BUREAU OF ECONOMIC GEOLOGY

Geological Circular 70-4

Depositional Systems in the Jackson Group of Texas -- Their Relationship to Oil, Gas, and Uranium

By
W. L. Fisher
C. V. Proctor, Jr.
W. E. Galloway
J. S. Nagle

REPRINTED FROM TRANSACTIONS OF THE
GULF COAST ASSOCIATION OF GEOLOGICAL SOCIETIES
VOL. XX, 1970

The University of Texas at Austin
October 1970

DEPOSITIONAL SYSTEMS IN THE JACKSON GROUP OF TEXAS

Their Relationship to Oil Gas, and Uranium[1]

W. L. Fisher
Bureau of Economic Geology
The University of Texas at Austin

W. E. Galloway[2]
Bureau of Economic Geology
The University of Texas at Austin

Cleo V. Proctor, Jr.
Bureau of Economic Geology
The University of Texas at Austin

J. S. Nagle[3]
Bureau of Economic Geology
The University of Texas at Austin

ABSTRACT

Five main depositional systems of the Jackson Group in Texas are delineated through regional outcrop and subsurface investigation. Dominant element in the central and eastern Texas Gulf Basin is the Fayette fluvial-delta system (bounded by Guadalupe River on the south and Neches River on the east) consisting of dip-oriented, lobate wedges of sands, muds, and lignites. Vertical sequence in updip subsurface and outcrop grades upward from marine muds through delta facies into fluvial sands and muds, reflecting net regression and progradation of the system. Longshore drift of sediments from the delta system contributed to the South Texas strandplain-barrier bar system, consisting of strike-trending sand bodies interbedded with marine and lagoonal muds. Landward of the strandplain-barrier bar system and extending into outcrop is a lagoonal-coastal plain system consisting of muds, local lignites, and minor, dip-oriented channel sand units. Gulfward of the strike-trending strandplain system is the South Texas shelf system, formed of marine muds derived largely from the delta system to the northeast. Beneath the South Texas strandplain-barrier bar and Fayette delta systems and extending eastward into Louisiana and Mississippi is the Yazoo-Moodys Branch shelf system consisting of marine, fossiliferous muds and minor glauconitic marls. Texas Jackson delta and associated systems are comparable to depositional systems of other Eocene units (Lower Wilcox and Yegua) of the Gulf Basin as well as the Holocene Mississippi delta and related systems of the northwestern Gulf of Mexico. Delineation of depositional systems and component facies facilitates definition of significant mineral trends (oil, gas, lignite, and uranium) that show the relationship between existing and potential areas of production.

INTRODUCTION

The Jackson Group (Upper Eocene) is one of the minor terrigenous clastic wedges of the western Gulf of Mexico Basin, with main clastic accumulation in the Texas and northern Mexico parts of the Basin. In Texas, the Jackson is an important group of rocks, providing reservoirs for oil, gas, and water, as well as deposits of uranium, lignite, and bentonitic clays.

Area of study includes approximately 25,000 square miles extending from the Sabine River on the east to the Rio Grande on the south in a 60-mile-wide belt extending from outcrop downdip through available subsurface control. Approximately 700 electric logs were utilized, supplemented by lithologic control from outcrop descriptions and samples from strategically located wells. Forty-two dip sections, spaced at intervals of 8 to 12 miles, depending on density of control, and two strike sections were prepared to determine three-dimensional relationship of main lithologic units.

The Jackson Group, as defined in this study, includes the section from the top of the Yegua to the base of the Catahoula Formations. In South Texas, a thin clay unit below the Catahoula in outcrop and shallow subsurface, commonly designated the Frio Clay (or less commonly, Yeager Formation) was also included in the Jackson Group. Base of Caddell marine muds or Moodys Branch glauconitic marls (where developed) served as datum in constructing dip and strike sections.

Stratigraphic terminology employed is informal, utilizing the concept of depositional systems as in previous studies of the Gulf Basin Wilcox Group (Fisher and McGowen, 1967; Fisher, 1969; Galloway, 1968) and the Eastern Shelf Upper Paleozoic Cisco Group (Brown, 1969a, 1969b; Galloway, 1970). Emphasis is placed on geometry, composition, distribution, and integration of specific facies with designation of genetic terms (*e. g.*, delta system, strandplain system) as judged by analogy to certain modern, process-defined facies and systems. Such informal genetic units are compared with previously established formal stratigraphic units in the Texas Jackson. The term Jackson as generally used is defined by foraminiferal zones (particularly in gulfward or downdip sections), or in most cases implies little more than the interval between the Catahoula above and Yegua below. Attempts have been made to specify usage as a rock unit (Jackson) and as a time stratigraphic unit (Jacksonian) (Murray and Wilbert, 1950). Formal stratigraphic nomenclature and definition of considered units are beyond the intent of this paper.

We thank L. F. Brown, Jr., Josephine Casey, P. T. Flawn, J. H. McGowen, and P. U. Rodda, Bureau of Economic Geology, The University of Texas at Austin, for critical reading of the manuscript. Well logs were supplied

[1]Publication authorized by the Director, Bureau of Economic Geology, The University of Texas at Austin.

[2]Present address: Continental Petroleum Company, Ponca City, Oklahoma.

[3]Present address: 711 Houston Club Building, Houston, Texas.

by the Texas Water Development Board and numerous Gulf Basin operators. During the course of this and other studies in the Texas Gulf Basin we have benefited from discussion with numerous working geologists, especially oil, gas, and uranium explorationists. Illustrations were prepared under direction of J. W. Macon, Bureau of Economic Geology, The University of Texas at Austin. E. T. Moore typed the manuscript.

PRINCIPAL DEPOSITIONAL SYSTEMS

Five main depositional systems make up the Jackson Group of Texas (Figs. 1a, 1b). Dominant element in the central and East Texas Gulf Basin is the Fayette fluvial-delta system consisting of lobate wedges of sand, mud, and lignite. Vertical sequence in outcrop and shallow subsurface, grading from marine muds upward through several delta facies into fluvial sands and muds, reflects the net regression and progradation of this system.

Southwestward transport of sands from the delta system, principally by longshore drift, produced the South Texas strandplain-barrier bar system, made up predominantly of strike-trending sand bodies interbedded with and bounded by marine and lagoonal muds. Updip and landward of the strandplain-barrier bar system and extending into outcrop, a complementary lagoonal-coastal plain system developed, made up chiefly of muds with local minor sand units. Gulfward of the strike-trending strandplain system is the South Texas shelf system, consisting of marine muds derived from the delta system to the northeast. East of the Fayette delta system and extending into Louisiana and Mississippi, as well as westward beneath the delta and strandplain systems, is the Yazoo-Moodys Branch shelf system, consisting of marine, fossiliferous muds and minor glauconitic marls.

Fayette Fluvial-Delta System

The Fayette fluvial-delta system includes most of the Jackson in the central and eastern Texas parts of the Gulf Basin. It extends in outcrop from western Fayette northeastward to south-central Angelina Counties, and in subsurface chiefly in the area between the Guadalupe River on the west and the Neches River on the east (Fig. 1a). The system has an areal extent of about 10,000 square miles. It ranges in thickness from about 600 feet in updip areas to about 1,200 feet in downdip sections.

Five major facies make up the Fayette system as here defined. These include (1) fluvial facies, largely coextensive with the Whitsett Formation as mapped and utilized by Renick (1936); (2) delta-plain facies, including most of the Manning Formation also as considered by Renick; (3) delta-front facies, including outcrop sands of the central and eastern Texas Wellborn Formation; (4) prodelta facies, including in outcrop most of the muds of the Caddell Fromation; and (5) interdeltaic facies, or sequences between main delta lobes, characterized by locally persistent sand units such as the Yuma, Tuttle, and Bedias. All fluvial and deltaic facies are developed in outcrop. The vertical sequence of the Jackson of this part of the basin reflects the net regression and progradation of the system (Fig. 2). Downdip, fluvial facies grade to delta-plain facies, delta-plain facies grade to delta-front sands, and delta-front sands grade to prodelta muds. Interdeltaic facies are developed along strike of the delta plain and delta-front facies (Fig. 2).

Fluvial Facies

Fluvial facies of the Fayette system consist chiefly of gray to buff, fine- to medium-grained, commonly tuffaceous sands. Sedimentary structures include moderate to large-scale trough or festoon cross-beds, small- to moderate-scale tabular cross-beds, and current-ripple marks and cross laminations. Woody materials, in the form of lignitic fragments and silicified logs, and angular mud or clay clasts are common within the sands. Associated muds are mostly gray to dark brown and generally carbonaceous or lignitic; bedded lignites are rare. Ash beds and tuffs occur locally in this facies of the Jackson.

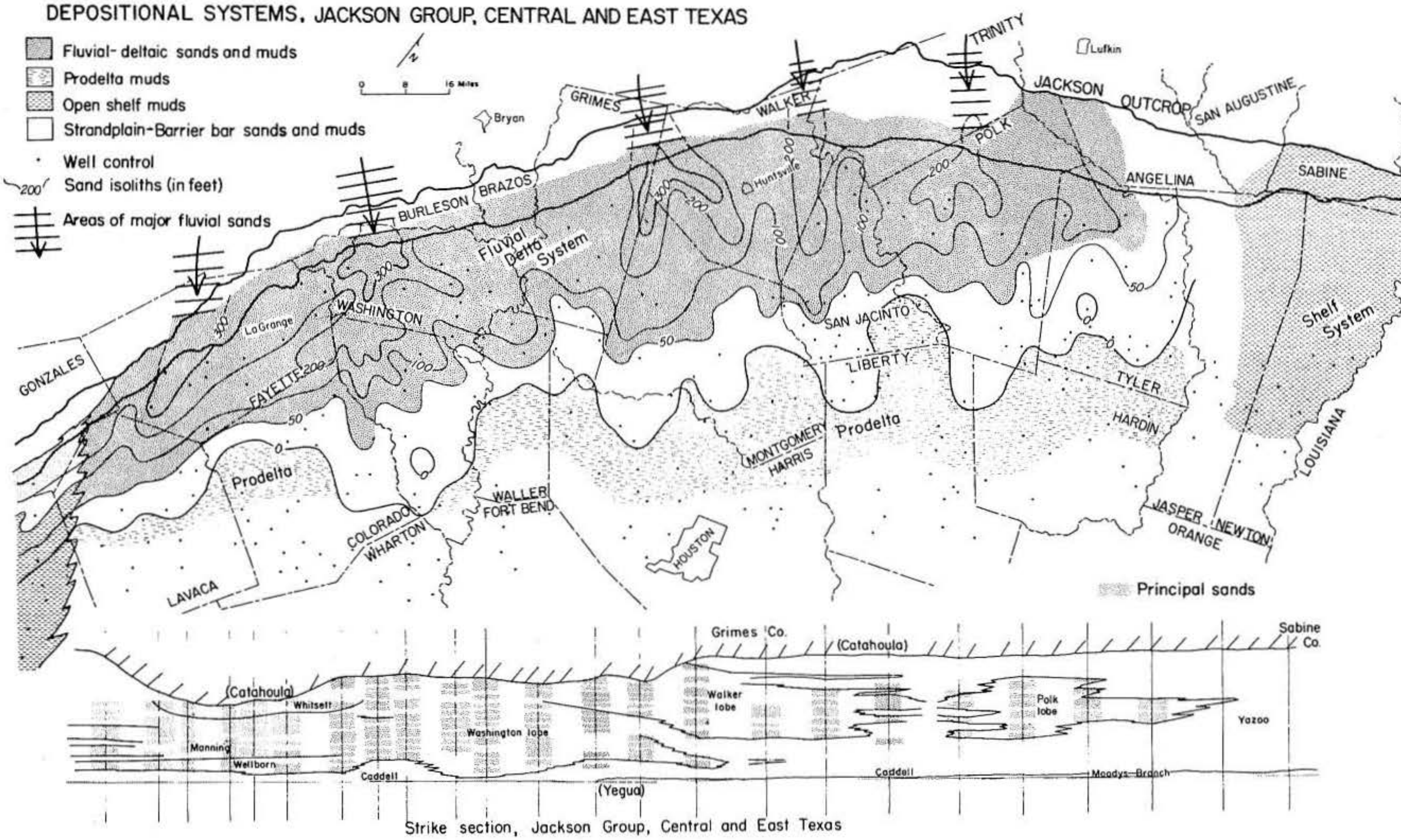
The fluvial facies of the Fayette system is largely coextensive with the Whitsett Formation as mapped and defined by Renick (1936), but not the Whitsett as generally defined in South Texas (Eargle, 1959a), nor elsewhere as defined by Ellisor (1933). It ranges in thickness from about 75 to nearly 200 feet. Individual sands attain maximum thickness of about 40 feet; they are commonly overlain by thin units of laminated, carbonaceous, or tuffaceous muds. Thicker sands form channel-shaped bodies with downward convex bases; maximum scouring is on the order of 30 feet. In vertical sequence, sand units become progressively finer in texture and thinner in bedding, grading to thin, laminated muds. The sharp basal contact and upward gradation in texture and bedding are reflected in E-log patterns of these sands, marked by a sharp basal deflection with progressively less deflection vertically. These features are shown on resistivity rather than S. P. profiles since the sands are generally charged with fresh water (Figs. 3 and 4).

The fluvial facies of the Fayette system crops out as discontinuous belts from central Fayette to eastern Trinity Counties. It can be traced downdip for about 20 miles along main axes of progradation and for shorter distances in intervening areas (Figs. 1a, 3). The facies forms a more or less continuous unit along strike but with maximum thickness and maximum development of sands in areas along axes of principal progradational deltaic lobes. Orientation of main sand bodies is parallel to dip.

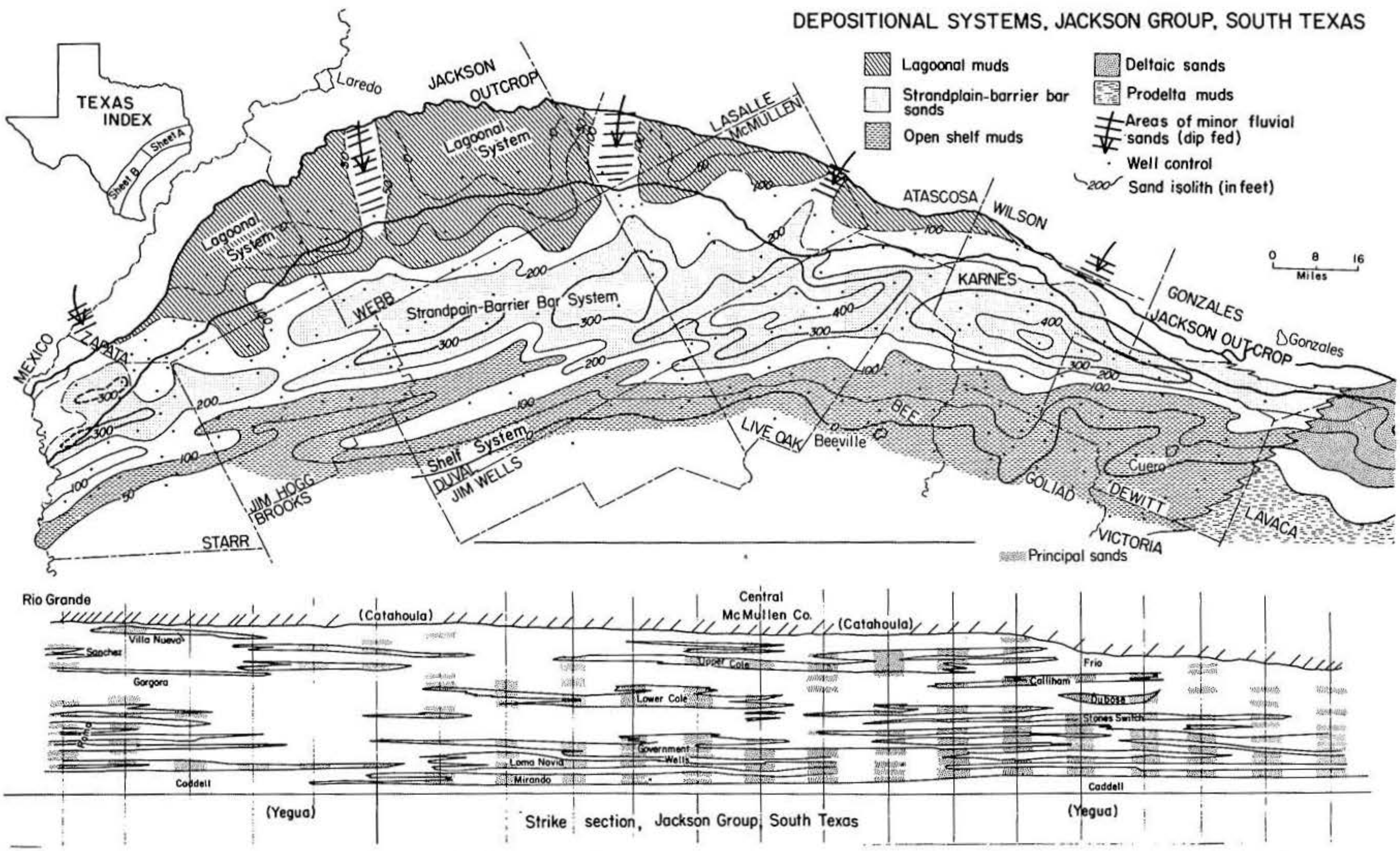
Vertical textural trends, elongate shape and trend, sedimentary structures and relationship to other facies within the system suggest that sands of this facies of the Jackson were deposited by highly sinuous streams as fine-grained meander belt deposits (*see* McGowen and Garner, 1970). The laminated carbonaceous and tuffaceous muds were deposited in overbank environments. These facies are similar to fluvial facies developed updip of delta systems in the Wilcox and Yegua of the Texas Gulf Coast Basin (Fisher and McGowen, 1967, 1969; Fisher, 1969).

Delta-Plain Facies

The delta-plain facies of the Fayette system consists of alternating sands, muds, and lignites (Fig. 2). Main sands are mostly fine grained, trough cross-bedded, and discontinuous. Individual sands are up to 50 feet in



1a. Principal depositional systems and strike profile, Jackson Group, central and eastern Texas Gulf Basin. Strike profile drawn along axis of maximum sand thickness. Figure overlaps with figure 1b.



1b. Principal depositional systems and strike profile, Jackson Group, South Texas. Strike profile drawn along axis of maximum sand thickness. Figure overlaps with figure 1a.

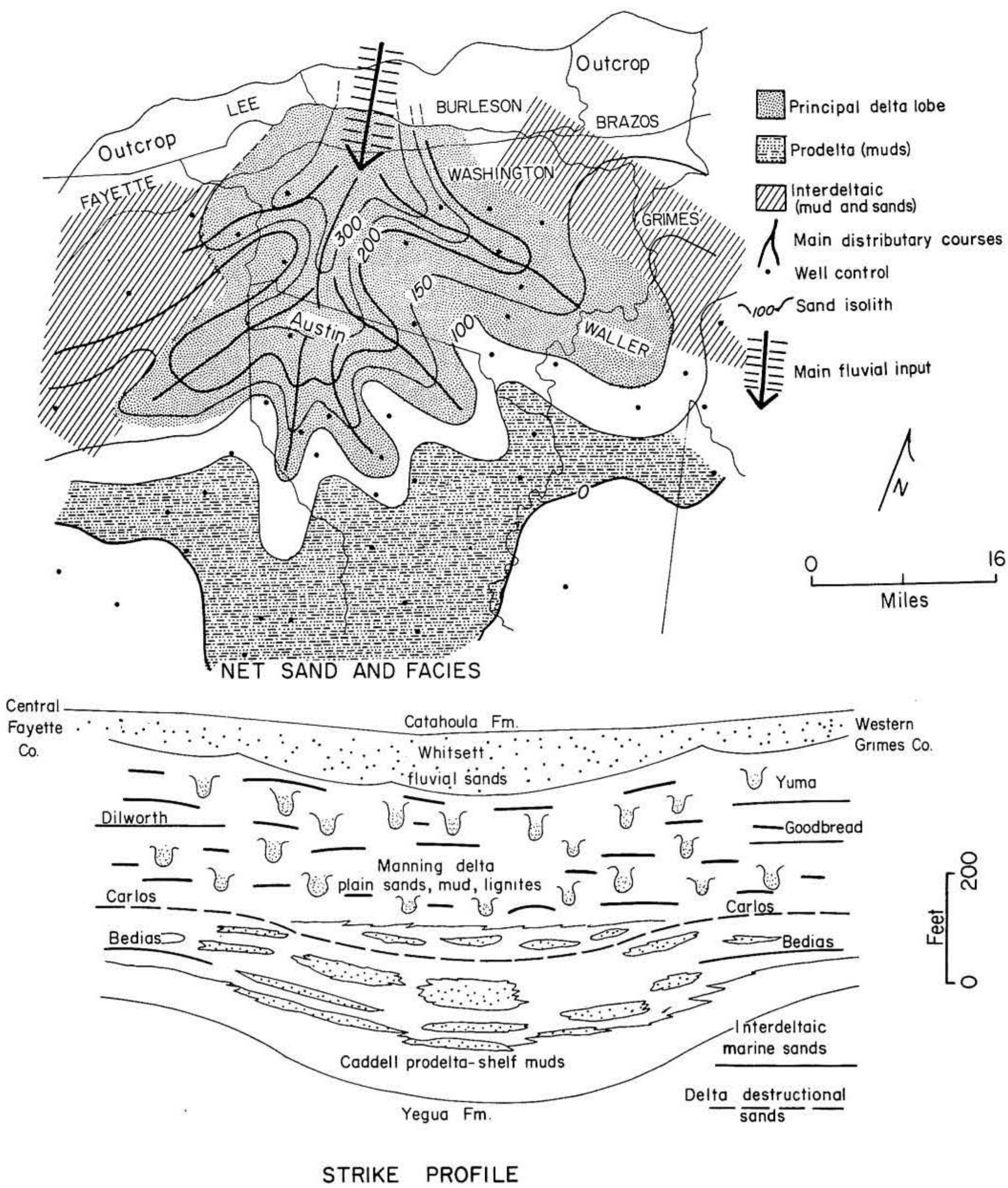
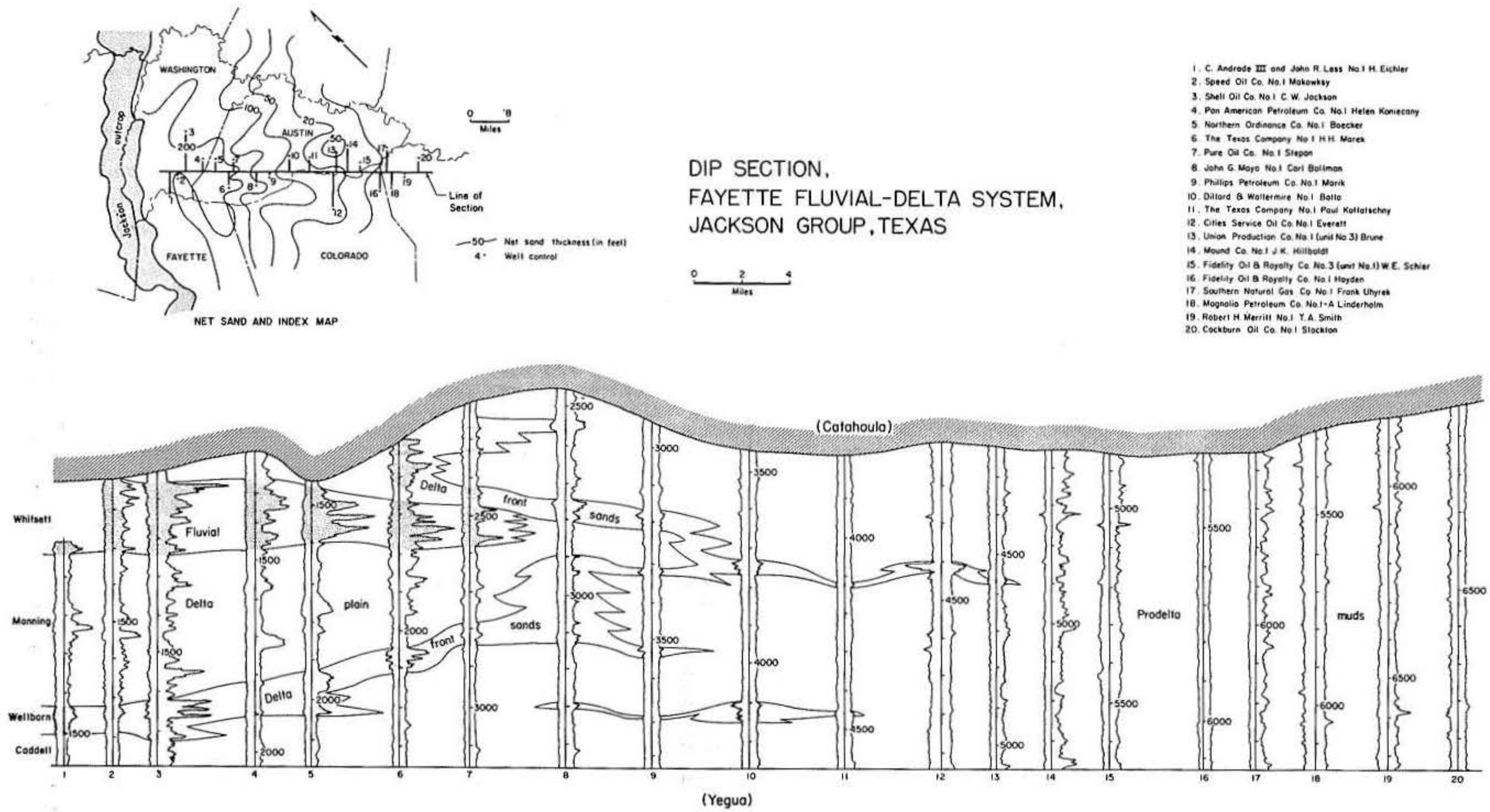
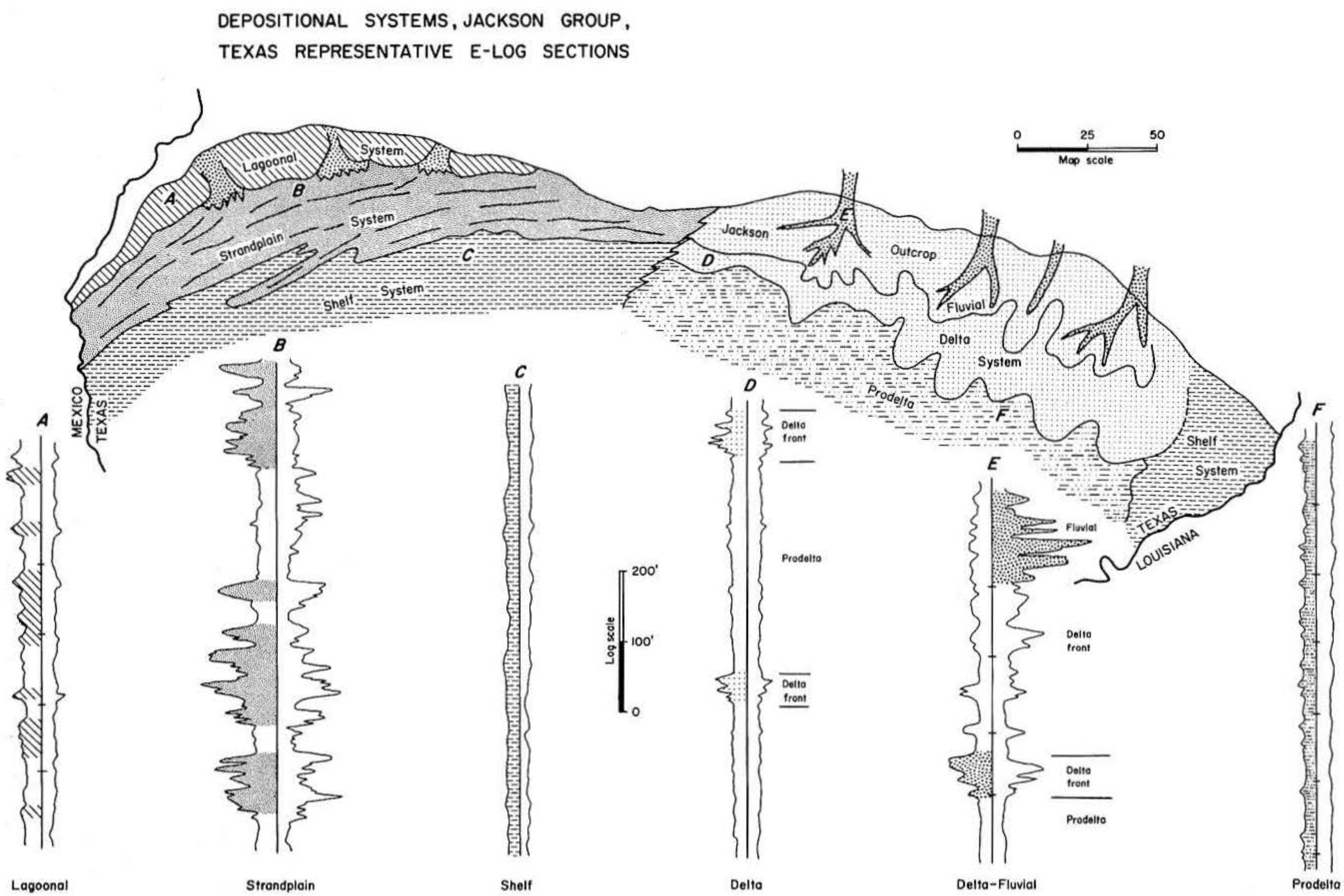


Figure 2. Net sand and diagrammatic subcrop strike section, Washington lobe, Fayette fluvial-delta system, Jackson Group, central Texas Gulf Basin.



3. Dip section, Fayette fluvial-delta system, Jackson Group, central Texas Gulf Basin. Net sand and index map from figure 1a.



4. Representative E-logs and log patterns of principal depositional systems and component facies, Jackson Group, Texas.

thickness, have a more nearly symmetrical channel cross-section than fluvial sands, and display an elongate distributary pattern in plan. Sands make up about 30 percent of the delta-plain facies in contrast to about 70 percent of the fluvial facies. Muds of the delta plain are chiefly thin bedded and laminated, dark gray, and carbonaceous. A third important and characteristic rock of this facies is lignite, which occurs as numerous, discontinuous, tabular beds. Most individual seams are 1 to 3 feet thick but locally beds are up to 20 feet thick.

The delta-plain facies of the Fayette system is well developed in outcrop from central Fayette eastward to western Angelina County (Fig. 1a). In the central Texas part of the coastal plain, this facies is largely coextensive with the Manning Formation as mapped and described by Renick (1936) (Fig. 2). The facies ranges in thickness from about 400 feet in outcrop and updip subsurface sections to about 200 feet downdip (Fig. 3) as it grades to marine, more distal delta facies (delta front and prodelta). Areas of maximum thickness occur along the axes of main deltaic progradation (Fig. 1a).

Based on geometry, distribution, and association with other units, the thicker sands in the facies are interpreted as distributary channel sands. Muds of the facies accumulated in intervening floodbasins and interdistributary basins. The thin, poorly developed sands represent deposition outside the main channel, either as levee deposits or as crevasse splays. Composition, distribution, and association of this facies with fluvial and other delta facies are similar to those of the delta-plain facies of the Lower Wilcox and Yegua of the Texas Gulf Basin (Fisher and McGowen, 1967, 1969; Fisher, 1969; and Fisher *et al.,* 1969). Holocene analogues include the delta-plain facies of presently inactive lobate deltas of the Mississippi system of the northwestern Gulf of Mexico (Fisk, 1960; Frazier, 1967; Frazier and Osanik, 1969). All are characterized by extensive bedded lignite or peat deposits.

Delta-Front Facies

The delta-front facies of the Fayette system consists entirely of fine-grained moderate- to well-sorted, light tan to gray sands and silts. This facies includes the lower sands of the Jackson sequence mapped and described from outcrops as Wellborn by Renick (1936), Russell (1955), and Shelby (1965) (Fig. 2). In outcrop, these sands are distributed chiefly through the lower 150 feet of the Fayette but also occur locally at higher stratigraphic positions (*e. g.,* sands mapped as Tuttle and Yuma). In outcrop and updip subsurface sections, delta-front sands grade vertically to delta-plain sands, muds, and lignites (Fig. 2). They grade downward in outcrop and updip sections (Fig. 2) as well as gulfward and downdip into marine prodelta muds (Fig. 3). In downdip sections of the Fayette system, delta-front sands, alternating with marine muds, are distributed throughout the entire sequence.

Two basic sand units characterize the delta-front facies; moderately thick (up to 50 feet) cross-bedded sands and thin-bedded, flaggy sands 1/2 to 3 inches in thickness. The thicker sands grade both downward and laterally to the thin-bedded flaggy sands, which in turn grade to marine muds. The thicker sands are generally biconvex in cross section; bedding types include very low-angle cross-beds, a few small to moderate scale trough cross-beds, and locally high-angle foreset bedding. Delta-front sands commonly contain disseminated lignite or wood fragments. Thin-bedded sands and silts generally show either horizontal bedding or very low angle cross-bedding; flute casts are common. These sands grade laterally away from the thicker sand units to marine, locally fossiliferous muds. Upper parts of the thicker sand units of the delta-front facies commonly are burrowed, contain molluscan fragments and imprints, and are very slightly glauconitic (*see* later section on Interdeltaic and Delta Destructional Facies). Certain of the thicker delta-front sands in outcrop have been extensively cemented by opal or chalcedony. These hard, topographically resistant beds (Carlos, Bedias, Tuttle, Yuma, and other units) are useful in local key bed, outcrop mapping (Renick, 1936; Russell, 1955; Shelby, 1965).

The progradational log pattern (Fig. 4) shown by sands of this facies is typical of that shown by sand sequences interpreted as delta-front sands in other Gulf Basin Tertiary delta systems (Fisher, 1969). Characteristic feature is a vertical increase in S. P. deflection (so-called inverted Christmas tree profile) resulting from upward coarsening of texture, thickening of individual sand units, and increase in total sand content. Such features are typical of progradational sequences and contrast with the sharp bases of scour-bounded fluvial and distributary-channel sands (Fig. 4). In subcrop sections of this facies, sands are charged with fresh water; progradational nature is reflected to some extent by the resistivity profile. Thicknesses of individual delta-front sand sequences in the Fayette deltas reach a maximum of about 150 feet (Fig. 3).

Vertical sequence, internal structures, facies relationships (updip gradation to delta-plain facies, downdip gradation to and interfingering with marine muds), as well as sand trend and pattern, are the basis for interpretation of these sands as delta-front deposits. They developed at the debouching terminus of distributary channels. The thicker sands represent chiefly shoal-water, channel mouth bars, and the thinner sands are the distal and marginal units of the delta front. Comparable units occur in the delta front of Holocene Mississippi deltas (Frazier, 1967). In outcrop, the delta-front facies is developed in the lower part of the Jackson chiefly between central Fayette County on the west and eastern Angelina County on the east (Fig. 1a). Downdip for distances up to a maximum of about 40 miles from outcrop, this facies includes most of the sands of the Jackson section from about the Guadalupe River on the west to the Neches River on the east. Maximum downdip extent is along the main progradation axes of the Fayette deltas. Gulfward, the sands grade to marine muds (Figs. 1a, 3). In areas between main progradational lobes, downdip extent of this facies is on the order of 30 miles or less.

Prodelta Facies

The farthest downdip sections of the Jackson penetrated by wells consist of relatively uniform, thick sequences of gray to dark muds. These generally contain finely disseminated organic matter and show textural or color laminations. A few zones contain a relatively abundant marine fauna, particularly mollusks and foraminifers. These zones are generally burrowed and slightly glauconitic. Muds of the Jackson of the central Texas Gulf Basin grade updip and interfinger with delta-front sands (Fig. 3). These muds represent the prodelta facies of the Fayette deltas and were deposited from suspension load seaward of the river mouths. The laminated muds were deposited rapidly during periods of active delta progradation. The more fossiliferous, glauconitic, and burrowed units mark a return of open shelf conditions with a much slower rate of deposition during periods of local or regional delta abandonment and destruction.

The prodelta facies of the Fayette system includes most of the marine muds of the Jackson between the Guadalupe River on the southwest and the Neches River on the east (Fig. 1a). Maximum development of the facies is in the subsurface. In outcrop and updip subsurface sections, the facies includes the muds of the Caddell Formation (excluding basal glauconitic units or Moodys Branch where that unit is developed) and most of the muds interbedded with delta-front sands of the Wellborn. Thickness of the facies in these updip sections is about 100 feet. Downdip from the outcrop for distances of 15 to 20 miles, prodelta muds increase only slightly in thickness. At distances of about 20 to 40 miles downdip of outcrop, the Fayette system consists predominantly of prodelta muds alternating with delta-front sands. From distances of about 40 miles from outcrop downdip through existing well control, the Fayette system is made up entirely of prodelta muds. Maximum thickness of about 1,200 feet is reached in farthest downdip sections (Fig. 3). Typical log pattern of this facies reflects the uniform mud composition of the facies (Fig. 4). Well defined foraminiferal zones within this facies permit correlations with other marine mud systems and facies of the Jackson. Foraminiferal assemblages indicate progressively deeper water deposition in a gulfward direction (Stuckey, 1960).

Interdeltaic and Delta Destructional Facies

Several thin, fossiliferous marine units are associated with main constructional facies of the Fayette deltas. In outcrop these include parts of the Bedias, Carlos, Yuma, and Tuttle, as well as several unnamed units. Maximum areal extent and greatest frequency of occurrence of these rocks are in areas between the major progradational lobes (Figs. 1a, 2). A few lentils can be traced along strike for distances up to 50 miles, but most have a much more limited extent. Principal marine fossil is the burrow of the mud shrimp *Callinassa,* associated locally with a low-diversity molluscan assemblage, chiefly made up of small bivalves. Impressions of eel grass are common in certain of these units. In addition, a few beds are slightly glauconitic. They formed under conditions of slow or limited terrigenous deposition either in interdeltaic areas where sands were redistributed and locally strike-fed from the active progradational lobes by littoral drift, or as destructional or marine transgressive units over distal parts of progradational lobes upon abandonment or lateral shifting of individual lobes.

Individual Deltas in the Fayette System

Regional mapping of main progradational (delta front) and aggradational (delta plain and fluvial) sands defines three main deltas or deltaic lobes within the Fayette system (Fig. 1a). These include the Washington lobe, with principal axis extending downdip through south-central Burleson, western Washington, northern Austin, and the easternmost tip of Fayette Counties (Fig. 2). A secondary lobe, probably related to the Washington lobe, is in central Fayette County. A second major delta lobe--the Walker lobe--is developed in western Walker, eastern Grimes, and northern Montgomery Counties with a secondary lobe extending from eastern Walker County into the western part of San Jacinto County. The easternmost lobe of the Fayette system--the Polk lobe--is centered in northern Polk County with parts extending into eastern San Jacinto and northwestern Tyler Counties. Strike profiles (Fig. 1a) through the Fayette system indicate the Washington lobe is in part stratigraphically lower than the other lobes and probably represents initial progradation into the basin; also it is partly overlapped by progradation of the Walker lobe.

Average size of individual delta lobes in the Fayette system is approximately 1,200 square miles. Thickness of individual lobes, as presently mapped, averages about 600 feet in updip sections increasing to a maximum of 1,200 feet in downdip sections made up chiefly of prodelta muds. Maximum net sand thickness within individual lobes is about 300 feet.

Deltas of the Fayette system are similar in size, shape, and facies composition to lobate high-constructive deltas developed in the Eocene Lower Wilcox (Rockdale delta system) of Texas and the Holocene Mississippi delta system of the northwestern Gulf of Mexico (Frazier, 1967; Fisher and McGowen, 1967, 1969; Fisher, 1968, 1969). However, size, number of lobes, and total thickness of the Fayette system are significantly less than in the Rockdale system.

South Texas Systems

The Jackson of South Texas includes a group of depositional systems and an assemblage of facies markedly different from those of East and central Texas Gulf Basin. South of a line approximately along the Fayette-Gonzales County line in outcrop and extending in subsurface generally along the Gonzales-Lavaca and Lavaca-DeWitt County lines, the Fayette fluvial-delta system to the northeast grades to an extensive series of strike-oriented sand units (Fig. 1a, 1b). These sands, making up the South Texas strandplain-barrier bar system, grade updip and downdip to predominantly mud systems (South Texas lagoonal-coastal plain and shelf systems, respectively). Average thickness of the entire Jackson sequence in South Texas is about 1,100 feet, thinning slightly updip and northeastward (due partly to overlap and erosion by the overlying Catahoula) and thickening slightly downdip and along strike toward the Rio Grande.

South Texas Strandplain-Barrier Bar System

The South Texas strandplain-barrier bar system is developed over an area of about 7,000 square miles. It trends south-southwest through southern Gonzales and northern DeWitt, through Karnes, northern Bee, Live Oak, southeastern McMullen, Duval, Jim Hogg, and Starr Counties. It occurs primarily in the subsurface but makes up the bulk of outcrop Jackson in Gonzales, northeastern Karnes, and western Starr Counties. Throughout much of South Texas, the lower part of the Jackson consists of a basal 100-foot sequence of marine muds (*see* Shelf System, discussed later), overlain by a 400-foot sequence consisting principally of sands. These include sands commonly designated as Wellborn, Stones Switch, Dilworth, as well as those in the McElroy in the Gonzales-Karnes County area (Eargle, 1959a), the Mirando, Loma Novia, and Government Wells sands of subsurface terminology (West, 1963), and the Roma sands of the Rio Grande or western Starr County area (Patterson, 1942). The middle portion of the Jackson over much of the area consists of a 200- to 400-foot sequence predominantly of muds. Within the upper 400 to 500 feet of South Texas, the Jackson has several sands developed, including chiefly the upper and lower Cole sands of subsurface, Calliham sand of the Karnes County area, and the Villa Nueva and Sanchez sands of the Rio Grande outcrop area.

Maximum net sand thickness along the axis of the system averages about 400 feet. Locally along strike, sand decreases to less than 200 feet or increases to as much as 500 feet. Net sand thickness decreases abruptly both updip and downdip. Sand isoliths of the entire system, which includes at least eight individual strandplain or barrier bar units, are comparable to isoliths of other Gulf Basin Eocene strike systems (*e.g.*, Lower Wilcox Cotulla Barrier Bar System (Fisher and McGowen, 1967) and South Texas Yegua (Fisher, 1969)). Contours of the seaward side of the system tend to be more regular than those of the landward or lagoon side, a feature of modern strike-oriented systems as well.

Sands of the South Texas strandplain-barrier bar system are light colored (commonly gray, buff, or green gray), mostly fine grained, well sorted, and locally tuffaceous or shardy. Primary sedimentary structures are predominantly very low-angle tabular cross-beds, some small-scale trough cross-beds, wave ripples, and armored mud balls. Silicified wood and stumps in growth position (mainly palm) occur in the sands. Characteristic feature of these sands is an abundance and variety of branching nodose burrows of the mud shrimp *Callinassa.* These burrows are mostly vertical, but in some thinner sands are horizontal. Molluscan fossils, chiefly small clams and oyster banks, are common adjuncts. Concentrations of shell material form calcareous concretions within the sands.

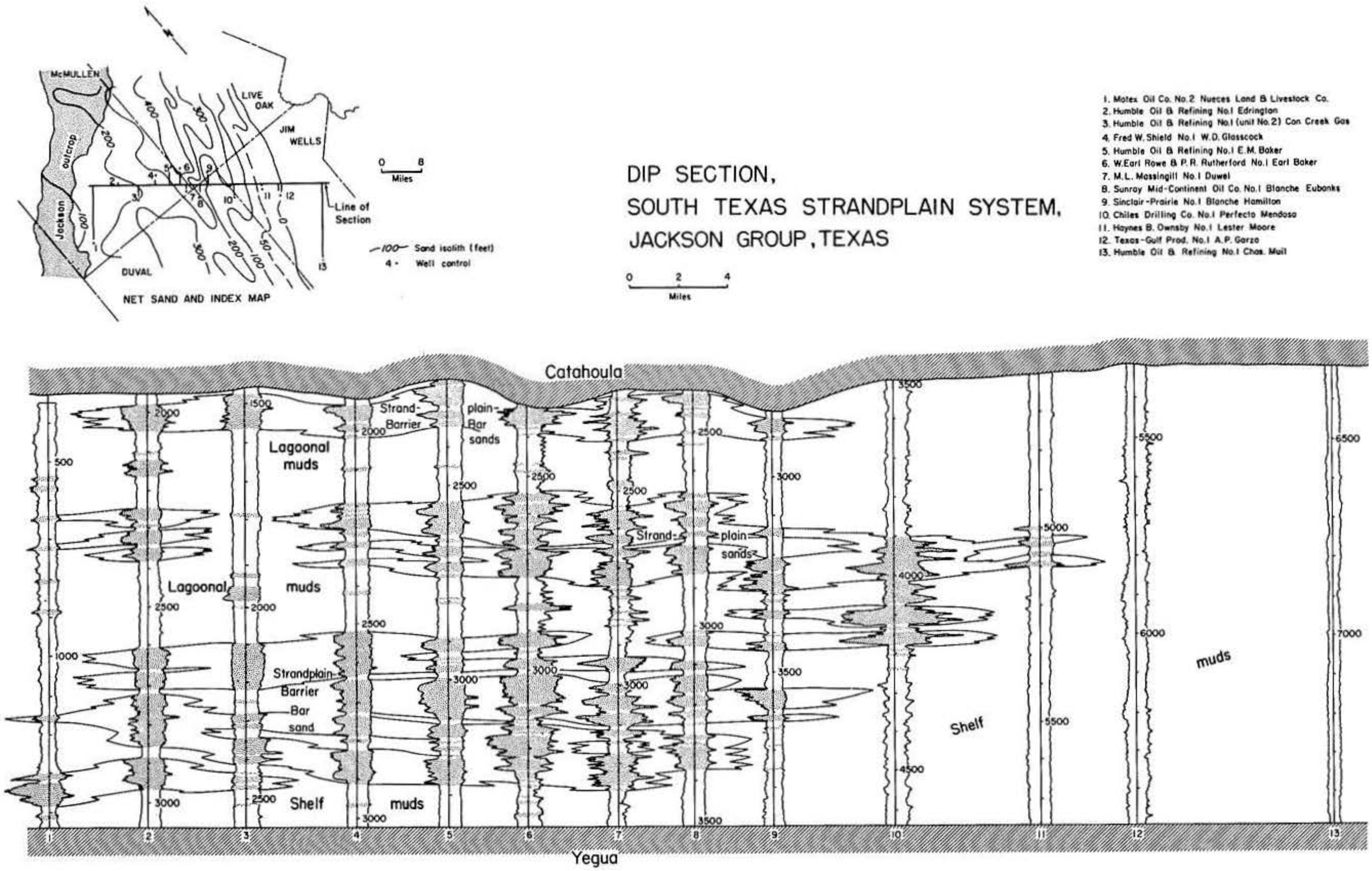
Individual sands range in thickness from a few inches up to a maximum of about 60 feet. Generally thinner, commonly burrowed sands grade upward from marine fossiliferous muddy sands to thicker bedded sands in which primary sedimentary structures are preserved. Such sequences are comparable to well-known modern shoreface units developed as parts of barrier bar and strandplain sands (Bernard and LeBlanc, 1965; Bernard *et al.*, 1970). Upward increase in amount, grain size, and thickness of sands in these strandplain-barrier bar sands is reflected in typical S. P. profiles (Figs. 4 and 5). Similar progradational patterns are shown by the thinner delta-front sand sequences of the delta-front facies in the Fayette delta system. However, several distinctions, such as lithic and structural composition, sand trend, and facies association, can be made.

Strike-oriented and strike-trending sand units of the South Texas strandplain-barrier bar system have appreciable lateral continuity and can be correlated or traced in detail. Individual sands commonly can be traced in dip direction for distances of 10 to 20 miles and along strike for distances of 30 to 60 miles, an areal extent on the order of 700 square miles. Individual sand units commonly merge in either dip or strike directions. Updip pinch-outs of these sands, commonly referred to as shoreline or strandline sands, have been documented in detail (Eargle, 1959a; West, 1963) (Figs. 5 and 6). These pinch-outs provide numerous stratigraphic traps in South Texas Jackson oil and gas fields (*see* later section on Oil and Gas).

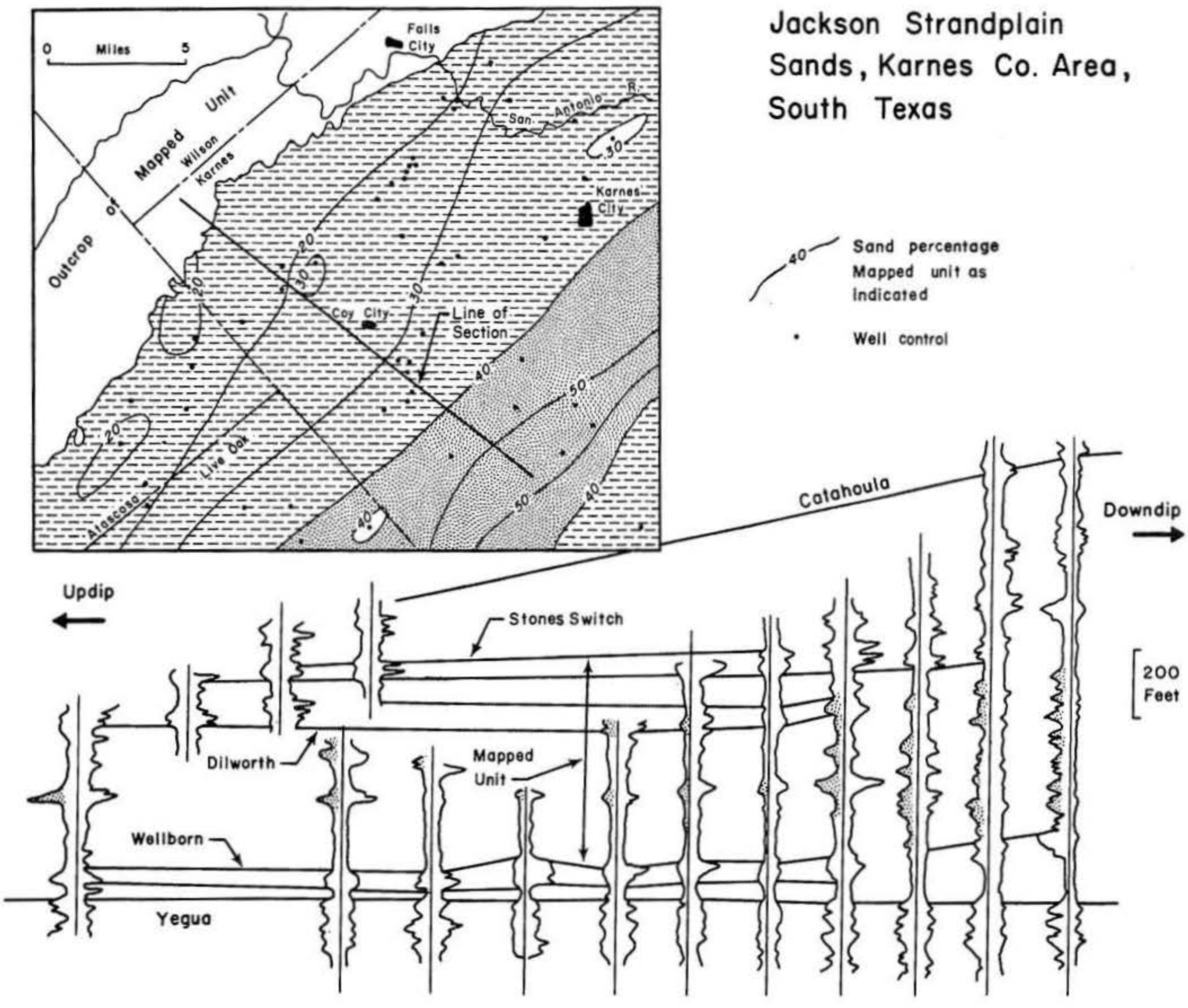
South Texas Lagoonal-Coastal Plain System

Updip and landward of the South Texas strandplain-barrier bar sands, the Jackson sequence is principally mud, with local sands, calcareous concretions, and oyster banks, and is here designated the South Texas lagoonal-coastal plain system. This system includes most of the Jackson of outcrop from central Zapata northward to southeastern Atascosa Counties and extends downdip a maximum of about 10 miles (Figs. 1b and 5). Average thickness of the system is about 1,000 feet. Thickness increases slightly along strike toward the Rio Grande and decreases slightly to the north, largely due to overlap and erosion by the overlying Catahoula Formation. Downdip, muds of this system grade to and interfinger with sands of the strandplain-barrier bar system.

Muds are chiefly gray to greenish gray. They range from finely laminated alternations of silts and clays to massive-appearing muds in which primary lamination has been obliterated by extensive burrowing. Units of fissile, carbonaceous shale are common. Locally a few thin, impure lignites are developed but not as extensively nor as commonly as in the delta-plain facies to the northeast. Plant material derived from both fresh- and salt-water marshes, as well as silicified wood fragments, is associated with the muds. A low diversity molluscan fauna occurs at several levels within the system. These include thick, commonly very large oysters (*Ostrea gigantissima*) which locally form banks traceable for distances of a few miles. Oyster banks are best developed along margins of updip strandplain sand pinch-outs. Other faunal elements in the South Texas lagoonal muds include small clams such as *Corbula* and *Corbicula.* At a few horizons within the sequence a slightly more diverse fauna, including gastropods and foraminifers, represents local shelf transgressions of the strandplain-lagoonal complex (*see* later section on South Texas Shelf System). Large, calcareous concretions are commonly associated with these lagoonal muds and appear to be of algal origin, similar to algal mounds common in the Lower Wilcox Indio Lagoon system (Fisher *et al.*, 1968; and Fisher and McGowen, in press). These concretions are similar in shape to sandy concretions developed in the outcrop of associated strandplain sands but differ in composition and internal structures. Strandplain concretions represent secondary cementation of more fossiliferous (shell material) parts of shoreface units.



5. Dip section, South Texas strandplain-barrier bar and associated depositional systems, Jackson Group, South Texas. Net sand and index map from figure 1 b.



6. Updip pinch-out and sand distribution, South Texas strandplain-barrier bar and lagoonal systems, Jackson Group, Karnes County, Texas. Modified from Eargle (1959a).

Jackson lagoonal muds are commonly selenitic and locally pyritic. Also associated with these muds, as with most Jackson strata, are numerous beds of volcanic ash and tuff. Clays in this facies are chiefly bentonitic and locally mined (Fayette and Gonzales Counties) as both ceramic and nonceramic raw materials.

Within the predominantly mud facies of outcrop and subcrop Jackson of South Texas are local sand units distinct from the downdip associated strandplain-barrier bar sands. These local sands are oriented in a dip direction at various positions within the Jackson, and are similar in composition and structure to fluvial sands in the Fayette system to the northeast. Five fairly well defined channel units are developed in belts about 5 to 10 miles in width (Fig. 16). Thickness of these channel-sand units averages about 40 feet. They are thinner and occupy less of the overall section than the fluvial sands associated with the delta progradations to the northeast. They represent local, supplementary dip-feeding of the predominantly strike-fed strandplain system. Downdip, they grade to marine strandplain sands. Strike sections of the strandplain sand system show an increase in total sand content immediately down strike (or down longshore current direction) of the axis of these local fluvial units. The Dubose sands of Karnes County represent one of these minor channel units. Another unit occurs in northeastern McMullen County approximately along the present-day Cibolo Creek. A third unit is locally developed in southeastern LaSalle County along a line north of the Frio River, and a fourth channel unit is developed in southern Webb County, along the approximate latitude of Pescadito and Aguileres. A final channel unit is partly preserved within the western Starr County outcrop.

South Texas Shelf System

Downdip of the Jackson outcrop in South Texas at distances of 25 to 40 miles, strike-oriented sands of the strandplain-barrier bar system grade to predominantly mud sequences (Figs. 1b and 5). This system, designated the South Texas shelf system, persists gulfward to the downdip limit of present well control. Average thickness is about 1,100 feet, as defined by foraminiferal zones. Muds of the shelf system are chiefly light colored and fossiliferous, with the more fossiliferous units occurring as discrete, thin, commonly glauconitic zones.

Yazoo-Moodys Branch Shelf System

Eastward from the Neches River, extending into Louisiana and Mississippi, deltaic facies of the Fayette system grade to and interfinger with a predominantly marine mud sequence, generally designated as the Yazoo Group (Murray, 1961). These argillaceous sediments overlie a regionally persistent glauconite (Moodys Branch); the two are here considered collectively as the Yazoo-Moodys Branch shelf system. Farther eastward into Alabama and the eastern Gulf Basin, glauconitic and argillaceous facies grade to and interfinger with a carbonate system, generally designated the Ocala Group (Fig. 7).

The Moodys Branch consists mostly of medium-grained, green, pelletoid glauconite, with local units of marl and clay. It is very fossiliferous, characterized by large foraminifers and a diverse molluscan assemblage. The glauconites are devoid of primary sedimentary structure and have been thoroughly burrowed and biologically reworked. The Moodys Branch overlies deltaic and paralic facies of the Yegua-Cockfield with regional marine disconformity (Stenzel, 1940, 1952; Treadwell, 1954). The unit can be traced westward both in outcrop and subsurface beneath the Fayette delta system to approximately the Brazos River, though and local glauconitic units occur at the base of the Jackson farther to the southwest. Thickness of the Moodys Branch rarely exceeds 10 feet.

Principal units of the northern Gulf Basin Jackson are marine muds of the Yazoo Group. In Louisiana, several units are developed (Fisk, 1938; Andersen, 1960). The lower part of the Yazoo (Tullos) consists of fossiliferous, marine clays about 100 feet thick. These clays grade upward into a 20-foot sequence of laminated muds with fossiliferous concretions (Union Church). Overlying this zone is a 250- to 300-foot sequence of slightly fossiliferous, carbonaceous muds interbedded with 10- to 20-foot thick marine sands (Verda Formation). The uppermost unit definitely assigned to the Jackson consists of fossiliferous, glauconitic muds (Danville Landing), similar in composition and fauna to the lower Jackson Tullos. A sequence of sands and carbonaceous muds (Mosely Hill) similar to the Verda occurs between the Danville Landing and the Catahoula Formations (Fig. 7); the lower part of this unit has been variously assigned to the Jackson or Vicksburg (Delaney, 1957).

Westward into East Texas, the Yazoo thickens to about 1,000 feet and grades to deltaic facies of the Fayette system. Facies comparable to those of central Louisiana persist westward, both above and below the easternmost lobe of the delta system, though the relative number of highly fossiliferous units decreases as the delta system is approached.

The Jackson of the northern Gulf Basin accumulated primarily as shelf to locally paralic (barrier bar and lagoonal) deposits. The basal Moodys Branch glauconites represent a westward extension of biogenic, nonterrigenous facies that characterize the Jackson of the eastern Gulf Basin. This unit was very slowly deposited as an open marine shelf and bank system prior to clastic influx associated with the Fayette deltas. Overlying muds of the Yazoo reflect progradation of the delta system to the west. Highly fossiliferous muds (Tullos and Danville Landing) developed marginal to the delta system, probably during progradation of the westernmost lobes of the system. Influx of suspended sediment from the deltas to the west was relatively small. Carbonaceous muds with brackish-water fauna and marine sands of the Verda make up a paralic facies (barrier bar-strandplain and complementary lagoonal deposits), reflecting closer proximity of delta progradation and increased rate of strike-distribution of sediments. The Verda occupies approximately the same stratigraphic position as principal delta lobes in the eastern part of the Fayette system.

Sand Dispersal Patterns

Two principal types of sand dispersal were operative during deposition of clastic facies of the Texas Jackson

(Fig. 8). These relate to the kind of depositional system developed. Within the fluvial-delta system, dominant dispersal was in a dip direction; within the strandplain and shelf systems, principal dispersal was along strike. Main introduction of clastics into the Gulf Basin during the Jackson was in Texas chiefly between the present Colorado and Neches Rivers. Fluvial sands and distributary channel sands of the delta system show marked dip orientation. These sands grade downdip to delta-front sands which show both dip orientation associated with zones of active progradation (channel mouth bars) and strike orientation where reworking and redistribution lateral to channel-mouth bars by wave action resulted in coalescing sheet sands. This resulted in a series of lobate delta-front sand masses trending subparallel to regional strike. Regional redistribution of sands from the shoal-water delta fronts by prevailing southwest longshore currents carried sands to the south, forming the extensive barrier-bar and strandplain units. The basic dispersal pattern in the Texas Jackson is comparable to other Eocene high-constructive delta systems and associated strike-fed systems of the Lower Wilcox and Yegua (Fisher 1969). In the Texas Jackson, overall thickness and net thickness of sand in the delta and associated strike systems are comparable. By contrast, delta systems of the lower Wilcox and Holocene Mississippi deltas are on the order of 5 to 10 times thicker than associated and supported strike systems. Two factors account for this difference. There was significantly more dip feeding by minor fluvial systems immediately updip of the Jackson strike systems than occurred in the lower Wilcox (Texas) or the Holocene (northwestern Gulf Coast). Secondly, part of the original Jackson delta system was eroded and reworked into the overlying Catahoula. Strike profiles and correlations (Figs. 1a, 1b, and 9) suggest that strike-oriented sands in the upper 600 feet of the South Texas Jackson (including the Cole sands and others) were derived in part from presently missing portions of the delta system to the northeast.

Formal Nomenclature and Paleontological Zonation

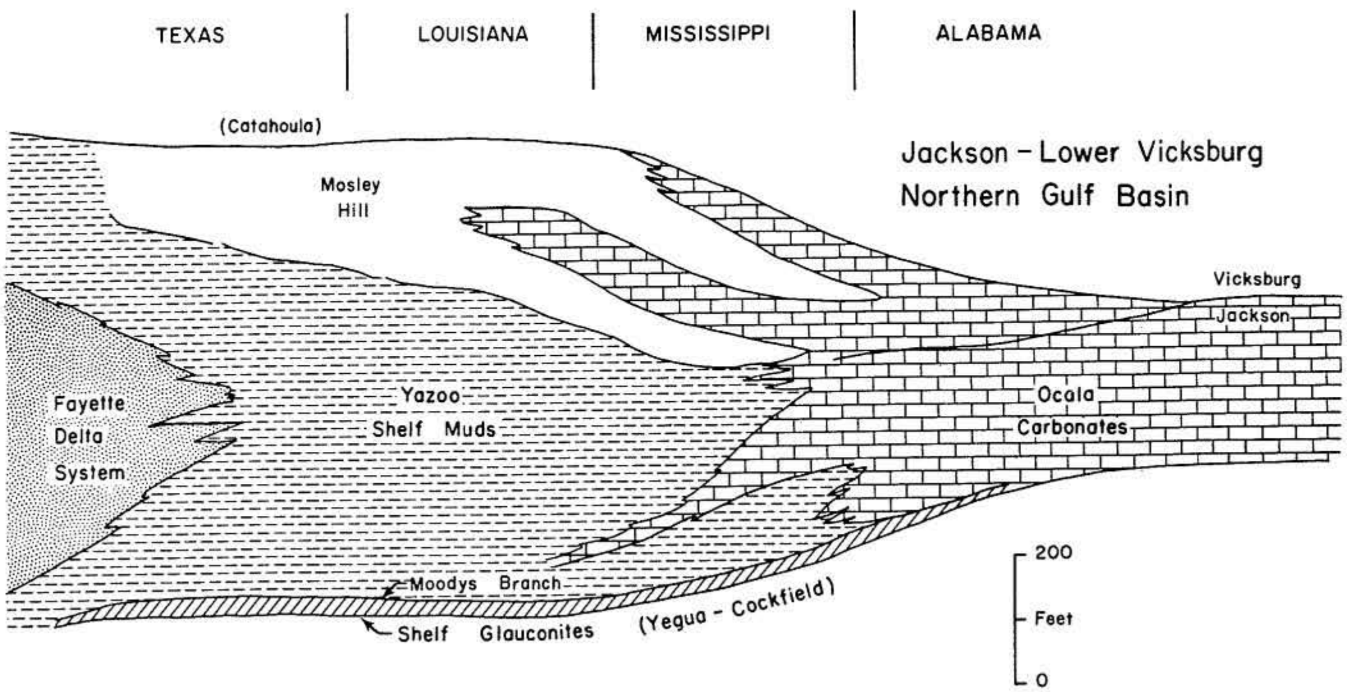
The Jackson sequence in Texas is one of the few terrigenous clastic wedges of the Gulf Basin that has significant development of marine facies in outcrop. Local strike persistence of certain units and fossiliferous distinction of others have resulted in a proliferate naming of key-bed bounded units, and faunal or biostratigraphic units. Key-bed delineation (chiefly of delta destructional, interdeltaic, and strandplain sands) well serves the purpose of local stratigraphy. However, attempts to correlate regionally, or the assumption of regional persistence of lithologically homotaxial units through unlike depositional systems, have led to nomenclatural confusion. Similarly, paleontologic zonation, chiefly based on foraminifers, is useful in delineation of biostratigraphic units in facies of uniform composition such as downdip shelf and prodelta muds. Attempts to carry these paleontologically defined units through varied facies and systems of differing composition have led to an unwarranted oversimplification of Jackson lithostratigraphy.

Nomenclatural history of Jackson rock and faunal units has been reviewed in detail by Eargle (1959b) and Stuckey (1960). Most of the Jackson nomenclature in Texas derives from two outcrop areas: East Texas (area from Angelina to Sabine Counties), where the Jackson consists largely of fossiliferous shelf muds flanking the Fayette deltas, and South Texas (Atascosa to Gonzales Counties), where the Jackson is made up chiefly of locally persistent strandplain and associated lagoonal deposits. The East Texas area has been type for such regionally applied nomenclatural units as the Manning, McElroy, and Caddell, plus some local units such as Wooleys Bluff (Sabine Parish, Louisiana), Mitchells Ferry, and Glendale. The South Texas area is type for Whitsett, a regionally employed unit, and several local strandplain sand and intervening lagoonal or shelf mud units such as Dilworth, Conquista (Falls City), Stones Switch, Calliham, and Fashing. The central Texas Gulf Basin or area of the Fayette delta system is type for Wellborn (delta-front sands) and several locally persistent sand units (delta destructional and interdeltaic) such as Yuma, Goodbread, Tuttle, Carlos, and Bedias. The Rio Grande outcrop, as well as South Texas subsurface, includes type areas for several Jackson units, but these have not been involved in most nomenclatural discourses. Relationship of these several type areas and corresponding nomenclatural units to the regional depositional systems as delineated here are shown in Figure 9.

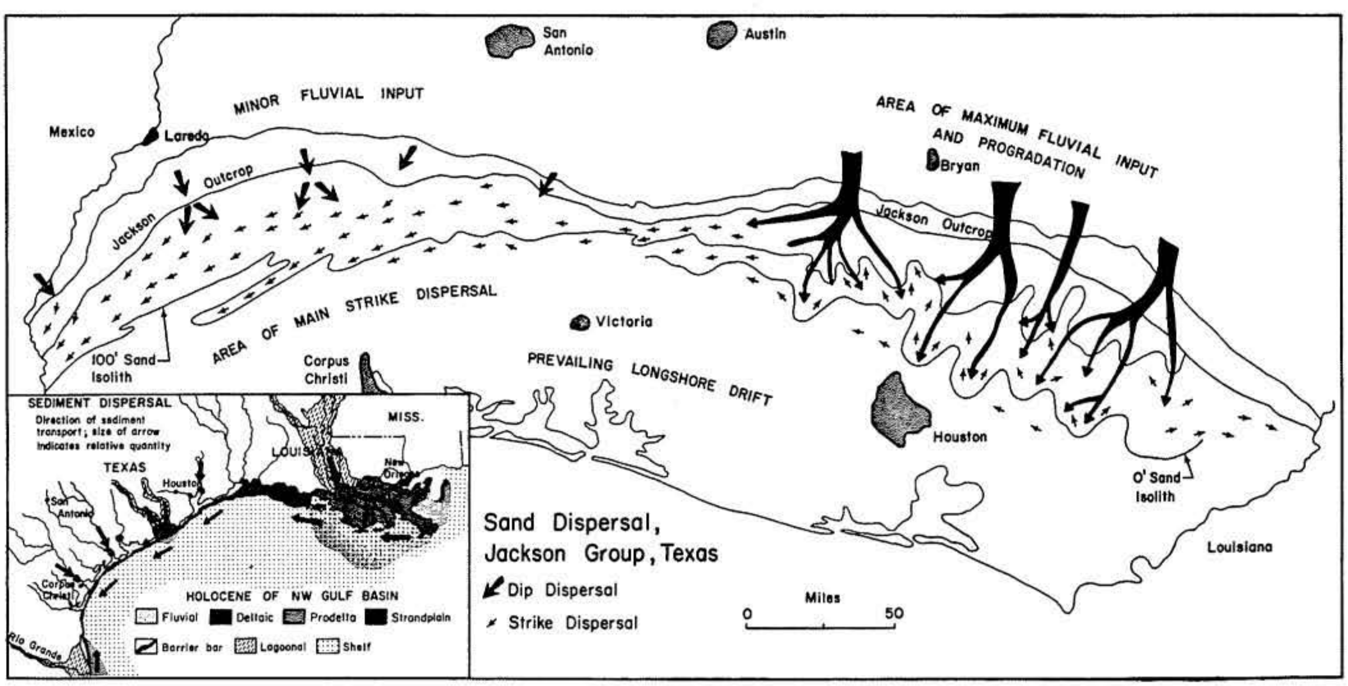
Several of the named units from one area or one system to another have homotaxial features of either lithologic or faunal composition. For example, the Dilworth of South Texas is a burrowed *(Callinassa)* sand developed as a strandplain deposit and a part of the South Texas strandplain system. Owing to strike persistence (coincidence of original strike trend and present-day outcrop) it is a well-defined key bed unit in outcrop. The term Dilworth has also been applied to a Jackson unit to the northeast which has homotaxial features (*Callinassa* burrows) and which occurs at approximately the same stratigraphic position. The Dilworth of the central part of the Texas Gulf Basin has local strike persistence and serves as a key-bed unit. However, it developed as a delta destructional and interdeltaic sand unit within the Fayette delta system distinct from the Dilworth of South Texas. Regional persistence of such units as these should not be presumed. Further, the use of such key bed units to bound and define larger units has resulted in regional correlation of genetically and lithologically dissimilar units. For example, the Manning Formation of South Texas includes a sequence of alternating strandplain sands and marine muds, in Central Texas it includes lignite-bearing delta-plain sequences and in East Texas it includes a sequence of marginal delta and associated shelf facies. Such terminology serves to obscure, rather than delineate, important and significant regional facies changes.

MINERAL OCCURRENCES: OIL, GAS, AND URANIUM

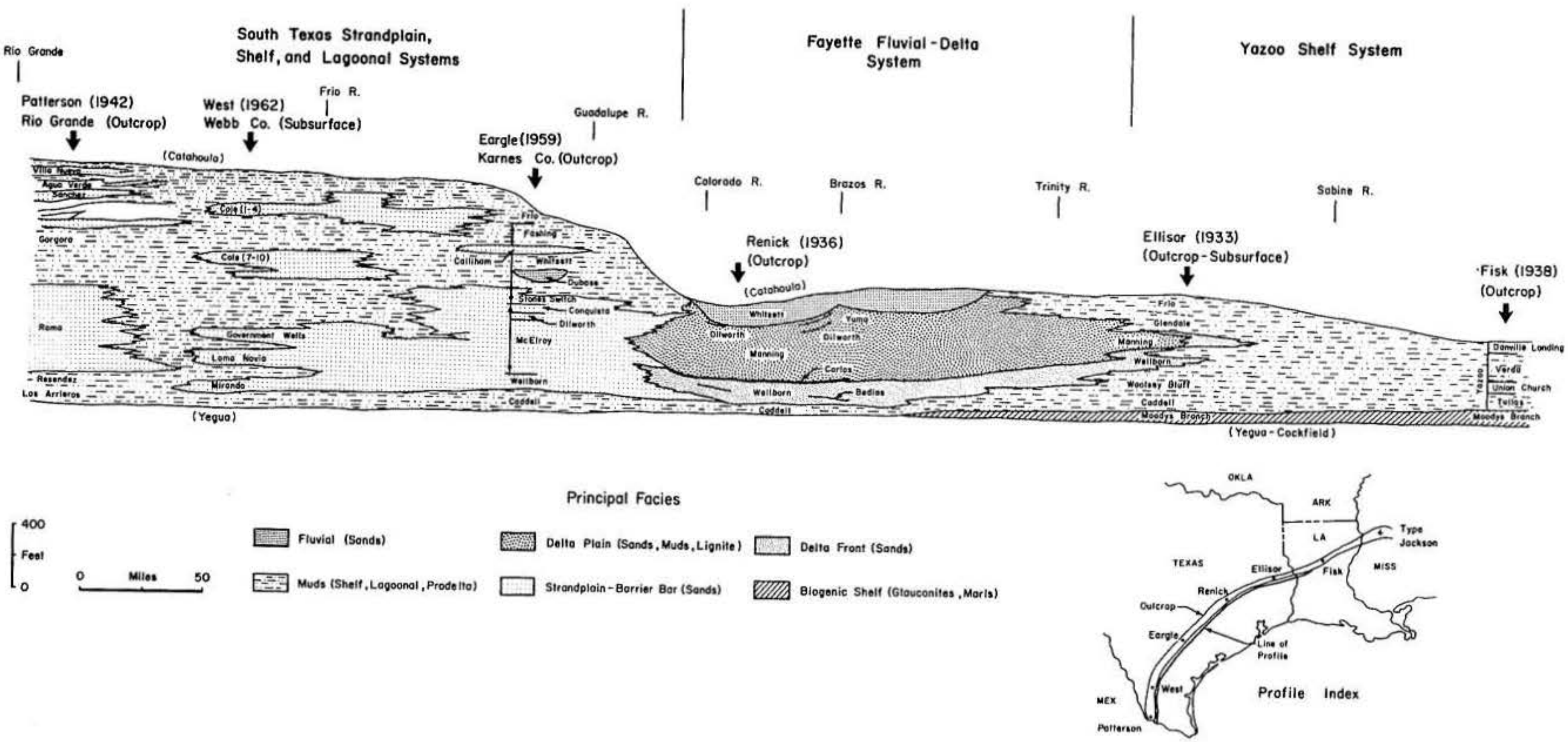
Jackson rocks in Texas provide significant reservoirs and sources for a variety of mineral raw materials, principally oil, gas and uranium. Oil and gas have been produced from Jackson reservoirs for more than 50 years. In recent years, the Jackson has been the objective of extensive uranium exploration. The first commercial deposits in the State were produced from Jackson rocks of Karnes County (Eargle, 1970; Flawn *et al.*, 1969). Several deposits of bentonite clay are mined from the Jackson



7. Relationship of Fayette delta system to argillaceous and calcareous facies of the northern Gulf Basin, Jackson Group. Modified from Murray (1961).



8. Sediment dispersal pattern, Jackson Group, Texas. Inset map: Sediment dispersal of Holocene northwestern Gulf of Mexico, adapted from Fisher *et al.*, 1969.



9. Strike profile of principal depositional systems, Jackson Group, Texas and Louisiana, compared to local formally-defined stratigraphic units. Local sections from sources as indicated.

(chiefly in Fayette and Gonzales Counties) for use as both ceramic and nonceramic raw materials. Although not a major source of lignite in the State, several Jackson strata were mined as fuel in years prior to the advent of natural gas; all lignite mining was in the central and eastern Texas Coastal Plain (Fisher, 1963). Jackson sands are locally important fresh-water aquifers.

Oil and Gas

Oil and gas occur in Jackson reservoirs in two principal trends--the delta trend of the central and eastern Texas part of the Gulf Basin and the strandplain-barrier bar trend of South Texas (Fig. 10). Only a dozen or so fields occur in the delta trend; nearly 300 have been discovered in the strandplain-barrier bar trend.

Delta Trend

Although the deltas of the Jackson cover extensive areas in the eastern and central Texas part of the Gulf Basin, few fields have been discovered or developed (Fig. 10). Most of the major delta production is limited to two fields: Raccoon Bend (nearly 40 million barrels cumulative production to date) and Livingston (approximately 20 million barrels to date). Other significant fields developed in the trend are confined to Polk County (Morgan Creek, Copeland Creek, and Goodrich) in the general vicinity of the Livingston field. All production in the delta trend is from delta-front sands; structural closure resulting from salt domes provides most of the traps. Oil and gas trends within other Gulf Basin delta systems of comparable distribution and facies, including lower Wilcox and Yegua, are much more prolific (Fisher and McGowen, 1967; Fisher *et al.*, 1969). The paucity of production from potential delta-front sand reservoirs and other delta-sand facies of the Texas Jackson probably is due to several factors: (1) Growth faulting, a common adjunct to comparable Wilcox and Yegua delta systems, is not well developed in the thinner Jackson deltas, reducing frequency of fault closure and traps. (2) Although several large salt dome structures are coincident with the areal distribution of Jackson delta-front sands, the possibility exists that these domes were not active during deposition or did not provide entrapping closure during critical periods of hydrocarbon migration. (3) The net thickness of Jackson delta-front sands is only a fraction of net thickness of delta-front sands in the Lower Wilcox and Yegua. (4) Sufficient tests of potential sand reservoirs within the delta trend possibly have not been made. Structures and stratigraphic traps within the gulfward extent of the several delta lobes should be explored. Main trends should develop at relatively shallow depths generally between the zero and 50-foot sand isoliths, extending from about the Colorado River eastward to the Neches River (Figs. 1a and 10).

Strandplain-Barrier Bar Trend

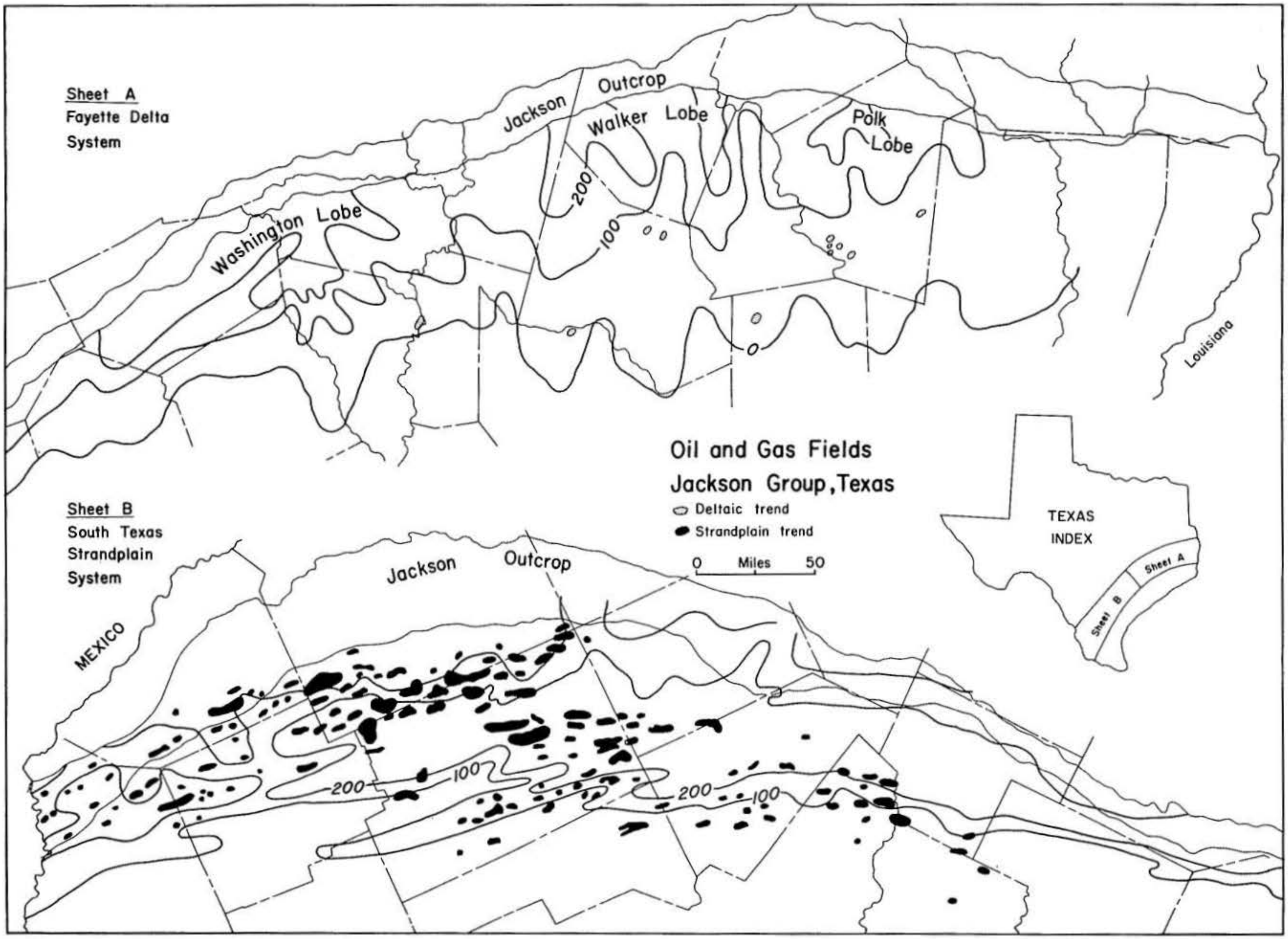
The strike-oriented strandplain and barrier-bar sands of the South Texas Jackson constitute reservoirs for several important oil and gas fields (Fig. 10). Significant features of this trend have been recognized for several years, since discovery of many of the major fields dates back to the 1920s. West (1963) presented an excellent summary of the South Texas Jackson, especially the relationship of oil and gas accumulation to updip pinch-out of sands. Nearly 300 fields have been discovered in the trend, ranging in size from small one-well fields to multimillion-barrel fields. Approximately 50 fields have cumulative production in excess of 1 million barrels; 10 fields exceed 10 million barrels in cumulative production to date. Ultimate recovery is estimated at about 10,000 to 20,000 barrels per acre in the better fields. Exploration in the South Texas Jackson reached a peak during World War II. Most fields discovered since that time have been relatively small, though a few large fields, such as Prado, have been developed in recent years.

All Jackson production is from depths ranging from as little as 150 feet in Starr County to maximum depths of about 4,000 feet. Porosity averages 30 to 35 percent. Permeability ranges from a few hundred to several thousand millidarcies.

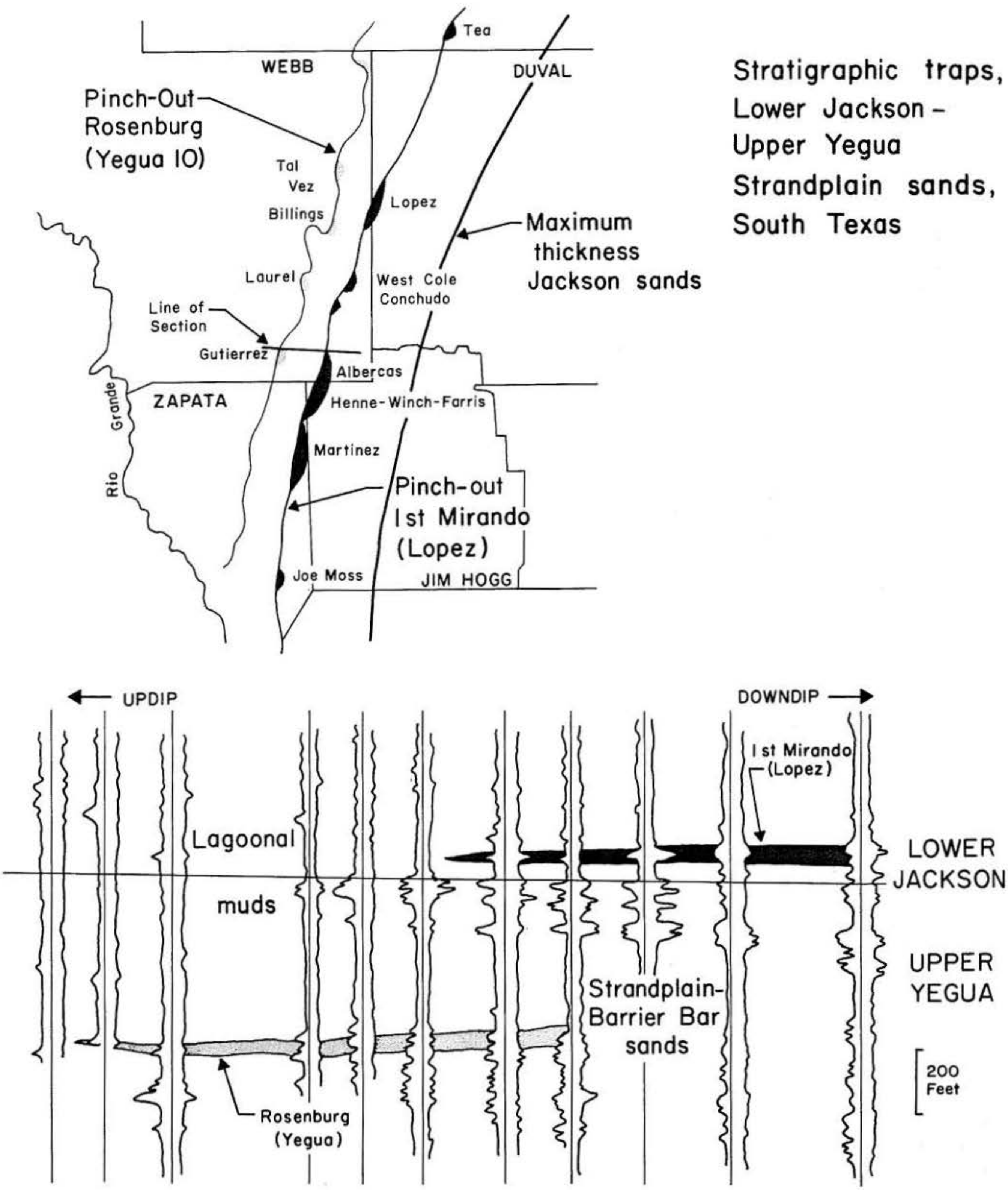
Principal production is from the Mirando, Loma Novia, and Government Wells sands of the lower Jackson and from the Cole sands of the middle and upper Jackson (Figs. 1b, 5, and 9). The main sand units trend in a strike direction and pinch out both updip and downdip. West (1963) reported about 50 individual sands along updip limits in the Jackson and the comparable underlying upper part of the Yegua. Several sands merge downdip into more massive and thicker sand units. Traps are within the updip portion of the sand units, either at the pinch-out or slightly downdip of actual point of pinch-out. The latter situation results from low permeability in the updip terminal parts of sand units or fault closure on sands downdip of pinch-out. Conformity of production trends to updip pinch-out of strike-oriented sands is well shown by the lineation of Jackson fields within the trend (Fig. 10) and by comparison of specific sand pinch-outs and related producing fields (Fig. 11). The Terryville system is situated lateral to a large delta system (Cotton Valley) to the east (Fisher, 1969) analogous to Jackson depositional systems in Texas.

Principal accumulation of oil and gas in the South Texas Jackson is stratigraphic. Two basic types reported by West (1963) are: (1) entirely stratigraphic sand pinch-outs with regional monoclinal dip, and (2) structural closure against shale, generally provided by a combination of monoclinal dip and down-to-the-coast faults.

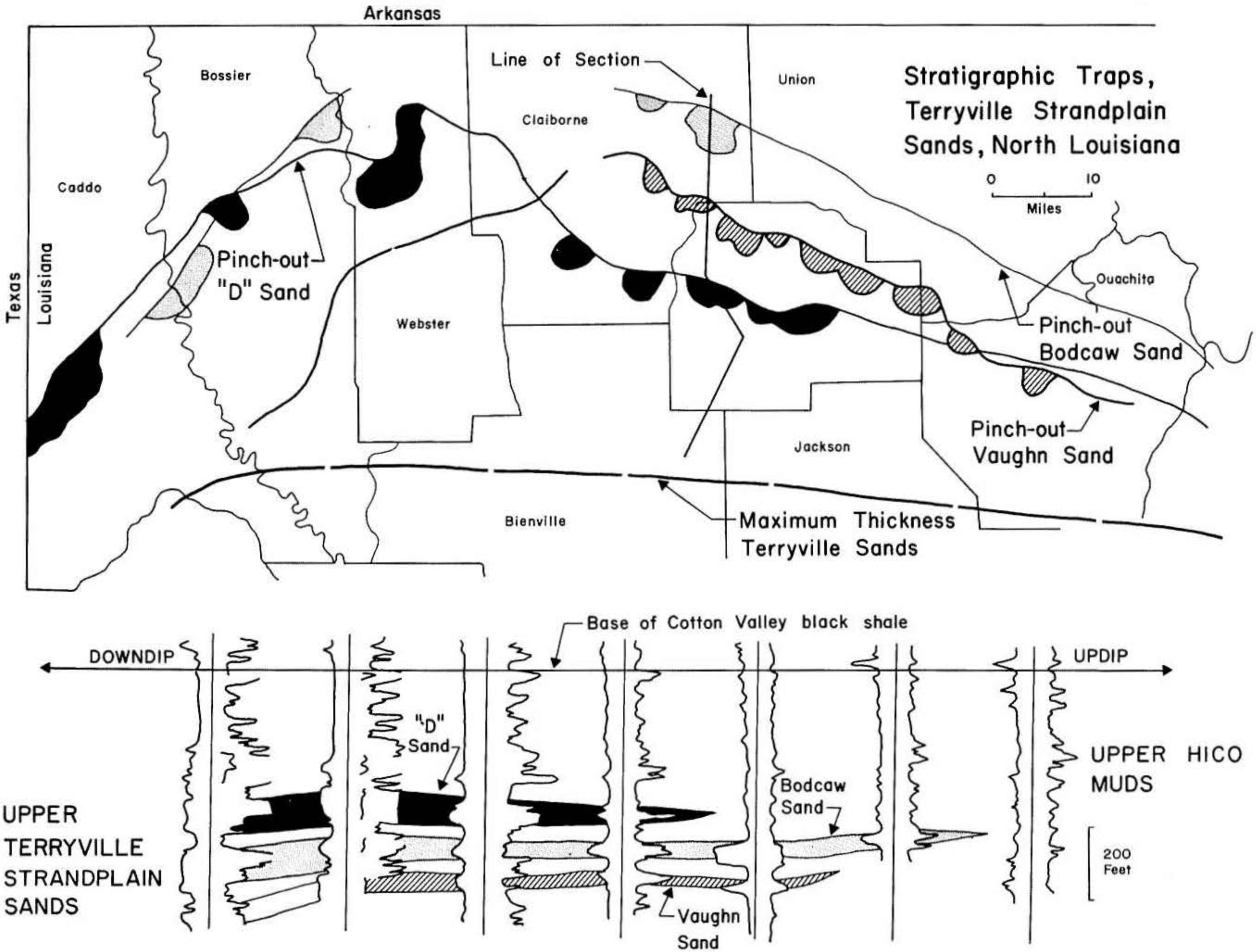
Most South Texas Jackson hydrocarbon production is confined to an area southwest of a line extending along the southern border of LaSalle, through southeastern McMullen, central Live Oak, and northern Bee Counties. North of this line Jackson strandplain and barrier-bar sands are normally nonproductive (Figs. 10 and 13). The largest fields as well as the greatest density of Jackson fields are in the area between central Zapata and Jim Hogg Counties on the south and the northern line of McMullen and Duval Counties on the north. Nearly all of the strike-oriented Jackson sands in this area pinch out short of outcrop. Except where local dip-oriented channel sands are developed, the zero sand isolith occurs at or downdip of outcrop (Fig. 13). Accordingly, sands of the entire section have depositional pinch-outs and are amenable to stratigraphic entrapment. Sand trends also conform closely with regional structural trends. Toward the north, Jackson



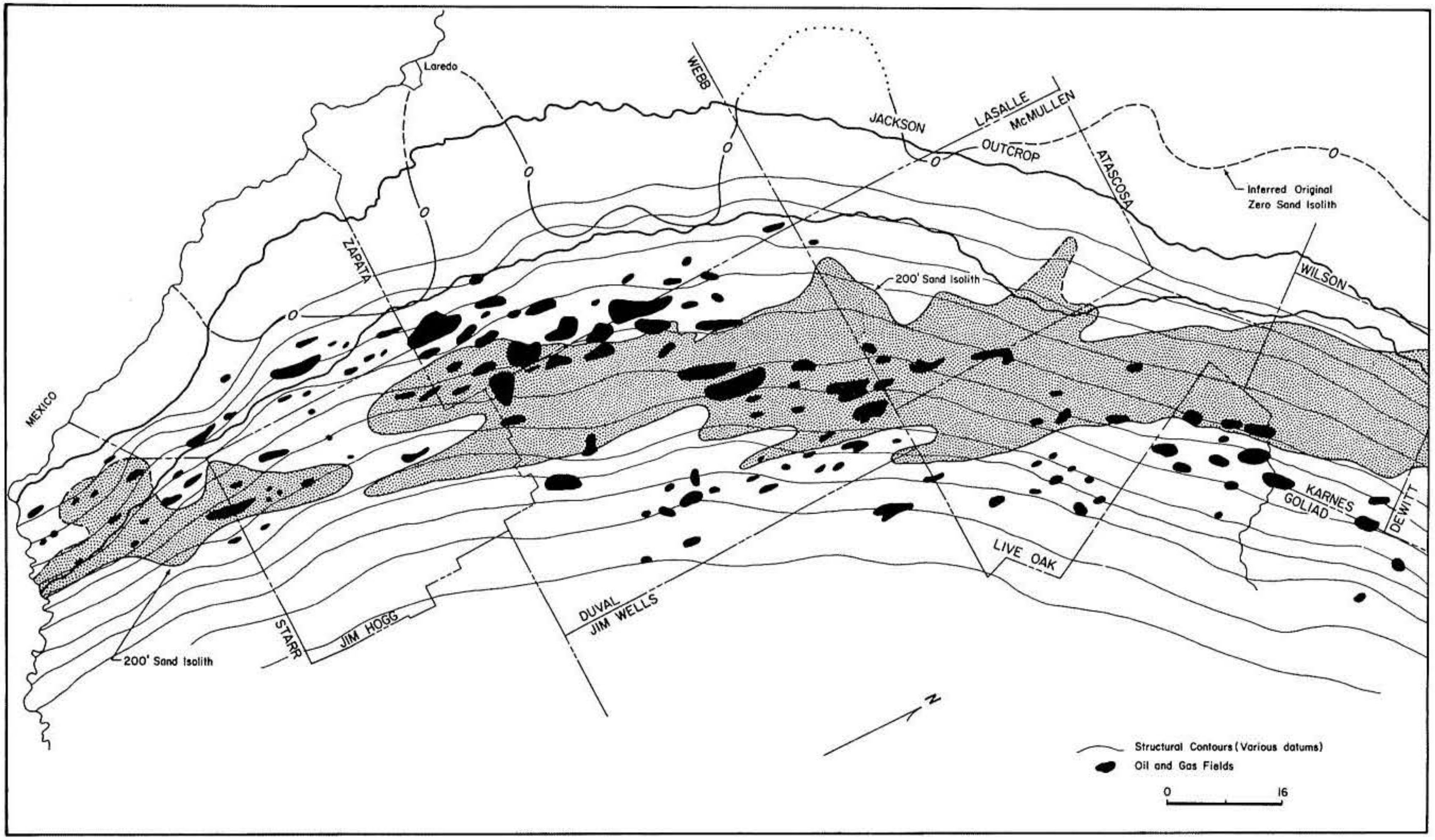
10. Occurrence and distribution of oil and gas fields, Jackson Group, Texas. Compare with figures 1a and 1b.



11. Association of stratigraphic traps and updip sand pinch-outs, lower Jackson and upper Yegua, South Texas. Modified from West (1963).



12. Association of stratigraphic traps and updip sand pinch-outs, Terryville barrier bar-strandplain system, Jurassic, northern Gulf Basin. Modified from Pate (1963).



13. Relationship of oil and gas production to regional structural and sand trend, South Texas strandplain-barrier bar system, Jackson Group.

sands climb regional structure, and as West (1963) has indicated, north closure becomes more critical. The main trend of the strike-oriented sands in the northern part of the area is also nearer outcrop, with the result that many Jackson sands in this area extend into outcrop without subsurface pinch-out. Due in part to the discordance of sand trends in reference to regional structural trends, the predominantly down-to-the-coast faults commonly fail to provide closure. Also in this area, individual sands are thicker so that greater amount of displacement along faults is necessary to provide adequate seal. In Starr County along the Rio Grande, numerous sands of the Jackson extend to outcrop, likewise limiting the number of potential stratigraphic traps. However, sands in the Rio Grande area display trends conformable with regional structural trends in contrast to the structure-climbing relationship of sands to the north. Several small fields and possibly a few large fields can probably be developed in this mature trent. Potential pay sands are numerous but exploration requires detailed mapping and correlation of thin strandplain sands as indicated by West (1963).

Uranium

Uranium deposits have been exploration objectives in the Jackson Group of Texas since 1954. The history of exploration, development, and mining has been summarized in several recent papers (Eargle, 1970; Flawn *et al.*, 1969). Uranium mineralization in the Jackson occurs in two distinct trends: (1) a strandplain-lagoonal trend of South Texas, and (2) a relatively minor delta trend, generally north of the Colorado River (Fig. 14). No known commercial deposits have been discovered in the delta trend, though local drilling programs have been conducted. By contrast, the South Texas strandplain-lagoonal trend contains significant deposits. Some have been mined out, some are currently being worked. This trend has been the objective of most Jackson exploration.

Delta Trend

The Fayette delta system of the Jackson crops out from central Fayette eastward to western Angelina Counties; maximum sand thickness is along main deltaic progradational axes (Fig. 1a). Radiation anomalies have been noted from the lignite-bearing delta plain facies of this system from western Fayette northward to northern Walker Counties. Principal units from which anomalies have been reported are lignites, carbonaceous muds, and thin, poorly sorted sands. These units are best developed adjacent and marginal to the axes of deltas which are made up of thicker and more massive channel-sand units.

Strandplain-Lagoonal Trend

An extensive strandplain-barrier bar with complementary updip lagoonal-marsh systems characterizes the Jackson of South Texas. All significant uranium mineralization and all known uranium deposits of the Jackson are associated with facies of these systems. Principal host rocks for uranium mineralization in this trend are strike-oriented strandplain sands in proximity to organic-rich lagoonal and marsh deposits. Main area of mineralization extends from southeastern Atascosa northward through Karnes into western Gonzales Counties. In this area, several strandplain sands extend into outcrop. A similar extension of strandplain sands into outcrop occurs in western Starr County along the Rio Grande but these show little known uranium mineralization. In the intervening area from central Zapata northward to southern Atascosa Counties, lagoonal muds are the dominant unit of Jackson outcrop, with few potential host sands.

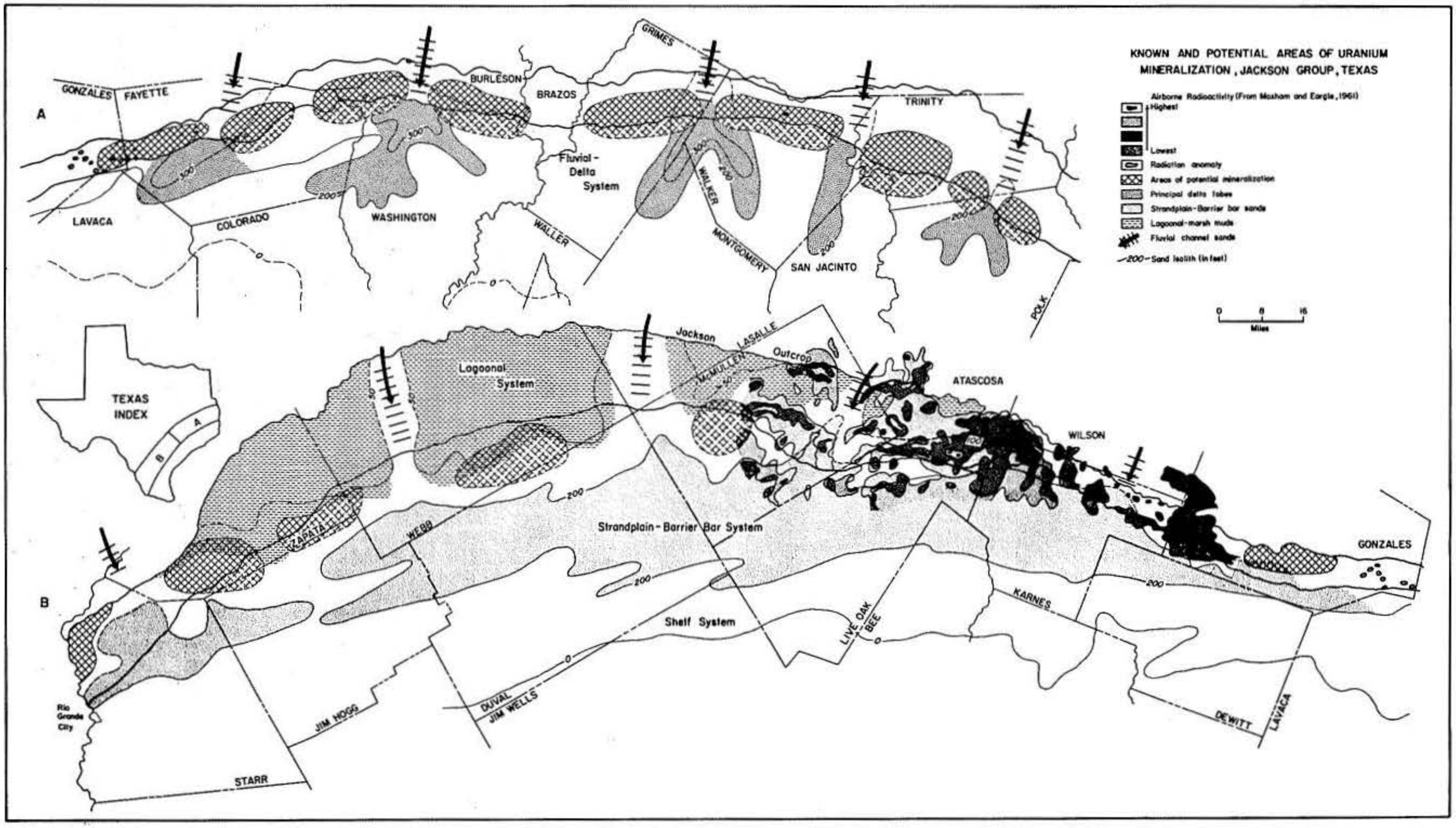
Uranium Mineralization

The distribution of uranium mineralization in strata-bound deposits is controlled by four major factors: (1) structural elements, (2) source and mode of transportation of the uranium, (3) depositional facies of the host rock, and (4) character of the concentration process.

A well-established fact in the South Texas Jackson mineralization trend is the association of ore deposits and fault trends. Eargle and Weeks (1951) noted that most of the uranium deposits in the Jackson of South Texas are slightly updip from faults upthrown to the east. They suggested that hydrogen sulfide gas from oil-gas reservoirs, conducted into the shallower host rock via faults, created a favorable geochemical environment for the precipitation and concentration of uranium ore deposits. The evidence for structural elements as major controlling factors in uranium mineralization in South Texas has been reinforced by exploration data from the Oakville fluvial system (Klohn and Pickens, 1970).

Within the South Texas Jackson uranium trend, relationship of areas of uranium mineralization to distribution of main depositional facies suggests an additional, possibly regional, control. The local areas along outcrop where dip-oriented channel sands occur are notably devoid of uranium mineralization (note area of channel sand development in northeastern McMullen County, Fig. 14). Further, where the dominant facies in outcrop is lagoonal muds with strandplain sands pinching out short of outcrop, little mineralization occurs. Maximum areas of mineralization are found between local belts of channel sand development where several strandplain sands extend into outcrop. This pattern is well illustrated in the area from northeastern McMullen northward to north-central Karnes Counties--the principal uranium district of the Texas Jackson. In this area the radioactivity-mineralization patterns decline in a dip orientation adjacent to the fluvial channel units. Highest radioactivity and maximum uranium mineralization occur between the bounding channel areas. These permeable channel sands apparently acted as conduits, with uranium-bearing ground waters flushed downdip.

Areas of known mineralization in the delta trend, though poorly developed as compared to the South Texas trend, appear to be related to specific depositional facies. The areas of main progradational fluvial and distributary channel sands are lacking in mineralization. The facies containing radiation anomalies are the intervening delta-plain sands, muds, and lignites. This pattern is shown in the area from northern Gonzales to southwestern Washington Counties (Fig. 14).



14. Distribution of known and potential areas of uranium mineralization, Jackson Group, Texas.

Source and Transportation

The source and redistribution of uranium in the Jackson Group appear to be the same as for most sandstone-lignite type deposits: (1) Uranium is leached from an acidic volcanic-rich source and (2) transported in the oxidized state by aqueous solution (Love, 1952; Waters and Granger, 1953; Denson and Gill, 1955; Masursky, 1955; Fischer and Stewart, 1960; Rosholt, 1960; Weeks and Eargle, 1963; Klohn and Pickens, 1970). The Jackson and associated strata (especially the overlying Catahoula) contain a large quantity of tuffaceous material. The high uranium content and abundance of this material make it the most likely original source for uranium mineralization in the Jackson.

Moderately alkaline ground-water solutions are the most favorable transporting media for the uranium ion (Gruner, 1956; Weeks and Eargle, 1963; Norton, 1970). Weeks and Eargle (1963) have shown that alkaline carbonate ground waters are characteristic of the Jackson of South Texas and are probably the important transporting agent for the uranium. They pointed out that the "composition of the ground waters in the Jackson . . . sediments clearly reflects the influence of the alteration of the volcanic detritus by their high content of silica, alkalies, bicarbonate-carbonate, flouride, and boron."

The chemical properties of uranium determine the degree of dissemination by ground water. Uranium normally occurs in the +4 oxidation state (insoluble in water) but may be oxidized to the extremely soluble +6 oxidation state. The oxidation potential for the reaction U^{+4} to U^{+6} is approximately the same as that for the reaction Fe^{+2} to Fe^{+3}. Therefore, the oxidation of uranium to the +6 state readily occurs in the oxidation zone of rocks.

Uranium in the +6 oxidation state is soluble because it forms the "uranyl ion," UO_2^{+2}, with the electronegative oxygen bonding with the hydrogen of water. When the UO_2^{+2} ion has hydrated sufficiently to remain in motion, the ion is "in solution" and will be transported according to ground-water movement.

Concentration Process

Uranium in solution in the U^{+6} state is precipitated as insoluble U^{+4} when the solution moves into a reducing environment. In the Jackson Group, reductants included: (1) hydrogen sulfide and hydrogen produced by anaerobic bacteria acting on carbonaceous material, and (2) hydrogen sulfide from oil-gas reservoirs as proposed by Eargle and Weeks (1961). The large quantity of carbonaceous material and geometry of known ore deposits suggest that a geochemical cell was a possible concentration mechanism for uranium in the Jackson.

In a geochemical cell a complex physical, chemical, and biochemical reaction is initiated in the host sand. The zone of reaction is a solution front, commonly called a "roll front." Down-gradient from the roll front, anaerobic bacteria act on cellulose and other indigenous organic material and produce hydrogen as a by-product (Rackley *et al.*, 1968). Hydrogen is a strong reducing agent and creates an environment which reduces and precipitates uranium and other metallic ions in the order of their solubility. Up-gradient from the roll front, an entirely different reaction takes place. In this zone, another type of bacteria produces an environment which oxidizes and takes into solution uranium and most minerals associated with uranium deposits. Therefore, as ground water moves through a host sand it first enters a strongly oxidizing environment. The metals oxidized in this zone are taken by ground-water movement through the cell into the reduced zone and precipitated by the changed in Eh and pH.

Metals present in the source and host rock in sufficient quantities to enter the reactions of the cell are concentrated. A zoning of concentrations takes place, with selenium and lead deposited in the area of the roll front, the more complex vanadium-uranium minerals in the next zone down-gradient, uranium left over in a zone still farther out, and molybdenum in a band outside and farther ahead of the uranium zone (Rackley *et al.*, 1968).

The basic characteristics of mineralization by a geochemical cell exist in known uranium-bearing facies of the Jackson Group; that is, (1) abundant carbonaceous material, (2) roll front geometry of the ore bodies, and (3) associated metals--particularly molybdenum and vanadium. Therefore, this mechanism possibly concentrated uranium in the Jackson sands.

Potential Areas of Uranium Mineralization

By application of the geochemical cell model to regional distribution of depositional systems and facies in the Texas Jackson, areas of potential mineralization can be outlined. Three parameters are considered in prediction of potentially productive trends by use of this mineralization-depositional facies approach: (1) disassociation from massive, highly permeable fluvial channel sands, (2) association of host sand to organic-rich muds, and (3) available sand thickness and permeability to form a suitable host unit. From these considerations the potential areas for uranium mineralization in the Jackson Group of Texas are indicated (Fig. 14). Several other factors, such as kind and amount of leaching, topographic position and Catahoula overlap, also may be involved in the localization of South Texas uranium mineralization.

Substantiation of general features of the above model is provided in the uranium district of Atascosa and Karnes Counties. Here principal mineralization in outcrop exists where several strike-oriented strandplain sands, interbedded with organic-rich lagoonal and marsh muds, reach outcrop. The local areas of channel-sand development are devoid of mineralization. Degree of mineralization decreases as channel areas are approached. A similar facies pattern and composition occur in Starr County along the Rio Grande where numerous sands extend into outcrop. Sands marginal to the local channel-sand belt in this area are sites of potential mineralization. Some uranium mineralization has been reported, though exploration has not been exhaustive.

In the area from central Zapata northward to southern Atascosa Counties, updip pinch-out of strandplain sands is short of outcrop. Principal outcrop facies is mud; paucity of host sands in this area (excepting local, highly permeable channel sands which tend to be flushed) accounts for the lack of outcrop mineralization and uranium accumulation. If the general model invoked here is valid, areas of potential mineralization can be expected in the subsurface, primarily in northeastern Zapata, eastern Webb, and southwestern McMullen Counties (Fig. 14).

Within the delta trend in the eastern and central parts of the Texas Gulf Basin, comparable facies and geochemical framework exist in the delta-plain facies. In areas along outcrop flanking the main progradational axes, the delta-plain facies is made up of sands and associated lignites and interdistributary muds. These areas are the most likely sites of mineralization in the trend. The main progradational axes consist chiefly of massive channel sands, and like those of the South Texas trend, probably are not potential mineralization sites. A principal limiting factor for uranium mineralization in the delta trend is the absence of an arid or semiarid climate with attendant alkaline ground-water conditions in recent history. Surficial calichification, a guide to present and recent aridity, generally does not occur north of the Colorado River. Prospects for significant mineralization in the delta system of the Jackson are judged marginal; a few salt domes occur within the Jackson outcrop of this system with some possibility of associated uranium mineralization.

COMPARISON WITH OTHER GULF BASIN TERRIGENOUS UNITS

The composition, distribution, and relationship of component facies of depositional systems in the Texas Jackson are similar to those of the lower Wilcox and Yegua (both Eocene) of the Gulf Basin (Fisher and McGowen, 1967; Fisher, 1969; Fisher *et al.*, 1969; and Galloway, 1968). Systems and facies developed in these units are further comparable to the Holocene Mississippi fluvial-delta system and related strike systems of the northwestern Gulf of Mexico. These Holocene systems and their component facies are well known from several excellent studies, notably Bernard and LeBlanc (1965), Bernard *et al.* (1970), Coleman and Gagliano (1964), Fisk (1955, 1960), Fisk *et al.* (1954), Frazier (1967), Frazier and Osanik (1969), Gould and McFarlan (1959), and Kolb and van Lopik (1966). These Holocene delta and related systems, devleoped in the same structural-depositional basin, provide models directly applicable to certain Tertiary terrigenous units such as the Texas Jackson.

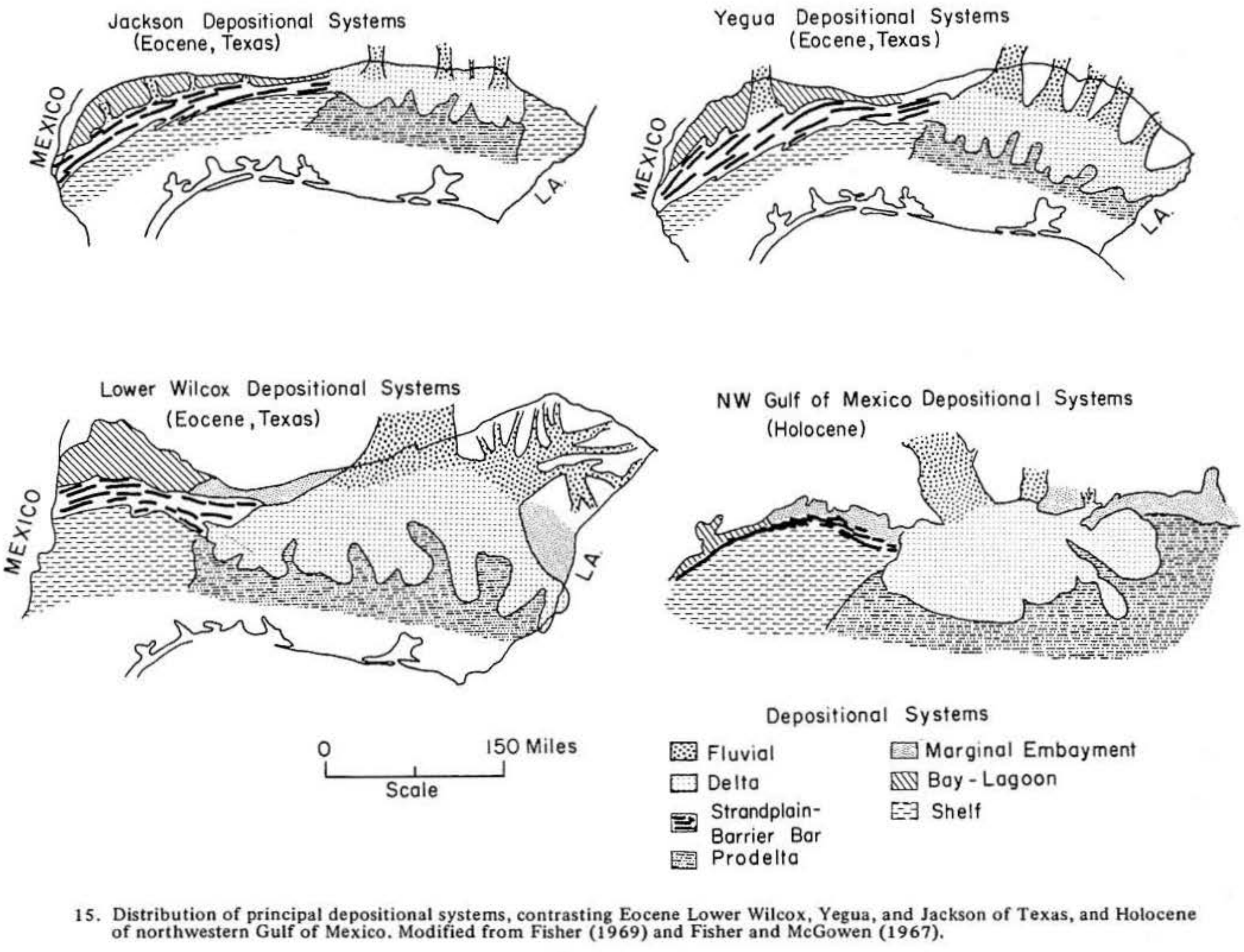
Dominant element in the Holocene northwestern Gulf of Mexico as in the Lower Wilcox, Yegua, and Jackson are large delta systems fed by extensive and distant source fluvial systems with high sediment discharge, particularly mud-sized suspended load (Fig. 15). The Holocene Mississippi delta system has an areal extent of about 20,000 square miles, the lower Wilcox Rockdale delta system of Texas (24,000 square miles), the Lower Wilcox Holly Springs delta of Louisiana and Mississippi (20,000 square miles), the Texas Yegua delta system (15,000 square miles), and the Jackson Fayette delta system (10,000 square miles). Maximum thickness, ranging from about 600 feet for the Holocene Mississippi to about 12,000 feet for the Eocene Lower Wilcox Rockdale system, depends on duration of the system. Principal facies are constructive types consisting chiefly of fluvial or fluvially influenced facies; destructive or marine facies are temporally distinct, forming during lobe abandonment, and volumetrically make up only a minor amount of the total system. These delta systems have been classed as high-constructive type systems which show pronounced marine modification of fluvial introduced and prograded sediments (Fisher, 1969). Fluvial facies of high-constructive deltas are localized along the basin edge. In the Texas Eocene, fluvial facies of these kinds of deltas are chiefly developed between the Colorado and Trinity Rivers. High-constructive delta systems develop extensive delta-plain facies characterized by elongate distributary channel sands, interdistributary and levee muds, and numerous bedded lignite deposits. Most of the commercial lignites of the Texas Gulf Basin are from delta plain facies of high-constructive deltas. Delta-plain facies grade downdip and down delta to delta-front sands with either elongate (barfinger) or lobate trends. Trends depend upon the rate and degree of sand storage in prograded channel mouth bars and the intensity of marine modification and redistribution of these prograded sand facies. Delta-front sands interfinger with and grade downdip or seaward to thick, organic-rich, prodelta muds.

Tertiary and Holocene high-constructive delta systems of the Gulf Basin support extensive strike-fed systems. In the Holocene northwestern Gulf, these include the chenier or strandplain system of southwestern Louisiana and the barrier bar and complementary lagoon-bay systems of the Upper Texas coast. In the Texas Eocene, comparable strike systems of the Lower Wilcox, Yegua, and Jackson are extensively developed in South Texas, generally south-southwest of the Guadalupe River. Sand- and mud-size sediments were reworked and redistributed from the delta systems by prevailingly southwest longshore currents. Sands accumulated as strandplain or barrier-bar units depending chiefly on rate of strike feeding. Both are bounded landware by lagoonal mud and seaward by marine shelf mud systems. Minor fluvial systems developed on the land side of these systems contributed local source of sediment to these predominantly strike-fed facies. Progradation associated with the minor dip-oriented units is slight. Most of the sediment is modified by marine processes and incorporated in the strike system. In the Holocene northwestern Gulf, such streams as the Colorado and Brazos contributed minor amounts of sediment to the Upper Texas strike systems. In the Lower Wilcox, no such fluvial units have been delineated. They were, however, important in the dispersal systems of both the Yegua and Jackson. The strike systems of the Yegua and Jackson are consequently comparable in thickness to the supporting delta systems.

REFERENCES

Andersen, H. V. (1960) Geology of Sabine Parish: Louisiana Geol. Survey, Geol. Bull. 34, 164 pp.

Bernard, H. A., and LeBlanc, R. J., Sr. (1965) Resume of Quaternary geology of the northwestern Gulf of



15. Distribution of principal depositional systems, contrasting Eocene Lower Wilcox, Yegua, and Jackson of Texas, and Holocene of northwestern Gulf of Mexico. Modified from Fisher (1969) and Fisher and McGowen (1967).

Mexico province, *in* The Quaternary of the United States: VII Congress of the International Association for Quaternary Research, Princeton Univ. Press, pp. 137-185.

——, Major, C. F., Jr., Parrott, B. S., and LeBlanc, R. J., Sr. (1970) Recent sediments of southeast Texas--A field guide to the Brazos alluvial and deltaic plains and the Galveston Barrier Island complex: Univ. Texas, Bur. Econ. Geology Guidebook 11.

Brown, L. F., Jr. (1969a) Geometry and distribution of fluvial and deltaic sandstones (Pennsylvanian and Permian), north-central Texas: Trans. Gulf Coast Assoc. Geol. Socs., vol. 19, pp. 23-47.

——, (1969b) North Texas (Eastern Shelf) Pennsylvanian delta systems, *in* Delta systems in the exploration for oil and gas: Univ. Texas, Bur. Econ. Geology Spec. Pub., pp. 40-53.

Byrne, J. V., LeRoy, D. O., and Riley, C. M. (1959) The chenier plain and its stratigraphy, southwestern Louisiana: Trans. Gulf Coast Assoc. Geol. Socs., vol. 9, pp. 237-260.

Coleman, J. M., and Gagliano, S. M. (1964) Cyclic sedimentation in the Mississippi River deltaic plain: Trans. Gulf Coast Assoc. Geol. Socs., vol. 14, pp. 67-80.

Cushman, J. A., and Applin, E. R. (1926) Texas Jackson Foraminifera: Bull. Amer. Assoc. Petrol. Geol., vol. 10, pp. 154-189.

Delaney, P. J. V. (1957) Stratigraphy of the Vicksburg equivalent of Louisiana: Louisiana State Univ., M. S. Thesis, 69 pp.

Denson, N. M., and Gill, J. R. (1955) Uranium-bearing lignite and its relation to volcanic tuffs in eastern Montana and North and South Dakota: U. S. Geol. Survey Paper 300, pp. 413-418.

Deussen, Alexander (1924) Geology of the Coastal Plain of Texas west of Brazos River: U. S. Geol. Survey Prof. Paper 126, pp. 80-181.

Dumble, E. T. (1918) The geology of East Texas: Univ. Texas Bull. 1869, 388 pp.

——, (1924) A revision of the Texas Tertiary section with special reference to the oil-well geology of the Coast Region: Bull. Amer. Assoc. Petrol. Geol., vol.8, pp. 424-444.

Eargle, D. H. (1959a) Sedimentation and structure, Jackson Group, south-central Texas: Trans. Gulf Coast Assoc. Geol. Socs., vol. 9, pp. 31-39.

——, (1959b) Stratigraphy of Jackson Group (Eocene), south-central Texas: Bull. Amer. Assoc. Petrol. Geol., vol. 43, pp. 2623-2635.

——, (1970) Uranium in Texas: U. S. Geol. Survey Open-File Report, 12 pp.

——, and Weeks, A. D. (1961) Possible relation between hydrogen sulfide-bearing hydrocarbons in fault-line oil fields and uranium deposits in the southeast Texas Coastal Plain: U. S. Geol. Survey Prof. Paper 424-D, pp. 7-9.

Ellisor, A. A. (1933) Jackson Group of formations in Texas, with notes on Frio and Vicksburg: Bull. Amer. Assoc. Petrol. Geol. Vol. 17, pp. 1293-1350.

Fisher, R. P., and Stewart, J. H. (1960) Distribution and lithologic characteristics of sandstone beds that contain deposits of copper, vanadium, and uranium: U. S. Geol. Survey Prof. Paper 400-B, pp. B42-B44.

Fisher, W. L. (1963) Lignites of the Texas Gulf Coastal Plain: Univ. Texas, Bur. Econ. Geology Rept. Inv. 50, 104 pp.

——, (1968) Basic delta systems in the Eocene of the Gulf Coast Basin: Trans. Gulf Coast Assoc. Geol. Socs., vol. 18, p. 48.

——, (1969) Facies characterization of Gulf Coast delta systems, with some Holocene analogues: Trans. Gulf Coast Assoc. Geol. Socs., vol. 19, pp. 239-261.

——, and McGowen, J. H. (1967) Depositional systems in the Wilcox Group of Texas and their relationship to occurrence of oil and gas: Trans. Gulf Coast Assoc. Geol. Socs., vol. 17, pp. 105-125.

——, and ——, (1969) Depositional systems in the Wilcox Group (Eocene) of Texas and their relationship to occurrence of oil and gas: Bull. Amer. Assoc. Petrol. Geol., vol. 53, pp. 30-54.

——, and ——, (in press) Lower Eocene lagoonal systems in the Texas Gulf Coast Basin: UNESCO Simposio Internacional sobre Lagunas Costeras, Mexico, D. F.

——, Brown, L. F., Jr., Scott, A. J., and McGowen, J. H. (1969) Delta systems in the exploration for oil and gas: Univ. Texas, Bur. Econ. Geology Spec. Pub., 212 pp.

——, McGowen, J. H., and Nagle, J. S. (1968) Indio Lagoon system, Wilcox Group, south Texas, *in* Environments of deposition, Wilcox Group, Texas Gulf Coast: Field Trip Guidebook, Houston Geol. Soc., pp. 28-43.

Fisk, H. N. (1938) Geology of Grant and LaSalle Parishes: Louisiana Geol. Survey, Geol. Bull. 10, pp. 89-176.

——, (1955) Sand facies of recent Mississippi delta deposits: World Petrol. Cong., 4th, Rome, 1955, Proc., sec. 1, pp. 377-398.

——, (1960) Recent Mississippi River sedimentation and peat accumulation: Cong. Av. Etudes de Stratigraphie et de Geologie du Carbonifere, 4th, Sept. 15-20, 1958, Heerlen, Compte rendu, pp. 187-199, Maastricht, Netherlands.

——, *et al.* (1954) Sedimentary framework of the modern Mississippi delta: Jour. Sed. Petrology, vol. 24, pp. 76-99.

Flawn, P. T., Fisher, W. L., and Leach, C. H. (1969) Uranium in Texas, *in* Uranium in the southern United States: prepared by Southern Interstate Nuclear Board for U. S. Atomic Energy Commission, pp. 97-147.

Frazier, D. E. (1967) Recent deltaic deposits of the Mississippi River: their development and chronology: Trans. Gulf Coast Assoc. Geol. Socs., vol. 17, pp. 287-315.

——, and Osanik, Alex (1969) Recent peat deposits--Louisiana coastal plain, *in* Environments of coal deposition: Geol. Soc. America, Spec. Paper 114, pp. 63-85.

Galloway, W. E. (1968) Depositional systems of the Lower Wilcox Group, north-central Gulf Coast Basin: Trans. Gulf Coast Assoc. Geol. Socs., vol. 18, pp. 275-289.

——, (1970) Depositional systems and shelf-slope relationships in uppermost Pennsylvanian rocks, north-central Texas: Univ. Texas at Austin, Ph. D. dissertation.

Garrels, R. M. (1957) Geochemistry of "sandstone type" uranium deposits, *in* Second Nuclear Engineering and

Science Conference: Amer. Soc. Mech. Eng., paper no. 57-NESC-121.

Gould, H. R., and McFarlan, E. (1959) Geologic history of the chenier plain, southwestern Louisiana: Trans. Gulf Coast Assoc. Geol. Socs., vol. 9, pp. 261-270.

Gravell, D. W., and Hanna, M. A. (1935) Larger Foraminifera from the Moodys Branch marl, Jackson Eocene of Texas, Louisiana and Mississippi: Jour. Paleontology, vol. 9, pp. 327-340.

Gruner, J. W. (1956) Concentration of uranium in sediments by multiple migration-accretion: Econ. Geology, vol. 51, pp. 495-520.

Kennedy, W. H. (1892) Report on Grimes, Brazos, and Robertson counties: Texas Geol. Survey, 4th Ann. Rept. (1891), pt. 1, pp. 1-84.

Klohn, M. L., and Pickens, W. R. (1970) Geology of the Felder uranium deposit, Live Oak County, Texas: Reprint no. 70-I-38, Soc. Mining Engineers (presented at the AIME Annual Meeting, Denver, Colo., Feb. 15-19, 1970).

Kolb, C. R., and van Lopik, J. R. (1966) Depositional environments of the Mississippi River deltaic plain--southeastern Louisiana, *in* Deltas in their geologic framework: Houston Geol. Soc., Houston, pp. 17-61.

LeBlanc, R. J., Sr., and Hodgson, W. D. (1959) Origin and development of the Texas shoreline: Trans. Gulf Coast Assoc. Geol. Socs., vol. 9, pp. 197-220.

Love, J. D. (1952) Preliminary report on uranium deposits in the Pumpkin Buttes area, Powder River Basin, Wyoming: U. S. Geol. Survey Circ. 176, 37 pp.

Masursky, Harold (1955) Trace elements in coal in the Red Desert, Wyoming: U. S. Geol. Survey Prof. Paper 300, pp. 439-444.

McGowen, J. H., and Garner, L. E. (1970) Physiographic features and stratification types of coarse-grained point bars: modern and ancient examples: Sedimentology, vol. 14, Elsevier, Amsterdam, pp. 77-111.

Moxham, R. M., and Eargle, D. H. (1961) Airborne radioactivity and geologic map of the Coastal Plain area, southeast Texas: U. S. Geol. Survey Geophys. Inv. Map GP 198, scale 1:250,000, section, text.

Murray, G. E. (1961) Geology of the Atlantic and Gulf Coastal Province of North America: Harper and Bros., New York, 692 pp.

———, and Wilbert, L. J., Jr. (1950) Jacksonian stage: Bull. Amer. Assoc. Petrol. Geol., vol. 34, pp. 1990-1997.

Norton, D. L. (1970) Uranium geology of the Gulf Coastal area: Corpus Christi Geol. Soc. Bull., vol. 10, no. 5, pp. 19-26.

Pate, B. G. (1963) Significant North Louisiana Cotton Valley stratigraphic traps: Trans. Gulf Coast Assoc. Geol. Socs. vol. 13, pp. 177-183.

Patterson, J. M. (1942) Stratigraphy of Eocene between Laredo and Rio Grande City, Texas: Bull. Amer. Assoc. Petrol. Geol., vol. 26, pp. 256-274.

Penrose, R. A. F. (1890) A preliminary report on the geology of the Gulf Tertiaries from Red River to the Rio Grande: Texas Geol. Survey, 1st Ann. Rept. (1889), 47 pp.

Rackley, R. I., Shockey, P. N., and Dahill, M. P. (1968) Concepts and methods of uranium exploration: Wyoming Geol. Assoc. Guidebook, Black Hills Area, 12th Annual Field Conf., 1968, pp. 115-124.

Renick, B. C. (1936) The Jackson Group and the Catahoula and Oakville Formations in a part of the Texas Gulf Coastal Plain: Univ. Texas Bull. 3619, 104 pp.

Rosholt, J. N. (1960) A study of uranium migration in sandstone-type ore deposits: U. S. Geol. Survey Prof. Paper 400-B, pp. B41-B42.

Russell, W. L. (1955) Stratigraphy of the Wellborn and Manning Formations in east-central Texas: Trans. Gulf Coast Assoc. Geol. Socs., vol. 5, pp. 165-172.

Shelby, C. A. (1965) Heavy minerals in the Wellborn Formation, Lee and Burleson Counties, Texas: Univ. Texas, Bur. Econ. Geology Rept. Inv. 55, 55 pp.

Stenzel, H. B. (1940) The Yegua problem: Univ. Texas Bull. 3945 (Dec. 1, 1939), pp. 847-910.

———, (1952) Boundary problems: Mississippi Geol. Soc., Guidebook, 9th field trip, pp. 11-31.

Stuckey, C. W. (1960) A correlation of the Gulf Coast Jackson: Trans. Gulf Coast Assoc. Geol. Socs., vol. 10, pp. 285-298.

Thomas, W. A., and Mann, C. J. (1966) Late Jurassic depositional environments, Louisiana and Arkansas: Bull. Amer. Assoc. Petrol. Geol., vol. 50, pp. 178-182.

Treadwell, R. C. (1954) Moodys Branch-Cockfield contact in Sabine Parish, Louisiana, and adjacent areas: Bull. Amer. Assoc. Petrol. Geol., vol. 38, pp. 2302-2323.

Trowbridge, A. C. (1932) Tertiary and Quaternary geology of the lower Rio Grande region of Texas: U. S. Geol. Survey Bull. 837, pp. 141-156.

Waters, A. C., and Granger, H. C. (1953) Volcanic debris in uraniferous sandstone and its possible bearing on the origin and precipitation of uranium: U. S. Geol. Survey Circ. 224, 26 pp.

Weeks, A. D., and Eargle, D. H. (1963) Relation of diagenetic alteration and soil-forming processes to the uranium deposits of the southeast Texas Coastal Plain, *in* Clays and clay minerals, vol. 10--Natl. Conf. Clays and Clay Minerals, 10th, 1961, Proc.: New York, Macmillan Co. (Internat. Ser. Mons. Earth Sci., vol. 12), pp. 23-41.

West, T. S. (1963) Typical stratigraphic traps, Jackson trend of South Texas: Trans. Gulf Coast Geol. Assoc. Geol. Socs., vol. 13, pp. 67-78.