	1.132
86	SR-11	Delta	1.314	Freedman 1-Deering	1870-2020	1.667
						SR-11 (upper) Average = 1.24%
87	SR-11	Delta	0.447	Freedman 1-Deering	2210-2390	0.9839
88	SR-11	Delta	0.883	Freedman 1-Deering	2210-2390	1.009
89	SR-11	Delta	1.310	Freedman 1-Deering	2210-2390	1.138
						SR-11 (lower) Average = 1.04%
						SR-11 Average = 1.14%
90	SR-12	Anderson	0.424	Killam 1-McKee	4890-4950	0.891
91	SR-12	Anderson	0.773	Killam 1-McKee	4890-4950	0.808
92	SR-12	Anderson	1.511	Killam 1-McKee	4890-4950	0.549
						SR-12 (upper) Average = 0.749%
93	SR-12	Anderson	0.398	Killam 1-McKee	5010-5100	0.928
94	SR-12	Anderson	0.977	Killam 1-McKee	5010-5100	0.732
						SR-12 (middle) Average = 0.897%
95	SR-12	Anderson	0.418	Killam 1-McKee	5175-5230	0.977
96	SR-12	Anderson	0.852	Killam 1-McKee	5175-5230	0.956
97	SR-12	Anderson	1.291	Killam 1-McKee	5175-5230	1.172
						SR-12 (lower) Average = 1.035%
						SR-12 Average = 0.90%
98	SR-13	Hunt	0.384	Humble 1-Anderson	1549-1701	1.775
99	SR-13	Hunt	0.761	Humble 1-Anderson	1549-1701	1.525

Sample No.	Sample Local.	County	Sample Wt. (grams)	Well Name/Outcrop	Depth Interval	% Carbon
100	SR-13	Hunt	1.336	Humble 1-Anderson	1549-1701	2.825
						SR-13 (upper) Average = 2.04%
101	SR-13	Hunt	0.405	Humble 1-Anderson	1828-1980	1.106
102	SR-13	Hunt	0.830	Humble 1-Anderson	1828-1980	1.035
103	SR-13	Hunt	1.262	Humble 1-Anderson	1828-1980	1.121
						SR-13 (lower) Average = 1.09%
						SR-13 Average = 1.56%
104	SR-14	Hopkins	0.330	Shell 1-Hedrick	2290-2440	1.281
105	SR-14	Hopkins	0.917	Shell 1-Hedrick	2290-2440	0.9781
106	SR-14	Hopkins	1.254	Shell 1-Hedrick	2290-2440	0.9477
						SR-14 (upper) Average = 1.07%
107	SR-14	Hopkins	0.451	Shell 1-Hedrick	2590-2740	1.013
108	SR-14	Hopkins	0.827	Shell 1-Hedrick	2590-2740	0.9042
109	SR-14	Hopkins	1.179	Shell 1-Hedrick	2590-2740	0.8177
						SR-14 (lower) Average = 0.91%
						SR-14 Average = 0.99%
110	SR-15	Franklin	0.256	Byars 1-Clifton	3100-3260	15.74
111	SR-15	Franklin	0.640	Byars 1-Clifton	3100-3260	11.35
112	SR-15	Franklin	1.224	Byars 1-Clifton	3100-3260	4.493
						SR-15 (upper) Average = 10.53%
113	SR-15	Franklin	0.411	Byars 1-Clifton	3367-3547	0.893
114	SR-15	Franklin	0.582	Byars 1-Clifton	3367-3547	2.538
115	SR-15	Franklin	1.240	Byars 1-Clifton	3367-3547	1.432
						SR-15 (lower) Average = 1.62%
						SR-15 Average = 6.07%
116	SR-16	Cherokee	0.511	Humble 1-Maness	5820-5940	1.040
117	SR-16	Cherokee	0.882	Humble 1-Maness	5820-5940	2.251
118	SR-16	Cherokee	1.222	Humble 1-Maness	5820-5940	2.667
						SR-16 (upper) Average = 1.98%
119	SR-16	Cherokee	0.465	Humble 1-Maness	6030-6150	1.385
120	SR-16	Cherokee	0.882	Humble 1-Maness	6030-6150	1.757
121	SR-16	Cherokee	1.217	Humble 1-Maness	6030-6150	2.479
						SR-16 (lower) Average = 1.87%
						SR-16 Average = 1.93%
122	SR-17	Cherokee	0.377	Humble 1-Martin	4315-4328	0.876
123	SR-17	Cherokee	0.578	Humble 1-Martin	4315-4328	0.956
124	SR-17	Cherokee	1.217	Humble 1-Martin	4315-4328	0.857
						SR-17 Average = 0.90%
125	SR-18	Kaufman	0.333	Atlantic Ref. 1-Griffith	3240-3280	0.974
126	SR-18	Kaufman	0.770	Atlantic Ref. 1-Griffith	3240-3280	1.229
127	SR-18	Kaufman	1.150	Atlantic Ref. 1-Griffith	3240-3280	1.205

Sample No.	Sample Local.	County	Sample Wt. (grams)	Well Name/Outcrop	Depth Interval	% Carbon
						SR-18 (upper) Average = 1.14%
128	SR-18	Kaufman	0.389	Atlantic Ref. 1-Griffith	3350-3380	1.393
129	SR-18	Kaufman	0.733	Atlantic Ref. 1-Griffith	3350-3380	1.264
130	SR-18	Kaufman	1.234	Atlantic Ref. 1-Griffith	3350-3380	1.318
						SR-18 (middle) Average = 1.33%
131	SR-18	Kaufman	0.410	Atlantic Ref. 1-Griffith	3470-3480	1.857
132	SR-18	Kaufman	0.743	Atlantic Ref. 1-Griffith	3470-3480	1.144
133	SR-18	Kaufman	1.241	Atlantic Ref. 1-Griffith	3470-3480	1.327
						SR-18 (lower) Average = 1.44%
						SR-18 Average = 1.30%
134	SR-19	Wood	0.488	Humble 1-Robinson	4409	1.027
135	SR-19	Wood	0.927	Humble 1-Robinson	4409	0.958
136	SR-19	Wood	1.242	Humble 1-Robinson	4409	0.962
						SR-19 Average = 0.98%
137	SR-20	Smith	0.485	Arkansas Fuel 1-Marsh	3470	1.012
138	SR-20	Smith	0.927	Arkansas Fuel 1-Marsh	3470	0.9586
139	SR-20	Smith	1.255	Arkansas Fuel 1-Marsh	3470	1.172
						SR-20 Average = 1.03%
140	SR-21	Navarro	0.395	Collins 1-Green Lee	1402-1591	0.857
141	SR-21	Navarro	0.780	Collins 1-Green Lee	1402-1591	0.748
142	SR-21	Navarro	1.186	Collins 1-Green Lee	1402-1591	0.7632
						SR-21 (upper) Average = 0.77%
143	SR-21	Navarro	0.378	Collins 1-Green Lee	1741-1892	0.813
144	SR-21	Navarro	0.673	Collins 1-Green Lee	1741-1892	0.803
145	SR-21	Navarro	1.186	Collins 1-Green Lee	1741-1892	0.6739
						SR-21 (lower) Average = 0.76%
146	SR-22	Lamar	0.464	Cooper Bros. 1-Hays	1126-1217	0.882
147	SR-22	Lamar	0.972	Cooper Bros. 1-Hays	1126-1217	0.845
148	SR-22	Lamar	1.238	Cooper Bros. 1-Hays	1126-1217	0.822
						SR-22 Average = 0.85%
149	SR-23	Rains	0.440	Humble 1-Mainord	4140-4260	1.179
150	SR-23	Rains	0.767	Humble 1-Mainord	4140-4260	1.53
151	SR-23	Rains	1.269	Humble 1-Mainord	4140-4260	1.328
						SR-23 (upper) Average = 1.34%
152	SR-23	Rains	0.396	Humble 1-Mainord	4320-4440	1.421
153	SR-23	Rains	0.890	Humble 1-Mainord	4320-4440	1.361
154	SR-23	Rains	1.325	Humble 1-Mainord	4320-4440	1.117
						SR-23 (lower) Average = 1.30%
						SR-23 Average = 1.32%
155	SR-24	Titus	0.430	Coats 1-Scott Lizzie	3030-3090	0.9138

Sample No.	Sample Local.	County	Sample Wt. (grams)	Well Name/Outcrop	Depth Interval	% Carbon
156	SR-24	Titus	0.766	Coats 1-Scott Lizzie	3030-3090	0.7381
157	SR-24	Titus	1.538	Coats 1-Scott Lizzie	3030-3090	0.6087
						SR-24 (upper) Average = 0.75%
158	SR-24	Titus	0.307	Coats 1-Scott Lizzie	3120-3170	0.828
159	SR-24	Titus	0.746	Coats 1-Scott Lizzie	3120-3170	0.7907
160	SR-24	Titus	1.355	Coats-Scott Lizzie	3120-3170	1.044
						SR-24 (middle) Average = 0.89%
161	SR-24	Titus	0.461	Coats 1-Scott Lizzie	3230-3295	0.999
167	SR-24	Titus	0.642	Coats 1-Scott Lizzie	3230-3295	0.9282
168	SR-24	Titus	1.127	Coats 1-Scott Lizzie	3230-3295	0.9022
						SR-24 (lower) Average = 0.94%
						SR-24 Average = 0.86%

APPENDIX IV
CALCULATIONS: POTENTIAL OIL GENERATED

PROCEDURE

The following procedure was adapted from Bishop et al. (1984, p. 44) for estimating kerogen quantity in a petroleum-generative province as an indicator of volume of oil generated (Fig. 24). The equation used is:

$$\text{Kerogen Quantity} = \text{Drainage Area} \times \text{Effective Source-Rock Thickness} \times \text{Residual T.O.C.}$$

An average of 1% T.O.C. was used for all calculations.

A conversion factor of 6 ft^3 = 1 barrel of oil was used for the final answer.

Province	Thickness (ft)	Area (mi^2)	Area (ft^2)	Residual Carbon	Kerogen Quantity (ft^3)
a.	400	462.4	1.3×10^{10}	1%	5.1×10^{10}
b.	500	1329.6	3.7×10^{10}	1%	1.8×10^{11}
c.	600	876.8	2.4×10^{10}	1%	1.5×10^{11}
d.	700	65.6	1.8×10^{9}	1%	1.3×10^{10}
e.	400	1280.0	3.5×10^{10}	1%	1.4×10^{11}
f.	400	587.2	1.6×10^{10}	1%	6.5×10^{10}
g.	500	182.5	5.1×10^{10}	1%	2.5×10^{10}
h.	600	41.6	1.2×10^{9}	1%	6.9×10^{9}
i.	700	57.6	1.6×10^{9}	1%	1.1×10^{10}
j.	300	9632.0	2.7×10^{11}	1%	8.0×10^{11}
k.	400	1856.0	5.2×10^{10}	1%	2.1×10^{11}
l.	200	7088.0	2.0×10^{11}	1%	4.0×10^{11}
m.	100	8960.0	2.5×10^{11}	1%	2.5×10^{11}
n.	50	4032.0	1.1×10^{11}	1%	5.6×10^{10}
o.	50	1056.0	2.9×10^{10}	1%	1.4×10^{10}
p.	50	896.0	2.5×10^{10}	1%	1.2×10^{10}
					Total = 2.4×10^{12}

$2.4 \times 10^{12}\ ft^3 \div 6\ ft^3/\text{barrel} = 4.0 \times 10^{11}$ barrels
or 400 billion barrels

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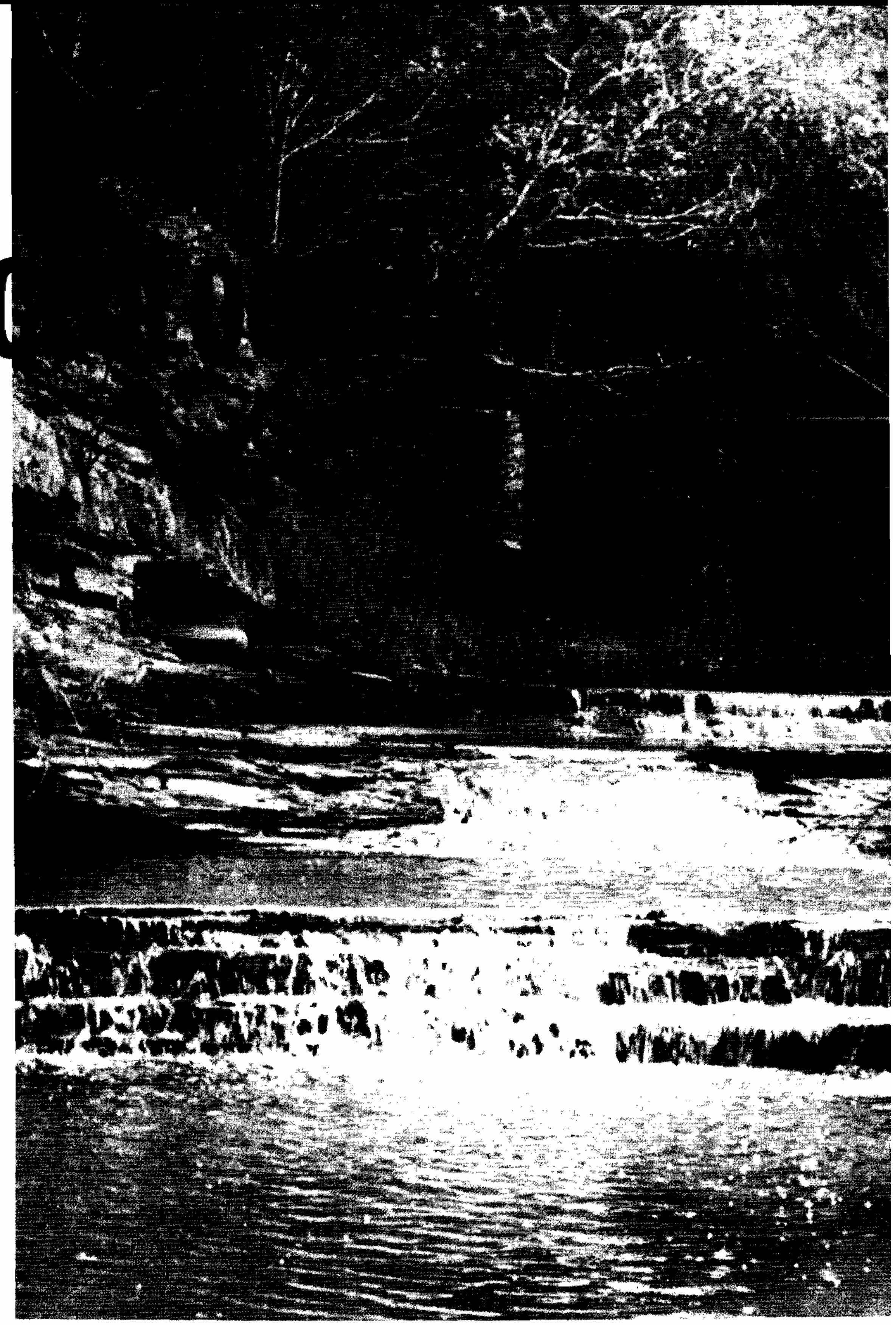

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Stratigraphy of the Eagle Ford Group (Upper Cretaceous) and Its Source-Rock Potential in the East Texas Basin

MILTON A. SURLES, JR.