Report of Investigations No. 97 - 1979

Depositional Framework of the Lower Dockum Group (Triassic)

Texas Panhandle

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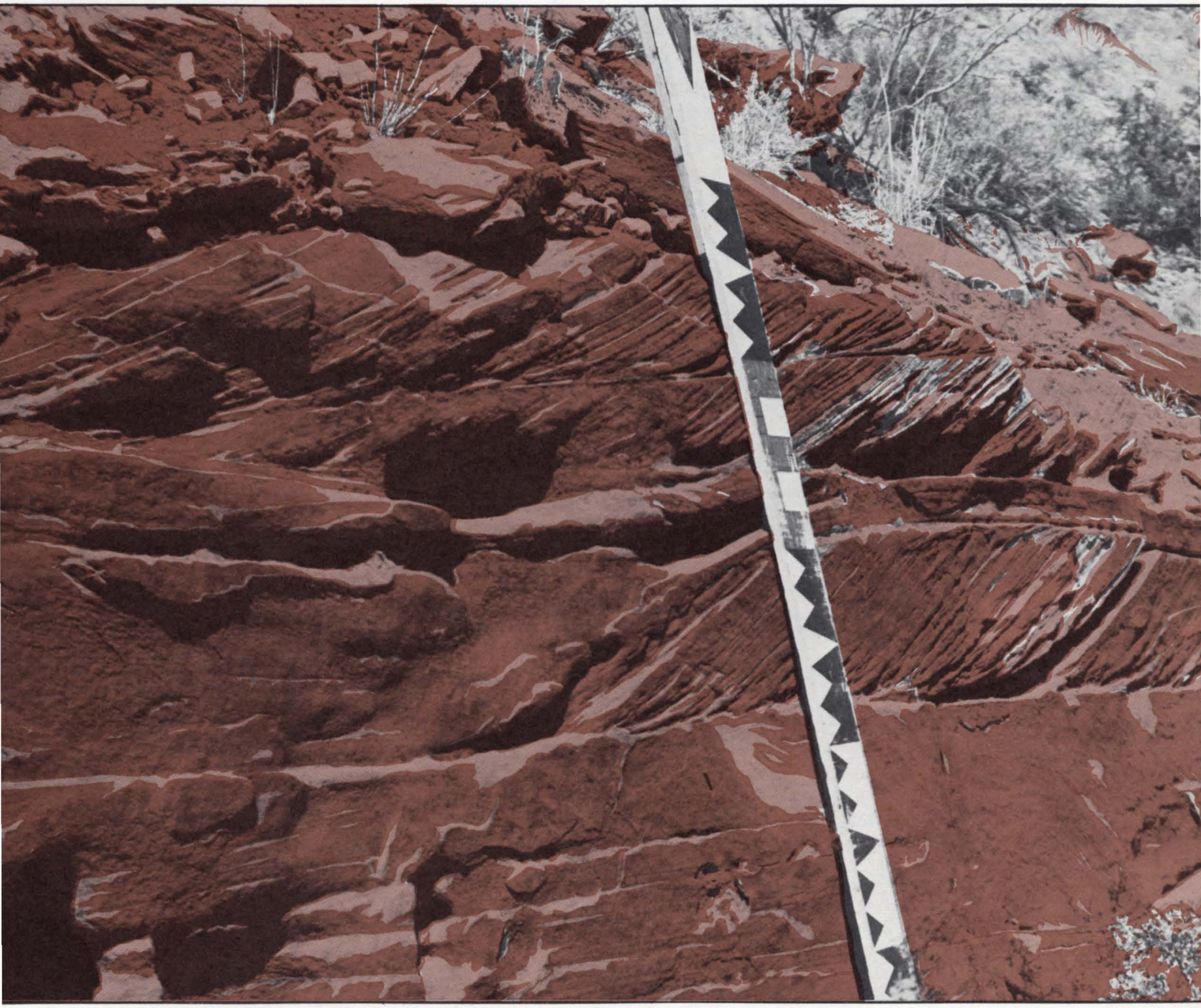

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ABSTRACT

The Upper Triassic Dockum Group of Texas and New Mexico is composed of 200 to 2,000 feet of complexly interrelated terrigenous clastic facies ranging from mudstone to conglomerate. The lower 200 to 1,000 feet of the Dockum accumulated in a fluvial-lacustrine basin defined by the Amarillo Uplift - Bravo Dome on the north and the Glass Mountains on the south.

Outcrop and subsurface data indicate that (1) the basin was filled peripherally, (2) the sediment sources were in Oklahoma, Texas, and New Mexico, and (3) the relict Paleozoic structures in concert with alternating humid and arid climatic cycles exerted considerable influence on the depositional style of the Dockum. An unconformity between the Permian and Triassic is obvious in the northern part of the basin, but physical evidence of an unconformity is lacking in the central basin area.

Arid Permian conditions gave way gradually to more humid conditions of the Triassic. Initial deposits of the Dockum, which record these humid conditions, accumulated in (1) braided and meandering streams, (2) alluvial fans and fan deltas, (3) high-constructive lobate deltas, and (4) lakes. Alluvial fans and fan deltas were best developed in northern and southern parts of the basin, whereas high-constructive lobate deltas dominated central basin areas. A change from humid to arid conditions produced (1) lowering of base level, (2) erosion (cannibalization) of older Dockum deposits, (3) replacement of meandering fluvial systems by headwardly eroding valleys and braided streams, and (4) development of small fan deltas.

Several depositional cycles are recognized in the area defined by Dickens, Crosby, Kent, and Garza Counties, Texas. A cycle comprises facies that accumulated during one high stand and one low stand of lake level. Thin progradational delta and attendant meanderbelt systems were deposited during high-stand, relatively stable base-level conditions. Progradational delta sequences are composed of extrabasinal sediments ranging in texture from clay to gravel. A typical delta sequence consists of lacustrine and prodelta mudstone-siltstone, delta-front siltstone-sandstone, channel-mouth bar and distributary sandstone, and meanderbelt sandstone-conglomerate. Splay units, consisting of poorly sorted intrabasinal sandstone and conglomerate, are constituents of interdistributary and floodplain deposits. Most delta sequences were partly cannibalized by superimposed meandering streams that migrated across the area.

With a shift toward arid conditions there was a lowering of base level accompanied by erosion of subjacent Dockum deposits. Sediment that composes the low-stand facies association ranges from reddish-brown mudstone to conglomerate. Abrupt vertical and lateral textural changes characterize these low-stand deposits. Lower Dockum red beds consist of (1) lacustrine mudstone, (2) prodelta mudstone-siltstone, (3) delta-front (delta foresets) siltstone to conglomerate, (4) delta-platform sandstone and conglomerate, and (5) interdeltaic mudstone exhibiting desiccation features, rare gypsum, salt hoppers, and chert.

INTRODUCTION

The Dockum Group in West Texas and eastern New Mexico was investigated in cooperation with the U. S. Geological Survey (Grant No. 14-08-001-G-410) for the purposes of (1) determining geological conditions that influenced deposition of the Dockum, (2) establishing relationships between uranium occurrence and depositional facies, and (3) deriving a depositional model that may be used in uranium exploration.

This paper, which concerns the depositional framework of the Dockum Group, examines the first phase of the more comprehensive study. Data derived from regional reconnaissance and locally detailed field work, in conjunction with a regional subsurface study, provide the basis for this report. Field work in other selected outcrop areas and additional subsurface work are in progress. In addition to subsurface and outcrop studies, the following supportive laboratory work is underway: (1) petrography of siltstones, sandstones, and conglomerates; (2) analyses of clay minerals from selected depositional environments; and (3) determination of uranium content of samples from throughout the study area.

Reconnaissance field work was conducted in De Baca, Guadalupe, San Miguel, and Quay Counties, New Mexico, and in the area from the Canadian River Valley to the Glass Mountains in Texas. Detailed outcrop studies were completed in Dickens, Crosby, Kent, and Garza Counties, Texas. A basin-wide subsurface study was coordinated with outcrop work. The subsurface aspects of this report deal with only the lower half of the Dockum in the region south of the Matador Arch. The study area includes 31 Texas counties and 3 New Mexico counties. Future reports will further consider the subsurface geology of the Dockum Group. More than 1,500 wells were utilized in this part of the subsurface study. Gamma-ray logs provided the principal subsurface data.

GEOLOGIC SETTING

The Upper Triassic Dockum Group accumulated in a basin that underlies parts of Texas, New Mexico, Colorado, Kansas, and Oklahoma (fig. 1). Location and geometry of the basin appear to be related to Paleozoic structural elements (fig. 2). In the northern part of the area, relict structural elements are the Amarillo Uplift and Bravo Dome, which probably originated during Late Mississippian (Nicholson, 1960). Structure in the southern part of the basin is partly obscured by evaporite solution resulting from Cenozoic surface drainage (Miller, 1955; Hills, 1972). Positive structural elements are the Matador Arch and Central Basin Platform. The Matador Arch was apparently inactive during Late Triassic (fig. 3) and exerted little influence on sedimentation. Sandstone depositional patterns in the lower half of the Dockum were unaffected by the Central Basin Platform (figs. 2, 3, and 4). Irregularities of the structural profile in Winkler County (fig. 3D) are related to evaporite solution.

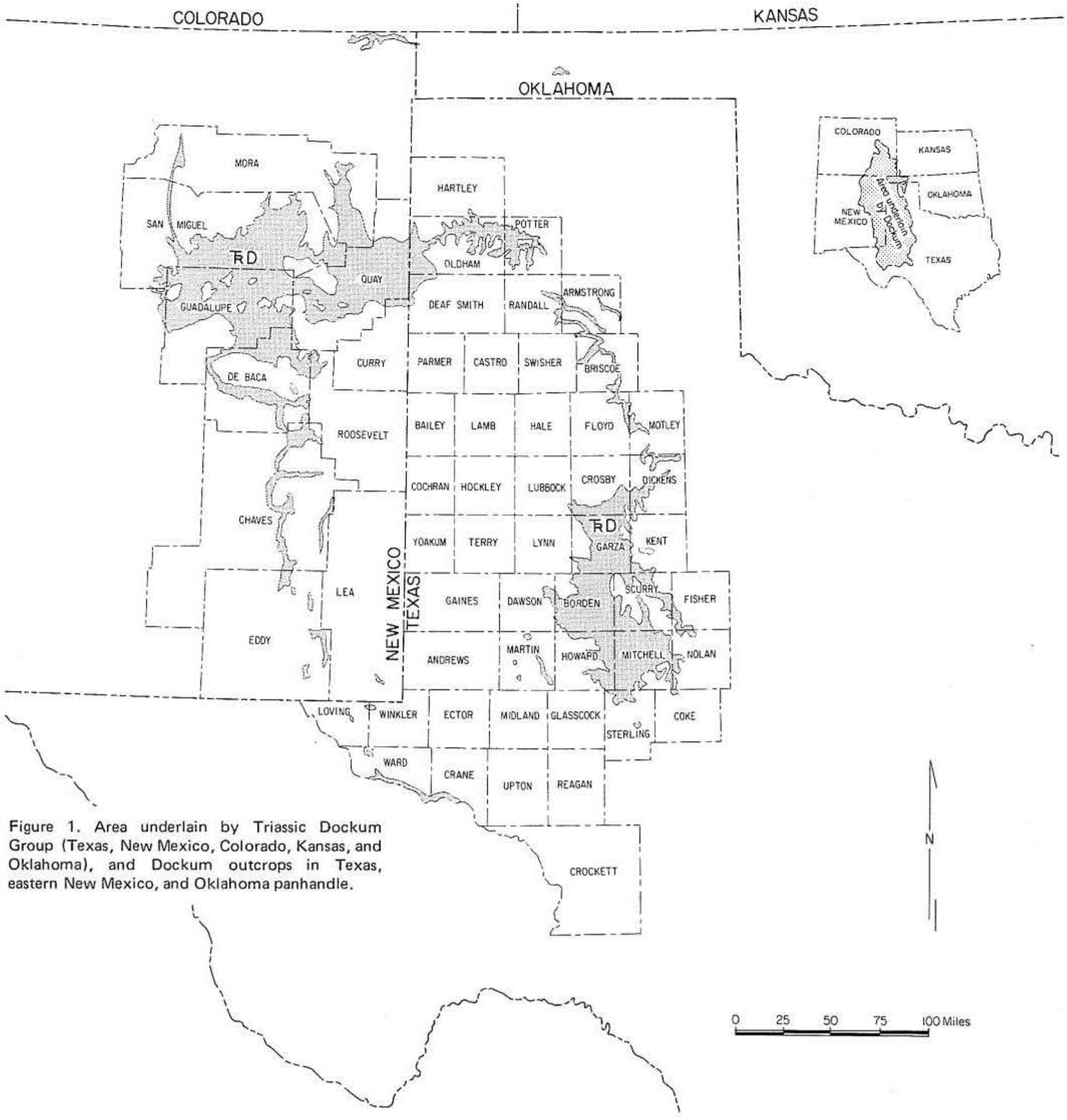


Figure 1. Area underlain by Triassic Dockum Group (Texas, New Mexico, Colorado, Kansas, and Oklahoma), and Dockum outcrops in Texas, eastern New Mexico, and Oklahoma panhandle.

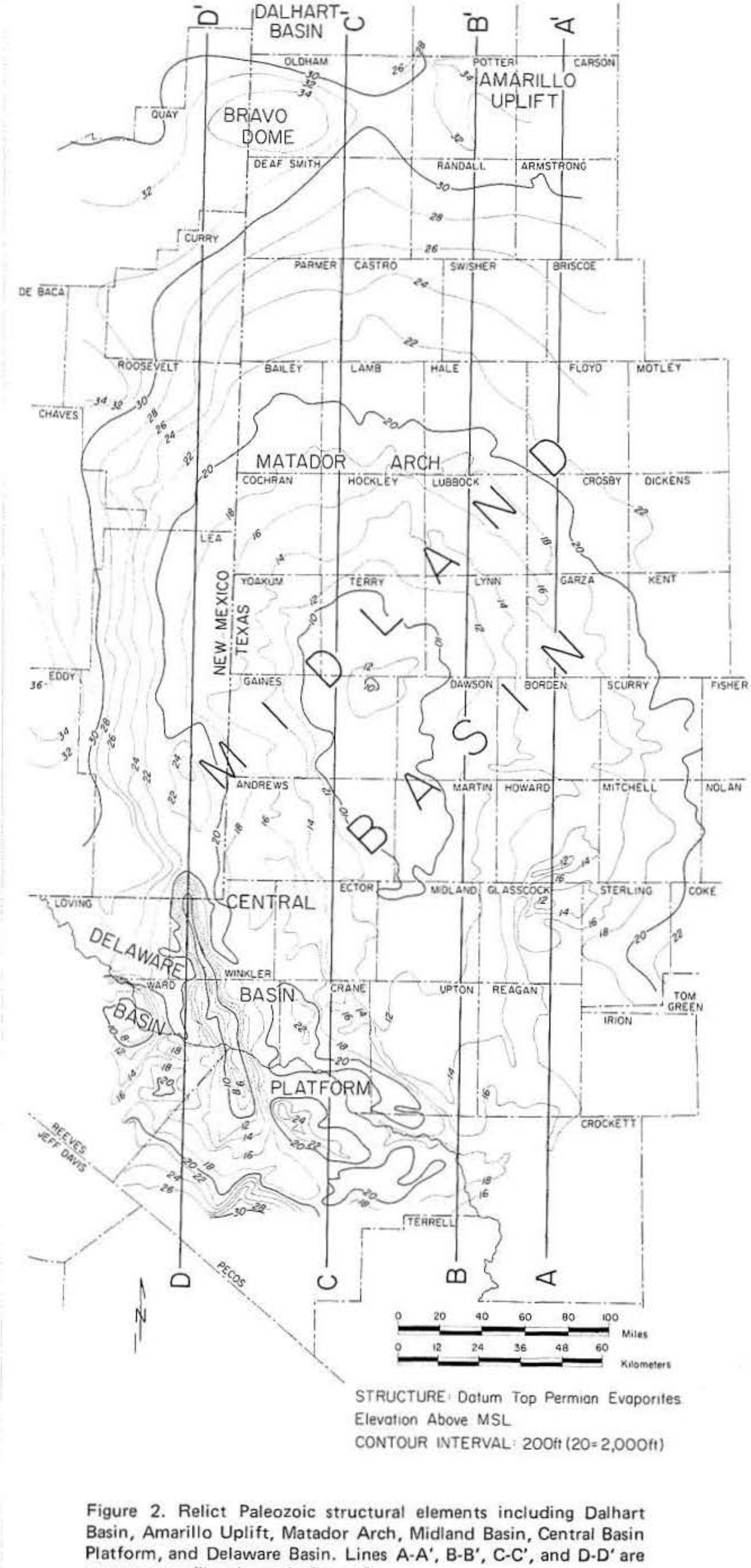


Figure 2. Relict Paleozoic structural elements including Dalhart Basin, Amarillo Uplift, Matador Arch, Midland Basin, Central Basin Platform, and Delaware Basin. Lines A-A', B-B', C-C', and D-D' are structure profiles shown in figure 3.

Dockum and underlying Permian strata are red, but Dockum facies, which accumulated in fluvial, deltaic, and lacustrine environments, are in marked contrast with Permian evaporites and terrigenous clastics that were deposited under arid conditions in restricted, shallow, hypersaline water bodies, tidal flats, and sabkhas. In some areas Permian and Triassic strata are separated by an unconformity. Elsewhere the contact is gradational, and sedimentation was probably continuous from Permian into Triassic. If this is so, then where are the Lower and Middle Triassic deposits? They are perhaps hidden in such Upper Permian deposits as Pierce Canyon Red Beds (Lang, 1935) and Dewey Lake Red Beds (Page and Adams, 1940). There was apparently a transition from the arid Permian climate to the pluvial climate of the Triassic.

The Dockum basin was peripherally filled, receiving sediment from the east, south, and west. Lowlands to the east and west were traversed chiefly by meandering streams. Higher gradient streams with flashy discharge existed at northern and southern ends of the basin. Chief sediment sources were Paleozoic sedimentary rocks.

The Dockum Group in the Texas Panhandle is composed of the basal, shaly Tecovas Formation and the overlying sands of the Trujillo Formation (Gould, 1906, 1907). In this report, Triassic strata are analyzed in terms of genetic facies that compose depositional systems.

DOCKUM GROUP: FLUVIAL, DELTAIC, AND LACUSTRINE SYSTEMS

Subsurface work by McKee and others (1959), which was substantiated by the present study, indicates that the Dockum basin was supplied with sediment by streams flowing from east, south, and west (fig. 5). A shallow lake (or lakes) was filled with distributary deltas and fan deltas.

Two apparent changes initiated Dockum sedimentation: (1) a shift from an arid Permian climate toward a more humid Triassic climate and (2) a rejuvenation of some Paleozoic structural elements (Asquith and Cramer, 1975). Opening of the Gulf of Mexico as postulated by Kehle (1972) can be inferred to have caused (1) a change in climate, (2) an uplift in part of the Ouachita Tectonic Belt, and (3) subsidence of the Dockum basin. With increasing precipitation, Permian sabkha environments were replaced by expanding lacustrine and fluvial-deltaic environments.

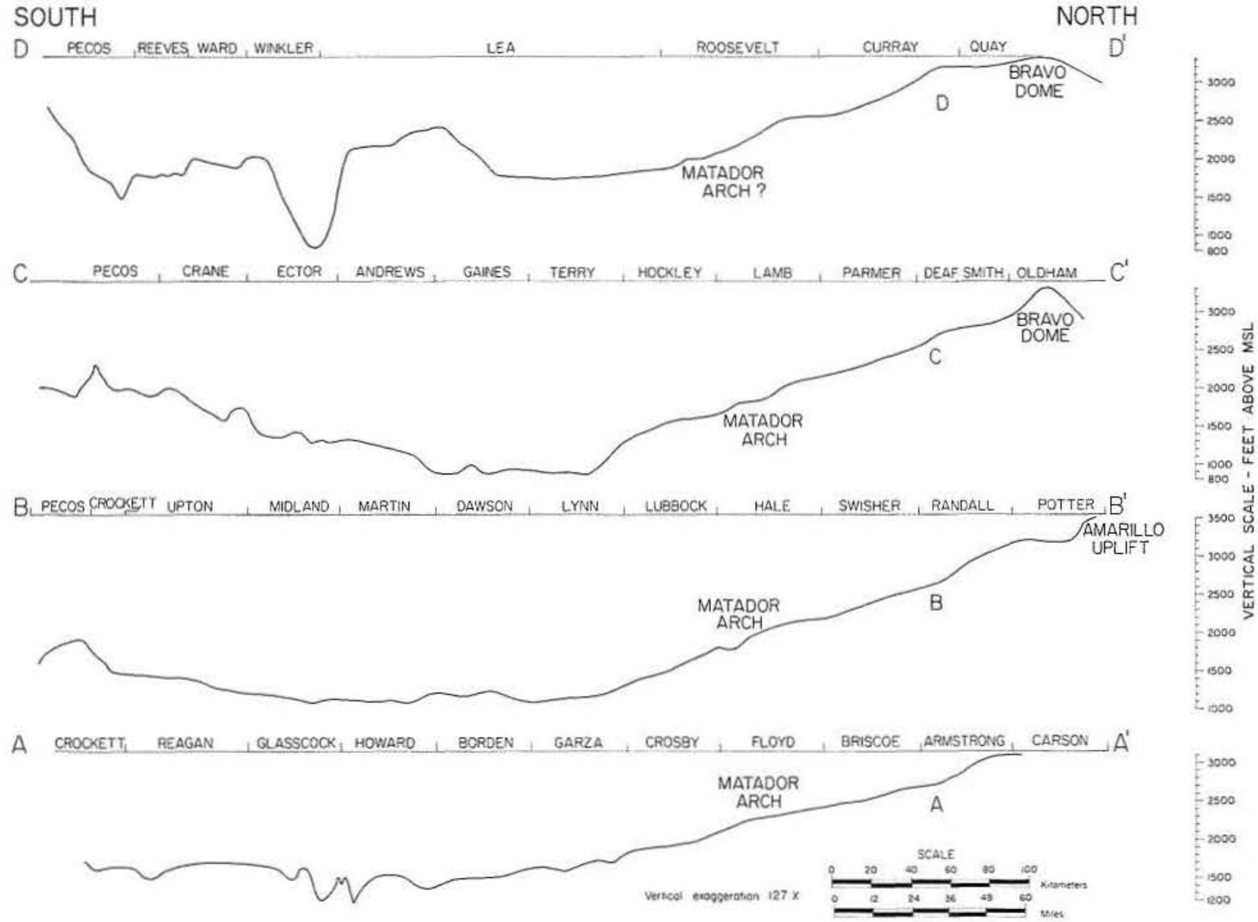


Figure 3. North-south structure profiles across relict Paleozoic structural elements (location of structural profiles shown in figure 2).

During early deposition of the Dockum, alluvial fans and fan deltas were concentrated in the southern and northern parts of the basin. Sediment transport was through braided streams. Meandering streams and high-constructive lobate deltas occupied the east- and west-central parts of the basin because (1) regional slopes were relatively low, (2) former tectonic belts were up to 200 miles away, and (3) total drainage area was large. Pluvial and arid conditions alternated throughout most of the Late Triassic. In Texas, rainfall and vegetation cover were probably greatest in uplands to the east and southeast. Rainfall and vegetation probably decreased to the west. Delta plains were almost barren, and vegetation was probably restricted to narrow bands adjacent to streams. Climate and depositional environments of the Dockum are inferred to have been similar to those of the present Omo Delta (Butzer, 1971).

Lake area and water depth fluctuated with changes in climate and sedimentation rates. Lake level was highest and most stable during pluvial periods. Maximum depth in the outcrop area, based on thicknesses of progradational sequences, was about 30 feet.

During arid cycles, base level dropped, valleys were scoured, and lake size decreased. Most of the meandering streams ceased to function at this time, and local braided streams became the dominant type of fluvial system. Rapid construction of small fan deltas occurred where these braided streams debouched from the eroded valleys into small lakes. Many of these fan deltas were reworked by succeeding floods. Consequently, fan deltas were constructed from debris eroded (cannibalized) from older Triassic deposits.

Interpretation that the Dockum Group was deposited as a complex of fluvial-deltaic-lacustrine systems has drawn on studies of Modern open and closed lakes (Bonython and Mason, 1953; Gould, 1960; Langbein, 1961; Gottschalk, 1964), Modern lacustrine deltas (Axelsson, 1967; Butzer, 1971; Born, 1972; Pezzetta, 1973), ancient lacustrine deltas (Butzer and others, 1969; Born, 1972; Lentz, 1975), Modern and ancient oceanic deltas (Fisher and others, 1969), Modern fan deltas (McGowen, 1971a), and Modern fluvial deposits (Ore, 1964; Bernard and others, 1970; McGowen and Garner, 1970; Smith, 1970; Church, 1972; Levey, 1976). The Dockum Group exhibits elements common to most of the above-mentioned systems. There is no existing single model that describes the variety of Dockum depositional systems.

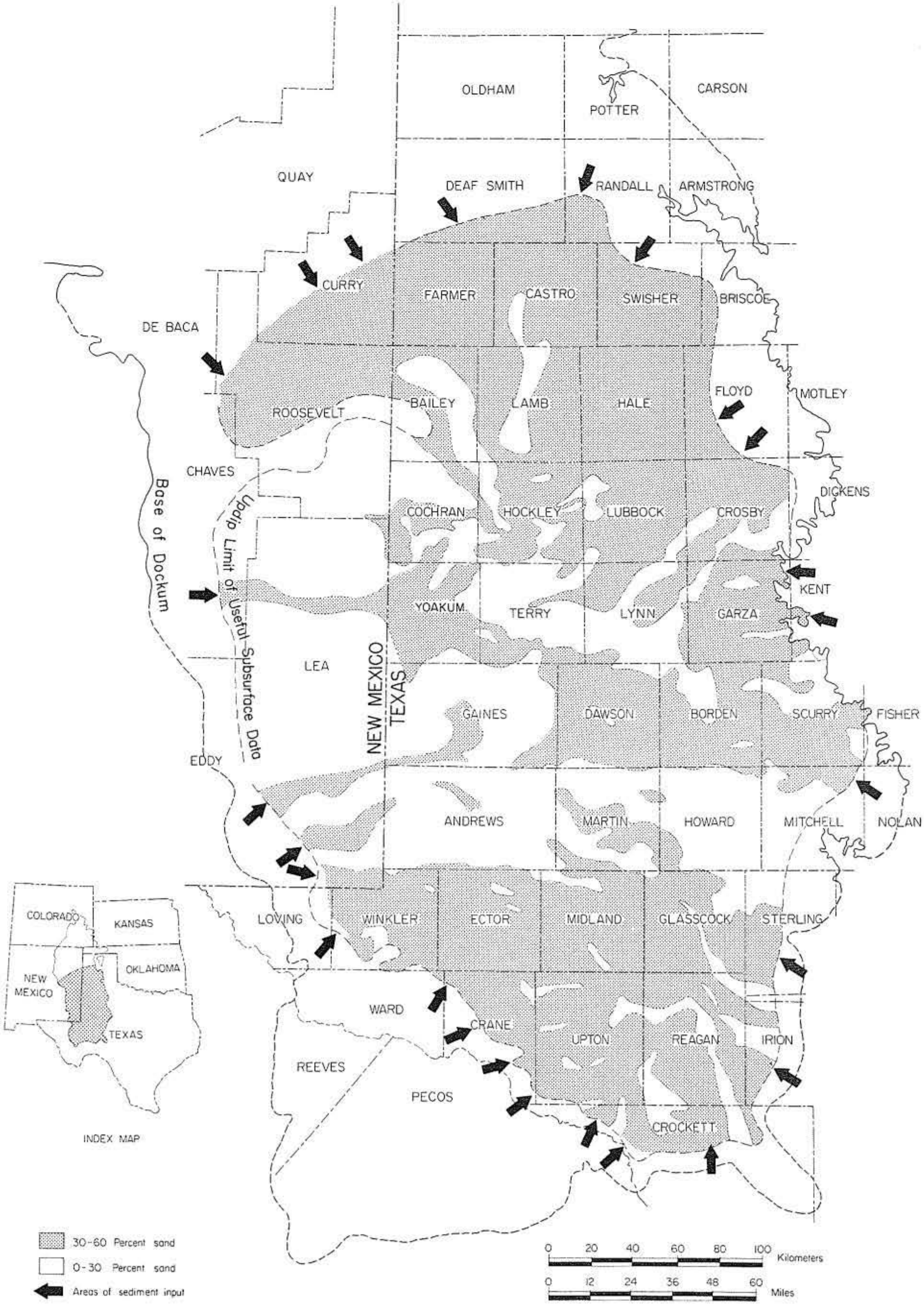


Figure 4. Generalized sandstone trends for the lower half of the Dockum Group in Texas and New Mexico, and inferred direction of sediment input.

DISTRIBUTION OF MAJOR DEPOSITIONAL ELEMENTS

Outcrop studies in the east-central part of the basin, supplemented by subsurface data, indicate that meandering streams and distributary deltas were dominant in Dickens, Crosby, Kent, Garza, Scurry, Mitchell, Sterling, Howard, Martin, Dawson, and Borden Counties, Texas. Log character and sand-percentage patterns (fig. 6) mapped in the west-central part of the basin (Chaves and Lea Counties, New Mexico, and Andrews, Gaines, Yoakum, Terry, Cochran, and Hockley Counties, Texas) suggest that similar depositional environments existed throughout that part of the basin. Log character and distribution patterns of the predominantly sand sequences south of Sterling, Glasscock, Midland, Ector, and Winkler Counties, Texas, are interpreted as representing coalescing fan deltas.

Fan or fan-delta facies are not exposed in the southern part of the basin. In the Glass Mountains, south of the Dockum basin, however, there is a complex of Triassic limestone and chert conglomerate, sandstone, reddish-brown mudstone, and thin limestone and dolomite beds that composes the Bissett Formation (King, 1930; 1935; 1937). Vertebrate and plant fossils indicate that the Bissett is older than the Dockum. Vertebrate and plant fossils from the Bissett Conglomerate were studied by Case and Read (King, 1935). According to Case, who studied the vertebrates, the formation could not be either Permian or Cretaceous. Read, who studied the flora, reported that all species are early Mesozoic types and that there are no elements of a Permian flora in the Bissett collections. According to Read, the Bissett flora is older than the flora in the Dockum localities farther north. King (1935)

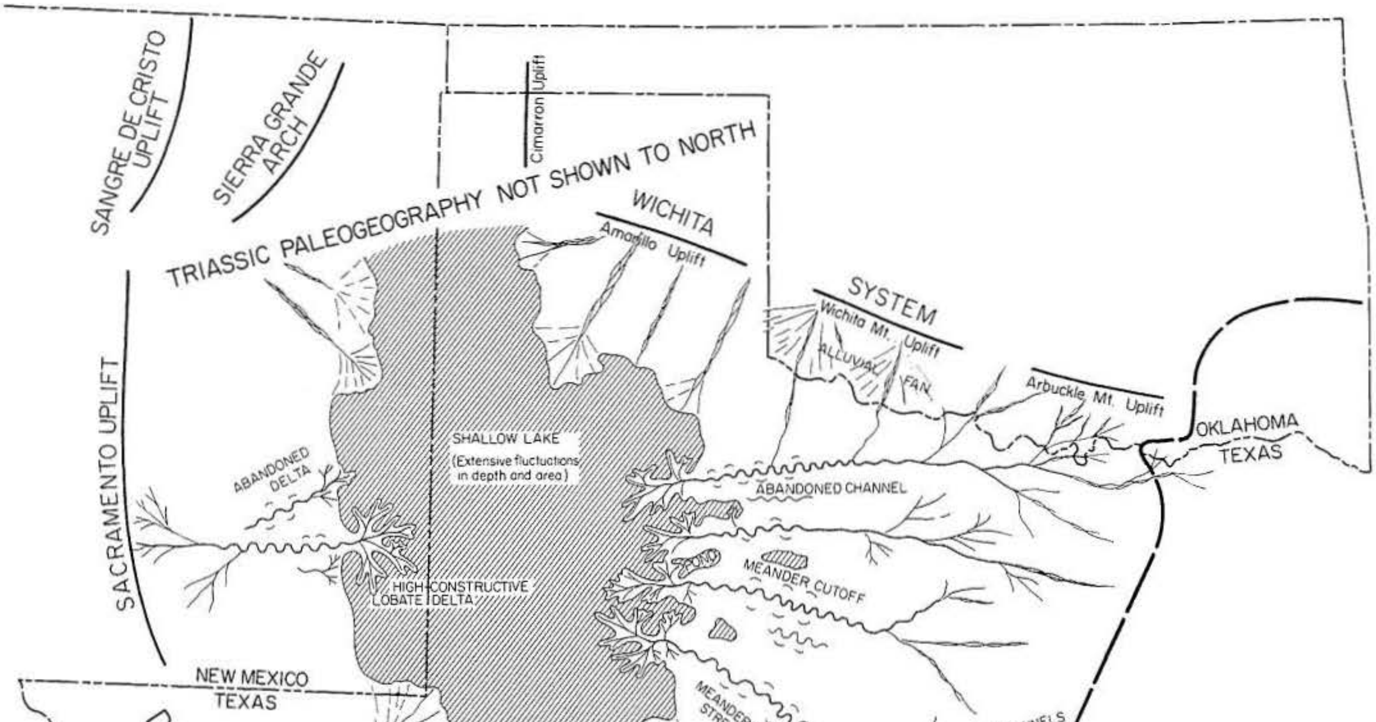


Figure 5. Inferred paleogeography during the initial stage of Dockum sedimentation in the area south of Amarillo Uplift - Bravo Dome. Depositional elements are braided streams, alluvial fans, fan deltas, meandering streams, distributary deltas, and shallow lakes.

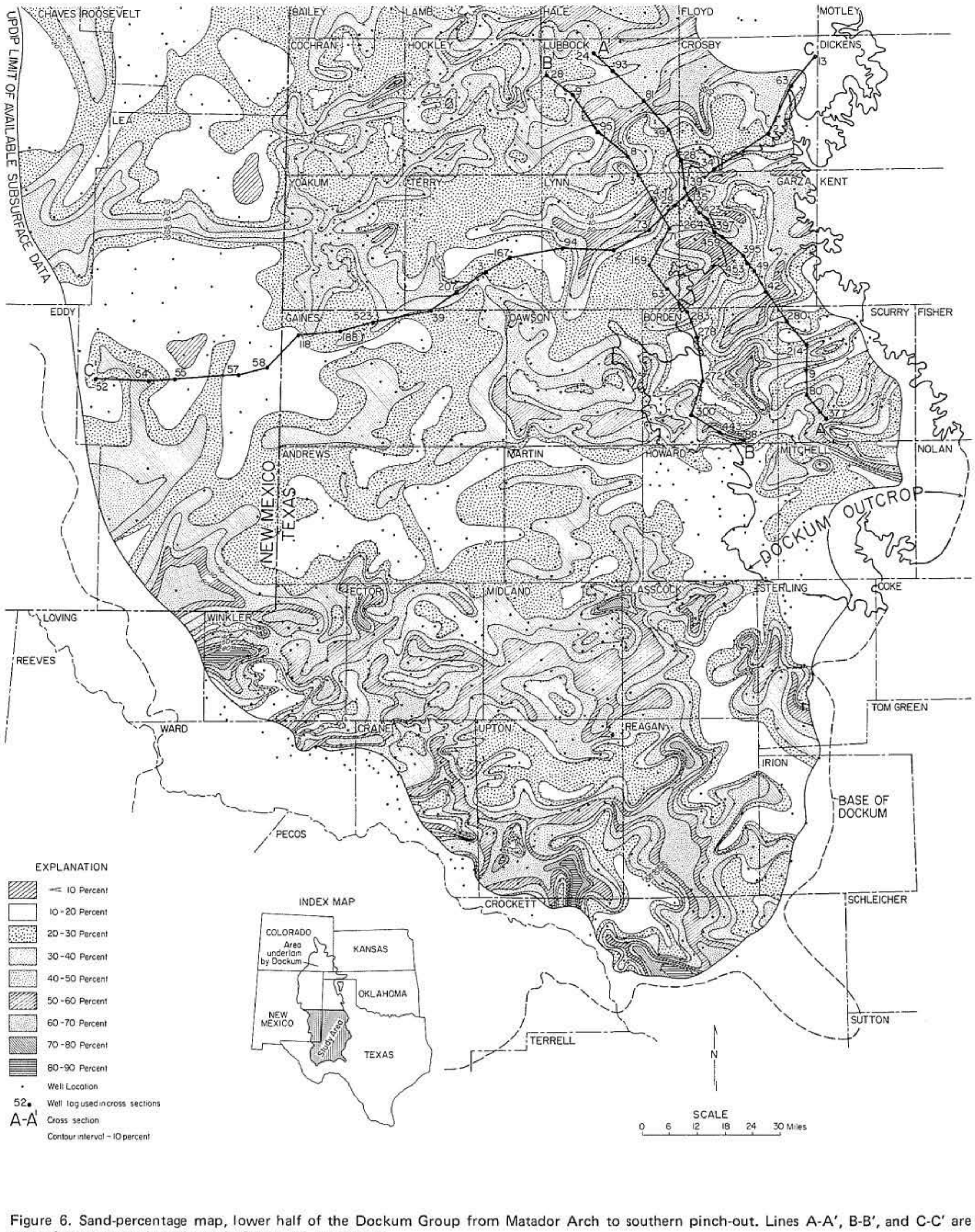


Figure 6. Sand-percentage map, lower half of the Dockum Group from Matador Arch to southern pinch-out. Lines A-A', B-B', and C-C' are subsurface cross sections shown in figures 34, 35, and 36.

concluded that physical and paleontological evidence favor an Early Triassic age for the Bissett. The Bissett Formation records initial Triassic alluvial fan and fan-delta sedimentation immediately north of the Ouachita Tectonic Belt.

The predominantly sand section north of the Ouachita Foldbelt, shown by various sandstone maps, is interpreted as coalescing fan-delta deposits. Thick-sandstone trends displayed on net-sandstone maps (fig. 4) and reconnaissance outcrop studies indicate that fan deltas also represent initial depositional systems along the northern part of the basin from Motley County, Texas, northwest along the Canadian River Valley to Quay, Guadalupe, and De Baca Counties, New Mexico.

SANTA ROSA AREA

Lupe (1977) reports that the Santa Rosa Sandstone in the vicinity of Santa Rosa, New Mexico, accumulated in braided-stream, floodplain, and lake environments. Four

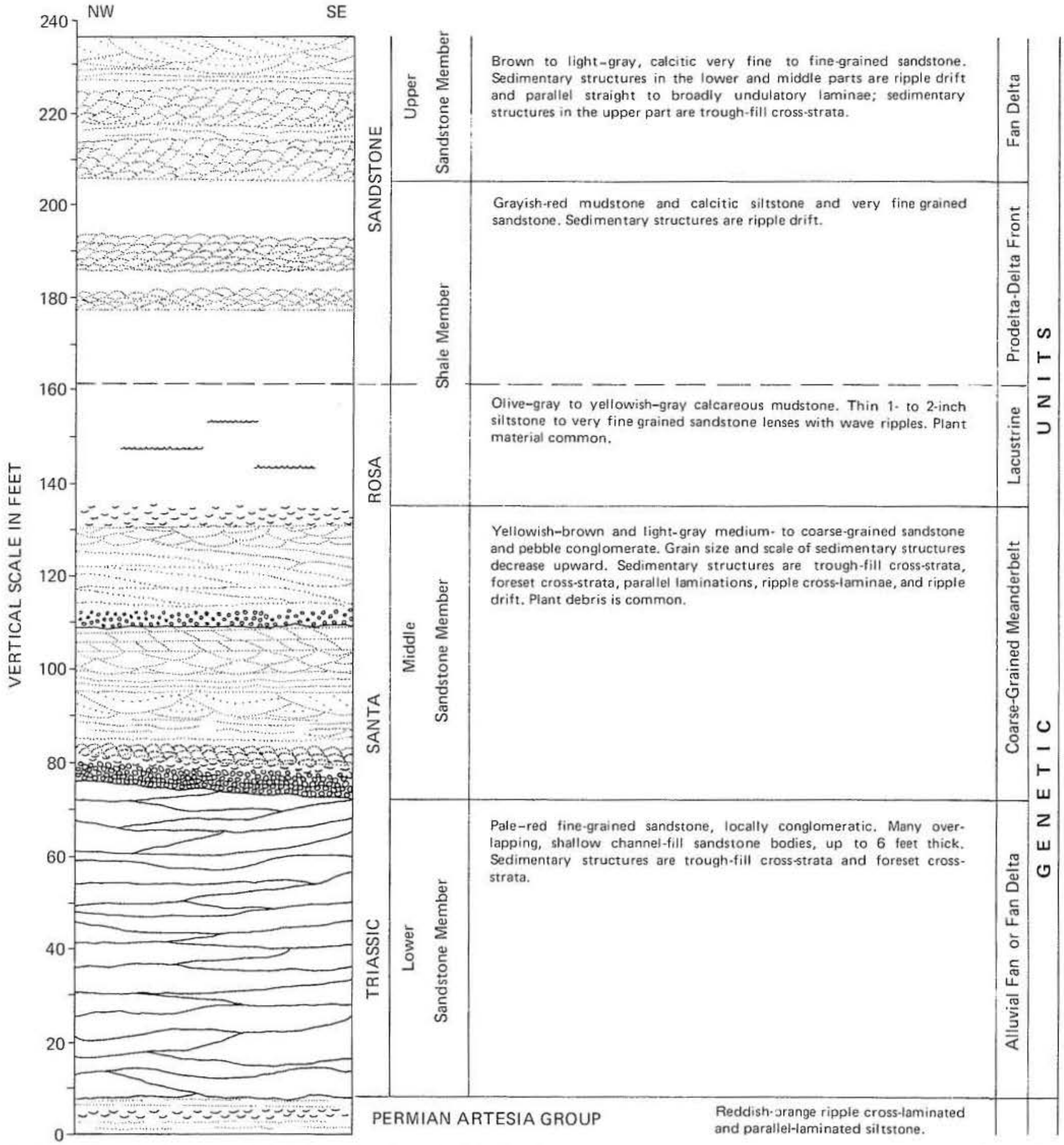


Figure 7. Generalized section of Santa Rosa Sandstone (principal reference section of Finch and Wright, 1975) Guadalupe County, New Mexico. Informal stratigraphic units after Finch and Wright. Refer to figures 10, 13, and 14 for explanation of sedimentary structure.

members of the Santa Rosa Formation (fig. 7), which were defined by Finch and Wright (1975), are genetic as well as descriptive (Lupe, 1977) and include in ascending order (1) lower sandstone, (2) middle sandstone, (3) shale, and (4) upper sandstone members.

A lower sandstone member, comprising medium-grained sandstone and some intrabasinal conglomerate (fig. 7), is characterized by numerous, overlapping, thin, relatively broad, channel-fill sandstone bodies. Channel fill is composed of 2 to 6 feet of trough-fill and foreset cross-strata. The lower sandstone is inferred to be either an alluvial fan or a fan-delta system. An unconformity separates the lower and middle sandstone members.

A middle sandstone member, interpreted as a coarse-grained meanderbelt sequence (McGowen and Garner, 1970; Levey, 1976), records multiple-channel migrations, and the basal 10 to 15 feet is composed of channel-lag conglomerate and abandoned channel fill consisting of very fine sandstone and siltstone. A complete vertical sequence, from scour pool through upper point-bar facies, is preserved at the top of the middle sandstone member. The sequence is approximately 40 feet thick and consists of (1) about 5 feet of conglomeratic medium-grained sandstone exhibiting large-scale trough-fill cross-strata, (2) from 4 to 6 feet of parallel-laminated medium-grained sandstone containing some large-scale trough-fill cross-strata, (3) approximately 20 feet of moderately well sorted medium-grained sandstone comprising small trough-fill cross-strata, and (4) about 5 feet of ripple cross-laminated fine- to medium-grained sandstone in 1-inch to 1-foot beds.

A shale member overlies the middle sandstone member. The lower 25 feet of the shale member is composed of olive-gray lacustrine claystone containing plant material, and siltstone and sandstone lenses. Wave ripples and wave-dominated combined-flow ripples (Harms, 1969) occur on bedding surfaces. The upper 45 feet of this unit is grayish-red prodelta mudstone that grades upward into distal delta-front siltstone and very fine grained sandstone. The uppermost 10 to 15 feet comprise alternating mudstone and ripple-drift siltstone and very fine grained sandstone.

A sequence through the upper sandstone member is composed of (1) 20 feet of basal ripple drift, horizontal and broadly undulatory laminated very fine grained to fine-grained sandstone and (2) 10 feet of superposed trough-fill cross-stratified, fine- to medium-grained sandstone. The uppermost sandstone member is representative of proximal fan-delta facies.

CANADIAN RIVER VALLEY

Sandstones in the lower part of the Dockum Group in parts of the Canadian River Valley and Palo Duro Canyon resemble the Santa Rosa section. However, the New Mexico and Texas sections differ principally in grain size and composition. Sandstone exposed in Palo Duro Canyon is mostly fine-grained feldspathic litharenite. The Santa Rosa Sandstone is composed mostly of fine- to coarse-grained quartz arenites (sandstone classification after Folk, 1974).

A basal Dockum mudstone sequence in the Canadian River Valley was not investigated. Dockum sandstones, west of Tascosa (south of the Canadian River), however, were studied. Sandstone sequences consist of overlapping, broad sandstone bodies from 10 to 30 feet thick (fig. 8). Some of these sandstone bodies are convex upward. Lateral margins of sandstone bodies are interbedded with mudstone and siltstone and are characterized by low-angle foresets. Dominant sandstone stratification is parallel horizontal or parallel inclined laminae; trough-fill cross-stratification represents a minor type. Thin channel-fill deposits (from 2 to 5 feet thick) occur locally within these sandstone sequences. Channel fill comprises fine-grained sandstone consisting chiefly of trough-fill cross-strata, some ripple cross-laminae (small-scale trough-fill cross-strata of Harms and Fahnestock, 1965), and mud drapes.

Reddish-brown mudstone and siltstone that underlie and interfinger with sandstone units record multiple depositional events (fig. 8). Most of these sedimentary sequences begin with coarse-grained siltstone or fine-grained sandstone characterized by parallel-laminated or massive mudstone. Soft-sediment deformation is common to this facies.

Straight channels up to 40 feet deep were scoured through sandstone bodies into underlying siltstone and mudstone (fig. 9). Channel fill is the product of multiple scour-and-fill episodes. Symmetrical and asymmetrical channel-fill deposits indicate that currents locally flowed both parallel and oblique to channel axes. Textural types composing the channel fill are (1) intrabasinal conglomerate (clasts were derived from older Dockum deposits) made up of sandstone, siltstone, mudstone, and caliche fragments; (2) sandstone comprising a mixture of quartz and sedimentary rock fragments; (3) siltstone that consists primarily of quartz; and (4) mudstone.

Stratification of channel fill comprises foreset cross-strata, trough-fill cross-strata, parallel laminae, ripple drift, and ripple cross-laminae. Foreset cross-stratified granule to pebble conglomerate is mostly confined near channel banks; foresets dip toward channel axes. Trough-fill cross-strata generally occur in conglomerate and sandstone that are confined to lower parts of the channel fill. The most common stratification type of the lower channel fill is parallel-laminated and ripple cross-laminated siltstone and very fine grained sandstone that conform to the channel perimeter; these deposits are ubiquitous. Some foreset cross-strata adjacent to channel flanks grade into parallel-laminated and ripple cross-laminated siltstone and sandstone sequences toward the deeper parts of the channel. As a general rule, coarser sediment accumulated along channel banks; and finer sediment, near channel axes. Major flood events are recorded by intrabasinal conglomerate and coarse-grained sandstone that exhibit a predominance of foreset cross-strata. Fine-grained sandstone and coarse siltstone, the sedimentary structures of which are parallel laminae, ripple cross-laminae, and soft-sediment deformation, accumulated either during low-flow conditions associated with a major flood or during lesser floods when depth of flow was shallow.

Lower Dockum strata near Tascosa in the Canadian River Valley are interpreted as a lacustrine fan-delta couple. Mudstone and siltstone accumulated in lacustrine and fan-delta, delta-front environments. Sandstones were deposited on fan-delta plains (McGowen, 1971a, 1971b;

McGowen and Scott, 1974). Channels were scoured and filled when the lake level was lowered.

PALO DURO CANYON AREA

From 300 to 400 feet of Dockum strata is exposed in Palo Duro Canyon. Reconnaissance studies indicate a complex depositional and erosional history for the Dockum Group in this area. The contact between Permian and Triassic strata is unconformable. A soil zone occurs locally at the base of the Dockum (Finch, personal communication, 1975). The soil is overlain by lacustrine mudstone facies and a complex of delta foresets and conglomerate-filled channels (fig. 10, units 2 through 8).

Delta foreset beds are similar to those reported by Gilbert (1890) for Pleistocene deltas in Lake Bonneville. Foresets are composed of (1) massive mudstone, (2) siltstone containing parallel inclined laminae and ripple cross-laminae, (3) siltstone and very fine grained sandstone that exhibit burrow-fill and penecontemporaneous deformation, and (4) lenses of intrabasinal conglomerate. Intrabasinal conglomerate consists of clasts derived from within the basin by erosion of older Dockum deposits. Clasts were eroded from mudstone, siltstone, sandstone, and caliche-bearing units. Foreset beds are not components of all fan deltas. Fan deltas constructed of very fine grained to fine-grained sand, which accumulated in extremely shallow water, did not develop foresets. This mudstone-conglom-

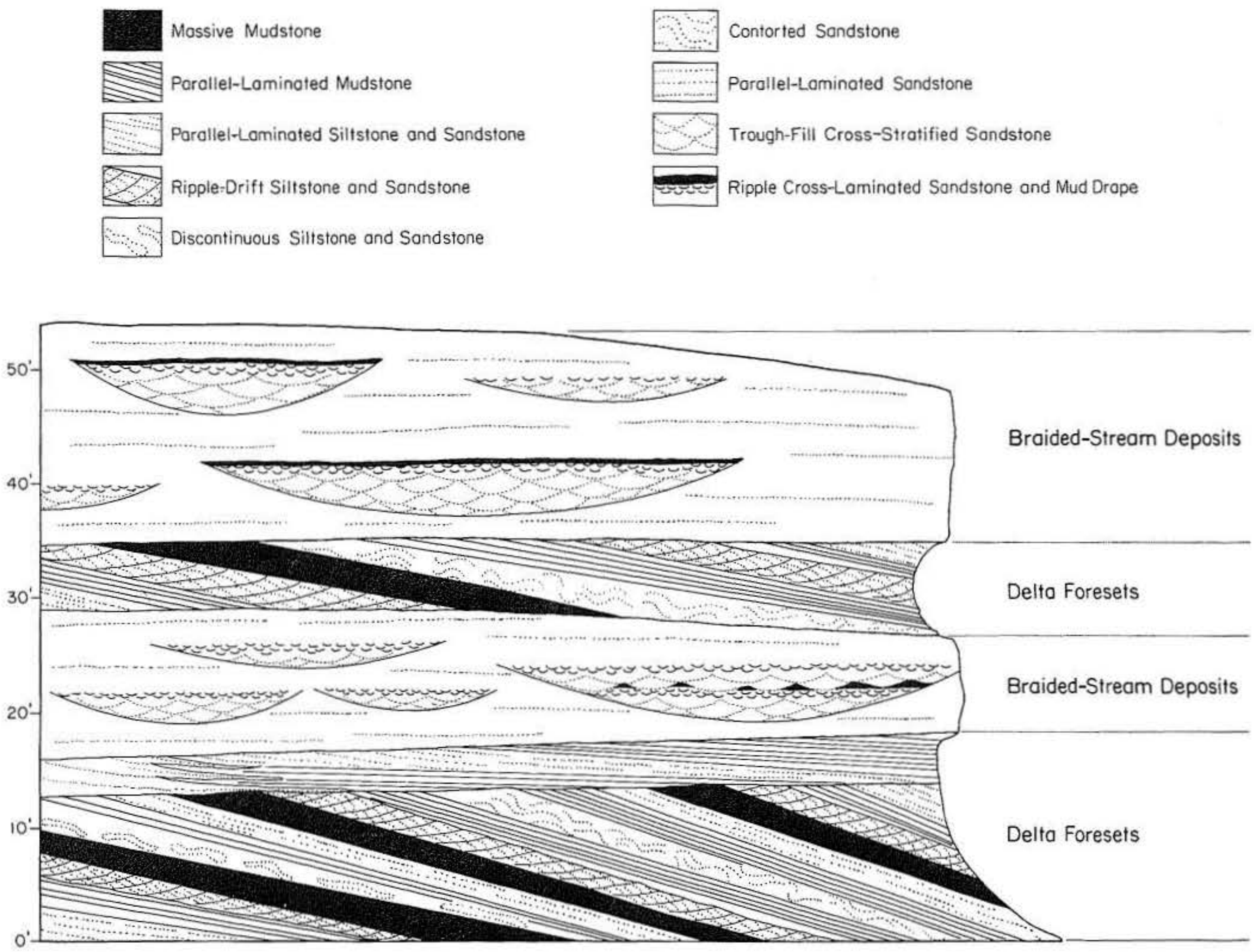


Figure 8. Schematic of fan-delta deposits in Oldham County, Texas (Boys Ranch 7.5-minute quadrangle), along right bank of Canadian River, west of U. S. Route 385 and south of Fort Worth and Denver Railroad. Shown here are (1) delta foresets consisting of (a) massive and parallel-laminated mudstone, (b) parallel-laminated siltstone and sandstone, (c) ripple-drift sandstone and siltstone, (d) discontinuous siltstone and sandstone (pull-aparts), and (e) contorted sandstone (penecontemporaneous deformation) and (2) braided-stream deposits consisting of (a) parallel-laminated fine sandstone, and (b) trough-fill cross-stratified and ripple cross-laminated fine sandstone with mud drapes confined to shallow braided channels. Braided-stream deposits comprise a fan-delta plain analogous to the Modern Gum Hollow fan delta (McGowen, 1971a).

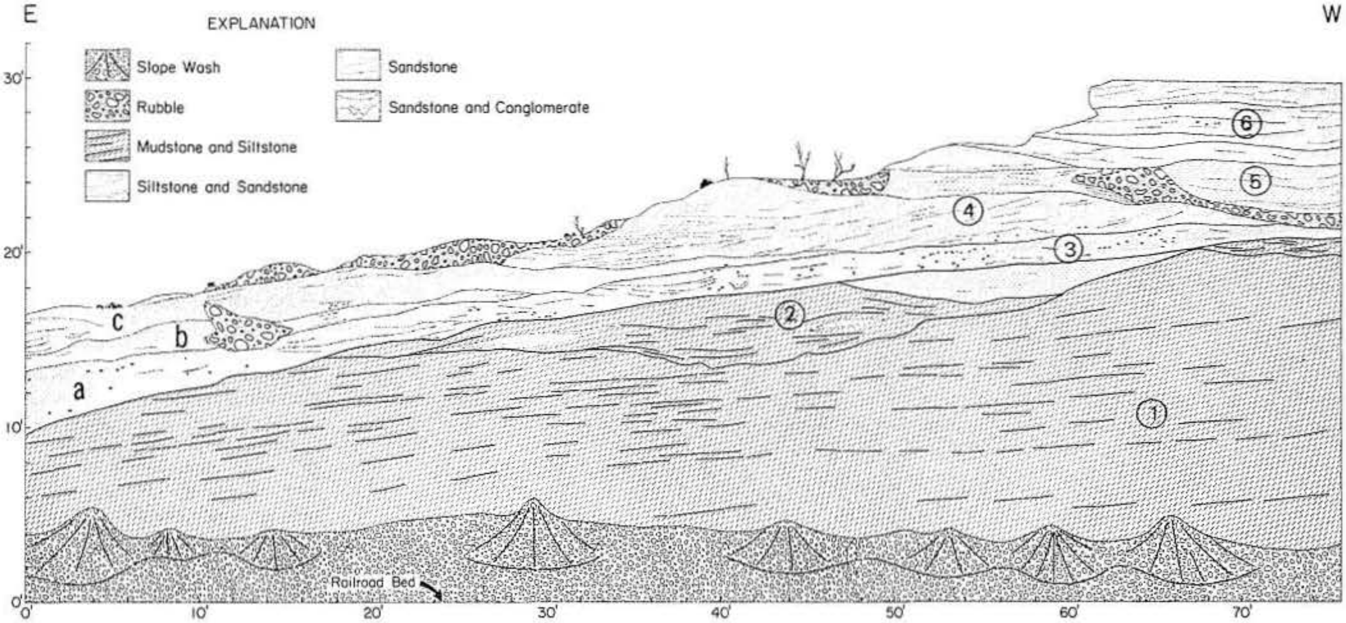


Figure 9. Sketch (made from a photomosaic) of part of a valley-fill sequence in Oldham County, Texas (Boys Ranch West 7.5-minute quadrangle), along a railroad cut west of U. S. Route 385. At this locality approximately 40 feet of Dockum deposits was removed by headwardly eroding streams. The sketch shows about 24 feet of sediment that accumulated near the west margin of the valley. The base of the sequence lies north of the railroad and consists of some 15 feet of granule intrabasinal conglomerate and conglomeratic fine sandstone; sedimentary features are massive conglomerate, and parallel laminae, trough-fill cross-strata, and low-angle foreset cross-strata in sandstones. Valley-fill deposits, shown in the sketch consist (in ascending order) of the following components: (1) Reddish-brown and greenish-light-gray sandstone, siltstone, and claystone; predominantly reddish-brown. Resistant units are greenish-light-gray, calcitic, very fine sandstone and coarse siltstone. Calcitic sandstone and siltstone consist mostly of quartz; these beds are about 3 to 7 inches thick, and are ripple cross-laminated (apparent transport direction S-SW). Reddish-brown, coarse siltstone to fine sandstone consists almost entirely of mudclasts; these beds are about 4 to 6 inches thick; sedimentary structures are parallel laminae, ripple cross-laminae, ripple drift, and soft-sediment deformation; (apparent transport direction was S-SW). Reddish-brown mudstone and claystone units are about 2 to 4 inches thick; they are either massive or parallel laminated. Depositional events are recorded by ripple cross-laminated, calcitic sandstone or siltstone, followed by parallel-laminated or ripple cross-laminated, reddish-brown sandstone or siltstone, and may be terminated with reddish-brown mudstone or claystone. (2) Greenish-gray to brownish-gray, conglomeratic, fine sandstone and coarse siltstone; granule-sized conglomerate at the base; granule- and sand-sized clasts were mostly derived from mudstones. Sedimentary structures are parallel laminae, ripple cross-laminae, and soft-sediment deformation. Parallel laminae conform to the channel bottom. (3) Greenish-gray and light-brown (brown surficial strain) conglomerate, conglomeratic sandstone, sandstone, and siltstone. (a) Predominantly calcitic, pebble, intrabasinal conglomerate; clasts comprise caliche, sandstone, siltstone, and mudstone. Massive and parallel inclined bedded with minor trough-fill cross-strata and soft-sediment deformation. To the east (beyond the limits of the photographic overlay) conglomerate contains thin layers of parallel-laminated, iron-cemented, fine-grained sandstone. (b) Alternating iron-cemented, coarse siltstone to very fine sandstone, and calcitic, granule, intrabasinal conglomerate. Conglomerate units are 0.5 to 1 inch thick. Siltstone and sandstone comprise 1-inch to 1.5-foot parallel-laminated and ripple cross-laminated units. (c) Intrabasinal granule conglomerate and coarse sandstone; unit fines upward. Massive and trough-fill cross-stratified at the base, becoming parallel laminated toward the top. (4) Light-brown, slightly calcitic, muscovitic, coarse siltstone, and very fine sandstone. Sedimentary structures are parallel (horizontal) and parallel inclined laminae; sedimentation units are 0.12 to 0.25 inch thick. (5) Light-brown with greenish-light-gray patches, slightly calcitic, coarse siltstone to very fine sandstone; clasts consist of quartz and mudstone. Sedimentary structures are ripple cross-laminae, ripple drift, and parallel laminae. From a distance ripple drift, to the west, gives a false impression of foreset cross-strata. (6) Eight units (not all are shown in this figure) make up sedimentary sequence 6. Because of the relatively high angle between the camera and sedimentary sequence 6, not all units are shown, and the thicknesses of the units that are depicted in this figure are less than true thickness. (a) A few inches to 0.5 foot. Yellowish-light-brown, calcitic intrabasinal granule conglomerate. Sedimentary structures are parallel laminae and trough-fill cross-strata; apparent transport direction was north. (b) 1.5 to 3.5 feet of reddish-brown, highly micaceous, very fine sandstone, clayey siltstone, and mudstone. West part of the unit comprises oversteepened foresets (dip angle about 60°, apparent dip direction S-SW). East part of unit consists of slightly calcitic, very fine sandstone; sedimentary structures are ripple drift with apparent migration to the west; east part of the unit was eroded, prior to deposition of west part of unit, and exhibits slump adjacent to channel margin. (c) A few inches to about 2 feet of light-brown, slightly calcitic, very fine sandstone; grains are quartz and mudclasts; contains a few reddish-brown, cobble-sized mudclasts that are elongate parallel to bedding. Sedimentary structures are predominantly parallel laminae; upper 2 to 6 inches are ripple cross-laminae, some of which have been deformed by soft-sediment movement. (d) A few inches to 1 foot of brown, clayey siltstone. Massive with parallel inclined laminae at the top of the thicker part of the unit. (e) 1 foot of grayish-green, slightly calcitic, micaceous, very fine sandstone. Sedimentary structures are ripple cross-laminae (apparent migration was W-SW), and shallow washouts (0.3 foot deep by 5 feet wide) that are filled with parallel laminae and ripple cross-laminae. (f) Lower 5 inches comprises greenish-gray, massive, calcitic, very fine sandstone. Upper 7 inches consists of greenish-gray, massive, calcitic, sandy pebble conglomerate; clasts are mostly caliche; other clasts are siltstone and mudstone. (g) 0.5 to 1 foot of olive-green, massive, friable, sandy, granule to pebble intrabasinal conglomerate (clasts were derived from mudstone). Carbonized plant debris is locally abundant. (h) 5 feet of greenish-gray, slightly calcitic, highly micaceous, fine sandstone. Sedimentary structures are mostly parallel inclined laminae; small trough-fill cross-strata and foreset cross-strata are present.

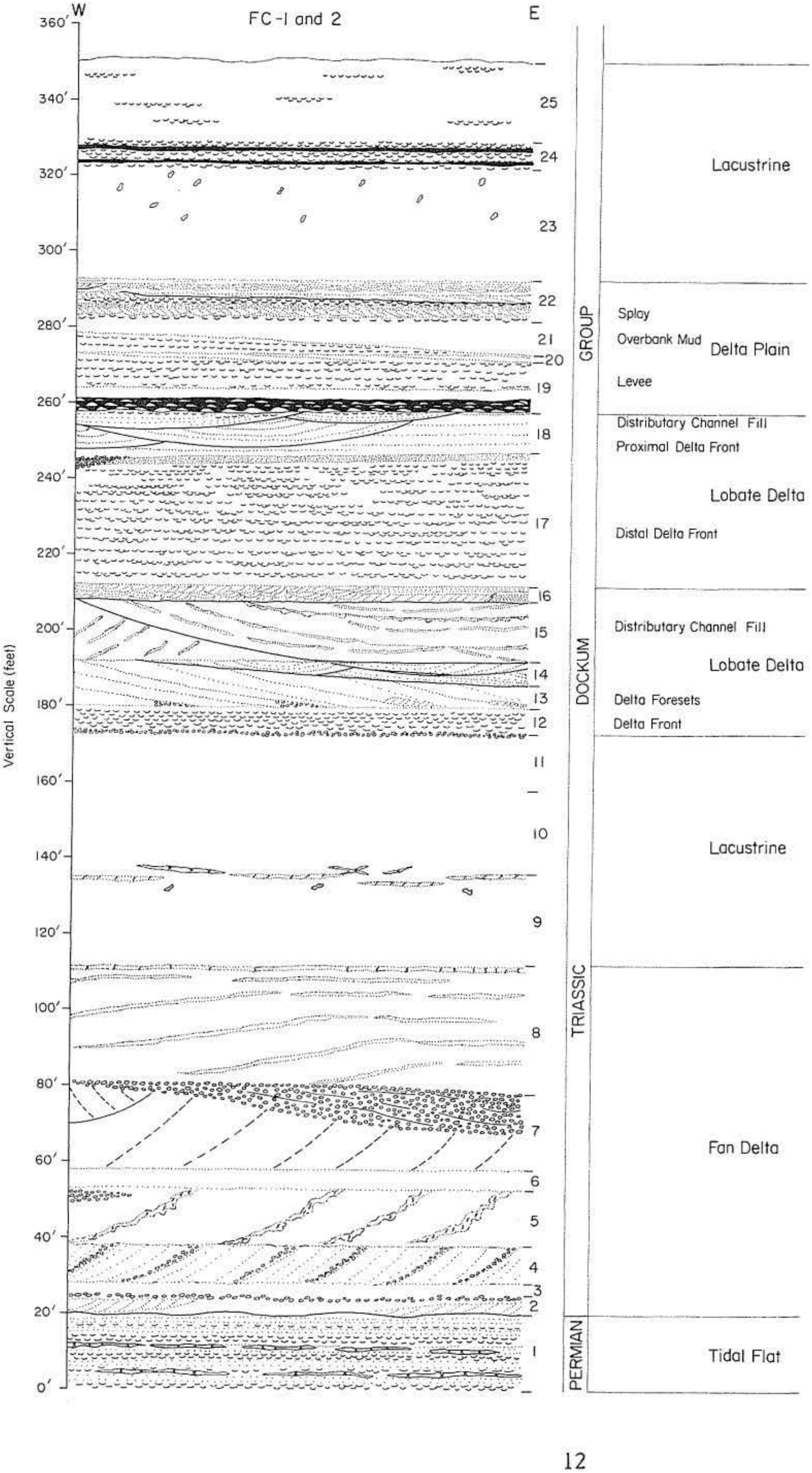


Figure 10. Composite section near east end of Palo Duro Canyon State Park, north of turnaround at east end of park (Fortress Cliff 7.5-minute quadrangle). Unit 1 is Permian Quartermaster Formation: *tidal-flat deposits*; thin beds of ripple cross-laminated coarse red siltstone and very fine sandstone with satinspar. Units 2 through 11 are probably equivalent to Tecovas Formation, Dockum Group, and units 12 through 25 are probably equivalent to Trujillo Formation, Dockum Group. Units 2 through 8 are *fan-delta facies* comprising conglomerate, sandstone, siltstone, and mudstone foresets (units 2 through 6); channel-fill conglomerate (unit 7); and uppermost mudstone and siltstone foresets whose dips decrease upward; intensively burrowed siltstone at top (unit 8). *Lacustrine deposits* (units 9 through 11) consist of thick, massive, yellow, medium-gray, reddish-brown, and purple mudstone with lenses of impure silty dolomite and satinspar veins. Two *progradational deltaic sequences* are defined by lower units 12 through 16, and upper units 17 and 18. *Lower progradational sequence* consists of delta-front, light-gray, ripple cross-laminated, very fine sandstone (unit 12); delta foresets, light-gray mudclast bearing very fine sandstone (unit 13); and distributary channel fill, alternating light-gray to greenish-gray very fine sandstone and coarse siltstone and reddish-brown mudstone (units 14 through 16); channels were alternately active and abandoned. *Upper progradational sequence* consists of *delta front*, alternating parallel-laminated reddish-brown clayey siltstone and ripple cross-laminated very fine to fine sandstone; *delta front and distributary channel fill* consist of greenish-gray parallel-laminated fine sandstone, and trough-fill cross-stratified and ripple cross-laminated fine sandstone, respectively. Overbank, delta-plain deposits (units 19 through 22) are greenish-gray parallel-laminated, ripple cross-laminated, and trough-fill cross-stratified siltstone and very fine sandstone; and massive brown, green, yellow, and maroon mudstone. *Lacustrine deposits* (units 23 through 25) that cap sequence are brown and reddish-brown mudstone with lenses of greenish-gray ripple cross-laminated siltstone and very fine sandstone.

erate facies assemblage is interpreted as a lacustrine-deltaic association that developed during initial flooding and sedimentation in the Triassic basin.

Delta-foreset beds are overlain by massive to horizontally bedded mudstone containing lenses of satinspar and burrowed, impure dolomite and limestone. This mudstone sequence probably accumulated from suspension in a shallow ephemeral lake.

Upper sandstone units in Palo Duro Canyon (fig. 10, units 12 through 20) are components of high-constructive lobate delta, meanderbelt, and valley-fill systems (meanderbelt and valley-fill deposits are not shown in fig. 10). Distal delta-front facies are composed of alternating thin beds of mudstone, siltstone, and sandstone. Proximal delta-front and channel-mouth bar sandstone facies are characterized by laterally persistent horizontal beds and parallel inclined laminae. Distributary channels are represented by channel-fill sandstone and abandoned channel-fill mudstone facies. Several sandstone lenses in the upper part of the Palo Duro sequence (fig. 10, units 19 through 22) accumulated in levee and delta-plain environments. Lacustrine mud deposition followed delta abandonment and foundering (fig. 10, units 23 through 25). At least 60 feet of reddish-brown mudstone containing some lenses of ripple cross-laminated siltstone and very fine grained sandstone accumulated following deposition of the upper sandstone. Mud accumulation is representative of delta abandonment, foundering, and inundation by lacustrine waters.

At Wayside Crossing the lower 70 to 80 feet of the Dockum is similar to the lower mudstone (beds 2 through 11, fig. 10) in Palo Duro Canyon State Park. There are some differences, however, particularly in the contact between Permian and Triassic strata, and in the presence of probable paleosols in the lower 10 to 15 feet of the Dockum at Wayside Crossing. The contact between Permian and Triassic in the road cut at Wayside Crossing appears to be gradational. The lower 5 feet or so of Triassic is mottled reddish-brown and purple, clayey siltstone to very fine sandstone that contains relict parallel laminae and ripple cross-laminae. The next 5 to 7 feet of Dockum consists of two massive, mottled purple, yellow, and brown, slightly silicic, very fine sandstones separated by mottled purple, yellow, and gray mudclast breccia. Chert lenses, about 0.06 to 2 inches thick, overlie each of the massive sandstones. There are two possible origins for chert lenses:

1. Chert lenses may have formed in a manner analogous to that of the complex sodium silicate presently forming in Lake Magadii, Kenya (Eugster, 1967, 1969; Eugster and Jones, 1968), and in Alkali Lake, Oregon (Rooney and others, 1969). The complex sodium silicate, magadiite, converts with age to chert.

2. Chert in Dockum may be a silcrete resulting from silica deposition by evapotranspiration from surficial and shallow subsurface waters (Stephens, 1971).

Immediately above the chert horizon there is about 6 feet of alternating purple and greenish-gray mudstone and reddish-brown and light-gray, massive, very well rounded, medium-grained to very coarse grained sandstone; this sequence comprises foresets that have an apparent dip to the south. The next 40 feet or so is covered and is probably predominantly mudstone. Overlying the mudstone section is approximately 85 feet of siltstone, sandstone, and intrabasinal conglomerate. The lower 40 feet or so of this sequence consists of intrabasinal conglomerate channel fill followed by foreset and trough-fill cross-stratified fine- to medium-grained sandstone that grades laterally (southward) into very fine grained sandstone and siltstone consisting of ripple drift and ripple cross-laminae. The sequence is tentatively interpreted as distal fan-delta facies. A period of erosion followed construction of the fan delta. Abandoned channel fill consisting of approximately 15 feet of reddish-brown, ripple cross-laminated siltstone and very fine sandstone indicates this erosion. Stratigraphically above the abandoned channel fill are three symmetrically filled channels; these were inaccessible for description, but they appear to be about 15 to 20 feet thick. Near the south end of the road cut there is a valley-fill sequence (about 45 feet of valley fill was measured; the base is not exposed). This valley was eroded during a lowering of base level coincident with a decrease in lake size. Triassic sandstone boulders accumulated along parts of the valley floor and walls. At least six scour-and-fill events are recorded within the valley-fill sequence. Sand-sized sediment was emplaced by bed-load streams (*bed-load streams* is used synonymously in this report with *braided streams*) during flooding; fine sediment (predominantly mud) accumulated during periods of relative inactivity.

Depositional and erosional history of Triassic strata in Palo Duro Canyon is complex, and the deltaic deposits shown in the upper part of figure 10 are only a part of the sequence. Elsewhere in the canyon, deltaic deposits were locally removed by erosion when base level was lowered. Valleys were incised (for example, at the west end of Palo Duro Canyon State Park, Wayside Crossing, and in Tule Canyon) as much as 200 feet into subjacent Dockum deposits. With a rise in base level, valleys were filled with transgressive fluvial, deltaic, and lacustrine deposits. Similar transgressive sequences from late Cenozoic strata in the Omo Basin have been reported by Butzer and others (1969).

TULE CANYON AREA

Studies by John Boone (Department of Geological Sciences at The University of Texas at Austin) indicate that the Dockum Group in Tule Canyon is approximately 600 feet thick. The lower 400 feet of sediment is interpreted by Boone as having accumulated in a fluvial environment, and the upper 200 feet is interpreted as lacustrine and deltaic facies. One of the thickest valley-fill deposits documented thus far in the Dockum Group occurs in the Tule Canyon area. A northwest-southeast trending valley is about 0.5 mile wide and 200 feet deep. The valley was eroded into older Triassic fluvial deposits and is filled mostly with intrabasinal conglomerate. The valley fill is overlain by a meanderbelt sequence, which is succeeded upward by deltaic facies.

SILVERTON-DICKENS AREA

Sand deposition was almost continuous from Late Permian through Late Triassic time from an area east of Silverton (Briscoe County) southward through Motley County. East of Silverton, in a road cut along State Highway 256, approximately 45 feet of Permian strata was measured. Here, the Permian comprises reddish-brown mudstone, siltstone, and very fine sandstone (predominantly sandstone) that accumulated in shallow, meandering tidal channels (channels were 5 to 15 feet deep, based on thicknesses of preserved channel-fill deposits). Where complete channel sequences are preserved, the deposits exhibit fining-upward textural and sedimentary structural trends. Basal channel fill comprises trough-fill and foreset cross-stratified sandstone, followed by parallel horizontal and parallel inclined (some are wedge sets) sandstone and siltstone laminae. An uppermost mudstone-siltstone sequence consists of combined-flow ripples with flasers and parallel laminae.

An abrupt change occurs in sandstone texture and composition and in depositional style between the Permian and Triassic. Overlying the Permian is approximately 35 feet of brown and greenish-gray, friable to slightly calcitic, poorly sorted, conglomeratic, angular to very well rounded, fine to very coarse Triassic sandstone. Gravel-sized clasts comprise granule to pebble chert, quartz, and quartzite. Depositional packages average 7 feet thick and consist mostly of two stratification types—trough-fill and foreset cross-strata. Basal parts of some sequences are massive, and upper parts of some sequences consist of parallel inclined laminae; soft-sediment deformation is common. This part of the Dockum was deposited by bed-load streams. There is slight erosional relief along the upper surface of the lowermost Dockum.

Approximately 30 feet of sandstone, muddy sandstone, mudstone, and chert overlies the braided-stream deposits; a massive chert bed a few inches to more than 3 feet thick caps these deposits. The lower 18 to 20 feet consists primarily of reddish-brown and greenish-gray, poorly sorted, angular to very well rounded, fine- to medium-grained sandstone with local occurrences of granule- to pebble-sized chert, quartz, and quartzite. Sedimentary structures are predominantly foreset cross-strata that range in thickness from a few inches to about 6 feet; some of these units wedge out into massive or parallel-laminated muddy sandstone. The upper 10 feet or so of this sedimentary sequence consists of mottled purple, reddish-brown, and greenish-gray mudstone and fine- to medium-grained sandstone. Primary sedimentary structures are poorly preserved; they have been partly obliterated by vertical reduction zones. Some sandstone lenses are foreset cross-stratified; others are highly convoluted, resulting from soft-sediment deformation. A few inches to more than 3 feet of bluish-white, very light gray, and pinkish-gray, massive chert forms the top of this sequence. Locally, chert contains very well rounded, medium sand-sized quartz grains. Chert grades westward into massive, friable to silica-cemented, fine- to medium-grained sandstone; sandstone appears to be a paleosol.

The chert horizon is succeeded upward by approximately 45 feet of reddish-brown claystone, mudstone, and siltstone, and greenish-gray (locally conglomeratic), very fine grained to medium-grained sandstone. Two sandstone bodies occupy this interval. The lower sandstone is a few inches to about 8 feet thick, and the upper one is up to 25 feet thick. Reddish-brown claystone to siltstone underlies each sandstone. The lower sandstone body grades eastward into siltstone and very fine sandstone foresets (apparent dip to the east), which pinch out into brown and reddish-brown mudstone. Sandstones are products of a braided-stream process, whereas claystones, mudstones, and siltstones accumulated in a lacustrine environment. The uppermost sandstone of this sequence was removed, to the east, by erosion that cut downward to within a few feet of the paleosol. Erosion created a valley; at least 50 feet of valley-fill deposits is exposed in the road cut.

Few well-exposed outcrops of the Dockum Group occur between Silverton and Dickens Counties. The basal part of the Dockum in parts of Floyd and Motley Counties is composed of chert and quartz granule to pebble conglomerate. Vertical sequences of sedimentary structures suggest that the basal Dockum may be a coarse-grained meander-belt system (McGowen and Garner, 1970; Levey, 1976). Uppermost exposures of Triassic strata in eastern Floyd County are characterized by braided-stream deposits that grade westward into delta foresets composed of alternating mudstone and sandstone. Rocks that underlie braided-stream deposits are, in ascending order, (1) massive mudstone that becomes parallel and ripple cross-laminated as silt content increases, (2) siltstone that is parallel laminated, ripple cross-laminated, and locally ripple-drift cross-stratified, and (3) sandstone that exhibits sedimentary structures similar to those in the siltstones. Siltstone and sandstone grade upward into delta foresets. The uppermost sandstone bodies, comprising braided-stream deposits and delta foresets, indicate a general westward progradation.

DICKENS COUNTY TO MITCHELL COUNTY AREA

The Dockum Group changes southward in the vicinity of northern Dickens County. From Dickens County southward through Mitchell County the Dockum contains more mudstone than do equivalent strata to the north. Within the eight-county outcrop belt defined by Dickens County on the north and Mitchell County on the south, the Dockum Group is characterized by cyclic sedimentation. At least five sedimentary cycles, each more than 100 feet thick, have been recognized in four counties (Dickens, Crosby, Kent, and Garza) where detailed field study was carried out.

CYCLIC SEDIMENTATION

Sedimentation in Dickens, Crosby, Kent, and Garza Counties was cyclic. Sedimentation cycles began after accumulation of the basal Dockum, which is a progradational sequence recognizable in outcrop and traceable westward in the subsurface almost to the Texas - New Mexico border. Basal Dockum deposits, which accumulated during expansion of the Dockum lake environment, are characterized upward by a basal lacustrine and deltaic mudstone and siltstone sequence, a middle thin deltaic sequence, and an upper thick fluvial sandstone.

Cyclic deposits that overlie the basal Dockum progradational sequence consist of red beds that grade upward into grayish-green, yellowish-brown, and orange siltstone, sandstone, and conglomerate. Red beds comprise a complex sediment suite ranging in texture from mudstone to cobble conglomerate. Clasts that compose sandstones and conglomerates within the red-bed suite were derived chiefly through erosion and resedimentation of older Dockum deposits; these sediments are termed *intrabasinal* in this report. Siltstones, sandstones, and conglomerates that overlie the red beds were derived mostly from sources outside the depositional basin; these sediments have been labeled *extrabasinal*.

Sediment properties (for example, color, texture, composition, sequences of sedimentary structures, geometry, cross-cutting relationships, and biological constituents) suggest that depositional cycles resulted principally from climatic changes. However, tectonic activity may be the prime factor that triggered climatic fluctuations. It is inferred that most of the red beds accumulated during arid parts of the cycle and that extrabasinal sediments were transported to the Dockum depositional basin when the climate was humid.

HIGH-STAND, HUMID PHASE

Cyclic Dockum sedimentation began when humid climatic conditions developed. Base level was relatively stable during the humid part of a cycle. Sediment was transported to the basin by meandering streams (fig. 11). High-constructive lobate deltas were the dominant lake-margin depositional systems. This depositional phase constituted the high-stand (lake level) part of a cycle (fig. 11). Subsurface data indicate that fan deltas were the dominant depositional systems in the southern part of the basin during both humid and arid cycles.

A vertical (upward) sequence of strata deposited during high stand in Triassic lakes commonly begins with reddish-brown, massive to parallel-laminated lacustrine or prodelta mudstone at the base. Horizontally bedded, grayish-green siltstone and very fine grained delta-front sandstone overlies lacustrine and prodelta facies. Delta-front siltstone and sandstone facies are mostly parallel laminated and ripple cross-laminated; they contain a few small washout channel-fill deposits. Distributary channel-fill sequences overlie delta-front sandstone facies; primary sedimentary structures are trough-fill cross-strata and parallel laminae that conform to the channel cross section. Upper parts of some delta-front and distributary channel-fill sandstone facies are burrowed. The youngest but coarsest grained fluvial sandstone deposits of the high-stand part of the cycle occur at lower paleotopographic levels than do older, high-stand deltaic and lacustrine deposits. These fining-upward sandstones were deposited by meandering streams that had cut downward into subjacent deltaic facies.

Sandstones that accumulated under high-stand conditions have relatively wide areal distribution. Meanderbelt sandstone bodies greater than 50 feet thick are commonly the only sandstone facies present in an area. Delta-front and distributary channel-fill sandstone facies are poorly preserved because of downcutting and lateral migration of the superimposed meanderbelt fluvial systems.

LOW-STAND, ARID PHASE

Humid-phase deposits are succeeded upward by red beds that are interpreted as representing sedimentation under arid or semiarid conditions. As humid conditions gave way to an arid climatic regime, several changes occurred: lake size and depth decreased (most lakes were then ephemeral); base level dropped; meanderbelt systems ceased to function; and older Triassic deposits were scoured by headwardly eroding streams. Intrabasinal sediments that were eroded from older Dockum deposits were transported through valleys up to 50 feet deep to small fan-delta systems at the basin margin (fig. 12).

Low-stand deposits are predominantly reddish-brown mudstone, siltstone, sandstone, and conglomerate that were derived, through erosion, principally from older Triassic deposits. Mudstones are thin, massive, or parallel laminated, and commonly burrowed. Some mudstone beds are desiccated and contain gypsum crystals and salt hoppers. Most siltstone units are components of fan deltas where they accumulated as bottomset and foreset facies. Sandstone and conglomerate constitute delta-foreset and delta-platform facies of small fan deltas. Combined thickness of multiple foreset and platform facies ranges from about 10 to 30 feet. Valleys that were eroded into the Dockum were filled with sediment ranging in texture from clay to gravel. Valley-fill sediment was emplaced by slope wash, braided streams, and suspension (settle-out within ponded water bodies).

Chief differences between high-stand and low-stand facies are that (1) the primarily intrabasinal source for low-stand mudstone, sandstone, and conglomerate exhibits no overall textural trends; and (2) high-stand deposits, derived chiefly from outside the basin, display both coarsening-upward and fining-upward textural sequences. There is no abrupt change or contact between high-stand and low-stand facies.

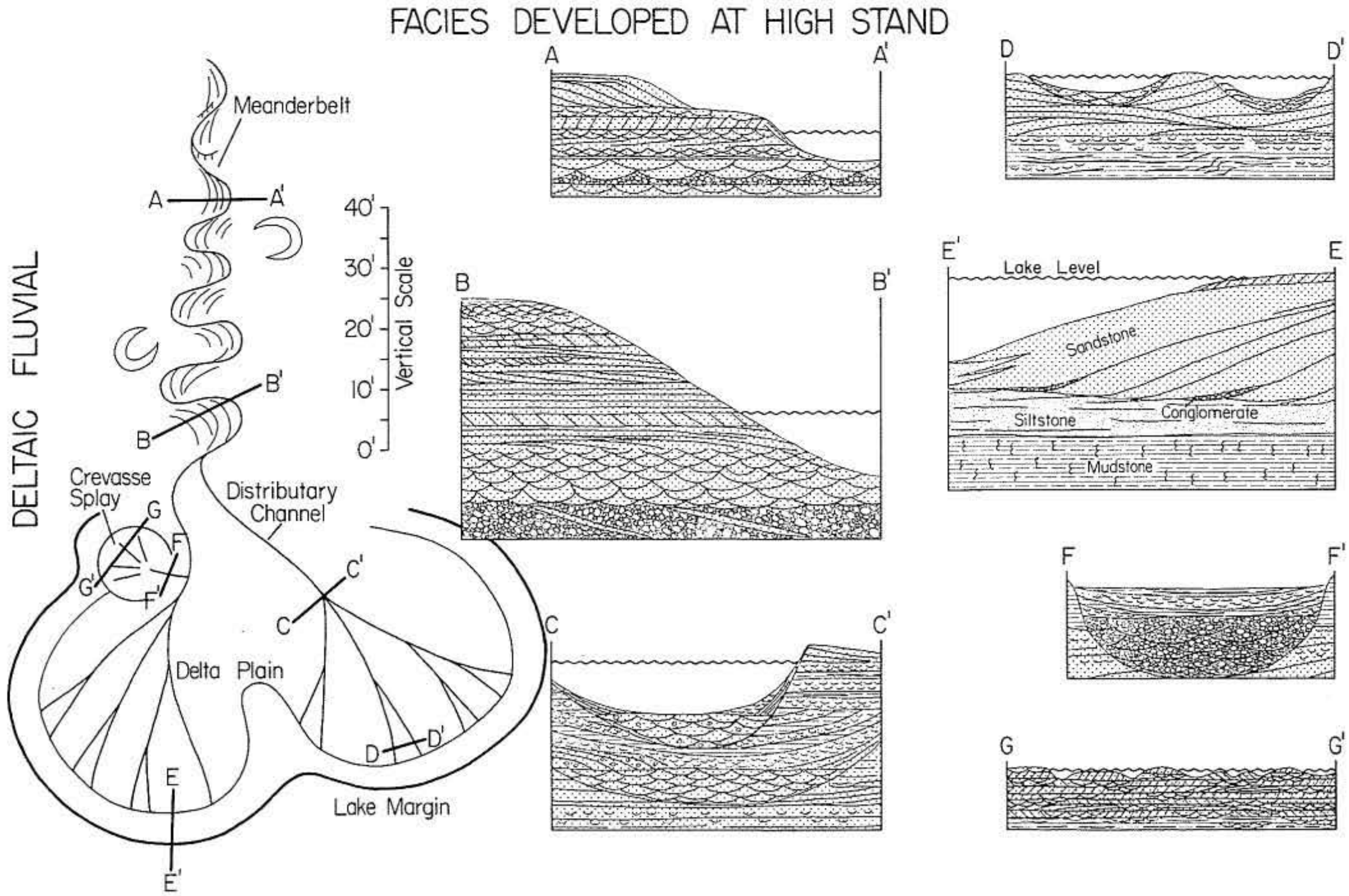


Figure 11. Major depositional elements during the high-stand, humid phase: meandering streams, distributary deltas, and shallow lakes. Facies tract and cross sections generalized from field observations. Cross section A-A' represents coarse-grained meanderbelt sequence, and B-B' is fine-grained meanderbelt sequence. Large distributary channel, and channel-fill deposits shown by C-C'. Small distributary channels, channel-mouth bar, and delta-front deposits shown by D-D'. Where deltas prograded into relatively deep water, delta front is represented by siltstone, sandstone, and conglomerate foresets that interfinger with prodelta deposits (E-E'). Crevassing is common to delta distributaries; cross sections F-F' and G-G' represent fill of crevasse channel and crevasse splay (splay-delta), respectively.

DEPOSITIONAL SYSTEMS

The Dockum Group accumulated within a variety of depositional systems, under the influence of base-level oscillations. Most of the red beds accumulated when lake area and depth were restricted—these are the low-stand facies associations comprising valley-fill, fan-delta, and lacustrine deposits. Meandering streams and associated high-constructive lobate deltas developed when climatic conditions were more humid and lake areas and level were at their maximum—these are the high-stand facies associations.

HIGH-STAND DEPOSITIONAL SYSTEMS

Two depositional systems typify the high-stand sediments. The basal deltaic system is characterized by a coarsening-upward, progradational sequence beginning with mudstone and terminating with fine-grained sandstone. Overlying the deltaic systems are fining-upward, thick, gravelly sandstone and sandstone bodies of a meandering fluvial system.

LOBATE DELTAIC SYSTEMS

Complete progradational sequences are rare because of partial erosion by succeeding, superposed meandering fluvial systems (figs. 11 and 13). Genetic facies that compose the coarsening-upward deltaic sequences are (1) lacustrine and prodelta, (2) delta-front, (3) channel-mouth bar, (4) distributary channel-fill, and (5) crevasse splay or splay-delta. Deltaic sequences in outcrop are 20 to 50 feet thick.

Lacustrine and Prodelta Facies

Thin reddish-brown, parallel-laminated mudstone, although not present everywhere, is the lowermost facies of the deltaic sequence. This facies is commonly gradational below with mudstones of low-stand origin. Sedimentary

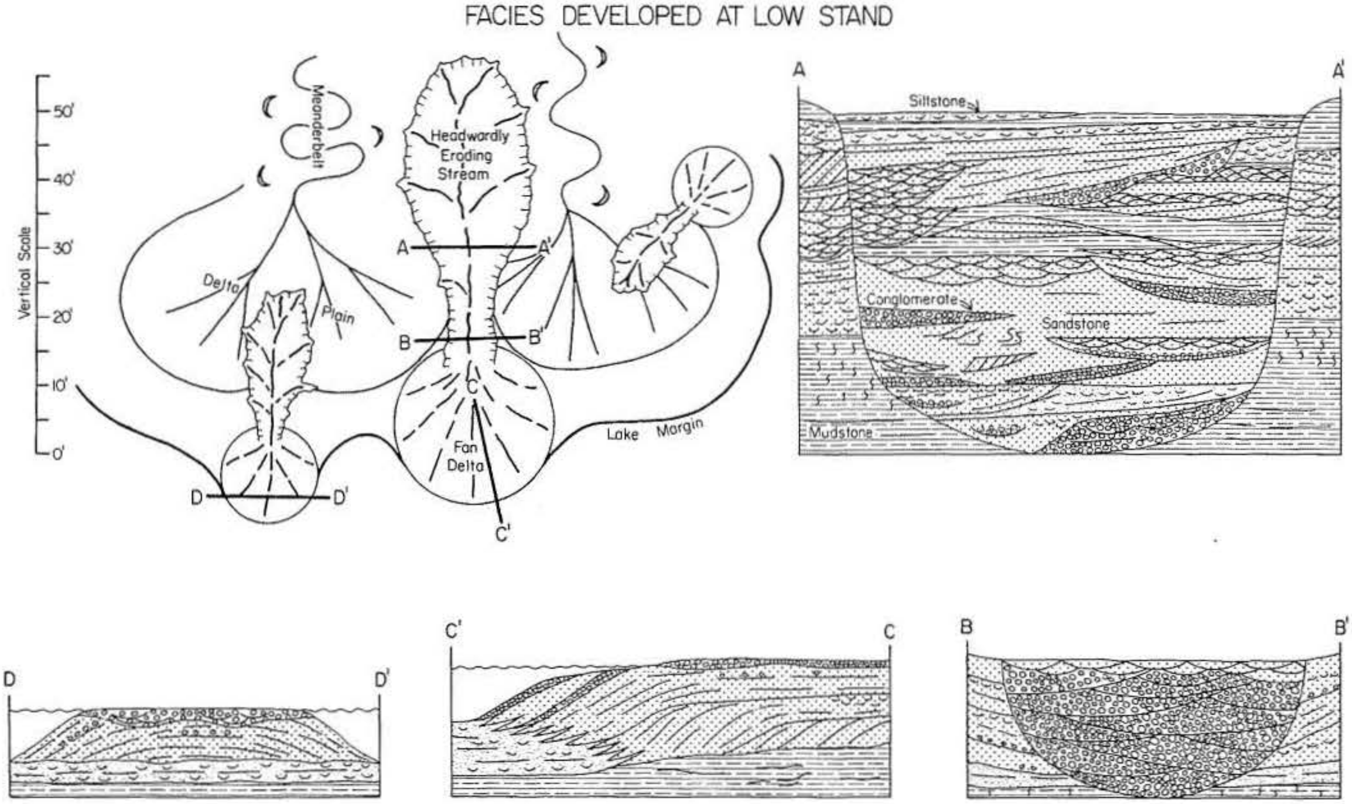


Figure 12. Major depositional elements during the low-stand, arid phase: headward-eroding streams, braided streams, small fan deltas, and small ephemeral lakes. Facies tract and cross sections generalized from field observations. Cross section A-A' is valley-fill sequence consisting of braided- and meandering-stream deposits, slopewash, and lacustrine mudstone and siltstone. Braided feeder channel-fill sequence near apex of small fan delta is shown by cross section B-B'; fill is chiefly trough-fill cross-stratified intrabasinal conglomerate. Delta platform, delta margin, and delta foresets are shown in cross section C-C' which is parallel to flow direction. Cross section D-D' is across distal part of small fan delta; this section shows delta foresets to be broadly convex upward.

structures are thin, horizontal to wavy laminae, exhibiting local soft-sediment deformation. Parallel-laminated mudstone, which records initial lacustrine or prodelta sedimentation, grades upward into delta-front siltstone and sandstone.

Delta-Front Facies

Delta-front siltstone and sandstone facies are mostly grayish green with reddish brown being dominant in the lower few feet of the unit. Bedding may be approximately horizontal or inclined in the direction of sediment transport (fig. 14). Sedimentation units thin and grain size decreases in a downcurrent direction. A few thin, low-angle foreset cross-strata and trough-fill cross-strata are associated with inclined beds. Thickness of sedimentation units, scale of sedimentary structures, and grain size increase upward. Foreset cross-strata and trough-fill cross-strata are best developed near the tops of these sequences (fig. 13).

Small washout channels are rare to common (fig. 13). Channels, 1 to 2 feet deep and 15 to 45 feet wide, are filled with parallel-laminated and low-angle foreset cross-stratified, fine-grained sandstone.

Siltstone and sandstone deposits are locally burrowed. Dominant burrow type is unornamented, small in diameter (0.25 inch), and may be oriented perpendicular or parallel to bedding. *Ophiomorpha* are rare. Other biological constituents are bone fragments and unidentified molluscan calcite shell fragments.

The thickness of inclined bedding units suggests that water depths were 10 to 15 feet. Horizontally bedded delta-front deposits probably accumulated in less than 10 feet of water. Washout channel fill, trough-fill cross-strata, foreset cross-strata, and conglomerate lenses record surges during flood events.

Channel-Mouth Bar Facies

Channel-mouth bars are gradational below with delta-front deposits and are in erosional contact with overlying distributary channel-fill facies. Lower parts of this facies generally consist of low-angle, foreset cross-stratified, very fine grained to fine-grained sandstone. Uppermost deposits comprise foreset cross-stratified and trough-fill cross-stratified sandstone. Thickness of this sequence is 5 to 10 feet (fig. 15). Very fine grained to fine-grained sandstone composing the facies displays no vertical textural trend. Bioturbation of channel-mouth bar facies is rare, as are fragments of bone and shell. Channel-mouth bar deposits are preserved only in areas where associated distributary channels were shallow (at or near the point where distributaries debouched into standing water).

Distributary Channel-Fill Facies

Distributary channel-fill conglomerate and sandstone bodies range from 5 to 15 feet thick and 30 to 200 feet wide. Multiple, superposed channel-fill units are 25 to 30 feet thick and up to 1,300 feet wide. Individual channels have parabolic cross sections; some are symmetrically filled indicating a straight channel pattern. Many channels were alternately active and inactive as suggested by channel-fill sequences of conglomerate, sandstone, and mudstone that exhibit attendant scour features.

Larger channel systems eroded through channel-mouth bar facies and into subjacent delta-front facies (fig. 13). Large channels were filled, for the most part, with trough-fill cross-stratified, fine-grained sandstone. There is a wider range of textural and structural types in the fill of small channels than in larger channel-fill bodies. Foreset cross-stratified, intrabasinal conglomerate floors many small channels. Conglomerate deposits are commonly overlain by sequences of alternating parallel-laminated sandstone and siltstone; laminae conform to the channel configuration. Parallel-laminated or massive mudstone overlies sandstone-siltstone units. The dominance of sigmoidal foreset cross-strata (fig. 16) can be observed in outcrops that parallel transport direction of the thicker channel-fill sequences. Reactivation surfaces, analogous to those reported by Harms (1975, p. 50-51), are common in the large sigmoidal foresets.

Distributary channels of the high-constructive lobate deltas are preserved as large and small sandstone-filled channels. Crevasse channel-fill and splay deposits are attendant features of distributary channels. Conglomerate-filled channels are representative of Triassic crevasse activity.

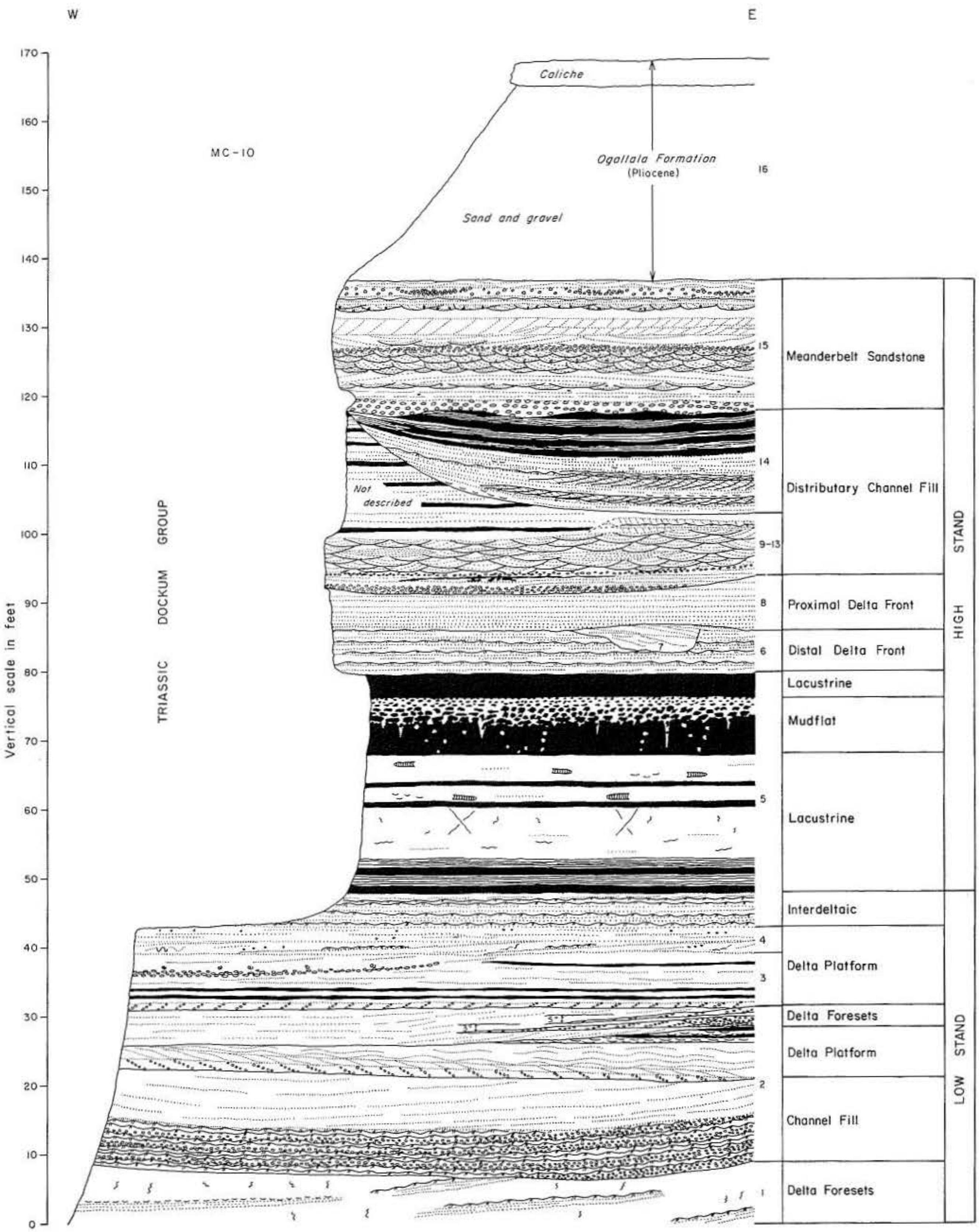
Crevasse Channel Facies

Conglomerate-filled crevasse channels are limited in distribution, and maximum thickness of the channel deposits is about 15 feet. There are two channel-fill end members: (1) one consists of reddish-brown to yellowish-brown, calcitic, granule to cobble conglomerate; sedimentary structures are massive beds, large trough-fill cross-strata, and low-angle foreset cross-strata; (2) the other type is grayish-green to dusky-yellowish-green, unsorted, sandy cobble to boulder conglomerate; major components are mudstone clasts. Primary sedimentary structures are poorly defined in these channel-fill deposits. Obvious structures are large-scale and can be identified only as cut-and-fill; some pebble conglomerate units exhibit trough-fill cross-strata. Because of poor sorting and compaction of mudstone clasts, these conglomeratic channel-fill deposits are relatively impermeable. *Unio* (fresh-water clam), bone fragments, and plant debris are rare to abundant. Some plant debris has been carbonized. Locally, relatively thick plano-convex sandstone bodies with dominant parallel laminae and subordinate trough-fill cross-strata overlie conglomerate-filled crevasse channels.

Crevasse Splay Facies

Conglomerate-filled crevasse channels grade downcurrent into sheetlike conglomerate and sandstone bodies that constitute the splay facies (these are splay deltas). Splay conglomerate and sandstone were emplaced by braided-stream processes, the Modern counterparts of which have been observed on the Omo Delta (Butzer, 1971). Because splays are products of unconfined flow, paleocurrent indicators exhibit a wide directional variation similar to those of fans and fan deltas (McGowen, 1971a; McGowen

Figure 13. Progradational sequence, Slaughter Ranch, southwestern Garza County, Texas (Middle Creek 7.5-minute quadrangle). High-stand and low-stand deposits represented in section. Units 1 through 4 are low-stand deposits, and units 5 through 15 are high-stand deposits; a transition occurs from low-stand to high-stand facies. *Low-stand deposits* (units 1 through 4) are components of *fan deltas*. For example, unit 1 and upper part of unit 2 are delta foresets consisting of reddish-brown mudstone, siltstone, very fine sandstone, and intrabasinal conglomerate; primary sedimentary structures are parallel inclined laminae, ripple cross-laminae, trough-fill cross-stratified, and low-angle delta foresets; small diameter (0.06 to 0.12 inch) burrows present. Lower part of unit 2 is a *multiple channel-fill sequence* (straight feeder channel) consisting of reddish-brown and greenish-gray very fine sandstone and granule to pebble intrabasinal conglomerate; primary sedimentary structures are massive conglomerate, parallel and ripple cross-laminated sandstone. *Delta platform* (middle part of unit 2 and units 3 and 4) consists of reddish-brown, very fine sandstone and granule to pebble intrabasinal conglomerate; sedimentary structures are high- and low-angle foreset cross-strata, wavy parallel laminations (wave length: 8 feet; amplitude: 0.5 foot), parallel laminae with mud drapes (*Unio* in unit 3), combined flow ripples (unit 4), and soft-sediment deformation (unit 4). *Interdeltaic deposits* (lower part of unit 5) are moderate-brown to reddish-brown, coarse siltstone and very fine sandstone; sedimentary structures are alternating parallel and ripple cross-laminae. *High-stand deposits* represented by *lacustrine deposits* (lower part of unit 5) consist of reddish-brown and red-purple claystone, mudstone, and siltstone (silt content increases upward); primary sedimentary structures are parallel laminae, sequence is mostly massive; burrows are common (*Scoyenia* and *Teichichnus*). *Mudflat deposits* (upper part of unit 5) consist of reddish-brown, red-purple, and green desiccated mudstone with caliche nodules and burrows in lower part. Lacustrine deposits (uppermost part of unit 5) consist of reduced grayish-green massive mudstone. *Distal delta front* (units 6 and 7) and *proximal delta front* (unit 8). *Distal delta front* is greenish-gray biotite-bearing coarse siltstone to very fine sandstone; primary sedimentary structures are alternating parallel laminae and ripple cross-laminae with washout channels (unit 7) 10 feet wide by 3 feet deep. *Proximal delta front* is grayish-green biotite-bearing very fine to fine sandstone; primary sedimentary structures are parallel laminae. *Distributary channel fill* (units 9 through 14) comprises greenish-gray granule to pebble intrabasinal conglomerate, conglomeratic fine sandstone, fine sandstone, and moderate-brown to reddish-brown mudstone, siltstone, and very fine sandstone; primary sedimentary structures are trough-fill cross-strata, high-angle foresets, parallel laminae (conform to channel floors), ripple drift, ripple cross-laminae, and settle-out mud and silt laminae. *Meanderbelt deposits* (unit 15) complete high-stand sequence. Unit 15 is composed of greenish-gray granule to pebble intrabasinal conglomerate and fine sandstone, light-gray to yellowish-light-gray coarse siltstone to medium sandstone; primary sedimentary structures are massive conglomerate, thin trough-fill cross-strata, parallel inclined laminae, medium-scale trough-fill cross-strata, high-angle foreset cross-strata, and wavy parallel laminae.



W
E
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Vertical scale in feet
MC-10
Caliche
Ogallala Formation
(Pliocene)
16
Sand and gravel
TRIASSIC DOCKUM GROUP
Not described
15
Meanderbelt Sandstone
14
Distributary Channel Fill
9-13
8
Proximal Delta Front
6
Distal Delta Front
Lacustrine
Mudflat
5
Lacustrine
Interdeltaic
4
Delta Platform
3
Delta Foresets
Delta Platform
2
Channel Fill
1
Delta Foresets
HIGH STAND
LOW STAND

Figure 13

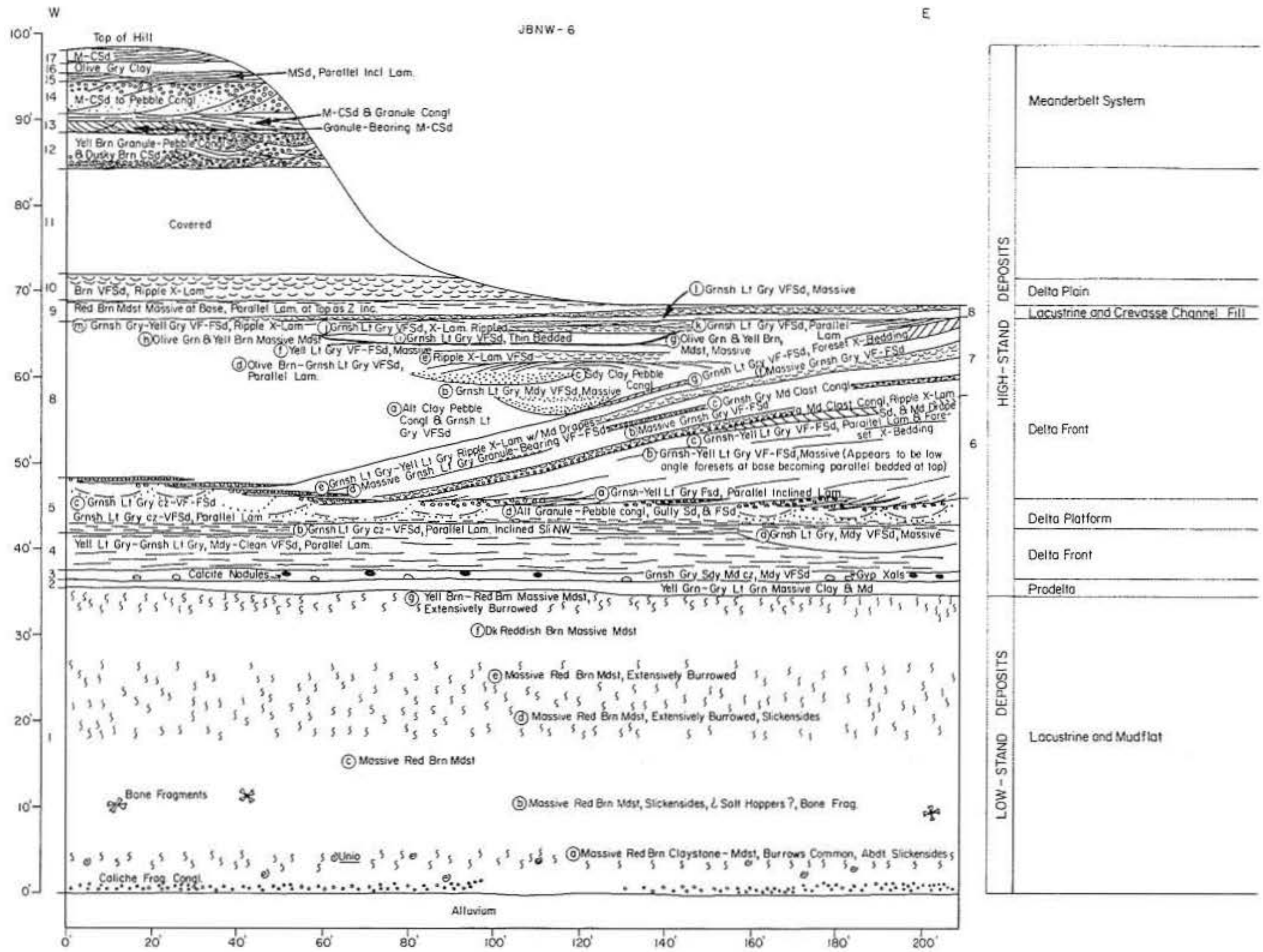


Figure 14. Delta-front facies associated with high-stand lobate delta, Dalby Ranch, Garza County, Texas (Justiceburg Northwest 7.5-minute quadrangle). High-stand and low-stand deposits represented in section. *Low-stand deposits* (unit 1) accumulated in *lacustrine* and *mudflat environments*; salt hoppers and *Unio* suggest alternating hypersaline and fresh-water environment; bone fragments and abundant *Scoyenia* (polychaaete worm burrows). *High-stand deposits* (units 2 through 17) accumulated under varying water-level conditions. Thin coarsening-upward sequence represented by units 2 through 5; unit 2 is interpreted as thin *prodelta mud;* units 3 and 4 as *delta-front sand*, and unit 5 as *delta platform. Delta foresets* (units 6 and 7) overlie delta platform; apparent dip angle is about 5° west (unit 6) and about 7° west (unit 7); sedimentation units thin westward. *Crevasse channel-fill, lacustrine mudstone,* and *crevasse splay* deposits represented by unit 8, which ranges from about 1 to 18 feet thick. *Delta-plain* (overbank) deposits represented by units 9 and 10. *Meanderbelt system* caps hill (units 12 through 17).

and Groat, 1971). In some instances flow directional features may trend in a direction opposite to paleoslope.

Splay facies possess all the attributes of braided-stream deposits. They are 1 to 9 feet thick and consist mostly of debris from levees and adjacent delta plain. Texturally, splay deposits range from granule-bearing sandstone to granule and pebble conglomerate. Trough-fill cross-strata are dominant sedimentary structures, and foreset cross-strata and parallel laminations are secondary types. Small channel-fill units up to 3 feet thick occur locally within these deposits.

Splay sandstone and conglomerate bodies lie in erosional contact on underlying mudstone. Splay deposits are overlain by a variety of mudstone facies (including lacustrine and floodplain deposits) or thick meanderbelt sandstone. Rare coal seams occur in the lower parts of some drab lacustrine mudstones that overlie splay units.

FLUVIAL SYSTEMS

Fining-upward meandering fluvial sandstone sequences commonly cap the high-stand facies association. Maximum thickness of meandering fluvial sandstone bodies is approximately 85 feet; maximum width, 6 miles. These sandstones are products of multiple depositional events, and complete fluvial sequences (from scour-pool to upper point-bar) are rarely preserved except in (1) the uppermost parts (last depositional unit) of meanderbelt sandstone bodies that are products of multiple depositional events, and (2) sandstone bodies that represent a single fluvial sandstone body, which normally occurs near meanderbelt margins. Single sandstone bodies range in thickness from 20 to 40 feet. Accretionary grain, a feature that results from point-bar migration is exhibited by some point-bar sandstones, the outcrops of which are approximately perpendicular to sand-body trend.

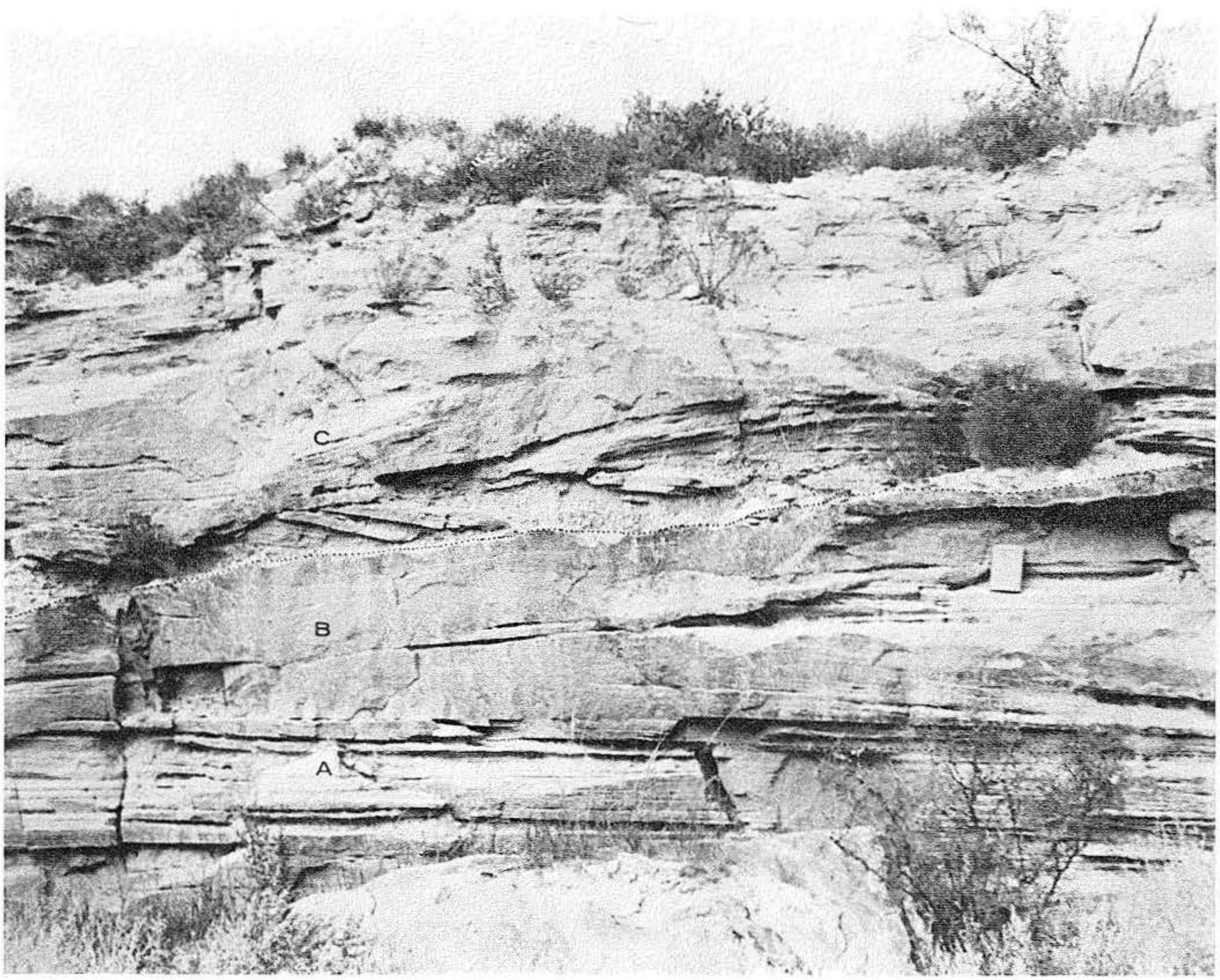


Figure 15. Thin progradational sequence, approximately 9 feet thick, on Dalby Ranch, Garza County, Texas (Post East 7.5-minute quadrangle). View west. Depositional units are (A) Greenish-gray, parallel-laminated, calcitic to friable, highly micaceous, very fine *delta-front sandstone*. (B) Very fine to fine *channel-mouth bar sandstone*. Channel-mouth bar gradational with underlying delta-front sandstone. Channel-mouth bar sandstone parallel laminated at base, becoming parallel inclined laminated (or low-angle foreset crossbedded) upward; change in inclination produces plano-convex sandstone unit. Apparent dip is 8° northwest and southeast. (C) Greenish-gray, mudclast-bearing, very fine to fine *distributary channel-fill sandstone*. Distributary sandstones 2 to 5 feet thick and 15 to 30 feet wide; they are symmetrically filled and in erosional contact with underlying channel-mouth bar deposits. Outcrop is representative of the more distal parts of distributary channels.

Upper parts of many meanderbelt sequences were removed through lateral erosion of younger channels. Consequently, lower parts of sandstone bodies are composed of 6- to 11-foot-thick depositional sequences consisting of (1) a lower massive, foreset and trough-fill cross-stratified, pebble to cobble conglomerate (scour-pool deposits) and (2) an upper trough-fill cross-stratified, conglomeratic, fine- to medium-grained sandstone (scour-pool and lower point-bar). Gravel clasts were derived from both intrabasinal and extrabasinal sources. Intrabasinal clasts are mudstone, siltstone, sandstone, and caliche. Extrabasinal clasts are mostly chert, quartz, and quartzite. Gravel contained in the oldest sandstone bodies of this facies (for example, in Kent and Crosby Counties) is mostly granule- to pebble-sized chert, quartz, and quartzite (fig. 17). Bone material and large plant fragments (for example, casts of logs and limbs) are rare to abundant in conglomerates. Most plant material has been leached.

Both coarse-grained (McGowen and Garner, 1970; Levey, 1976) and fine-grained point-bar deposits (Bernard and others, 1970) occur in Dockum meanderbelt sequences. A succession of sedimentary structures similar to Modern coarse-grained point bars consists of the following (in ascending order): (1) massive or trough-fill cross-stratified conglomerate or conglomeratic fine- to medium-grained sandstone: (2) alternating foreset and trough-fill cross-stratified granule-bearing fine-grained sandstone; (3) either simple low-angle foresets 5 to 9 feet thick or an interval of compound foresets of comparable thickness; and (4) parallel-laminated and ripple cross-laminated siltstone and very fine grained sandstone that alternate with parallel-laminated or massive mudstone (fig. 18).

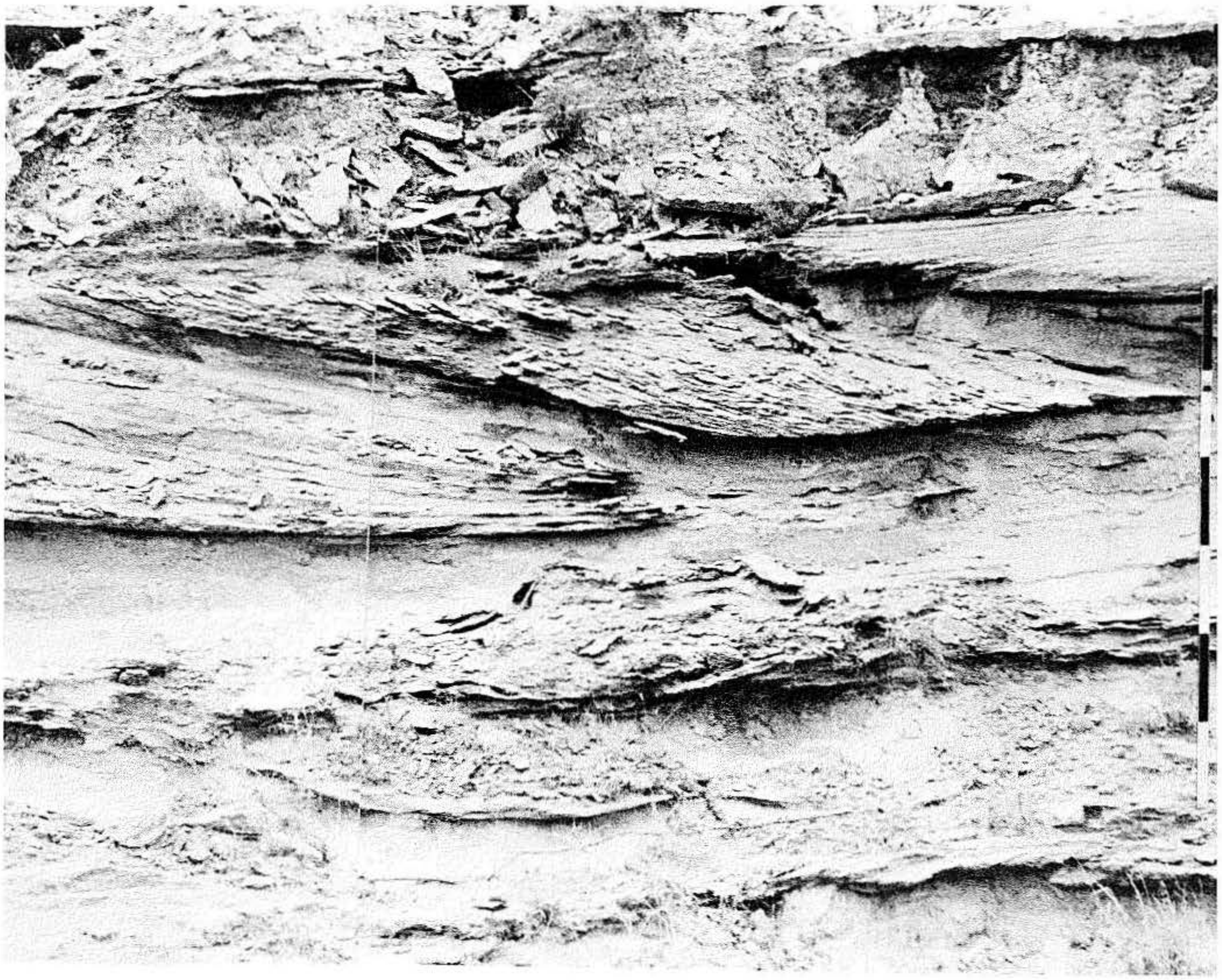


Figure 16. Large sigmoidal foreset cross-strata in lower part of distributary channel fill in road cut on Farm Road 669, south of Double Mountain Fork of Brazos River, southwest Garza County, Texas (Middle Creek 7.5-minute quadrangle). View west. Apparent transport direction north. Reactivation surfaces common in sequence. Jacob's staff is 6 feet long.

The analogy between Modern coarse-grained meanderbelt sequences and those of the Dockum Group is not perfect. The chief difference lies in grain size. Dockum coarse-grained point bars comprise mostly fine- to medium-grained sandstone, whereas Modern coarse-grained point bars commonly exhibit coarse sand and gravel within the upper point bar. Both Modern and Dockum coarse-grained point bars display similar suites of primary sedimentary structures. Galloway (1977) prefers to use the terms *bedload* and *mixed load* to distinguish between ancient fluvial deposits. This terminology solves the problem of variation between certain fluvial models and the rock record.

Fine-grained point-bar sequences (fig. 19) vary slightly from coarse-grained sequences. Thick foresets or compound foresets are absent in fine-grained point-bar deposits. Parallel horizontal or parallel inclined laminae composed of very fine grained to fine-grained sandstone typify upper point bars in fine-grained meanderbelt systems. Other stratification types such as thin foreset cross-strata, trough-fill cross-strata, and ripple cross-laminae also occur within the upper point-bar facies of fine-grained meanderbelt sandstones.

Meander cutoffs and abandoned stream courses are components of meanderbelt systems (fig. 11). Abandoned channels are filled with mudstone and sandstone. Mudstone lenses, 15 to 30 feet thick, are reddish brown and dark greenish gray. Reddish-brown mudstones, which are massive or parallel laminated, contain (1) lenses of ripple cross-laminated siltstone and very fine grained sandstone and (2) very fine grained sandstone wedges that thicken toward neck cutoffs. Parallel inclined laminae (low-angle wedge sets) are principal sedimentary structures in abandoned-channel sandstone wedges or plugs. Dark-greenish-gray mudstones are generally massive and contain a few parallel-laminated horizons consisting of a high percentage of siltstone and plant debris. Some irregular masses of very fine grained sandstone occur within gray mudstones; these discontinuous sandstone bodies were deposited as rippled sands that foundered into a "soupy" mud substrate. Rare to common coprolites and carbonized plant material (mostly leaves and twigs) have been observed in some gray mudstones.

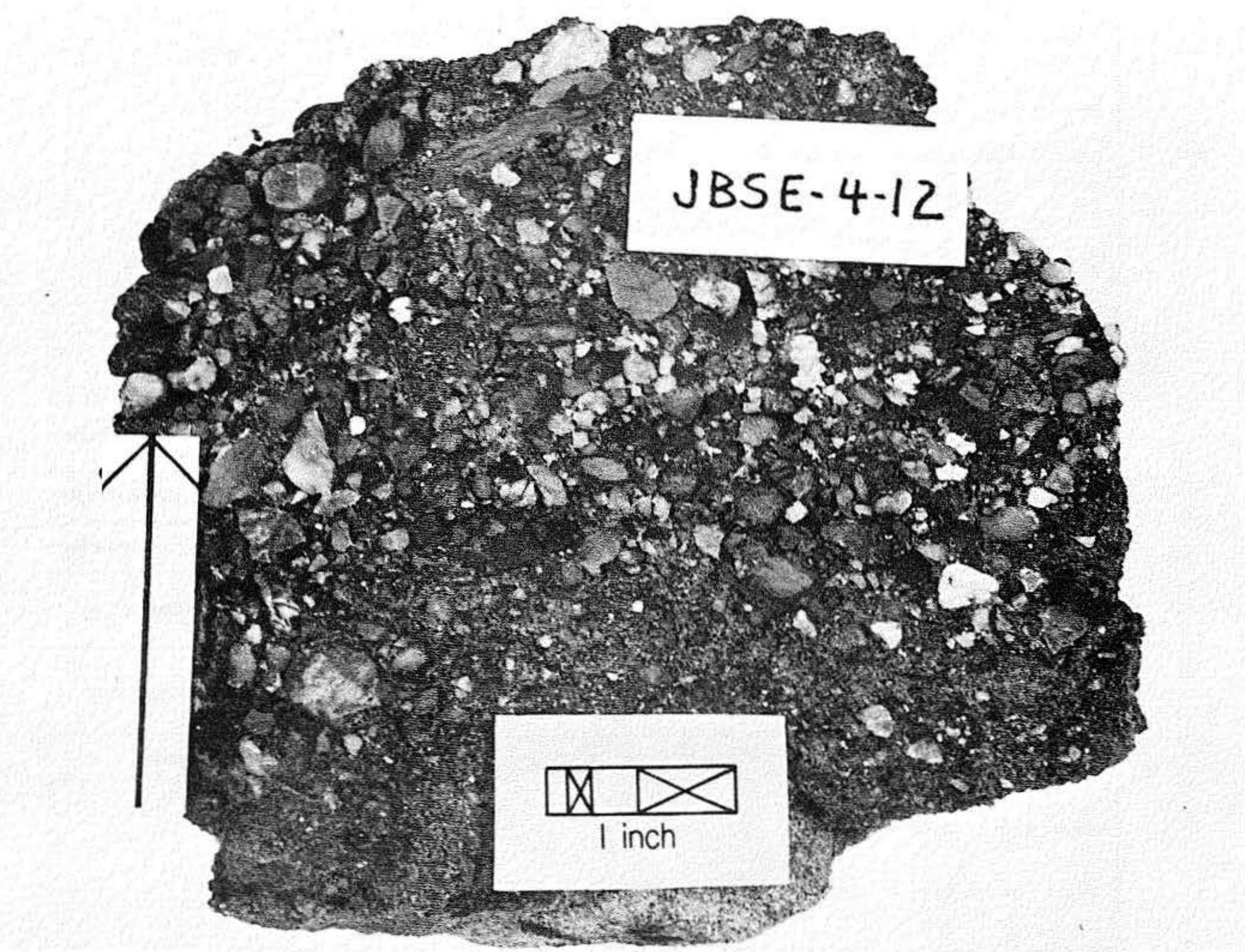


Figure 17. Channel-lag conglomerate, Johnson Ranch, Kent County, Texas (Justiceburg Southeast 7.5-minute quadrangle). Moderate-brown granule to pebble (extrabasinal) conglomerate. Chert, quartzite, and vein quartz clasts. Chert is angular to subround. Quartzite and vein quartz are subround to well rounded. Sample from base of meanderbelt sandstone.

LOW-STAND DEPOSITIONAL SYSTEMS

Deposits of the low-stand association are products of sporadic, high-intensity, short-duration depositional events. Depositional environments included small shallow lakes, small fan deltas, interdeltaic mudflats, and ephemeral streams contained within headwardly eroding valleys. Low-stand deposits include lacustrine, fan-delta, and ephemeral-stream systems composed of the following facies: (1) lacustrine and prodelta (bottomsets), (2) delta-foreset, (3) delta-platform, (4) mudflat, and (5) valley-fill. Single deltaic sequences comprising foresets and delta platform are about 10 feet thick. Lacustrine and prodelta facies are generally thin (5 to 10 feet thick), and valley-fill facies range from a few feet to about 50 feet (see fig. 12).

FAN-DELTA SYSTEMS

Fan deltas were the dominant depositional system along margins of ephemeral lakes during the arid part of a climatic cycle. Drainage systems, which fed the fan deltas, were small, and the associated streams are assumed to have been high-gradient. High-intensity flow was of short duration; lag time between precipitation and runoff was brief. Sediment and water were transported from the source area to the fan-delta apex through a valley that confined the flow. Upon reaching the apex, flow became unconfined and was dissipated radially across the fan-delta platform by shallow braided streams. In the lake, sediment and water were dispersed by homopycnal flow (Bates, 1953). Delta foresets developed at the lake margin (if there was sufficient depth in the receiving basin). Sediment was moved along the foresets by bottom currents and by avalanching under the influence of gravity. A minor amount of sediment from suspension accumulated along the foresets. Sediment was emplaced on the lake floor by bottom currents and settled out of the water column from suspension.

Lacustrine and Prodelta Facies

Reddish-brown mudstone and siltstone compose lacustrine and prodelta deposits. Several mudstone and siltstone types make up these deposits, which represent the lowest

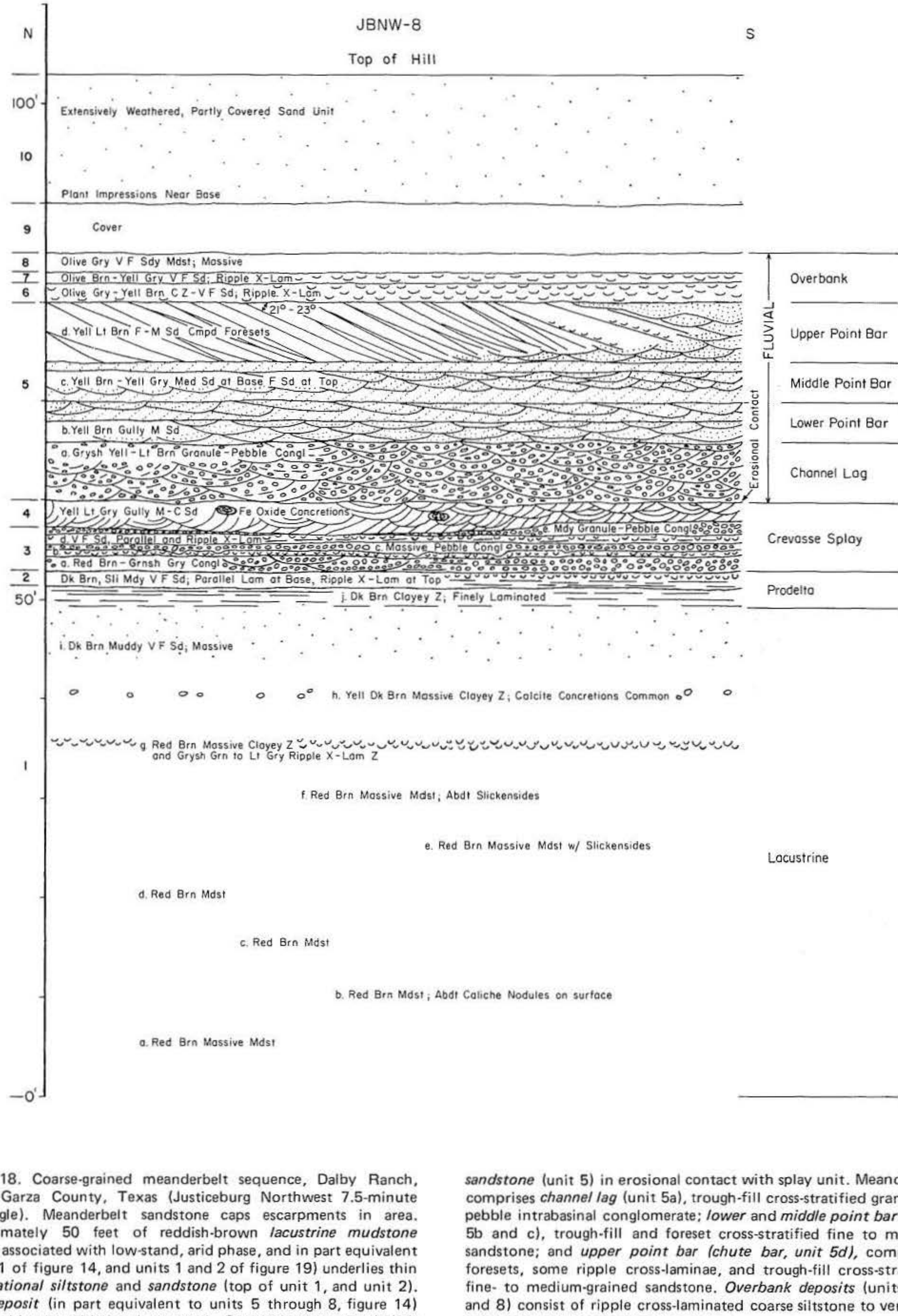


Figure 18. Coarse-grained meanderbelt sequence, Dalby Ranch, central Garza County, Texas (Justiceburg Northwest 7.5-minute quadrangle). Meanderbelt sandstone caps escarpments in area. Approximately 50 feet of reddish-brown *lacustrine mudstone* (mostly associated with low-stand, arid phase, and in part equivalent to unit 1 of figure 14, and units 1 and 2 of figure 19) underlies thin *progradational siltstone* and *sandstone* (top of unit 1, and unit 2). *Splay deposit* (in part equivalent to units 5 through 8, figure 14) overlies thin progradational sequence. *Coarse-grained meanderbelt sandstone* (unit 5) in erosional contact with splay unit. Meanderbelt comprises *channel lag* (unit 5a), trough-fill cross-stratified granule to pebble intrabasinal conglomerate; *lower* and *middle point bar* (units 5b and c), trough-fill and foreset cross-stratified fine to medium sandstone; and *upper point bar (chute bar, unit 5d)*, compound foresets, some ripple cross-laminae, and trough-fill cross-stratified fine- to medium-grained sandstone. *Overbank deposits* (units 6, 7, and 8) consist of ripple cross-laminated coarse siltstone to very fine sandstone and massive sandy mudstone.

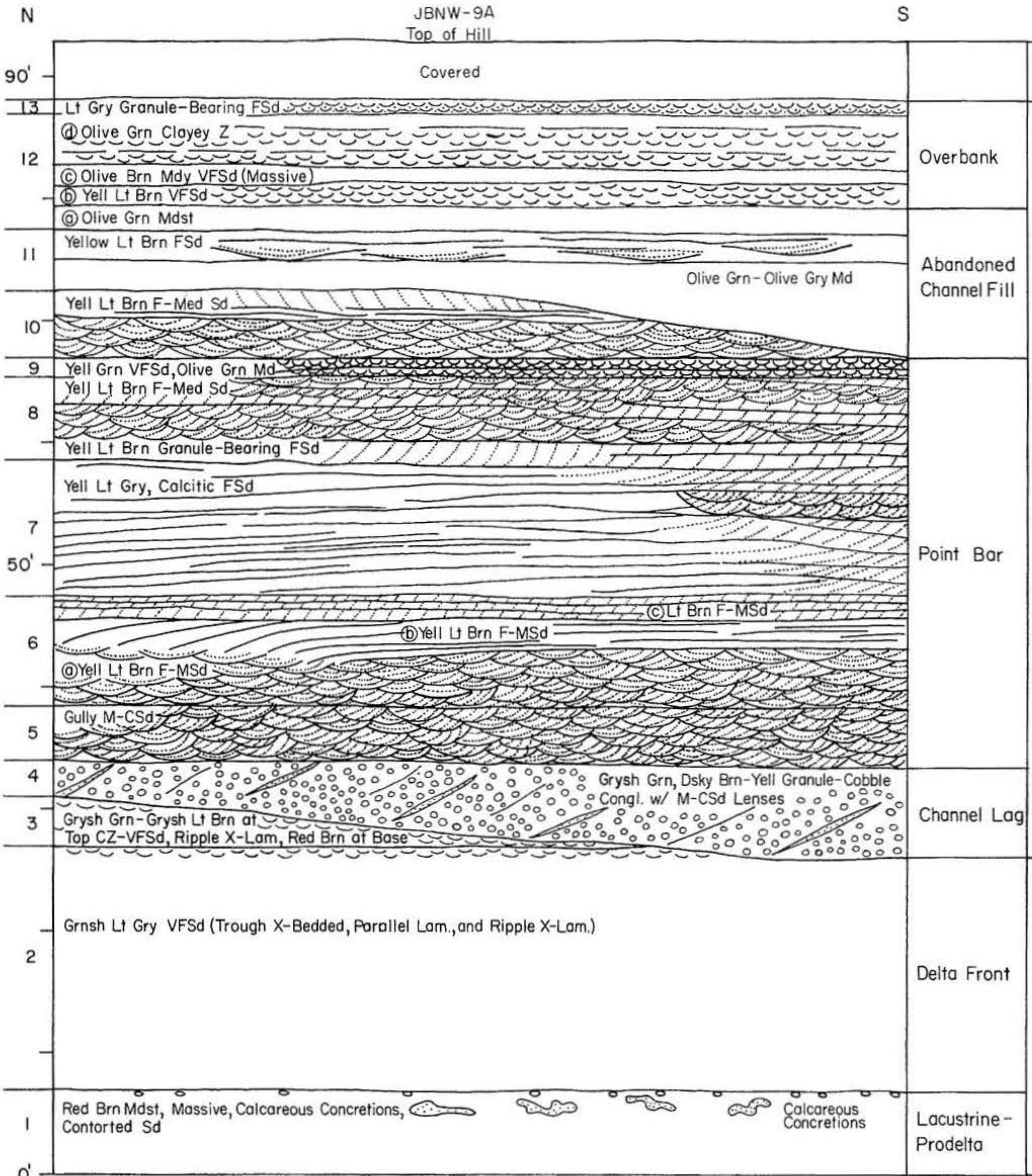


Figure 19. Fine-grained meanderbelt sequence, Dalby Ranch, central Garza County, Texas (Justiceburg Northwest 7.5-minute quadrangle). Meanderbelt sandstone caps escarpment. Meandering stream cut into deltaic deposits. Unit 1 is *lacustrine-prodelta mudstone*. Unit 2 is a *delta-front sequence* equivalent to units 2 through 8 (fig. 14). Units 4 through 13 are components of a *fine-grained meanderbelt sequence*. Unit 4 is yellowish-brown granule to cobble channel-lag conglomerate with lenses of medium- to coarse-grained sandstone. Units 5 through 10 are *point-bar deposits* that exhibit general upward decrease in grain size and thickness of sedimentation units; vertical succession of stratification types is trough-fill cross-strata (units 5 and 6), parallel inclined laminae and foreset cross-strata (top unit 6), foreset cross-strata, parallel inclined laminae, and trough-fill cross-strata (unit 7), foreset cross-strata and trough-fill cross-strata (unit 8), ripple cross-laminae, and wavy laminae (unit 9), trough-fill cross-strata, wavy laminae, and foreset cross-strata (unit 10). Unit 11 is *abandoned channel fill* (mudstone mostly massive). Siltstone lenses within mudstone are ripple cross-laminated and contain abundant carbonized plant leaves and stems. Units 12 and 13 are ripple cross-laminated, massive, and parallel-laminated *overbank mudstone, siltstone* (z), and *sandstone*.

physical-energy environment of the low-stand depositional system. Lacustrine and prodelta facies of the low-stand depositional system may overlie any other facies including deposits of both high-stand and low-stand depositional systems. Lacustrine and prodelta deposits consist of burrowed, massive and parallel-laminated mudstone, and parallel and ripple cross-laminated mudstone and siltstone. In the discussion of lacustrine and prodelta facies that follows, the various mudstone and siltstone facies have been arranged in order of increasing physical energy. This arrangement implies that each of the successive facies exhibits evidence of an increasing influence of fluvial processes. Genetic terms (for example, lake margin and lake center) were not applied to these mudstone and siltstone units because, at this time, we are not certain that such terms are applicable.

Burrowed mudstones are grayish red purple. They indicate slow rates of sediment accumulation. Three burrow types are recognized: (1) randomly oriented small burrows (0.1- to 0.2-inch diameter); (2) burrow fill with a ropy texture (0.2- to 0.5-inch diameter); and (3) spreite, meaning something spread between two supports (0.5- to 0.7-inch diameter). All burrow types are attributed to the activity of worms. *Scoyenia*, the burrow with a ropy texture, and *Teichichnus*, the spreite, were produced by polychaetes (Teichert, 1975). Nondescript, small burrows occur in both fine- and coarse-grained rocks, but *Scoyenia* and *Teichichnus* were observed only in mudstones and siltstones.

Massive reddish-brown lacustrine and prodelta mudstones are gradational with all low-stand facies except delta-platform fluvial and valley-fill fluvial facies. Massive mudstone is characterized by subconchoidal fracture, irregularly shaped grayish-green reduction patches, and slickensides (fig. 20). Slickensides do not appear to be facies restricted. Any facies (either reddish-brown or grayish-green) with a high mud content may contain slickensides. Galloway (1977) reports that slickensides were common and demonstrably genetic features of lacustrine clay and some soil zones in the Catahoula Formation.

Lacustrine and prodelta mudstones that are close to delta foresets commonly display well-preserved sedimentary structures. Reworking of mudstones by infauna is slight. Reddish-brown, parallel-laminated mudstone (fig. 21) exhibiting slickensides and grayish-green reduction patches is a minor rock type within the low-stand facies association. These beds are commonly less than 5 feet thick and are

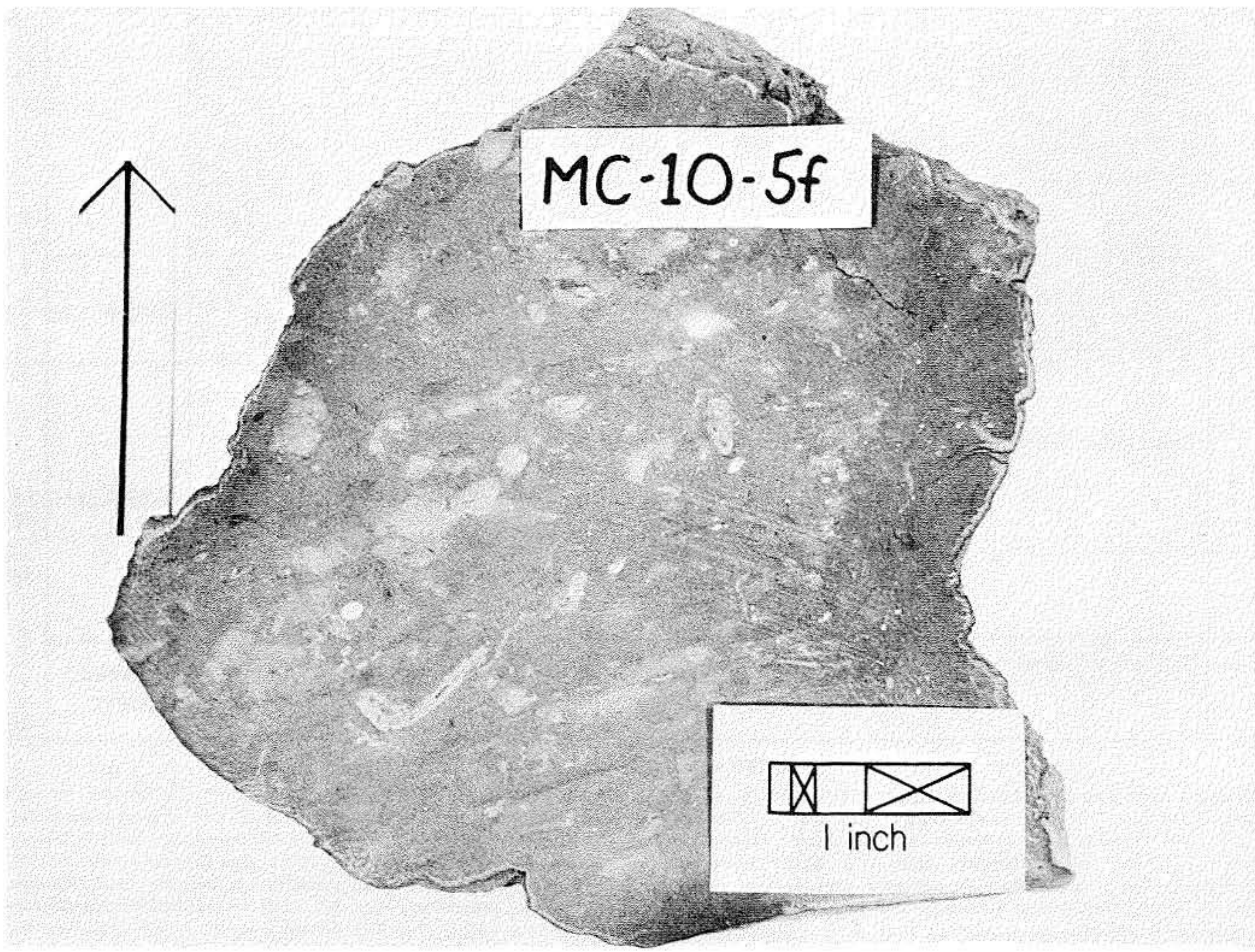


Figure 20. Pale-reddish-brown (10 R 5/4) massive mudstone with greenish-gray (5 G 6/1) reduction patches, Slaughter Ranch, southwest Garza County, Texas (Middle Creek 7.5-minute quadrangle). Sample from mudstone that grades vertically and laterally into burrowed mudstone with well-preserved *Teichichnus*.

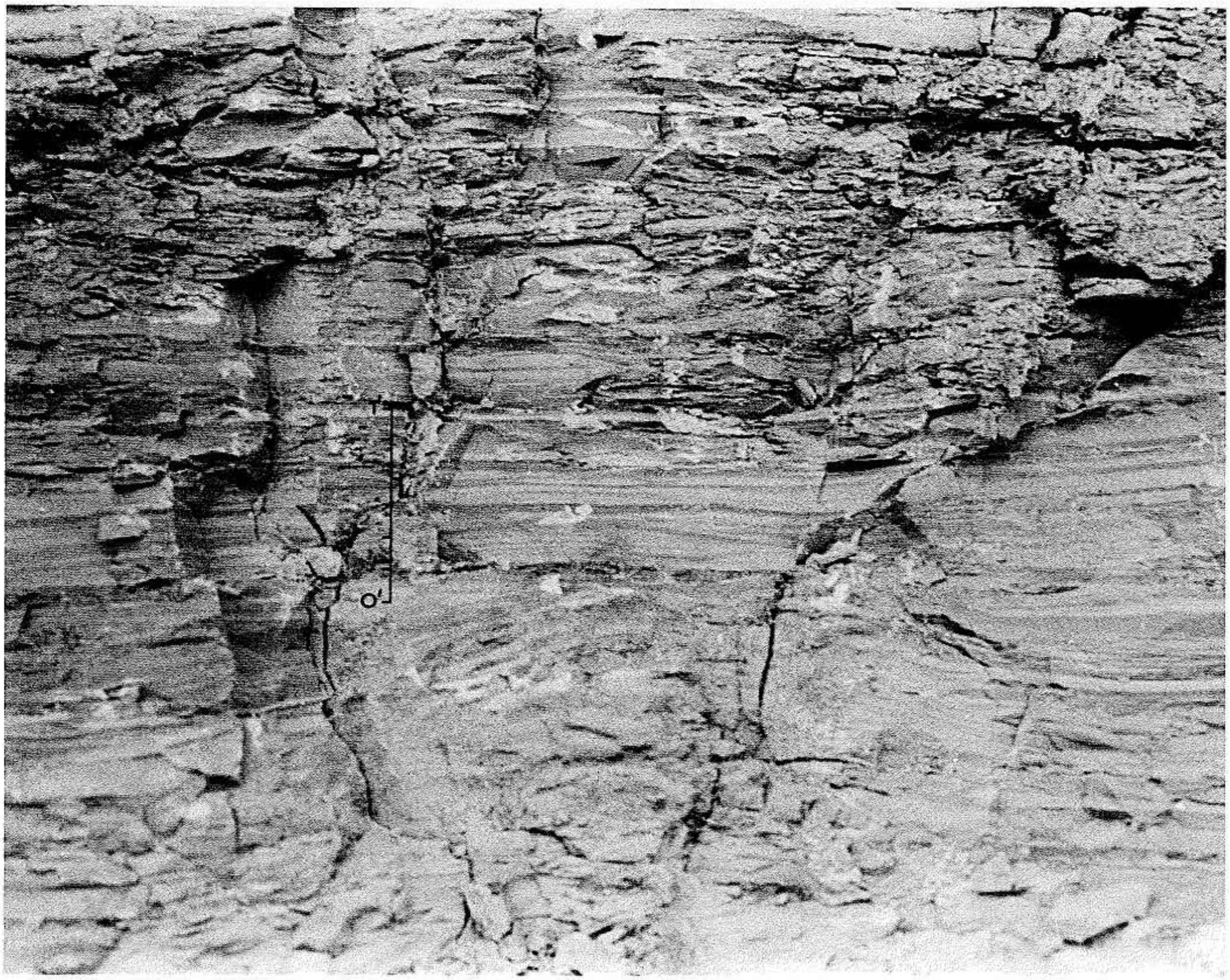


Figure 21. Lacustrine mudstone and siltstone, Johnson Ranch, Kent County, Texas (Justiceburg Southeast 7.5-minute quadrangle). View north. Vertical scale: 1 foot. Alternating moderate-brown parallel-laminated mudstone and light-brown wavy-laminated calcitic siltstone.

composed of horizontal, inclined, straight or wavy 0.5- to 2-mm laminae. Parallel-laminated mudstones are normally associated with the ripple cross-laminated siltstone that is a part of large foreset units. Locally, parallel-laminated mudstones occupy a position between delta foreset and massive or burrowed mudstone.

Near the transition from lacustrine or bottomset deposits to delta foresets, bottom currents produced an increase in silt content and stratification. The dominant sediment type is reddish-brown, parallel-laminated mudstone and siltstone and ripple cross-laminated, grayish-green, well-sorted, calcitic siltstone. Sedimentation units are 0.5- to 2-inch lenses of intrabasinal and extrabasinal materials. This lithic type is situated laterally to massive and burrowed mudstones and intrabasinal conglomerates (these are mostly delta-platform), and it occurs along lower (distal) parts of some of the thicker delta foresets. These transition deposits overlie delta-platform deposits, delta-foreset deposits, and massive lacustrine mudstones.

Delta-Foreset Facies

Perhaps the most striking facies that developed during the low-stand, arid phase are delta-foreset beds (fig. 22). Mudstone, siltstone, sandstone, and intrabasinal conglomerate compose the foresets. Foresets range in thickness from about 2 to 10 feet. Multiple foresets, consisting of as many as four units, are up to 30 feet thick. Dips of foresets range from 4° to 16°. Outcrops oriented approximately perpendicular to transport direction exhibit horizontal or broadly convex upward stratification.

Delta foresets are products of multiple high and low physical-energy conditions. Highly variable energy conditions are recorded by scour-and-fill, ripple bed forms that migrated up foreset slopes (the ripple bed forms produced ripple-drift stratification), intrabasinal conglomerate foresets, erosional surfaces, and discordance in dip angle and orientation between successive depositional units.

Most foreset sequences display (1) a downcurrent

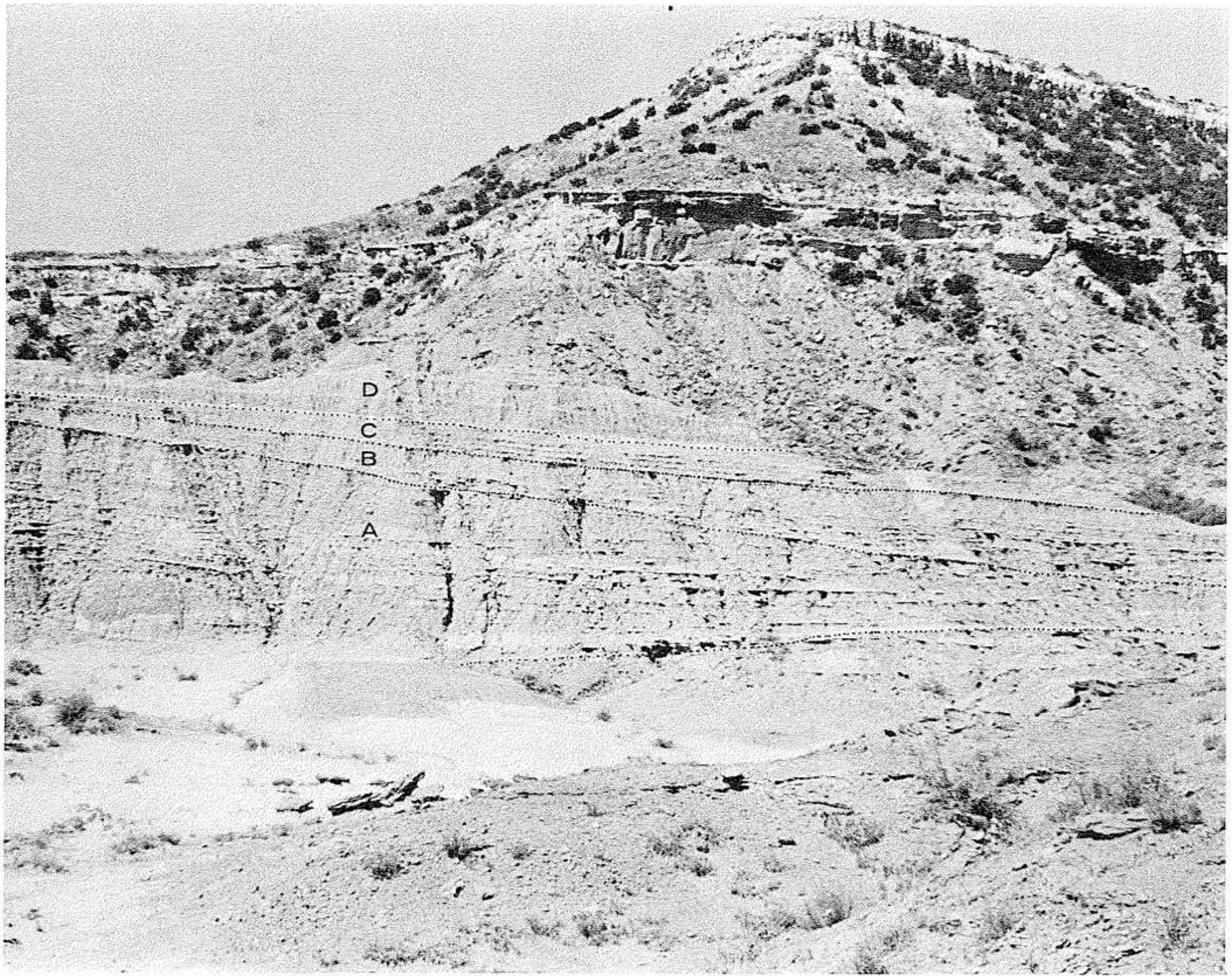


Figure 22. Delta foresets associated with small fan deltas, Macy Ranch, southwest Garza County, Texas (Grassland Southeast 7.5-minute quadrangle). View southwest. At least four depositional episodes recorded in 20-foot-thick foreset sequence. (A) Moderate-brown, parallel inclined laminated and ripple cross-laminated, granule-bearing coarse siltstone to very fine sandstone; foresets dip 4° to 9° north. (B) Light-brown to moderate-brown, parallel inclined laminated and ripple cross-laminated very fine to fine sandstone; foresets dip 6° to 8° north. (C) Light- to moderate-brown, ripple cross-laminated very fine sandstone, and moderate-brown, parallel inclined laminated coarse siltstone; foresets dip about 4° north. (D) Moderate-brown to reddish-brown, parallel-laminated, clayey siltstone, and grayish-green, ripple cross-laminated very fine sandstone; foresets dip about 3° north.

decrease in dip angle and bedding thickness, (2) conglomerate lenses that are thickest near tops of foresets but generally pinch out before reaching the toe, and (3) soft-sediment deformation that is normally confined to sandstone units.

Sedimentation units include (1) parallel-laminated mudstone and siltstone, (2) ripple cross-laminated siltstone and very fine grained sandstone, (3) ripple-drift siltstone and very fine sandstone (fig. 23), and (4) 1- to 6-inch beds of granule to pebble intrabasinal conglomerate (fig. 24). Thin, high-angle foresets are commonly accompanied by regressive ripples (Jopling, 1961).

Delta-Platform Facies

Delta foresets are capped by conglomerate and sandstone that were deposited by braided streams. Conglomerate, the dominant textural type, was derived from Triassic mudstone, siltstone, sandstone, and caliche. Minor gravel-sized clasts are wood debris (some wood fragments have been leached, others have been silicified), bone fragments, and *Unio* shells in various stages of disarticulation, fragmentation, and rounding (fig. 25).

Two geometric types, sheet and channel-fill, compose the delta-platform fluvial facies. Sheetlike conglomerate beds 1 to 5 feet thick conformably overlie delta foresets. Some of the conglomerate beds grade basinward into delta foresets. Conglomerate sheets consist of alternating granule to pebble conglomerate and very fine grained to very coarse grained sandstone. Sedimentary structures in conglomerates are trough-fill cross-strata, minor foreset cross-strata, and parallel bedding. Sedimentary structures in sandstones are trough-fill cross-strata and parallel laminae. Sheet-like geometry and suites of sedimentary structures exhibited by

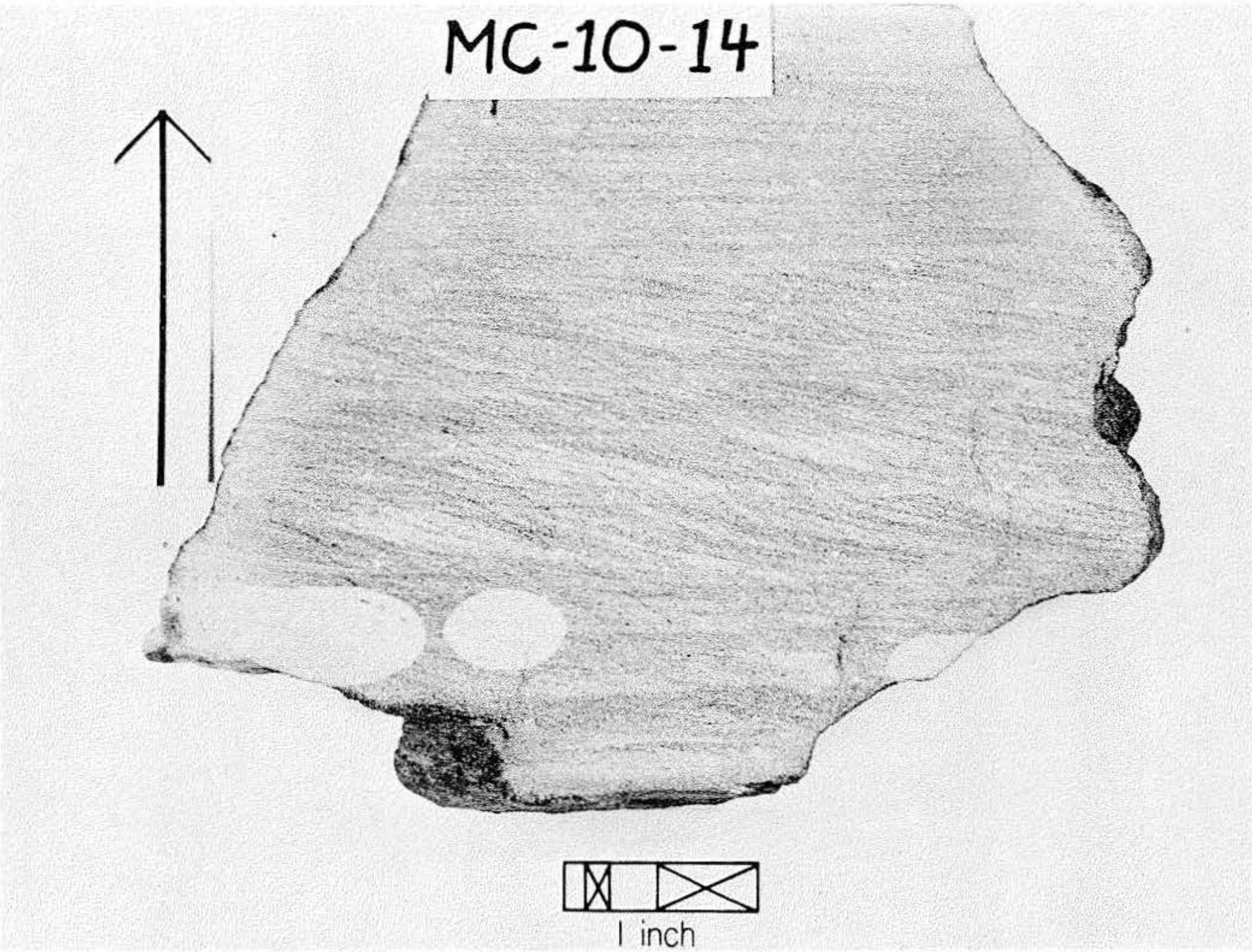


Figure 23. Ripple-drift siltstone and sandstone, Slaughter Ranch, southwest Garza County, Texas (Middle Creek 7.5-minute quadrangle). Pale-red (5 R 6/2) coarse siltstone to very fine sandstone with light-greenish-gray (5 G 8/1) reduction patches. Ripple drift (migration from left to right) grades upward into parallel laminae.

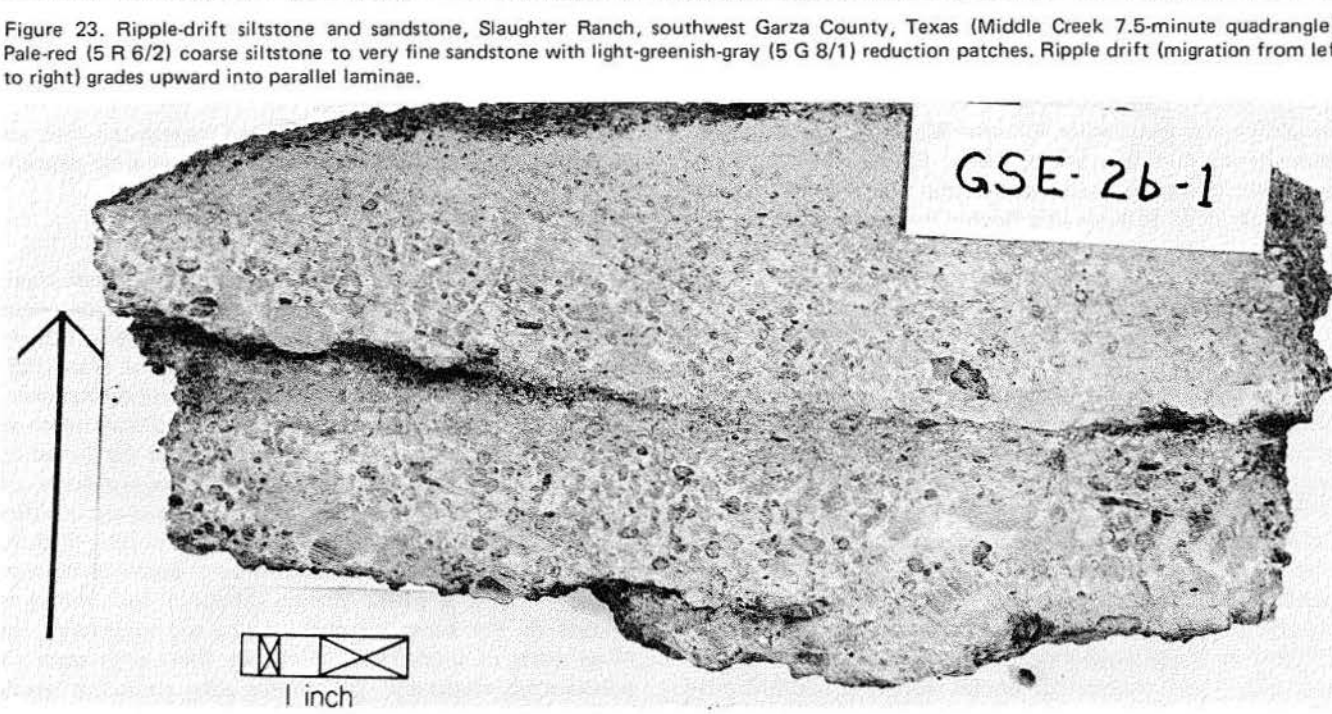


Figure 24. Intrabasinal conglomerate, Macy Ranch, southwest Garza County, Texas (Grassland Southeast 7.5-minute quadrangle). Moderate-brown calcitic granule to pebble intrabasinal conglomerate. Clasts are round to well-rounded mudstone, siltstone, and caliche. Two graded sedimentation units constitute this sample.

Figure 25. Fresh-water clam, *Unio*, on upper surface of delta platform, Slaughter Ranch, southwest Garza County, Texas (Cooper Creek 7.5-minute quadrangle). Carpenter's rule is 6 inches long, 1.7 inches wide.

conglomerates are similar to some Modern braided-stream deposits (Ore, 1963; Smith, 1970; Church, 1972). Conglomerate sheet deposits become thin and are transitional with finer delta foresets in a downcurrent direction. Upper surfaces of some sheet conglomerates contain *Ophiomorpha* and rare to abundant, randomly oriented, juvenile and adult, articulated and disarticulated *Unio*.

Channel-fill conglomerates are of two types. The first is represented by thin granule to pebble lenses flooring straight channels that have parabolic cross sections (fig. 26). Channels were about 15 feet deep and were alternately active and inactive as indicated by channel-fill sequences of conglomerate, sandstone, and siltstone. Most channel-fill sedimentation units conform to the channel configuration. Conglomerate beds are a few inches to about 3 feet thick and are either structureless or display indistinct parallel bedding and trough-fill cross-strata. A second type of channel-fill conglomerate accumulated within feeder systems for sheet conglomerates and delta foresets (figs. 26 and 27). These channel-fill bodies display a width/depth ratio of about 25 to 1 and are filled chiefly with trough-fill cross-stratified, granule to cobble conglomerate. Clast types are similar to those in sheetlike conglomerates. Wood and bone fragments and disarticulated and fragmented *Unio* are rare to common in the second type of channel-fill deposit.

Mudflat Facies

Mudflat deposits apparently accumulated upon abandoned fan-delta platforms, between contemporaneous deltas, and in desiccating ponds and lakes. Green, brown, and purple mudstone facies contain traces of evaporites, including mud-filled chert nodules. It is possible that chert accumulated initially as a complex sodium silicate (such as magadiite; see Eugster, 1967) that was later converted to chert. Mudflat deposits commonly display evidence of desiccation. Thoroughly desiccated mudstones are mottled reddish brown, grayish green, and grayish purple. Slightly desiccated mudstones are reddish brown. Some desiccation cracks are calcite filled. Zoning (about 1 foot thick) is evident in the more intensely desiccated mudstones. In lower parts of mudstones, cracks are filled with sand- to pebble-sized mudclasts. The middle zone comprises many small cracks that created a pebble to cobble breccia (clasts do not appear to have been transported). Angular to round, sand- to pebble-sized mudclasts (indicating some transport)

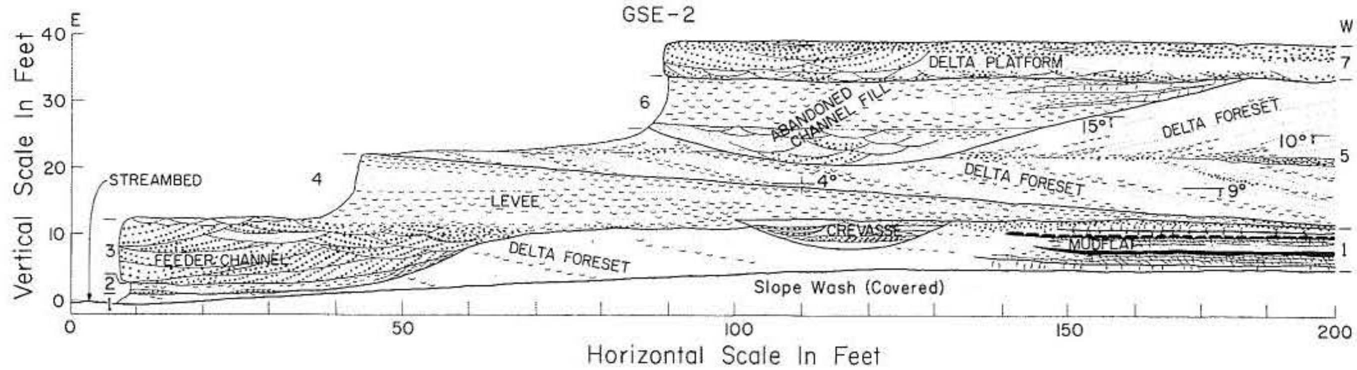


Figure 26. Facies developed during low stand, southeastern Garza County, Texas (Macy Ranch, Grassland Southeast 7.5-minute quadrangle). Seven facies depicted in outcrop sketch: delta foresets, mudflat, feeder channel, crevasse channel, levee, abandoned channel fill, and delta platform. *Delta foresets* have apparent dips of 9° to 15° and consist of parallel-laminated mudstone, siltstone, very fine sandstone, and granule conglomerate. Lateral to upper parts of some foresets are *mudflat deposits* consisting of burrowed, ripple cross-laminated, contorted, and desiccated claystone, siltstone, and very fine sandstone. *Feeder channels* are filled at base (see unit 2) with parallel-laminated, contorted foreset crossbeds and ripple-drift siltstone to granule conglomerate. Most feeder channels are filled with coarse sandstone to cobble intrabasinal conglomerate; sedimentary structures are trough-fill cross-strata 15 to 30 feet wide and 1 to 3 feet thick at base. *Crevasse channel* characterized by multiple scour-and-fill events; fill is muddy fine sandstone to granule conglomerate; sedimentary structures are parallel laminae, foreset cross-strata poorly defined trough-fill cross-strata, and ripple cross-laminae. *Levee deposits* are wedge shaped (thickest at east and pinch out to west); sediment is clayey siltstone to very fine sandstone; sedimentary structures are parallel laminae and ripple cross-laminae. *Abandoned channel fill* is about 12 feet thick composed of trough-fill cross-stratified fine sandstone to granule conglomerate, with central part filled with ripple cross-laminated clayey coarse siltstone to muddy very fine sandstone, and channel margin of fill composed of alternating ripple cross-laminated siltstone to very fine sandstone and massive to burrowed muddy very fine sandstone. Uppermost unit is *delta platform* consisting of trough-fill cross-stratified coarse sandstone to granule conglomerate, parallel-laminated very fine to fine sandstone, and massive pebble intrabasinal conglomerate with *Unio* and sand-filled burrows on bedding surfaces; this unit grades into delta foresets to the west.

characterize the upper part of the zone (fig. 28). Desiccated mudstones commonly overlie massive or burrowed lacustrine and prodelta mudstone, and may themselves be overlain by lacustrine and prodelta mudstone or delta foresets.

VALLEY-FILL FLUVIAL SYSTEMS

Lowering of base level during arid cycles caused entrenchment of existing streams and created new headwardly eroding streams. The net result was development of numerous valleys, the maximum depths of which, in the area defined by Dickens, Crosby, Kent, and Garza Counties, were about 50 feet. The valleys are characterized by a complex sequence of fill deposits that records many depositional and erosional events. The deposits range in texture from mudstone to cobble conglomerate. Valleys were filled with debris that was transported down the valley by braided and meandering streams, eroded from valley walls by slope wash, and deposited from suspension as the valley was flooded with rising lake waters (fig. 29).

Sediment that was eroded from older Dockum deposits through entrenchment of older streams and by headwardly eroding streams was the dominant sediment available to construct the small fan deltas.

MINOR FACIES

Local occurrences of gypsum, dolomite, chert, and salt hoppers in some of the Dockum deposits suggest the presence of small water bodies with varying salinities. Primary and secondary gypsum occur throughout the Dockum. Primary gypsum crystals are scattered through some thin reddish-brown mudstones and siltstones that accumulated during a low-stand, arid phase. Secondary satinspar veins cut diagonally across bedding in low-stand facies. Secondary selenite layers were emplaced at the base of meanderbelt sandstone facies containing abundant carbonized plant debris.

Dolomite has been observed only in the lower part of the Dockum Group. It occurs locally as thin, irregular, bioturbated lenses within lacustrine mudstone and siltstone beds. In Kent County, 1- to 3-inch dolomite beds are restricted to a 3-foot-thick zone 70 feet above the Permian-Triassic boundary. Thin dolomite beds and lenses are contained within reddish-brown, massive, clayey siltstone and yellowish-gray to light-brown, calcitic, ripple cross-laminated siltstone. Dolomite is mottled, moderate brown, grayish pink, and yellowish gray. It is extensively bioturbated and consists of finely crystalline brown dolomite, coarsely crystalline limpid dolomite, and sparry calcite that fills vugs and fractures (fig. 30). Folk and Siedlecka (1974) and Folk and Land (1975) concluded that the association of finely crystalline dolomite and the coarsely crystalline, euhedral, transparent limpid dolomite is the product of a "schizohaline" environment. The schizohaline environment is characterized by shallow hypersaline waters that are suddenly and drastically changed to almost fresh water by fresh-water flooding or storm activity. Examples of such environments are sabkhas and shallow bays and lagoons, such as Baffin Bay, Texas. Finely crystalline dolomite forms under hypersaline conditions when dolomite crystallization rates are high and impurities are abundant. Limpid dolomite forms when salinity has been greatly reduced (Mg/Ca ratio remaining about the same as in hypersaline conditions), impurities are few, and

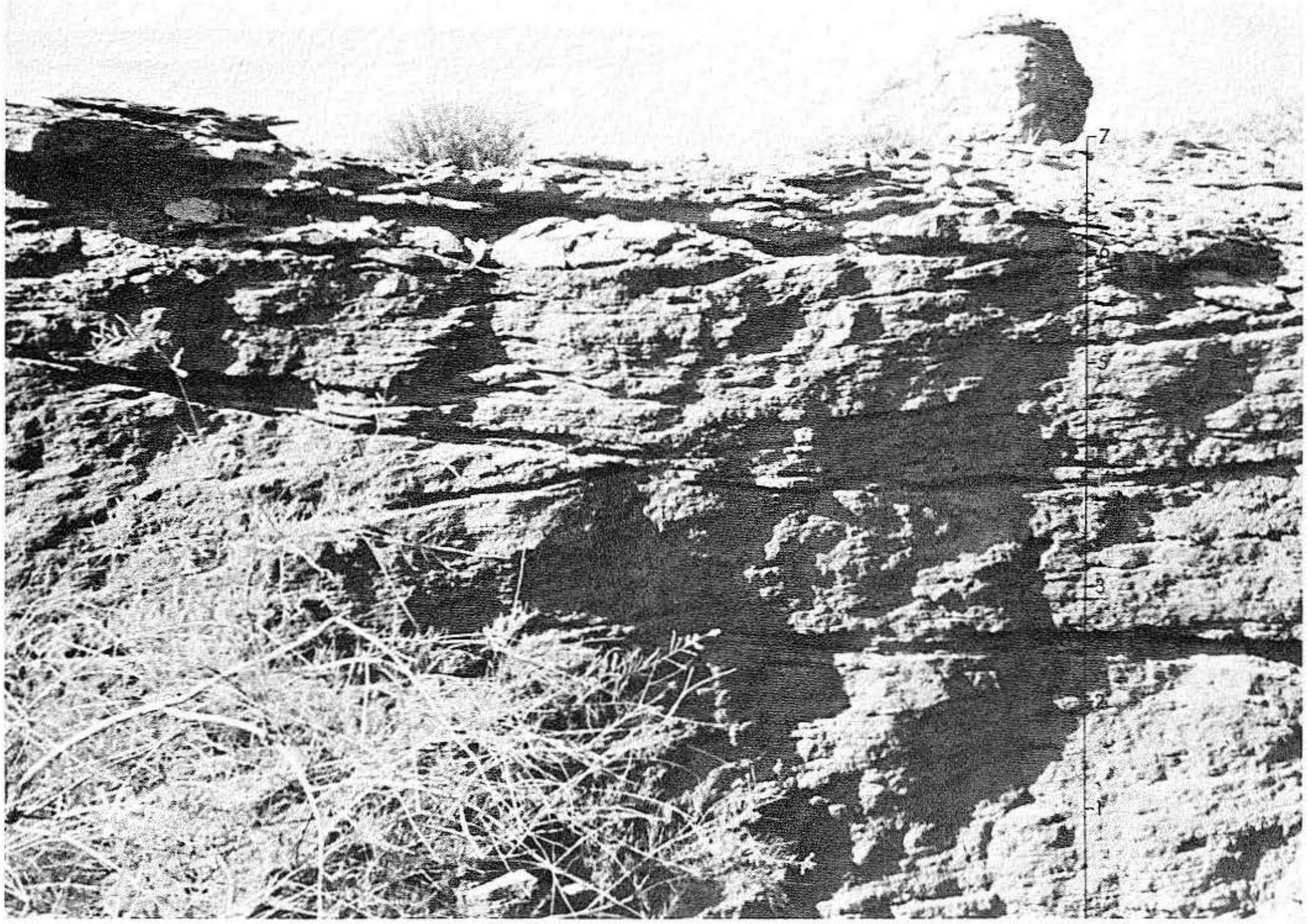


Figure 27. Feeder channel for small fan-delta system, Macy Ranch, southwest Garza County, Texas (Grassland Southeast 7.5-minute quadrangle). View south. Vertical scale in feet. Channel fill comprises reddish-brown to moderate-brown, calcitic, granule to pebble intrabasinal conglomerate; clasts comprise mudstone, siltstone, sandstone, caliche, *Unio* valves, and bone fragments. Primary sedimentary structures are predominantly trough-fill cross-strata. In the lower part of channel fill, trough-fill cross-strata are 15 to 30 feet wide and 1 to 3 feet thick. In the upper part of channel fill trough-fill cross-strata are 3 to 4 feet wide and about 0.5 foot thick. Grain size decreases upward from pebble conglomerate at base to granule-bearing coarse sandstone at top.

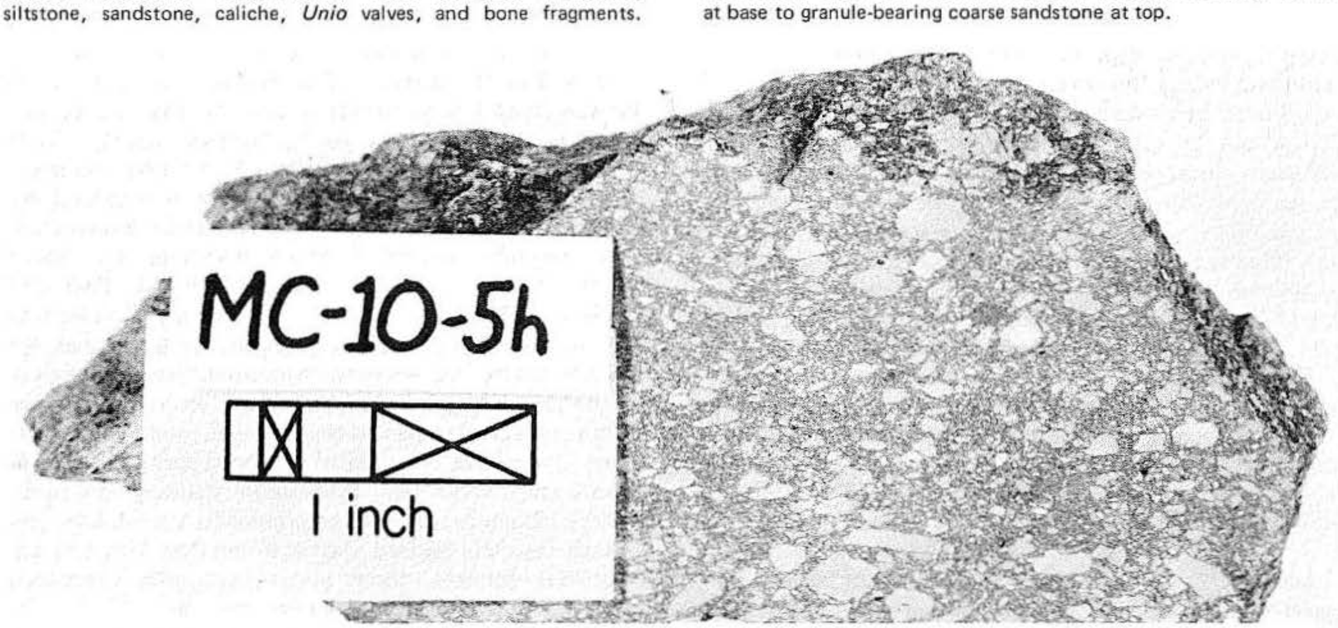


Figure 28. Desiccation breccia, Slaughter Ranch, southwest Garza County, Texas (Middle Creek 7.5-minute quadrangle). Grayish-red-purple (5 RP 4/2) granule breccia. Clasts are greenish-gray mudstone in a matrix of purple mudstone. Mudstone clasts are angular to subangular. This lithologic type overlies mudstone with desiccation cracks.

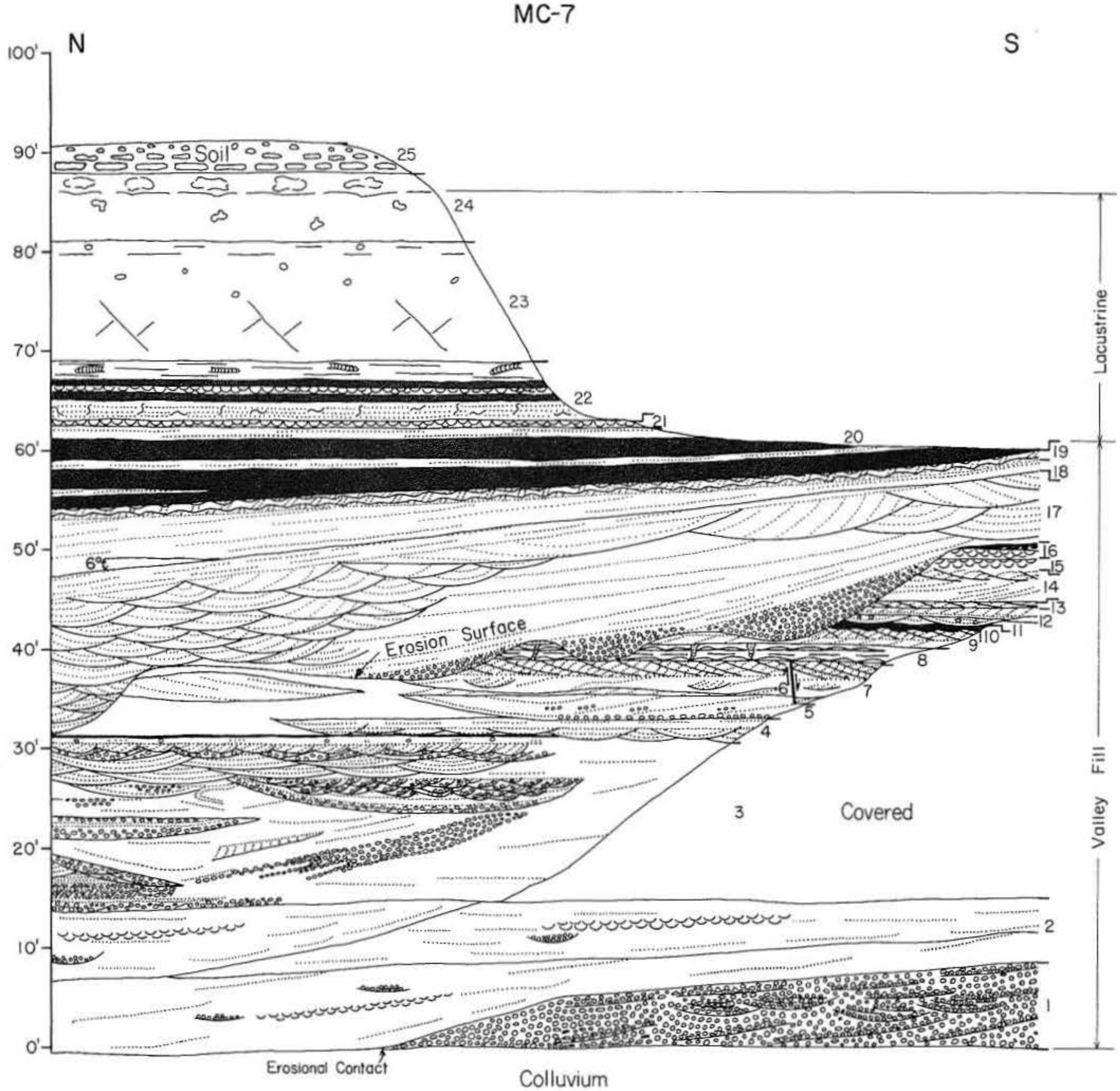


Figure 29. Valley-fill and lacustrine deposits, Slaughter Ranch, southwest Garza County, Texas (Middle Creek 7.5-minute quadrangle). Represented in outcrop sketch are *valley-fill deposits* (units 1 through 19), *lacustrine deposits* (units 20 through 24), and *soil* (top unit 24 and unit 25). At least three sedimentary sequences are represented in *valley fill*: units 1 through 3 (base not exposed), characterized by intrabasinal conglomerate, fine sandstone, and siltstone; conglomerates, mostly lenses of trough-fill and foreset cross-strata; *Unio* fragments abundant in some conglomerates; fine sandstones contain parallel and ripple cross-laminae, trough-fill and foreset cross-strata, and soft-sediment deformation; siltstone is parallel laminated and ripple cross-laminated. Units 4 through 16 (sequence bounded by erosional surfaces) consist of mudstone, siltstone, and very fine to fine sandstone with a few lenses of granule conglomerate; primary sedimentary structures are trough-fill cross-strata, low-angle foreset crossbeds, parallel inclined laminae, ripple drift, ripple cross-laminae, and starved ripples; post-depositional features are desiccation cracks and faults with little displacement. Units 17 through 19 (erosional at base, gradational at top into lacustrine deposits) consist of siltstone, very fine to fine sandstone, and granule to pebble intrabasinal conglomerate; sedimentary structures are trough-fill cross-strata, parallel inclined laminae, and ripple cross-laminae. *Lacustrine deposits* (units 20 through 24) consist of mudstone, siltstone, and very fine sandstone; primary sedimentary structures are parallel laminae and ripple cross-laminae; burrows are common in unit 22 (*Teichichnus* occurs near top of unit). Postdepositional features in mudstones (units 23 and 24) are slickensides, reduction patches, and pyrite-filled fractures. Top of unit 24 and unit 25 comprise soil.

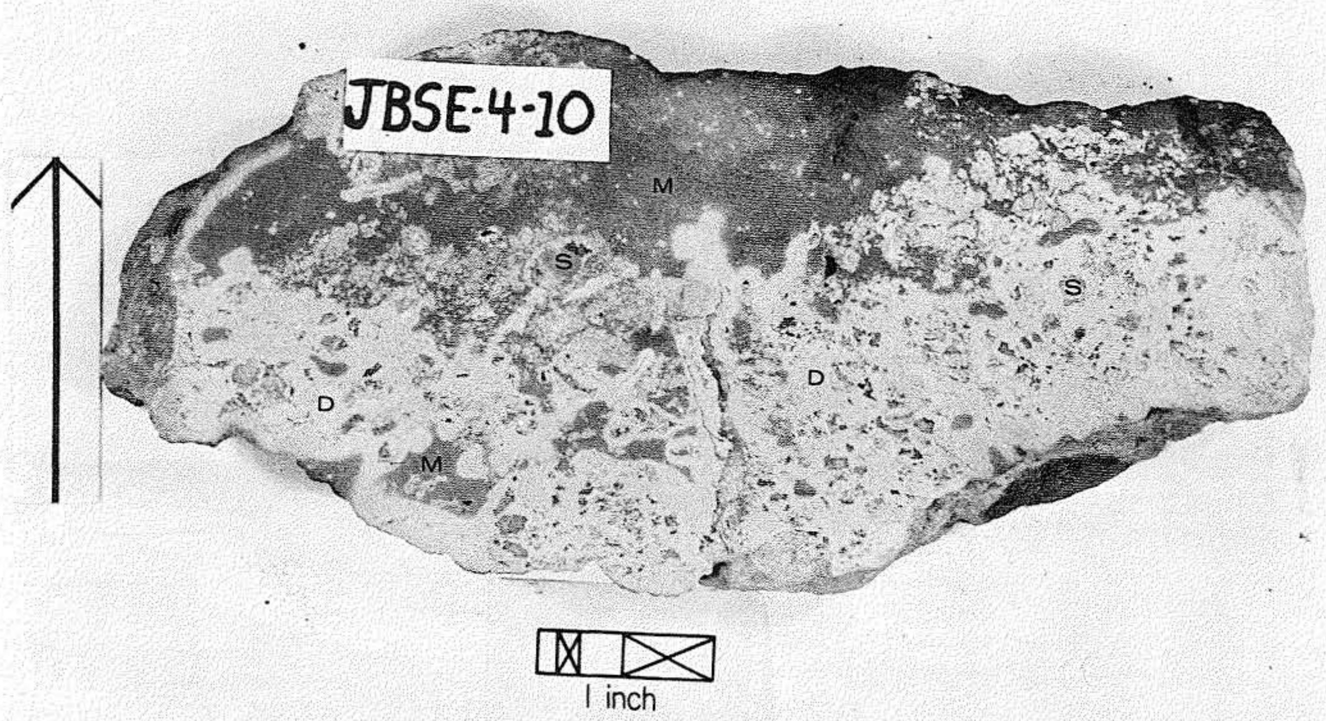


Figure 30. Lacustrine dolomite from lower 70 feet of Dockum Group, Johnson Ranch, Kent County, Texas (Justiceburg Southeast 7.5-minute quadrangle). Mottled pale-red (10 R 6/2) dolomite, pale-reddish-brown (10 R 5/4) dolomitic mudstone, and light gray (N 7) sparry calcite and limpid dolomite. Rock is thoroughly bioturbated and comprises dolomitic mudstone (M), muddy, finely crystalline dolomite (D), vugs and fractures filled with calcite (C), and sparry calcite and limpid dolomite (S).

crystallization rate is slow. Dolomite in the lower part of the Dockum Group is probably a product of schizohaline conditions. A shallow lacustrine water body that was alternately hypersaline and almost fresh is an appropriate setting.

Chert has been observed about 5 feet above the Permian-Triassic boundary in Armstrong County, 60 to 65 feet above the boundary in Briscoe County (approximately equal to the stratigraphic position of dolomite in Kent County), and approximately 40 feet below the Triassic-Cretaceous contact in southwest Garza County.

In Armstrong County (Wayside Crossing) chert lenses (fig. 31) directly overlie paleosols. In Briscoe County (Silverton section) a chert bed a few inches to more than 3 feet thick directly overlies lacustrine deposits, the upper 5 to 10 feet of which are extensively mottled; this chert bed is relatively widespread and locally grades laterally into a paleosol. The type of chert observed in Armstrong and Briscoe Counties has been interpreted as a silcrete (Finch, oral communication, 1975). Silcrete consists of a matrix of secondary silica and generally incorporates widely varying amounts of fragments of rock gravels, grits, and sands of the kinds most resistant to weathering and abrasion (Stephens, 1971). Silcrete is, in effect, a silica-cemented conglomerate or sandstone. In Australia, the major regional occurrences of silcrete, called "billy" (Stephens, 1971), resulted chiefly from deposition during the Pliocene of silica by evapotranspiration from surficial and shallow subsurface waters that arose in a very large subcontinental zone occupied predominantly by lateritic soils. These waters then traversed adjoining but somewhat smaller and drier zones of sufficient evaporative capacity to ensure deposition in areas of suitably low relief and restricted surface drainage (Stephens, 1971). Our tentative interpretation is that chert lenses and beds in Armstrong and Briscoe Counties are silcretes whose origin is analogous to that of silcrete in Australia (Stephens, 1971). Some of the chert lenses may represent accumulation of former magadiite in small ponds or potholes similar to those on Alkali Lake, Oregon, where magadiite is precipitating today (Rooney and others, 1969).

Chert nodules, 3 to 4 inches in diameter along major axes, occur within a mudstone and siltstone section about 30 feet thick which overlies a burrowed, muddy, very fine grained sandstone. Nodules have crinkled outer surfaces similar to those of the sodium silicate—magadiite—currently forming in Lake Magadi, Kenya (Eugster, 1967, 1969; Eugster and Jones, 1968).

Salt hoppers observed only in central Garza County, Texas, occur in low-stand facies composed of massive, reddish-brown, lacustrine and mudflat mudstone which overlies burrowed mudstone.

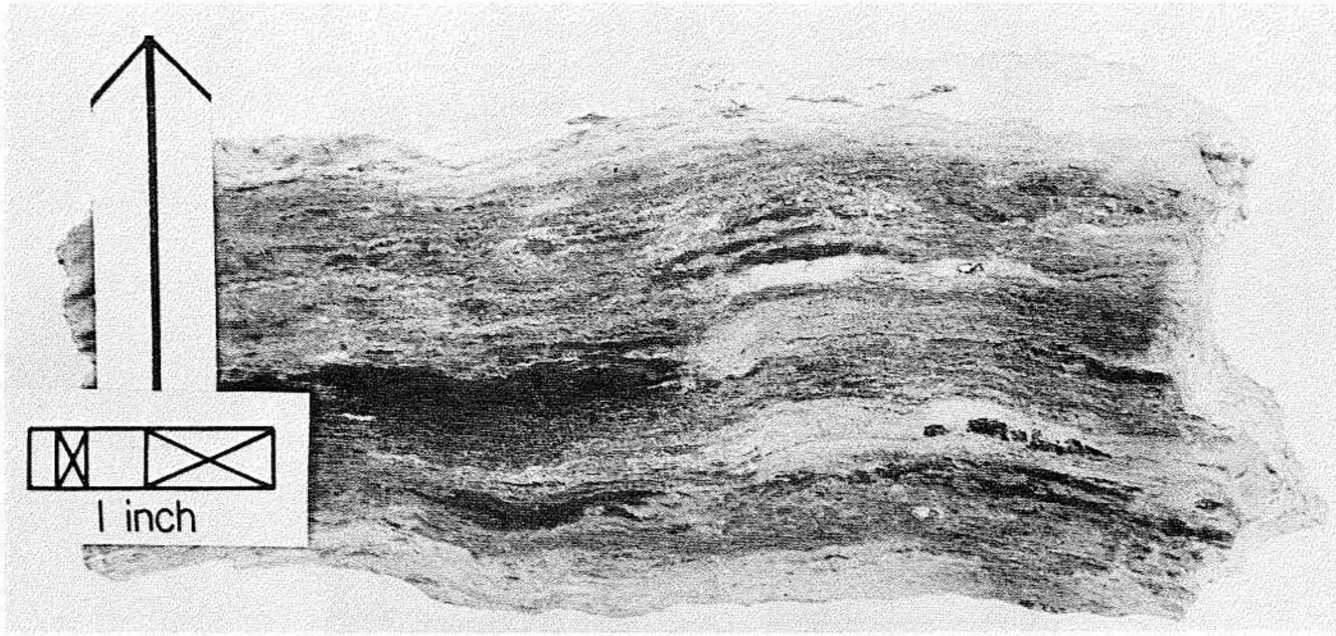


Figure 31. Lenticular chert from lower part of Dockum in road cut at Wayside Crossing, Armstrong County, Texas. Irregular wavy purple, red, yellow, and gray laminae; few mud inclusions.

SUBSURFACE DISTRIBUTION OF LOWER DOCKUM DEPOSITIONAL SYSTEMS

An area of approximately 60,000 square miles in Texas and eastern New Mexico is underlain by the Triassic Dockum Group, or its equivalent. In this report we are concerned only with the lower half of the Dockum Group that underlies an area of approximately 38,500 square miles in 31 counties in Texas and 3 counties in New Mexico. Included in this report are subsurface strata equivalent to Dockum deposits that crop out along the basin margin.

Objectives of the subsurface study are (1) to map the regional distribution of sandstone facies, (2) to interpret the nature and regional distribution of depositional systems, and (3) to correlate uranium occurrence with depositional facies and ground-water properties. This report studies the first two objectives for the lower part of the Dockum Group. Future reports will study the subsurface of the upper half of the Dockum, as well as specific interrelationships among facies, uranium, and ground water.

SUBSURFACE PROCEDURES

Approximately 1,500 gamma-ray logs were used to construct sand-percentage maps and cross sections. A few electric logs were available for the area, but most of them were of poor quality because of highly saline drilling fluid produced by Permian salt penetrated by the wells. Gamma-ray logs measure the natural radioactivity of rocks (Pirson, 1963). Radioactive elements such as uranium, thorium, and potassium emit gamma rays. Sediment containing clays with a high potassium content (for example, illite) has higher gamma radiation levels than do clean (no interstitial clay) terrigenous silt and sand. Lithic composition of the subsurface Dockum Group was inferred by assuming that fine-grained rocks (mudstones) emit more gamma radiation than do coarse-grained rocks (siltstones and sandstones). This assumption was verified by comparing lithic composition from well cuttings with gamma-ray log properties. However, clear-cut distinction between siltstone and sandstone cannot be made with gamma-ray logs. Consequently, it is probable that some siltstone has been included in the sand-percentage maps. It is also possible that background uranium content of some sandstone would result in an erroneous mudstone interpretation.

Gamma-ray logs have been used to interpret depositional environments of terrigenous clastic deposits that underlie parts of the North Sea (Selley, 1976), and to interpret the sedimentology of petroleum-bearing strata in the Niger Delta area (Weber, 1971). In these two studies gamma-ray logs were used to determine textural trends in the manner that SP curves are so used.

For this interpretation, an arbitrary base line was consistently used on each gamma log to define sandstone,

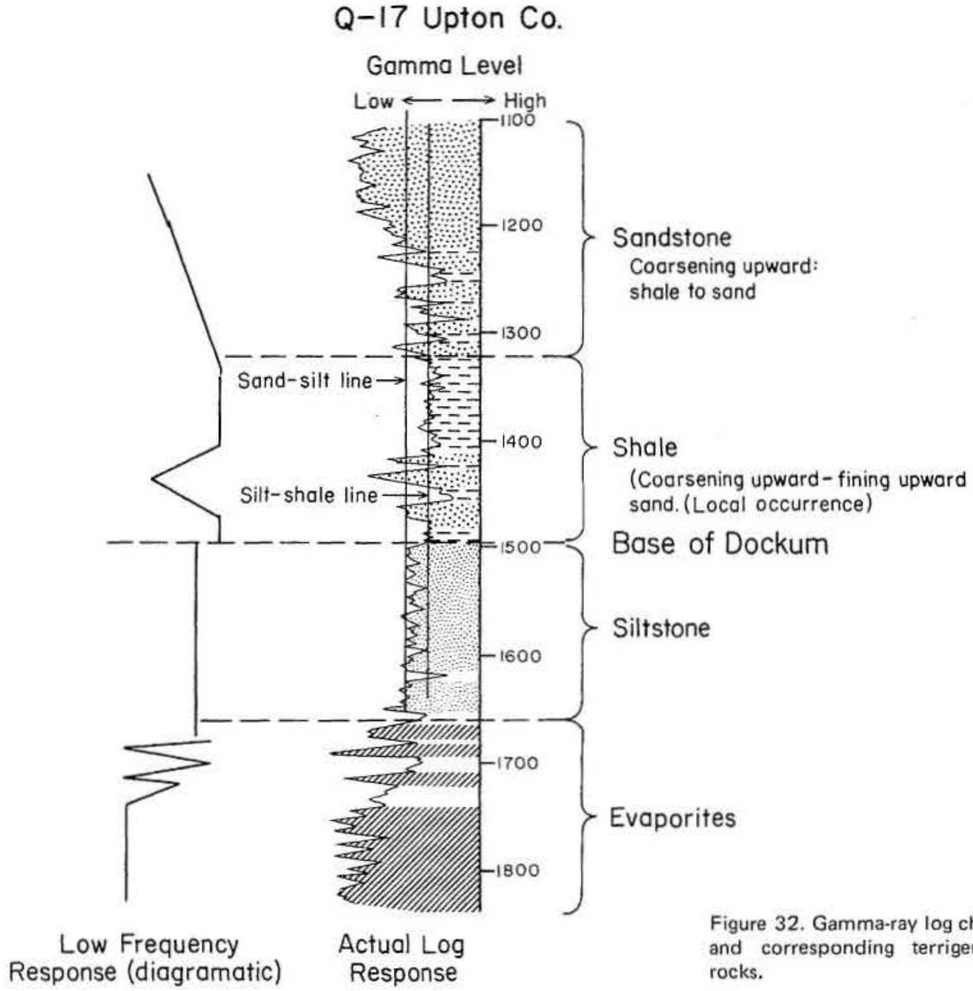


Figure 32. Gamma-ray log characteristics and corresponding terrigenous clastic rocks.

siltstone, and mudstone. The mudstone-siltstone base line was set at a gamma level sufficiently low to exclude the bulk of the sub-Dockum siltstone section. This siltstone, considered the youngest Permian sequence in the Texas - New Mexico area by some workers (Miller, 1955), is known as the Pierce Canyon Red Beds (Lang, 1935) in the Delaware Basin and is called Dewey Lake Red Beds (Page and Adams, 1940) in the Midland Basin. According to Miller (1955), the Pierce Canyon and Dewey Lake Red Beds are lithically homogeneous and consist of very thinly and evenly bedded, clayey and sandy siltstone cemented with gypsum and calcite. From subsurface data generated during this investigation, the Dewey Lake appears to be lithically uniform over a large part of the basin, thereby producing a common relative datum for comparison even though variability in logging tools and amplification (scales) exists among logs. The base of the Dockum Group in this study was selected to agree with the top of the Dewey Lake. A lithic change that is recognizable over a large part of the Midland Basin was chosen as the base (see figs. 32 and 33; well from Upton County).

SANDSTONE DISTRIBUTION PATTERNS

Sandstone-percentage maps were prepared for the lower part of the Dockum Group by arbitrarily dividing the Triassic section in each well at its arithmetic midpoint. This boundary was used consistently except toward the basin margins where the upper part of the Dockum Group has been removed by erosion. Near the basin margins, the arbitrary boundary was placed above thick sands that consistently occur in the lower part of the Dockum section. Sand-percentage maps, rather than net-sand maps, were prepared because they do not reflect erosional thinning of the section as dramatically as do net-sand maps. Furthermore, sand percentage emphasizes dip orientation of sand trends by eliminating effects of regional changes in thickness of the map interval.

The subsurface area included in this report extends from the Matador Arch (fig. 2) southward to the Dockum pinchout. Although the lower part of the Dockum is as much as 1,100 feet thick near the center of the basin, persistent sand distribution patterns are obvious (fig. 4).

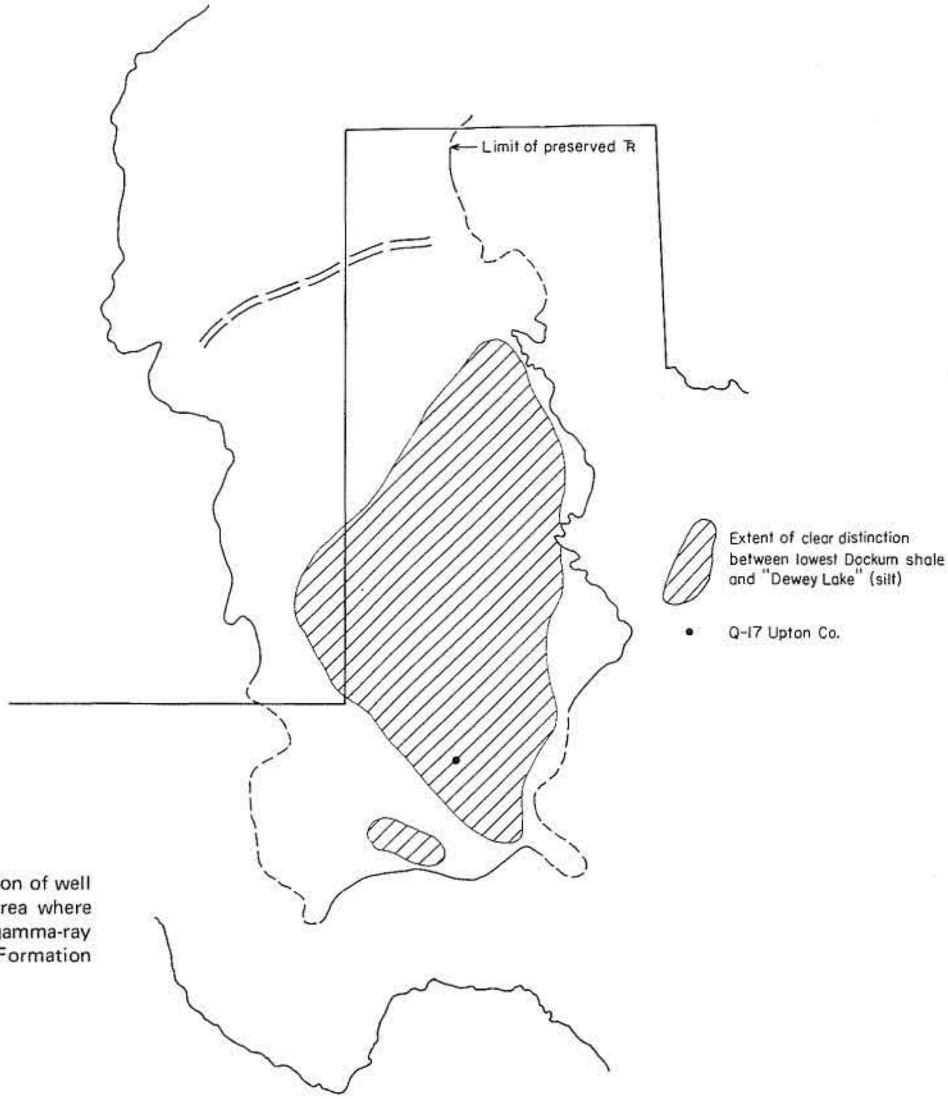


Figure 33. Map showing location of well illustrated in figure 32 and area where clear distinction exists on gamma-ray logs between Dewey Lake Formation (silt) and basal Dockum shale.

Outcrop data, subsurface sandstone trends, and gamma-log patterns indicate that fan deltas and high-constructive lobate deltas and their attendant fluvial systems were the major depositional systems operating during deposition of the lower part of the Dockum Group. Deltas prograded from the east, south, and west, and perhaps at times coalesced.

From Mitchell through Garza Counties, high-constructive lobate deltas migrated westward as far as Terry County. To the north, in the area of Dickens, Crosby, Floyd, and Motley Counties, high-percent sandstone trends exhibit wide lateral distribution associated with inferred fan-delta accumulation. Percent-sandstone patterns bifurcate in Lubbock and Hockley Counties, marking a transition between fan deltas in the north and high-constructive lobate deltas in the central basin area. In the southern part of the basin, between Loving and Sterling Counties, high-percent sandstone trends are poorly defined, but more sandstone occurs in this area than elsewhere in the basin. The wide lateral sandstone-percent distribution in the south is attributed to fan-delta deposition during both humid and arid cycles. High-percent sandstone in eastern New Mexico extends from Chaves County, across Lea County, and into Yoakum County, Texas, where it defines a distributary pattern. This pattern is probably the product of a high-stand high-constructive lobate deltaic system.

Regional high-percent sandstone patterns based on subsurface data coincide with depositional systems recognized in outcrop. However, depositional cycles recognized in outcrop and attributed to base-level changes have not been identified in the subsurface. There are several explanations for the absence of such depositional cycles in the subsurface. First, the scale of some depositional and erosional features precludes recognition from available subsurface data. For example, valley-fill sequences may be up to 200 feet thick, but they are relatively narrow stratigraphic sequences about 0.5 to 0.75 mile wide. Regional well spacing, from 2 to 8 miles apart, is inadequate to define valley-fill deposits. Sediments that compose low-stand deposits were eroded from older Triassic deposits, and consequently, a large proportion of these sediments were derived from older mudstone facies. Many sand- and gravel-sized clasts are undoubtedly recorded as mudstone or siltstone on gamma-ray logs. A relatively higher percentage of extrabasinal sediments reside in high-stand deposits principally because of differences in duration and intensity of depositional processes operating during high and low base-level stands. High-intensity, short-duration depositional episodes associated with low stand were not conducive to sorting of sediment, either by size or density. Lower intensity, longer duration depositional events operating during high-stand conditions were favorable for grain-size sorting. Well-sorted (cleaner) sands and silts are therefore restricted primarily to high-stand cycles, and sand-percentage maps probably reflect principally depositional systems operating during high stand.

An outstanding feature of the lower part of the Dockum Group is an east-west trending high-mudstone (low-percent sandstone) belt between fan deltas to the south and high-constructive lobate deltas in the central basin area. This region of high mudstone composition includes much of Mitchell, Howard, Martin, and Andrews Counties, Texas, and extends into southeastern Lea County, New Mexico. High mud deposition persisted in this region throughout Dockum deposition and can be recognized in adjacent outcrop, as well as in the subsurface. In outcrop, the mudstone sequences are of lacustrine and interdeltaic origin.

FACIES IMPLICATIONS OF GAMMA-RAY LOG PATTERNS

During the past decade electric-log patterns have been used to interpret many depositional facies (Fisher, 1969; Brown, 1969; Galloway, 1970, 1977; Erxleben, 1975; and Cleaves, 1975). Examples of some terrigenous clastic facies that may exhibit distinctive electric-log patterns are (1) fluvial channel-fill; (2) delta-plain; (3) delta-front, including channel-mouth bar; and (4) prodelta. Erxleben (1975) demonstrated that fan deltas may also exhibit diagnostic electric-log patterns. Most terrigenous clastic deposits display vertical changes in grain size, and such changes may be recorded by the self-potential or resistivity curves or by both. Contacts between superposed terrigenous clastic facies may be gradational or abrupt (such as erosional contact). These boundary relationships may be displayed by specific, distinctive electric-log patterns. Response to texture or composition or to both should also be exhibited by gamma-ray logs (Weber, 1971; Selley, 1976). At this time, however, we can make only general interpretations of genetic facies within the Dockum Group by using gamma-ray logs. Extensive investigation and correlation of gamma-ray logs and lithic facies in a basin, however, can lead to reasonably accurate interpretation of vertical variations in texture and grain size.

Two strike cross sections and one dip cross section display Dockum stratigraphy downdip from sampled outcrop areas (figs. 4, 34, 35, and 36). Strike sections A-A' and B-B' transect fluvial-deltaic systems in Lubbock, Garza, and Scurry Counties. Fluvial-deltaic patterns (fig. 34) are arbitrarily inferred within areas consisting of 40 percent or more sand within a stratigraphic interval of 200 to 1,050 feet.

Lacustrine and prodelta mudstone and siltstone represent the initial 100 to 170 feet of Triassic sediment in the Dockum basin (figs. 35 and 36). Coarsening-upward, progradational deltaic deposits overlie these lacustrine and prodelta mudstone-siltstone facies. In Scurry County, the lacustrine and prodelta mudstone-siltstone sequence is overlain chiefly by fining-upward fluvial deposits (figs. 35 and 36). In figure 35, multiple, coarsening-upward sequences characterize the Garza fluvial-deltaic system. Individual coarsening-upward sequences are 25 to 100 feet thick; some are succeeded by fining-upward fluvial sequences. Maximum composite thickness of the Garza fluvial-deltaic system along profile A-A' is approximately 300 feet (fig. 35, well 423, Garza County). The Garza fluvial-deltaic system thins to the west in Lynn County (fig. 35), where multiple fining-upward sequences reach thicknesses of 90 feet; the average sequence is 50 feet thick.

In addition to coarsening-upward sequences, the Lubbock fluvial-deltaic system exhibits gamma-ray log patterns that display abrupt lower and upper contacts similar to electric-log patterns of the Pennsylvanian Henrietta fan-delta system of North-Central Texas (Erxleben, 1975). Although coarsening-upward sequences characterize the southeastern part of the Lubbock fluvial-deltaic system, the system was dominated by braided-stream and fan-delta systems interpreted from sandstones that exhibit gamma-ray log patterns with abrupt bases and tops.

The Garza fluvial-deltaic system extends southwestward from Garza County through Lynn County and into Terry County (figs. 34 and 36), where it joins the Scurry and Chaves fluvial-deltaic systems. Multiple coarsening-upward and fining-upward sequences within a composite section 400 feet thick define the Chaves system. To the southwest, the Chaves system is overlain by an unnamed fan-delta system that prograded into the basin from Eddy and Lea Counties, New Mexico, and from Loving County, Texas. This fan-delta system composes most of the lower part of the Dockum Group in Lea County (fig. 36).

Interpretation of the lower part of the Dockum above the previously described basal deltaic sequences is tentative at this time. These deposits probably represent sedimentation under fluctuating base-level conditions. Clear-cut depositional trends have not been recognized in the upper part of the lower half of the Dockum Group, but studies of these facies continue.

SEDIMENT DISPERSAL PATTERNS

Several sedimentary features have been used by numerous researchers to determine dispersal trends of terrigenous clastic rocks. Among these features are sand-body geometry, lateral changes in mean clast size, clast orientation, clast roundness, changes in scale and type of sedimentary structures, and orientation of sedimentary

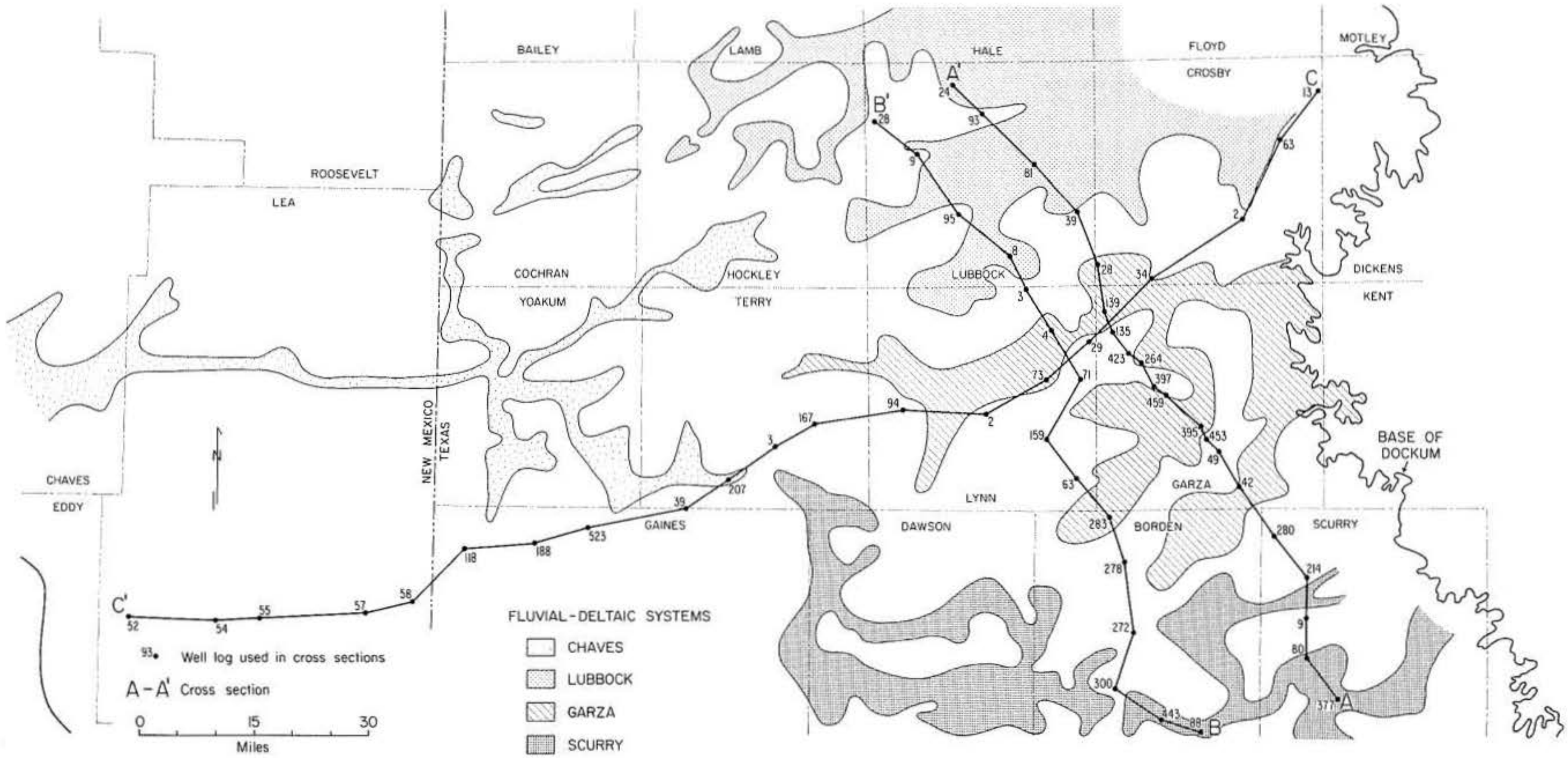


Figure 34. Informal names of fluvial-deltaic systems, Texas and New Mexico area south of Matador Arch. Cross sections A-A', B-B', and C-C' shown in figures 35 and 36.

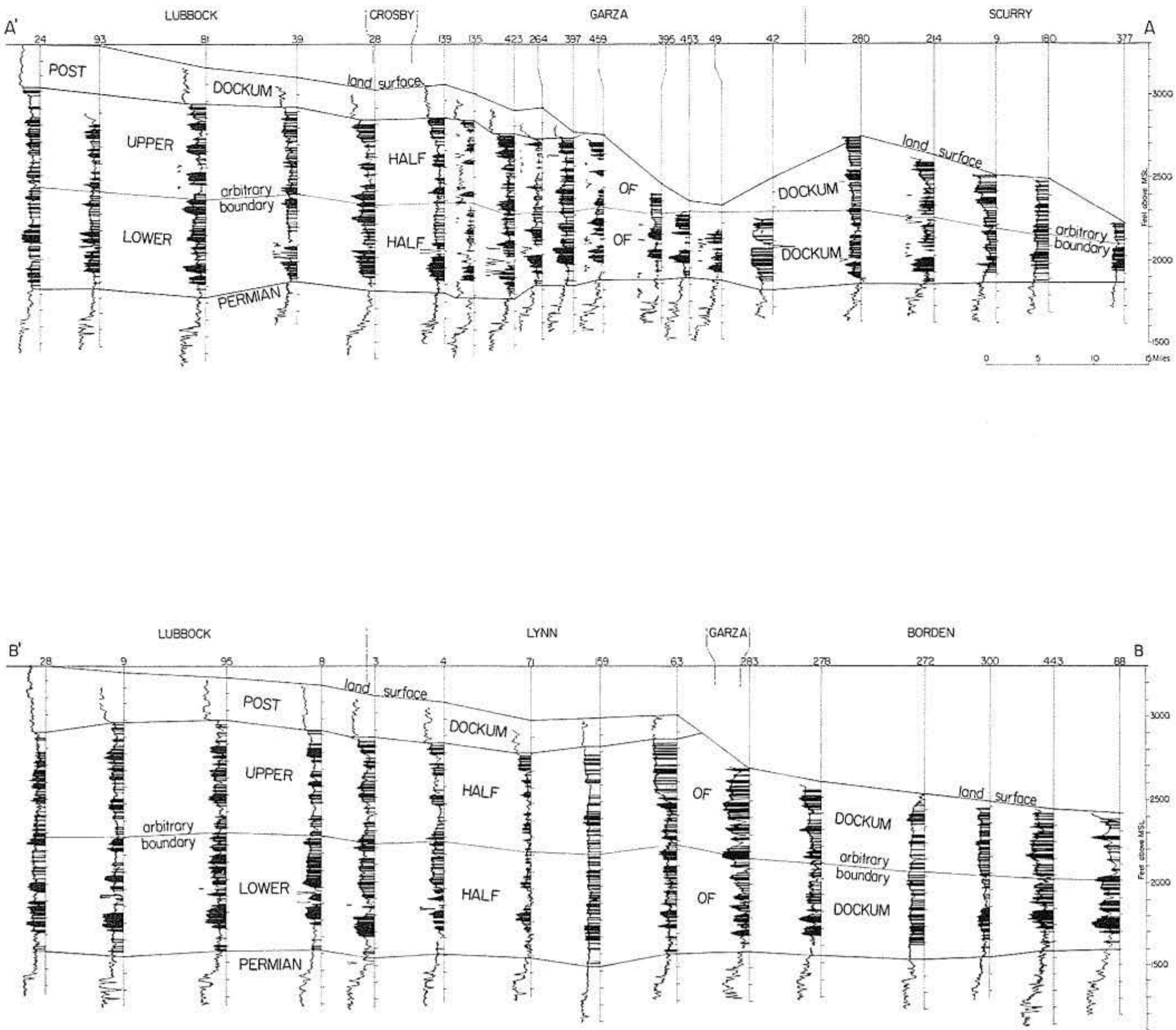

A'
LUBBOCK
CROSBY
GARZA
SCURRY
A
24
93
81
39
28
139
135
423
264
397
459
395
453
49
42
280
214
9
180
377
POST
DOCKUM
land surface
UPPER
HALF
OF
DOCKUM
arbitrary boundary
LOWER
HALF
OF
DOCKUM
PERMIAN
land surface
arbitrary boundary
Feet above MSL
3000
2500
2000
1500
0
5
10
15 Miles
B'
LUBBOCK
LYNN
GARZA
BORDEN
B
28
9
95
8
3
4
71
159
63
283
278
272
300
443
88
land surface
POST
DOCKUM
UPPER
HALF
OF
DOCKUM
arbitrary boundary
LOWER
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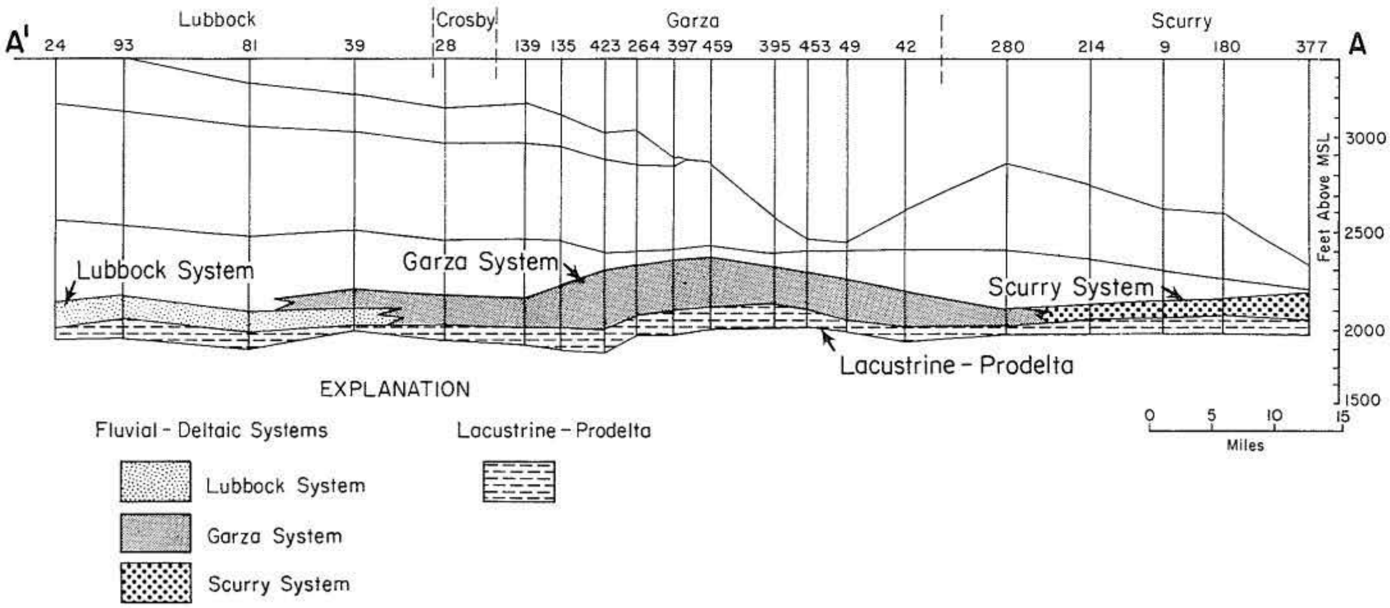
Figure 35



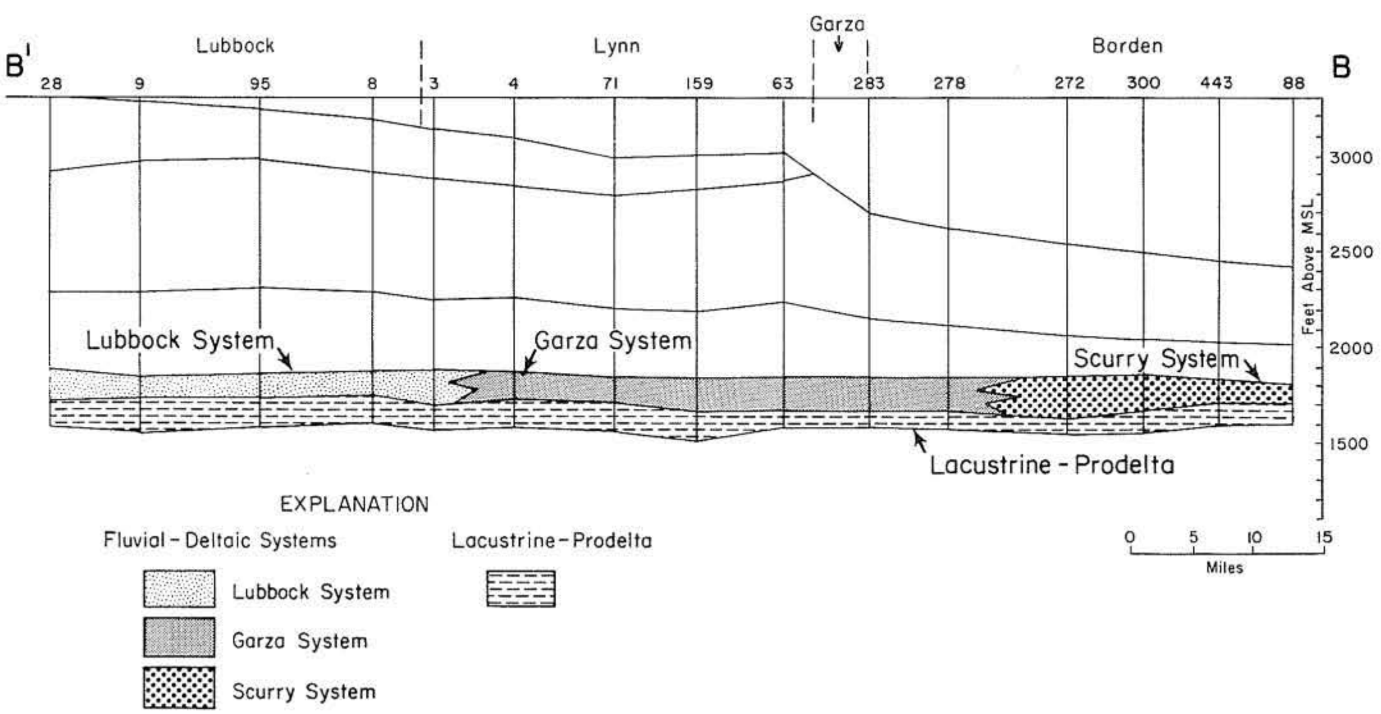


Figure 35. Strike cross sections across parts of Lubbock, Garza, and Scurry fluvial-deltaic systems. Section shows gamma-ray log profile, lithic interpretation (sandstone—black; shale/siltstone—white; A, B), and boundaries of principal depositional systems (C). Line of section shown in figure 34.

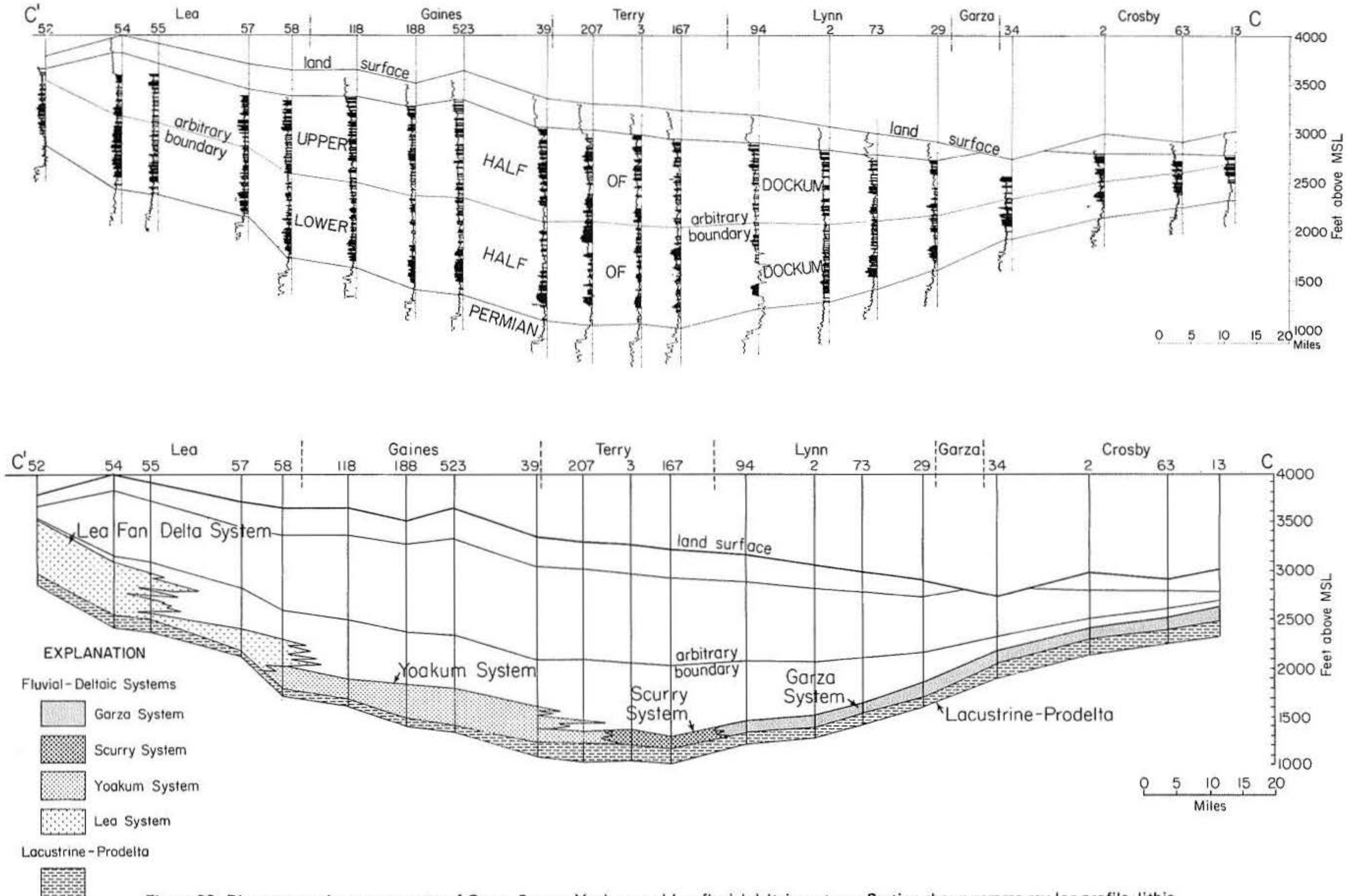


Figure 36. Dip cross section across parts of Garza, Scurry, Yoakum, and Lea fluvial-deltaic systems. Section shows gamma-ray log profile, lithic interpretation (sandstone—black; shale/siltstone—white; A), and boundaries of principal depositional systems (B). Line of section shown in figure 34.

structures. During the past 2 decades at least three paleocurrent investigations have been made of the Dockum Group (Kiatta, 1960; Cazeau, 1962; Cramer, 1973). Kiatta and Cramer studied approximately the same outcrop area from Oldham through Mitchell Counties, Texas. Kiatta (1960, p. 21) concluded that 80 percent of his measurements lay in the western half of the compass; 65 percent of these fell in the interval from N. 45° W. to S. 45° W. Kiatta's data show a preferred cross-strata dip direction to the west. Cazeau's observations included parts of both Texas and New Mexico. In Texas, Cazeau studied outcrops in the area from Dickens County southward through Mitchell County, and in northeastern New Mexico he observed paleocurrent directions in six counties. According to Cazeau (1962, p. 38), cross-strata in West Texas and northeastern New Mexico exhibit a preferred dip direction to the northwest. Cramer (1973, p. 14) states that paleocurrents for the Dockum Group in the southern two-thirds of the outcrop area in Texas flowed to the northwest and that northward the transport direction became more northerly.

Although this study deals primarily with the depositional framework of the lower part of the Dockum Group, directional features were examined in outcrop, and subsurface trends of coarser clastic facies were mapped. Sandstone-percent maps (figs. 4 and 6) indicate that the basin was filled peripherally. For purposes of this report, most of the outcrop paleocurrent data (1) were treated in a manner similar to that of previous workers (Kiatta, 1960; Cazeau, 1962; Cramer, 1973) in order to have a basis for comparison and (2) were analyzed for specific genetic facies. For example, all paleocurrent readings from a particular outcrop were grouped (this includes readings from different stratigraphic positions and totally unrelated genetic units), and for each outcrop, resultant vector azimuths were determined by the method used by Curray (1956).

Directional readings from selected outcrops of Santa Rosa Sandstone in Guadalupe and De Baca Counties, New Mexico (fig. 37), suggest transport directions to the east and south. In Guadalupe County, crossbed orientations within the Santa Rosa Sandstone were also grouped by genetic units with a resulting shift in transport direction from northeast to southeast between deposition of the middle and upper members of the Santa Rosa Sandstone. This shift in paleocurrent direction agrees with directional measurements reported by Lupe (1977) for the Santa Rosa Sandstone. Directional readings taken on the upper surface of a sandstone body within the Santa Rosa Sandstone in San Miguel County, New Mexico, indicate westerly flowing paleocurrents. Differences in apparent transport direction between Guadalupe and San Miguel Counties may be attributed to deposition in adjacent subbasins (see Oriel and Mudge, 1956).

Approximately 390 directional readings were made in the outcrop area between Dickens and Mitchell Counties, Texas (figs. 38 and 39). Stratification types from which a directional sense was determined are trough-fill cross-strata, foreset cross-strata, ripple cross-laminae, and parting lineation. A directional feature was not measured unless it could definitely be identified on a bedding surface. There is a wide spread in directions of resultant vector azimuths, particularly in Garza County (fig. 38). Most readings in Mitchell and Scurry Counties (fig. 39) were from meanderbelt sandstones (locality S4 is a splay deposit), where resultant vector azimuths lie mostly in the southwest quadrant.

Perhaps primary sedimentary structures are better indicators of depositional processes than they are of paleoslopes. Sequences of stratification types have been successfully employed in interpreting numerous terrigenous depositional systems (Fisher and Brown, 1972; Hayes and Kana, 1976). Allen (1966) reports that there is considerable deviation between the trend of a river and current directions deduced from measuring stratification types associated with deposits of the river. Variation in directional features, when used in conjunction with suites of primary sedimentary structures, is helpful in delineating genetically related depositional sequences. Two examples from the Dockum of southwest Garza County are represented here.

A Dockum meanderbelt (point-bar) sandstone (fig. 40) displays a rather wide range of transport directions. This range is characteristic of sands laid down by meandering streams (Allen, 1966). Occurring within the same area, but about 80 feet stratigraphically below the meanderbelt sandstone, is 50 feet of reddish-brown mudstone and siltstone, greenish-gray sandstone, and reddish-brown intrabasinal conglomerate that composes two crevasse splays and a delta-foreset unit (fig. 41). Directional features on bedding surfaces of sandstones that cap each splay unit and the dip direction of delta foresets were determined. During construction of the oldest splay (fig. 41A), current direction was north to east. Westward-flowing currents prevailed while the second splay was active (fig. 41B). Dip direction of delta foresets (fig. 41C) indicates a northwest flow direction. When directional data of these three stratigraphically *unrelated facies* are treated indiscriminately, bimodal current system is indicated (fig. 41C).

It is assumed that sand-body geometry (and sandstone-percentage trends) are first-order paleocurrent (and paleoslope) indicators. Dip directions of foreset cross-strata and plunge directions of trough-fill axes are perhaps the second most reliable paleocurrent indicator (Allen, 1966). When subsurface Dockum sandstone trends and sand-body orientation in outcrop are compared with directional features from outcrop observations, there is an obvious conflict in paleocurrent interpretation. Sandstone trends and primary sedimentary structures do not necessarily coincide (fig. 42). For example, in Garza County, resultant vector azimuths determined for each of 39 outcrops were grouped into quadrants and presented as a single rose diagram positioned in the center of the county. Outcrop data from other counties were treated similarly. Sandstone percentages are assumed to reflect the average transport direction (and paleoslope) of the lower Dockum rivers. Trends displayed by sandstone percentages (fig. 42) are southwest, west, and north. High sandstone-percentage trends are first-order directional features (Allen, 1966) and should more closely reflect overall paleoslope than do specific primary sedimentary structures. It may be desirable to restrict the use of primary sedimentary structures as paleocurrent indicators to genetically related sedimentary facies.

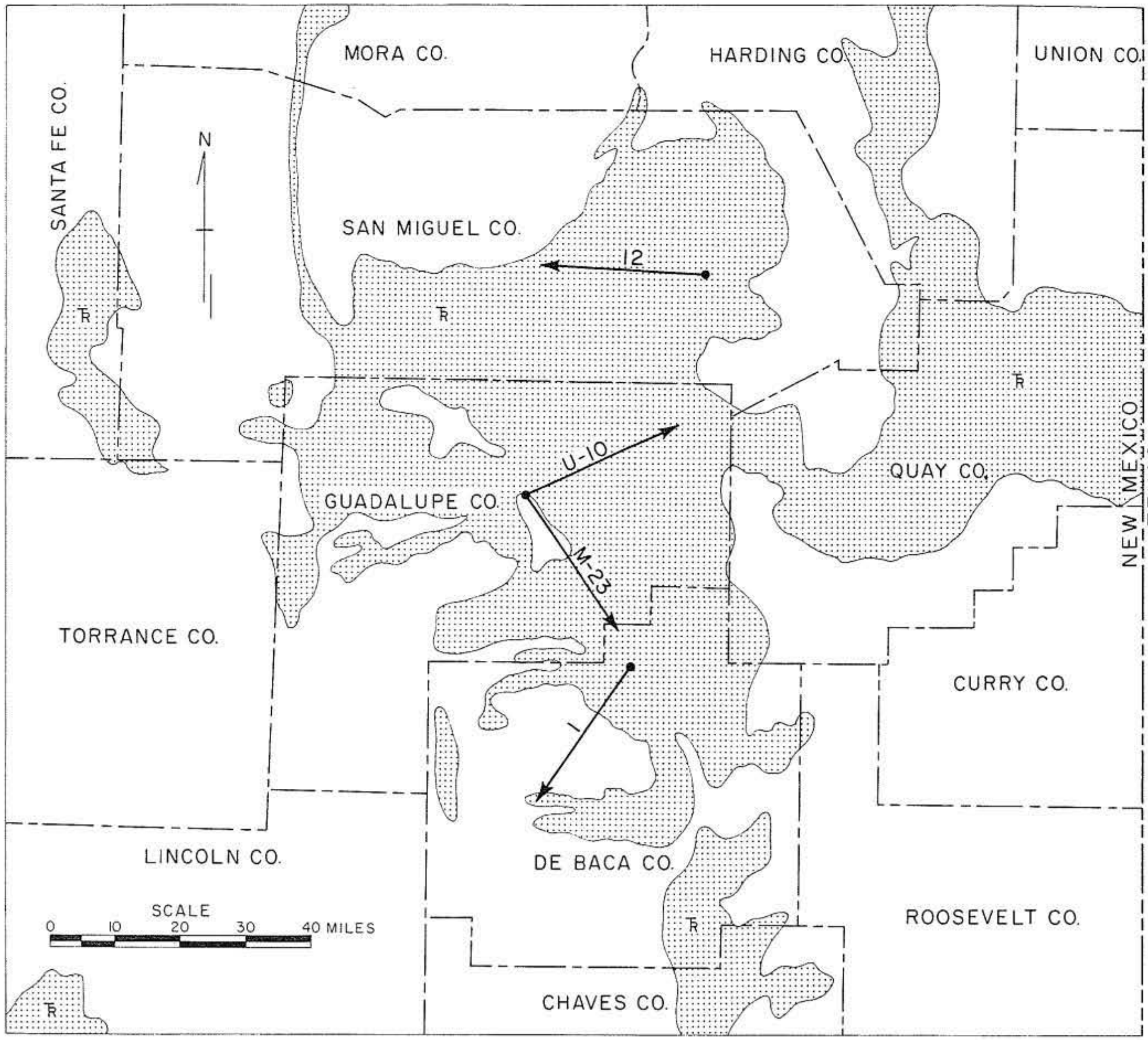


Figure 37. Current directional features, Santa Rosa Sandstone, Dockum Group, northeastern New Mexico. Resultant vector azimuth for each locality. Number of readings shown for each locality. In Guadalupe County readings are from middle (M) and upper (U) sandstone members of Santa Rosa Sandstone.

CONCLUSIONS

Numerous studies have been made of the Dockum Group during the past 80 to 90 years. Cummins (1889) named the Dockum Group. Gould (1906 and 1907) divided the Dockum in the Canadian River Valley area into a lower mudstone (Tecovas Formation) and upper sandstone (Trujillo Formation). Adams (1929) was among the first to interpret the depositional environment of the Dockum. He believed that the Triassic deposits south of the 33d parallel accumulated in a floodplain - alluvial fan setting.

Several dissertations and theses have dealt with specific stratigraphic, paleontologic, and sedimentologic aspects of the Dockum Group (Green, 1954; Kiatta, 1960; Cramer, 1973). Asquith and Cramer (1975) studied sandstones within the Tecovas and Trujillo Formations. All these workers agree that the Dockum is the product of a continental regime.

According to Green (1954), the Dockum probably accumulated under prevailing semiarid conditions that at some times became more humid and at other times shifted toward aridity. Kiatta (1960) believed that the Tecovas was deposited on a floodplain and that the Trujillo accumulated in stream channels. Cazeau (1962) stated that early deposition of the Dockum Group was chiefly on floodplains, succeeded by deposition in lacustrine or estuarine environments. Asquith and Cramer (1975) state that sandstone bodies within the Tecovas represent point bars of meandering streams and that Trujillo sandstone bodies were laid down by braided alluvial sheets.

Finch (1975) discussed the occurrence of uranium in the Triassic. He inferred that the Tecovas Formation represents chiefly lacustrine and deltaic sedimentation and that the Trujillo Formation consists of fluvial sandstone and conglomerate and lacustrine and deltaic mudstone.

Interpretations presented in this report are that the

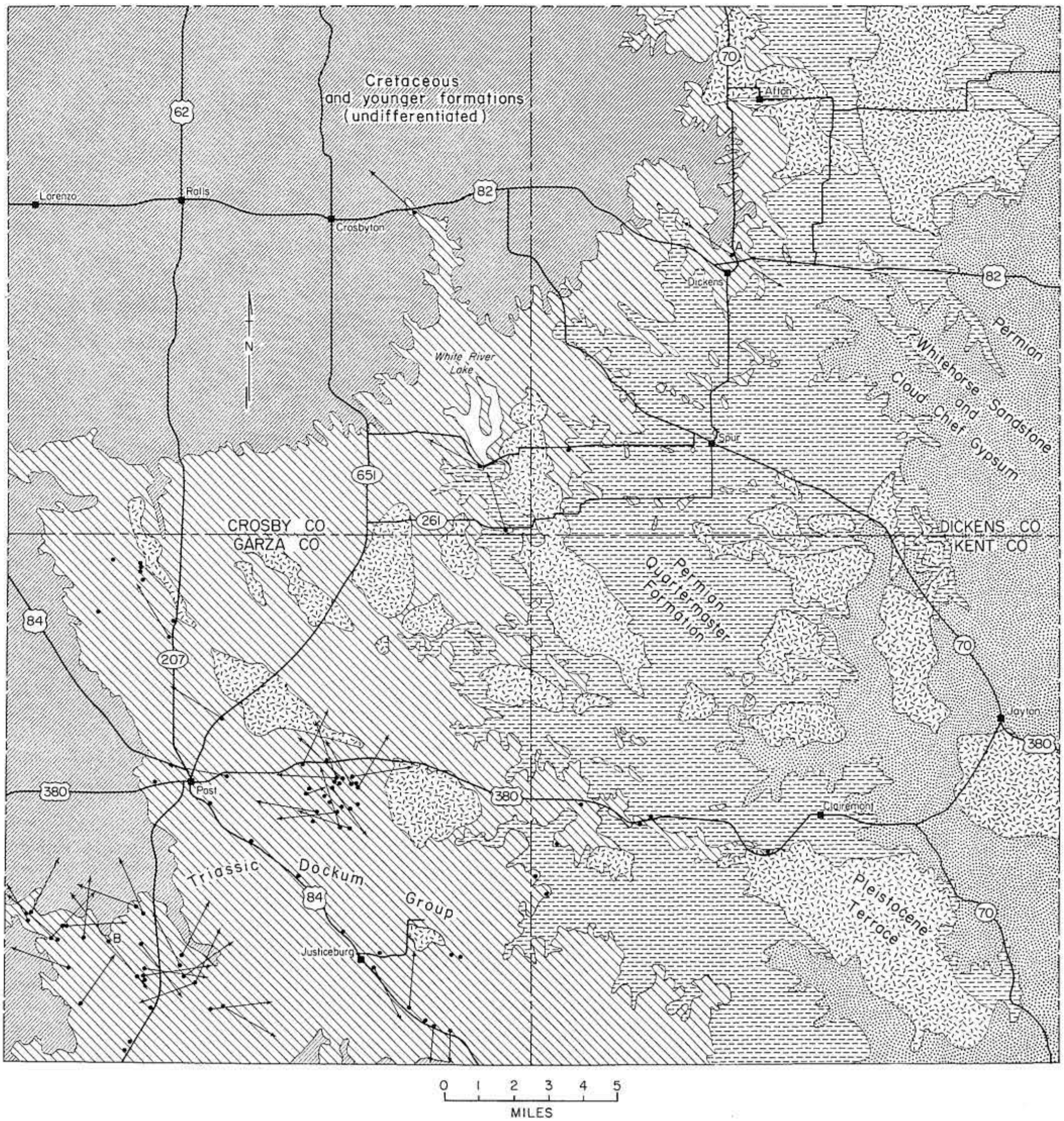


Figure 38. Current directional features, Dockum Group, Dickens, Kent, Crosby, and Garza Counties, Texas. Resultant vector azimuth for each locality. Readings from parting-step lineation shown at locality A (Dickens County) and locality B (Garza County).

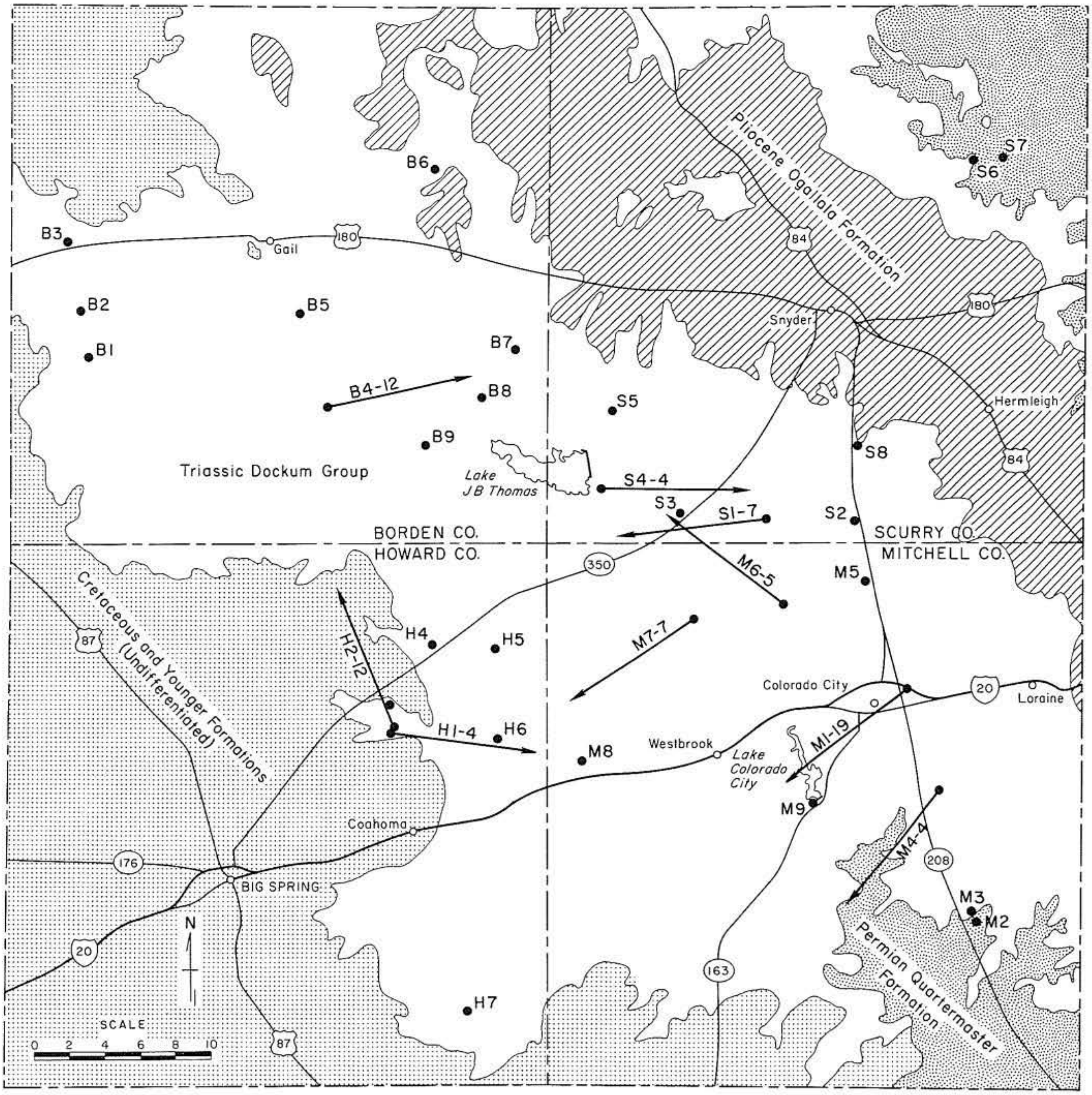


Figure 39. Current directional features, Dockum Group, Scurry, Mitchell, Borden, and Howard Counties, Texas. Resultant vector azimuth and number of readings given for each locality. Measured sections are S2, B4, H5, and M3 for Scurry, Borden, Howard, and Mitchell Counties, respectively.

Dockum Group in Texas and New Mexico accumulated in an inland fluvial-lacustrine basin under the influence of various fluvial and deltaic systems. In outcrop, fluvial facies are dominant. Subsidence within the basin, in concert with a change from the arid climatic conditions of the Permian to the more pluvial conditions of the Triassic, was perhaps related to the opening of the Gulf of Mexico and to the reactivation of relict Paleozoic structural elements. Outcrop and subsurface data suggest that sediment was derived mostly from older sedimentary rocks lying east, west, and south of the basin.

Climatic conditions fluctuated between humid and arid or semiarid throughout the deposition of the Dockum Group. Climatic fluctuations produced changes in base level, depth, and area of lakes, and in types of streams that discharged into the basin. During humid climatic conditions, lakes were relatively large; base level was relatively stable; and fluvial systems were characterized by meandering streams that constructed lobate deltas along lake margins. Alternating arid climatic conditions were accompanied by small ephemeral lakes, lowered base level, eroded valleys (some of which attained depths of 200 feet),

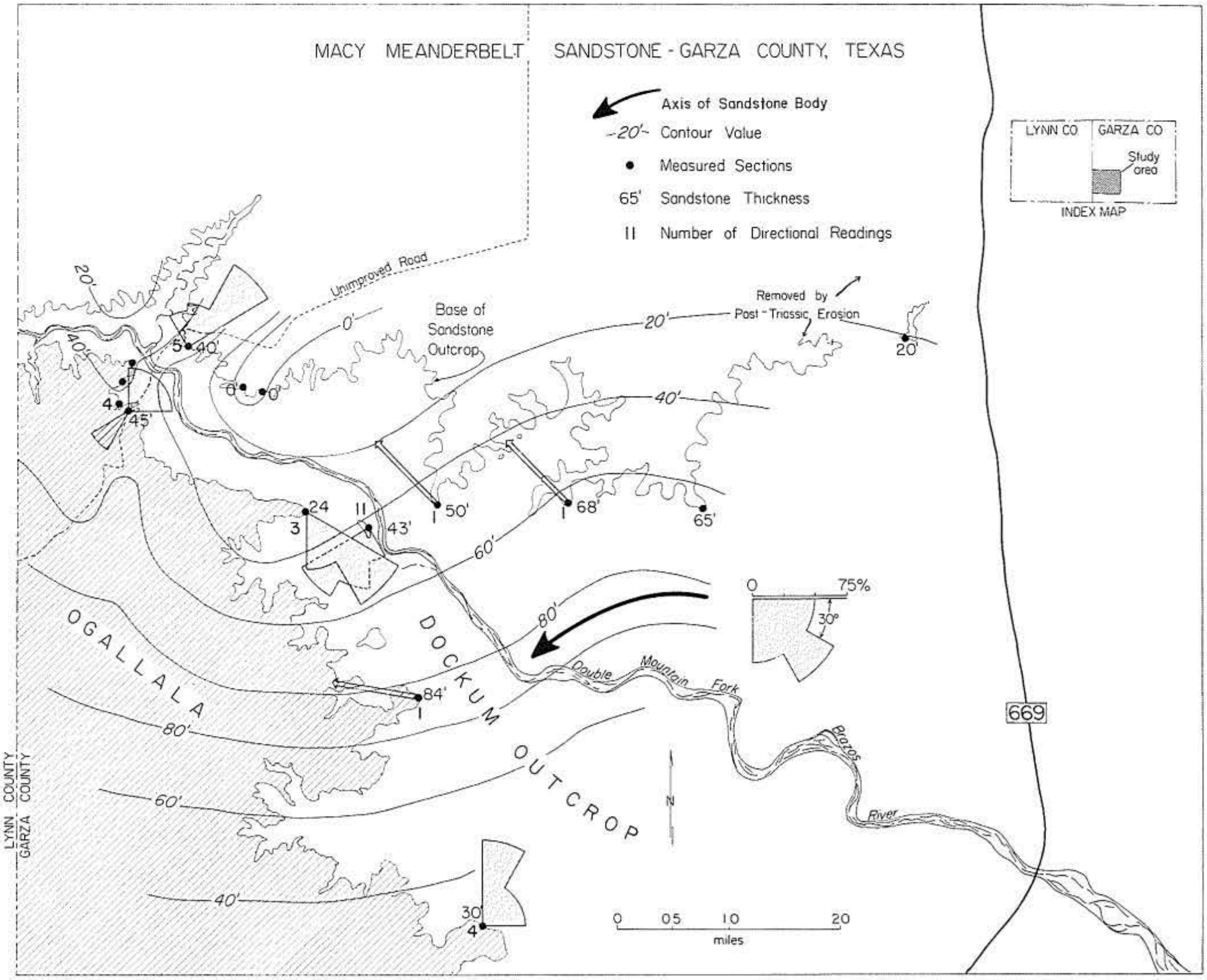


Figure 40. Sandstone-body trend and current directional features, Dockum Group, southwest Garza County, Texas (Grassland Southeast and Middle Creek 7.5-minute quadrangles). Sandstone-body trend shown by contours; directional data presented as rose diagrams. Sandstone body trends approximately west. Paleocurrent direction, indicated by primary sedimentary structures, ranges from northeast to southwest and deviates up to 120° from trend of sandstone body.

and small braided streams (many of which built small fan deltas along lake margins).

Two possible Modern analogues for the Dockum Group are the Omo Delta in Ethiopia (Butzer, 1971) and Lake Eyre in Australia (Bonython and Mason, 1953). The Omo Delta is a distributary delta characterized by a delta plain that is a virtually barren mudflat across which the shoreline of Lake Rudolph transgresses and regresses about 16 kilometers each year. Climate in the region of the headwaters of the Omo River is humid; the climate becomes progressively drier toward the delta. On the delta plain, vegetation is restricted primarily to the area adjacent to distributaries.

Lake Eyre in south Australia is normally a dry basin. Heavy rains that occur about twice per century create a fresh-water lake that attains maximum depth of about 13 feet and covers an area of some 3,000 square miles. Filling and drying of Lake Eyre occur in about 3.5 years. Water and sediment are discharged into the lake from all sides. Immediately after the lake is filled with fresh water, the desert blooms with vegetation. Salts are deposited on the lake bottom as water evaporates.

Minor facies within the Dockum (salt hoppers, gypsum crystals, dolomite, and chert) indicate that at times small, hypersaline water bodies existed during low stand.

The Dockum Group exhibits most of the elements (except estuarine facies) that have been reported by previous researchers. This study has attempted to integrate relationships among geologic setting, climatic conditions, and depositional facies.

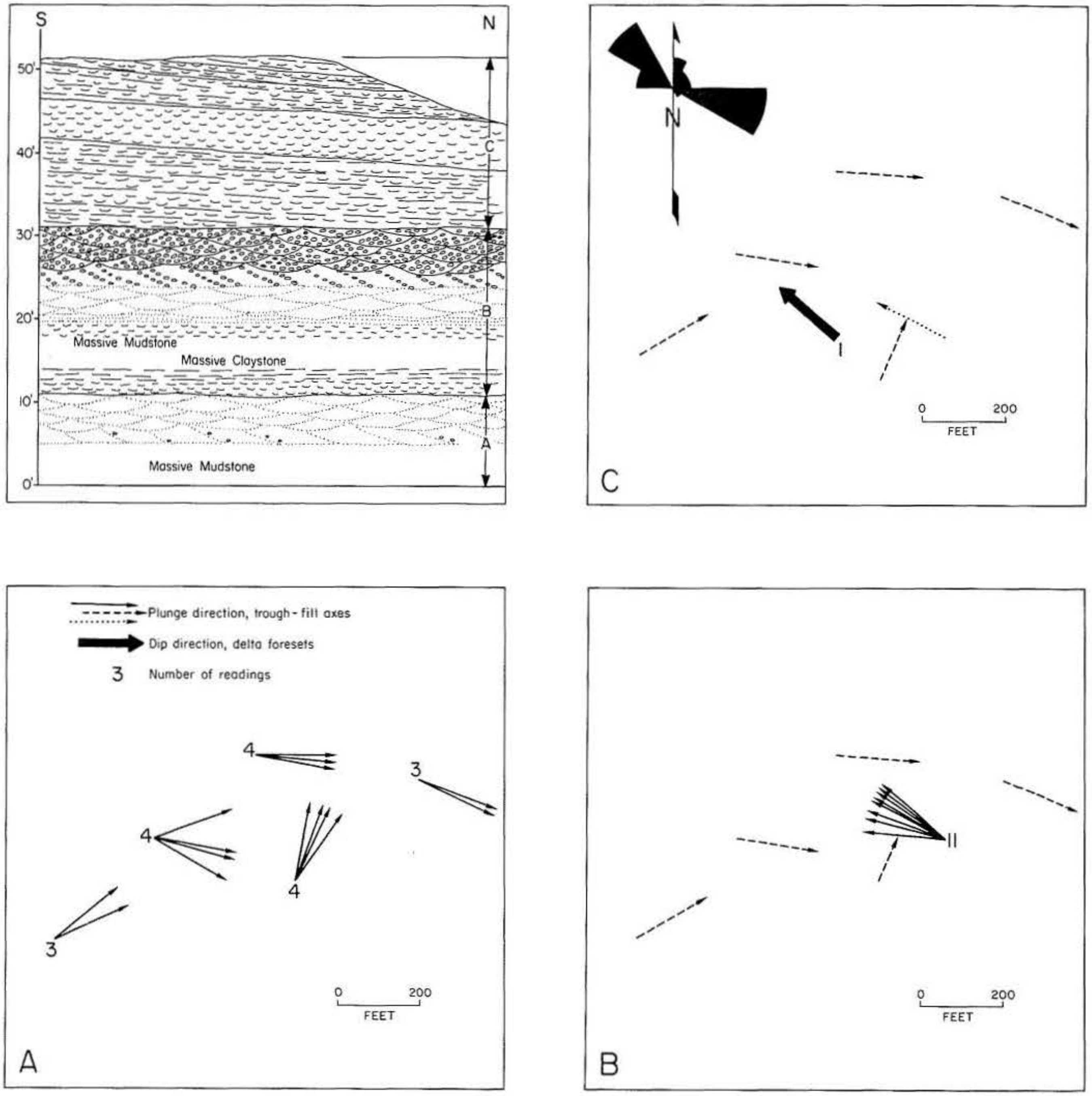


Figure 41. Paleocurrent direction from three stratigraphically different crevasse splay and delta-foreset units, Macy Ranch, southwest Garza County, Texas (Grassland Southeast 7.5-minute quadrangle). Upper left diagram shows vertical succession of facies. Map A shows paleocurrent measurement in lowermost splay unit comprising lower massive mudstone and upper foreset and trough-fill cross-stratified fine sandstone with some intrabasinal clasts. Map B shows paleocurrent measurements in a crevasse splay sequence consisting of ripple cross-laminated and parallel-laminated siltstone, massive claystone and mudstone, ripple cross-laminated siltstone, parallel-laminated very fine sandstone, trough-fill cross-stratified fine sandstone, and foreset and trough-fill cross-stratified granule to pebble intrabasinal conglomerate. Map C shows paleocurrent measurements of a delta-foreset sequence. Foresets dip northward from 4 to 9 degrees; dip angle along single foreset unit decreases northward. Primary sedimentary structures are parallel laminae and ripple cross-laminae; ripples migrated northward. During deposition of trough-fill cross-stratified sandstone of splay unit A (map A), currents flowed toward north to southeast. Map A shows spatial distribution of trough axes on bedding surface of crevasse splay A. Paleocurrents during deposition of trough-fill cross-stratified conglomerate at top of crevasse splay B (map B) were to west and northwest. Delta foresets (map C) were deposited by currents that flowed northwestward. Rose diagram (upper part of map C) utilizing all directional readings shows a bimodal paleocurrent distribution.

SUBSURFACE SANDSTONE DISTRIBUTION PATTERN
AND OUTCROP DIRECTIONAL TRENDS

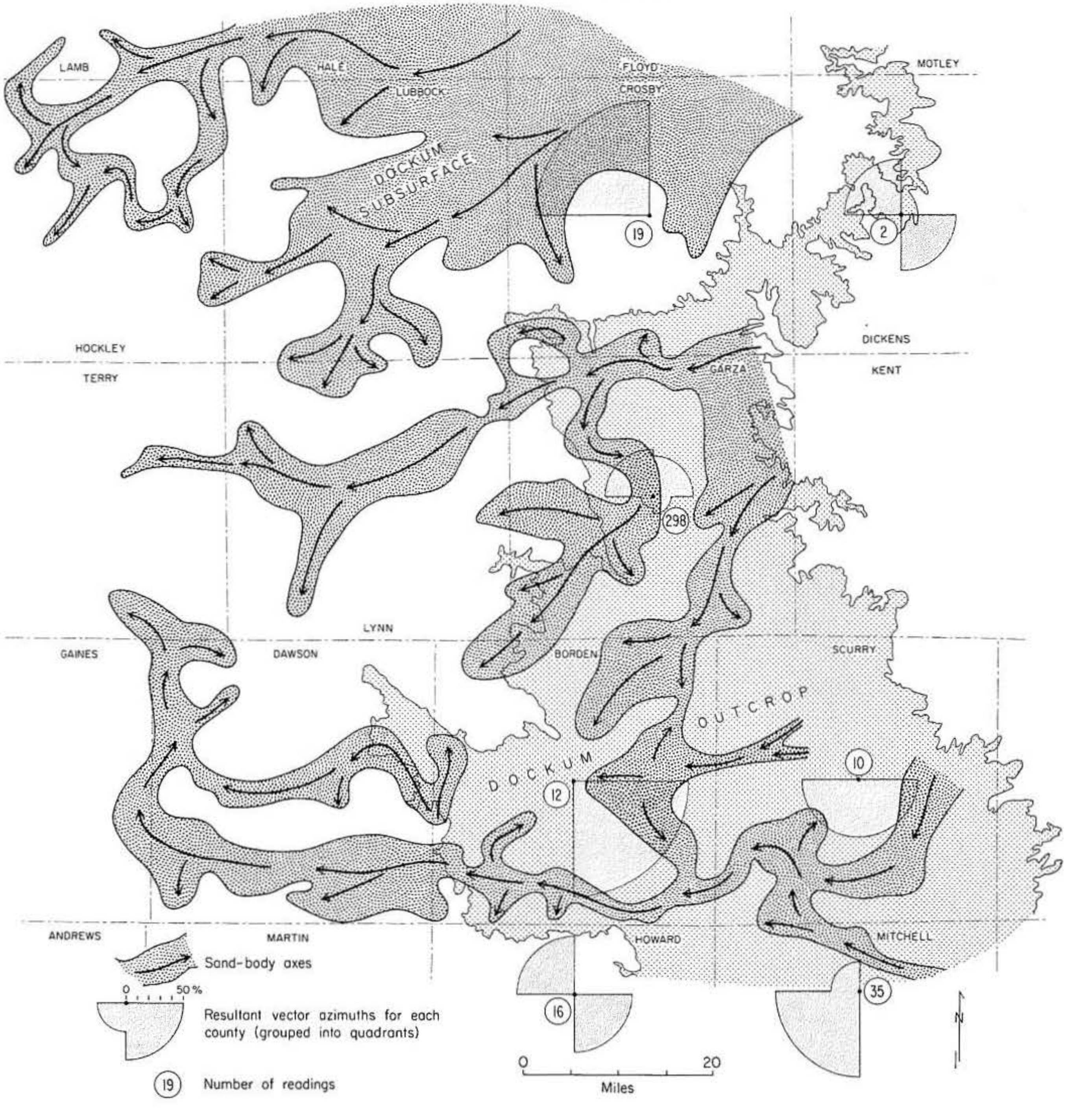


Figure 42. Subsurface sandstone distribution patterns and outcrop directional trends, lower part of Dockum Group, West Texas. Distribution patterns of sandstones are considered first-order paleoslope (paleocurrent) indicators, whereas trends defined by primary sedimentary structures are, at best, second-order paleocurrent (paleoslope) indicators.

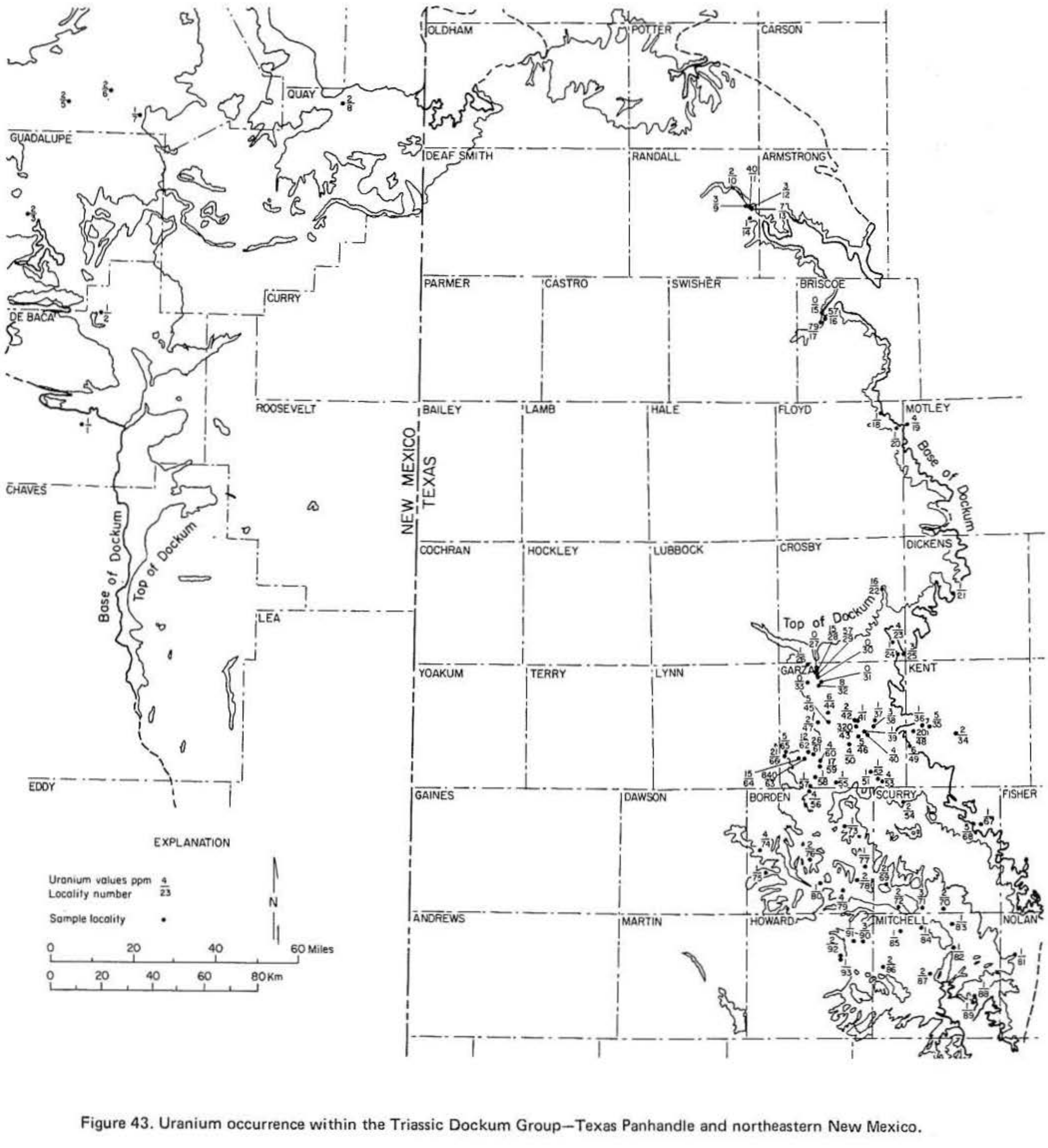


Figure 43. Uranium occurrence within the Triassic Dockum Group—Texas Panhandle and northeastern New Mexico.

URANIUM OCCURRENCE: LOWER PART OF TRIASSIC DOCKUM GROUP

Depositional systems that constitute the Dockum Group are fluvial, deltaic, lacustrine, valley-fill, and beach. Some of the depositional facies that comprise these systems were altered through soil-forming processes; however, most of these facies are readily identified. Underlying Permian deposits are chiefly components of a tidal-flat system. Dockum Group rocks that crop out in Texas and New Mexico accumulated in 26 distinct depositional environments (table 1).

Table 1. Depositional systems and depositional environments (facies) operative during accumulation of the Dockum Group.

Depositional system	Depositional environment (facies)
Fluvial	Meanderbelt Point bar Channel lag Levee Crevasse splay Floodplain Abandoned channel fill Braided stream
Deltaic	Distributary channel Abandoned distributary Channel-mouth bar Delta front Frontal splay Interdistributary Lacustrine-Interdistributary Interdeltaic Delta platform Delta foresets Crevasse splay - Splay delta
Lacustrine	Lacustrine Lacustrine-Mudflat Mudflat Lacustrine-Deltaic
Valley fill	Valley fill
Soil (paleosols)	Soil
Beach	Beach

There are 8 fluvial facies, 11 deltaic facies, and 4 lacustrine facies. Individual facies of valley-fill systems are not shown in table 1 (these are enumerated in that part of the text that deals with depositional systems). Paleosols, although not considered a depositional facies, are common in Dockum outcrops. Beach deposits were recognized in only one exposure of Dockum rocks.

Rocks that accumulated in fluvial environments include about 41 percent of the recognized facies within the 93 localities from which uranium data were collected. Deltaic facies compose about 38 percent of the recognized facies; valley fill and paleosols, about 2 percent each; and beach deposits, approximately 0.5 percent. These percentages represent only the frequency of occurrence of strata that accumulated in the above-mentioned environments which were sampled during this investigation; the numbers do not represent volume of rock.

Fluvial systems dominate the Dockum in outcrop. Two broad classes of fluvial deposits comprise these systems. They are braided-stream deposits (16 percent) and deposits that were laid down by meandering streams (84 percent). Meandering-stream deposits include about 27-percent point-bar and about 14-percent channel deposits.

Deltaic facies are almost equal to fluvial facies with respect to frequency of occurrence. Delta-front facies make up about 23 percent of the deltaic rocks. Second in frequency of occurrence are distributary-channel facies at about 20 percent. Splays constitute a little more than 16 percent; delta foresets, about 11 percent; and the remaining facies, 0.6 to greater than 5 percent.

Four facies make up the lacustrine system. Lacustrine facies were interpreted through association with other facies. Some 87 percent of these rocks were categorized as "lacustrine"; these rocks probably represent sediment that accumulated toward the center of Dockum lakes. Mudflat facies constitute a little more than 4 percent of the lacustrine deposits, whereas lacustrine-mudflat deposits make up about 3 percent. Lacustrine-deltaic facies constitute about 6 percent of the lacustrine system.

Valley fill, paleosols, and beach sediment occur less frequently than do other Dockum facies. Only one occurrence of beach deposits was recognized. Paleosols and valley-fill sequences are common in some areas of Dockum outcrop; however, their distribution is somewhat restricted.

The frequency of occurrence of the numerous fluvial, deltaic, and lacustrine facies within the Dockum Group shows that fluvial deposits are most abundant in outcrop, with deltaic deposits occurring only slightly less frequently; uranium should occur mostly within fluvial facies. This assumption is not correct with respect to either frequency of occurrence or highest ppm U_3O_8 (fig. 43, table 2).

Preliminary evaluation has been made of the uranium-bearing potential of the many different depositional facies of the Dockum Group exposed in outcrop. In order to make this evaluation we (1) identified, in outcrop, the depositional systems and component facies and (2) collected samples that exhibited the total range of textures and stratification types of each depositional facies. These samples were analyzed for U_3O_8 at the Mineral Studies Laboratory, Bureau of Economic Geology. To date, more than 400 samples have been analyzed (table 2). Approximately 10 percent of these samples contained more than 5 ppm U_3O_8; 90 percent of the samples contained less than 5 ppm U_3O_8.

A total of nine samples from the fluvial facies contained more than 5 ppm U_3O_8 (range of 5 to 79 ppm).

Table 2. Associations among rock type, depositional environment (facies), and U_3O_8 content as determined from samples from 93 localities in Texas and New Mexico.

Locality No.	Rock type	Environment (facies)	U_3O_8 ppm
1	siltstone (Permian)	tidal flat	<1
2	sandstone	braided stream	1
3.i	medium sandstone	braided stream	<1
h	very fine sandstone	delta front	<1
g	very fine sandstone	delta front	<1
f	mudstone	lacustrine	<1
e	fine sandstone	upper point bar	1
d	medium sandstone	lower point bar	<1
c	sandy conglomerate	channel lag	2
b	medium sandstone	braided stream	1
a	intrabasinal conglomerate	braided stream	<1
4	fine sandstone	delta front	1
5	fine-medium sandstone	braided stream	2
6	chert pebble conglomerate	braided stream	2
7	limestone	lacustrine	<1
8	chert pebble conglomerate	channel lag	2
9.d	mudstone	distributary channel	<1
c	mudstone	distributary channel	3
b	mudstone	distributary channel	<1
a	conglomerate	distributary channel	3
10.d	sandstone	splay	1
c	sandstone	splay	<1
b	sandstone	splay	<1
a	mudstone	splay	2
11.q	mudstone	interdistributary	4
p	mudstone	interdistributary	2
o	mudstone	interdistributary	3
n	mudstone	interdistributary	<1
m	sandstone	distributary channel	1
l	sandstone	distributary channel	1
k	sandstone	distributary channel	<1
j	mineralized log	distributary channel	14
i	carbonized log	distributary channel (base)	40
h	sandstone	distributary channel (base)	<1
g	mudstone	lacustrine	<1
f	mudstone	lacustrine-interdistributary	1
e	mudstone	lacustrine-interdistributary	1
d	conglomerate	splay	2
c	mudstone	interdistributary	2
b	conglomerate	splay	1
a	mudstone	lacustrine-interdistributary	1
12.r	sandstone	fluvial channel fill	<1
q	sandstone	delta front	<1
p	sandstone	distributary channel	<1
o	sandstone	delta front	2
n	mudstone	delta front	1
m	mudstone	interdistributary	<1
l	mudstone	interdistributary	1
k	conglomerate	fluvial channel fill	1
j	conglomerate	fluvial channel fill	<1
i	sandstone	fluvial channel fill	2
h	sandstone	fluvial channel fill	2
g	mudstone	interdistributary	3
f	conglomerate	splay	1
e	conglomerate	splay	3
d	mudstone	lacustrine	<1
c	mudstone	lacustrine	<1
b	mudstone	lacustrine	<1
a	mudstone	lacustrine	2
13.h	conglomerate	delta platform	7
g	sandstone	delta front - splay	1
f	sandstone	delta front - splay	2
e	mudstone	delta front - splay	2
d	mudstone	lacustrine	2
c	mudstone	lacustrine	<1
b	mudstone	lacustrine	3
a	mudstone	lacustrine	1
14.b	quartz geode	paleosol	<1
a	quartz geode	paleosol	1
15	siltstone	floodplain	<1
16	carbonized log	valley fill	57
17.c	carbonized log	channel lag	79
b	carbonized log	channel lag	15
a	carbonized log	channel lag	18
18	conglomeratic sandstone	braided stream	<1
19.b	conglomeratic sandstone	lower point bar	<1
a	chert conglomerate	channel lag	4

Locality No.	Rock type	Environment (facies)	U_3O_8 ppm
20.e	sandstone	braided stream	1
d	conglomerate	braided stream	1
c	conglomerate	braided stream	1
b	sandstone	upper point bar	<1
a	sandstone	upper point bar	1
21.f	conglomerate	abandoned channel fill	1
a	very fine sandstone	beach	<1
22.e	alternating mudstone and sandstone	lacustrine	1
d	sandstone	lacustrine	4
c	mudstone-siltstone	lacustrine	3
b	mudstone	lacustrine	16
a	mudstone	lacustrine	5
23.g	conglomerate	braided stream	4
e	medium sandstone	delta front	<1
d	fine sandstone	delta front	<1
b	conglomerate	braided stream	1
a	siltstone	tidal flat (Permian)	2
24.e	mudstone and sandstone	abandoned channel fill	<1
d	conglomerate	abandoned channel fill	1
c	very fine sand	delta front	<1
b	fine sand	delta front	<1
a	mudstone and sandstone	tidal flat (Permian)	1
25.d	conglomerate	channel lag	1
c	sandstone	delta front	<1
b	fine sand	delta front	1
a	mudstone and sandstone	tidal flat (Permian)	3
26.g_3	conglomerate	distributary channel fill	1
g_2	sandstone	distributary channel fill	1
g_1	mudstone	distributary channel fill	<1
b_2	red mudstone	lacustrine	<1
b_1	green mudstone	lacustrine	1
27	mudstone-conglomerate	lacustrine-deltaic	not reported
28.c	fine sandstone	point bar	15
29.h	fine sandstone	delta front	23
e	mudstone	lacustrine	9
d	very fine sandstone	distal delta front	57
30	mudstone-sandstone	lacustrine-deltaic	not reported
31	conglomeratic sandstone	meanderbelt	not reported
32.q	fine sandstone	abandoned channel fill	<1
p	very fine sandstone	abandoned channel fill	<1
o	siltstone-sandstone	abandoned channel fill	1
n	sandstone	braided stream	<1
m	sandstone	braided stream	<1
l	sandstone	braided stream	1
k	sandstone	braided stream	2
j	sandstone	braided stream	<1
i	sandstone	braided stream	1
h	sandstone	distributary channel fill	6
g	sandstone	distributary channel fill	1
f	conglomeratic sandstone	distributary channel fill	7
e	sandstone-conglomerate	delta front	4
d	sandstone	delta front	1
c	sandstone	delta front	4
b	mudstone-siltstone	lacustrine	8
a	mudstone-siltstone	lacustrine	2
33	mudstone-conglomerate	crevasse splay splay delta	not reported
34.e	mudstone	tidal flat (Permian)	2
d	siltstone-mudstone	tidal flat (Permian)	2
c	siltstone	tidal flat (Permian)	1
b	sandstone-siltstone	tidal flat (Permian)	<1
a	very fine sandstone	tidal flat (Permian)	<1
35.b	conglomeratic sandstone	channel lag	1
a	conglomeratic sandstone	channel lag	2
36.d_4	conglomeratic sandstone	abandoned channel fill	<1
b_2	medium sandstone	abandoned channel fill	<1
b_1	medium sandstone	abandoned channel fill	<1
37.c	coarse sandstone	distributary channel	<1
b	medium sandstone	delta front	2
a	mudstone	lacustrine	1
38	gray mudstone	abandoned channel fill	3
39.k	fine sandstone	point bar	1
f	conglomeratic sandstone	point bar	1
e	medium sandstone	point bar	1
40	carbonized log	point bar	4
	carbonized log	point bar	1
	carbonized log	point bar	<1
	carbonized log	point bar	<1

Locality No.	Rock type	Environment (facies)	U_3O_8 ppm
41.b	conglomerate	channel lag	1
a	sandstone	point bar	1
42.o	fine sandstone	point bar	1
h	fine sandstone	point bar	<1
g	medium sandstone	distributary channel	<1
f	conglomerate	distributary channel	1
e	fine-medium sandstone	delta front	<1
c_2	conglomeratic sandstone	channel-mouth bar	<1
c_1	fine sandstone	channel-mouth bar	<1
b	very fine sand	delta front	1
43	mineralized calcite nodule in burrowed mudstone	lacustrine	320
44.i	muddy sandstone	floodplain	1
h	sandstone	point bar	<1
g	sandstone	point bar	<1
f	sandstone	point bar	<1
d	conglomerate	channel lag	1
c	fine sandstone	point bar	2
a	mudstone	floodplain	6
45.d	conglomerate	crevasse splay	1
c	mudstone	floodplain	5
a	mudstone	floodplain	3
46.e_2	siltstone-sandstone	delta foresets	1
c_2	sandstone	splay delta	1
c_1	conglomerate	splay delta	3
a_8	mudstone	lacustrine	1
a_7	mudstone (burrowed)	lacustrine	1
a_6	mudstone (burrowed)	lacustrine	1
a_5	mudstone (burrowed)	lacustrine	2
a_4	mudstone (desiccated)	mudflat	5
a_3	mudstone	lacustrine	2
a_2	mudstone	soil horizon	1
a_1	mudstone	floodplain	1
47.f	sandstone	channel-mouth bar	<1
e_2	sandstone (burrowed)	abandoned distributary	<1
e_1	sandstone (burrowed)	abandoned distributary	<1
d	conglomerate	distributary channel	2
c	mudstone	abandoned distributary	1
b	sandstone	distributary channel	1
a_2	sandstone	delta front	1
a_1	sandstone	delta front	1
48.d	fine sand	point bar	2
c	chert conglomerate	channel lag	20
49.m	conglomeratic sandstone	channel lag	6
l_6	sandstone	point bar	1
l_5	medium sandstone	point bar	<1
l_4	sandstone-conglomerate	channel lag	1
k	mudstone-siltstone	lacustrine	2
f	mudstone	lacustrine	1
e	fine-medium sandstone	floodplain	1
d	mudstone-siltstone	tidal flat (Permian)	2
50.e	sandstone	braided stream	4
d	sandstone	braided stream	2
c	sandstone	braided stream	2
b	sandstone	braided stream	3
a	sandstone	braided stream	<1
51.b	siltstone	delta foresets	1
52.b	fine sandstone	crevasse splay	1
a	fine sandstone	crevasse splay	<1
53.c	mudstone-siltstone	floodplain	1
a	sandstone	meanderbelt	4
54.b	mudstone	lacustrine	1
a	mudstone	lacustrine	2
55.b_5	mudstone (burrowed)	lacustrine	1
56.e_3	mudstone-siltstone	lacustrine	2
e_2	mudstone-siltstone	lacustrine	2
e_1	mudstone-siltstone	abandoned channel fill	2
d	conglomerate	abandoned channel fill	4
c	mudstone-siltstone	abandoned channel fill	2
b_2	sandstone	abandoned channel fill	2
b_1	conglomerate	abandoned channel fill	4
a	mudstone	abandoned channel fill	3
57.j_2	manganese	point bar	1
j_1	limonitic log	point bar	2
i	sandstone	point bar	1
g	mudstone-sandstone	abandoned channel fill	2
e	mudstone	abandoned channel fill	2
d	sandstone	abandoned channel fill	1
c	sandstone	upper point bar	1
b	sandstone	upper point bar	1
a	sandstone	lower point bar	1

Locality No.	Rock type	Environment (facies)	U_3O_8 ppm
58.h	sandstone	channel-mouth bar	<1
f	mudstone	lacustrine	1
e	mudstone	abandoned distributary	<1
d	sandstone	distributary channel	<1
b	mudstone	lacustrine	1
a	sandstone	delta front	<1
59.g_3	mudstone-siltstone	delta foresets	2
e_3	mudstone-siltstone	delta foresets	5
e_2	mudstone-siltstone	delta foresets	<1
e_1	mudstone-siltstone	delta foresets	16
d_2	mudstone-siltstone	delta foresets	<1
d_1	mudstone-siltstone	delta foresets	17
c	conglomerate	splay	11
b	mudstone	lacustrine	<1
a	mudstone	lacustrine	1
60.x_2	siltstone	paleosol	4
x_1	mudstone	paleosol	1
w_3	siltstone	lacustrine	1
w_2	mudstone	lacustrine	1
w_1	mudstone	lacustrine	1
v	mudstone-sandstone	lacustrine	<1
t	mudstone	lacustrine	1
r	siltstone-sandstone	valley fill	1
p	siltstone	valley fill	<1
h_2	siltstone	valley fill	<1
h_1	siltstone	valley fill	1
c	mudstone-conglomerate	valley fill	<1
b	siltstone-sandstone	valley fill	1
61.l	sandstone	delta front	1
i_3	sandstone	point bar	2
i_1	siltstone-sandstone	point bar	2
h_6	fine sandstone	delta front	15
h_4	conglomerate	frontal splay	26
h_1	fine sandstone	delta front	7
g	mudstone	lacustrine	3
f_4	conglomerate	frontal splay	6
f_3	siltstone-sandstone	delta front	3
f_1	fine sandstone	abandoned channel fill	3
c	siltstone-sandstone	delta front	5
a_4	conglomerate	frontal splay	5
a_3	siltstone	delta foresets	3
a_2	siltstone	delta foresets	6

Locality No.	Rock type	Environment (facies)	U_3O_8 ppm
a_1	siltstone	delta foresets	6
62.o_4	conglomeratic sandstone	point bar	1
o_3	sandstone	point bar	2
o_1	conglomerate	channel lag	2
n_2	mudstone-sandstone	abandoned distributary channel	<1
m	sandstone	distributary channel	<1
k_1	siltstone	abandoned distributary channel	1
j	sandstone	distributary channel	1
i	conglomerate	distributary channel	2
h	sandstone	proximal delta front	1
g	sandstone	distal delta front	1
e_{12}	mudstone	mudflat	12
e_8	mudstone breccia	mudflat	12
e_5	siltstone (burrowed)	lacustrine	2
e_4	siltstone (burrowed)	lacustrine	<1
e_3	claystone-mudstone	lacustrine	1
e_2	siltstone-sandstone	interdeltaic	1
e_1	siltstone-sandstone	interdeltaic	<1
d	conglomeratic sandstone	delta platform	<1
c	mudstone-sandstone	delta platform	<1
b_7	siltstone-conglomerate	delta foresets	<1
b_6	mudstone-sandstone	delta foresets	1
b_5	sandstone	delta platform	1
b_4	sandstone	delta platform	1
b_3	conglomerate	delta platform	2
b_2	sandstone	channel fill	2
b_1	sandstone-conglomerate	channel fill	6
a	mudstone-sandstone	delta foresets	3
63.v_3u*	sandstone	abandoned channel fill	2
v_3l*	mudstone-sandstone	abandoned channel fill	2
v_2	siltstone	abandoned channel fill	2
v_1	siltstone	abandoned channel fill	2
t_2	mudstone-sandstone	abandoned channel fill	1
r	conglomerate	channel lag	2
p	mudstone-siltstone	paleosol	1

Locality No.	Rock type	Environment (facies)	U_3O_8 ppm
n_3	siltstone-sandstone	delta foresets	1
m_1	sandstone	splay	3
l	conglomerate	splay	4
k_{12}	siltstone	lacustrine	2
k_7	siltstone	lacustrine	2
j	sandstone	delta foresets	2
g_2	siltstone-sandstone	splay	5
d_4u*	siltstone (burrowed)	lacustrine	840
d_4l*	siltstone (burrowed)	lacustrine	1
64.o_3	mudstone	floodplain	2
o_2	sandstone	floodplain	<1
l	conglomerate	channel lag	2
j	conglomeratic sandstone	channel lag	1
h_4	sandstone	point bar	<1
h_3	conglomeratic sandstone	point bar	4
g	mudstone-siltstone	lacustrine	1
f_3	siltstone	delta foresets	1
65.s	sandstone	splay	2
r	mudstone	floodplain	1
q_2	sandstone	splay	2
q_1	sandstone-conglomerate	splay	<1
p_2	sandstone	point bar	2
p_1	sandstone	point bar	1
n_4	mudstone-siltstone	floodplain	1
n_3	sandstone	point bar	1
n_2	sandstone	point bar	2
n_1	sandstone-conglomerate	channel lag	3
m	sandstone	delta front	2
l_4	mudstone (desiccation-cracked)	lacustrine-mudflat	1
l_3	mudstone-siltstone	delta front	1
l_2	sandstone-conglomerate	splay	1
l_1	mudstone-siltstone	delta front	3
k_2	siltstone-sandstone	delta platform	1
k_1	sandstone-conglomerate	delta platform	1
j_3	siltstone	delta front	2
j_2	sandstone	delta front	<1
j_1	sandstone	delta front	1
i	siltstone	delta front	2
h	mudstone-siltstone	lacustrine	1
g	siltstone	lacustrine	2
f	siltstone	lacustrine	5
e	siltstone	lacustrine	2
d_3	sandstone	splay	1
d_2	sandstone	splay	1
d_1	sandstone	splay	1
c	conglomerate	splay	3
b	conglomerate	braided stream	5
a	sandstone	channel fill	2
66a.b	sandstone-conglomerate	splay	3
a	siltstone-sandstone	delta foresets	1
66b.e	sandstone-conglomerate	delta platform	<1
d_2	mudstone-sandstone	abandoned channel fill	<1
d_1	sandstone-conglomerate	abandoned channel fill	3
b_1	siltstone-sandstone	levee	1
a	sandstone-conglomerate	channel fill	4
66c.k_{1c}	siltstone-mudstone	levee	2
k_{1b}	siltstone-sandstone	floodplain	2
k_{1a}	sandstone	splay	<1
j	mudstone	floodplain	2
i	sandstone	splay	21
g_{3b}	sandstone-conglomerate	point bar	1
g_{3a}	conglomerate	channel lag	1
g_2	sandstone	distributary channel	1
g_1	sandstone	channel-mouth bar	1
f	conglomeratic sandstone	channel lag	1
e	sandstone	delta front	1
c	mudstone-breccia	lacustrine-mudflat	1
b	mudstone-sandstone	lacustrine	1
67	siltstone	tidal flat (Permian)	<1
68	sandstone	meanderbelt	5
69.c	conglomerate	splay	2
b	siltstone (burrowed)	lacustrine-delta front	2
70	conglomerate	channel lag	2
71.h_{2b}	sandstone	splay	1
h_{2a}	conglomerate	splay	3
f	siltstone	splay	2
c	siltstone	levee	1
a_7	sandstone	point bar	2
a_4	sandstone	point bar	<1
72	sandstone	meanderbelt	2
73	sandstone	delta front	1
74	mudstone-sandstone	abandoned channel fill	4
75	sandstone	crevasse channel	1
76.b	sandstone	braided stream	2
a	sandstone	braided stream	<1

Locality No.	Rock type	Environment (facies)	U_3O_8 ppm
77	sandstone	point bar	<1
78.a	sandstone	channel-mouth bar	2
79.b	siltstone-sandstone	distributary channel	4
a	siltstone-sandstone	distributary channel	1
80.b	sandstone	meanderbelt	<1
a	sandstone	meanderbelt	<1
81	sandstone	meanderbelt	<1
82	sandstone-conglomerate	meanderbelt	<1
83	sandstone	meanderbelt	1
84.b	sandstone	meanderbelt	1
85	sandstone	braided stream	<1
86.c	caliche	paleosol	1
b	gypsiferous mudstone	lacustrine	2
a	mudstone	lacustrine	2
87.d	sandstone	point bar	2
b_2	sandstone	point bar	<1
88	conglomeratic sandstone	meanderbelt	1

Locality No.	Rock type	Environment (facies)	U_3O_8 ppm
89	siltstone-sandstone	tidal flat (Permian)	<1
90.c	sandstone	delta front - lacustrine	1
b	sandstone	distributary channel	2
a	conglomerate	distributary channel	3
91.a	sandstone	channel fill	1
92	sandstone	distributary channel	<1
93.eu*	mudstone	floodplain	<1
el*	mudstone-siltstone	levee	1
d	siltstone	upper point bar	<1
c	sandstone	upper point bar	<1
b	sandstone	point bar (lateral bar)	1
a	sandstone	channel lag	1

*u = upper; l = lower

Meandering-stream deposits exhibited the highest U_3O_8 content, most of which was contained within channel-lag deposits (total of five samples with U_3O_8 range of 6 to 79 ppm). Braided-stream deposits had the lowest U_3O_8 content. Only one sample from the braided-stream facies contained U_3O_8 in the 5 ppm range.

Deltaic facies yielded 21 samples with U_3O_8 content greater than 5 ppm. All of these samples were derived from six deltaic facies, which in order of decreasing numbers are (1) delta foresets (five samples, range of 5 to 17 ppm); (2) distributary channel and delta front (four samples each, range of 5 to 57 ppm); and (3) frontal splay and crevasse splay (three samples each, range of 5 to 26 ppm).

Ten samples collected from facies of the lacustrine system had U_3O_8 content greater than 5 ppm. Two facies contained all these samples. Lacustrine facies yielded seven of these samples and exhibited U_3O_8 range of 5 to 840 ppm. Mudflat deposits (three samples) had U_3O_8 range of 5 to 12 ppm.

Valley-fill deposits yielded a single sample with U_3O_8 value greater than 5 ppm; U_3O_8 content was 57 ppm. Numerous depositional facies are associated with valley-fill systems, and they have been discussed in the section on depositional systems.

The highest U_3O_8 values for the various facies are (1) 79 ppm, fluvial facies (channel lag) (2) 57 ppm, deltaic facies (distal delta front) (3) 840 ppm, lacustrine facies (lacustrine center?) and (4) 57 ppm, valley fill (carbonized logs in channel lag). Highest U_3O_8 values in both fluvial and valley-fill systems are in Tule Canyon, where the dominant texture in each is conglomerate (fig. 43, localities 16 and 17). Within the deltaic system most of the higher U_3O_8 values are associated with sandstone bodies that were constructed during humid climatic cycles. These facies are (1) distributary channel (40 ppm, fig. 43, locality 11); (2) delta front (23 ppm, fig. 43, locality 29); (3) distal delta front (57 ppm, fig. 43, locality 29); (4) frontal splay (26 ppm, fig. 43, locality 61); and (5) crevasse splay (21 ppm, fig. 43, locality 61). Relatively high U_3O_8 values are exhibited by delta-foreset and lacustrine deposits that accumulated during arid cycles. Highest U_3O_8 concentrations in delta foresets are 16 to 17 ppm at locality 59 (fig. 43), and highest values in lacustrine deposits are 320 and 840 ppm at localities 43 and 63, respectively (fig. 43). Lacustrine deposits exhibited the highest U_3O_8 values found within the Dockum Group. However, U_3O_8 in these lacustrine deposits is associated with burrow fill. Burrows in lacustrine siltstone and mudstone were filled with sand that was subsequently cemented with calcite and quartz and mineralized with copper and uranium; these deposits appear to be volumetrically insignificant.

With data available at this time one can postulate that if uranium occurs in commercial quantities in the outcrops of the Dockum Group, two areas in Texas will be favorable for exploration. These are the Dickens-Crosby-Kent-Garza Counties area and the Palo Duro - Tule Canyon area. Uranium can be expected to be found in fluvial, deltaic, and lacustrine facies. Although the highest U_3O_8 values encountered in the present study were from samples taken from lacustrine facies, commercial deposits of uranium are not likely to occur within this facies because of the extremely small amounts contained within burrow-fill sandstones. Deltaic deposits have the highest number of U_3O_8 values exceeding 5 ppm of any facies within the Dockum Group. Highest values encountered in deltaic systems are in delta-front facies, where maximum concentration was less than 60 ppm. Distributary channel facies have maximum U_3O_8 values of about 40 ppm. Deltaic sandstones are generally poorly preserved because of erosion subsequent to deposition. The erosion occurred as a consequence of lowering of base level and scouring action of streams that meandered back and forth over rather wide areas underlain by older Dockum deposits. Relatively high U_3O_8 values (greater than 75 ppm) were found in the channel-lag facies of coarse-grained and fine-grained meandering-stream deposits. Because of (1) the rather large volume of conglomerate and sandstone contained within these fluvial deposits, (2) the concentration within this facies of plant debris that would serve as a reductant for uranium precipitation and concentration, and (3) the high permeability and porosity of the facies that would be favorable to movement of uranium-bearing ground water through the system, one can speculate that most of the uranium in the Triassic Dockum Group of Texas will occur in channel-lag facies.

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