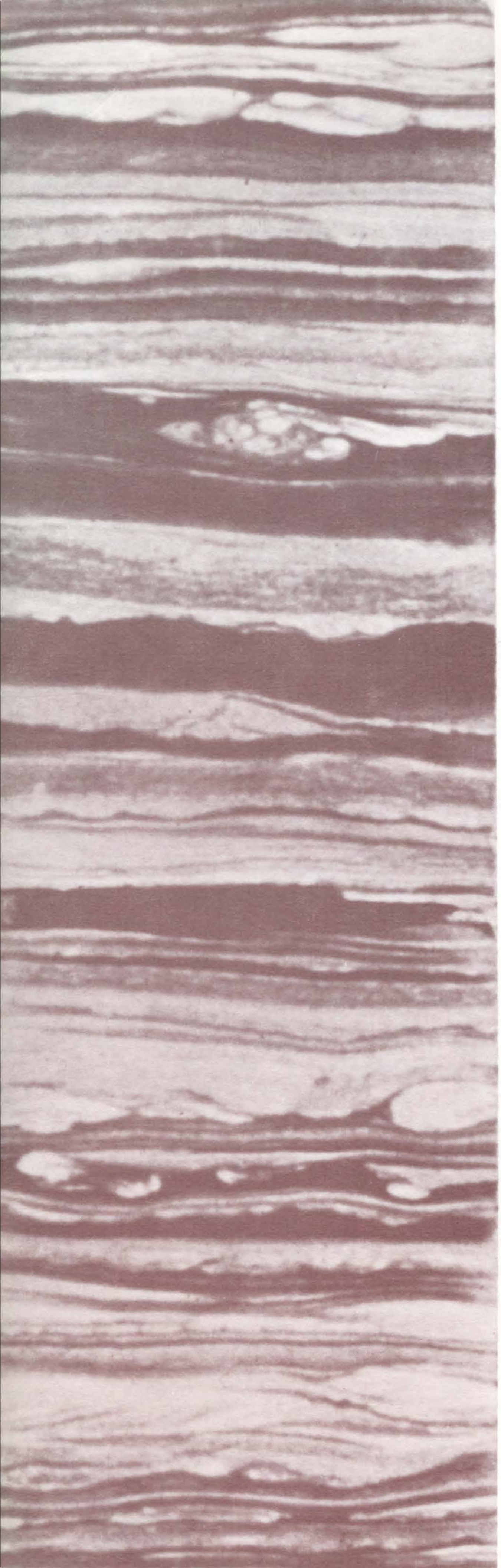

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Report of Investigations—No. 75

DEPOSITIONAL SYSTEMS AND SHELF-SLOPE RELATIONSHIPS IN UPPER PENNSYLVANIAN ROCKS, NORTH-CENTRAL TEXAS

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DEPOSITIONAL SYSTEMS AND SHELF-SLOPE RELATIONSHIPS IN UPPER PENNSYLVANIAN ROCKS, NORTH-CENTRAL TEXAS

William E. Galloway[1] and L. F. Brown, Jr.[2]

ABSTRACT

The Eastern Shelf was a constructional platform developed on the margin of the sediment-starved Midland Basin during Late Pennsylvanian and Early Permian time. A mixed terrigenous-carbonate sedimentary province characterized the shelf during most of its history. Sediments were derived from highlands to the east and northeast. Along the outcrop in Eastland, Stephens, Young, and Jack counties, uppermost Pennsylvanian beds comprise the Harpersville Formation, a boundary-defined rock stratigraphic unit within the Cisco Group. Harpersville facies extend westward into the subsurface 50 to 60 miles, where they grade into equivalent shelf margin carbonate and slope terrigenous facies. Preserved relief between the shelf margin and basin floor ranges from 600 to 1,100 feet with dips up to 5 degrees.

Three component depositional systems, recognized on the basis of gross lithologic composition and position relative to the shelf edges, are the Cisco fluvial-deltaic system, the Sylvester shelf-edge bank system, and the Sweetwater slope system. The Cisco fluvial-deltaic system is composed of dip-fed fluvial-deltaic facies and associated strike-fed interdeltaic embayment facies. Eight deltaic lobes have been mapped. The Sweetwater slope system is composed of several slope wedges, or fans, each of which includes shelf margin, slope trough, and distal slope sandstone facies, as well as slope mudstone facies. Terrigenous sediments were transported across the shelf by prograding fluvial-deltaic channels that locally extended through the Sylvester shelf-edge bank system and onto the slope where deposition in the deeper basin constructed submarine fans.

The Eastern Shelf prograded into the Midland Basin through contemporaneous, local upbuilding by fluvial, deltaic, and shelf-edge bank deposition and outbuilding by slope-fan deposition. Sites of shelf construction or outbuilding shifted through time in response to sedimentary and structurally controlled abandonment of major delta lobes. Extrabasinal controls such as eustatic sea-level changes were of secondary importance in developing the depositional fabric of the shelf of the Harpersville Formation.

INTRODUCTION

Upper Pennsylvanian shelf, slope, and basin facies on the eastern flank of the Midland Basin preserve a complete sediment-dispersal system extending from the piedmont and coastal plain across the shelf and slope and onto the basin floor. Though individual parts of this system have been recognized by various authors, their genetic relationships have not been determined in detail. The purpose of this report is to define the principal components of the sediment dispersal network called depositional systems. Though regional, the scale is sufficiently detailed to provide a model for the infilling of a stable, moderately deep cratonic sea, such as existed in the Midland Basin.

LOCATION AND NATURE OF EASTERN SHELF

The Eastern Shelf, as delineated in this report, is a paleogeographic unit that lies on the older Concho Platform along the eastern flank of the Midland Basin (fig. 1). It consists of facies deposited in a variety of environments, including deltaic, embayment, open shelf, and shelf-edge bank. During its construction, the Eastern Shelf formed a structurally stable platform. Subsequently, it was affected only by regional tilting and minor faulting (Wermund and Jenkins, 1969). The physiography of the Eastern Shelf resembled that of modern constructional continental shelves but on a smaller scale.

The distinction between usage of the terms shelf, open shelf, and Eastern Shelf is as follows: A *shelf* is a geomorphic feature bounded by the

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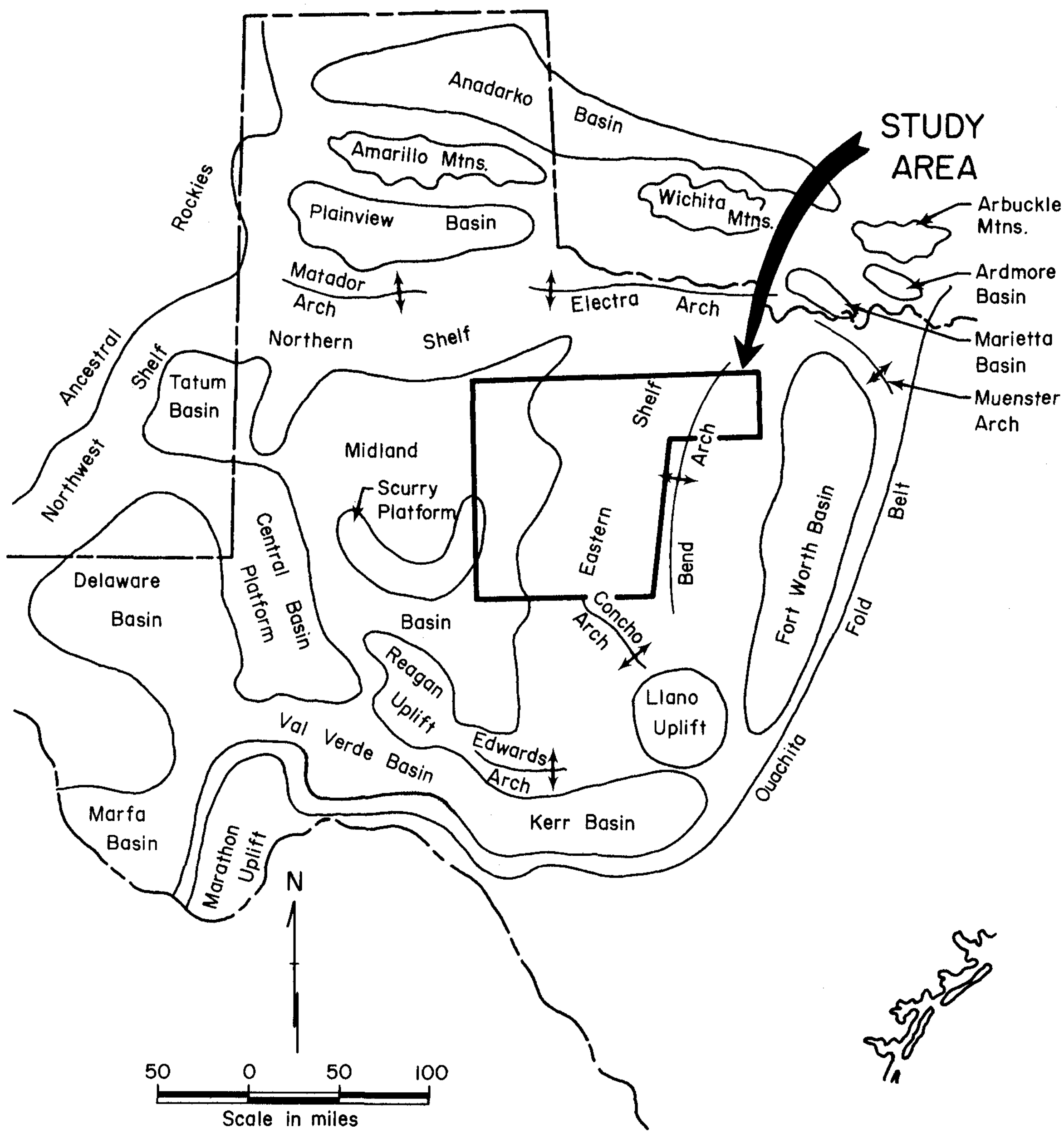

FIG. 1. Regional geologic setting and location of the study area. After Wermund and Jenkins, 1969.

shoreline and the pronounced break in slope at the continental margin. An *open shelf* refers to a specific depositional environment. The *Eastern Shelf* is a specific paleogeographic and structural feature of the Midland Basin.

Figure 1 shows the location and areal extent of the study area. Rocks of Late Pennsylvanian age crop out in Eastland, Stephens, Young, and Jack counties in an arcuate north to northeast-trending belt. Approximately 3,500 well logs were used for facies mapping in all or part of 14 additional counties—Throckmorton, Haskell, Stonewall, Kent, Shackelford, Jones, Fisher, Scurry, Callahan, Taylor, Nolan, Mitchell, Coleman, and Runnels. The study area includes about 10,000 square miles.

STRATIGRAPHY AND REGIONAL SETTING

Nomenclature used in this report is rock stratigraphic. A variety of names and time-rock correlations for the Pennsylvanian and Permian sections in north-central Texas have been presented and debated by numerous authors. A simplified nomenclature (fig. 2) based on the Abilene Sheet of the Geologic Atlas of Texas (Barnes, in press) is followed in this report. According to Brown (1959), the Cisco Group as defined at outcrop includes Late Pennsylvanian (Virgilian) and Early Permian (Wolfcampian) strata and incorporates several boundary-defined formations consisting of complexly alternating terrigenous clastic and limestone units. It overlies a carbonate and mudstone sequence comprising the Canyon Group of Missourian age and grades upward into uppermost Wolfcampian and Leonard redbed, carbonate, and evaporite facies of the Wichita-Albany and Clear Fork Groups.

Uppermost Pennsylvanian and lowermost Permian rocks are included in the Harpersville Formation, which lies near the middle of the Cisco Group, as defined herein, and consist of all strata between the base of the Breckenridge Limestone and the base of the Saddle Creek Limestone (fig. 2). The

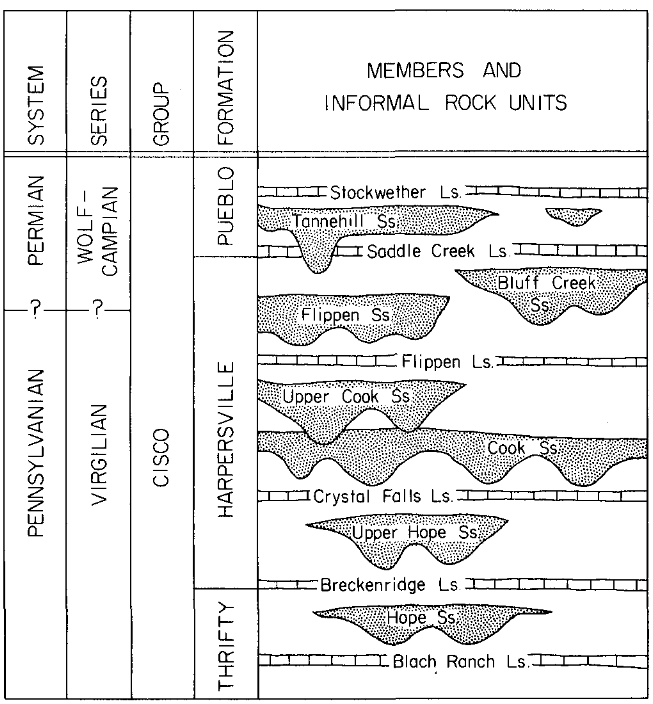

FIG. 2. Schematic stratigraphic section showing named units of the outcrop and shallow subsurface (*after* Abilene Sheet of the Geologic Atlas of Texas, Barnes, in press; and Wermund and Jenkins, 1969). The interval discussed in this report lies between the base of the Saddle Creek and base of the Breckenridge limestones.

outcrop extent of the Harpersville and equivalent facies has been mapped in Eastland and Stephens counties (Barnes, in press), in Young and Jack counties by Brown (1960, 1962), and in southwestern Stephens County by McGowen (1964). Earlier workers include Lee (1938) and Plummer and Moore (1922). The Virgil-Wolfcamp boundary has been placed at several stratigraphic levels within the Harpersville Formation by different workers (San Angelo Geological Society, 1958).

Surface terminology has been used in the subsurface and generally corresponds with names employed by petroleum geologists (Seals, 1965; Brown, 1969a). Informal names for sandstones, such as Hope, Cook, Flippen, and Bluff Creek, are used in accordance with the usage of geologists in the region. In addition, a prominent limestone zone, the Flippen limestone, that is not delineated at the outcrop is a useful subsurface marker in the area. Correlation of the four most persistent limestone zones—the Saddle Creek, Flippen, Crystal Falls, and Breckenridge—allows subdivision of the Harpersville section into three subequal parts. These parts are referred to as intervals one, two, and three; they can be distinguished over most of the Eastern Shelf. Strata approximately equivalent to these shelf-defined units have been traced into the basin (Van Siclen, 1958; Jackson, 1964).

The regional geologic setting of the Eastern Shelf is illustrated in figure 1. The Midland Basin was a small to moderate-sized interior basin that formed during and after Ouachita structural deformation. By Late Pennsylvanian time, the Fort Worth Basin, an Early to Middle Pennsylvanian foreland trough, had filled and was being tilted westward and northwestward toward the subsiding Midland Basin. To the north, the Red River-Electra and Matador arches were also growing during Cisco deposition, and the exposed Wichita-Amarillo highlands were shedding sediment south and north (Wermund and Jenkins, 1969). The Eastern Shelf was bounded on the east by the Ouachita highlands and on the south by the Llano Uplift and Concho Arch. Throughout Late Pennsylvanian and Early Permian time, the basin was actively infilled by westward progradation of the Eastern Shelf (Jackson, 1964; Wermund and Jenkins, 1969). The principal source of sediment was the eroded trunk of the Ouachita fold belt (Bay, 1932) and second-cycle material derived from the uplifted Fort Worth Basin.

Cisco rocks are undeformed except for minor faults in the northern part of the area. Regional dips average ½ to 1½ degrees to the west and northwest. Stratigraphic sections parallel to paleoslope (figs. 3–11) show that dips of limestone marker beds abruptly increase by several degrees along the western margin of the shelf. The observation that underlying and overlying marker beds do not reflect the dip change proves the steepening is not related to a structural hinge. Van Siclen (1958) related these steeper dips to depositional topography using the terms undaform, clinoform, and fondoform (originally proposed by Rich, 1951) or in the terminology of this paper, shelf, slope, and basin floor. Shelf, as defined by Swift (1969, p. DS-4-1), is the zone extending from low-water line to the depth at which there is a marked increase in slope (the shelf edge); and slope, as defined by Stanley (1969, p. DJS-8-5), is the "relatively steeply inclined (generally 3° to 6°) portion of the sea floor lying seaward of the usually sharp shelf break." The basin floor begins where the slope decreases to nearly zero or is reversed.

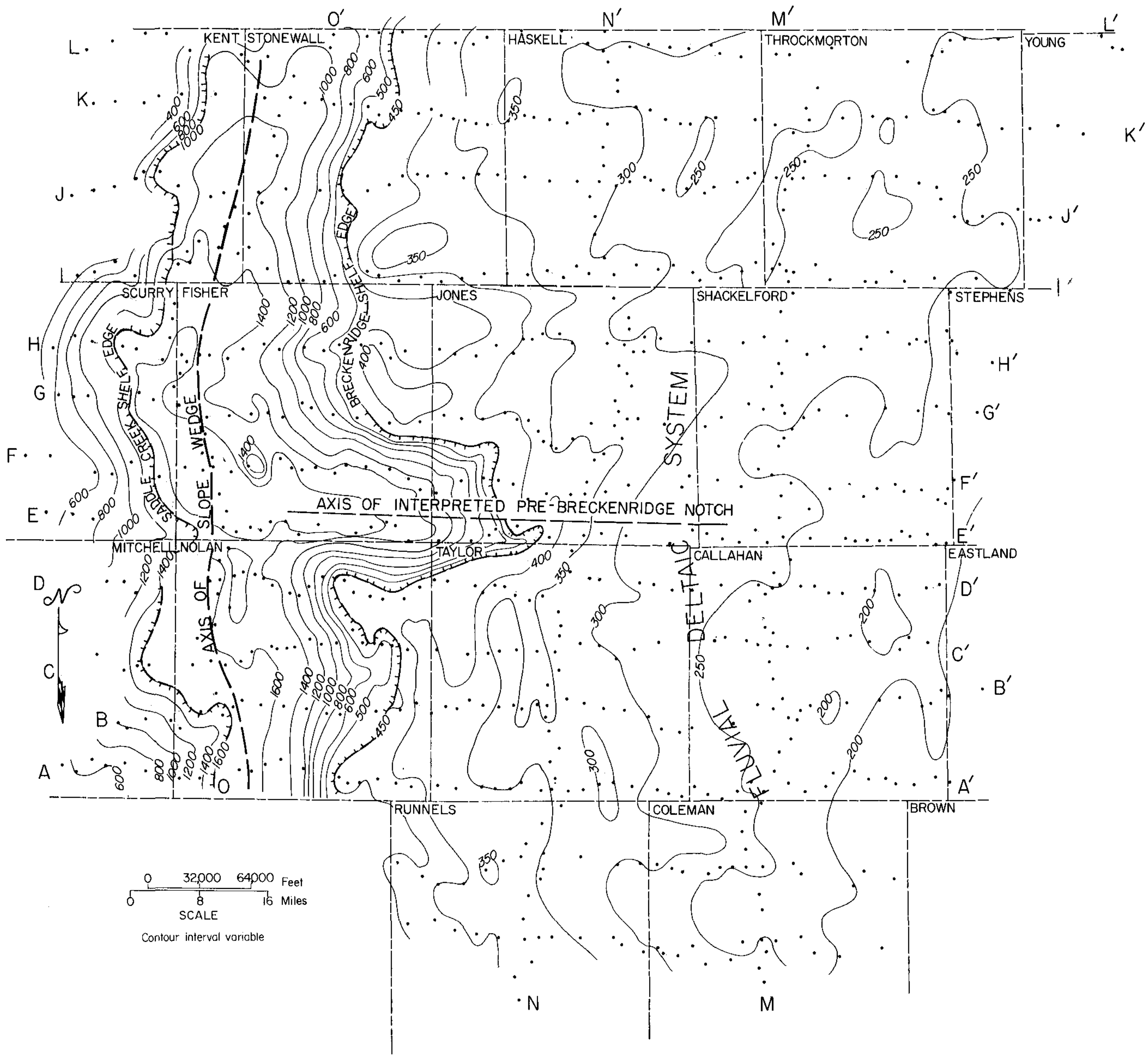

FIG. 3. Isopach map of Harpersville and equivalent units showing abrupt thickening along the western edge of the area. The axis of maximum slope deposition and a subordinate axis related to a pre-Breckenridge notch in the shelf edge are indicated by dashed lines. Shelf edges of the bounding marker limestones (hatchured) define the thickest slope wedge. Locations of wells used in construction of strike and dip sections (A-A′, etc.) are shown as dots.

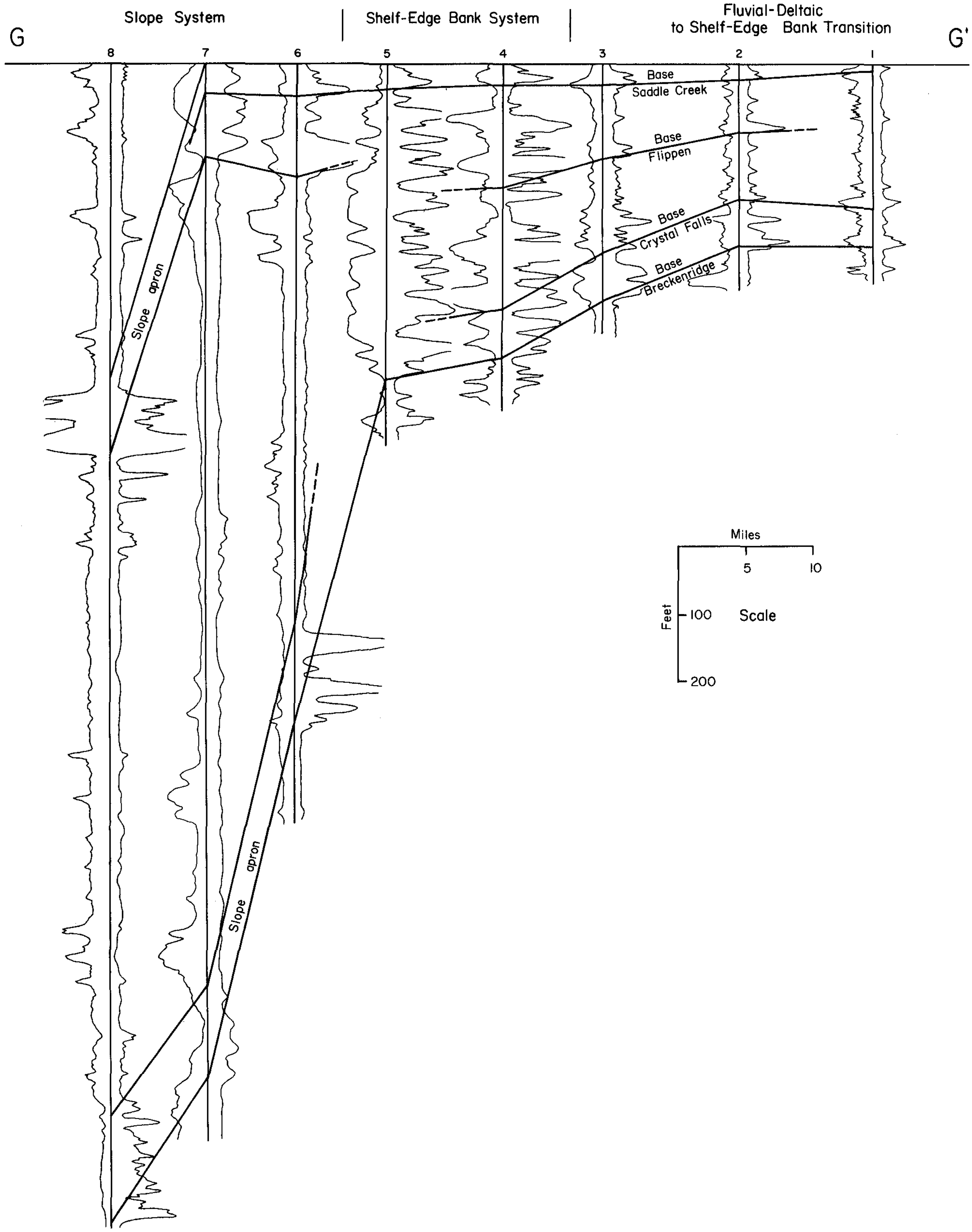

FIG. 4. Typical electric log patterns along dip section G-G′ (*see* fig. 3 for location and Appendix III for well index).

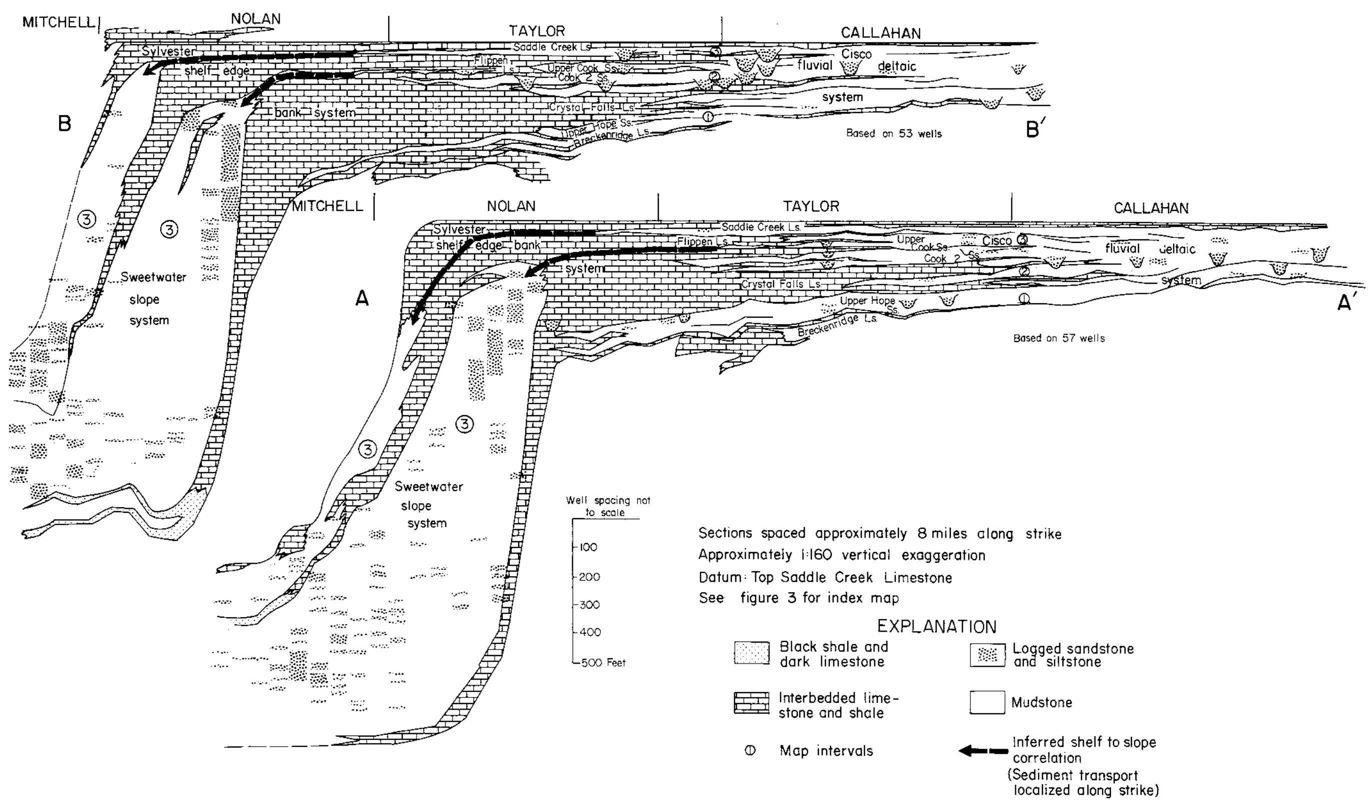

Fig. 5. Paleoslope sections A-A′ and B-B′ of the Harpersville Formation and equivalent slope wedges. These and the following sections (figs. 6-11) illustrate the buried depositional topography and three-fold facies distribution that is the basis for recognition of the depositional systems.

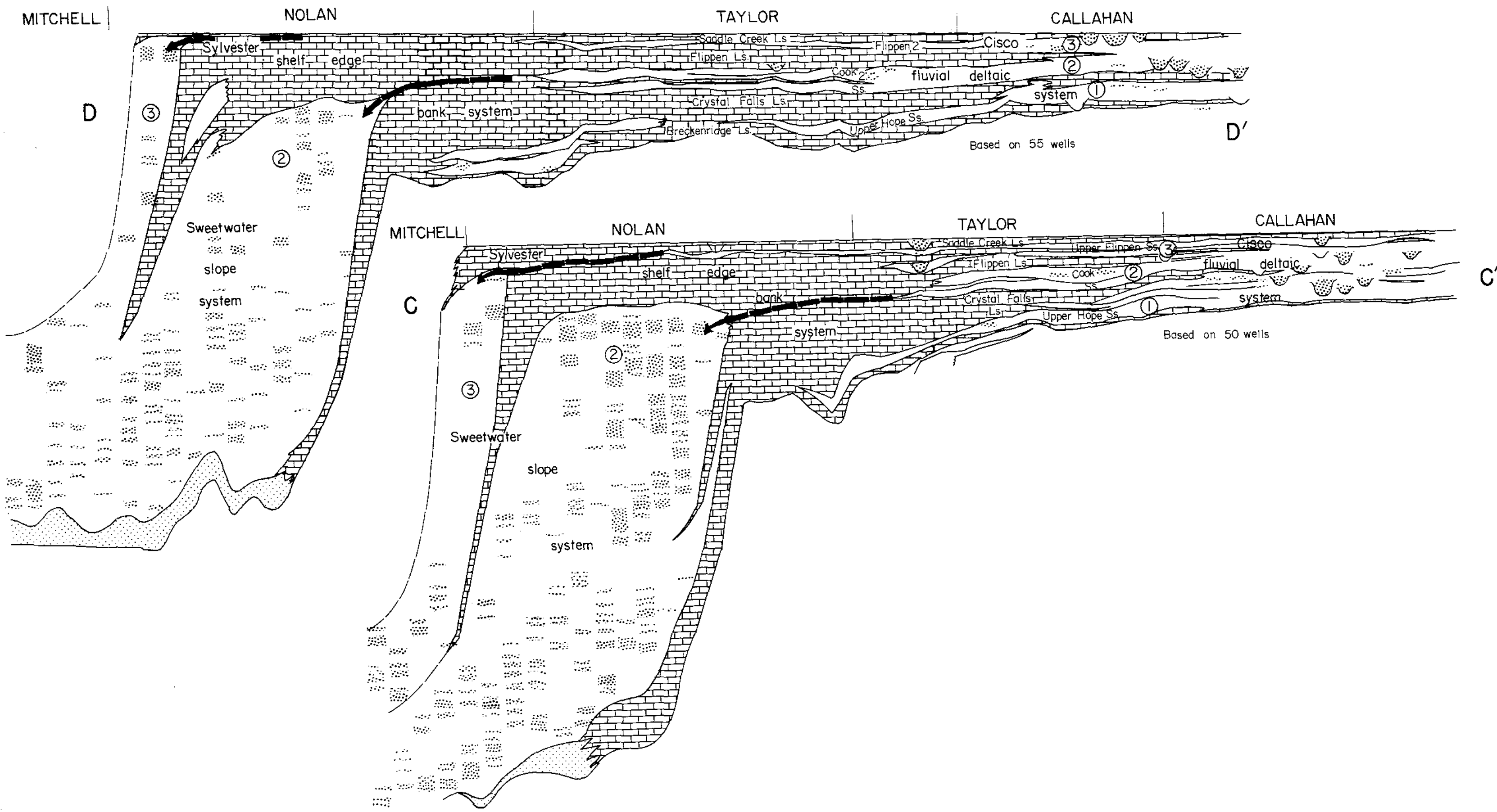

FIG. 6. Paleoslope sections C-C′ and D-D′. For explanation, *see* figure 5.

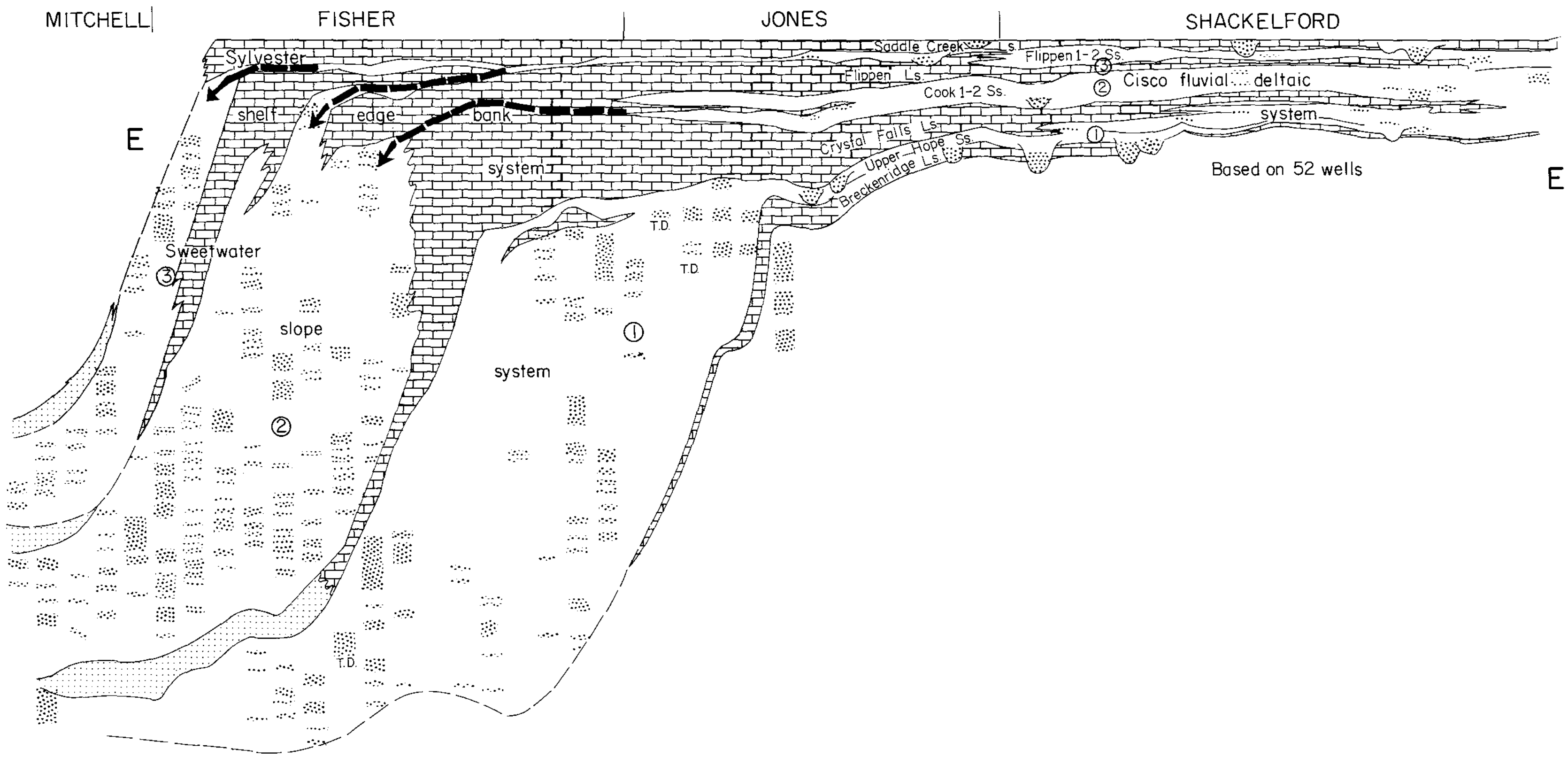

FIG. 7. Paleoslope section E-E'. For explanation, *see* figure 5.

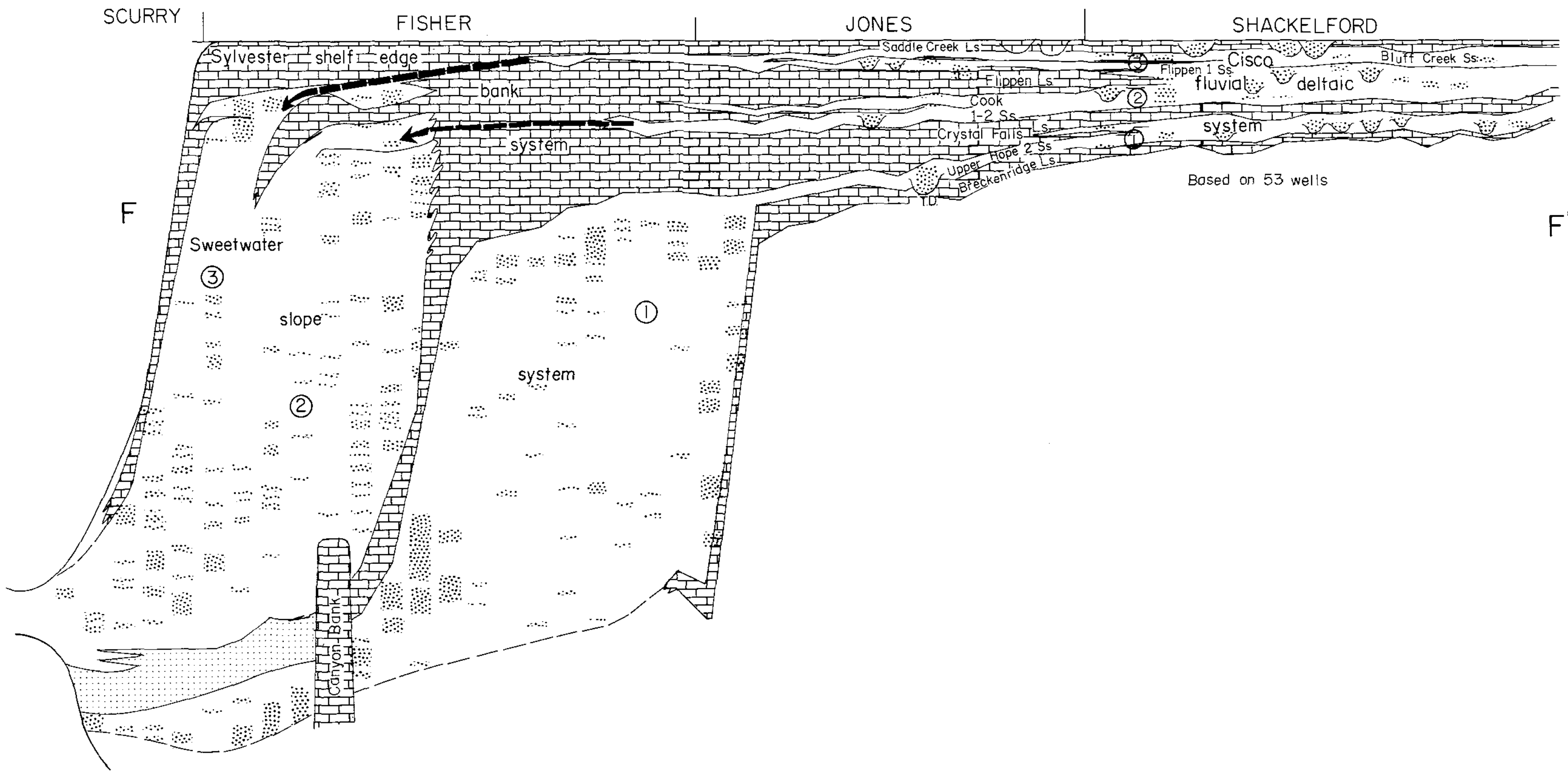

FIG. 8. Paleoslope section F-F′. For explanation, *see* figure 5.

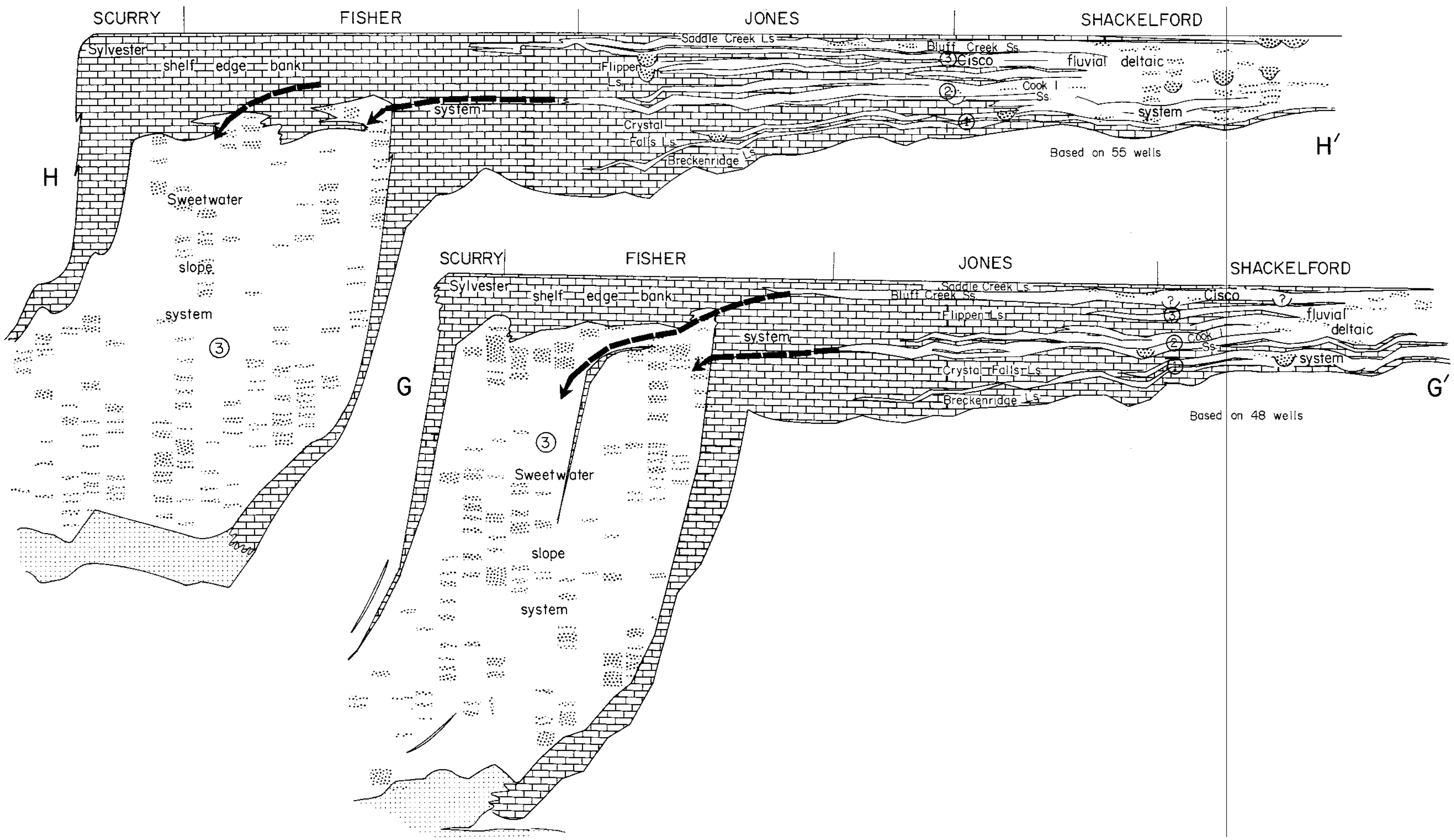

FIG. 9. Paleoslope sections G-G′ and H-H′. For explanation, *see* figure 5.

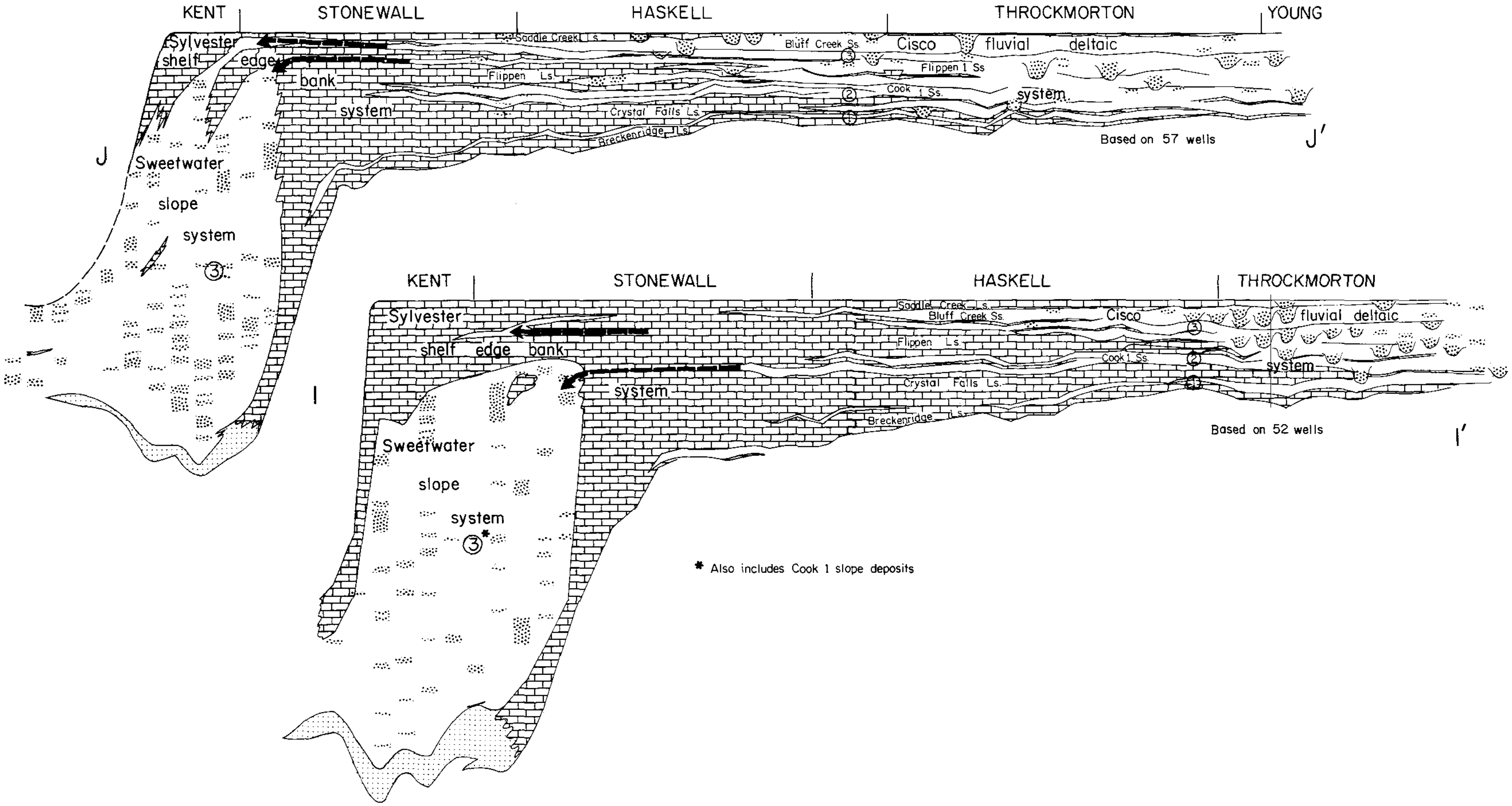

FIG. 10. Paleoslope sections I-I′ and J-J′. For explanation, *see* figure 5.

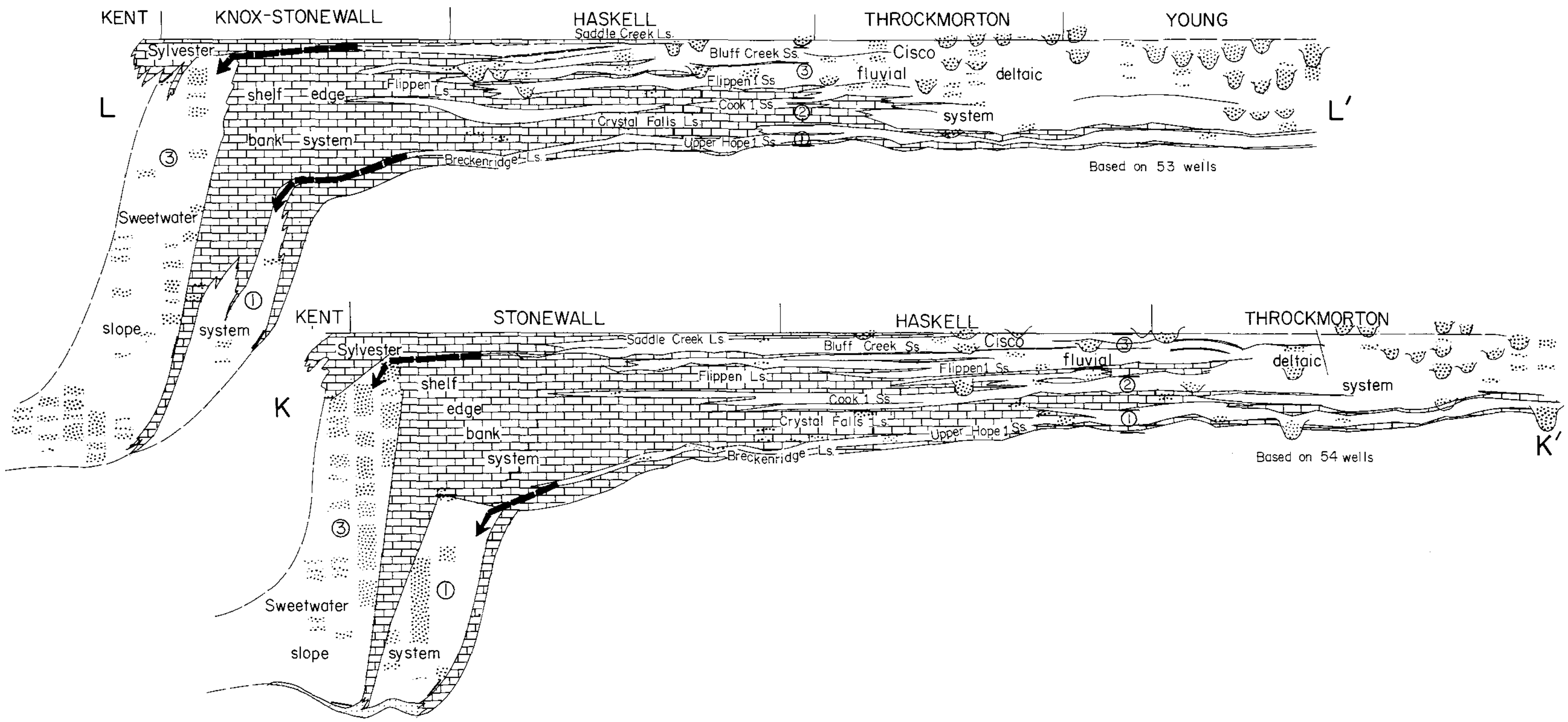

FIG. 11. Paleoslope sections K-K′ and L-L′. For explanation, *see* figure 5.

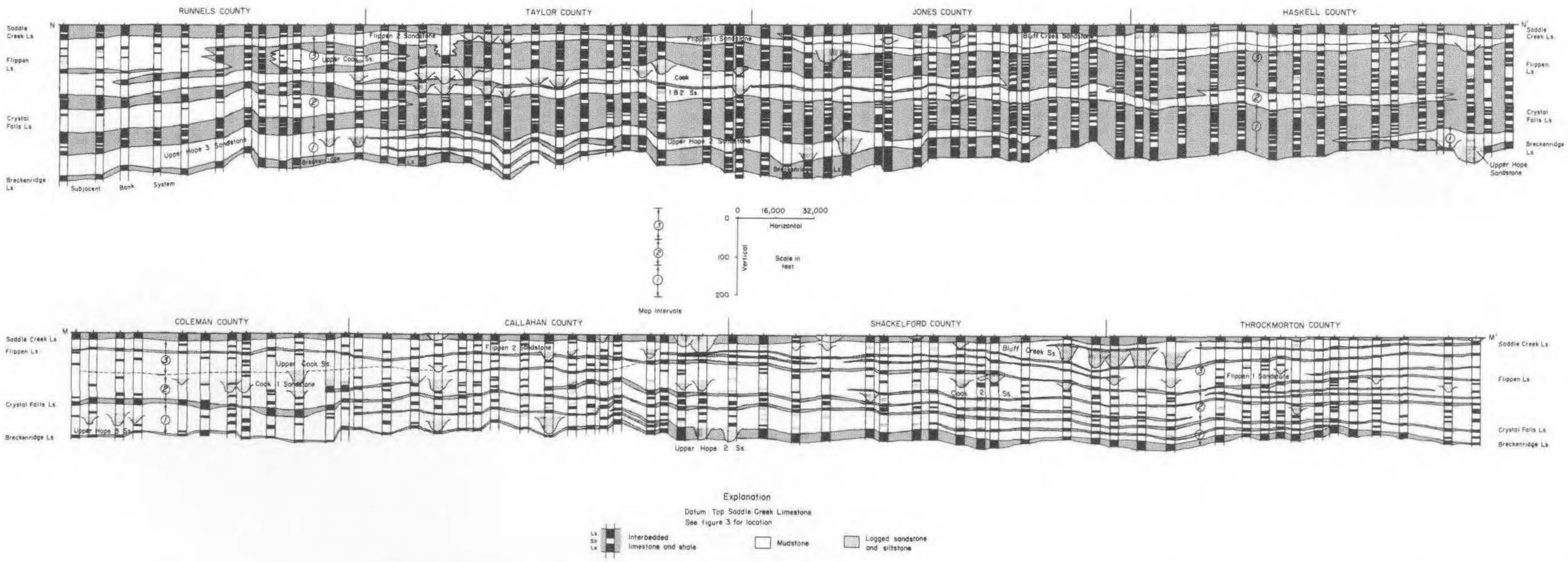

FIG. 12. Paleostrike sections through the Cisco fluvial-deltaic system showing distribution of the fluvial-deltaic lobes and correlation of limestone beds or packages. As shown on the index map (fig. 3), M-M′ is the most updip section.

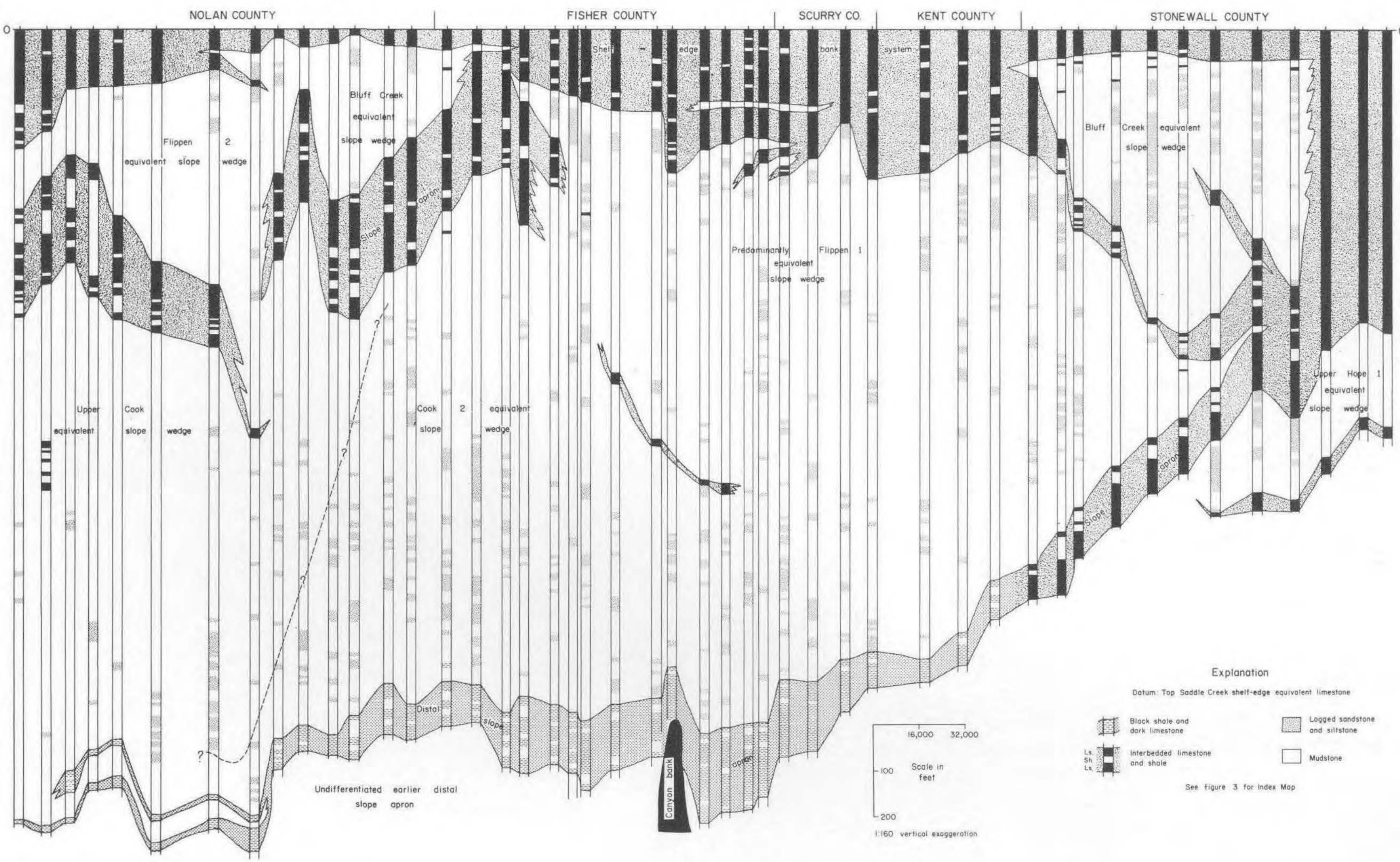

FIG. 13. Paleostrike section O-O′ through the Sweetwater slope system illustrating the lateral imbrication of slope wedges and correlation of carbonate slope aprons. Slope wedges are labeled to indicate their interpreted correlation to fluvial-deltaic lobes.

PURPOSE AND SCOPE OF STUDY

This study had three objectives. The first was to map the depositional systems that compose the uppermost Pennsylvanian rocks. The concept of a depositional system as an informal rock stratigraphic unit was introduced by Fisher and McGowen (1967). The term refers to an assemblage of process-related sedimentary facies that are the stratigraphic analog of major geomorphic units. Examples are delta systems, alluvial fan systems, and continental slope systems. A depositional system is composed of a suite of environmentally related sedimentary facies. Smaller groups of genetically related facies are herein termed facies associations. A variety of criteria is used to recognize depositional systems, including facies geometry and relationships, internal sedimentary structures, vertical and lateral sequences of structures or bedding characteristics, petrographic composition, and faunal content. The second objective was to relate the interpreted depositional systems to a regional terrigenous clastic sediment-dispersal system. The third was to outline the processes and sequential development of the shelf. An inherent question is the relative importance of local tectonics, eustatic sea-level changes, and sedimentary controls within the basin and source area in determining the depositional fabric of the shelf.

Terminology used for sedimentary structures and bedding features is explained in Appendix I. Appendix II discusses facies mapping techniques. Selected electric log data, measured sections, and localities are listed in Appendices III, IV, and V, respectively.

ACKNOWLEDGMENTS

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In addition, the writers wish to thank A. V. Jones, A. V. Jones and Sons; Stanton Ball, Pan American Oil Company; W. M. Hensel, Jr., Sun Oil Company; and Vaughn Moore, Marshall R. Young Company, for their help in locating and securing cores. R. R. Bloomer provided access to logs and sample descriptions in the Abilene Well Log Library.

DEPOSITIONAL SYSTEMS

The twelve dip and three strike sections (figs. 5–13) and sandstone isolith maps of the subdivisions of the Harpersville Formation (Pls. I–III, in pocket) clearly show three depositional systems: (1) the Cisco fluvial-deltaic system, (2) the Sylvester shelf-edge bank system, and (3) the Sweetwater slope system. Each of these systems is a geomorphic-lithologic unit characterized by lithologic composition and by position relative to shelf edges.

The Cisco fluvial-deltaic system is located updip from contemporaneous shelf edges and consists of sandstone and mudstone interbedded with subordinate limestone and coal. Internal composition of the system is similar to and its areal extent coincident with the Cisco Group as defined at outcrop. Components of both fluvial and delta systems are closely associated within this system. Elements of the delta system include distributary channel fill, distributary mouth-bar sandstone, delta margin sandstone, delta plain mud and siltstone, and prodelta and interdistributary embayment mudstone. Fluvial facies include channel sandstone, crevasse splay sandstone and siltstone, overbank mudstone, and lacustrine deposits.

The Sylvester shelf-edge bank system, which occupies a position on the shelf adjacent to the shelf edge, consists of limestone with subordinate mudstone and dolomite. The Sweetwater slope system lies basinward of the shelf edge and consists of mudstone and sandstone divided by relatively thin, steeply dipping (2 to 5 degrees) carbonate aprons. Because the threefold lithologic division and offlapping relationship persist throughout the Cisco, the systems defined herein may logically be extended beyond the boundaries of the Harpersville Formation and encompass most, if not all, of the Cisco Group.

CISCO FLUVIAL-DELTAIC SYSTEM

The Cisco fluvial-deltaic system extends 50 to 70 miles westward from the outcrop belt into the subsurface where it grades basinward into limestone facies of the Sylvester shelf-edge bank system. Fluvial and deltaic facies of this system occupy about two-thirds of the preserved shelf. A complementary tributary fluvial plain or piedmont system, which was deposited upslope from the fluvial-deltaic system, has been removed by erosional truncation. Two principal groups of closely related facies compose the Cisco system: (1) Fluvial-deltaic facies consist of channel sandstone, aggradational fluvial overbank sand and mudstone, and progradational deltaic sand and mudstone; and (2) interdeltaic embayment facies consist of sheet sandstone, mud and siltstone, coal and coaly mudstone, and limestone. Remnants of the tributary fluvial system, consisting of fluvial channel and overbank facies, are preserved at outcrop in eastern Jack and southwestern Montague counties (Pl. IV, in pocket).

FLUVIAL-DELTAIC FACIES ASSOCIATION

Fluvial-deltaic facies consist of a framework of elongate, lenticular channel sandstones enclosed within overbank mudstones.

Channel sandstone facies.—The distribution of the channel facies is displayed by sandstone isolith maps (Pls. I–III). Although channel facies are found over most of the shelf, they are concentrated in local areas. Each concentration of channel sandstones correlates with a major outcropping sandstone unit (Pl. IV) and defines localized fluvial-deltaic lobes that extended down paleoslope across the shelf. Each lobe is a composite product of deposition in many smaller delta lobes. For convenience in further discussion, the major lobes are given informal names corresponding to subsurface nomenclature commonly applied to these sandstones:

Interval 1: Breckenridge Limestone to base of Crystal Falls Limestone—
- **Upper Hope 1 lobe ---------- Northern area**
- **Upper Hope 2 lobe ---------- Middle area**
- **Upper Hope 3 lobe ---------- Southern area**

Interval 2: Base of Crystal Falls Limestone to base of Flippen limestone—
- **Cook 1 lobe ---------- Middle area**
- **Cook 2 lobe ---------- Southern area**

Interval 3: Base of Flippen limestone to base of Saddle Creek Limestone—
- **Flippen 1 lobe ---------- Northern area**
- **Bluff Creek lobe ---------- Northern and middle areas**
- **Upper Cook/Flippen 2 lobe ---------- Southern area**

Each lobe consists of numerous individual channel systems occupying slightly different stratigraphic intervals and forming both distributary and anastomosing areal patterns. The Upper Hope 2 and 3, Cook 1 and 2, and Bluff Creek lobes display distributary patterns; Flippen 1 and Upper Cook/-Flippen 2 lobes are typified by anastomosing, or interweaving, patterns.

Multiple shifting of individual delta lobes produced extremely complex sandstone distribution patterns, such as those displayed by the Cook and Flippen sandstones in Young County. Such shifting is a result of channel avulsion, abandonment, and reoccupation during the deposition of the lobe. The broad belts of sandstone recognized at the outcrop and in the shallow subsurface consist of numerous coalescing channels and are not representative of actual channel geometry. Farther down paleoslope, such belts divide into relatively narrow, bifurcating units that are difficult or impossible to trace with available well control. These narrow sandstone bodies are single channel fills and, therefore, representative of actual stream geometry and size.

Groups of channels occur as multilateral belts or as unusually thick multistory sandstone bodies. Multilateral belts, such as the Cook sandstone of northern Eastland County, form broad, relatively continuous sandstone units several miles in width that are composed of numerous intersecting channel fills. Vertical stacking of successive channels produces multistory sandstone units. Brown (1969a) has shown that multilateral belts occur because differential compaction of muds around less compactable channel sands results in lateral offsetting of distributaries as successive delta lobes occupy the same area. Channel stacking results from reoccupation of a channel course because of subtle structural control of the distributary network.

Individual channel segments can be classified on the basis of sand body geometry as channel fill with symmetrical cross section, channel fill in belted sandstone bodies, and channel fill in tabular sandstone bodies. Internal structure can be reasonably inferred from external geometry of a sandstone unit. Generally, tabular sandstones grade basinward into belted units that, in turn, bifurcate into symmetrical channel fills. Maps and sections graphically portray the resultant downslope decrease in width to thickness ratio of elongate sandstone units.

Symmetrical channel sandstones are distributary channel fills characterized by low to moderately sloping concave sides (up to 20 degrees) and lenticular cross sectional shape. Widths range from a few tens to a few thousand feet; thickness is less than 30 feet. Bedding parallels the channel margin, and a core of medium to large-scale trough-crossbedded sandstone locally grades vertically and laterally into parallel and ripple laminated sandstone. Contorted bedding is common (Pl. V, A). Localities SP-13 and YO-12 illustrate varieties of symmetrical channel fill. Closely associated facies include coarsening-upward sequences grading from finely wavy, ripple or lenticular laminated, burrowed siltstone and mudstone into medium trough cross-laminated and massive, burrowed, rippled siltstone. The Bluff Creek lobe provides several good examples of distributary and delta margin sandstones (fig. 14; Pl. V, B). Distributary sandstone units are typically isolated but may form local multilateral or multistory belts.

Belted sandstone bodies consist of channel fill and point bar facies of slightly to moderately sinuous streams. They are the most common variety observed along the outcrop belt and in the shallow subsurface. Widths of sandstone bodies may be several miles, though thickness rarely exceeds 50 feet (fig. 15). Belts have an irregular rectangular cross section. The sandstones exhibit a characteristic vertical sequence from a basal core of medium to large-scale trough-crossbedded sandstone or gravelly sandstone grading upward into finer sand, silt, and mudstone displaying lateral accretion bedding and a variety of small-scale sedimentary structures such as medium trough, parallel, ripple, and climbing ripple laminations (fig. 16, A, B). Contorted bedding is less common than in symmetrical channels. A basal channel lag of mud or limestone clasts, wood fragments, or chert conglomerate is commonly present. Lateral accretion bedding in the upper part of channel fills combined with fining-upward textures and structures indicates channel meandering and is characteristic of point bars (Frazier and Osanik, 1961; Harms et al, 1963). Most of the sandstones exhibit sharp lateral and basal contacts with fossiliferous, coaly, or fine-grained facies. Evidence of considerable scour, including limestone cutouts (fig. 15), truncation of underlying units, and channel lags containing fragments of subjacent units (Brown, 1962), is common. Contemporaneous overbank floodplain deposits are thin, and multilateral and multistory belts are common. The Upper Cook/Flippen 2 lobe contains outstanding examples of belted sandstone bodies.

Tabular sandstone units suggest deposition in braided streams or coarse-grained meander belts (McGowen and Garner, 1970). Sandstones of this facies form broad, coalescing units with very high width to thickness ratios. Structures consist dominantly of tabular crossbedding and horizontal bedding with less common large to medium troughs in a fining-upward sequence of structures and grain size (fig. 16, C). The lowermost fill consists of massive, sandy chert conglomerate grading upward

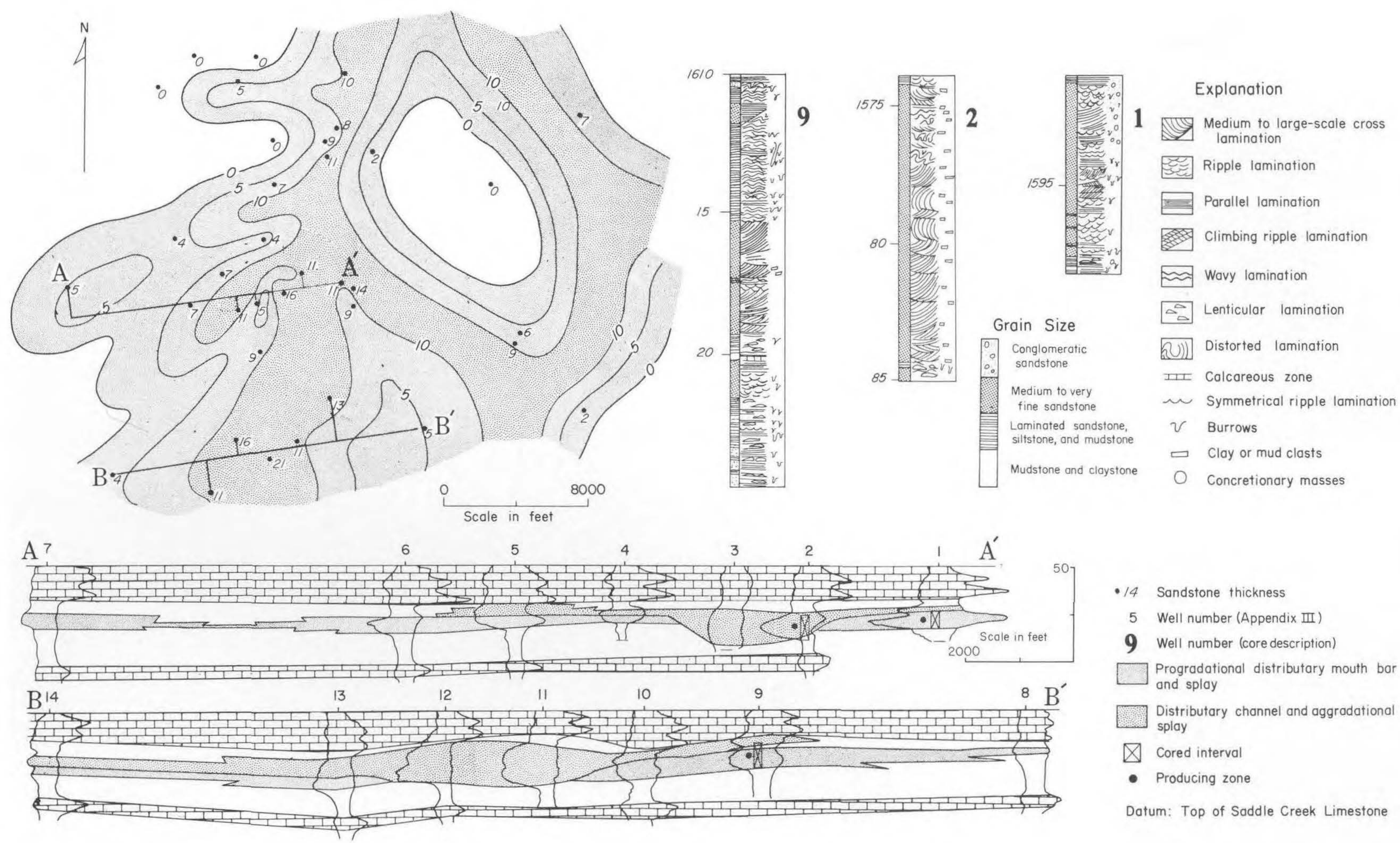


FIG. 14. Areal and cross sectional geometry and internal composition of deltaic distributary and delta margin sandstone facies (Bluff Creek sandstone, Shackelford County). Location of the map area is shown on Plate III; well names are given in Appendix III.

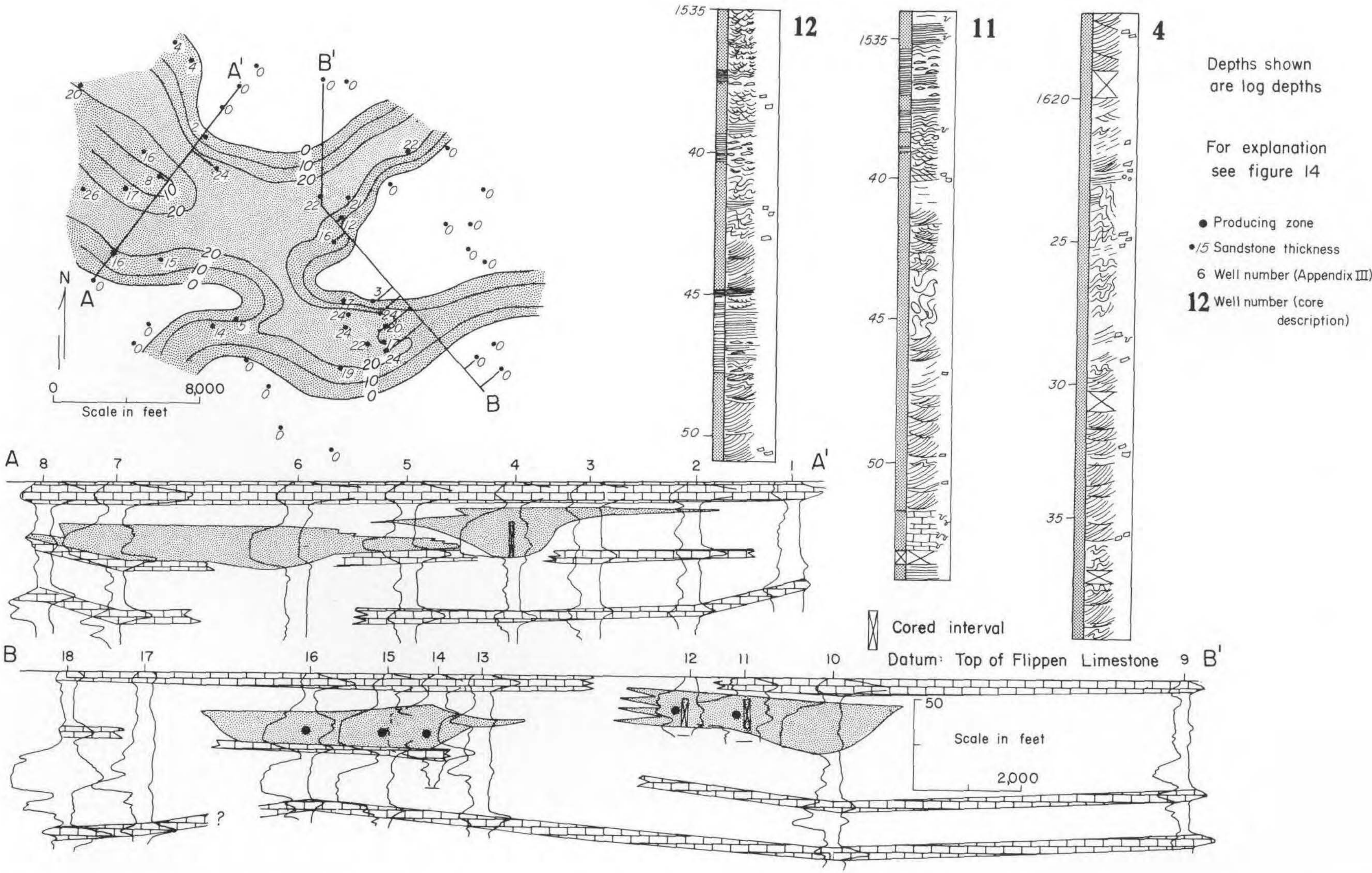


FIG. 15. Areal and cross sectional geometry and internal composition of channel fill and point bar sandstone facies (Cook sandstone, Shackelford County). Location of the map area is shown on Plate II; well names are given in Appendix III.

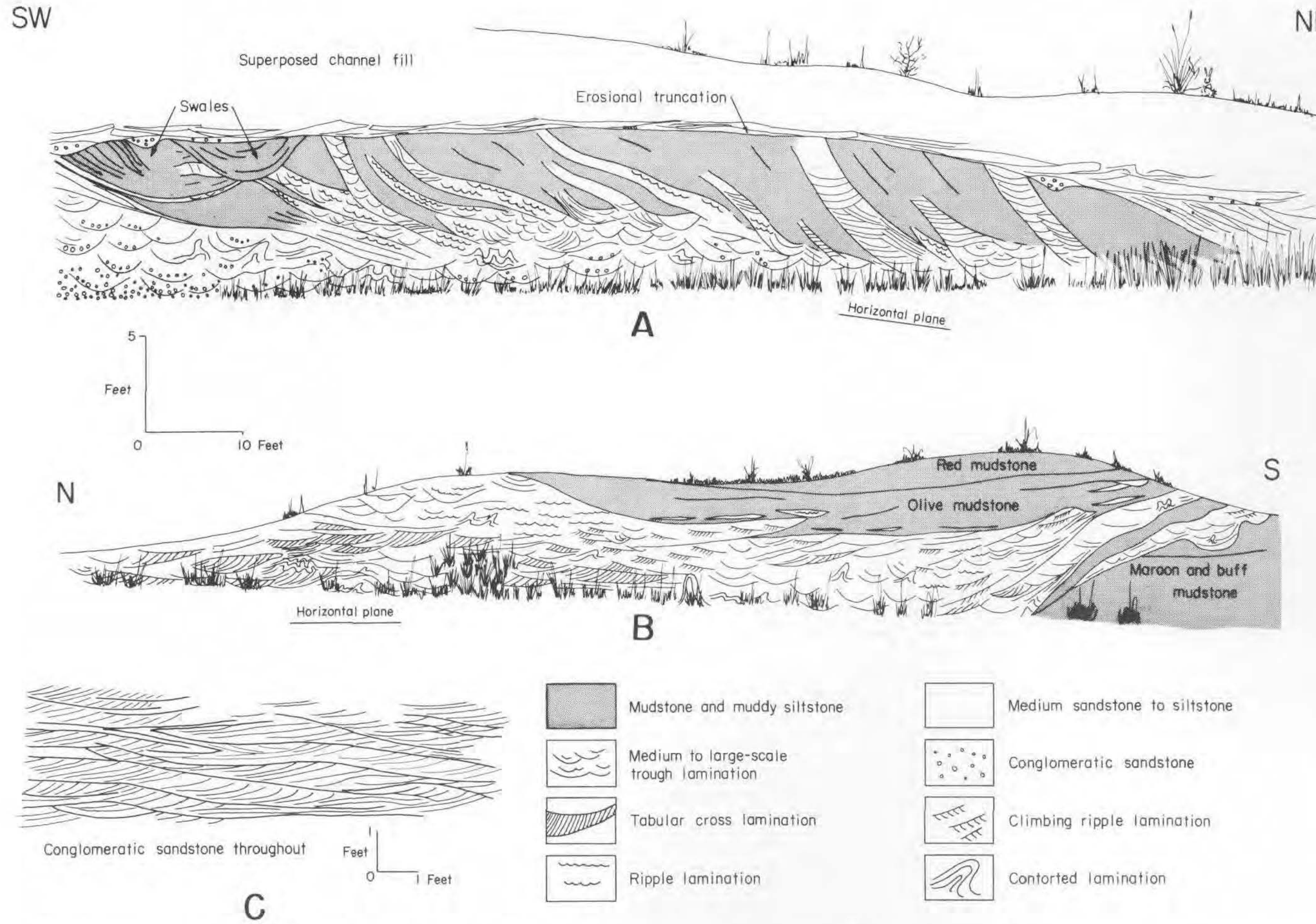


FIG. 16. Internal structure of fluvial channel fills. A, Point bar sequence in the Lake Cisco conglomerate (Cook equivalent) showing vertical sequence of massive, conglomeratic sandstone with large-scale trough crossbedding grading up into interbedded fine sand, silt, and mudstone of the upper point bar. Lateral accretion bedding with bar accretion toward the northeast and local mud and siltstone-filled swales are prominent. Locality EA-7. B, Fine-grained point bar and channel fill sandstone exposed at locality YO-15. Sedimentary structures are typical of fine-grained fluvial facies. C, Internal structures, dominated by tabular and medium to large-scale trough crossbeds, in a braided channel fill (Lake Cisco conglomerate, locality EA-5).

into sandy conglomerate, granular sandstone, and coarse sandstone. Associated structures that may be a part of the same sequence (locality EA-8) include intricately bedded sand, silt, and mudstones containing broad, shallow scour troughs and large 8- to 10-foot, inversely graded foreset beds. Both braided and coarse-grained meander belt models contain elements characteristic of this facies (Ore, 1963; McGowen and Garner, 1970; Smith, 1970) and are compatible with the coarse composition and tabular geometry. The upper part of the Lake Cisco conglomerate (e. g., at localities EA-4, 5, and 8) consists of multilateral tabular sandstone units.

Mudstone or clay plugs filled part or all of some abandoned channels, particularly if abandonment was abrupt. Mudstone plugs have been recognized in both the subsurface and outcrop where the local absence of continuous marker beds indicates channeling.

The petrographic characteristics of channel sandstone samples examined with a binocular microscope and supplemented by thin section study are listed in table 1. Sandstones of channel facies are brown to gray, mature to immature quartzarenites to subchertarenites (Folk, 1968). The amount of chert depends on the relative amount of coarse sand to pebble size modes. Grain size ranges from medium pebble conglomerate in channel cores to muddy siltstone in middle and upper point bar units. Sorting is typically poor to moderate in pebbly or granular sandstones and good in finer size grades. All pebbles are subangular to subrounded, varicolored white and pastel chert. A variety of cements is present, but quartz overgrowths and authigenic illite (recognizable only in thin section) are most important. Minor constituents include clay and mud clasts, large *Catamites* fragments, and macerated reedy plant debris.

Overbank facies.—Silt and mudstones associated with channel sandstone facies were deposited in a variety of overbank environments, including natural levee, floodplain, and crevasse splay (Allen, 1965) but were not differentiated in this study. The overbank facies are characterized by complexly inter-

TABLE 1. *Petrographic properties of fluvial-deltaic sandstone facies.* Numbers indicate the percent of the total number of samples in each facies (column) that exhibit the particular property (row). Because some samples may exhibit several colors or cements, column totals may exceed 100 percent.

SANDSTONE FACIES		Sheet sandstone facies			Channel sandstone facies			
		Upper	Lower	Undifferentiated	Channel core	Middle-upper point bar	Braided/coarse meandering	Bioturbated beds
Color class	5-YR	27	15	17	33	31	31	0
	10-YR	18	38	25	25	23	69	25
	5-Y	45	46	40	25	38	12	50
	Other	9	8	21	16	15	12	50
Cement	Siliceous	91	92	54	83	85	94	38
	Calcareous	55	31	37	0	0	0	38
	Chloritic	9	0	21	0	0	0	25
Sorting	Poor to moderate	0	15	13	50	15	62	38
	Well	64	38	67	42	77	37	62
	Very well	36	38	17	8	8	6	12
Grain size	Siltstone and very fine sandstone	36	62	46	8	54	6	87
	Fine sandstone	64	23	51	8	31	25	12
	Medium to coarse sandstone	0	8	4	76	15	37	0
	Conglomeratic sandstone	0	0	0	8	0	31	0
Mineralogy	Quartzarenite	91	77	92	32	61	36	100
	Slightly cherty quartzarenite	0	8	4	23	38	24	0
	Subchertarenite	9	15	4	23	0	30	0
	Chertarenite	0	0	0	23	0	11	0
Total number of samples		11	13	24	12	13	16	8

bedded, finely laminated fine sandstone, siltstone, and mudstone containing diverse types of delicately preserved ripple and climbing ripple laminations, planar lamination, and medium to large parallel laminated scour troughs. Small symmetrical fine sand, silt, and mudstone-filled channels exhibit medium trough and abundant ripple and parallel lamination, and massive maroon and cream mudstones and light olive to cream, blocky, muddy siltstones are common (*see* locality YO-16, Appendix V).

Other deltaic facies.—Facies associated with the distal margins of distributary channel sandstones are highly varied. Moderately thick (up to 20 feet) sequences of medium to thin-bedded, ripple, trough, lenticular, wavy, and parallel-laminated fine to very fine, well-sorted quartzarenite and silty mudstone are intimately associated with and dissected by distributary channel fills. These units (Pl. V, B; localities SP-15 and EA-2) contain highly contorted zones, burrows and trails, and symmetrical long-crested ripple marks and are similar to modern distributary mouth bar and delta margin sheet sands (Coleman and Gagliano, 1965). Associated mudstones are gray to olive and commonly contain macerated plant fragments. Because exposures are generally poor, internal structures that may be present in the mudstones are not well displayed; analogous mudstones in modern deltaic environments occupy interdistributary and prodeltaic areas (Kolb and Van Lopik, 1966).

Modem deltaic systems.—Certain similarities between the Cisco fluvial-deltaic system and the Holocene Mississippi deltaic system have been noted. Orientation of Cisco sandstones parallel to paleoslope and the dominance of fluvial deposition over marine reworking indicate deposition of the lobes as high constructional elongate to lobate deltas (Fisher et al., 1969) similar in many ways to lobes of the Mississippi delta system (although absolute size differs). This type of delta can be contrasted to high destructional deltas in which marine processes such as wave or tidal reworking are dominant in shaping the external geometry and internal facies composition of the deltaic system. Modern high destructional deltas include those of the Rhone and Irrawaddy Rivers. The low reservoir tidal and wave energy and general lack of marine reworking of the Cisco delta system can be attributed to dampening of waves and tidal fluctuations by the broad, shallow shelf upon which the lobes were constructed.

Active and abandoned channels of the Mississippi exhibit anastomosing (Lafourche lobe), distributary (St. Bernard lobe), and multilateral belt (Plaquemines-Modern lobe) patterns (Frazier, 1967, fig. 5). Individual Mississippi channels are straight to moderately sinuous, and width varies from a few hundred feet low on the delta plain to a maximum of several miles high on the deltaic plain where point bars occur. Width to thickness ratios are characteristically lower on the lower deltaic plain (Kolb, 1963). The basinward changes in channel geometry in the Cisco are similar to changes occurring down the Mississippi deltaic plain. Both the Mississippi and Cisco systems grade down the delta plain from moderately sinuous meandering to slightly sinuous and straight channels terminating in progradational distributary mouth-bar sequences. Internal features of each channel type are also comparable, but considerably more coarse material occurs in channel facies of the Cisco system. Braided or coarse-grained meander deposits are entirely absent on the Mississippi delta plain. Also, Cisco sandstones are better sorted than comparable Mississippi sands, perhaps due in part to the monomineralic composition of Upper Pennsylvanian sandstones.

The great lateral extent of thin units and the minor development of progradational facies indicate that the Cisco fluvial-deltaic system prograded onto a very stable and shallow shelf. This is in marked contrast to the Mississippi delta where active basinal subsidence caused by depositional loading and progradation into water up to 300 feet deep have resulted in deposition and preservation of thick delta front and prodeltaic sequences (Frazier, 1967). The effects of a stable, shallow shelf on the development of deltas were discussed by Donaldson (1969) and Donaldson et al. (1970) in relation to the Pennsylvanian Conemaugh and Monongahela Groups of West Virginia. Both Donaldson (1969) and Martin (1969) compared Pennsylvanian deltas with the Guadalupe delta, a small bayhead delta prograding into the shallow water of San Antonio Bay, Texas. Important similarities between the Cisco and Guadalupe delta lobes include: (1) progradation onto a stable, slowly subsiding platform; (2) low rates of marine reworking resulting in a digitate sand distribution; (3) incision and reworking of distributary mouth bar, delta front sheet sands, and prodeltaic facies by advancing distributaries; (4) subordination or complete absence of prodeltaic deposits; and (5) erosion by distributaries into underlying beds unrelated to the modern delta. As a result, progradational facies (prodelta mud, delta front sheet sand, and distributary mouth-bar sand) are thin and partially to totally reworked by the advancing distributaries, and aggradational facies (delta floodplain, natural levee, channel fill, and crevasse splay) predominate. Furthermore, a delta prograding into an extremely shallow body of water may fill parts of the basin with prodeltaic muds, forming broad mudflats in front of the prograding delta and thus precluding development of the progradational sequence. Filling of San Antonio Bay is predicted by Donaldson (1969) to occur before the Guadalupe delta reaches the barrier islands.

An extremely shallow, stable shelf platform has other ramifications for the development of delta facies. Because the thalweg of deeper channels is cut below underlying progradational or aggradational deposits, perhaps in limestone or compacted clay, channel stability is increased much like the Mississippi is stabilized where it flows through Pleistocene clays (Kolb, 1963). Meandering on the delta plain is inhibited by this channel stabilization. Preservation of *in situ* organic deposits as a deltaic plain coal or lignite facies will be rare, unlike the modern Mississippi delta system, where compactional subsidence of the prodelta and embayment muds causes rapid burial and preservation of thick peat deposits (Frazier and Osanik, 1969). Little coal or coaly mudstone is present in association with deltaic plain facies of the Cisco.

The Cisco system is unique compared with well-known modern deltaic systems because of the intimate association of deltaic clastic facies with extensive carbonate facies. Cisco limestones originated in a number of depositional environments including embayment, fresh-water lake, and open shelf. Many of the less extensive limestones are environmentally analogous to modern bay and sound facies that are deposited over abandoned deltaic lobes during delta destruction and submergence (Coleman and Gagliano, 1964; Fisher et al., 1969).

Paleohydrology.— Deviation of Cisco high-constructional deltas from characteristics listed in Fisher et al. (1969) can be explained in terms of their paleohydrologic régimé. First, the source area for the fluvial system or systems that carried sediment across the Eastern Shelf lay adjacent to the basin margin. Drainage basins were less than 100 to 200 miles in length. During the Paleozoic, upland vegetation was probably limited to stream margins; thus upland erosion resembled modern erosion in semiarid areas (Schumm, 1968). In such a setting, streams would tend to transport a higher proportion of bedload relative to suspended load and to exhibit relatively short but intense periods of peak discharge. Mixed load, "flashy" streams such as early channels of the Murrumbidgee River, New Zealand (Schumm, 1968), tend to have broad, shallow channels of moderate to low sinuosity similar to those observed in the Cisco. Schumm, in his discussion of geologic time before vegetal occupation of interfluvial areas, stated "Large floods could have caused periodic shifts in the channel position and an influx of coarse sediment." Sediment stored over a period of time in the vegetated stream valleys would be flushed out during occasional large "threshold floods" because of the unstable, oversteepened gradient, punctuating the continual deposition of finer-grained sediments with brief pulses of relatively coarse sediment (Schumm, 1968). This mechanism provides a possible explanation for the deposition of gravel in channel deposits of the lower reaches of the Cisco fluvial-deltaic system.

INTERDELTAIC EMBAYMENT FACIES

A distinctive facies suite flanking the delta lobes (fig. 17) is composed of olive, gray, and red mudstone, broken by thin, relatively continuous beds of sandstone, burrowed siltstone, coal, and limestone. At the outcrop in Stephens and northern Eastland counties, these facies flank Cook and Flippen deltas. In Eastland, northern and southern Stephens, and southern Young counties and over a 30- to 80-foot interval above the Breckenridge Limestone in Young and Jack counties, they flank Upper Hope deltas. The distribution of the facies suite coincides with the limits of outcropping coal deposits (Pl. IV). Embayment facies grade laterally and downdip into fluvial-deltaic facies, and similar sequences occupy other inter-lobe areas, as in northeastern Coleman County flanking Upper Hope deltas.

Sheet sandstone facies.—Thin to medium-bedded sandstones up to 5 feet thick and several tens or hundreds of square miles in areal extent are a common and distinctive interdeltaic facies. Several such sandstones were mapped by McGowen (1964), and one sandstone, herein named informally the Spy Mountain sandstone for excellent exposures at Spy Mountain in Stephens County (fig. 18), provides a three-dimensional example of a sheet sandstone. Where most completely developed, sheet sandstones have a gradational base with the underlying gray or olive embayment mudstones and are characterized by an upward increase in bed thickness and median grain size (fig. 18, sections A, B, and C). Basal beds are thin and contain ripple, wavy, and parallel

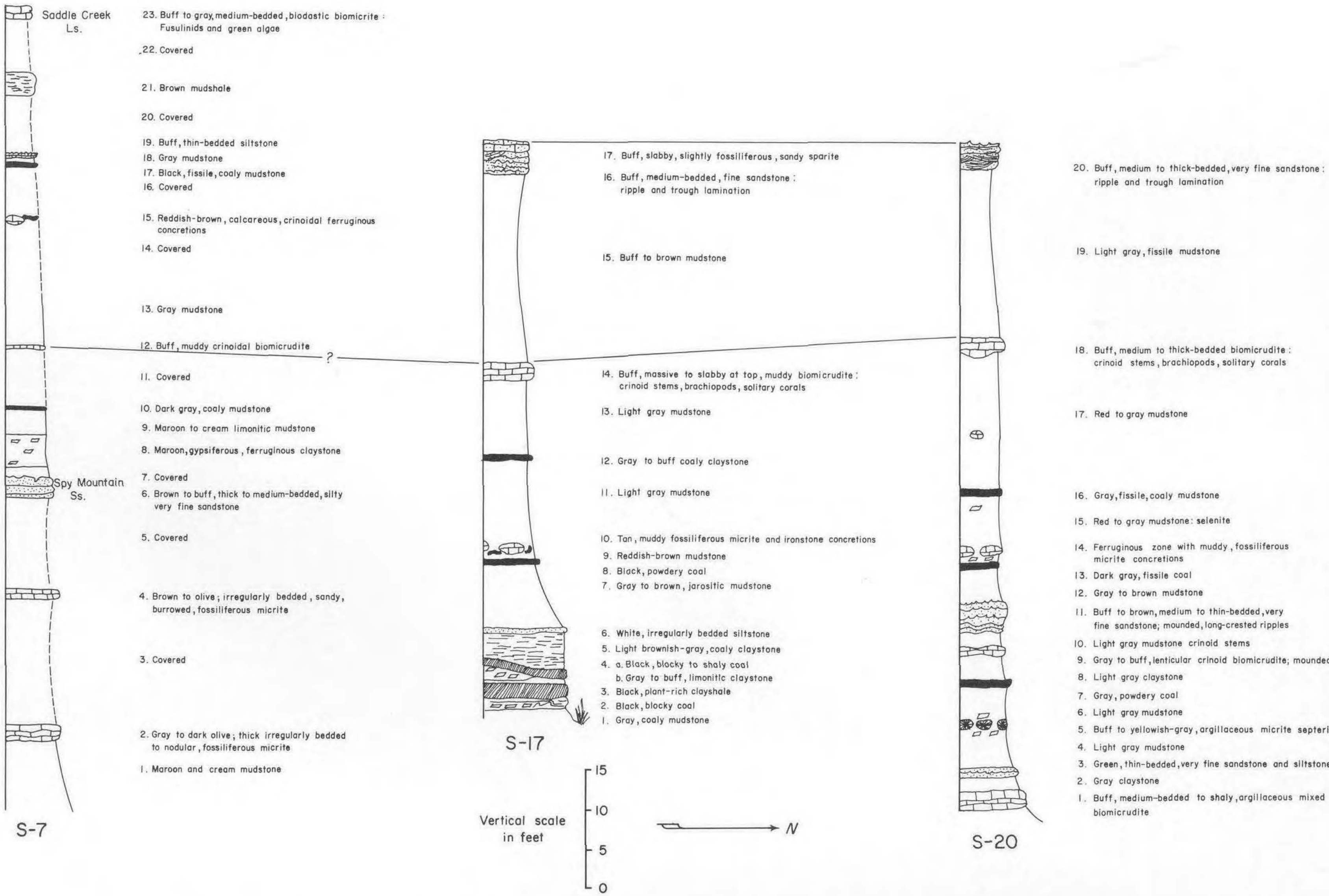


FIG. 17. Representative measured sections of Cook-Flippen equivalent interdeltaic embayment facies. Sections are located and described in Appendix IV.

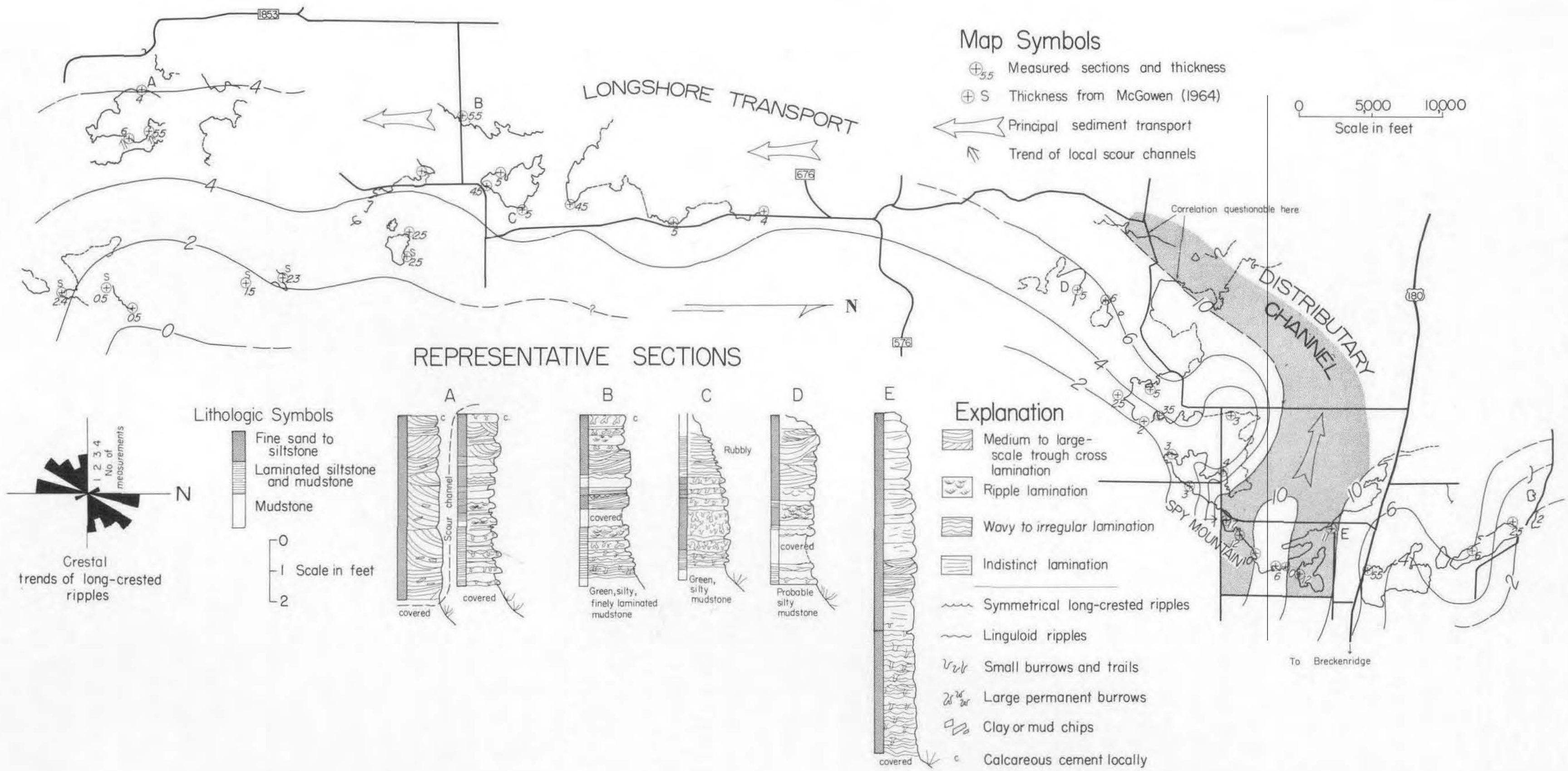


FIG. 18. Isopach map and representative measured sections of the Spy Mountain sandstone, a sheet sandstone that forms part of the interdeltaic facies suite flanking Flippen fluvial-deltaic lobes in Stephens County. Crestal trends of symmetrical long-crested ripples indicate waves that impinged on the shoreface from the northwest. *See* Appendix IV and Plate IV for description and location of measured sections mentioned in text.

lamination. Symmetrical long-crested ripples, burrows and trails, and flaser bedding are common. Superposed medium beds are massive or display broad, shallow trough or parallel lamination. The uppermost beds commonly contain large permanent burrows, symmetrical ripple marks, and calcite cement. Large scours filled by parallel-laminated sandstone locally cap sheet sandstones (fig. 18, section D. At some localities, these scours completely cut out the typical gradational sequence and are filled with medium-bedded to massive fine sandstone containing large trough crossbedding and an abundance of mud chips up to 5 cm in diameter (section A). Internal structure of the Spy Mountain sandstone is highly variable. A sandstone isolith map (fig. 18) based on measured sections shows that the Spy Mountain is thickest along depositional strike and grades at its northern end into a massive, burrowed, indistinctly laminated, dip-oriented sandstone body 17 feet thick and 2 miles wide. The Spy Mountain and other sheet sandstone facies are typically very well to well-sorted fine sand to silt-sized quartzarenite (table 1). Siliceous, calcareous, and chloritic cements are common.

Based on its strike orientation, suite of sedimentary structures, coarsening-upward sequence, and textural and mineralogical maturity, the Spy Mountain and other similar sheet sandstone facies are interpreted to be strike-fed strandplain and shoreface sand facies reworked and transported laterally by marine processes from inactive lobes. Lateral relationships of sheet sandstones indicate southward longshore transport; number and thickness of sheet sandstones decrease southward across Stephens County and away from equivalent deltaic facies.

Mudstone and siltstone facies.—The bulk of the interdeltaic embayment facies suite consists of mudstone (fig. 17). Mudstones are typically blocky and massive, but some fissile or splintery beds contain a sparse marine fauna or well-preserved plant fragments. Color ranges from maroon, brown, cream, and yellow to gray and olive gray; variegated beds are common. Few primary structures were observed in mudstone facies, probably in part due to the deeply weathered exposures. Many of the thin, muddy siltstone beds are bioturbated. Ferruginous and calcareous concretion zones occur at local horizons, and selenite crystals and masses are disseminated through some beds. The modern interdeltaic environment is characterized by fresh, brackish, and moderately saline water.

Coal facies.—Coal and coaly claystone occur in beds from a few inches to 3 feet thick. Lateral extent of individual beds is difficult to ascertain, but the persistent occurrence of coal at specific stratigraphic positions indicates that many beds are continuous for tens of square miles. Thicker coaly intervals consist of a basal fissile clay-shale containing abundant bedded plant fragments (including fern fronds and other recognizable material) overlain by an impure, powdery lignite or bituminous coal and capped by a second plant-rich clay-shale or thin, muddy siltstone (fig. 17, section 17; locality YO-10). Secondary gypsum and jarosite are commonly associated with coaly sequences. Finely laminated plant debris within many coals and associated clay-shales and the common vertical gradation from undisturbed plant-rich clay-shales into bituminous coal, indicate that organic detritus accumulated in ponded water bodies, possibly small lakes or protected lagoons. Root-mottled underclays were not recognized at any coal locality.

Limestone facies.— Numerous thin, moderately continuous limestone beds occur in interdeltaic embayment areas. The thickness and distribution of several such limestones were described by McGowen (1964). Composition of Cisco limestones has been discussed by Waller (1969). Limestones range from a few inches to 2 feet thick and exhibit nodular, platy, concretionary, or massive bedding; most have an impure, bioturbated appearance. Nearly all samples are biomicrudites, biomicrites, or micrites in the classification of Folk (1968). Petrographic properties of 64 samples are summarized in table 2. Vertical variability within an individual bed is normally minor, but beds commonly display a wide lateral variation in faunal content, though faunal diversity appears to be limited. Two facies worthy of note are bioclastic scour channel lags (biosparrudites) exposed at localities EA-1 and SP-3 and local biostromes of *Syringopora* or horn corals (McGowen, 1964).

Chamosite facies.—Lenticular masses of pisolitic chamosite, weathered in part to hematite and limonite, compose a minor facies. Thicker beds terminate abruptly into mudstone and are interpreted to be channel fills. The pisolites are about one centimeter in diameter and are interspersed in a sandy matrix of hematite and carbonate cement. James (1966) noted that chamosite may be a product of the reaction of ferrous iron with detrital clay particles in solutions of slightly negative Eh and nearly neutral pH. The pisolitic structure characteristic of chamosite indicates deposition in agitated water within an interdeltaic environment.

Mounds.—Elongate, low amplitude (1 to 4 feet)

TABLE 2. *Petrographic properties of limestone facies.* Numbers show the percent of the total number of samples in each facies, or column, that possess the composition, allochems, or impurities listed on the left.

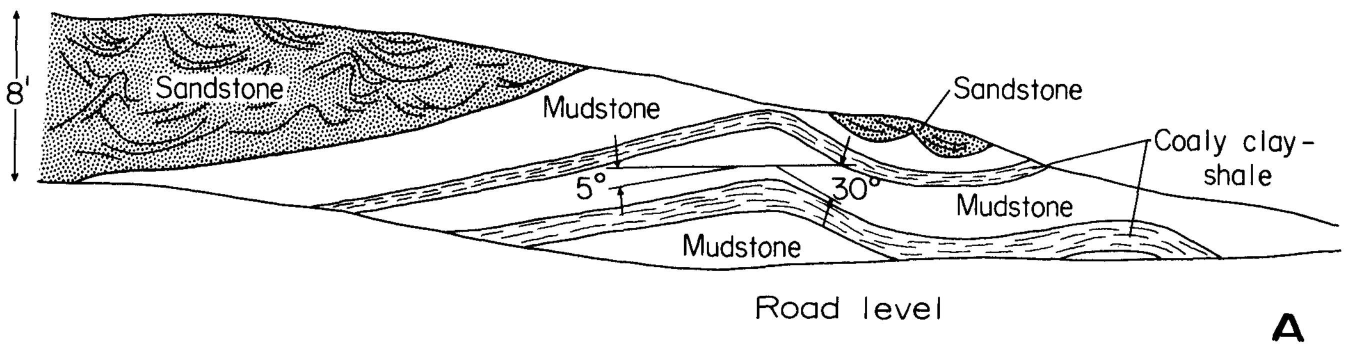
LIMESTONE FACIES	Inter-deltaic embayment limestone facies	Open-shelf limestone facies			
		Brecken-ridge	Crystal Falls	Saddle Creek	
				Transi-tional*	Normal*
Micrite	23	30	46	0	0
Biomicrite	45	59	31	50	50
Biomicrudite	23	6	15	33	50
Biosparite/ Biosparrudite	9	6	7	17	0
Pellets	4	12	15	0	33
Blue-green algae	0	6	0	17	33
Phylloid algae	4	6	23	50	33
Crinoid columnals	77	59	69	100	17
Bryozoans	59	41	62	83	33
Brachiopods	67	71	85	50	67
Encrusting forams	45	24	54	33	50
Fusulinids	32	53	46	33	17
Other forams	36	47	72	33	17
Molluscs	13	24	15	0	17
Ostracodes	32	41	38	17	50
Muddy	23	6	8	0	0
Sandy	18	18	0	67	17
Ferruginous	32	18	38	50	0
Total number of samples	22	17	13	6	6

**See* page 29 for explanation of terms transitional and normal.

limestone and sandstone mounds several feet to tens of feet wide are common in and unique to inter-deltaic embayment facies. Several types of mounds occur (Brown, 1960). The most common variety shows no relationship to warping or thickness of underlying units and is not simply the result of draping over channel fills or bioherms. Mounds are best displayed on stripped surfaces of resistant lime-stone or sheet sandstone beds. Uniformity of bed thickness and ripple-mark orientation in sheet sand-stones (locality SP-4) and relative amount of bio-clastic debris in limestones across mound crests and troughs suggest that mounding was not contempora-neous with deposition of the mounded bed. On the other hand, features such as healed microslump scars and recumbent microfolds on the flanks of mounds (locality YO-2) indicate that mounding occurred soon after burial while sediments were subject to gravity-induced intrastratal flow. Mounds are probably incipient mudlumps formed by the compaction and flow of saturated mud during load-ing (by advancing superposed distributaries). Evi-dence for this interpretation is seen at locality JK-2 (fig. 19) where coaly mudstone beds were squeezed outward and upward beneath a massive channel sandstone forming at least two asymmetrical mounds similar in geometry to incipient mudlumps illustrated by Morgan et al. (1963). This hypothesis is supported by the observation that the most extensive area of large mounds occurs in northern Stephens and southern Young counties where mounds are interbedded with or overlain by massive channel sandstones.

Modern delta flank facies.—Delta flank facies of the Mississippi River have been described by Morgan et al. (1953), Treadwell (1955), Coleman (1966), and Beall (1968). Flanking environments include swamp, marsh (fresh, brackish, and saline), beach-chenier, lake and bay, oyster reef, mudflat, and nearshore marine. Bays and lakes are filled with laminated, shelly mud that locally contains abundant macerated plant material. Faunas in the bays are characterized by low species diversity. During periods of high sediment influx, subaqueous to intertidal mudflats consisting of structureless mud and clay are rapidly prograded into bay and marine areas. Slower rates of progradation result in more wave reworking of the introduced sediment and intertidal sand flats and nearshore marine sands, which exhibit most of the sedimentary structures and facies relationships of the Cisco sheet sandstones. Tidal channels and scours locally cut across mud and sand flats to the restricted bays and lakes (such as Vermilion Bay) and commonly occupy abandoned distributary channels; they are filled with silt and mud following abandonment. Mud and clay are deposited farther offshore. Oyster reefs grow on the nearshore shelf and seaward bay margins, producing large areas of calcareous mud, which is the closest modern analog to limestone facies of the Cisco. Marsh and swamp environments produce peat and organic-rich mud and clays.

In summary, interdeltaic embayment facies of the Cisco consist of a variety of facies deposited in marginal deltaic environments, similar to those west of the modern Mississippi deltaic plain. Included are closed embayment (coals and fissile, plant-rich or fossiliferous clay and mudstones), mudflat (varicolored mudstones), nearshore marine sand flat (sheet sandstones and burrowed siltstones), and open embayment (limestones) facies.



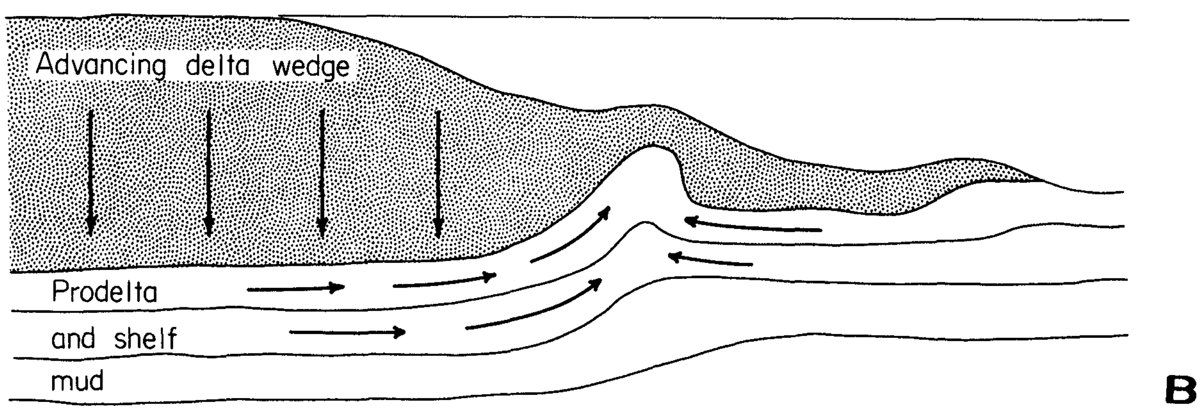


FIG. 19. A, Schematic diagram of mounding of two coaly shale beds (locality JK-2). Asymmetry of the mounds indicates an origin by squeezing of soft mud from beneath the overlying massive channel sand unit. B, Incipient mudlump formation in front of an advancing deltaic wedge. Squeezing of soft prodelta mud from below the sandy wedge forms asymmetrical mudlumps similar to mounds. From Morgan et al. (1963).

OPEN SHELF LIMESTONE FACIES

Widespread limestone facies reflect periods of reduced fluvial-deltaic sedimentation over broad areas of the Eastern Shelf. The Saddle Creek, Crystal Falls, and Breckenridge Limestones are tongues of these open-shelf limestone facies and are rarely more than 7 feet thick at the outcrop. These thin, extensive limestones are characterized by distinctive faunal content and vertical faunal zonation (table 2). Principal lithologic types are fusulinid and algal biomicrites and mixed fossiliferous micrite or sparse biomicrite. For example, the Breckenridge Limestone in northern Stephens County grades from a basal fusulinid-rich mixed biomicrite to a mixed bioclastic micrite that is in turn capped by a zone of marly, nodular ostracod-rich mixed bioclastic micrite (Brown, 1960). Both the Crystal Falls and Saddle Creek Limestones are vertically zoned in central Stephens County (section 15; locality SP-5).

Open shelf limestones display similar facies along miles of outcrop, though internal facies variability on a scale of many miles is present. Although each tongue is an important regional marker bed, the limestones pinch out at the northern or northeastern end of the outcrop belt. The Breckenridge and Crystal Falls Limestones thin and pinch out in Young County. The normal Saddle Creek Limestone facies grades through a transitional zone of sandy biomicrite and biomicrudite into a calcareous, fossiliferous sheet sandstone in northern Stephens County. Sandy, highly burrowed foraminiferal biomicrite and mixed biomicrite at locality SP-11 are probably equivalent to the Saddle Creek. Each widespread shelf limestone tongue is locally split by thin clastic wedges of fluvial-deltaic facies. The Breckenridge Limestone, for example, splits in Callahan and Taylor counties, the two resultant beds apparently pinching out into the intervening clastic wedge (fig. 12). McGowen (1964, fig. 2) described a split in the Crystal Falls Limestone in south-central Stephens County.

Splits in regional limestone tongues indicate that clastic deltaic deposition occurred in some parts of the shelf during even the most extensive transgressions, making the use of such limestones for precise intra- or inter-basin correlation questionable.

CISCO FLUVIAL-DELTAIC MODEL

The Cisco fluvial-deltaic system is the product of continuous or nearly continuous clastic deposition in a series of shifting, dip-oriented fluvial-deltaic lobe complexes and flanking strike-fed interdeltaic embayments, punctuated by widespread destructional phase limestone deposition (fig. 20). Individual elongate to lobate high constructional delta lobes prograded across an extremely stable, shallow shelf; repeated channel abandonment, switching, and reoccupation produced complex lobe patterns. Minor amounts of fine sand and mud were transported laterally into interdeltaic embayments by southward longshore drift. Deltaic deposition produced extremely thin progradational facies that were incised and in part reworked by advancing fluvial channels as progradation continued. Aggradational facies, therefore, are dominant in most Cisco delta lobes. The deltaic plains maintained shallow gradients and were at most a few feet above sea level, preserving little evidence of subaerial exposure, such as mud cracks, root-mottled sandstones, soil zones, or supratidal carbonates. Stability of the shelf resulted primarily in offset rather than stacked delta lobes. The modern Mississippi and Guadalupe deltas provide a composite depositional model that explains processes, distribution, and facies geometry of the Cisco fluvial-deltaic system.

SYLVESTER SHELF-EDGE BANK SYSTEM

The shelf-edge bank system is an offlapping series of elongate, strike-oriented, prismatic carbonate bodies 10 to 30 miles wide. The banks consist of interbedded limestone, mudstone, and dolomite locally cut by narrow, dip-oriented sandstone stringers (figs. 5–11). Basinward termination of the banks is abrupt, though some massive dolomite and siliceous limestone drape down the upper part of the forebank slope (sections J and K). The eastern or upslope edge of the bank system consists of a broad, gradational band of interfingering limestone and terrigenous facies of the fluvial-deltaic system. Many of the open shelf limestone beds that punctuate fluvial-deltaic deposits on the upper shelf grade into more massive limestones of the bank system. Thus, the boundary between the bank and fluvial-deltaic systems is arbitrarily defined by relative proportions of terrigenous and carbonate sediment. Shelf-edge bank deposition continued throughout Upper Pennsylvanian and Lower Permian but was most extensive during the uppermost Pennsylvanian (Harpersville equivalent) when the massive “Cisco Lime” was deposited.

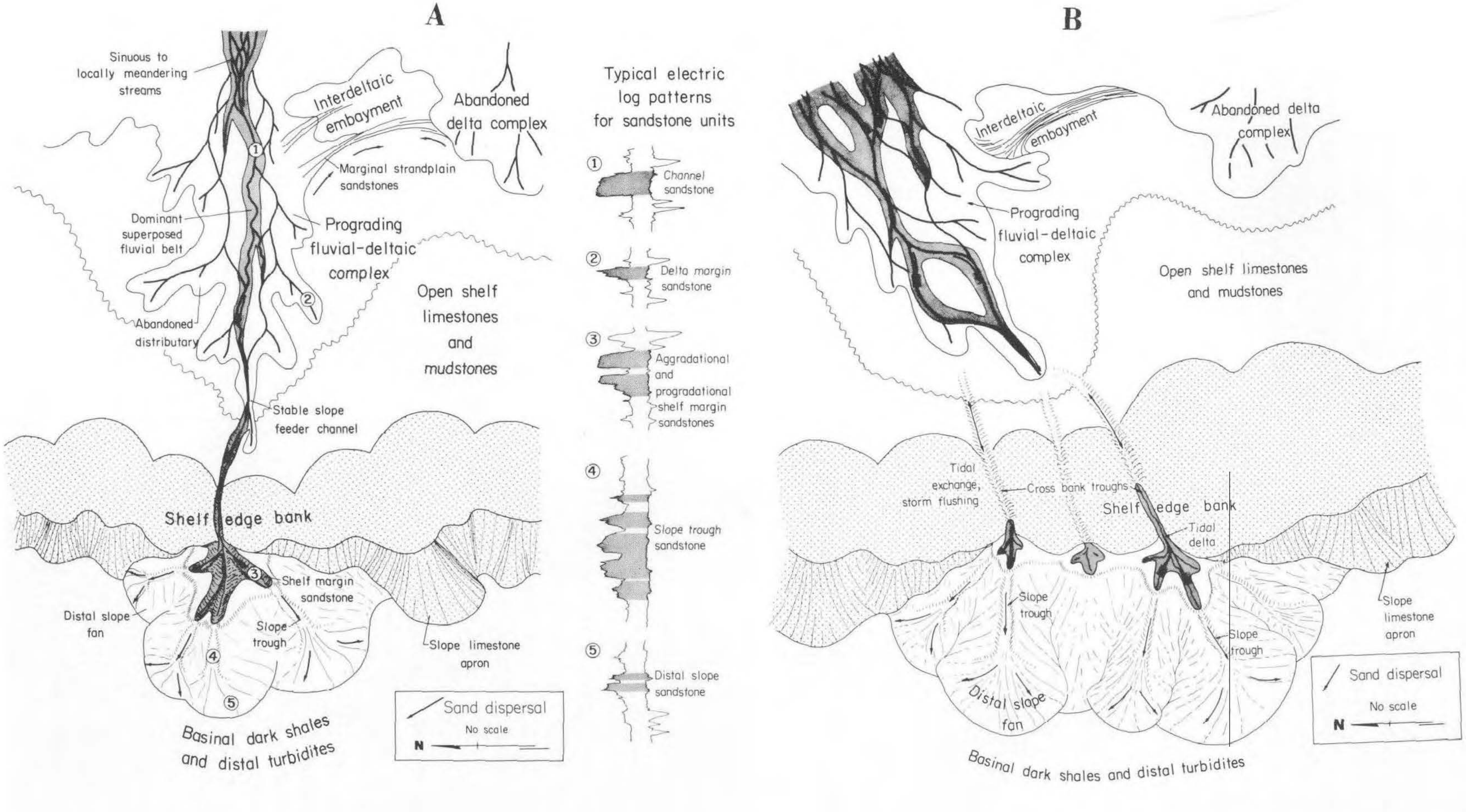


FIG. 20. Proposed models for sediment dispersal on the Eastern Shelf during Cisco deposition. A, Delta distributaries prograde to the shelf edge and onto the fan crest where sediment is discharged directly onto the slope. B, The carbonate bank system is a zone of terrigenous sediment bypass. Mud and sand are transported in troughs or channels through the bank complex by storm tide ebb or peak discharge, flood-generated currents.

PETROGRAPHY

Few data are available on the lithologic composition of the bank system. Electric logs show that most carbonate is thick bedded to massive; correlation of individual shale breaks is possible over distances of only a few miles, indicating lenticular geometry of limestone units. Drill samples are skeletal lime mudstones with minor oolitic zones; most have been diagenetically altered or leached. Secondary leaching produced a chalky, highly porous limestone. Locally dolomitized lower beds of the bank display patchy, highly porous, completely recrystallized, buff euhedral dolomite. Silicification of limestone and interbedded light olive green and gray mudstone is common.

Carbonate banks in the underlying Canyon Group, which are in part analogous to Sylvester banks, have been described by Wermund (1969) and Raish (1964). Canyon banks are elongate biostromes in which local biohermal facies occur. A framework of the phylloid algae *Eugonophyllum* acted as a sediment baffle, which trapped lime mud. Algal and bioclastic micrites are the principal component facies, and although Canyon banks studied at the outcrop do not occupy a shelf-edge position, some topographic expression is indicated by the accentuated dips of flanking beds (Raish, 1964).

PHYSIOGRAPHIC EXPRESSION

Several lines of evidence indicate that banks stood slightly above the shelf floor as a partial barrier to circulation between the shelf and open basin: (1) The presence of sparites, oolites, and dripping flank beds has led Wermund (1969) and Raish (1964) to conclude that Canyon biostromes stood slightly above the adjacent sea floor. (2) As shown by figures 21 and 22, sandstones that cross the shelf-edge banks do so only in very narrow belts, are thin, and appear to occupy erosional channels within the massive carbonate. Their laterally equivalent shale breaks are thin. (3) Most sandstone bodies terminate along the shoreward margin of the bank system even though transfer of terrigenous sediment across the shelf edge was necessary for formation of the slope system (p. 43). Normally the bank system was a site of terrigenous sediment bypass. (4) As documented by Newell and Rigby (1957) in studies of the Bahaman Platform, shelf edges are prime loci for carbonate deposition because upwelling cold basinal waters saturated with dissolved carbonate are warmed and agitated, thus favoring precipitation of calcium carbonate.

No evidence suggests that the shelf was ever completely restricted. Neither evaporites, supratidal dolomite, nor extensive zones of severely restricted faunas have been recognized in the Cisco Group. All evidence favors deposition in normal marine to brackish water.

SWEETWATER SLOPE SYSTEM

The Sweetwater slope system consists of broad, coalescing (e.g., Cook and Flippen equivalent) to relatively restricted (e.g., Breckenridge and Bluff Creek equivalent) wedges of terrigenous facies 800 to 1,200 feet thick. The edge of the Eastern Shelf shifted westward about 20 miles as a result of slope deposition during the uppermost Pennsylvanian, and from 70 to 80 percent of the terrigenous Clastics of the Eastern Shelf are stored in the Sweetwater slope system. The system terminates abruptly updip into massive limestones of the contemporaneous Sylvester shelf-edge bank system. Downdip slope facies grade into basinal facies where the relatively steep dips of 1½ to 5 degrees decrease to regional values of ½ to 1 degree. Distal toes of slope sandstone and mudstone facies, interbedded with dark basinal shales, extend far into the basin (Adams et al., 1951).

Two principal groups of facies, the slope sandstone facies association and the slope mudstone facies association, compose the Sweetwater system. Thin limestone aprons extend down the slope from the shelf-edge banks and are useful marker beds for subdivision of the slope system into its component clastic wedges and for correlation of these wedges with approximately equivalent Cisco fluvial-deltaic lobes. Regional dip sections (figs. 5–11) and detailed shelf-slope sections (figs. 21 and 23) illustrate relationships between shelf-edge bank carbonates and slope limestone aprons.

SANDSTONE FACIES

Sandstone distribution in the slope wedges forms fan-shaped patterns that are elongated perpendicular to the shelf edge and change from relatively narrow, restricted belts upslope to more irregular, broad patches downslope. Sandstones in the slope wedges can be approximately correlated with Cisco fluvial-deltaic lobes and related to the map intervals defined on the shelf. Sandstone facies consist of a shelf margin sandstone facies, slope trough sandstone facies, and distal slope sandstone facies (figs. 23 and 24).

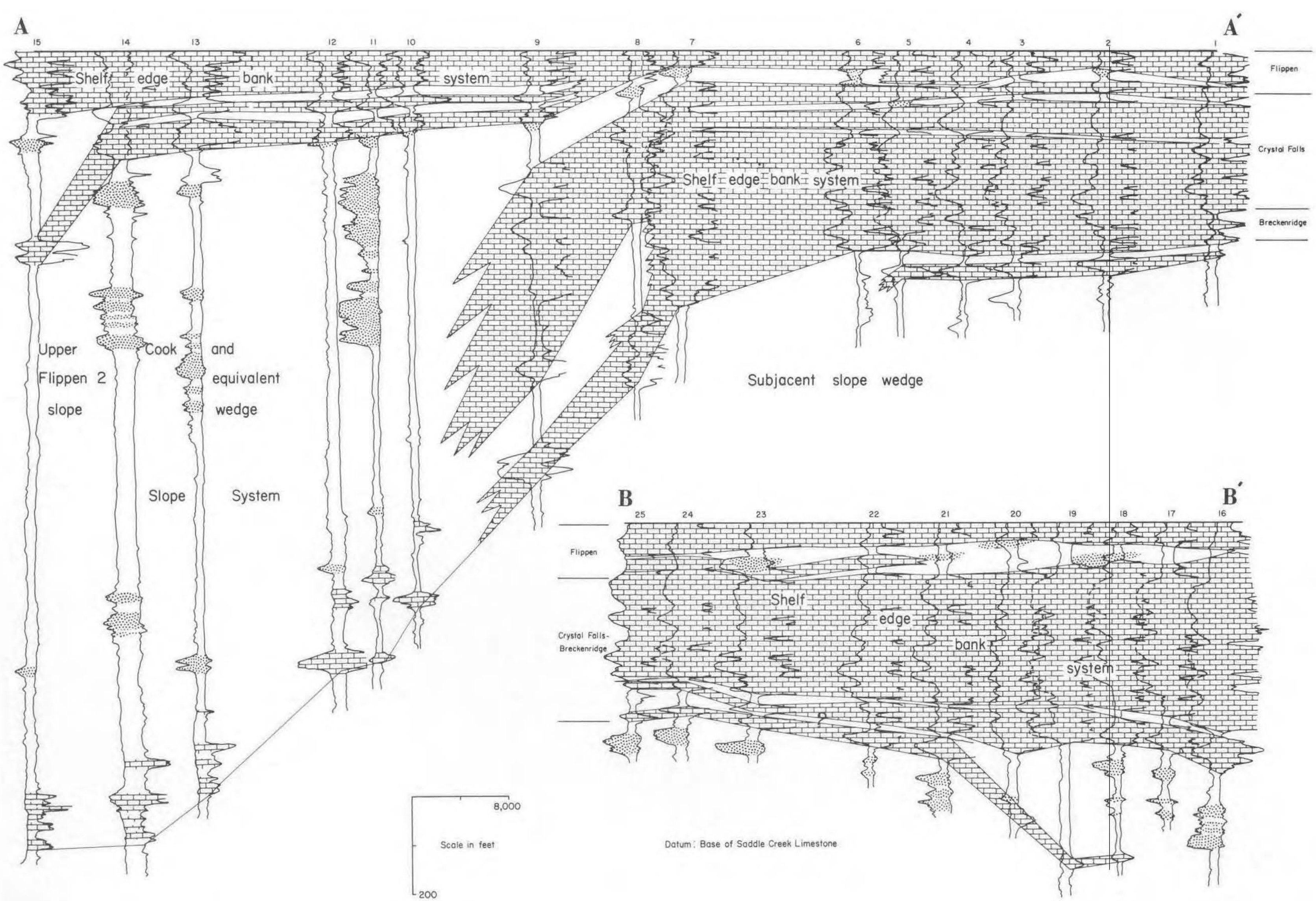


FIG. 21. Strike and dip sections through the Flippen 2 and Upper Cook shelf-slope transition. Limestones of the shelf-edge bank system drape over several local shelf edges in this area. For location of sections, *see* figure 22.

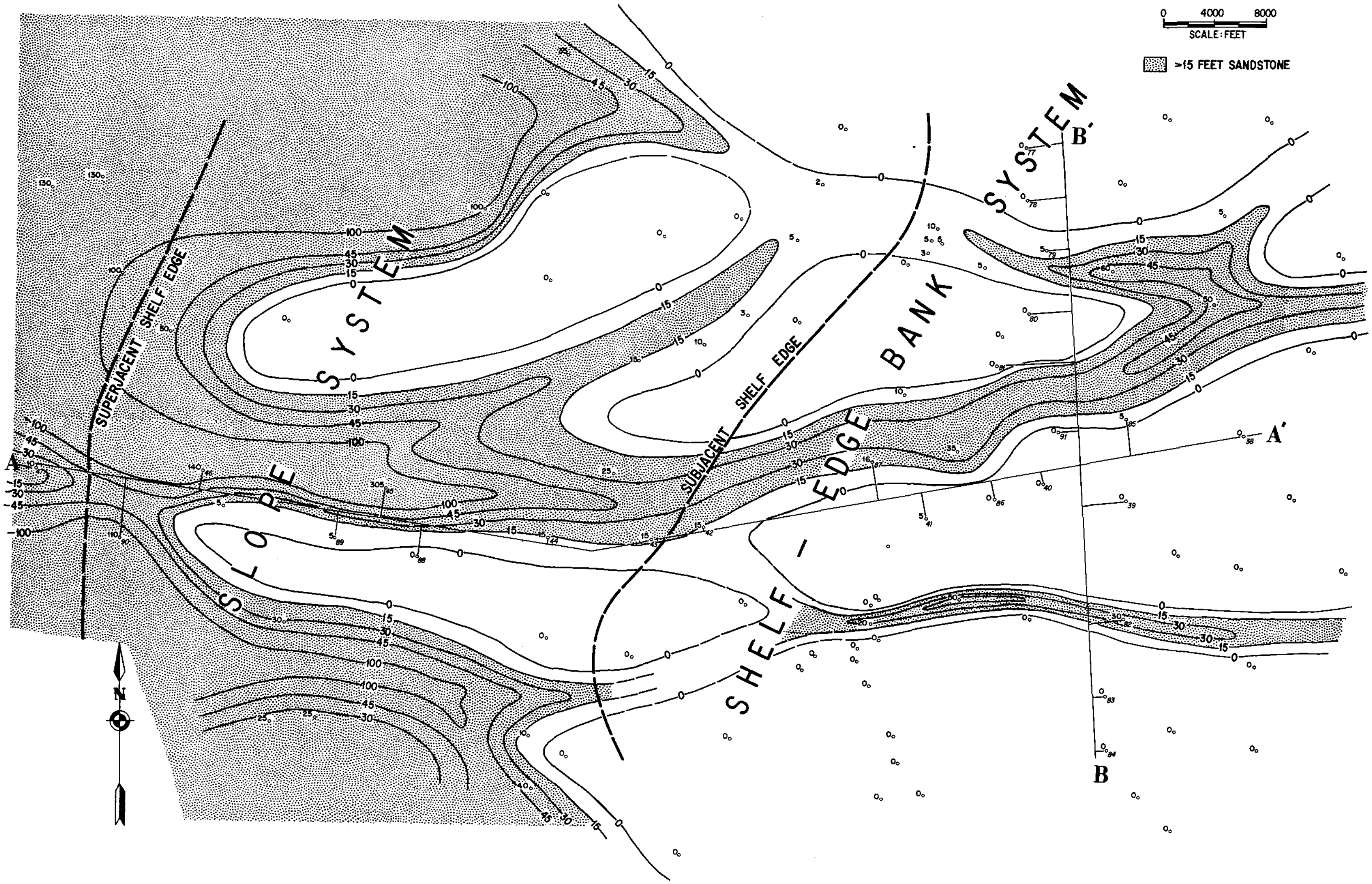


FIG. 22. Sandstone isolith map of the updip portion of the Flippen 2—Upper Cook slope wedge and its extension into the shelf-edge bank system. For location, *see* Plate III.

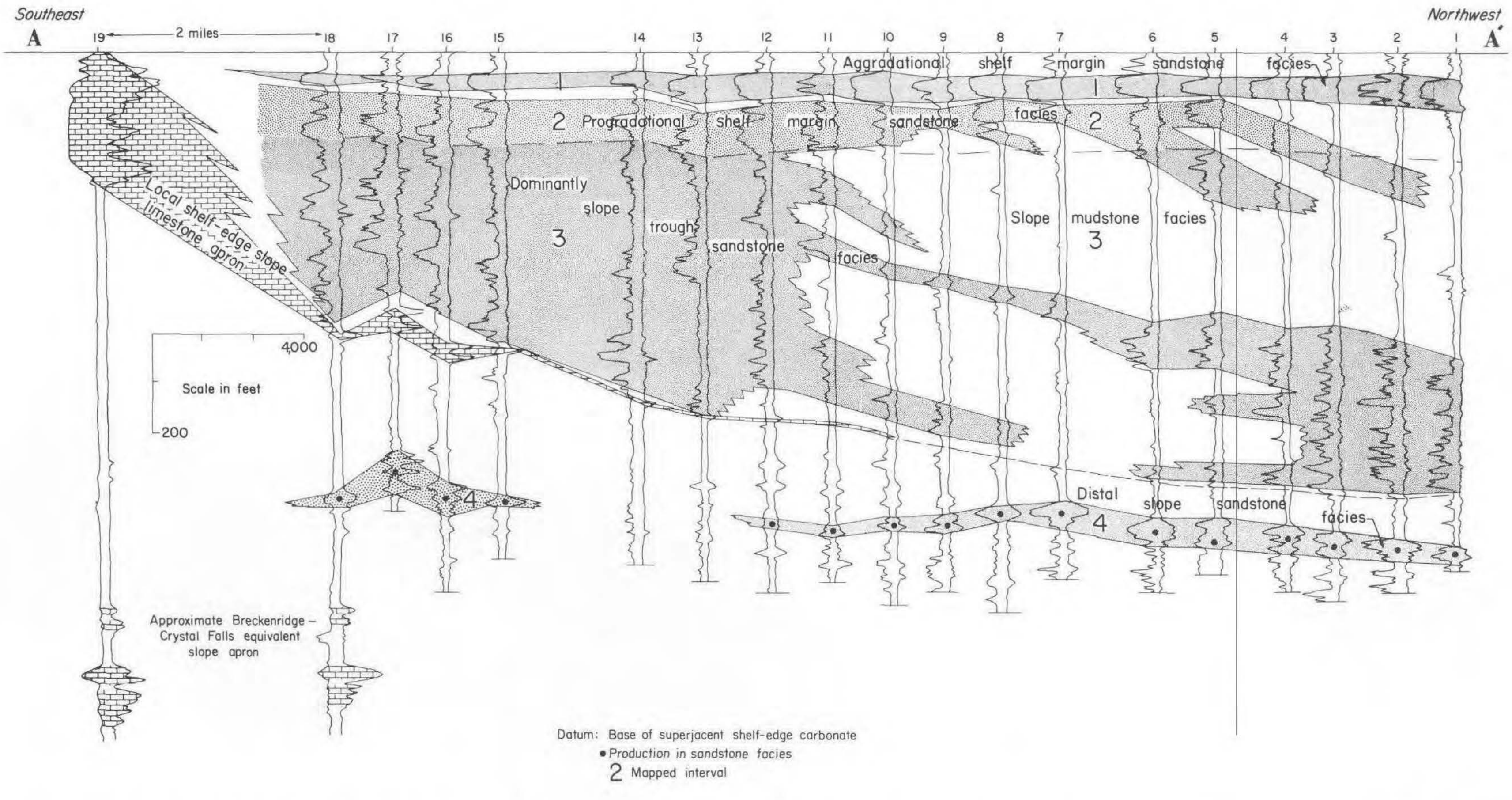


FIG. 23. Cross section through the Flippen 2 equivalent slope wedge showing spatial distribution and log characteristics of the component facies. Section uses dense well control of Lake Trammel field, Nolan County. Wells are listed in Appendix III. *See* figure 24 for line of section.

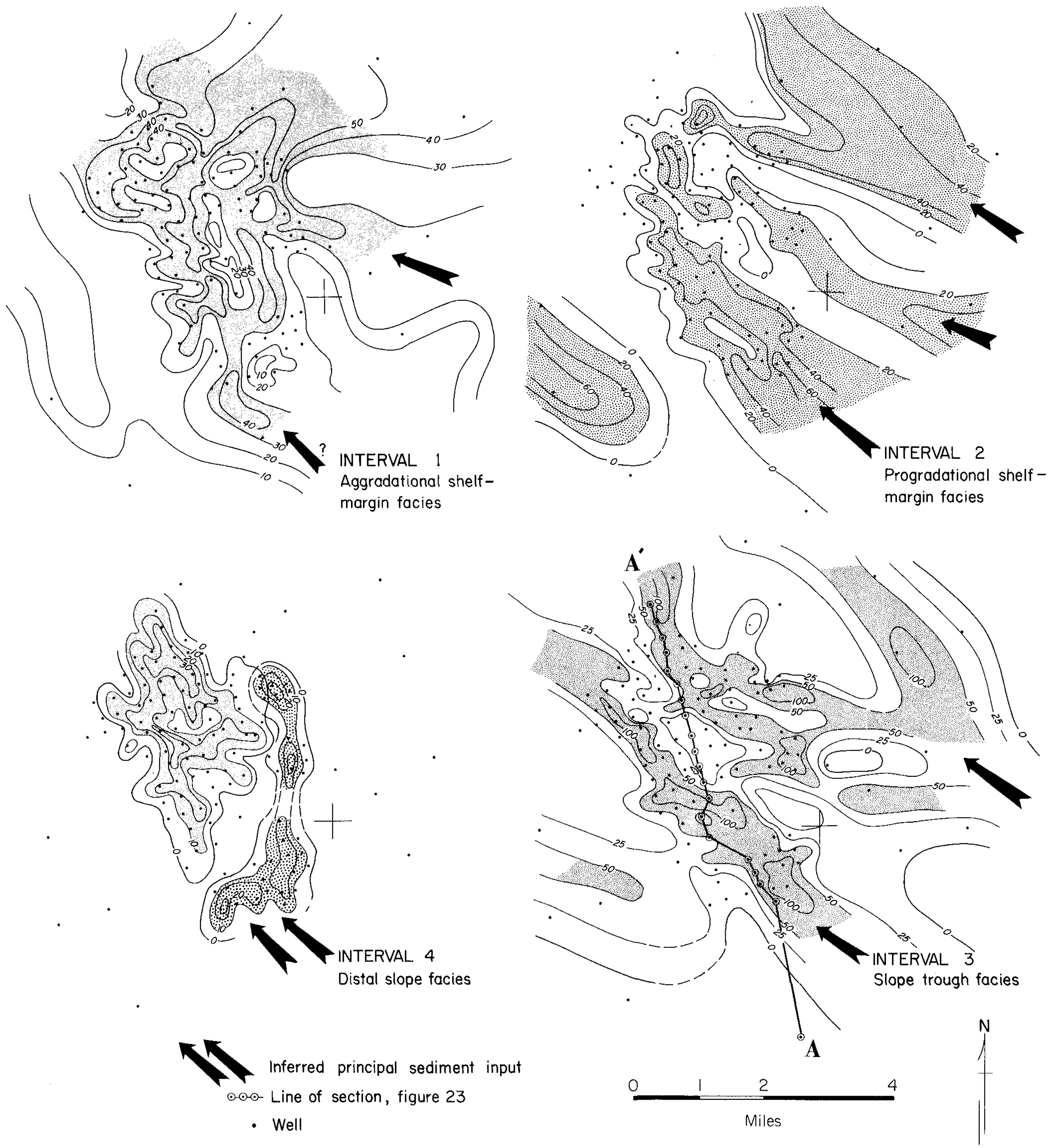


FIG. 24. Sandstone isolith maps of four differentiated sandstone facies of the Flippen 2 equivalent slope wedge, Lake Trammel field, Nolan County. Figure 23 shows the stratigraphic positions of the map units. Location is shown on Plate III.

Shelf-margin sandstone facies.—Shelf-margin sandstones cap slope wedges (fig. 23). Progradational shelf margin sandstones form an elongate, subparallel series of dip-oriented isolith thicks that emanate from a point source along the shelf margin (fig. 24, interval 2). These sandstones are characterized by basal progradational contacts with underlying mudstones of the slope wedge (fig. 23, wells 6, 12, 13, and 15). In some slope wedges, progradational sandstones are overlain by aggradational facies characterized by more persistent sandstone distribution and both dip and strike-oriented thickness trends (fig. 24, interval 1). Aggradational sandstones exhibit abrupt basal contacts with underlying mudstones that separate them from progradational facies. Shelf-margin aggradational and progradational sandstone bodies are 10 to 50 feet thick and moderately continuous. Aggradational sandstones grade downdip into progradational sandstones where the underlying progradational sandstone platform pinches out (as at the north end of the section in fig. 23). Updip, shelf-margin sandstones display one of three relationships with shelf-edge carbonate facies: (1) A few sandstones are continuous with lenticular sandstone bodies that connect through the bank system to distal distributary sandstones of the Upper Hope 2 and Upper Cook/Flippen 2 lobes (fig. 22). These sandstones are simply extensions of the delta system out onto the slope wedge. (2) Other sandstones extend as narrow fingers a few miles into bank facies but do not appear to connect directly with deltaic units. (3) Most shelf-margin sandstone units pinch out updip at the shelf edge, although it is possible that narrow sandstone bodies connecting them with distributary units could weave through the available well control. The numerous examples of updip pinch-outs suggest that the bank system was commonly a zone of terrigenous sediment bypass.

Shelf-margin sandstone facies are massive, well-sorted fine to very fine quartzarenites that are carbonaceous and cemented by quartz overgrowths and, locally, calcite.

Slope-trough sandstone facies.—Belts of interbedded slope sandstone and mudstone averaging 1 to 2 miles wide and with aggregate thicknesses of up to several hundred feet extend 5 to 20 miles down paleoslope through the slope wedge (figs. 23 and 24). Updip, these belts correlate with and grade into thicker parts of progradational shelf-margin sandstone facies; downdip, they grade into broad, irregularly shaped sandstones that form the distal part of slope wedges.

Individual beds of the slope-trough facies are discontinuous and difficult to impossible to correlate, even over distances of a few thousand feet, although the sandy zone forming the belt can be traced down the slope wedge (fig. 23). Cores from the lower slope-trough facies show a variety of characteristic subfacies (Pl. V). Massive sandstone beds, 5 cm to a meter thick, exhibit various types of graded and massive bedding and contain abundant fine to coarse, poorly oriented plant detritus and penecontemporaneous rounded to angular, deformed mudclasts (Pl. V, C). Grain size varies from sandy fine pebble conglomerate to siltstone. Some beds are current-ripple laminated and contain concentrations of plant detritus at the top. Contorted bedding and planar lamination are common. Graded units have sharp bases with load casts. Sands are poorly sorted, submature, siliceous quartzarenites and cherty, conglomeratic quartzarenites. As in sandstones of the fluvial-deltaic system, chert comprises the pebble size fraction. Mudclast conglomerates with a sandy matrix are a minor but significant rock type.

In contrast to the sandstone facies, the medium to thinly interbedded sand, silt, and mudstone subfacies displays a greater variety of fine-scale structures characteristic of turbidite sequences (Pl. V, D). Beds range from a few centimeters to millimeters thick; many are micrograded with sharp bases sculptured by small uniformly oriented tool marks and flame structures. Most beds are current-ripple laminated at the top, many thinner sandstone beds are ripple laminated throughout, and flaser bedding is common. Ripple foresets have consistent trends over several feet vertically. Various types of contorted lamination and microslumping are also characteristic of this subfacies. Finely macerated plant material is abundant. A few small sand-filled, subhorizontal burrows in some mudstone beds are the only evidence for biologic reworking. Sandstones are fine to very fine, poorly sorted, submature to immature siliceous quartzarenites. No particular vertical sequence of structures or composition is apparent, but individual cores 10 to 30 feet long consist predominantly of one subfacies, indicating local persistence of depositional environments.

Distal-slope sandstone facies.—Distal-slope sandstones are similar to slope-trough facies but are more continuous, less steeply dipping, and have a more irregular external geometry (figs. 23 and 24, interval 4).

SLOPE-MUDSTONE FACIES

The Sweetwater slope system is predominantly gray, massive to interbedded silty and sandy mudstone and muddy sandstone. Sandy zones are commonly contorted and may exhibit size grading. Plant debris is common in the mudstones.

LIMESTONE APRONS

Limestone aprons, composed in part of debris from the shelf-edge bank system, accumulated on the surfaces of inactive slope wedges, preserving slope topography. This series of mappable limestone beds subdivides slope wedges and is useful for correlating slope and basin deposition with shelf depositional episodes (Jackson, 1964). Slope aprons consist of siliceous, dark-colored micrite and crystalline dolomite that grade distally into gray basinal shales and along the slope crest into facies of the shelf-edge bank system.

SUBMARINE SLOPE PROCESSES

Facies composing the Sweetwater slope system indicate deposition by a variety of sedimentary processes. Gravity-induced slumping is reflected by slump scars and contorted beds. Sand and gravel were introduced sporadically, probably by turbidity currents and their associated traction carpets, and subsequently reworked by marine currents into the abundant ripple laminations. Absence of structures such as climbing ripples (indicative of rapid deposition of suspended sediment), predominance of well-sorted sandstones with little mud matrix, and the absence of flute casts mitigate against deposition from turbulent suspensions (Sanders, 1965). Sandy slope mudstones may, however, include some suspension deposits. Mudclasts and tool and scour marks at the base of sandstone beds indicate that erosion and deposition were commonly related to the same depositional event.

MODERN SLOPE SYSTEMS

Deposition on Holocene continental slopes is limited primarily to submarine fans or to more widespread continental rises. In the Sweetwater slope system, deposition was on the margin of a moderately deep, cratonic basin, and not on an oceanic continental slope. However, though scale is different, the regional depositional setting and probable mechanisms of sediment transport are comparable. Thus, studies of modem submarine fans by Shepard et al. (1969), Carlson and Nelson (1969), Huang and Goodell (1970), and Normark (1970) provide data for the construction of a composite submarine fan model applicable to interpretation of Sweetwater slope wedges (fig. 25).

Sediment dispersal directly down primary depositional slopes by gravity-induced processes such as turbidity currents, slumping, grain flow, and rip currents characterizes submarine fans. However, modern fans are typically located in comparatively deep water at the mouths of submarine canyons that cut across the upper continental slope. Large canyons are unusual features in the Sweetwater slope system; where present they extend updip into the shelf-edge bank limestones. Shepard and Dill (1966) noted that submarine canyons are erosional features cut into older sediments. The observation that most submarine fans are presently inactive, although adjacent canyons continue to erode headward, has led many writers to conclude that canyon cutting is a process resulting from regrading of the slope during a rising sea level (Normark and Piper, 1969). Dietz (1963) argued that upper continental slopes and shelf edges are now undergoing erosion by slumping and canyon cutting because of submergence by postglacial sea-level rise and that sediment derived from this leveling or regrading of the slope is being redeposited on the continental rise. Canyon cutting is a destructional process acting on the slope that may regrade it, but, without significant influx of new sediment into the system, it cannot produce a net progradation of the shelf edge and will, in fact, result in incision and net retreat. Submarine canyons are prominent features of Holocene shelf-slope transitions because of the widespread, major fluctuations in sea level during the Pleistocene. Modern fans were depositionally active during low stands of sea level when sediment entered the basin at or very near the shelf edge. Blankets of pelagic Holocene mud in fan valleys indicate inactivity during the modern high stand (Shepard and Dill, 1966; Shepard et al., 1969; Carlson and Nelson, 1969; Huang and Goodell, 1970; Normark, 1970). Large canyons would not be a necessary or even probable feature on a depositionally active, prograding slope; their absence may be, in fact, an argument against repeated, large-scale fluctuations in relative sea level or sediment input.

A shelf-edge reentrant or notch occurs immediately below the Breckenridge Limestone (fig. 26). The south flank of this possible canyon could not be mapped because the Breckenridge equivalent

PLATE V

Representative cores of deltaic facies

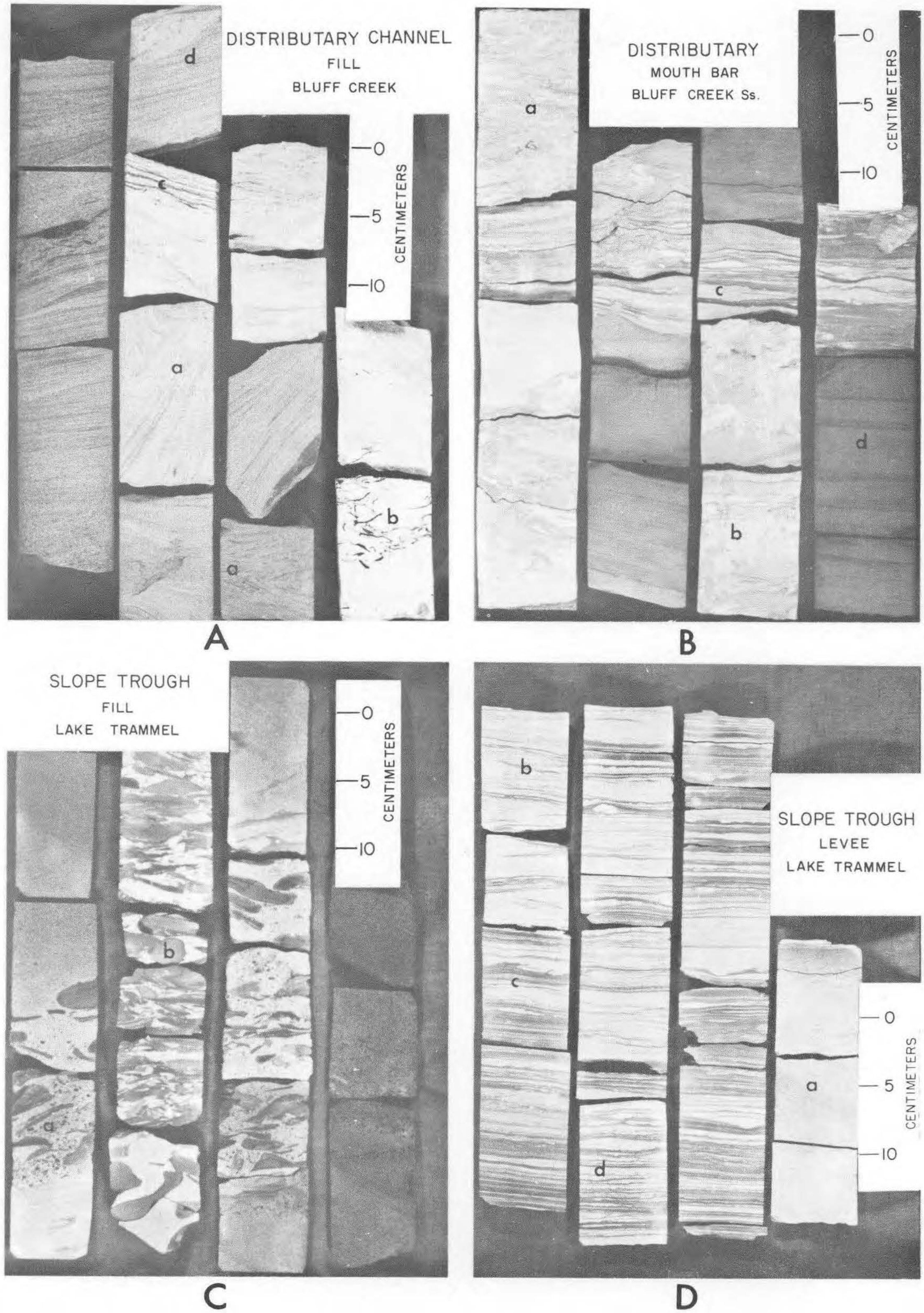
A. Distributary channel fill (Bluff Creek Sandstone, Shackelford County). Diagnostic structures include contorted bedding (a), plant fragments (b), organic laminae (c), and cross stratification (d).

B. Distributary mouth bar facies (Bluff Creek Sandstone, Shackelford County). Characteristic features are bioturbated zones (a) and distinct burrows (b), ripple-laminated sand and mudstone (c), and cross-laminated sandstone beds (d).

Representative cores of slope facies

C. Slope trough fill from the lower part of the Upper Cook/Flippen 2 equivalent slope wedge (Lake Trammel field, Nolan County). Diagnostic features include thick, graded beds containing chert granules (a) and large, deformed and rounded mudstone clasts (b).

D. Slope trough levee sequence from the lower part of the Upper Cook/-Flippen 2 equivalent slope wedge (Lake Trammel field, Nolan County). Typical structures include thin to medium-graded beds (a) with alternating thin beds of ripple-laminated sandstone and parallel-laminated, dark gray mudstone (b), flame structures (c), and abundant tool marks (d). Macerated plant fragments are common.


DISTRIBUTARY CHANNEL
FILL
BLUFF CREEK
CENTIMETERS
0
5
10
a
b
c
d
A
DISTRIBUTARY
MOUTH BAR
BLUFF CREEK Ss.
CENTIMETERS
0
5
10
a
b
c
d
B
SLOPE TROUGH
FILL
LAKE TRAMMEL
CENTIMETERS
0
5
10
a
b
C
SLOPE TROUGH
LEVEE
LAKE TRAMMEL
CENTIMETERS
0
5
10
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D

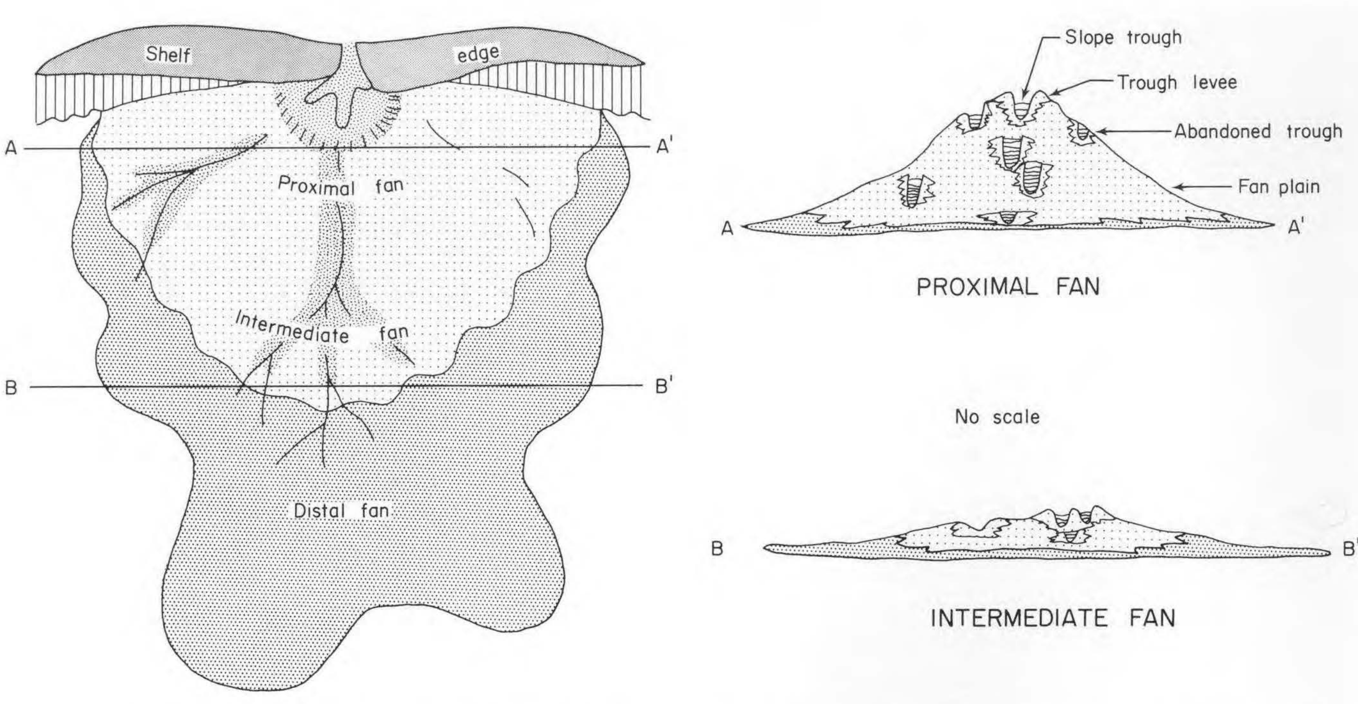

FIG. 25. Composite submarine fan model applicable to Sweetwater slope wedges. Model is based on studies of modern submarine fans by Shepard et al. (1969), Carlson and Nelson (1969), and Normark (1970).

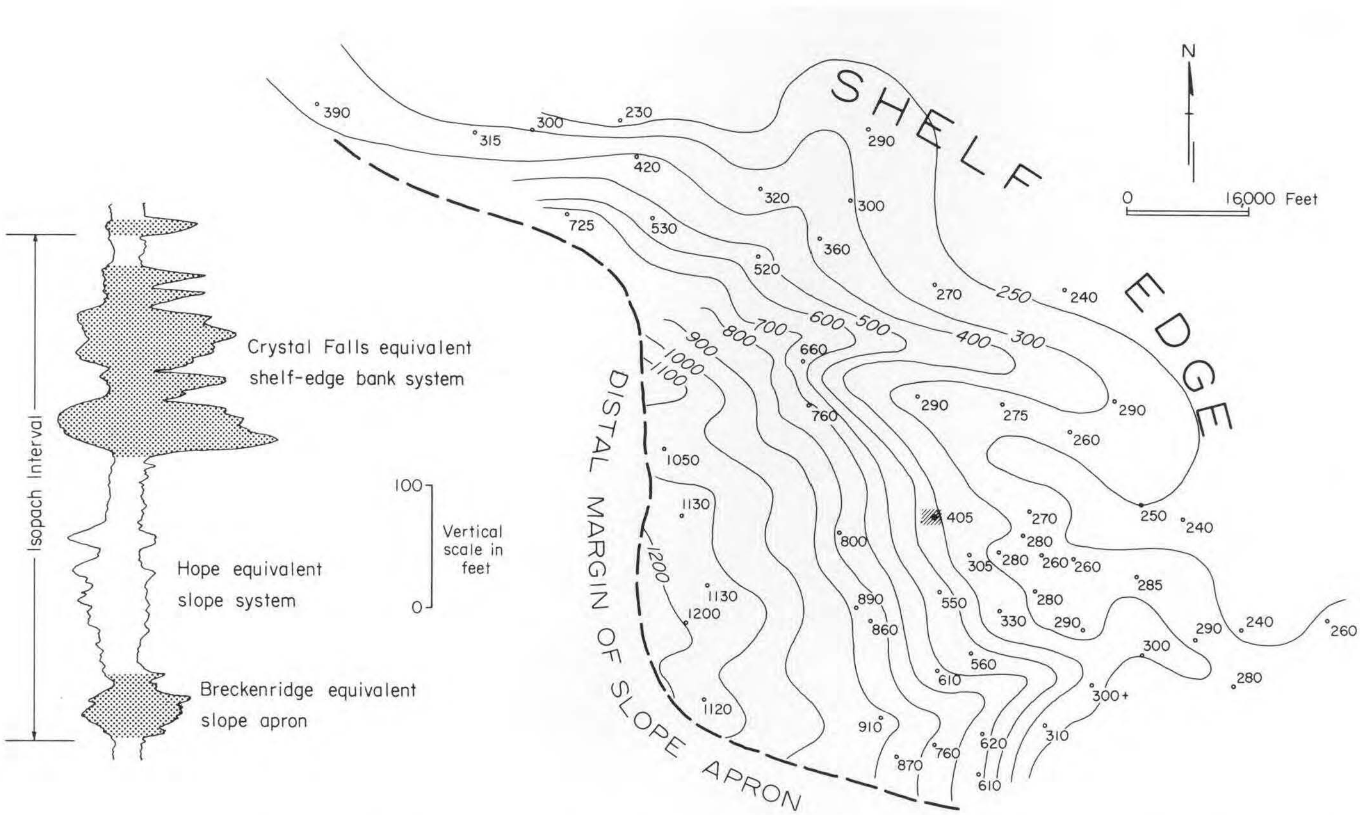

FIG. 26. Isopach map outlining the paleotopography of a possible pre-Breckenridge submarine canyon. For location, *see* **Plate I.**

slope apron pinches out, but its geometry may be inferred from the distribution of sandstone in the Upper Hope 2 slope wedge (Pl. I). Size of the notch is comparable to many submarine canyon heads (Shepard and Dill, 1966). Erosion that formed the notch preceded deposition of the Breckenridge Limestone and thus is not directly related to Upper Hope deposition. Examination of figure 12 shows that the position of the notch coincides with a break-up of the Breckenridge Limestone in an area of difficult correlation. Therefore, it is not related to maximum development of an extensive open-shelf limestone unit as might be expected. Its origin was most likely associated with fluvial-deltaic or slope deposition that preceded or was in part equivalent with Breckenridge deposition.

Smaller erosional features, called gullies, exist seaward of several modern deltas that are actively prograding onto the continental slope. Narrow gullies extend down the prodelta slopes of the Mississippi and Fraser deltas, but they die out at depths of only a few hundred feet and do not contain sand (Shepard and Dill, 1966). Erosion and filling of several minor tributaries of the Rio Balsas submarine canyon system are directly related to the shifting and abandonment of adjacent deltaic distributaries (Reimnitz and Gutierrez-Estrada, 1970). Somewhat larger prodelta valleys seaward of the Magdalena Delta have gradients of over 200 feet per mile and extend from distributary mouths to the base of the fore-delta slope (Shepard and Dill, 1966). Elmendorf and Heezen (1957) cited evidence of turbidity currents and slumping in these valleys, especially during periods of peak river discharge. Though rather poorly known, the fore-delta slope of the Magdalena is a possible modern example of an actively prograding, distributary-fed submarine fan. The prodelta valleys are analogous to fan valleys or, in the terminology of this report, slope troughs.

Active processes and resultant facies of the La Jolla and Astoria submarine fans were documented by Shepard et al. (1969) and Carlson and Nelson (1969), respectively. Table 3 compares features of these two highly studied fans with facies recognized in the Sweetwater slope system. Slope trough, distal slope, and slope mudstone facies are comparable in composition, geometry, and structure with fan valley and levee, distal fan, and fan plain deposits.

Because of their deep-water setting, modern fans have no depositional environment analogous to the shelf-edge position of the shelf-margin sand facies. Geometry of the sands indicates that they were funneled through the shelf-edge bank complex in one or more restricted channels. Upon reaching the crest of the slope wedge, coarser sediment moved through moderately straight channels to the shelf edge where it was dumped into adjacent slope troughs. Sands were reworked, producing basal progradational sequences and lateral redistribution much like the distributary mouth bar or bar finger of a high constructive delta. The aggradational shelf-margin sands extended across this platform and were subjected to wave reworking, resulting in prominent dip and strike-oriented isolith maxima (fig. 24).

The exact mechanism by which sand was fed through the carbonate bank system remains in question. Deltas may have prograded across the carbonate bank system and onto the active fan crest. This is a reasonable explanation for the Upper Hope 2 and Upper Cook/Flippen 2 lobes in which sand can be traced directly into slope wedges. Channeled, sporadic currents draining the broad, flat shelf of wind-generated tides or flood runoff provide an alternative transport mechanism that could explain the general terrigenous sediment bypass nature of the carbonate bank system.

Walker (1966) described a similar suite of interpreted fore-delta slope facies in Upper Carboniferous rocks in Great Britain. Shelf, slope, and basinal systems in Late Cretaceous strata of Wyoming have been outlined recently by Asquith (1970). Geometry, thickness, and composition of progradational slope wedges of Lewis Shale and Fox Hills Sandstone are grossly similar to those of the Eastern Shelf and are directly related by Asquith to deltaic progradation. Van DeGraaff (1971) recognized a sequence of Upper Pennsylvanian slope turbidites and associated high destructive deltas and shelf carbonates in the Cantabrian Mountains, northwestern Spain, that closely resemble many of the facies present in the Eastern Shelf.

TABLE 3. *Comparison of modern submarine fans with Sweetwater slope wedges.*

Geomorphic/facies units	Modern fan systems	Sweetwater slope system
Fan valley/fan valley fill	Graded to homogeneous sandstone and gravel	Graded to massively bedded subfacies of slope trough sandstone facies
Gradient	Astoria: less than 1:100 La Jolla: less than 1:100	Maximum dip of 5° = 8:100
Geometry	Astoria: bifurcating fan valleys La Jolla: single fan valley Valleys straight to moderately sinuous; widths of a few hundred feet to about 1 mile; grade downslope into undissected distal fan	Multiple bifurcating (?) troughs Straight to moderately sinuous isolith trends; belts are commonly a few thousand feet in width; troughs grade downslope into distal slope sandstone facies
Sediments	Moderately to poorly sorted; some gravel, mud, and clay fragments; mica and plant debris common. No down-valley gradient in grain size or sorting	Submature to immature sandstone; conglomeratic sandstone; mudclast conglomerate; abundant plant detritus. Coarse-grained material cored near base of slope
Internal structures	Discontinuous beds; textural grading in mid- and distal fan; homogeneous beds; horizontal and ripple lamination; small-scale slumping and microfaulting	Correlation of beds nearly impossible; texturally graded and homogeneous beds; horizontal and ripple lamination; contorted, slumped, and churned beds
Fan valley levee	Developed adjacent to fan valleys	Interbedded sand, silt, and mudstone subfacies of the slope trough sandstone facies
Sediments	Thin- to medium-bedded micaceous silt and mud; sand increases in medial and distal fan	Thin- to medium-bedded, finely laminated fine sand, silt, and mudstone; abundant plant debris
Internal structures	Micrograded beds; current ripple lamination; burrows and small-scale sole marks; small-scale slumping	Micrograded and ripple-laminated thin beds; tool marks and flame structures; burrows; contorted lamination and microslump scars
Fan plain	Forms most of fan surface	Slope mudstone facies are volumetrically the most important unit
Sediments	Mostly mud with beds of very fine sand and thicker layers of sandy mud	Gray mudstone and sandy mudstone
Internal structures	Muddy graded beds	Graded muddy sandstone and sandy mudstone; contorted bedding

CONSTRUCTION OF THE EASTERN SHELF

The three depositional systems (fluvial-deltaic, shelf-edge bank, and slope) recognized in uppermost Pennsylvanian rocks of north-central Texas define two slightly different facies tracts (fig. 20). Dip-fed clastic sediment passed across the shelf through one or more prograding lobe complexes of the fluvial-deltaic system into passes or fluvial channels that breached the shelf-edge carbonate bank system; sediment was then transported onto and down a prograding slope wedge and into the Midland Basin. Evidence for the genetic relationship between active fluvial-deltaic lobes and prograding slope wedges includes: (1) areal coincidence of larger delta lobes and stratigraphically equivalent slope wedges (Pls. I–III); (2) distributary sandstones which extend through the carbonate-bank system and connect with shelf-margin sandstones (fig. 22); and (3) similarities of sand mineralogy and minor components such as chert and plant debris.

Construction of the Eastern Shelf resulted from both upbuilding, or vertical accretion of the shelf by fluvial-deltaic and carbonate-bank deposition, and from outbuilding, or basinward progradation, by successively offlapping slope wedges (terminology from Curray and Moore, 1964). Abandoned slope wedges subsided by compaction of muds and are capped by basinward extensions of the shelf-edge carbonate facies.

SHELF MODEL

Rona (1969) proposed two models to explain progradation of the middle Atlantic continental terrace (shelf, slope, and continental rise). The models differ according to whether upbuilding and outbuilding were contemporaneous or temporally distinct processes. The assumption that all parts of a shelf might not be in the same stage of development requires four models (fig. 27): (A) Upbuilding and outbuilding are contemporaneous throughout the shelf and slope. (B) Upbuilding and outbuilding are temporally distinct processes, but the entire shelf and slope are at the same stage of development at any one time. (C) Upbuilding and outbuilding are contemporaneous but restricted to local areas of the shelf and slope. (D) Upbuilding and outbuilding are temporally distinct, and different parts of the shelf and slope may be in different

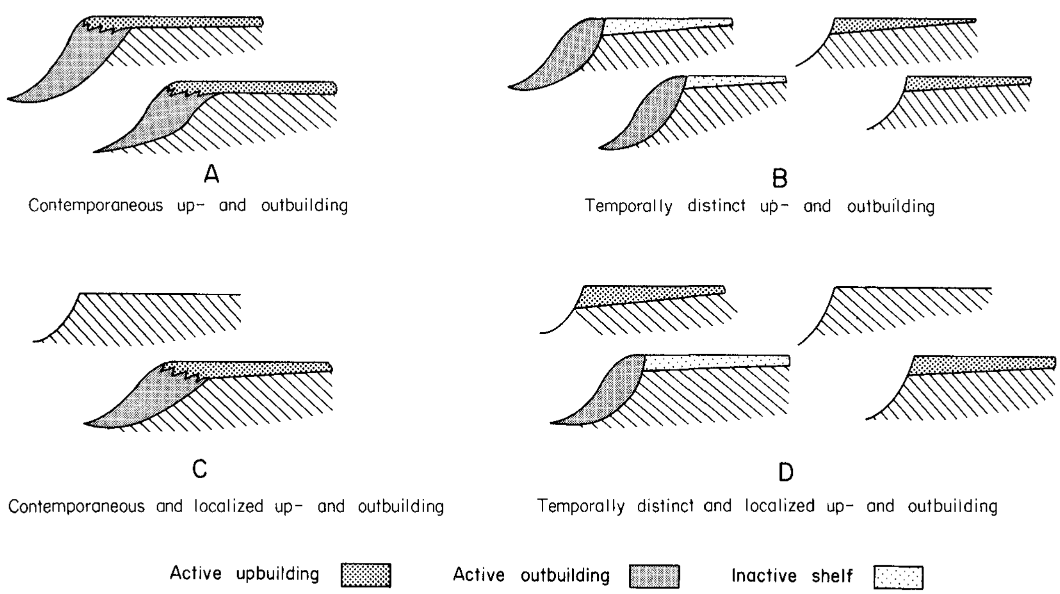

FIG. 27. Possible models for construction of a depositional shelf. In part after Rona (1969).

stages of development at any one time. For example, upbuilding on the shelf in one area may be contemporaneous with outbuilding in another area and nondeposition in a third area.

Comparison of these possible models with the Eastern Shelf indicates that simultaneous up- and outbuilding (construction) by terrigenous clastic deposition on portions of the shelf was contemporaneous with relatively inactive shelf areas characterized by carbonate deposition and marginal erosion or destruction (fig. 27, C). Arguments for contemporaneity of fluvial-deltaic and slope-wedge deposition have already been presented (p. 43). Examination of cross sections (fig. 28), which illustrate the geometry and distribution of slope wedges along each of the dip sections, indicates the lateral discontinuity of individual wedges composing the Sweetwater slope system. This restricted distribution of slope wedges is further evidence that the slope was fed through local, stratigraphically distinct fluvial-deltaic lobes. Figure 28 also shows that individual shelf edges are not continuous but areally restricted, occupying a variety of stratigraphic positions. In contrast, the Costa de Nayarit, Mexico, a similar constructional shelf, developed during Pleistocene low stands of sea level by prograding delta lobes, which extended to the shelf edge and fed submarine slope wedges. This Mexican shelf system contains shelf edges that are continuous and mappable for over 100 nautical miles along strike (Curray and Moore, 1964).

Detailed sections of Sweetwater shelf edges and proximal slope wedges (figs. 21, 23) show numerous minor, local shelf edges, which are identified by shelf-edge limestones and aprons. These locally developed shelf edges indicate brief periods of destruction during temporary abandonment of the delta lobe that fed the slope wedge. Multiple abandonment and reoccupation also explain the development of aggradational shelf-margin sands that are distinctly separated from underlying progradational sands (figs. 23, 29).

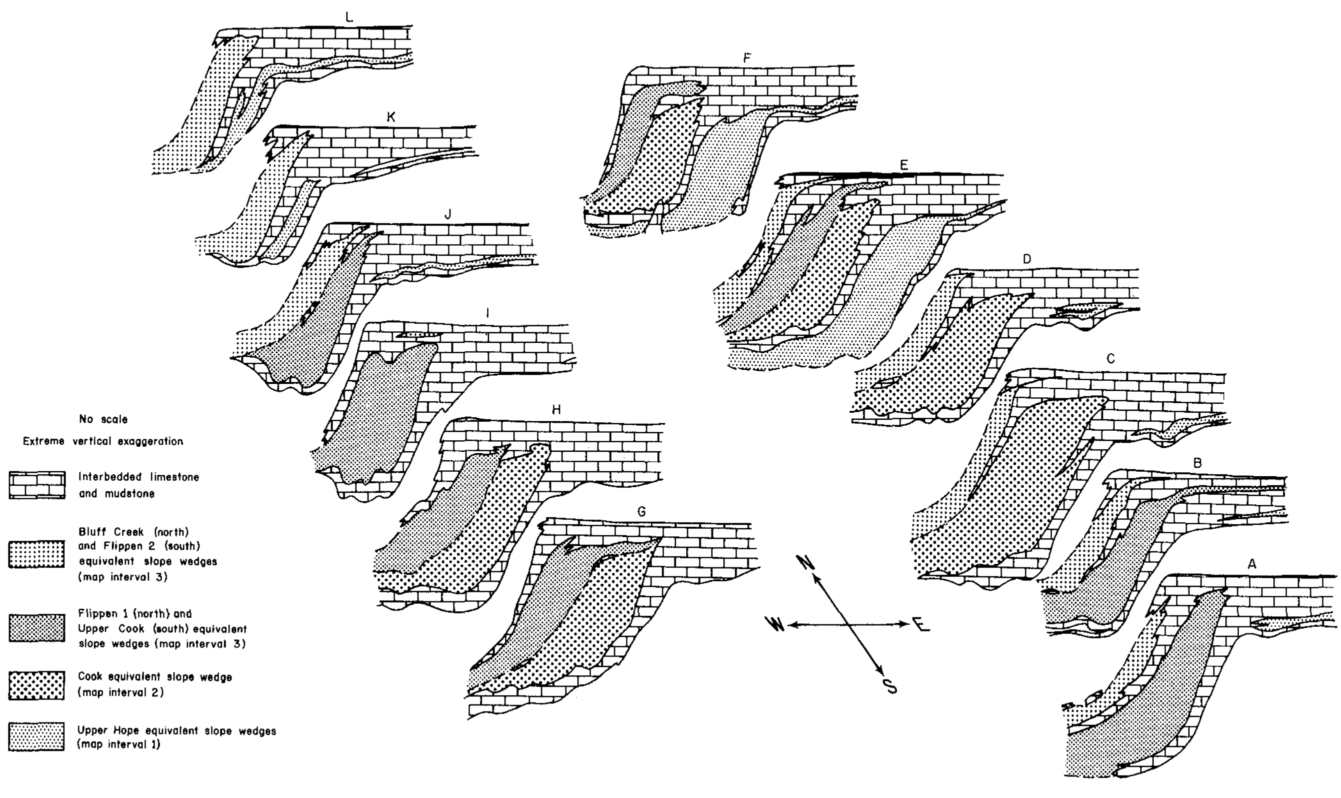

FIG. 28. Interpreted lateral relationships of the major Sweetwater slope wedges outlined by the stratigraphic dip sections and their correlation with delta lobes of the shelf. Letter designations above each section refer to the section on the index map (fig. 3).

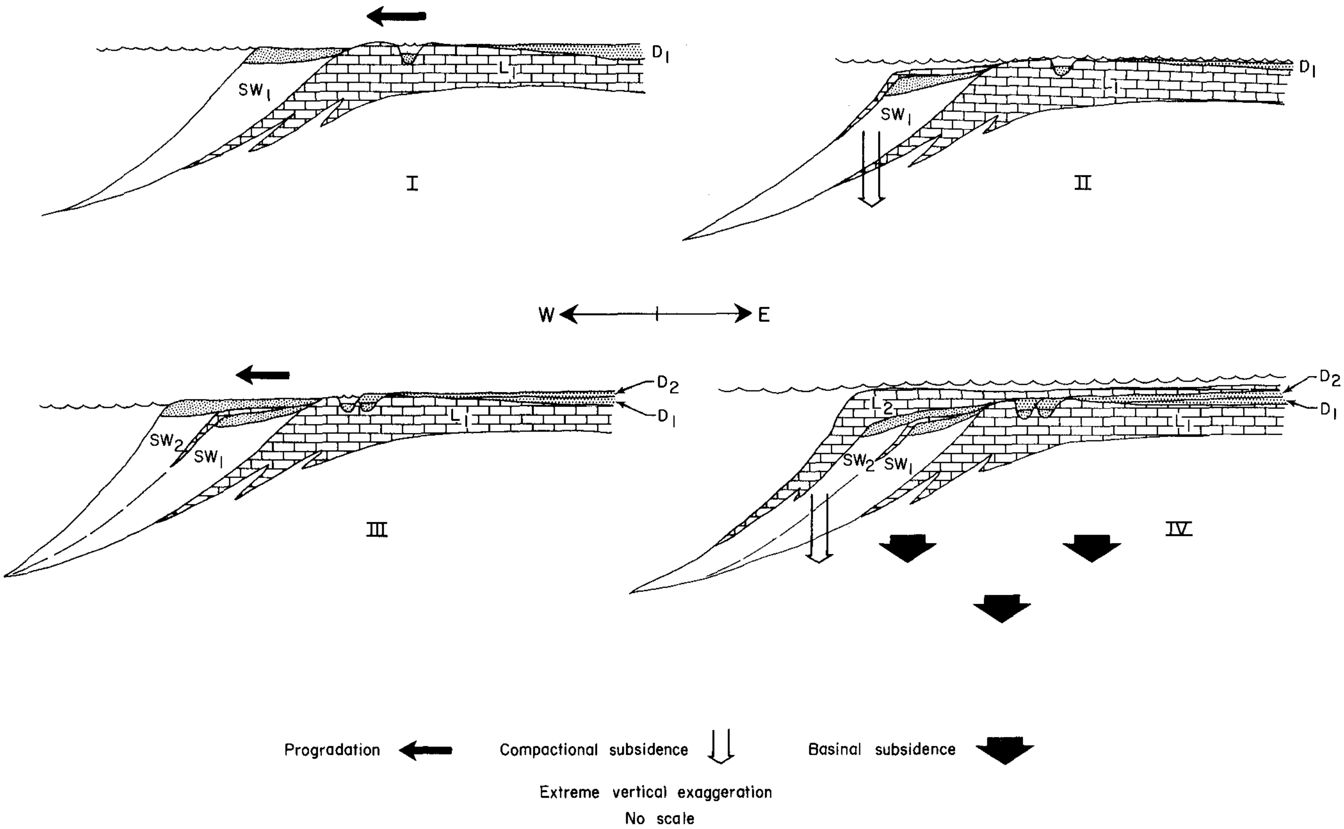

FIG. 29. Development of a shelf margin, Eastern Shelf. I, Advancing delta D_1 progrades across shelf-edge bank and constructs a slope wedge (SW_1). II, Temporary abandonment of the delta and slope wedge is followed by compactional subsidence and deposition of a carbonate cap. III, Reoccupation of the delta (D_2) progrades a new slope wedge (SW_2). IV, Final abandonment of the delta complex allows growth of the shelf-edge bank complex (L_2) at the newly constructed shelf edge.

COMPARISON WITH NORTHERN GULF COAST SYSTEMS

Depositional systems of the Tertiary of the northern Gulf of Mexico basin have been well documented by Fisher and McGowen (1967), Fisher et al. (1969, 1970), Galloway (1968), and Fisher (1970). The Gulf Coast Basin was filled from the north by a series of thick, terrigenous clastic wedges. The upslope part of these wedges consists of both the high-constructional and wave-dominated high-destructional fluvial-deltaic sequences. The high-constructional delta systems are flanked by well-developed strandplain-barrier bar systems. Major deltaic systems are separated vertically by relatively thin, extensive, glauconitic marine sands and shelf mudstones. Fronting the deltaic complexes are thick, massive sections of prodelta mudstone and slope facies. Slope systems are complicated by salt flowage and growth faulting resulting from loading by rapidly deposited clastics.

Compaction of the prodeltaic wedge and subsidence of the basin in response to depositional loading have produced thick, vertically stacked sequences of similar facies in the Gulf Coast Basin. This is in marked contrast to the Eastern Shelf, which formed a shallow, stable platform characterized by widespread, thin progradational sequences and vertical juxtaposition of divergent facies. Instability of the Gulf margin and rapid rates of deposition have obscured all but the largest structures (Galloway, 1968). Brown (1969a) emphasized the importance of minor structural features in controlling deposition of fluvial-deltaic facies in north-central Texas.

Cisco fluvial-deltaic lobes are comparable to high-constructional elongate deltas characteristic of many Gulf coast clastic wedges; however, differences in detail are apparent. (1) Gulf Coast Basin high-constructional deltas of Tertiary age were fed by large rivers draining the distant continental interior and forming well-developed meander belts in their lower reaches. The source for Cisco Clastics, on the other hand, was a nearby highland that abutted the margin of the depositional basin. (2) Sediment input along the northern Gulf was moderately continuous and dominated by fine sand and mud. Cisco deposits are rich in coarser sands and gravel and indicative of highly variable rates of input. (3) The Gulf Coast Basin is a fat basin with thick, well-developed progradational facies; Cisco deltas are characterized by thin, poorly preserved progradational sequences. (4) Carbonate facies of the Gulf are volumetrically insignificant; destructional and marine transgressive deposits consist of glauconitic and bioclastic sands and burrowed mudstones. Though these are environmentally analogous to the upslope limestones of the Eastern Shelf, they are not as numerous nor as prominent. (5) Cisco deltas supported no large-scale strike-fed systems. (6) Areal geometries of Cisco and Gulf coast high-constructional deltas are comparable, but thickness of genetic sequences and facies organization differ significantly.

Facies organization of northern Gulf slope systems is dominated by local structural complexities caused by contemporaneous mobilization of the underlying salt and formation of growth faults. The slope, much like the slope fronting the modern Mississippi delta, is segmented into a number of smaller sediment traps (Lehner, 1969). Like the Eastern Shelf, a considerable volume of sediment including mud and sand is stored in slope systems, though the size and extent of Tertiary slope units are poorly known because of their present depth of burial. The Gulf coast Tertiary lacks a shelf-margin carbonate complex comparable to that which so effectively segregates fluvial-deltaic and slope systems of the Eastern Shelf.

In summary, the Tertiary northern Gulf of Mexico basin is grossly similar to the Eastern Shelf in its progradational fabric and component depositional systems. Observed differences are predictable and result from divergent structural and paleohydrological settings and marine energy régimés of the two basins.

TECTONIC, EUSTATIC, AND SEDIMENTARY CONTROLS

The apparent cyclicity displayed by Upper Pennsylvanian and Lower Permian strata of the Eastern Shelf, which is similar in many aspects to the cyclothems of the Midcontinent, has been emphasized by Van Siclen (1958), Shankle (1960), and Jackson (1964). All have attributed cyclicity to eustatic sea-level fluctuations. However, Duff et al. (1967) pointed out that cyclicity is influenced by intrabasinal variations in uplift and subsidence or sedimentary controls as well as by extrabasinal controls, such as eustatic sea-level changes or climatic changes. Moore (1959) stated that cyclicity is an inherent feature of deltaic deposition. Brown (1969a), in a report on part of the Cisco fluvial-deltaic system, pointed out the absence of widely developed soil zones or dissected valley systems, both of which are prominent aspects of cyclical Pleistocene deposits of the Texas Gulf Coastal Plain (Bernard and LeBlanc, 1965). In addition, the presence of fluvial-deltaic clastic wedges splitting coals and limestones believed representative of regional submergence (Brown, 1969b) is another argument against primary eustatic control. As will be shown, additional evidence from this study indicates that intrabasinal controls commonly overshadow any active extrabasinal controls. Sea-level changes and other world-wide cyclical phenomena are not precluded, but sedimentary and structural activity in north-central Texas dominated the depositional fabric of the area. Even minor changes of a few feet in relative sea level would have a profound effect on a broad, shallow platform such as the Eastern Shelf. For example, Van Lopik (1955) showed that a 15-foot rise in sea level would inundate several thousand square miles of the Mississippi deltaic plain. Thus, at the outset it would seem that the magnitude of possible Pennsylvanian sea-level changes may have been overemphasized by various workers.

Evidence for primary intrabasinal control of apparent cyclicity includes the following: (1) Most limestones are correlative only as zones and not as continuous beds. Although many of these limestone zones are persistent for tens of miles along strike, on a regional scale the limestone packages break up and grade into terrigenous facies. For example, the Breckenridge Limestone grades southward in Callahan County into a major fluvial-deltaic lobe (fig. 12). The Upper Cook sandstone occurs within the Flippen limestone package, and Bluff Creek sandstone was deposited between beds correlative with an undivided Saddle Creek Limestone zone of the central and southern parts of the area (fig. 12). (2) Distributary rather than tributary channel patterns are most common on the shelf. (3) Evidence of considerable contemporaneous marine reworking of fluvial-deltaic sandstones includes adjacent laterally equivalent sheet sandstones at numerous stratigraphic levels. Large-scale sea-level fluctuations would tend to segregate marine and nonmarine deposition into discrete intervals. Reworking is also indicated by sandstone and conglomerate tongues in gradational contact with fossiliferous marine facies as, for example, in sections 3 and 4, which are adjacent to the Lake Cisco (Cook) conglomerate outcrop. (4) No systematic change was observed in depth of channeling across the shelf, as would be expected if large-scale changes in sea level and consequent regrading of streams occurred. (5) Shelf edges are local and developed at a variety of different stratigraphic positions (fig. 28). (6) Slope wedges, according to the model for shelf construction, are localized areally and stratigraphically along the shelf margin and correlate with deltaic lobes that occupy at least five stratigraphic positions (Upper Hope, Cook, Upper Cook, Flippen, and Bluff Creek). (7) Little dissection of the shelf-edge bank system or upper shelf margin can be documented, with the exception of a possible pre-Breckenridge notch (fig. 26). Sandstone-filled channels cut across shelf-edge banks in only a few places, contrary to what would be expected if the shelf had been exposed to subaerial erosion by fluvial channels. Normark and Piper (1969) maintained that modern submarine canyons are erosional features most likely produced during periods of rising sea level by headward erosion of fan valleys. Dietz (1963) argued that erosion of upper slope and shelf margin by slumping and turbidity currents occurs during periods of nondeposition, such as after submergence of a large part of the shelf by rising sea level. In either case, the general regularity of uppermost Pennsylvanian shelf edges indicates that extensive destruction or erosion of the upper slope related to a rising sea level did not occur.

Depositional or erosional events occurring simultaneously over the entire Eastern Shelf, a necessary consequence of cyclic extrabasinal controls, are not indicated by the data. This conclusion agrees with the results of other recent investigators of cyclothemic sequences, including Duff et al. (1967), Beerbower (1969), Donaldson (1969), Cocke

(1969), and Brown (1969b).

Synthesis of all depositional, stratigraphic, and other pertinent data results in the model for sequential development of the Eastern Shelf shown in figure 30. Deposition of the Upper Hope fluvial-deltaic lobes filled in the pre-Breckenridge shelf-margin notch. Cook lobes, prograding principally across the central part of the shelf, built a complex slope prism, which produced a bulge in the shelf margin. Later, Upper Cook, Flippen, and Bluff Creek lobes, which extended primarily across the southern and northern parts of the shelf, filled in the flanking basin margin, smoothing the outline of the shelf edge before widespread deposition of the Saddle Creek Limestone.

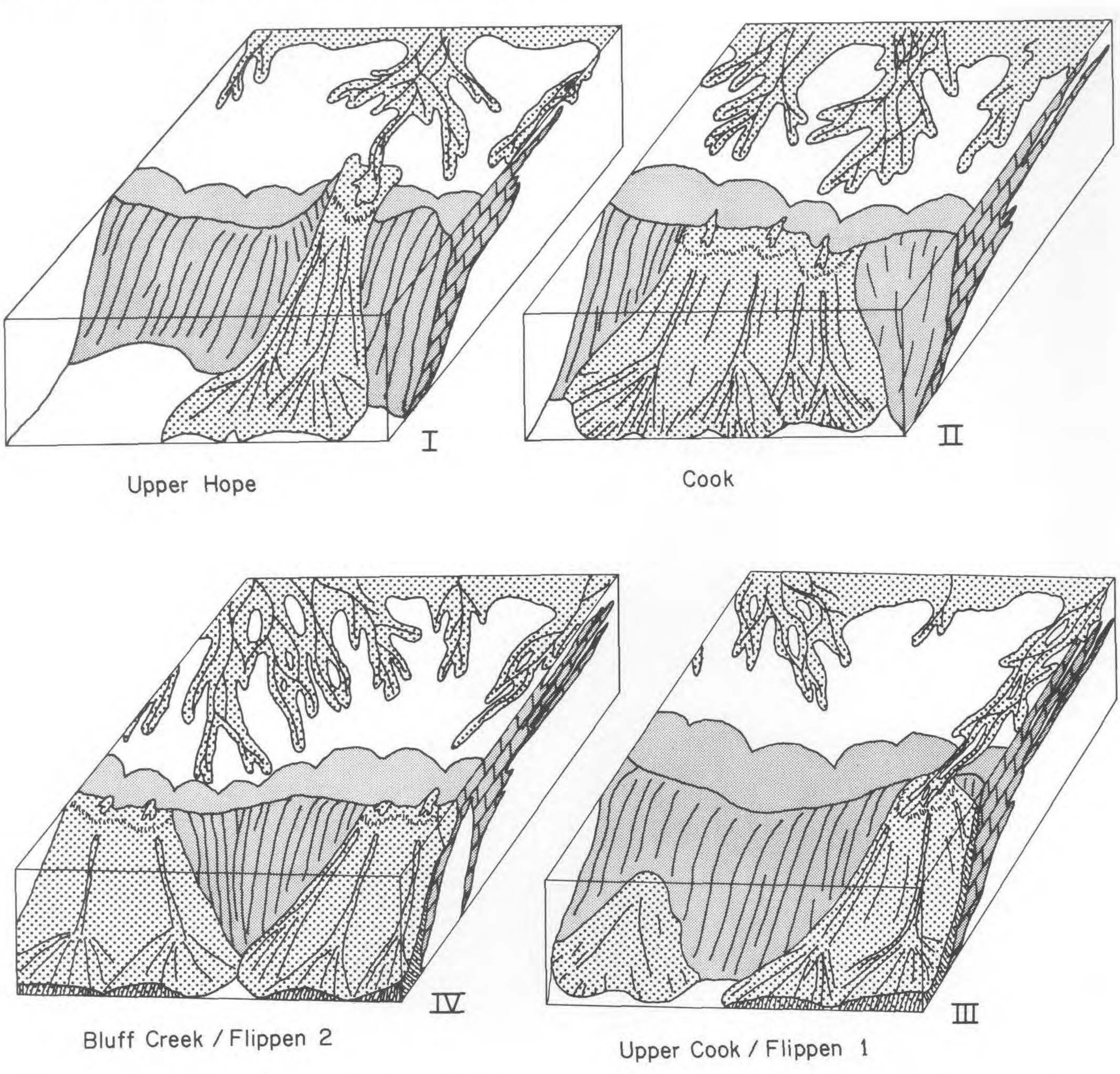

FIG. 30. Sequential development of the Eastern Shelf during deposition of the Harpersville Formation and equivalent facies.

MINERAL RESOURCES

Oil, coal, and ceramic clay have been extracted from Upper Pennsylvanian rocks in north-central Texas. Coal and clay deposits are related to specific depositional facies; petroleum distribution is controlled by a complex interrelationship of facies and structural development.

PETROLEUM

The distribution and specific characteristics of oil fields in north-central Texas are described in publications of the Abilene Geological Society (1957, 1960a, 1960b). As in any geologic province, presence of a source, a reservoir, and a trap is necessary for accumulation of petroleum. Probable source beds include prodelta, delta flank, and slope mudstone facies. At shallow depths, both fluvial and distributary channel sandstones of the Cisco fluvial-deltaic system provide reservoirs (fig. 31). Structural, stratigraphic, and combination traps occur. Maps and cross sections (figs. 14 and 15) illustrate producing sand bodies in the Cook field, a fluvial channel reservoir, and the Morris Buie—Blaco fields, which produce from Bluff Creek distributary channel and channel mouth bar sandstones. Also, local porous zones in carbonate facies of the Sylvester shelf-edge bank system are reservoirs.

It is evident from the localized production (fig. 31) that factors other than reservoir distribution must limit production on the shelf. On the basis of several types of structure and facies derivative maps, Brown (*in* Fisher et al., 1969) concluded that a regional but subtle NE-SW-trending structural lineation or hinge developed contemporaneously with deposition across southern Shackelford County. Production is concentrated on the northwest, or positive, side of this hinge. Similarly, another possible hinge with a similar trend is postulated to extend across central Callahan County, restricting Flippen, Cook, and Upper Hope production to its northwestern flank (fig. 31). The Callahan Divide, a Cretaceous salient that extends east-west across the Cisco outcrop in southern Eastland County (Pl. IV), coincides with the postulated structural low that forms the southeastern flank of the hinge. Neither of the hinges displays the expected close relationship to trends of underlying Canyon bank systems. These postulated structural hinges are poorly delineated by regional structure maps contoured from elevation data; however, their persistence on a variety of independently produced derivative maps suggests their validity. Low-order trend and residual structure maps of the Eastern Shelf should be the best approach for outlining such large-scale but extremely subtle structural features.

If the presence of the structural hinges is accepted, the distribution of petroleum on the shelf can be explained, in part, by early migration along channel sandstone conduits from the slightly negative areas to more positive areas where entrapment was controlled by sandstone pinch-outs, differential compaction over subjacent sand bodies, and local structural noses.

Facies control of petroleum distribution from the Sweetwater slope system is more pronounced, and although the number of fields in this system is limited, many are relatively large with production in millions of barrels. The Group 4000, Noodle Central, and Southwest Noodle produce from sandstones of the shelf-margin facies; Lake Trammel and Lake Trammel South (fig. 23), Claytonville, and Sweetwater Canyon fields produce from traps in lower slope and distal slope sandstone facies. Proximal slope-trough facies are to date unproductive. Entrapment, particularly in slope-trough sandstones, is primarily stratigraphic, a result of updip pinch-out of the trough sandstones. Because of depositional dips of several degrees on the slope and laterally restricted geometry of this facies, structure is unnecessary for the formation of traps. Slope-margin sandstones are more continuous and deposited on a more nearly horizontal surface; thus, combination and structural traps are important.

COAL

Mapel (1967) mapped the distribution of the principal coals in north-central Texas, including the Bull Creek, Newcastle, and Saddle Creek coals, which are stratigraphic equivalents of the Cook and post-Cook sandstones, post-Flippen and pre-Bluff Creek sandstones, and Bluff Creek sandstones, respectively. Distribution of Harpersville coal recorded in measured sections and localities is shown on the geologic map (Pl. IV). Although coal has been mined locally, most is of poor quality. Beds consist of thin, impure lignite and bituminous ashy, sulfurous coal; mud and siltstone splits are common.

Without exception, coals observed in outcrop are detrital accumulations of plant debris associated with facies of the interdeltaic embayment facies

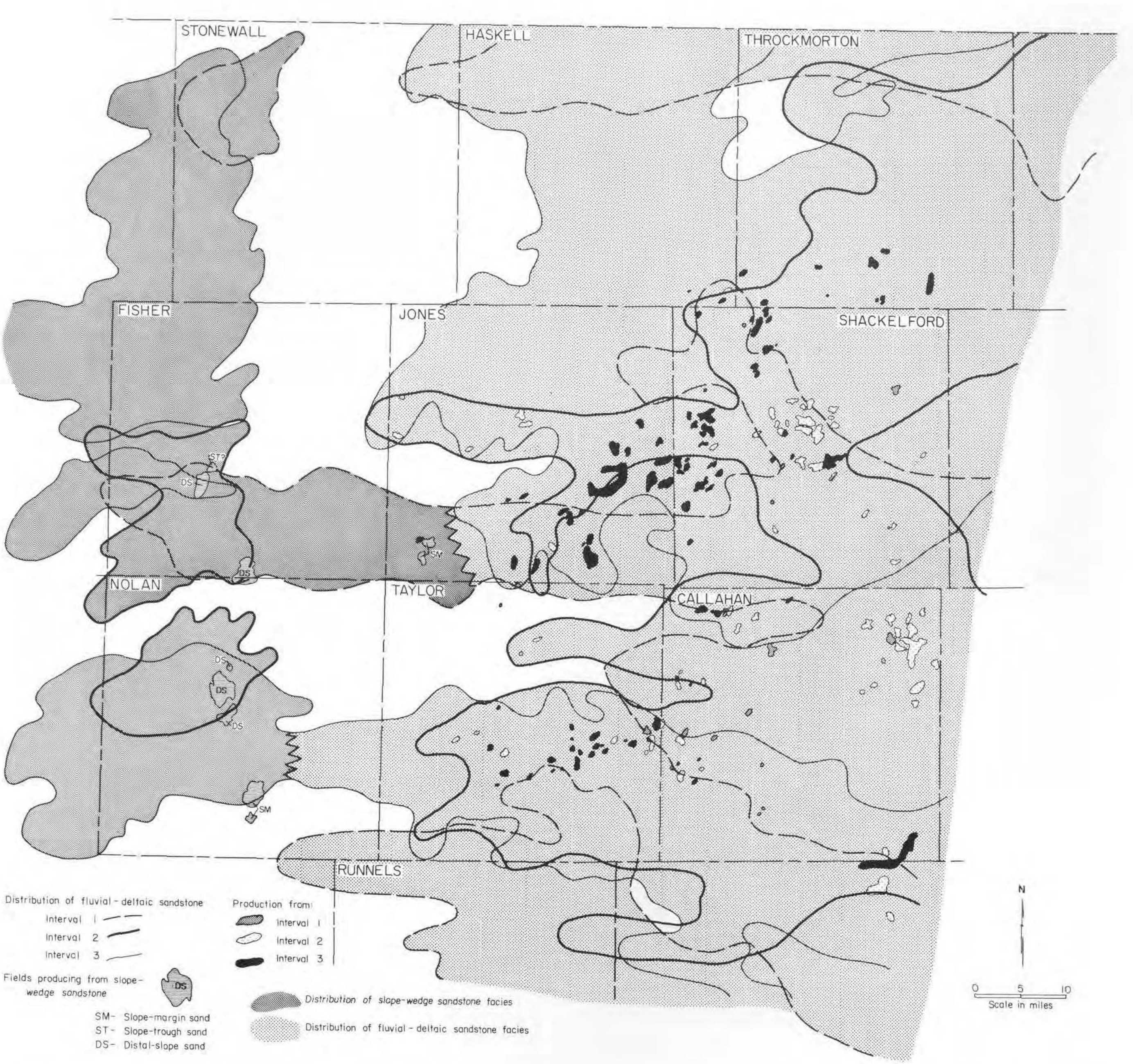

FIG. 31. Outline of the major Harpersville delta lobe complexes and slope wedges with distribution of oil fields superimposed. In part after Abilene Geological Society (1960b).

association. Thickest and most numerous coal beds occur along the flanks of major fluvial-deltaic lobes. In contrast, Pennsylvanian coals in the large coal basins of North America consist of *in situ* accumulations of organic material deposited in swampy or marshy environments. Wanless et al. (1969) cataloged environments of coal deposition, including: (1) deltaic plains, (2) unfilled alluvial or distributary channels, (3) estuaries, (4) coastal marshes similar to the modern Atlantic coast, (5) local meander cut-offs, (6) lagoons behind offshore bars, (7) exposed plains following an abrupt marine regression, and (8) level depositional plains formed after burial of pre-Pennsylvanian topography. Most large coal beds accumulated in deltaic plain swamps and marshes and are associated with root-mottled underclays. Some of the lagoonal coals may resemble Harpersville coals, and coal beds formed in meander cut-offs or oxbow lakes are in part similar detrital accumulations.

Absence of coal within the fluvial-deltaic facies of the Cisco system is a consequence of deposition from "flashy" mixed load streams and lack of sufficient compactable subjacent prodelta muds.

CERAMIC CLAY

Distribution of ceramic clays in the Upper Pennsylvanian of Stephens and Young counties was outlined by Plummer et al. (1949), who listed three beds of potential economic value—the Quinn, Curray, and Craddock Clays. The Quinn Clay occurs between the Breckenridge and Crystal Falls Limestones, the Curray Clay lies between the Crystal Falls and the next overlying limestone (the Upper Crystal Falls Limestone of Brown, 1960), and the Craddock Clay lies below one of the Newcastle coals, about midway between the Crystal Falls and Saddle Creek Limestones. These clays typically weather purplish red, maroon, and greenish red; are massive and unbedded; and are of variable thickness. Each contains plant debris, local concretion and selenitic zones, and thin coal and sandstone beds. Clay composition ranges from about 1/4 to 1/3 kaolinite, 1/2 to 2/3 illite, and minor amounts of expandable clays and chlorite.

Like coals, the ceramic clays are best developed adjacent to major lobes as interdeltaic embayment facies. The best ceramic clays are laterally associated with thinner deltaic sequences in the lower part of the Harpersville, particularly the Upper Hope sandstone. A reasonable modern analog to the depositional environment of these clays exists in marginal deltaic mudflats of the Mississippi delta system described by Morgan et al. (1953). These mudflats are rapidly prograded as unbedded slurries into delta flank embayments of the Mississippi where they are colonized by marsh vegetation. Presumably, exposure of the clays to early leaching in such an acidic, stagnant environment, combined with a source of potassium, could result in diagenesis of the various clay minerals to kaolinite and illite (Krauskopf, 1967, p. 191).

In a comprehensive study of clay mineral assemblages in the Cisco Group, Shover (1961) found that clays interpreted to have formed in subaerial environments, particularly those associated with coal or plant debris, were enriched in kaolinite, but marine clays were high in chlorite content.

CONCLUSIONS

1. Uppermost Pennsylvanian strata of the Eastern Shelf are composed of three depositional systems, the Cisco fluvial-deltaic system, the Sylvester shelf-edge bank system, and the Sweetwater slope system.
2. The fluvial-deltaic system can be subdivided into dip-fed fluvial-deltaic facies and strike-fed interdeltaic embayment facies. Eight fluvial-deltaic lobes are delineated in the system between the Breckenridge and Saddle Creek Limestones. The slope system is subdivided into several discrete, fanlike slope wedges by locally developed limestone aprons. Each wedge is composed of shelf margin, slope trough, and distal slope sandstone facies and slope mudstone facies. Toes of the slope wedges extend far into the basin and are interbedded with basinal dark shales.
3. Terrigenous clastic sediments were dispersed across the shelf by prograding fluvial-deltaic lobes, which locally breached the shelf-edge carbonate bank system and debouched onto the slope where submarine fans were constructed into the Midland Basin. Alternately, where distributary channels failed to reach the shelf edge, wind tidal or flood currents swept terrigenous clastic sediment across the banks through local passes.
4. The Eastern Shelf prograded into the Midland Basin by local, contemporaneous upbuilding and outbuilding. Deposition within the fluvial-deltaic and bank systems built up the shelf while outbuilding proceeded by deposition on areally restricted slope wedges. Sites of shelf construction shifted through time in response to sedimentary and structurally controlled abandonment and relocation of the lobes.
5. There is no evidence of regional subaerial exposure or total submergence of the shelf. Extrabasinal controls such as eustatic sea-level changes were of secondary importance in determining the sedimentary fabric of the shelf.
6. Coal and ceramic clay deposits occur exclusively as interdeltaic embayment facies. Broad, subtle structural flexures controlled the distribution of first-order petroleum trends in the fluvial-deltaic system; minor structures and reservoir pinch-outs localize production in channel and distributary mouth-bar sandstone facies. Production in the slope system is limited to shelf margin, distal slope, and lower slope trough sandstone facies.

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APPENDIX I

GLOSSARY OF TERMS

This section is not intended to provide definitions of all technical terms used in the report. Rather, it provides a guide to common but possibly ambiguous descriptive terms.

Anastomosing: Composed of multiple interweaving channels.
Bedding thickness:
  Thin bedding—beds less than 1 inch thick.
  Medium bedding—beds 1 to 6 inches thick.
  Thick bedding—beds over 6 inches thick.
Coarse-grained meander belt: Point-bar facies deposited by mixed-load streams characterized by variable discharge.
Cross stratification:
  Large scale—crossbed dimensions in feet.
  Medium scale—crossbed dimensions in inches.
Dip-fed: Sediment is transported parallel to depositional slope, as in a fluvial system.
Flashy stream: Stream characterized by highly variable flow that is punctuated by short duration floods.
Lamination: Sheet of sediment less than 1 cm thick.
Parallel lamination: Individual laminae are parallel to the underlying surface.
Planar lamination: Individual laminae are planar and parallel to bedding.
Ripple lamination: Small-scale trough lamination produced by migrating ripple trains.
Sinusoidal ripple lamination: Wavy lamination exhibiting symmetrical stoss and lee slopes and little migration of the ripple crest through the coset.
Strike-fed: Sediment is transported parallel to depositional strike, as in a strandplain system flanking a delta lobe.
Tabular cross-stratification: Planar foresets bounded by nearly parallel upper and lower surfaces; the origin of the basal scour surface is unrelated to later infilling.
Trough cross-stratification: Spoon-shaped scours filled with parallel laminated sediment; scouring is genetically related to infilling.

APPENDIX II

PREPARATION OF FACIES MAPS AND CROSS SECTIONS

Approximately 3,500 wells averaging 275 per county were used to prepare sandstone isolith maps and other maps and sections.

Facies maps.—Total sandstone thickness was calculated from electric logs using the SP profile. No rigorous geometric technique was used to arrive at net sandstone values; rather, visual estimation to the nearest 5 feet proved sufficiently accurate and consistent. Total sandstone thickness, stratigraphic position, and character of SP profile for each of the three map intervals were recorded on data sheets and transferred to base maps.

Cross sections.—Regional dip sections were constructed at approximately 8-mile intervals along strike. About 50 wells were projected into the line of section, and graphic strip logs were prepared by interpretation of the SP and resistivity profiles. Sandstone, limestone/black shale/coal, and mudstone were differentiated. Interpretations were checked against sample logs and cores. Strip logs were then used to construct the sections.

APPENDIX III

ELECTRIC LOGS USED IN FIGURES

FIGURE 4

1. B. W. Payne Davis Crow No. 1; sec. 1558, TE&L survey.
2. John H. DeFord, Trustee, Dell Newell No. 1; sec. 168, ETRR survey.
3. G. C. Howell Gillespie No. 1; sec. 45, O.A.L. survey.
4. Humble Oil & Refining A. Kingsberry No. 1; sec. 52, blk. 2, SP survey.
5. Fox and Ransdell Turner No. 1; A. E. Williams survey.
6. General Crude Parker No. 1; Steel and Milsapp subd., blk. 13, BSL survey.
7. Southern Minerals Hefner No. 1; sec. 45, blk. 3, H&TC survey.
8. Monsanto Chemical Company Monsanto Crenshaw No. 1; sec. 93, blk. 2, H&TC survey.

FIGURE 14

1. Marshall Young Morris 201-A No. 60; sec. 201, ETRR survey.
2. Marshall Young Morris 201-A No. 64; sec. 201-A, ETRR survey.
3. Marshall Young Morris No. 63; sec. 201-A, ETRR survey.
4. Black Morris No. 2-A; sec. 204, ETRR survey.
5. Black Morris No. 1-A; sec. 204, ETRR survey.
6. K. L. Fenner et al. Morris "B" No. 3; sec. 204, ETRR survey.
7. L. A. Hedrick G. Odell No. 1; sec. 211, ETRR survey.
8. J. S. Smith Davis No. 1; sec. 220, ETRR survey.
9. Marshall Young Dawson-Conway No. 52; sec. 202, ETRR survey.
10. Aztec Salvage Davis No. 4; sec. 219, ETRR survey.
11. Aztec Salvage Davis No. 3; sec. 219, ETRR survey.
12. Aztec Salvage Davis No. 21; sec. 218, ETRR survey.
13. Aztec Salvage Davis No. 1; sec. 218, ETRR survey.
14. West Central Drlg. Baker No. 10-A; sec. 217, ETRR survey.

FIGURE 15
(Selected)

3. Marshall Young Cook 140-A No. 10; sec. 140-A, ETRR survey.
4. Marshall Young Cook 117-A No. 36; sec. 117-A, ETRR survey.
5. Marshall Young Cook 140-A No. 11; sec. 140-A, ETRR survey.
6. Marshall Young Cook 140-A No. 9; sec. 140-A, ETRR survey.
7. Marshall Young Cook 140-A No. 8; sec. 140-A, ETRR survey.
8. Marshall Young Cook 144-A No. 4; sec. 144-A, ETRR survey.
9. Marshall Young Cook 111-A No. 42; sec. 111-A, ETRR survey.
10. Marshall Young Cook 112-A No. 8; sec. 112, ETRR survey.
11. Marshall Young Cook 112-A No. 18; sec. 112, ETRR survey.
12. Marshall Young Cook 113-B No. 20; sec. 113, ETRR survey.
13. Marshall Young Cook 113-A No. 23; sec. 113, ETRR survey.
14. Marshall Young Cook 113-A No. 26; sec. 113, ETRR survey.
15. Great Expectations Newell No. 21-A; sec. 114, ETRR survey.
16. Great Expectations Newell No. 18-B; sec. 114, ETRR survey.
17. H. F. Pettigrew Newell "B" No. 2;sec. 87, ETRR survey.

FIGURE 21

1. British American Wilson No. 1; sec. 216, blk. 64, H&TC survey.
2. Moore and Moore Drlg. Co. and Lloyd Smith J. A. Lee No. 1; sec. 288, blk. 64, H&TC survey.
3. General Crude Bennett No. 1; sec. 283, blk. 64, H&TC survey.
4. A. W. and Blair Cherry M. D. Earwood No. 1; sec. 250, blk. 64, H&TC survey.
5. General Crude G. C. Cave No. 1; sec. 249, blk. 64, H&TC survey.
6. Ard Drlg. and Ray Oil Co. McKee No. 1; sec. 3, blk. Z, T&PRR survey.
7. R. S. Lytle F. Sanders No. 1; sec. 9, blk. Z, T&PRR survey.
8. Sweetwater Exploration Co. W. W. Davis No. 1; sec. 165, blk. 1-A, H&TC survey.
9. Barnhart and Roberts W. W. Davis No. 1; sec. 164, blk. 1-A, H&TC survey.
10. Stephens Petroleum Co. Caldwell No. 1; sec. 162, blk. 1-A, H&TC survey.
11. Honolulu Oil Co. Herring No. 1; sec. 170, blk. 1-A, H&TC survey.
12. Kewanee Oil Co. Jewell No. 1; sec. 160, blk. 1-A, H&TC survey.
13. Feldman Oil and Gas Cook No. 1; sec. 173, blk. 1-A, H&TC survey.
14. Humble Oil and Rep. M. Sears No. 1; sec. 157, blk. 1-A, H&TC survey.
15. L. Hunt Est. R. B. Jones No. 1; sec. 197, blk. 1-A, H&TC survey.
16. H. C. Hargrove Brownfield No. 1; sec. 44, blk. 5, T&PRR survey.
17. R. Maguire Phillips No. 1; sec. 44, blk. 5, T&PRR survey.
18. Perkins-Prothro S. Dennis No. 1; sec. 43, blk. 5, T&PRR survey.
19. General Crude V. M. Ussery No. 3; sec. 42, blk. 5, T&PRR survey.
20. General Crude J. P. Brown No. 1; sec. 286, blk. 64, H&TC survey.
21. Moore and Moore C. C. Lee No. 1; sec. 282, blk. 64, H&TC survey.
22. Norsworthy J. W. Wilson Est. No. 1; sec. 252, blk. 64,

H&TC survey.
23. British American Wilson Est. No. 1; sec. 245, blk. 64, H&TC survey.
24. National Associated Petroleum Barwood No. 1; sec. 197, blk. 64, H&TC survey.
25. Garrett and Moore and Moore Drlg. Earwood No. 1; sec. 197, blk. 64, H&TC survey.

FIGURE 23

1. Union W. T. Scott No. 6-79; sec. 79, blk. 22, T&PRR survey.
2. Union W. T. Scott No. 5-79; sec. 79, blk. 22, T&PRR survey.
3. Union W. T. Scott No. 2; sec. 79, blk. 22, T&PRR survey.
4. Skelly E. S. Cox No. 24; sec. 90, blk. 22, T&PRR survey.
5. Skelly E. S. Cox No. 19; sec. 90, blk. 22, T&PRR survey.
6. Skelly E. S. Cox No. 16; sec. 90, blk. 22, T&PRR survey.
7. Duffy and Union E. Cox No. 6; sec. 91, blk. 22, T&PRR survey.
8. Duffy and Union E. Cox No. 5; sec. 91, blk. 22, T&PRR survey.
9. Skelly E. S. Cox No. 13; sec. 91, blk. 22, T&PRR survey.
10. Skelly E. S. Cox No. 12; sec. 91, blk. 22, T&PRR survey.
11. Union M. Campbell No. 1-15; sec. 15, blk. X, T&PRR survey.
12. Union M. Campbell “A” No. 3-315; sec. 15, blk. X, T&PRR survey.
13. Union and TXL Ltd. TXL Fee No. 1-15; sec. 15, blk. X, T&PRR survey.
14. Union TXL Fee No. 4-15; sec. 15, blk. X, T&PRR survey.
15. Union M. Campbell No. 5-34; sec. 34, blk. X, T&PRR survey.
16. Union M. Campbell No. 2-34; sec. 34, blk. X, T&PRR survey.
17. Union M. Campbell No. 1; sec. 34, blk. X, T&PRR survey.
18. Honolulu B. K. Stone No. 1; sec. 34, blk. X, T&PRR survey.
19. Sun B. K. Stone No. 4; sec. 100, blk. X, T&PRR survey.

APPENDIX IV

MEASURED SECTIONS

The locations of measured sections used in preparation of the surface geologic map and interpretation of depositional environments are shown on Plate IV. Each section was selected as representative of the stratigraphic succession and facies types in its immediate area. Detailed section descriptions are in Galloway (1970).

EASTLAND COUNTY

Section 1. Measured from gully up hill slope southeast of road cut. Interdeltaic embayment facies capped by Saddle Creek Limestone. Section dominantly varicolored mudstones with a few thin coals and limestones and an unusual bed of *Syringapora*-rich grayish-green claystone. Total—66 feet.

Section 2. Hill slope at the north side of Lake Cisco Park. Interdeltaic embayment facies lying between the Crystal Falls and Breckenridge Limestones. Varicolored mudstones are poorly exposed. Total—39 feet.

Section 3. Measured along the creek bed and then southward up the hill lying north of U. S. Highway No. 380. Interdeltaic and delta-margin facies capped by the Saddle Creek Limestone. Upper part of the section consists of several thin coals and limestones with interbedded mudstone. Thin to medium-bedded sandstones dominate the middle part, and interbedded limestones and mudstones comprise the basal 10 feet. Total—143 feet.

Section 4. Measured northward from private road up hill to Saddle Creek outlier. Interdeltaic embayment and delta-margin facies, capped by Saddle Creek Limestone. Interbedded mudstone, sandstone, and limestone grading down into sand, silt, and mudstone. Total—115 feet.

Section 5. Measured up south side of isolated hill west of highway. Interdeltaic embayment facies above Crystal Falls Limestone. Mudstone, sheet sandstone, and limestone beds dominate. Total—68 feet.

Section 6. Measured up southeast flank of the isolated hill just south of the Eastland County line. Interdeltaic embayment facies including claystone, coal, limestone, and sheet sandstone units; capped by Saddle Creek Limestone; base is Crystal Falls Limestone. Total—128 feet.

STEPHENS COUNTY

Section 7. Measured up isolated hill east of pasture road. Saddle Creek Limestone underlain by interdeltaic embayment facies. Contains mudstone, limestone, sheet sandstone, and coal beds. Total—92 feet.

Section 8. Measured up the hill on the northwest side of the road. Saddle Creek Limestone caps sequence of mudstone, limestone, and sheet sandstone interdeltaic facies. Total—110 feet.

Section 9. Measured up hill to west of county road. Mudstone-dominated interdeltaic facies capped by Saddle Creek Limestone. Contains several thin sheet sandstones and limestones. Total—136 feet.

Section 10. Measured up the northwest side of Double Mountain, area of the type section of the Harpersville Formation. Coaly interdeltaic embayment facies overlain by several delta margin and distributary channel sandstones. Abundant large woody fragments locally occur in channel sands. Total—145 feet.

Section 11. Measured up north end of hill to west of county road. Mudstone-dominated interdeltaic embayment facies containing a few sheet sandstones and thin limestones. Total—58 feet.

Section 12. Measured from the lease road up east end of hill. Sand and mudstones of the interdeltaic facies suite capped by a massive post-Saddle Creek channel sandstone and underlain by the Crystal Falls Limestone. Total—127 feet.

Section 13. Measured from pasture road up southeast side of hill. Interdeltaic embayment facies, including mudstone, siltstone, sandstone, and limestone. Total—81 feet.

Section 14. Measured from gully beside county road up Spy Mountain. Type section for Spy Mountain sandstone and includes associated mud, sand, and siltstones of the interdeltaic embayment facies. Seventeen feet of Spy Mountain delta-margin sandstone facies. Total—112 feet.

Section 15. Measured in the barrow ditch and road cut along county road. Upper Hope meander-belt sandstone overlain by delta plain and interdeltaic facies; bounded by the Breckenridge and Crystal Falls Limestones. Crystal Falls is mounded. Total—51 feet.

Section 16. Up hill slope north of U. S. Highway No. 180. Interdeltaic embayment facies with several sandstone units, mudstone, and coal. Total—36 feet.

Section 17. Measured up small, isolated hill just west of U. S. Highway No. 183. Interdeltaic embayment facies with unusually thick sequence of coal and coaly shale at the base. Mudstone and claystone dominate section. Total—74 feet.

Section 18. Measured along hill slope and road cut adjacent to gravel road below Hubbard Creek dam. Typical suite of interdeltaic embayment facies capped by thick, well-developed sheet sandstone. Total—78 feet.

Section 19. Measured up hill just north of county road. Flippen and Bluff Creek equivalent interdeltaic facies suite capped by Saddle Creek transitional limestone facies, a very sandy crinoid biosparite. Total—47 feet.

Section 20. Measured from creek bed up southwest side of small hill. Interdeltaic embayment facies suite dominated by mudstone with several limestone, coal, claystone, and sheet sandstone beds. Total—94 feet.

YOUNG COUNTY

Section 21. Measured from county road along gravel lease road westward up the scarp. Locally prominent mounded limestone at base overlain by limestone and mudstone interdeltaic embayment facies and capped by massive sandstones of the Cook/Flippen fluvial-deltaic complex. Total—62 feet.

Section 22. Measured from gully up the southeast flank of Belknap Mountain. Upper Hope equivalent interdeltaic embayment facies suite containing a thin, pisolitic chamosite bed; capped by Cook/Flippen delta-margin and channel sandstones. Total—83 feet.

Section 23. Measured west of State Highway No. 251, about 1 mile north of Newcastle. Mudstone-dominated interdeltaic embayment facies containing several coaly intervals and capped by delta margin sandstone facies. Total—69 feet.

Section 24. Measured from lease road up hill about 1 mile west of State Highway No. 61. Fluvial-deltaic facies, including delta-margin and distributary channel sandstone facies, and delta plain and fluvial overbank mudstones and siltstones. Several micrite concretion zones are present. Total—109 feet.

Section 25. Measured up small hill north of State Highway No. 199, west of Jermyn. Basal Upper Hope equivalent interdeltaic embayment sequence overlain by Cook and Flippen fluvial-deltaic facies. Breckenridge Limestone at base; section capped by a prominent delta-margin sandstone unit. Total—130 feet.

Section 26. Measured from lease road up hill just west of Young County line. Sequence of fluvial-deltaic facies dominated by mud, clay, silt, and sandstone with some coaly zones. Total—105 feet.

APPENDIX V

LOCALITIES

Each outcrop locality includes representative exposures of facies and other features described in the text. Locations are shown on the geologic map (Pl. IV). Localities are numbered consecutively in each county.

EASTLAND COUNTY

EA-1. Two beds of extremely fossiliferous mixed biomicrudite are exposed in the barrow ditch on the west side of the road. Crinoid columnals, fenestrate and branching bryozoans, *Myalina,* and brachiopods are common. Below the lower bed is a 1- to 10-inch lenticular bed of crinoid biosparrudite, interpreted to be a bioclastic lag filling a small scour channel.

EA-2. Gully along the east side of the road exposes 13 feet of thick- to thin-bedded sandstone of the delta margin, and abandoned distributary facies. A basal 4-foot bed of large-scale trough-bedded fine sandstone is overlain by numerous beds of alternating very fine sand, silt, and mudstone. A variety of structures, including parallel, wavy, ripple, climbing ripple, and medium trough laminations, is prominently displayed. Symmetrical, long-crested ripples and burrows occur near the top. Sandstone beds are lenticular, and the base of the lower unit is sharp.

EA-3. Road cuts expose superposed Cook and post-Saddle Creek channel-fill deposits. Locality is described in Brown and Wermund (1969) under S4, second day. Section 1, measured just to the south, records the typical upper Harpersville interdeltaic embayment facies of mudstone, thin limestones, and coal. Sandstones cropping out on the hill slope south of the road cut exhibit a variety of fine lamination types, including climbing sinusoidal ripples, and are interpreted to be overbank crevasse or natural levee deposits of the Cook channel. The correlation is not certain because intervening facies are cut out by the superposed post-Saddle Creek channel.

EA-4. Exposure in abandoned railroad cut exhibits stacked channels characteristic of the northern part of the Lake Cisco (Cook) conglomerate. Massive, large-scale trough crossbedding and contorted, brown, cherty, coarse to fine sandstone are erosionally truncated and capped by several feet of massive trough and tabular crossbedded sandy conglomerate and conglomeratic sandstone. Grain size and bedding scale decrease upward, tabular and plane lamination are dominant toward the top, and sandstone clasts are common at the base of the upper channel fill. Interpreted as lower meandering channel fill capped and truncated by a slightly younger braided channel fill.

EA-5. Well location on lease road into Kleiner oil field. Massive, fine to coarse, cherty sandstone exhibiting lateral accretion bedding truncated and overlain by massive chert conglomerate and conglomeratic sandstone. Lower unit of the two-cycle channel sequence contains zones of mudclasts, and stratification types include parallel, medium, and ripple lamination. Tabular foresets and planar lamination dominate the overlying conglomeratic unit. Typical two-cycle Lake Cisco conglomerate found around Cisco area (*see* EA-7 and EA-8).

EA-6. Road cut along U. S. Highway No. 380 at Cisco Junior College. Fifty-five-foot section of mudstone, sheet sandstone, coal, and limestone facies of the interdeltaic embayment association. Locality is described in Brown and Wermund (1969, pp. 62–64).

EA-7. Road cuts along old U. S. Highway No. 380 at each end of Lake Cisco dam. Road cut at north end of dam best displays a section through a point-bar sequence characterized by fining upward of grain size and structures and by the development of lateral accretion bedding. The unit is truncated by irregularly bedded sandstone and minor conglomerate equivalent to the conglomeratic unit described at the following locality. Road cut is shown in figure 16.

EA-8. Series of three road cuts along U. S. Highway No. 380 below the Lake Cisco dam. Southernmost cut displays a sequence of interdeltaic facies capped by the Saddle Creek Limestone. Middle cut, lying on the south side of the valley, shows a massive, lenticular sandstone truncated by an extensive, massive unit composed of irregular lenses of conglomerate, conglomeratic sandstone, and sandstone. Structures in the overlying unit are dominated by tabular foresets and planar lamination. Foresets dip uniformly south. Grain size and magnitude of structures generally decrease upward. A two-cycle sequence is also present in the northern cut, but the overlying unit consists mainly of lenticular sandstone beds grading at the north end into well-developed giant foresets several feet high. The basal scour is overlain by local lenses of conglomerate and mudclasts. A possible third channel caps the cut. Structures characteristic of the conglomeratic unit are shown in figure 16, C. Facies are interpreted to be that of a sinuous, meandering channel overlain and partially truncated by deposits of a braided or coarse-grained meandering stream and associated valley fill.

EA-9. Breckenridge Limestone exposed in road cut on highway at north side of Cedar Creek. Three distinct beds here.

JACK COUNTY

JK-1. Road cut on Farm-to-Market Road No. 1191 cuts a middle to upper channel-fill sequence and adjacent overbank and natural levee facies. Some lateral accretion and resultant point bar development are apparent.

JK-2. Cross section of a mounded coaly shale and superjacent massive channel-fill sandstone shown in figure 19 is exposed in the road cut and barrow ditch.

JK-3. Road cut on U. S. Highway No. 281 exposes a good section of a distributary mouth bar—delta front sheet sandstone sequence overlying a marine destructional sheet sandstone that contains burrows and fossil debris. Stratigraphic position of the upper sandstone is uncertain, but it is approximately correlative with the Upper Hope interval.

JK-4. Gully to south of county road contains good outcrops of fluvial and upper delta plain overbank facies.

STEPHENS COUNTY

SP-1. Road cut exposure of Saddle Creek Limestone along Farm-to-Market Road No. 1853. Three and one-half feet of gray biomicrudite.

SP-2. Hill slope and road cut west of bridge on Farm-to-Market Road No. 1032 expose good section of Spy Mountain sandstone. Zonation of burrows and types of sedimentary structures are well displayed, as shown diagrammatically on figure 18.

SP-3. Road cut exposure on Farm-to-Market Road No. 536 just east of Eolian community provides a cross section of a mounded, interdeltaic limestone bed locally replaced by a lime grainstone that appears to fill a small channel.

SP-4. Creek bed next to county road leading to Hubbard Creek Reservoir exposes crests of a mounded sheet sandstone correlated with the Spy Mountain sandstone. Ripple marks are common on bedding planes and show no divergence around the mound crests. Mound amplitude is about 4 feet.

SP-5. Road cut exposure of Saddle Creek Limestone along U. S. Highway No. 180, west of Breckenridge. Transitional facies.

SP-6. Road cut along U. S. Highway No. 183 north of Breckenridge exposes a cross section through a post-Breckenridge (Upper Hope) sandstone channel fill. Interpreted as a multiply-occupied distributary channel.

SP-7. Road cut exposure along U. S. Highway No. 183, south of intersection with Farm-to-Market Road No. 578. Small troughs or channels within a sheet sandstone that is stratigraphically equivalent to the channel fill exposed at locality SP-6. Thin limestone bed at base of cut contains bryozoan hash.

SP-8. Hill slope exposures adjacent to gravel road leading to housing developments along southeastern shore of Hubbard Creek Reservoir contain a sheet sandstone grading laterally into several lenticular, ripple-laminated channel fills 3 to 6 feet thick. Hills are capped by calcareous, fossiliferous sandstone approximately equivalent to the Saddle Creek Limestone.

SP-9. Road cut along U. S. Highway No. 183 just north of intersection with Farm-to-Market Road No. 578 exposes mounded interdeltaic limestone and sheet sandstone facies flanked and overlain by broad, shallow troughs filled by parallel-laminated sandstone.

SP-10. Road cut along gravel road that runs parallel with and below Hubbard Creek dam. Good section through a sheet sandstone of the interdeltaic embayment facies association showing typical structures and bedding characteristics.

SP-11. Creek bed adjacent to lease road that runs through Stribling oil field exposes 1 foot of burrowed, fossiliferous, sandy biomicrudite interpreted to be transitional facies of the Saddle Creek Limestone.

SP-12. Road cut along Farm-to-Market Road No. 578 south of county line cuts a symmetrically filled distributary channel unit. Fine-scale structures are characteristic. Only one flank of the channel fill is cut, and beds dip up to 13 degrees.

SP-13. Slightly north of locality SP-12, road cuts through another symmetrically filled distributary channel containing an abundance of macerated plant debris. Both are Cook/Flippen equivalent channels.

SP-14. Crystal Falls outlier east of road displays incised mounds. (Locality 39 of Brown, 1960.)

SP-15. Bluff along creek bed to east of road in Donnell oil field consists of 18 feet of medium- to thin-bedded sandstone interpreted to be a distributary mouth bar—delta margin sheet sandstone complex. Ripple and other small-scale lamination types predominate.

YOUNG COUNTY

YO-1. Exposure along gravel road south of Farm-to-Market Road No. 1974 of Crystal Falls Limestone displaying mound structure.

YO-2. Gully below well location to northwest of lease road exposes an interdeltaic sequence containing complexly mounded sheet sandstone beds. Mound amplitude up to 15 feet. Coal and limestone also exposed.

YO-3. Roadside outcrop of Crystal Falls Limestone.

YO-4 Roadside exposure of dark gray limestone bed believed to be Crystal Falls.

YO-5. Pasture and hill slope west of county road expose stripped mound crests of a prominent, local limestone bed. Mounds locally breached by small gullies.

YO-6. Excellent outcrops of mounded limestone and delta margin sheet sandstone in floor of gully and along flanks of small hill to east of county road. Coal and thin limestone beds characteristic of the interdeltaic association are also present.

YO-7. Cut on east side of bridge exposes two sheet sandstone beds and a third sandstone unit consisting of several barlike sand bodies interpreted to be small cheniers or berms.

YO-8. Outcrop of Breckenridge Limestone in gully at east side of road. (Locality 68 of Brown, 1962.)

YO-9. Road-metal pit displays upper point-bar deposits truncated and overlain by massive, partly conglomeratic sandstone of a superjacent channel fill. Lateral accretion bedding is prominent in the lower sand body, which contains abundant macerated plant debris and interbedded mudstone.

YO-10. Road-metal pit to north of county road contains a good exposure of an unusually thick coal and organic-rich shale bed. The edge of the pit is formed by 6 feet of an Upper Hope equivalent sheet sandstone unit.

YO-11. Hill at side of Farm-to-Market Road No. 2652 is capped by a well-exposed small sandstone channel fill. A thin basal progradational sequence is locally cut out, and mudclast conglomerate rests on the underlying mudstone.

YO-12. Symmetrical channel fill in road cut on Farm-to-Market Road No. 2652. Bedding within fill dips steeply, and local slumping is evident.

YO-13. Road cut on Farm-to-Market Road No. 1769 exposes sections through four small channels in delta plain overbank deposits. The channel fills are slightly to moderately asymmetric and grade laterally into overbank mudstones and thin siltstones.

YO-14. Abandoned railroad cut just south of State Highway No. 199 displays a section through the flank of the exhumed Upper Hope channel shown on the geologic map (Pl. IV). Though erosional at the base in most of the area, the sandstone body displays internal structures characteristic of distributary channel fill.

YO-15. Excellent exposure of a fine-grained point-bar and channel-fill sequence along road cut on Farm-to-Market Road No. 1769. Sedimentary structures are particularly well displayed (fig. 16, B).

YO-16. Hill slopes and cuts throughout the valley expose sand, silt, and mudstones of the delta plain—fluvial overbank facies.