GEOLOGICAL CIRCULAR 75-3

Upper Pennsylvanian Limestone Banks, North Central Texas

BY

E. G. WERMUND

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E. G. Wermund

INTRODUCTION

Nelson and others (1962) define a *bank* as "... a skeletal deposit formed by organisms which do not have the ecologic potential to erect a rigid wave-resistant structure." They explain that a bank may have any geometry. The principal types or end members are biostromes which are thin, flat to lenticular deposits, or bioherms which are mounds. The American Geological Institute Glossary of Geology (1972) accepts this definition and adds "It is thinner than, and lacks the structural framework of, an organic reef." It is this kind of limestone bank which is the subject of the following report.

The purpose of this report is twofold: (1) to describe the regional distribution of upper Pennsylvanian, especially Missourian (Canyon), limestone banks in the subsurface of North-Central Texas, and (2) to relate the different calcareous facies observed in outcrops of Missourian limestone banks to modern calcareous environments.

There have been numerous, recent papers about the Missourian terrigenous clastic rocks in North-Central Texas but few describing limestone facies. Brown and Goodson (1972), Brown and others (1973), Erxleben (1974), Galloway and Brown (1972, 1973), and Wermund and Jenkins (1970) have shown extensive deltaic deposition during Missourian and Virgilian times. Galloway and Brown (1972, 1973) have also shown how clastic slope deposits infill the basins in the same region.

Although there have been several studies of outcrops of Missourian calcareous facies, this research does not appear in the literature. Unfortunately, work by Pollard (1970) in the Possum Kingdom area of Palo Pinto County, Raish (1964) in the Chico Ridge Bank of Wise County, and Roepke (1970) in the Colorado River valley has not been published. I have previously described some aspects of the limestones in the Possum Kingdom Bank of Palo Pinto County (Wermund, 1966, 1969) but never demonstrated entirely the regional significance of the Pennsylvanian calcareous rocks. Modern calcareous environments have been described in depth in the recent literature, but no analogs of modern and Missourian calcareous sediments have been suggested.

Both the regional distribution and modern analogs of Missourian limestones are emphasized here. Analogs of modern sedimentation are interpreted from outcrop studies. Locations of significant outcrops are listed in an appendix and are intended as potential field trip stops.

Acknowledgments.—Much of the work which is described herein was done while I was employed at the Field Research Laboratory of the Mobil Research and Development Corporation. I am grateful for their support, encouragement, and release of the data. At Mobil, I had the opportunity to discuss numerous ideas presented herein with Dan E. Feray, William A. Jenkins, Jr., and Eugene L. Jones, all of whom made valuable critical comments. I was able to spend a week in Florida where Karl Klement, The University of Texas at El Paso, showed me the activity of calcareous algae. I have also received careful reviews by D. G. Bebout and R. S. Kier of the Bureau of Economic Geology.

The manuscript was typed by Jamie Tillerson and initially edited by Elizabeth Moore. Drafting was supervised by Alexander S. Pearce III of Mobil and James Macon of the Bureau. Final editing was by Kelley Kennedy and composing was by Fannie Mae Sellingsloh.

REGIONAL SETTING

Pennsylvanian Tectonic Framework

The study area of this paper lies within the Eastern shelf of the West Texas basin (fig. 1). Throughout the deposition of Missourian limestone banks, the shelf was inclined gently northwestward into the Midland basin. Present-day structure on top of the Missourian Series dips less than 40 feet per mile northwestward (Wermund and Jenkins, 1969). Extensive terrigenous deposits, which sometimes interfered with calcareous bank deposition, originated both from the north in mountains which occupied the present location of the Amarillo uplift, Wichita Mountains, and Arbuckle Mountains, and from the east and north in mountains which occupied the present position of the buried Ouachita folded belt. Most of the Fort Worth basin was filled before Missourian time, after which it was occupied by a foreland or piedmont plain of the Ouachita system. The Llano uplift stood barely above sea level and was never a significant highland source (Wermund and Jenkins, 1970).

The Eastern shelf was extensively inundated by a shallow epeiric sea in a relatively stable tectonic setting except for Ouachita epeirogenesis and tilting of the Eastern shelf during late Missourian (Wermund and Jenkins, 1964). The western edge of the shelf sloped steeply into the Midland basin where major slope deposits accumulated (Galloway and Brown, 1972, 1973).

Stratigraphy

The composition of Missourian rocks in a generalized section includes terrigenous mudstone (shale), sandstone, limestone, and rare thin coals (fig. 2). Most shales are gray shales, but red shales are present in the northern mapped areas. Sandstones are rarely laterally persistent units, whereas limestones are commonly persistent for as much as 100 miles along a sedimentary strike. The thin coals are rarely persistent and cannot be correlated through the subsurface using controls of this study (Evans, 1974). The composition of an average well, obtained by cumulating data from 2,500 wells drilled into Missourian rocks, is 67 percent terrigenous mudstone, 12 percent sandstone, and 21 percent limestone.

Examination of cuttings and study of sample logs show that dolomite is very rare, generally absent in all subsurface banks of the upper Pennsylvanian Eastern shelf.

Also there is a dense, black pyritic shale observed in cuttings which, in the central part of the Midland basin, is equivalent to the bank limestones at the shelf edge in late Desmoinesian and early Missourian. The black shale represents an euxinic, nearly non-depositional phase of Midland basin history, representative of the starved basin described by Adams and others (1951).

Figure 2 shows the formal stratigraphy of the outcrop compared to numbered units of the subsurface described previously by Wermund and Jenkins (1970). The top of the Missourian is the top of subsurface equivalents of the Home Creek Limestone, and the base of the Missourian is the top of subsurface equivalents of the Capps and Dog Bend Limestones. The numbered units are intervals of approximately equal thickness except for adjustments to correlations at the shelf edge and slope.

Although Missourian limestones occur throughout the Missourian section, only the thickest and most widespread calcareous banks are described. Therefore, the regional distribution of limestones in intervals 5-6 and 9-10 is emphasized.

A review of previous work was published by Wermund (1966), and a report containing the rationale for subdividing the formal and subsurface stratigraphy is in preparation for publication in 1975. Therefore, it is recommended that interested readers look into these subjects in the cited references.

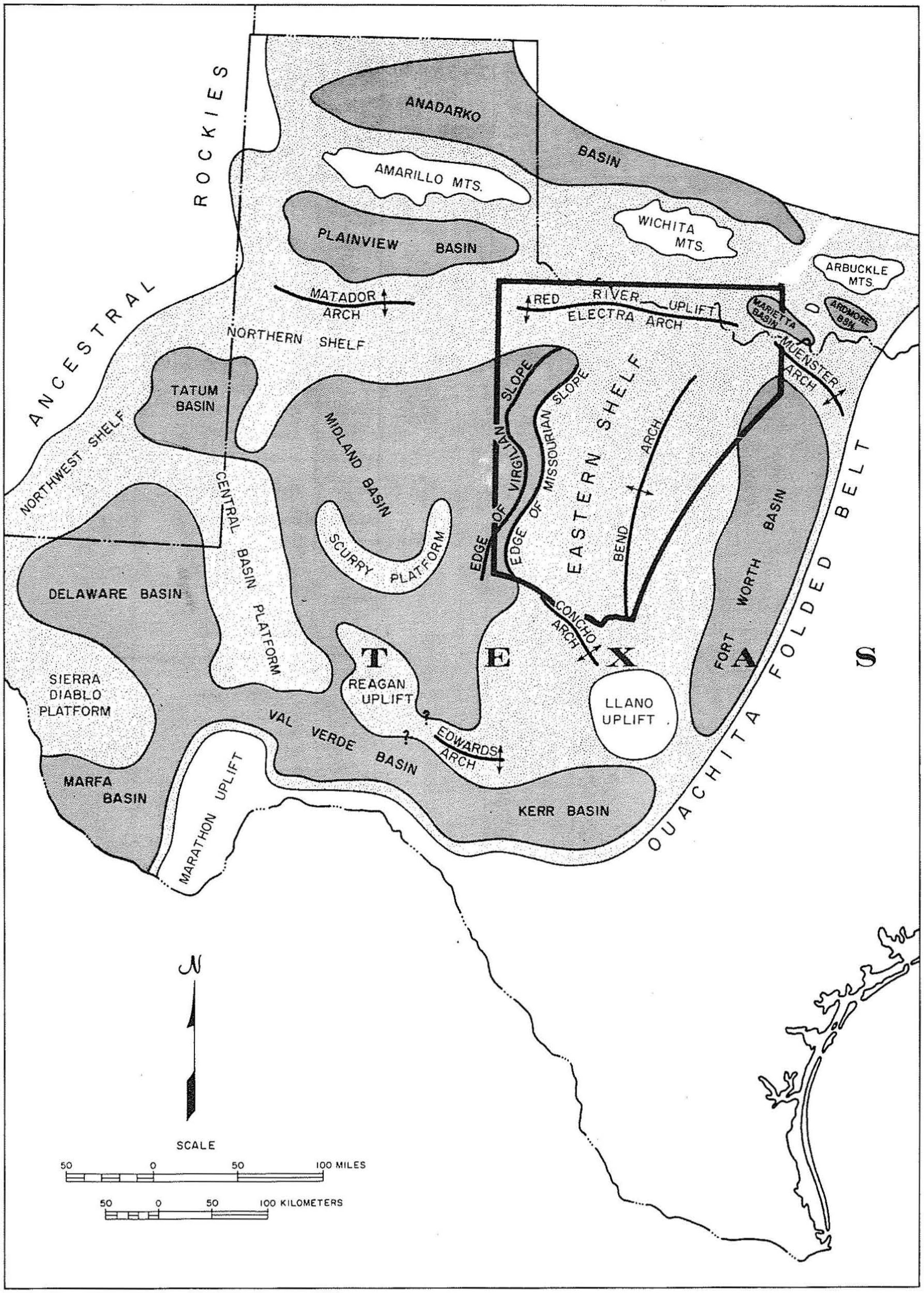


Figure 1. Upper Pennsylvanian tectonic setting surrounding the Eastern shelf of North-Central Texas during limestone bank deposition.

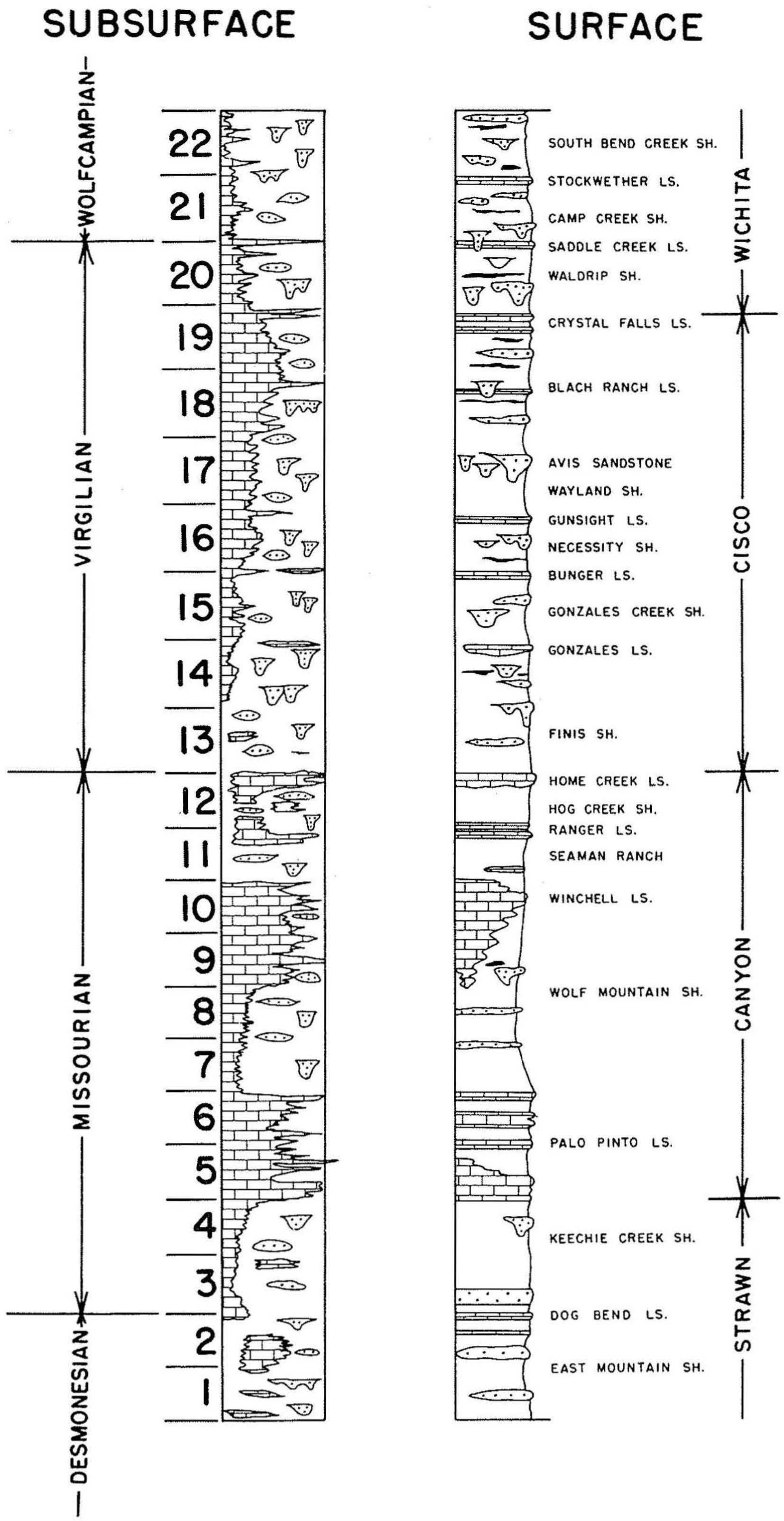


Figure 2. Stratigraphy-formal nomenclature at the surface and geometric subdivisions of the subsurface.

REGIONAL DISTRIBUTION OF LIMESTONES

A number of previous workers have studied outcrops of the Missourian limestones and reported interpretations of the facies (Bretsky, 1966; Brooks and Bretsky, 1966; Pollard, 1970; Raish, 1964; Roepke, 1970; and Wermund, 1966, 1969). Harrington and Hazlewood, 1962; Kerr, 1969; and Toomey and Winland, 1973 have described aspects of the limestone facies in the subsurface. The regional extent and the geometry of the limestone banks have not been described previously. As shown in the following, the limestone banks are moderately thick but extensive deposits.

Areal Distribution of Limestones

Only a small part of the Missourian limestone banks of the Eastern shelf (less than one percent) are exposed in outcrops of North-Central Texas. It is necessary to study subsurface equivalents of the outcropping banks to appreciate their areal extent. As part of a regional study by Wermund and Jenkins (1969, 1970), Missourian limestones were correlated in 2,500 wells throughout much of North-Central Texas, representing approximately 19,000 square miles. The amount of limestone, sandstone, and terrigenous mudstone was measured in each interval from mechanical logs. Although one sample log was used for each 10 mechanical logs, the sample logs, which were old, did not have detailed lithologic descriptions. Furthermore, no cores were available in the study. From these data, a variety of lithofacies maps were constructed in which the areal distribution of the carbonate banks is demonstrated.

The Palo Pinto and Winchell limestone banks are emphasized in this paper because they well represent the Missourian limestone banks in both the surface and subsurface. In the subsurface, the Palo Pinto limestone bank occurs in subsurface intervals 5 and 6, whereas the Winchell limestone bank occurs in intervals 9 and 10 (fig. 2). Isolith maps showing the percentage of limestone portray the areal distribution of the Palo Pinto and Winchell banks (figs. 3 and 4).

Patterns.—Three patterns of Missourian limestone banks are clearly represented in a sequence of subsurface lithofacies maps. They are elongate trends, oblate patches that persist vertically at one locality through several intervals, and isolated patches that only occur in one interval.

The three elongate trends of the Palo Pinto and Winchell bank limestones (figs. 3 and 4) are characteristic of Missourian lithofacies patterns. They are two northeast trends and one east-west trend. The east-west elongate bank overlies the Red River uplift and corresponds to eastward-striking series of buried granitic highs. In places, it is documented that Missourian limestone immediately overlies granite. The two elongate northeastward-trending banks are not known to overlie older structures. Generally, the stable oblate patches are widespread in older intervals and decrease in area in successively younger intervals, resulting in a cone-shaped deposit.

Extent.—The areal extent of the Missourian limestone banks is large. Where the 60 percent isolith contour of the Winchell limestone bank intersects (crops out) the surface in Palo Pinto County (fig. 4), the thickness of Winchell limestone bank is measured as nearly 150 feet of continuous limestone (Wermund, 1969). Therefore, the 60 percent isolith is the basis for the following measurements.

For the Palo Pinto limestone bank, the elongate east-west bank (area A of fig. 3) is approximately 75 miles long and a maximum of 33 miles wide. It includes 1,075 square miles. The westernmost elongate trend (B) is 125 miles long and up to 20 miles wide. The mapped extent measures 1,300 square miles; an additional southwestern part of the bank has not been mapped. The easternmost elongate trend includes a series of lesser trends, the largest of which extends from Callahan into Young County. This last limestone bank (C) is 70 miles long, 13 miles wide, and 550 square miles in extent. The smaller trends, part of the general Palo Pinto depositional strike, include from southwest to northeast 140 (D), 175 (E), 120 (F), and 100 (G) square miles. The stable oblate patch in Baylor and Archer Counties covers 135 square miles. Isolated ephemeral bank deposits in Stonewall and Knox Counties are, respectively, 14 and 7 square miles in area.

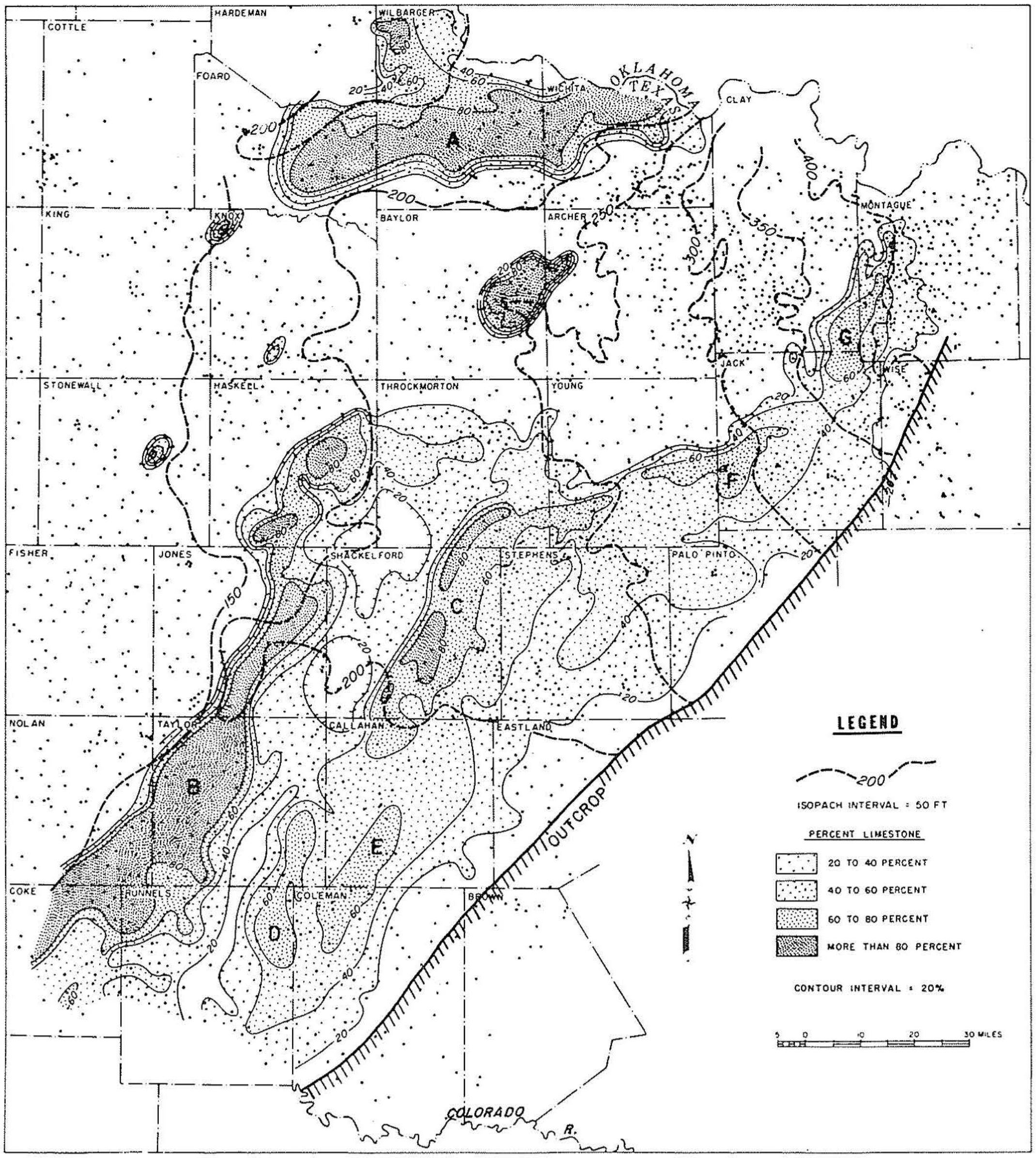


Figure 3. Isolith map for the percentage of limestone in equivalents of the Palo Pinto Limestone—subsurface intervals 5 and 6. Letters refer to bank limestones whose size is described in text.

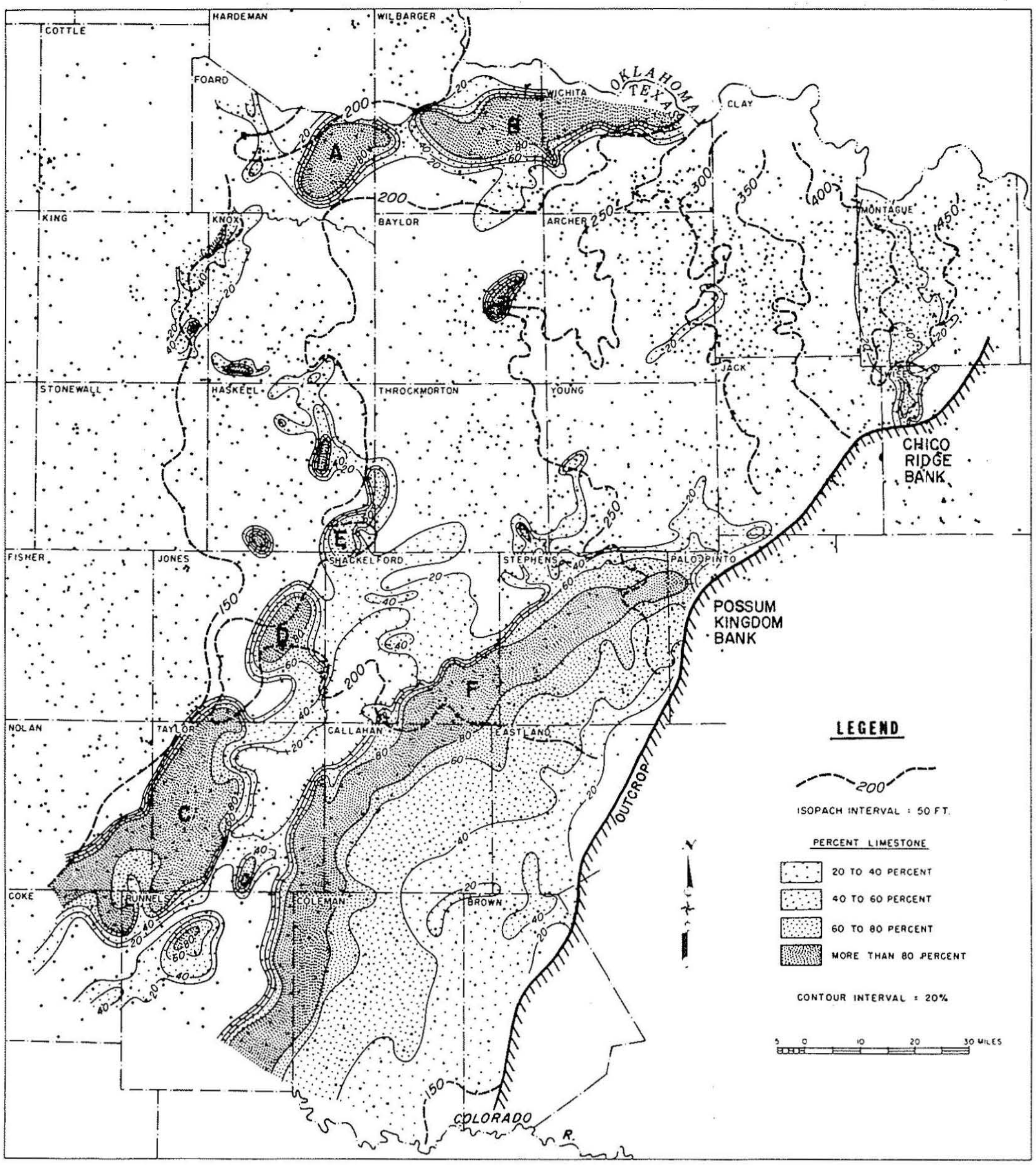


Figure 4. Isolith map for the percentage of limestone in equivalents of the Winchell Limestone—subsurface intervals 9 and 10. Letters refer to bank limestones whose size is described in the text. Major bank limestones crop out at Chico Ridge and the Possum Kingdom vicinity.

Paralleling the Red River uplift, there are two Winchell limestone banks. The westernmost bank (area A of fig. 4) is 22 miles long, 12 miles wide, and 175 square miles in area. The easternmost buildup (B), not completely mapped as it extends beyond the study area into Oklahoma, is 45 miles long and 10 miles wide and approaches 400 square miles in extent. The westernmost elongate trend is a series of banks, the largest of which has not been completely mapped to the southwest. However, the mapped portion (C) is more than 32 miles long and up to 17 miles wide including 675 square miles of bank deposits. Smaller elongate deposits of the same trend include 135 square miles in Jones County (D) and 50 square miles in Haskell and Throckmorton Counties (E). The easternmost elongate trend has not been mapped south of the Colorado River. Nevertheless, it is the largest known Missourian limestone bank. The mapped part (F) is 127 miles long, a maximum of 20 miles wide, and 1,720 square miles in extent.

The permanent oblate area containing Palo Pinto and Winchell limestones, in Baylor County, includes 21 square miles. A small elongate patch in Wise County, part of which is exposed at Lake Bridgeport, includes 28 square miles. This small elongate bank has been called the Chico Bank by Feray and Brooks (1966). Three oblate banks, occurring in only Winchell equivalents, include 14 square miles in Knox County, 14 square miles in southern Haskell County, and 7 square miles in northeastern Haskell County. The latter deposit should be considered an extension of the westernmost of the two northeastward-trending Winchell limestone banks.

It is important to note that the extent of thinner extensions of the limestone banks which intercalate with the surrounding terrigenous facies can be interpreted from examining the spacing of the percent limestone contours of the isolith map (figs. 3 and 4). Where there is an abrupt transition from limestone bank (greater than 60 percent limestone) to terrigenous mudstone, the contours are close together. Where intercalations include extensive fingers of limestone transitional to shale, the contours are widely spaced (figs. 3 and 4).

Intercalations.—Several generalities about the areal distribution of Missourian limestone bank-terrigenous mudstone facies transitions are apparent. In both the persistent and ephemeral small oblate banks, intercalations occur in relatively short distances in all directions. This narrow transition zone is also evident on the elongate east-west-trending banks. However, on the elongate northeastward-trending banks there is a narrow zone of intercalation to the west and a broad area of interfingering to the east, best developed on the eastern (most landward) limestone bank.

Regional versus local distribution.—One way of separating regional and local dispersal patterns of facies is the use of polynomial surface fittings, sometimes called trend surface mapping. The mechanics of how surfaces can be fit to facies data for identifying regional and local elements of deposition are explained in detail by Wermund and Jenkins (1970). Related to a selected polynomial function, the sum of the squares of all points is best fitted to a curved surface, algebraically defined. This surface represents the regional trend of mapped values and can be contoured relative to input values, in our case the percentage of limestone. Values that fall above the best fitted surface are positive residuals, and those below the surface are negative residuals. Residuals are dominated by local controls.

To introduce polynomial surface maps of limestone bank facies and to amplify prior descriptions of the areal distribution of the Missourian limestone bank facies, the results of two different lithofacies mapping techniques are shown here. Interval 10 is shown as an example of a three-component map of the limestone, sandstone, and shale in upper Winchell equivalents (fig. 5). It can be compared to a fourth-order polynomial trend surface map which shows the percentage of limestone in the same stratigraphic interval (fig. 6).

The basic patterns of larger elongate trends and local concentrations of limestone banks are repeated in both types of lithofacies maps. The intercalations of limestone and shale are also repeated in similar proportions. Somewhat more limestone is evident locally on the three-component map (fig. 5), as in eastern Young County. The elongate trends of limestone banks appear narrower on the polynomial surface map (fig. 6). This is to be expected as the trends in the latter map type are local residuals contoured as positive features. The *regional* distribution of limestone banks is indicated by the polynomial fit as shown by the heavy contour lines. The regional contour lines show that a northeast-southwest trend dominates for the mapped upper Winchell

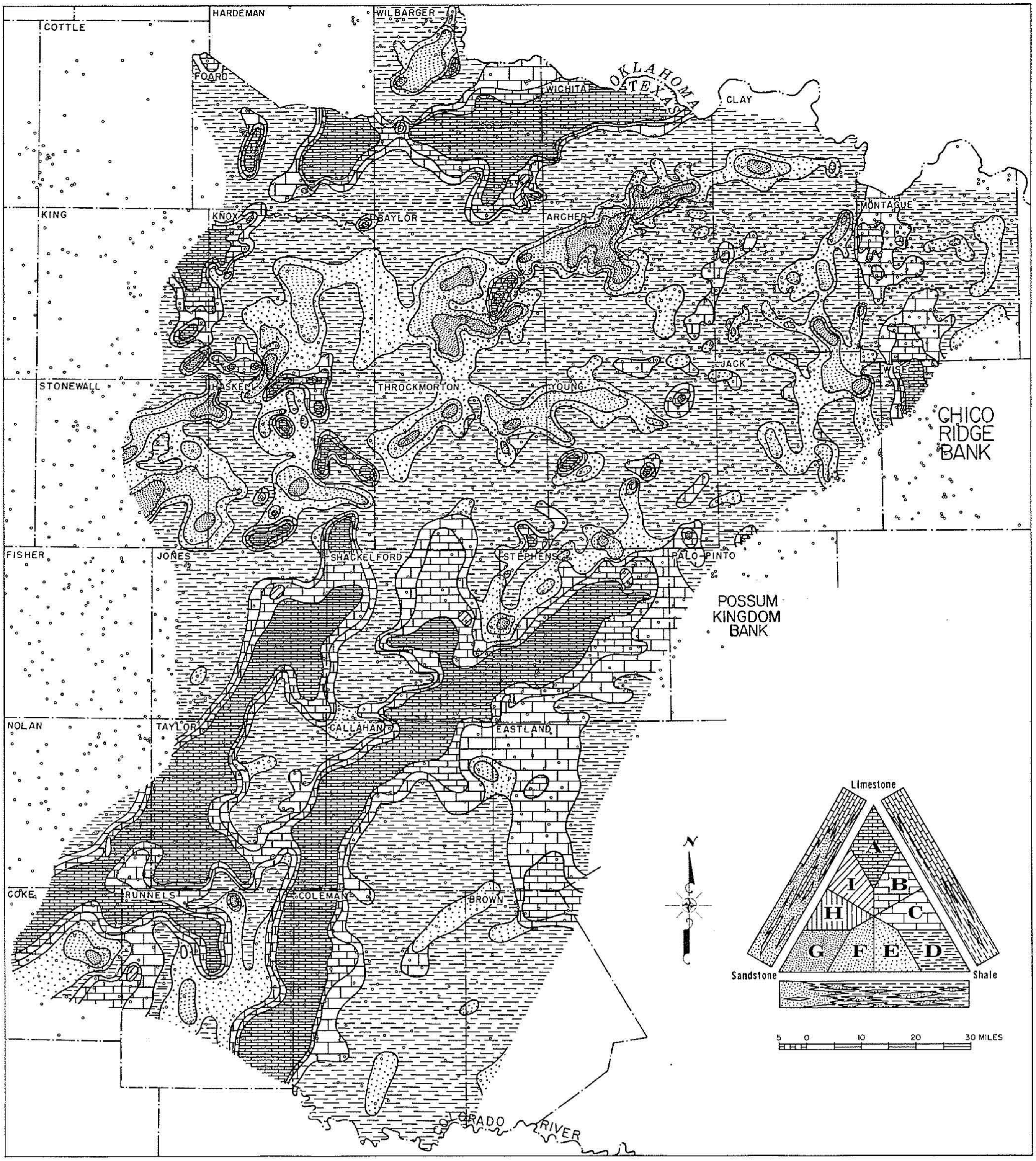


Figure 5. Three-component map of subsurface interval 10—upper Winchell Limestone. Notice a major sand body intercepts bank deposition between the Possum Kingdom bank and Chico Ridge bank.

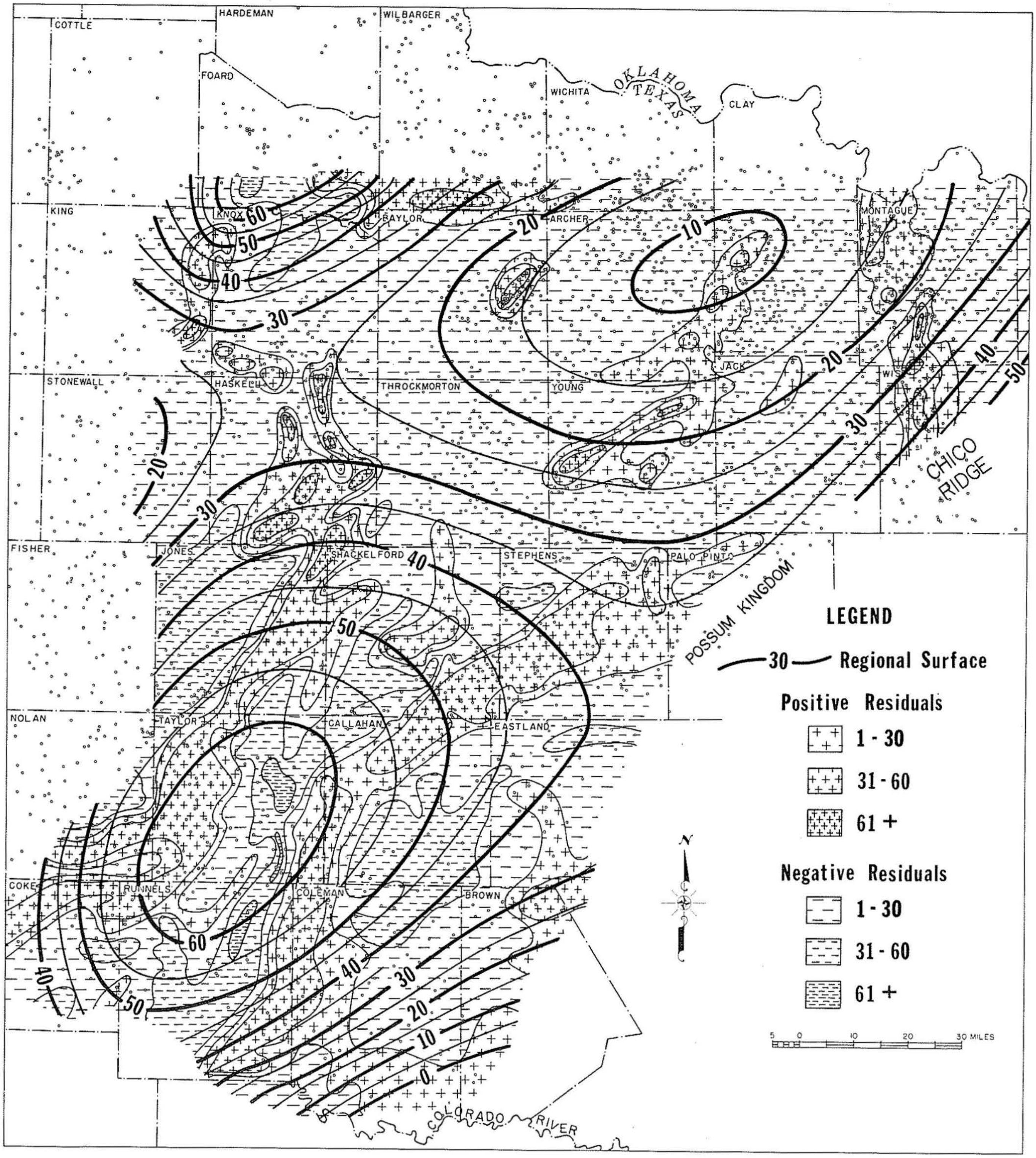


Figure 6. Map of an order 4 polynomial surface fitted to the percentage of limestone in subsurface interval 10. Both the regional surface and residual anomalies, positive and negative, are contoured.

limestone bank, interval 10 (fig. 2). Note that the negative residuals (shale pattern) also trend northeast-southwest between and parallel to the elongate limestone banks (fig. 7).

The trends of the negative residuals are an important aspect of the regional areal distribution of Missourian limestone banks. This is shown in a sequence of abstracted polynomial surface maps, wherein only the major regional contours and local effects of patterned residuals are highlighted (fig. 7). The most characteristic regional contours remain; the positive residuals are shown as a limestone pattern; and the directional sense of prominent negative residuals are shown as lines. Negative residuals of limestone characteristically have a dendritic pattern as if headward erosion into the elongate limestone banks developed normal to major trends (figs. 6 and 7) and carried detritus into the deeper basins. For comparative purposes, polynomial maps of the same area show the percentage of sandstone (fig. 8).

There is a change in the major trend of regional contours from intervals 5 through 12. Regional contours (trend surface values) strike generally northeast in intervals 5 through 10. They strike generally north in intervals 11 and 12 reflecting regional epeirogenesis reported previously by Wermund and Jenkins (1964).

Vertical Distribution of Limestones

The vertical distribution of limestones is illustrated by two cross sections representative of all the cross sections constructed in the study. In both cross sections, the thickness of extensive limestone banks is exaggerated where they are less than 20 feet in thickness. One cross section follows an elongate bank, parallel to a probable shoreline and to the regional sedimentary strike (fig. 9). This section was constructed on top of the first subsurface appearance of the Home Creek Limestone, top of the Missourian rocks, below downdip levels of casing.

The other cross section reflects the dip of the Eastern shelf into the Midland basin (fig. 10). The Coleman Junction Limestone is the datum for construction. Missourian, Virgilian, and Wolfcampian rocks are displayed.

Sedimentary strike.—The effective shape of most Missourian limestone banks is biostromal (fig. 9). A continuous Palo Pinto limestone bank is more than 150 miles long; its maximum thickness is 340 feet of bank limestones with minor intercalated terrigenous mudstones located in Jack County. Northeast into Montague County, it separates into thinner and thinner bank limestones, more persistent at the base. Southwest into Stephens County, it becomes nearly continuous limestone, 210 feet thick, and from there it breaks into thinner bank limestones more persistent at the top.

The Winchell limestone bank extends 370 miles from the Colorado River into central Jack County. It has a maximum thickness of 220 feet of continuous limestone in Stephens County. Northeast of Young County, the Winchell bank pinches out very rapidly in Jack County against equivalent rocks of sand and shale belonging to the Missourian Perrin delta of equivalent age (Erxleben, 1974). In Wise and Montague Counties, a less extensive Winchell limestone bank is more than 100 miles long with up to 220 feet of bank limestones and some interbedded terrigenous mudstones.

Above the Winchell banks, there are thinner, less extensive banks of the Ranger and Home Creek Formations (fig. 8).

Shelf-slope geometry.—Normal to the shoreline, the top of the Winchell Limestone approximates depositional dip on the shelf (fig. 10). Several aspects of the geometry of upper Paleozoic limestone banks are illustrated. In the younger section above the Home Creek Limestone, the Virgilian and Wolfcampian Limestones form a thick bank up to 900 feet thick. East and landward of the thick buildup of bank limestones, there are long fingers of bank limestone intercalating with terrigenous mudstone. The limestones of the buildup and the shoreward facies are light colored and generally fossiliferous. West and basinward of most of the upper part of the thick bank, there is a rapid transition to terrigenous mudstone. West and basinward of the base of the buildup is also a limestone ramp which conforms with a depositional slope into the Midland basin. In ditch samples, these slope limestones are dark black micrites which contain only rare transported or abraded fossils.

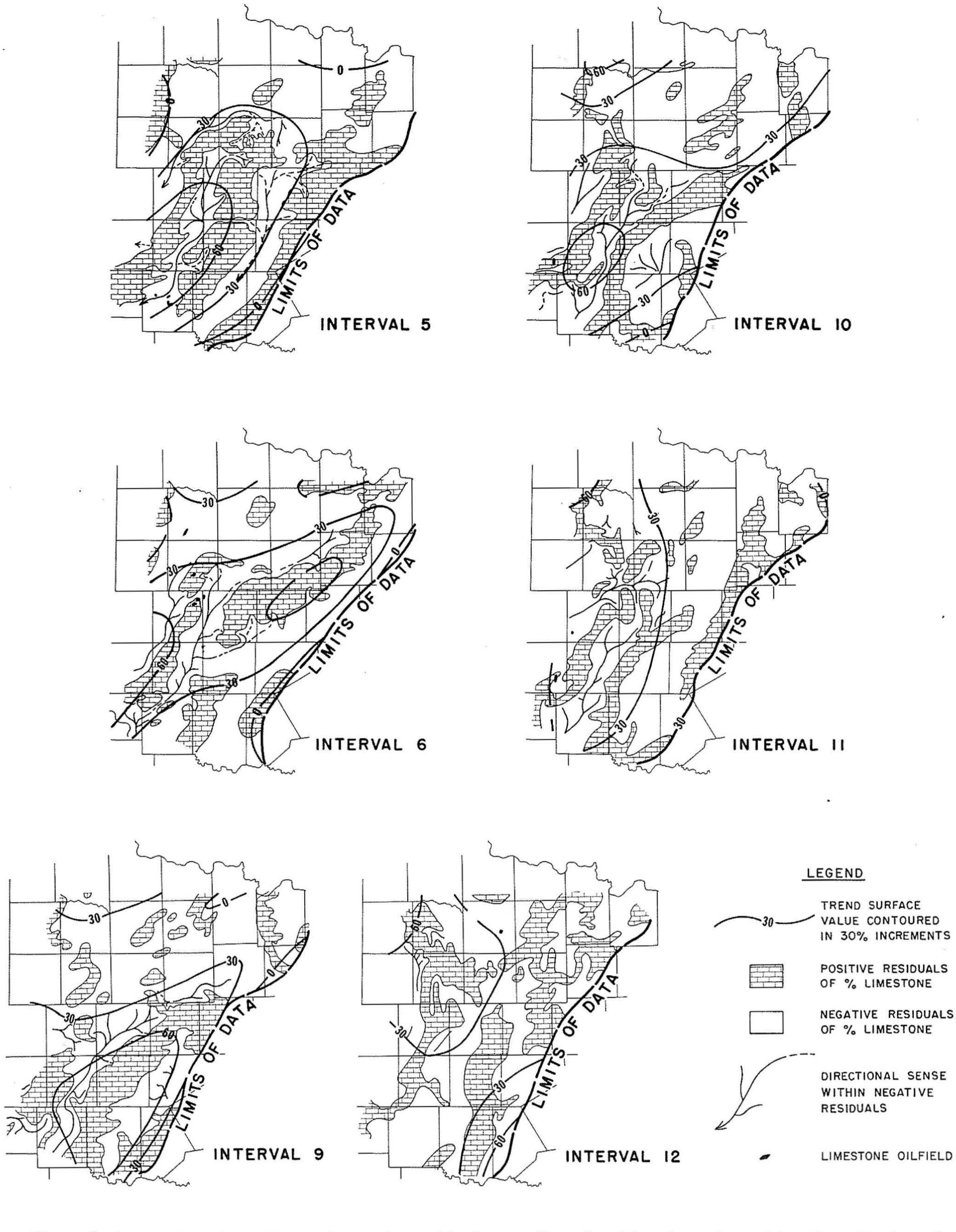


Figure 7. Schematics of positive and negative residual anomalies of a 4th-order polynomial surface fitted to the percentage of limestone in Missourian subsurface intervals 5, 6, and 9-12. Compare figure 6 to schematic of subsurface interval 10 of this figure.

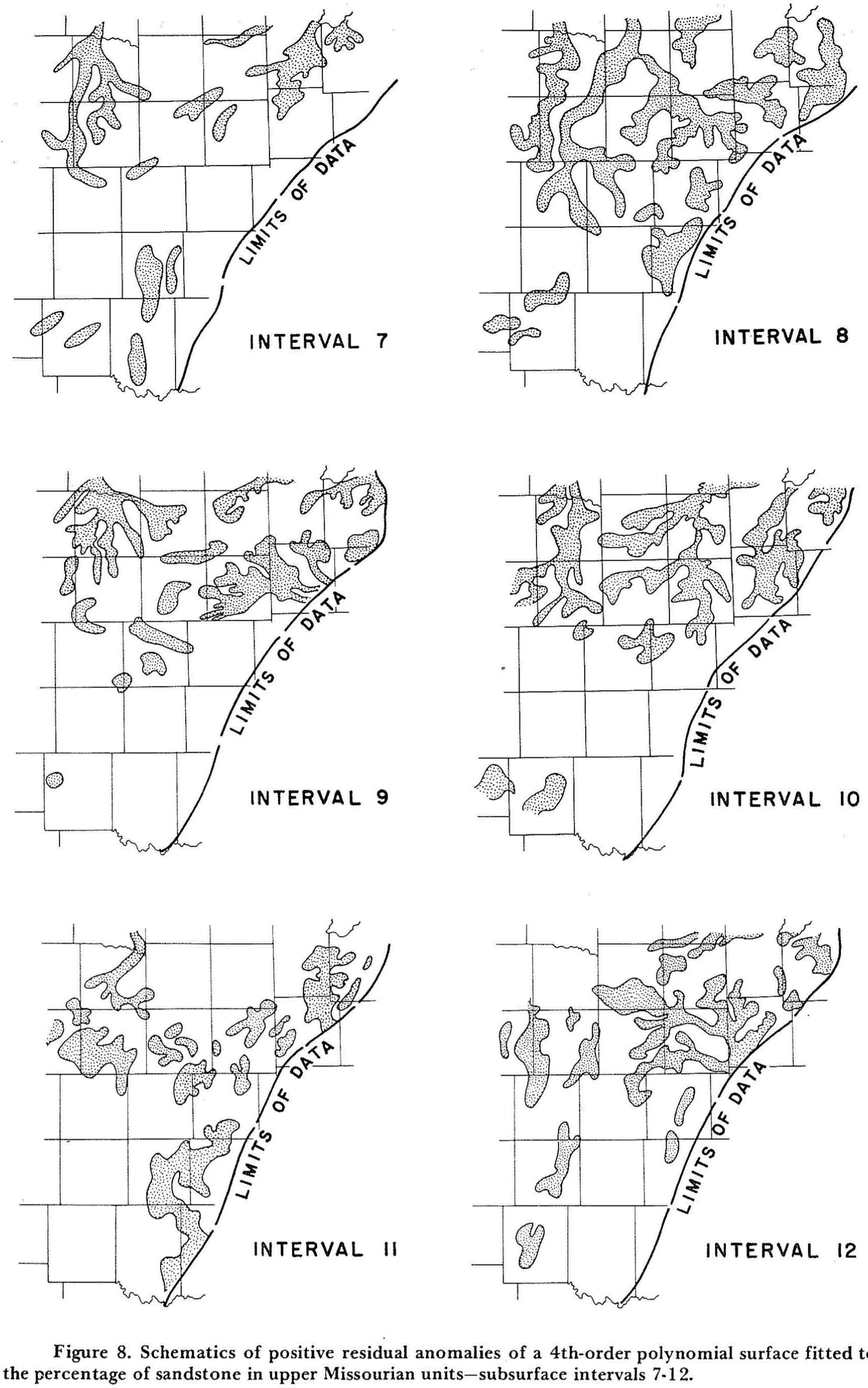


Figure 8. Schematics of positive residual anomalies of a 4th-order polynomial surface fitted to the percentage of sandstone in upper Missourian units—subsurface intervals 7-12.

The slope limestones dipping into the basin were first recognized as conforming to depositional dip (clinothems) by Rall and Rall (1958) and Van Siclen (1958). Galloway and Brown (1972, 1973) interpret cross sections of Virgilian rocks (similar to fig. 10) in which a slope system dominated by sand and mud eventually fills the basin.

Below the Home Creek Limestone, a markedly different geometry is formed by limestone banks of Missourian and Desmoinesian age. There is again a thick buildup of limestone bank at the shelf edge, more than 1,200 feet of nearly continuous limestone. These shelf-edge limestones are light colored and fossiliferous in well cuttings and are much like limestones in outcrops described later in this paper. Basinward of the shelf-edge bank limestone, there is a rapid transition to mudstone. The clinoform beds or slope limestones were not recognized from the widely spaced wells. On the opposite side of the basin, the eastern side of the Scurry limestone bank (described as a reef atoll by Myers and others, 1956) has a similar geometry.

Between the thicker limestone banks, as described earlier in plan view, are local buildups of limestone banks. An example is the Palo Pinto equivalent in well 80 of Shackelford County (fig. 10).

Additional aspects of the calcareous-terrigenous relationships are important toward developing a model of regional limestone bank deposition. Limestone banks may be in contact with sandstones. The most common case shows limestone clearly resting on sandstone well 65 in Shackelford County (fig. 10). The equal proximity of sandstone and limestone at the same level in adjacent wells indicates the sandstone may grade into limestone (well 67 in Shackelford County).

VARIABLE ELEMENTS IN LIMESTONE BANKS

Most published reports concerning facies variations in Pennsylvanian limestone banks are from studies of outcrops. Exceptions are a few studies of cores and cuttings in producing fields by Harrington and Hazlewood (1962), Kerr (1969), and Toomey and Winland (1973). Furthermore, as pointed out in the introduction, not all of the outcrop studies are published. The following is an interpretation of facies which are observable in outcrops based on work by Perkins (1964) in Jack and Wise Counties, Pollard (1970) in the Possum Kingdom area of Palo Pinto County, Raish (1964) in the Chico Ridge Bank of Wise County, Roepke (1970) in the Colorado River valley, Wermund (1966, 1969) and some recent field work in the Possum Kingdom Bank of Palo Pinto County (figs. 3 and 4 for localities).

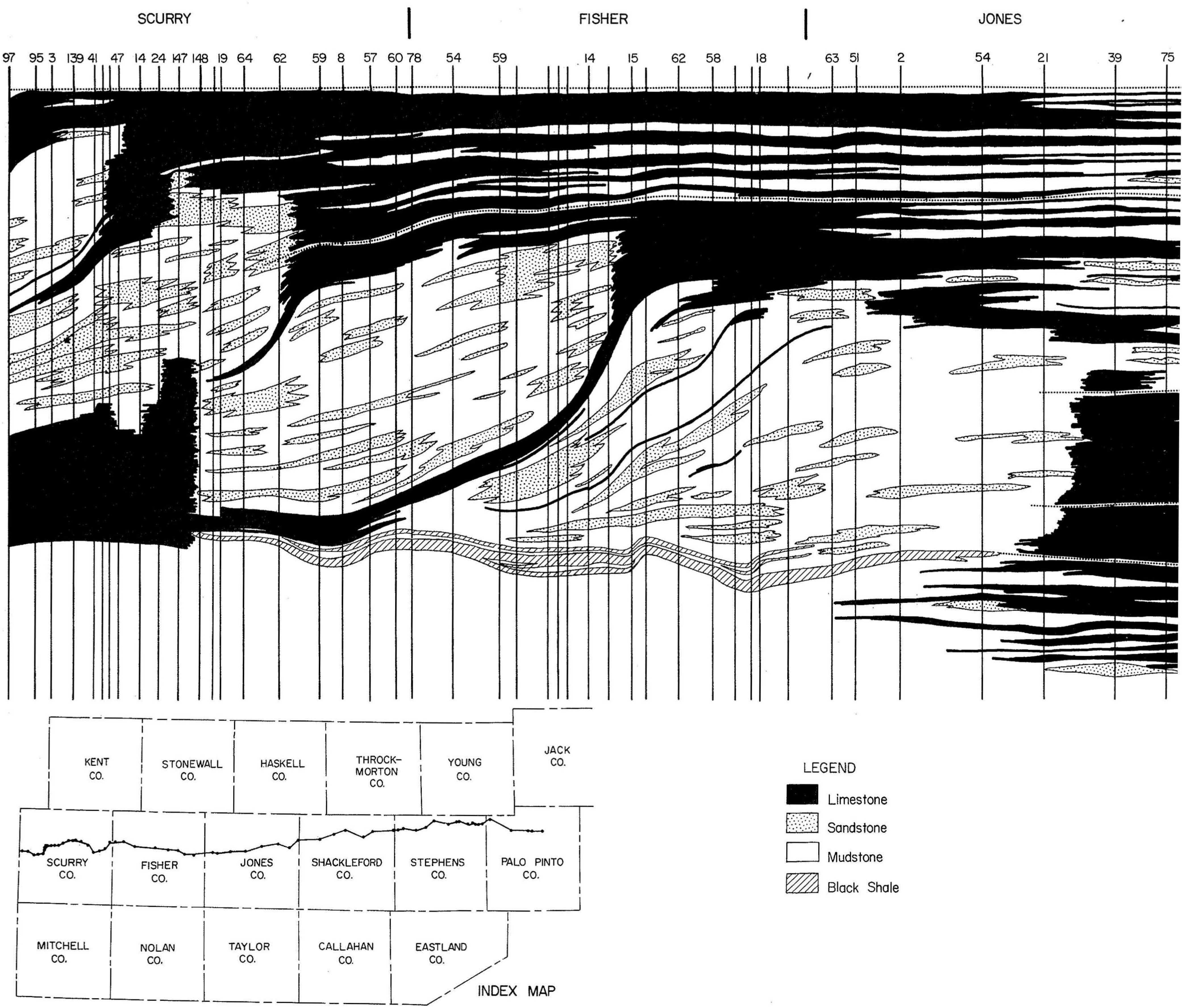
The major facies variations in Pennsylvanian limestone banks are (1) grain composition, (2) carbonate texture and fabric, (3) geometry and bed forms, and (4) relationship to terrigenous sediments.

Grain Composition

Allochems or minute fragments of allochems form the bulk of upper Pennsylvanian bank limestones. A majority of the allochems are faunal remains. The following table (table 1) identifies the major faunal contributors to bank accumulations according to several authors.

In table 1, the list of Raish (1964) is presented in the order in which he first mentions each organic allochem. In discussing the phylloid algae, he describes both *Eugonophyllum* which appears most abundantly in the thicker limestone bank and *Archaeolithophyllum* which occurs with greater frequency in thin limestone beds surrounded by shale. He identifies more sponges than the other listings and considers echinoderm remains ubiquitous in the limestone of the Wise County area. Phylloid algae, echinoderms, sponges, and fusulinids can be used to identify discrete facies. The remaining forms can occur in any facies especially bioclastic rocks. Raish's identification is based mainly on field identification and study of polished slabs.

Roepke's (1970, p. 55) list of organic allochems is presented in order of decreasing



SCURRY
FISHER
JONES
97 95 3 139 41 47 14 24 147 148 19 64 62 59 8 57 60 78 54 59 14 15 62 58 18 63 51 2 54 21 39 75
KENT CO.
STONEWALL CO.
HASKELL CO.
THROCK-MORTON CO.
YOUNG CO.
JACK CO.
SCURRY CO.
FISHER CO.
JONES CO.
SHACKLEFORD CO.
STEPHENS CO.
PALO PINTO CO.
MITCHELL CO.
NOLAN CO.
TAYLOR CO.
CALLAHAN CO.
EASTLAND CO.
INDEX MAP
LEGEND
Limestone
Sandstone
Mudstone
Black Shale

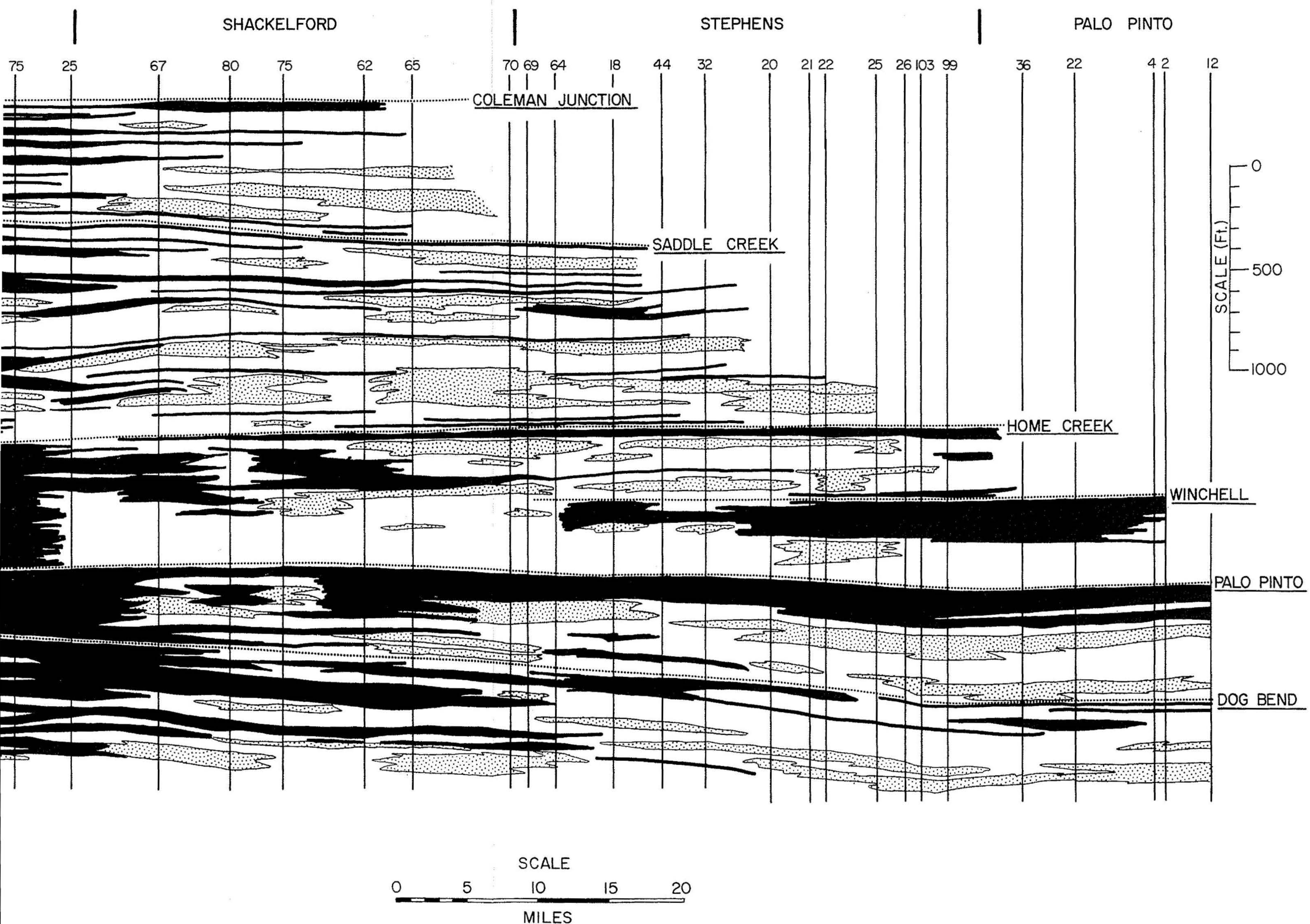


Figure 10. Section of the subsurface distribution of limestone banks downdip from the Ouachita shoreline across the Midland basin to the Scurry atoll of Myers and others (1956). Winchell age limestones in wells Stephens 18 through Palo Pinto 2 are downdip extensions of the Possum Kingdom bank.

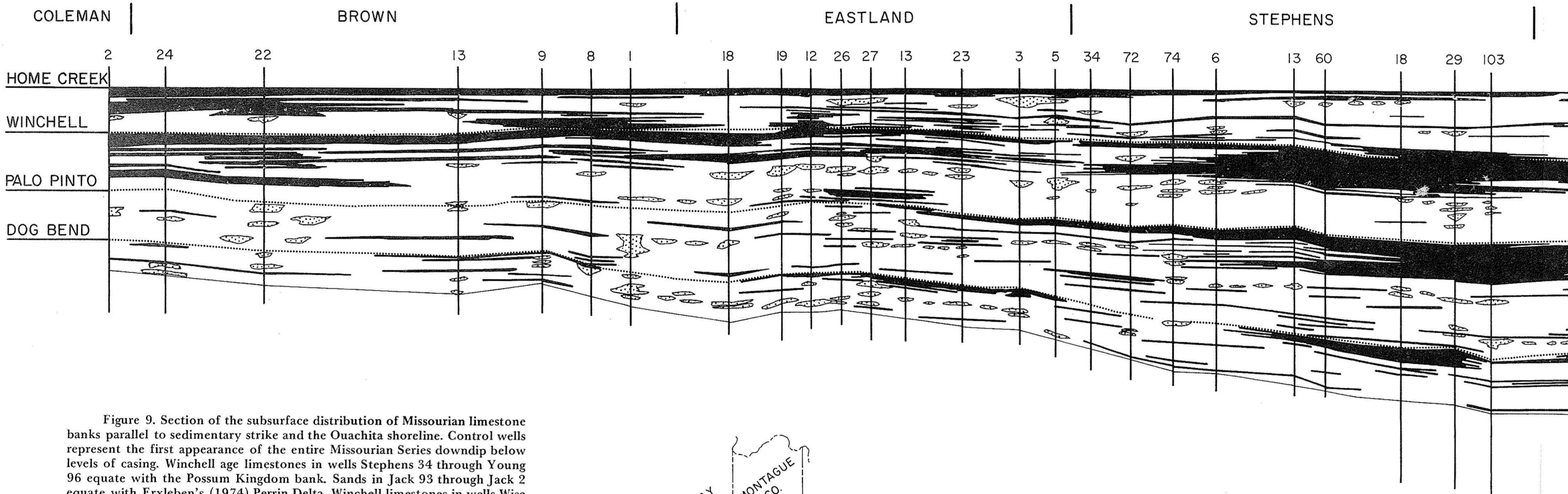
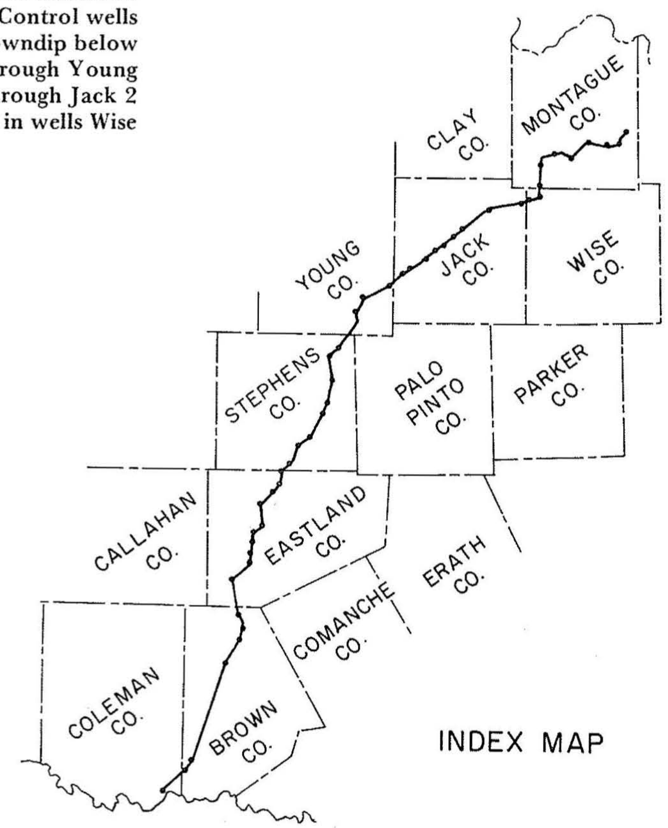
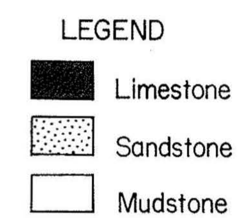


Figure 9. Section of the subsurface distribution of Missourian limestone banks parallel to sedimentary strike and the Ouachita shoreline. Control wells represent the first appearance of the entire Missourian Series downdip below levels of casing. Winchell age limestones in wells Stephens 34 through Young 96 equate with the Possum Kingdom bank. Sands in Jack 93 through Jack 2 equate with Erxleben's (1974) Perrin Delta. Winchell limestones in wells Wise 2 through Montague 132 are downdip of the Chico Ridge bank.





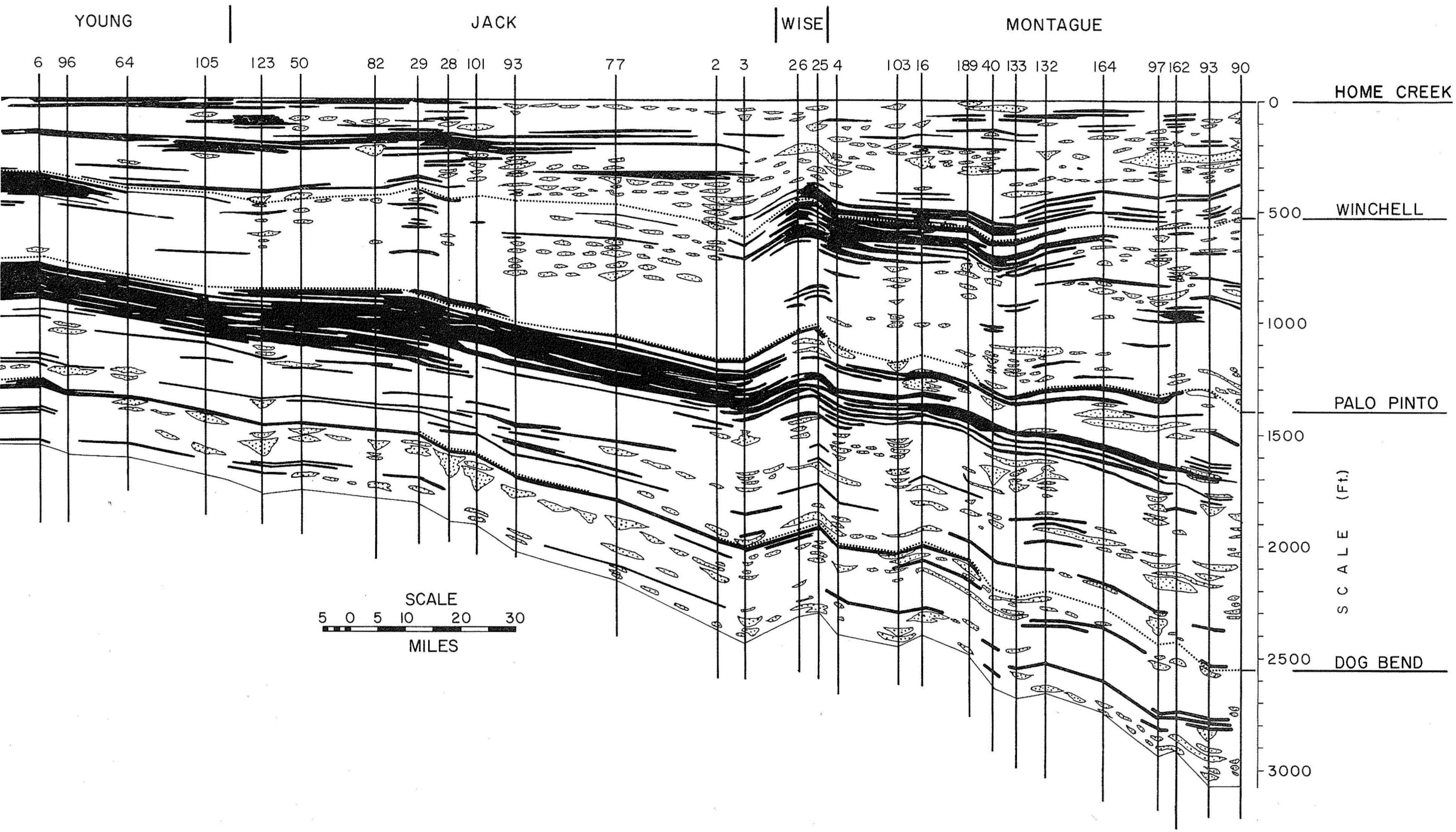

YOUNG
JACK
WISE
MONTAGUE
6 96 64 105 123 50 82 29 28 101 93 77 2 3 26 25 4 103 16 189 40 133 132 164 97 162 93 90
HOME CREEK
WINCHELL
PALO PINTO
DOG BEND
0
500
1000
1500
2000
2500
3000
SCALE (Ft.)
SCALE
5 0 5 10 20 30
MILES

Table 1. Organic allochems observed in upper Pennsylvanian bank limestones.

Raish	Roepke	Wermund
Phylloid algae	Phylloid algae	Phylloid algae
Echinoderm remains	Encrusting foraminifers	Osagiid algae and encrusting foraminifers
Sponges	Fusulinids	Echinoderm remains
Fusulinids	Echinoderm remains	Bryozoans
Ostracodes	Bryozoans	Brachiopods
Bryozoans	Brachiopods	Fusulinids
Mollusks	Gastropods	Gastropods
Brachiopods	Sponge spicules	Pelecypods
Dasycladacean algae	Dasycladacean algae	Dasycladacean algae
Encrusting foraminifers	Ostracodes	Sponges
Corals	Sponges	Corals
	Codiacean algae	Ostracodes
	Trilobites	

abundance. Phylloid algae are dominantly *Archaeolithophyllum; Eugonophyllum* is sparsely represented. *Eugonophyllum* occurs only in the thickest bed of his study area, the Colorado River valley. The most abundant foraminifers are encrusting types of *Apterinella,* and fusulinids are common. Composite brachiopods are abundant in the limestone which contains increasing numbers of spirifer and punctid forms with increasing terrigenous content. Roepke utilized 88 thin sections and 200 peels in his study.

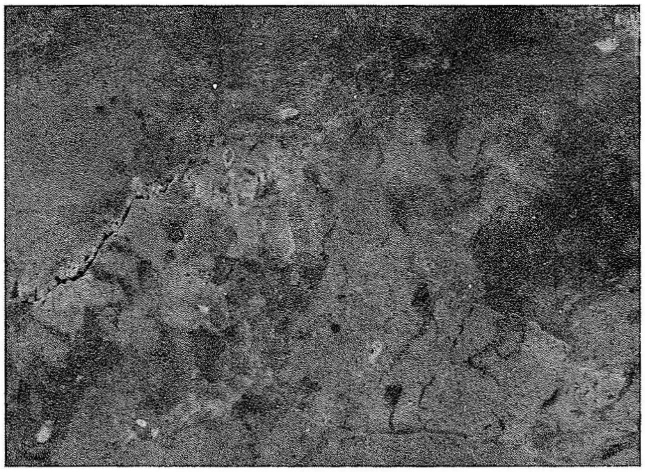
The column of Wermund (1966, 1969, and this paper) lists the occurrence of faunal allochems in decreasing abundance. *Eugonophyllum* dominate thick pure limestones, whereas *Archaeolithophyllum* are abundant in thin limestones intercalating with shale. Pollard (1970) has observed the same proportions. *Osagia* (not common in modern usage) is an older term for encrusting algae and foraminifers (like *Girvanella*); they can be confused with oolites. Osagiid limestones, like all limestone types, contain abundant echinoderm remains. Bank limestones commonly contain some bryozoan remains, usually fenestrate forms. Composite brachiopods and fusulinids are common in mud-supported limestones. Where limestones contain some terrigenous detritus, the common fossils are spirifer and productid brachiopods, myalinid and pinnate pelecypods, and bellerophontid gastropods. Wermund's identification of allochems is based equally on field observations and binocular study of 240 polished limestone slabs.

Other allochems.—Oolites are common in the limestone bank in Wise County, uncommon in the Possum Kingdom Bank, and extremely rare in the Colorado River valley. Pellets, possibly of faecal origin, are described as ubiquitous in the Colorado River area and uncommon in the Possum Kingdom Bank; they are rare in Wise County.

Limestone Types

Although there is some variation in allochems, as described above in previous reports about three separated areas of Missourian outcrop, the relative abundance of upper Pennsylvanian rock types is similar throughout the outcrop. Observations of rock types in the Possum Kingdom area are believed representative, and therefore, variations in limestone type are described from that area (figs. 11 and 12). In the following discussion, the limestone types are described in order from finest to coarsest textures.

Rare calcareous mudstones occur without allochems and can be structureless. Normally these calcareous mudstones are fractured or pseudobrecciated producing dismicrites (fig. 11A), probably related to the loss of water during diagenesis and primary lithification. Carbonate mudstones with sparse intraclasts (fig. 11B) occur sporadically in the Possum Kingdom Bank but are typical near the base of the bank (in sections 2-7, Plate 2JW of Wermund, 1966). Mudstones in which muddy intraclasts dominate the rock are scarce.



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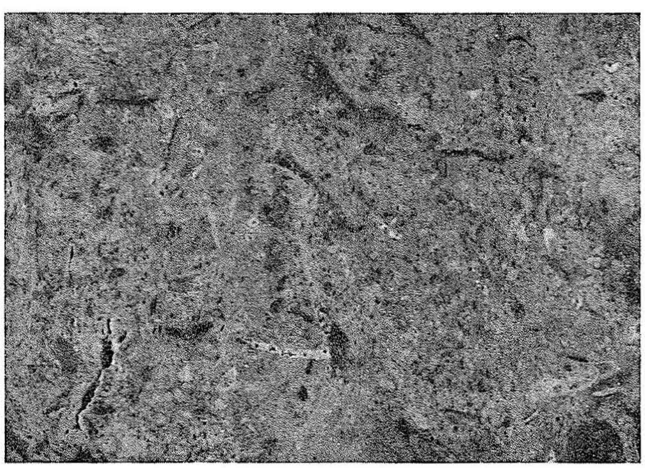

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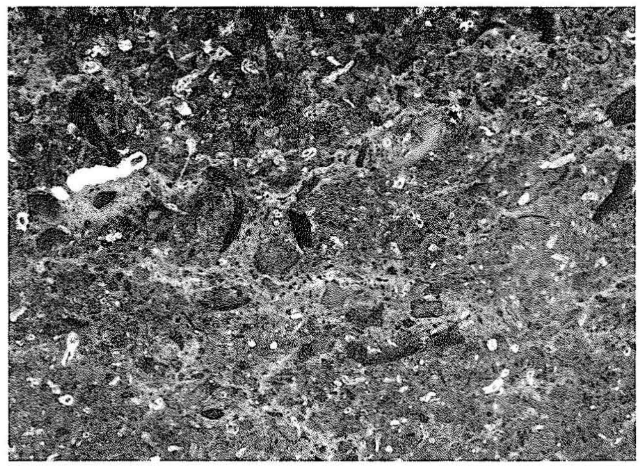

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Exceptions are limestones with subangular to subrounded rip-up intraclasts as large as 7 mm in Palo Pinto County (near the top of Stop 4, Wermund, 1969, p. 48) and up to 2 cm in the Rock Hill Limestone of Wise County (U. S. Hwy. 380 and the west side of Lake Bridgeport).

Limestone types are dominantly mud-supported and usually contain organic allochems which vary through a large size range, from small tubular foraminifers of .05 mm (fig. 11C, E) to bellerophontid gastropods of 20 cm (Brown and Wermund, 1969, p. 49). Abundant, large organic allochems are usually phylloid algae (fig. 11D). In addition to the size of the allochems, the proportion of allochems to mud matrix strongly influences the limestone type. As the proportion of allochems increases, whether fossils (fig. 11E) or even silt-sized quartz (fig. 11F), the separation of mud-supported versus grain-supported is indistinct. Some limestone beds are partly mud-supported and partly grain-supported (fig. 12A). Mud-supported rock types are interpreted to have been deposited in quiet water relatively unaffected by currents. An exception are those types containing abundant silt-sized allochems of organic fragments or quartz which had to be transported to muddy sites.

Grain-supported limestone types with phylloid algal fragments are abundant in the Possum Kingdom Bank (fig. 12B, C). Where pellets are considered as grains (fig. 12B), they usually contain phylloid algae. Pelletal grain-supported rocks were found to be uncommon in the Possum Kingdom area, perhaps because no thin-section studies were made. Where pellets are not present in grain-supported rocks containing phylloid algae, the matrix usually has abundant silt-sized allochems of foraminifer and bryozoan fragments (fig. 12C). Grain-supported phylloid algal types with microcrystalline mud matrix are uncommon. This may also be true in Wise County (Raish, 1964, pls. IIIB and IVC). Commonly grain-supported phylloid algal rocks contain some spar. Spar occurs replacing allochems and filling voids beneath the algal plates which appear to have represented primary pore space. Toomey and Winland (1973) noted the same phenomena in the subsurface.

Grain-supported types with sparry matrixes are common, and they seem always to contain few to many echinoderm grains (figs. 12A, B, C, D). Textures range from fine-grained sand to pebble-sized conglomerates. An abundant grain-supported type is osagiid grainstone (fig. 12E). Because the grains are invariably surrounded by the encrusting algae and foraminifers, this rock must occur in current agitated environments. The symmetrical nature of the encrustations suggests an energy realm where grains are in constant motion. Grain-supported allochems of nonencrusted echinoderms were possibly deposited more rapidly as they have been washed clean of fine allochems.

Figure 11. Mud-supported limestones, 5x, from polished slabs.

A. MUDSTONE (DISMICRITE) with sparse bryozoan fragments and with abundant fractures with displacement. Some solution along fracture in left of scene. Bed IVk in supplementary section of Stop 2, Brown and Wermund (1969, p. 44).

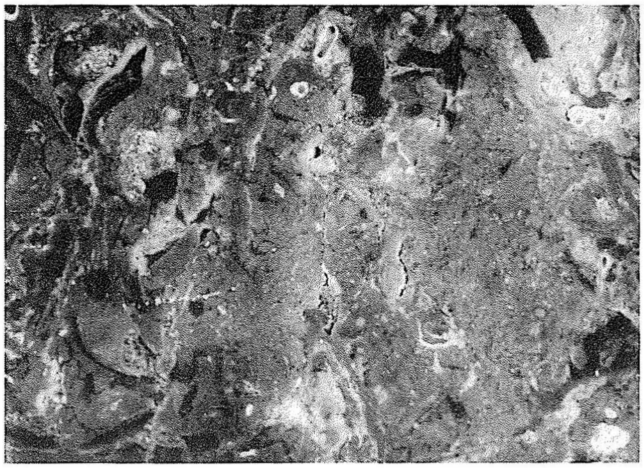
B. INTRACLASTIC MUDSTONE with sparse subangular intraclasts in a mud matrix with fracture solution in lower third of scene. Bed IVg.2 in ravine section of Stop 1, Brown and Wermund (1969, p. 42).

C. BRYOZOAN-OSTRACOD WACKESTONE with fine comminuted faunal debris including echinoderm fragments and tubular foraminifers in microcrystalline mud matrix. Bed IIc of Stop 3, Brown and Wermund (1969, p. 46).

D. ALGAL WACKESTONE with echinoderm fragments, composite brachiopods, and sponge in mud matrix which is pelletal in part. Bed IVc of mound section at Stop 2, Brown and Wermund (1969, p. 44).

E. BRYOZOAN-FORAMINIFERAL WACKESTONE with predominantly silt-sized grains. Recognized as a micrite on the outcrop containing scattered *Neospirifer* and *Bellerophon*. Allochems nearly form a packstone. Bed IV A-2 of Stop 1, Brown and Wermund (1969, p. 42).

F. SANDY MUDSTONE with quartzose silt to very fine sand and containing scattered *Myalina* and *Bellerophon*. Bed IVi of Section 26 in Stop 2, Brown and Wermund (1969, p. 44).



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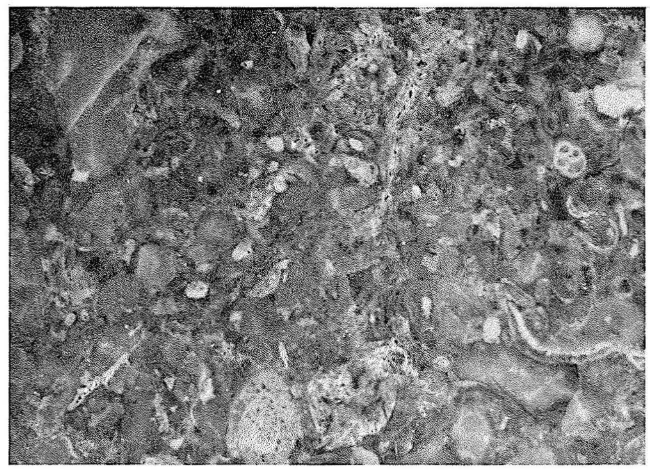

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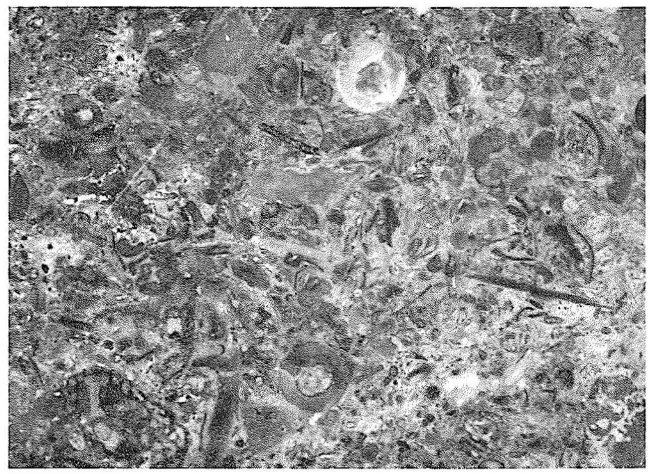

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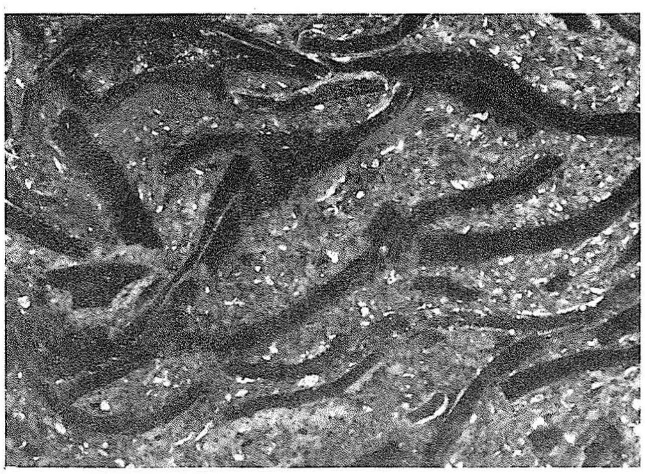

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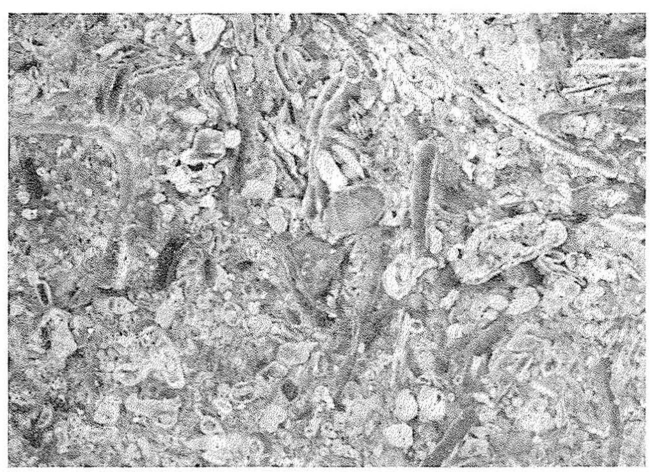

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Depositional Topography and Bed Forms

The most spectacular depositional topography in the Possum Kingdom Bank occurs where rare mud mounds have a relief of 10 m. Two such mud mounds occur in a ravine near Possum Kingdom Dam (Brown and Wermund, 1969, p. 42). The mud mounds are composed of dismicrite; allochems are sparse or absent. The mounds are draped by osagiid and echinoderm grainstones with measured dips up to 7°. The mud mounds are massive with rare bedding, whereas the grainstone beds are 20 to 35 cm thick. The grainstone beds appear crossbedded. Pollard (1970) described three mounds in the same study area with maximum depositional relief of 1.5 m, 3.5 m, and 1.35 m. He did not describe the lithology in detail nor did he mention associated grainstones.

Raish (1964) described oolitic grainstones in Wise County having dips greater than 10°. He interpreted a depositional topography, possibly submarine dunes, having a minimal relief of 12 m.

Also, there are small areas, like patch reefs, in which organisms originally formed up to 0.5 m relief. In the ravine near Possum Kingdom Dam, small deposits of algae, horn corals, and *Chaetetes* developed small bioherms up to 1 m high. These bioherms overlie a small anticlinal structure of osagiid grainstones dipping greater than 6° (Brown and Wermund, 1969, p. 46). At several localities in the Palo Pinto limestones, biohermal heads of *Syringopora* are 0.5 m high; thin beds of fusulinid grainstone are developed over them. In the Chico Ridge Bank in Wise County, fistuliporid bryozoans form a 1 m high bioherm (Raish, 1964, Plate VI A).

Many bed forms indicate small-scale topography having depositional surfaces with relief up to 0.5 m. Numerous grainstone deposits (Sections ABCD and AA, Wermund, 1966) have pinch-and-swell bedding where the swellings are 1 m thick. Crossbedding up to 0.7 m thick is typical. Algal packstones commonly have rippled surfaces with wave lengths approximating 2 m and amplitudes of nearly 4 cm. Roepke (1970, p. 127) observed wavy partings in the Missourian mudstones of the Colorado River valley.

Figure 12. Grain-supported limestones, 5x, from polished slabs.

A. ALGAL PACKSTONE AND WACKESTONE with fragments of phylloid algae, bryozoa irregularly distributed in a mud matrix which is pelletal in part. Fractures in major zones of mud are dissolved. Bed IVc in supplementary section at Stop 2, Brown and Wermund (1969, p. 44).

B. ALGAL PACKSTONE with encrusting algae and foraminifers on phylloidal fragments with echinoderm particles. Mud matrix has pelletal nature. Bed IVe-2 of Stop 1, Brown and Wermund (1969, p. 42).

C. ALGAL PACKSTONE in silt-sized mudstone matrix containing fragments of bryozoans and tubular foraminifers. Small amounts of sparite fill former cavities below algal plates in upper left. Bed IV A-4 at Stop 1, Brown and Wermund (1969, p. 42).

D. ECHINODERM GRAINSTONE with bryozoan, endothyrid foraminifers and fusulinids. Forms mounds and pinch-and-swell beddings. Bed IVf of Stop 1, Brown and Wermund (1969, p. 42).

E. ECHINODERM PACKSTONE with dasycladacean algae, bryozoans, gastropods, and composite brachiopod fragments. Mud matrix may be pelletal in part. Bed IV in supplementary section of Stop 2, Brown and Wermund (1969, p. 44).

F. OSAGIID GRAINSTONE with encrusted phylloid algal fragments and echinoderm remains. Bed IVC of Stop 1, Brown and Wermund (1969, p. 42).

Noncalcitic Minerals

Noncalcitic minerals are sparse, generally less than one percent, in surface exposures of upper Pennsylvanian rocks of the Eastern shelf in North-Central Texas. In order of decreasing abundance, the significant noncalcitic minerals are terrigenous quartz, terrigenous clay, chert, limonite, and dolomite.

Terrigenous quartz.—Because the limestone banks grade or intercalate shoreward into terrigenous rocks, limestones commonly contain minor quartz in the zones of gradation or intercalation (usually less than 6 percent according to Raish, 1964). Terrigenous quartz is also common in basal beds of the limestone banks. The quartz is generally fine-grained sand or commonly approaches silt size. The grains are angular to subrounded and normally well sorted according to Roepke (1970, p. 119). In limestones where quartz is an allochem, scattered large pelecypod fossils are prevalent.

Terrigenous clay.—Clay minerals entrained in limestone are very difficult to detect except in thin sections or in analyses of insoluble residues. All workers observed the numerous clay partings in certain limestone beds. Only Roepke (1970) studied enough thin sections and residues to recognize clay in the limestone, and his generalizations may apply to all the upper Pennsylvanian limestones. Clay is generally incorporated in only the basal part of any limestone bed; it is sparse or absent in the top of any bed. Terrigenous clay also occurs as backfill in burrows and borings.

Chert.—Chert generally occurs in limestones adjacent to terrigenous sediments. Chert is commonly found on bedding planes, has a platy or lenticular geometry, and replaces fossils so that their remains are preserved. Roepke (1970) observed an association of chert and jointing in outcrops. Raish (1964) found rare chert nodules up to 7.5 cm diameter.

Limonite.—Limonite is rare but occurs disseminated in several rock types. It is disseminated in basal mudstones, often intraclastic mudstones overlying dark shale. It also occurs in mudstones interfingering with shales. The limonite appears pseudomorphic after pyrite and may represent alteration of terrigenous allochems.

Dolomite.—Dolomite was not observed in the Possum Kingdom Bank. In the Chico Ridge Bank, dolomite is rare and is generally surficial in outcropping limestones. However, Raish (1964) described a dolomite-rich zone nearly five feet thick in cores. His illustrations show that the dolomite has selectively replaced fossils and composes as much as 30 percent of the rock. Roepke (1970) found only 3 of 288 samples to contain dolomite in the Colorado River valley. Based on petrographic analyses, he concluded that the dolomite was formed after lithification.

Bank and Associated Facies

From the petrologic and field relationships described above, it is possible to recognize discrete carbonate facies in the limestone bank and associated rocks. They are described in table 2 with a location provided for later field investigations. These facies will be related to modern analogous deposits in later discussions and descriptions of a model Pennsylvanian limestone bank.

Table 2. Properties of bank limestone facies.

DEPOSITIONAL FACIES	LITHOLOGIES	ALLOCHEMS	STRUCTURES	REMARKS	LOCATION
Phylloid Algal Mudstone	algal wackestone algal packstone biomicrudite	phylloid algae fenestrate bryozoans echinoderms fusulinids composite brachiopods	broad ripples rare imbrication sheltered porosity geopetal structure	sometimes pelletal groundmass	Brown and Wermund 1969, p. 42, Bed IVb
Open Marine Mudstone	wackestone mudstone	composite brachiopods echinoderms endothyrid foraminifers intraclasts rugose corals heliospongid sponges	burrows broad ripples pellets		Brown and Wermund 1969, p.42, Bed IVg3
Bay Mudstone	mudstone	spiriferid brachiopods productid brachiopods agglutinated foraminifers bellerophontid gastropods fenestrate bryozoans	burrows	pyrite-pseudomorphic limonite	Brown and Wermund 1969, p. 42, Bed IVa
Lagoonal Mudstone	mudstone micrite	pinnate clams bellerophontid gastropods	burrows	fine sand or silt matrix	Wermund, 1966, Plate 2 JW, Sect. 7, Bed IVb
Rip-Up Mudstone	intramicrite intraclastic wackestone intraclastic packstone	intraclasts		subangular to angular probable storm deposits	Brown and Wermund, 1969, p. 48, 58 ft. above base
Mud Mounds	mudstone dismicrite	sparse	pseudobreccia fractures sparry veins	relief up to 10 m	Brown and Wermund 1969, p. 42, Bed IVj
Arenite Bars, Channels, and Dunes	oolitic grainstone osagiid grainstone	oolites osagiid algae echinoderms	crossbeds pinch and swell cut and fill current scour rills primary porosity	well sorted	Brown and Wermund 1969, p. 42, Bed IVc
Arenite Drapes	osagiid grainstone	osagiid algae echinoderms fenestrate bryozoa	cut and fill plain crossbedding poorly sorted primary porosity		Brown and Wermund 1969, p. 42, Bed IVj
Patch Reefs	boundstone	syringoporid coral fistuliporid bryozoan	flanking crossbeds		Brown and Wermund 1969, p. 46, Bed IIb
Fusulinid Shoreface	fusulinid grainstone	fusulinid	aligned tests	may be storm deposits	Wermund, 1966, plate 2JW, Sect. 12, Bed IVe
Echinodermal Rudaceous Bars and Beaches	echinodermal grainstone	echinoderms	crossbedded uniformly sorted		Wermund, 1966 plate 5 JW, Sect. 34, Bed IVb
Molluscan Shoreface or Delta-Front Sand	quartzose mudstone	myalinid clams bellerophontid gastropods	uniform silt		Brown and Wermund 1969, p. 44, Bed IVg
Tidal Channel	packstone biomicrudite	myalinid clams echinoderm productid brachiopods claystone intraclasts	imbricated shells festoon crossbedding plain crossbedding		Erxleben, 1974 p. 42

COMPARABLE DEPOSITS IN OTHER AREAS

Pennsylvanian Banks of the Mid-Continental Region

Harbaugh (1959, 1960) described Pennsylvanian marine limestone banks in Kansas which are very similar to those in Texas. He suggested that algal packstones thickened and formed on marine banks above the sea floor. Relief was several tens of feet, and deposits extended over at least 150 square miles. Most algal crusts are fragmented, perhaps by current activity. The algal and other biotic debris was loosely packed upon deposition as evidenced by the sheltered porosity later filled by sparite. The banks unlike reefs did not form wave-resistant frameworks. Where fracturing and pseudobrecciation are evident (dismicrite?), banks may have desiccated if parts had subaerial exposure.

Heckel and Cocke (1969), extending the study of phylloid algal mounds into Oklahoma, found numerous mounds built during Missourian and Virgilian. In the Oklahoma and Kansas outcrops of limestone mounds, they recognize three major limestone facies: (1) a mound facies, (2) a mound-associated facies, and (3) open marine facies. The mound facies is commonly a phylloid algal packstone; nonalgal-bearing calcareous mudstone rarely forms mounds. The authors suggest the mud of the mounds comes from total disintegration of algal blades, grain dimunition of red algae to calcilutite, or dissolution of aragonitic green algae with subsequent closing of voids by soft mud.

The mound-associated facies (Heckel and Cocke, 1969) is composed of lenticular packstones ranging from unabraded echinoderm fragments to abraded and coated (*Osagia?*) grains. The open marine limestones have thin regular bedding and are commonly interbedded with shale. It appears that their open marine facies is quite similar to the Cottonwood Limestone of Oklahoma, Kansas, and Nebraska in which La Porte (1962) defined five facies: an osagiid facies, a fusuline facies, a platy algal facies, a shelly facies, and a silty osagiid facies. The bioclastic facies in which *Osagia* are dominant has scour-and-fill structures similar to those described in the Possum Kingdom Bank. The fusuline facies is named after a dominant fusuline taxa and contains significant *Osagia* as well. The platy algae facies does not form mounds and includes abundant red *Anchicodium*; the platy algae generally parallel bedding. The shelly facies is commonly burrowed and has a diverse and abundant fauna of brachiopods, molluscans and foraminifers, and bryozoan and echinoderms, which are locally concentrated. A silty *Osagia* facies is his most variable facies. The most abundant rock type is a well-sorted, fine-grained osagiid grainstone containing abundant quartzic silt, but rocks similar to the shelly facies are also common.

Examples of all the preceding facies crop out in North-Central Texas, although examples of mounds clearly built of phylloid algae remains are rare in Texas compared to the mid-continent region.

Modern Carbonates in South Florida and the Bahamas

Both Heckel (1972) and Wermund (1966, 1969) described a shallow-water environment for upper Pennsylvanian bank limestones similar to modern environments of southern Florida. Pennsylvanian phylloid algal wackestones and packstones with a very fine mud matrix or micrite (figs. 11D and 12A) are believed comparable to Florida Bay muds in which Klement (1966) described rich growths of *Penicillus* and *Udotia* (fig. 13A). In Florida, the algae form a flexible maze which baffles currents with suspended carbonate sediment causing fine particles to drop out.

It is interpreted that the phylloid algal wackestones and packstones having a silt-size matrix (fig. 12C) illustrate sedimentation in a more rigid biotic framework growing in strong currents. Rigid attached biota would trap coarse particles first allowing fine suspended particles to pass in an area of strong currents. In Florida, this type of framework (fig. 13B) occurs in a lagoon behind the outer reef, the inner reef tract of Ginsburg (1956). Here a slightly rigid framework exists where abundant *Halimeda* along with small corals like *Porites* and *Siderastrea* are more effective than

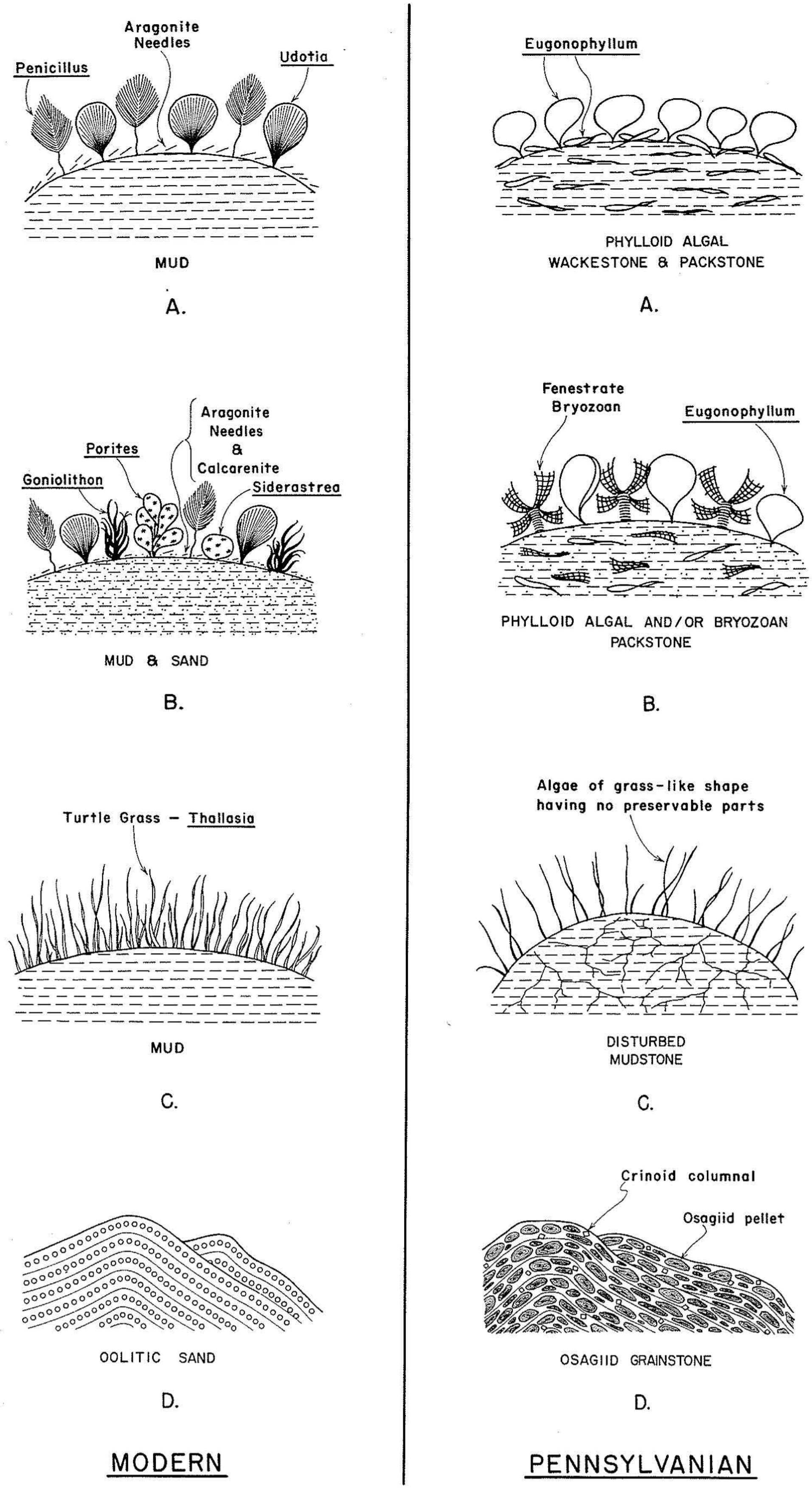


Figure 13. Analogs of modern and Pennsylvanian carbonate sediments.

flexible algae, *Penicillus* and *Udotia*, in trapping sediment. It appears that the rigid forms also add more and larger indigenous particles to the sediment. In Pennsylvanian sediments fenestrate bryozoans are believed to have played the role of the small corals and *Halimeda* prior to their breaking apart after death. Another feature of Pennsylvanian phylloid algal wackestones are burrows and associated pelletal matrices (fig. 12B) similar to those described in Florida by Shinn (1968).

The dismicrite mud mounds of the Possum Kingdom Bank collate with mud banks described in Florida Bay that are in part covered by turtle grass (Thalassia) (Ginsburg, 1956). The Florida mud banks build upward by the baffling and/or trapping of fine carbonate sediment. In the Pennsylvanian carbonate mudstone mounds, a similar plant type, although not grass, is inferred. The plant may have been an algae formed of aragonite needles, like *Penicillus* or *Udotia*, but having an unknown form (fig. 13C). Pennsylvanian limestone mud mounds rarely contain a fossil. In Florida Bay, the mud banks are commonly burrowed by *Callianassa* shrimp (Shinn, 1968). Although burrows are not found in the Pennsylvanian calcareous mudstone mounds, certain of the pseudobrecciated structures of dismicrites might relate to collapsed burrows. However, expected pellets of burrows are not identified in polished slabs of the mudstone mounds.

Some coarser grained analogs are also interpreted from the modern sediments of the Bahamas and Pennsylvanian bank limestones in Texas. The crossbedded oolitic grainstone of the Chico Ridge Bank (Raish, 1964, pls. VA and VIIIA) and grainstones of the oolitic sand belt of the Bahamas described by M. M. Ball (1967, fig. 6) are comparable. In Pennsylvanian rocks, *Osagia* may fill the place of modern oolites (fig. 13D) as shown by La Porte (1962) and Wermund (1969). Pennsylvanian deposits of abraded osagiid algae, echinoderm fragments, and rounded shell may compare with the grassless, rippled sand deposits formed of rounded shell and foraminifers at White Banks behind the Florida Reef Tract.

FACIES OF LIMESTONE BANKS AND ASSOCIATED TERRIGENOUS SEDIMENTS IN OUTCROP

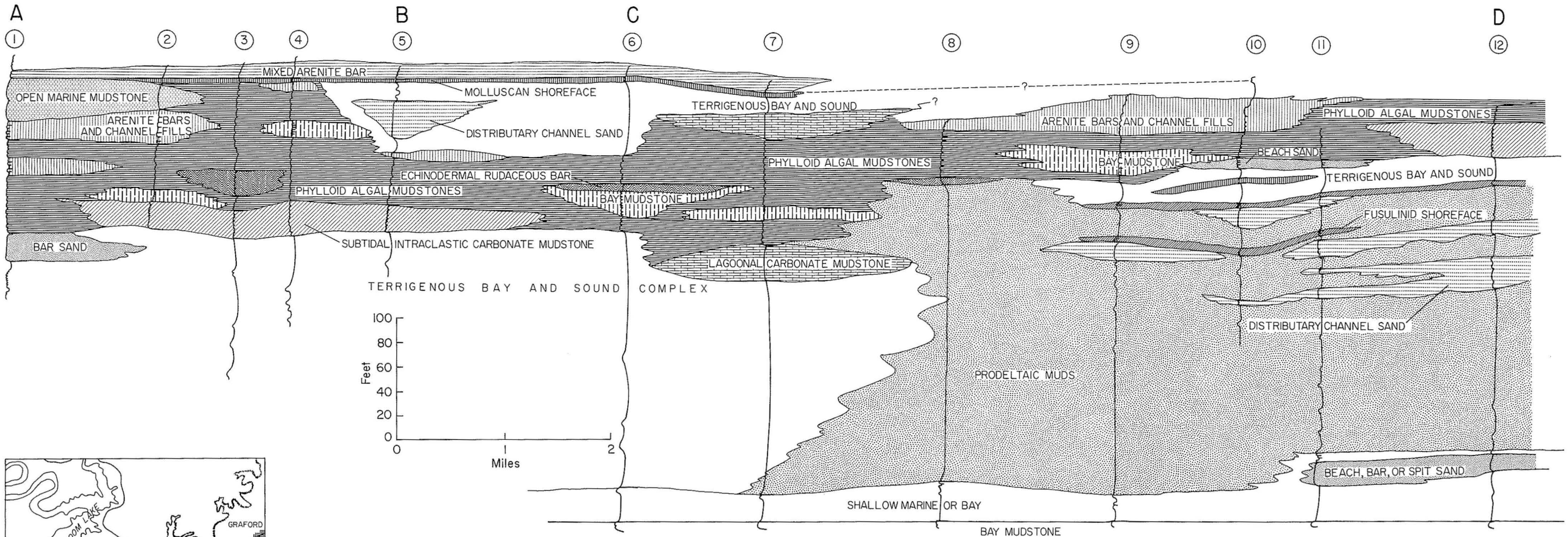
The relationships of the limestone banks and terrigenous sediments are displayed in exposures of the Possum Kingdom Bank (fig. 14). I previously discussed the interrelationship of the carbonate and terrigenous facies in a general way (Wermund, 1966, 1969). As a result of additional field work and the publications by Brown (1969a, b) and Brown and others (1973), a more comprehensive interpretation is now possible.

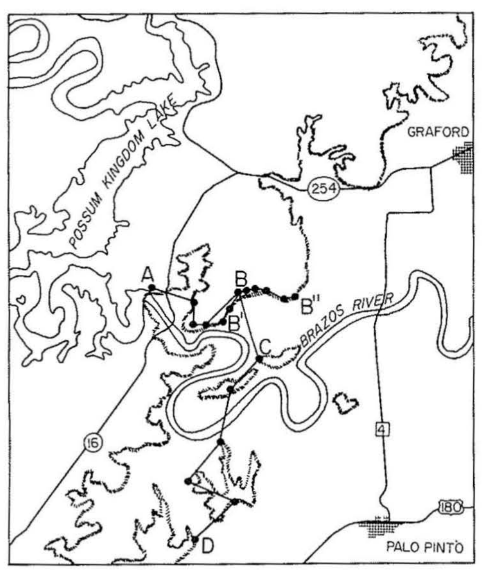
Limestone Bank Facies

The Possum Kingdom Bank is the surface expression of an extensive limestone buildup in subsurface strata of the Eastern shelf (fig. 4). In Palo Pinto County, the sedimentary strike is nearly east-west, seaward is northwest and landward is southeast. The section AB (fig. 14, ABCD) nearly parallels depositional strike, and the limestone facies are dominated by phylloid algal mudstones. Irregularly dispersed throughout the bank are the osagiid-echinoderm grainstones, forming bars, channels, and dunes of coarse, well-washed debris. A subtidal intraclastic calcareous mudstone is commonly the basal facies for much of the bank. A restricted bay fauna of spiriferid brachiopods and bellerophontid gastropods comprises a significant subfacies of the subtidal unit.

Bay calcareous mudstones occur intermittently throughout the bank indicating the variability of water depths and current velocities during deposition. Open marine limestone is rare and occurs near the center of the bank (point A of fig. 14). Reconnaissance shows that a large volume of open marine limestone crops out west of the cross section ABCD (fig. 14).

The upward succession in the marine bank shows a general alternation from shallow-water to deep-water facies. Subtidal intraclastic and bay calcareous mudstones pass into algal mudstones, grainstones, and open marine limestone. They are capped by a molluscan shoreface facies containing abundant *Myalina*. The overlying mixed arenite bar





PALO PINTO 15' QUADRANGLE

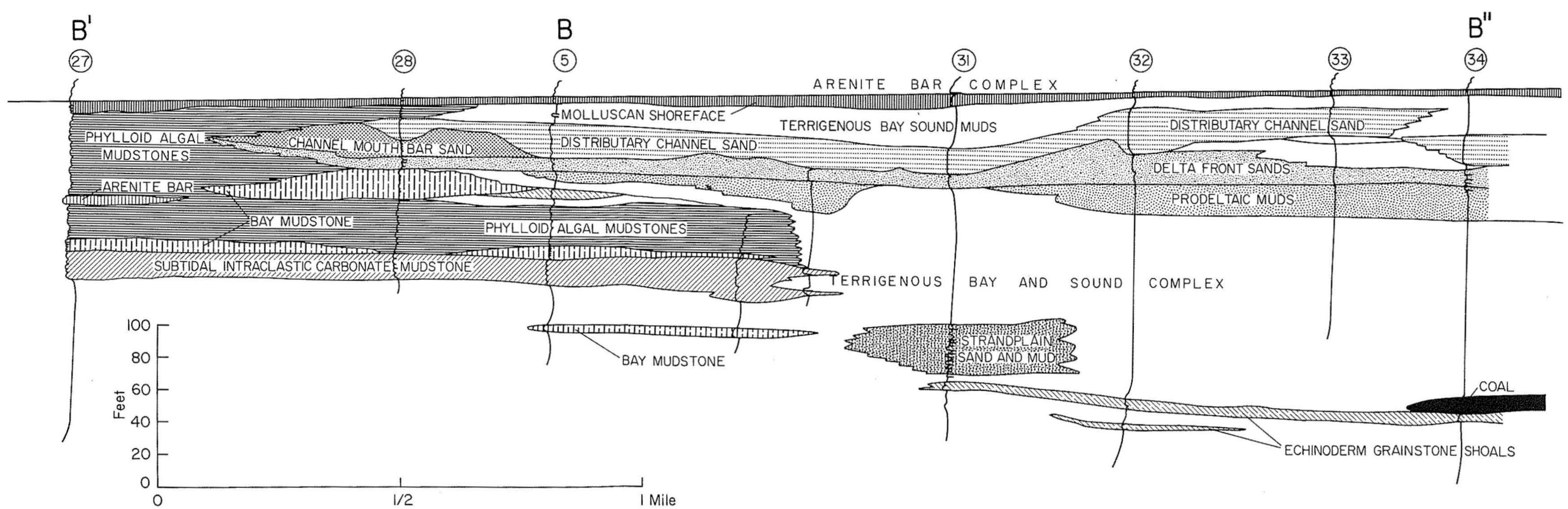


Figure 14. Outcropping interrelationship of facies of limestone banks and intercalated terrigenous facies. Locations of measured sections and descriptive lithologies in Wermund (1966, 1969).

facies differs from the marine grainstones within the body of the bank. This facies contains patches of mud-supported rock, a rich diversified fauna including abundant composite brachiopods and numerous burrows. Crossbedding is sparse. The mixed arenite bar facies is generally overlain by fossiliferous shale or bay terrigenous mudstones, but outcrops are rare.

Proceeding landward (C-D), a lagoonal mudstone dominates the bank facies. This facies is characterized by large *Aviculopinna* up to 30 cm long; burrows are common in completely mud-supported sediment. Shoreward of the lagoonal facies (CD), the proportion of algal mudstone decreases. Landward in shallow water, shoreface facies of limestones are common. Examples are the fusulinid grainstone and molluscan packstones having both sedimentary structures and textures comparable to modern shoreface, bayhead, or delta-front sediments. The thickness of the carbonate bank decreases markedly, and intercalated terrigenous sediments increase.

Terrigenous Facies

The terrigenous facies associated with the Possum Kingdom Bank is part of a deltaic complex for which the general outline was recognized by Wermund and Jenkins (1970) and definitively described as the Perrin delta complex by Erxleben (1974). Using criteria established by Brown and others (1973), discrete units of deltaic complex can be identified (ABCD and B′BB″, fig. 14). Two fine-grained facies are the prodeltaic muds and a terrigenous bay-sound complex. The prodeltaic muds are characterized by (1) dominance of plastic clays, (2) laminations, (3) squeezed sands, (4) scarce shelly fossils but common macerated plant debris, and (5) reworked sands in the upper part of the mud. On the other hand, the terrigenous bay-sound complexes are characterized by (1) silt and clay, (2) poor bedding, (3) laminated or mottled sands, (4) numerous horizons of abundant fossils, and (5) a wide spectrum of facies. The terrigenous bay-sound muds are considered marine by previous authors especially where nuculoid clams and pleurotomerid snails are abundant (see Heuer, 1973). However, the proximity of the Perrin deltaic complex indicates generally shallow water in the area of the Possum Kingdom Bank. (The areas shown as recessed in measured sections of figure 14 included both exposed muds and covered slopes.)

The sandy facies include distributary channel sands, delta-front sands, strandplain sands, and a bar sand. The distributary channel sands have a clearly identifiable channel shape. In the basal part, there are remnant coarse-grained deposits with pebbles of chert or clay and festoon crossbedding. Upward the channel is filled with fine-grained sand to silt, and plain crossbedding dominates. The distributary channels commonly overlie delta-front sands (near D in ABCD and near B″ in B′BB″ of fig. 14). The delta-front sands are sometimes convoluted and generally winnowed of fines. Strandplain sands are generally thin units with pseudolaminated bedding and are intercalated with muds. The bar sands or beach sands are generally massive and associated with fossiliferous terrigenous bay muds.

Intercalated Bank and Terrigenous Facies

Detailed properties of the intercalations of terrigenous and limestone bank facies in Jack and Palo Pinto Counties are described by Erxleben (1974). Wermund (1966, 1969) previously observed that (1) bank facies generally overlie coarser terrigenous facies, (2) bank facies grade rapidly into terrigenous facies seaward but intercalate over broad areas landward, and (3) individual thin limestones grade laterally into marls and fossiliferous muds which are herein recognized as bay muds.

Pennsylvanian phylloid algal limestone banks often grow on a foundered delta (fig. 14). As filled distributary channels sink into surrounding muds, they are a hospitable site for organisms to accumulate at the sea surface, like *Myalina* in molluscan shoreface facies (fig. 14). Also where shorefaces occur, faunal remains can be rolled up and concentrated like the fusulinid grainstones.

The limestone banks grew on both prodeltaic deposits and terrigenous bay-sound complexes (fig.

14). Where banks grew on top of bay-sound terrigenous sediments, the bottom was commonly firmed by a sand bar or spit (A in ABCD) or concentrations of loose shells (B″ of B′BB″).

Intercalations of limestones and terrigenous muds are common. Only three instances were observed in outcrop where sandstone grades laterally into limestone (one is shown in B′BB″ of fig. 14). In every case, pure quartzose sand grades into increasingly fossiliferous sand with fusulinids and/or osagiid algal limestone. The carbonate facies was commonly grainstone.

A SUMMARY OF A PHYLLOID ALGAL BANK SYSTEM IN TEXAS

The Pennsylvanian phylloid algal banks commence growth in areas of firm substrate. In both subsurface (figs. 9 and 10) and outcrop (fig. 14), part of the bank overlies sand-size sediment. Commonly, banks either begin or laterally extend growth over a subsiding deltaic complex of an older depositional system. Also, banks commonly originate in sediments overlying an older carbonate bank. Wermund (1966) observed that these sediments become increasingly fossiliferous and coarser prior to the establishment of a new bank complex. There may be structural control which influences the superposition of limestone banks and which elevates the sea flood and affects winnowing.

Pennsylvanian limestone banks are accumulations of whole or broken fossils, commonly in a calcareous mud matrix. The predominant fauna are phylloidal and osagiid algae, fenestrate bryozoans, echinoderms, and composite brachiopods (table 1). They include animals which are dependent on light and survive on microscopic food, indicating that the seawater must have been clear for the major bank builders to survive. Extensive deltaic progradation effectively made limestone banks retreat seaward or cease deposition (Wermund and Jenkins, 1970; Erxleben, 1974), in part because the water became too turbid for animals filtering minute food particles or depending on light for photosynthesis.

The dominance of algal builders in the bank facies (figs. 11 and 12) also suggests that the banks have been deposited in relatively shallow water. The algae were probably deposited in water depths less than 120 feet (Wermund, 1966; Heckel, 1972), much less considering a high probability of some turbidity of the water offshore of deltaic mouths.

All of the facies here are believed to have formed in shallow subtidal water. Supratidal features like disconformable or oxidized surfaces, mud cracks, and algal laminated limestones are absent.

Several lines of evidence suggest that the limestones of banks were deposited in a humid climate. The absence of dolomite and anhydrite shows that there are no evaporitic supratidal sediments comparable to the modern and ancient evaporitic-carbonate shoreline deposits described from arid climates by Lucia (1972). In associated sediments, there are sparse coals and concentrations of carbonatized wood fragments, especially in the deltaic complexes (fig. 14, B″).

Periodic storms are indicated by the calcareous mudstones containing large (> 5 mm) intraclasts like the intraclastic limestone of the Rock Hill Limestone in Wise County and the same lithology in the Winchell Limestone (table 2). Similar lithologies were interpreted by S. M. Ball (1971) to record storm deposits in the Westphalia Limestone of Kansas. Ball also concludes that thick accumulations of abundant fusulines in the Westphalia Limestone were probably formed by storms carrying fusulines shoreward. These fusulinid limestones have similar texture to the fusuline shoreface facies in the Possum Kingdom Bank (fig. 14). Interpretation of fusulinid grainstones as storm-deposited or normally wave-deposited depends upon the original depth occupied by living Pennsylvanian fusulines.

In the exposed Possum Kingdom Bank, both mud-supported and grain-supported limestones are common. The abundant mud-supported rocks indicate widespread areas of deposition which lacked currents effective in winnowing and transporting calcareous muds. Even in the phylloid algal grain-supported mudstones, those with geopetal structure or sheltered porosity indicate only slight currents. Strong currents would have reworked the algal plates thus destroying the shelter effect. Many of the phylloid algal mudstones were in areas of some wave motion as indicated by the broad, rippled bedding planes.

On the other hand, the echinoderm and/or osagiid grainstones indicate moderate currents and waves. As osagiid grains are coated on all sides, they indicate rolling and even saltation by currents and waves. Pinch-and-swell bedding and channelized bedding illustrate the currents. Small channels up to 0.3 m deep and 1.0 m cross sectional width are common. Plain crossbedding is relatively common, but this is difficult to document where all the particles have essentially the same size and composition.

Maximum relief at the site of bank accumulation was about 10 m. Mudstone mounds of dismicrite attain this relief at rarely observed localities. Relief of this order is also interpreted in mud mounds of producing oil fields (Toomey and Winland, 1973). Pennsylvanian barchan dunes of echinoderms and oolites (probably osagiid grainstones) approach the same relief in the Chico Ridge Bank of Raish (1964).

The Pennsylvanian algal banks of Texas have a remarkable regional persistence (figs. 3-6). They form both elongate biostromes of considerable extent and small bioherms the size of a few sections. During deposition, there were widespread, nearly flat expanses of calcareous sedimentation providing a monotonous submarine landscape. The landward side of the elongate banks was strongly influenced by terrigenous sedimentation, offlapping and onlapping tens of miles. The seaward side maintained nearly constant deposition yielding a steep seaward edge in which there may be abundant grainstones. The lithofacies patterns (fig. 8) strongly suggest that bioclastic debris off the seaward front of the banks was carried down the depositional slope by currents flowing between elongate banks. At the edge of the Midland basin, thin limestones were sometimes deposited down the basin slope during times of less active terrigenous sedimentation.

Further refinement of a model of the development of Pennsylvanian limestone banks awaits a regional facies and diagenetic study of cores and ditch samples of the subsurface Eastern shelf.

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