DEPOSITIONAL FRAMEWORK OF THE LOWER
DOCKUM GROUP (TRIASSIC),
TEXAS PANHANDLE

Annual Report

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DEPOSITIONAL FRAMEWORK OF THE LOWER DOCKUM GROUP (TRIASSIC), TEXAS PANHANDLE

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ABSTRACT

The Late 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 Glass Mountains on the south, and is the topic of this paper.

Outcrop and subsurface data indicate that (1) the basin was filled peripherally, (2) sediment sources were in Oklahoma, Texas and New Mexico, and (3) relict Paleozoic structures in concert with alternating humid and arid climatic cycles exerted considerable influence on 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, central basin areas were dominated by high constructive lobate deltas. 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. A cycle comprises facies that accumulated during one high- 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 flood plain 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 lowstand facies association ranges from reddish-brown mudstone to conglomerate. Abrupt vertical and lateral textural changes characterize these lowstand deposits. Lower Dockum red beds consist of lacustrine mudstone, prodelta mudstone-siltstone, delta front (delta foresets) siltstone to conglomerate, delta platform sandstone and conglomerate, and interdeltaic mudstone exhibiting desiccation features, and 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 Number 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 which may be utilized in uranium exploration.

This paper, which concerns the depositional framework of the Dockum Group, addresses 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 DeBaca, Guadalupe, San Miguel and Quay Counties, New Mexico, and from the Canadian River valley to the Glass Mountains in Texas. Detailed outcrop studies were carried out 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 only with the lower half of the Dockum in the region south of the Matador Arch, and includes 31 Texas counties and three counties in New Mexico. Future reports will consider further the subsurface geology of the Dockum Group. More than 1,500 wells were utilized in this part of the subsurface study. Gamma logs provided the principal subsurface data.

ACKNOWLEDGEMENTS

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GEOLOGIC SETTING

The Upper Triassic Dockum Group accumulated in a basin that underlies parts of Texas, New Mexico, Colorado, Kansas and Oklahoma (Fig. 1).

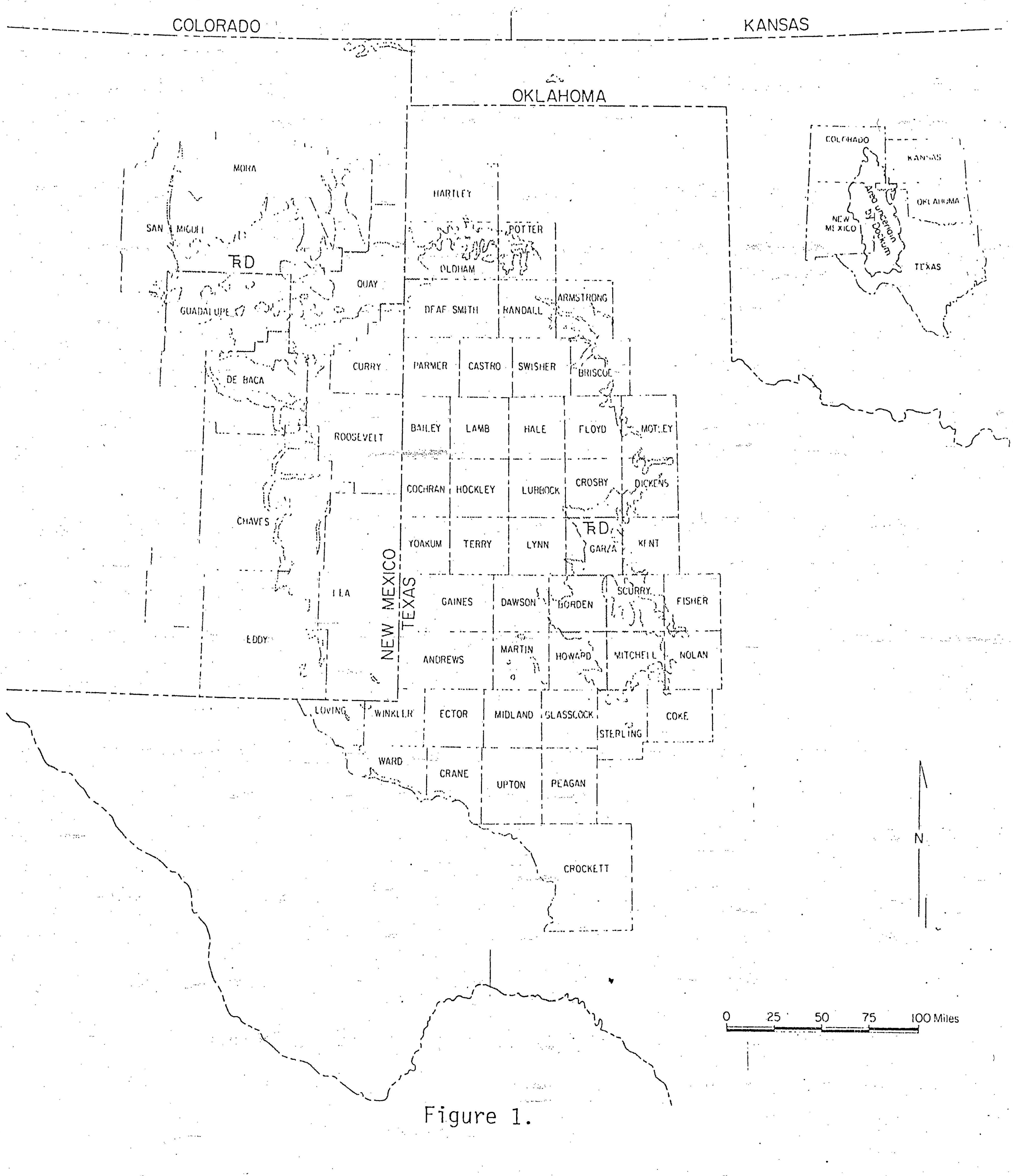


Figure 1.

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

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 in Late Mississippian (Nicholson, 1960). Structure in the southern part of the basin is partially 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 apparently was 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). Structural irregularities along the structural profile in Winkler County (Fig. 3D) are related to evaporite solution.

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 which 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 it is assumed that sedimentation was 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 redbeds (Lang, 1935) and Dewey Lake redbeds (Page and Adams, 1940). There was apparently a transition from the arid Permian climate into the pluvial climate of the Triassic.

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 on figure 3.

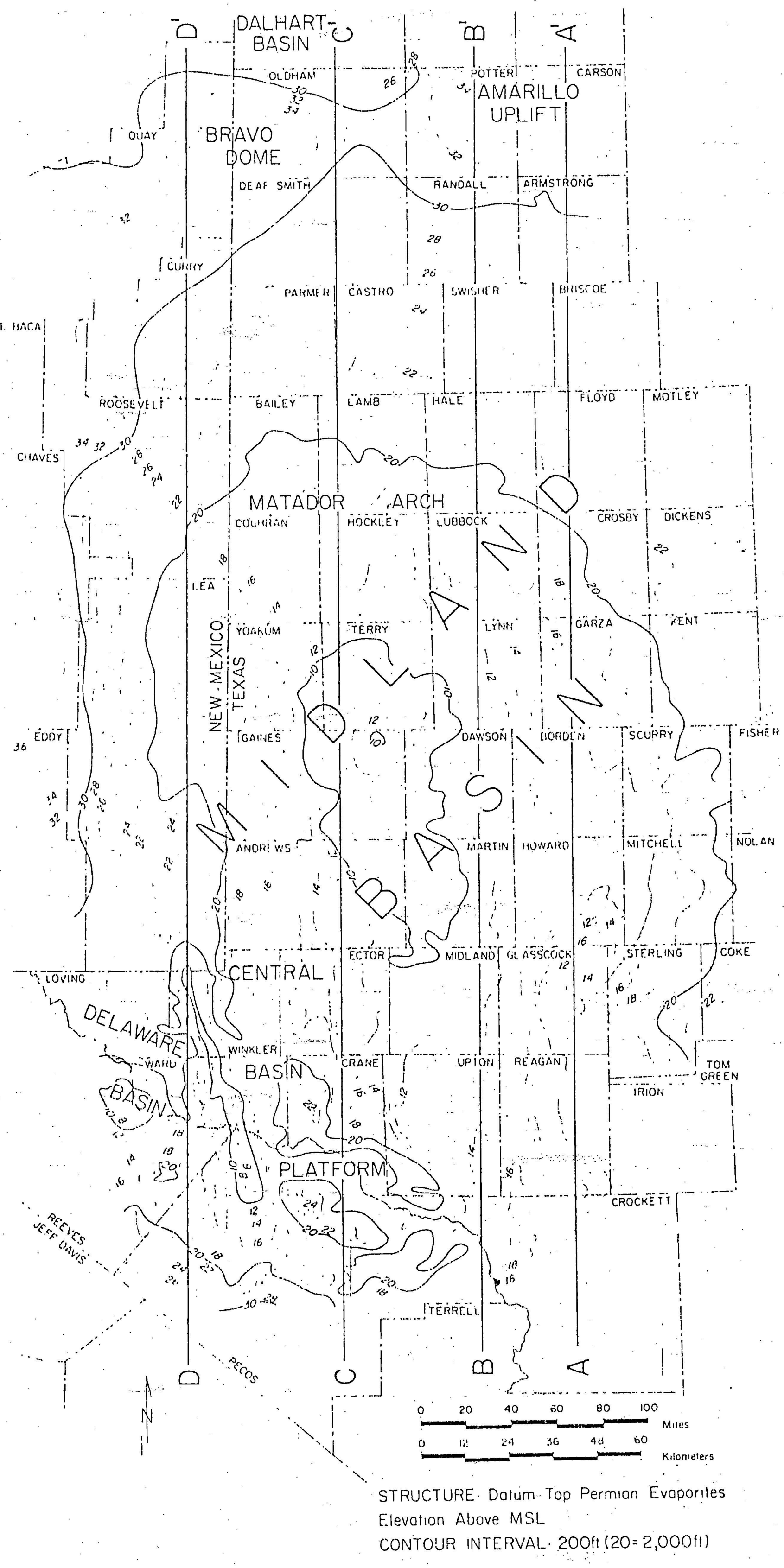

DALHART BASIN
AMARILLO UPLIFT
BRAVO DOME
MATADOR ARCH
MIDLAND BASIN
NEW MEXICO
TEXAS
CENTRAL BASIN PLATFORM
DELAWARE BASIN
OLDHAM
POTTER
CARSON
QUAY
DEAF SMITH
RANDALL
ARMSTRONG
CURRY
PARMER
CASTRO
SWISHER
BRISCOE
DE BACA
ROOSEVELT
BAILEY
LAMB
HALE
FLOYD
MOTLEY
CHAVES
COCHRAN
HOCKLEY
LUBBOCK
CROSBY
DICKENS
LEA
YOAKUM
TERRY
LYNN
GARZA
KENT
EDDY
GAINES
DAWSON
BORDEN
SCURRY
FISHER
ANDREWS
MARTIN
HOWARD
MITCHELL
NOLAN
ECTOR
MIDLAND
GLASSCOCK
STERLING
COKE
LOVING
WINKLER
WARD
CRANE
UPTON
REAGAN
TOM GREEN
IRION
CROCKETT
REEVES
JEFF DAVIS
PECOS
TERRELL
A
A'
B
B'
C
C'
D
D'
N
0 20 40 60 80 100 Miles
0 12 24 36 48 60 Kilometers
STRUCTURE Datum Top Permian Evaporites
Elevation Above MSL
CONTOUR INTERVAL 200ft (20=2,000ft)

Figure 2.

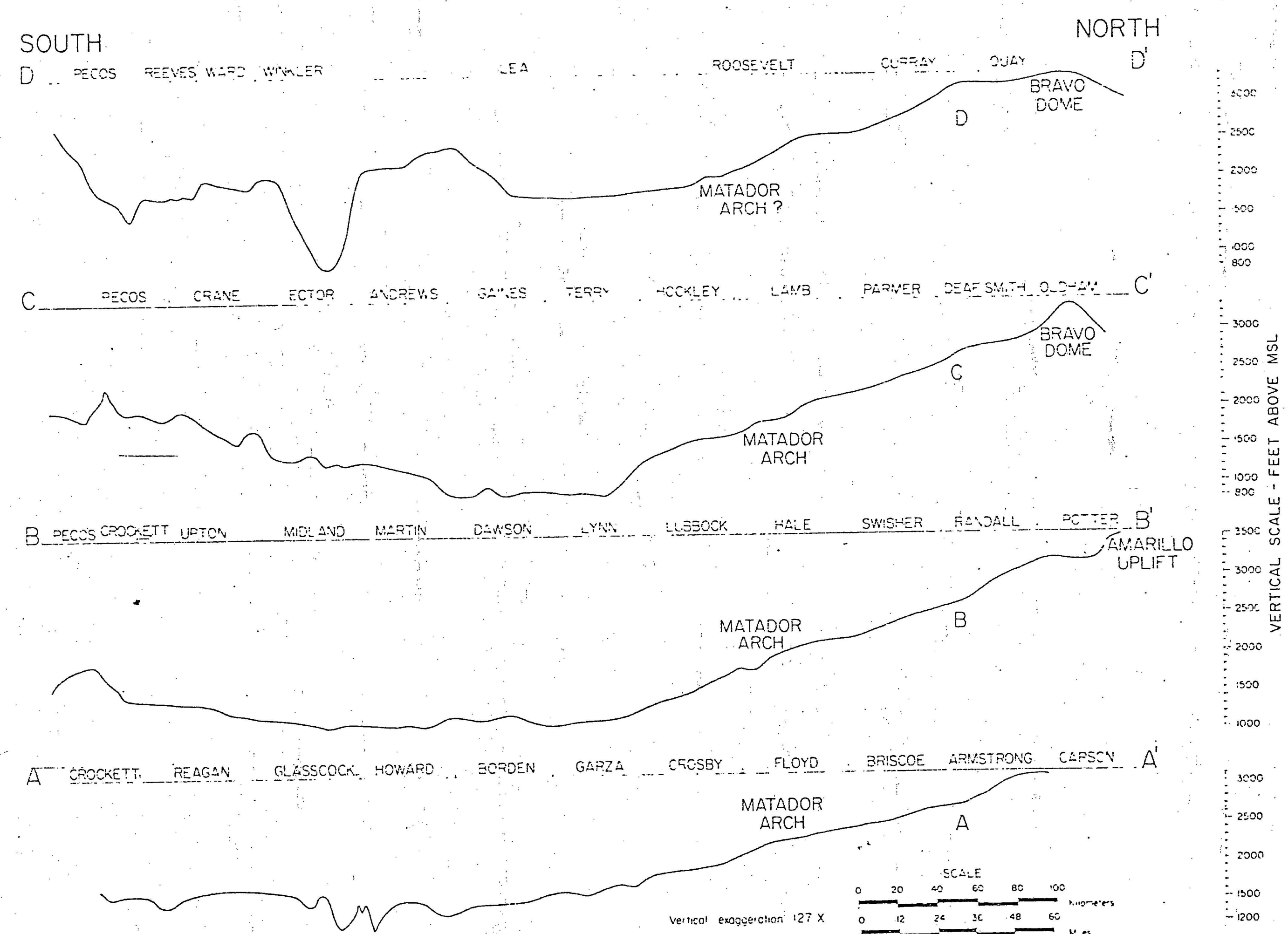


Figure 3. North-south structure profiles across relict Paleozoic structural elements. Location of structural profiles shown on figure 2.

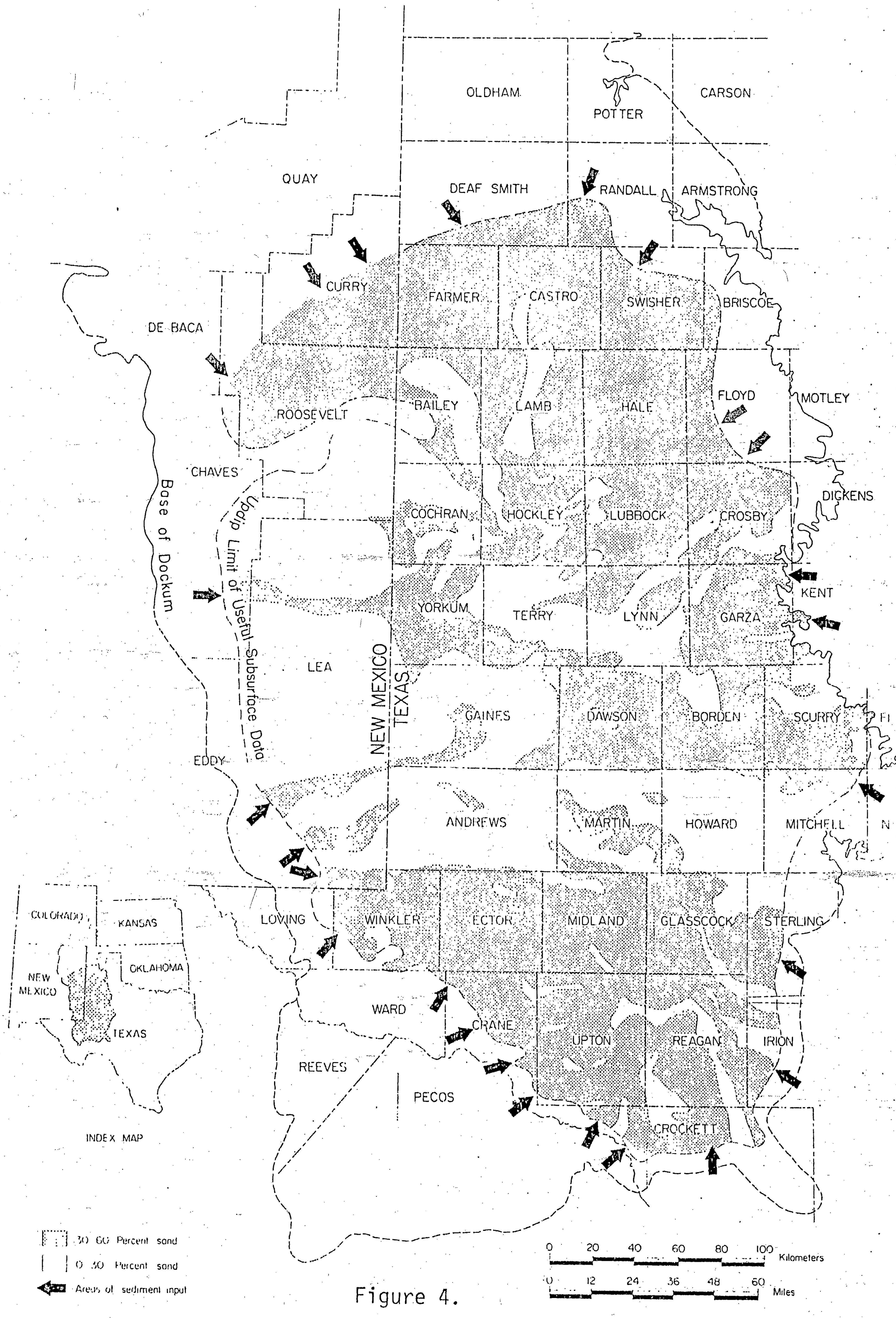


Figure 4.

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

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 is the only formal stratigraphic term applied.

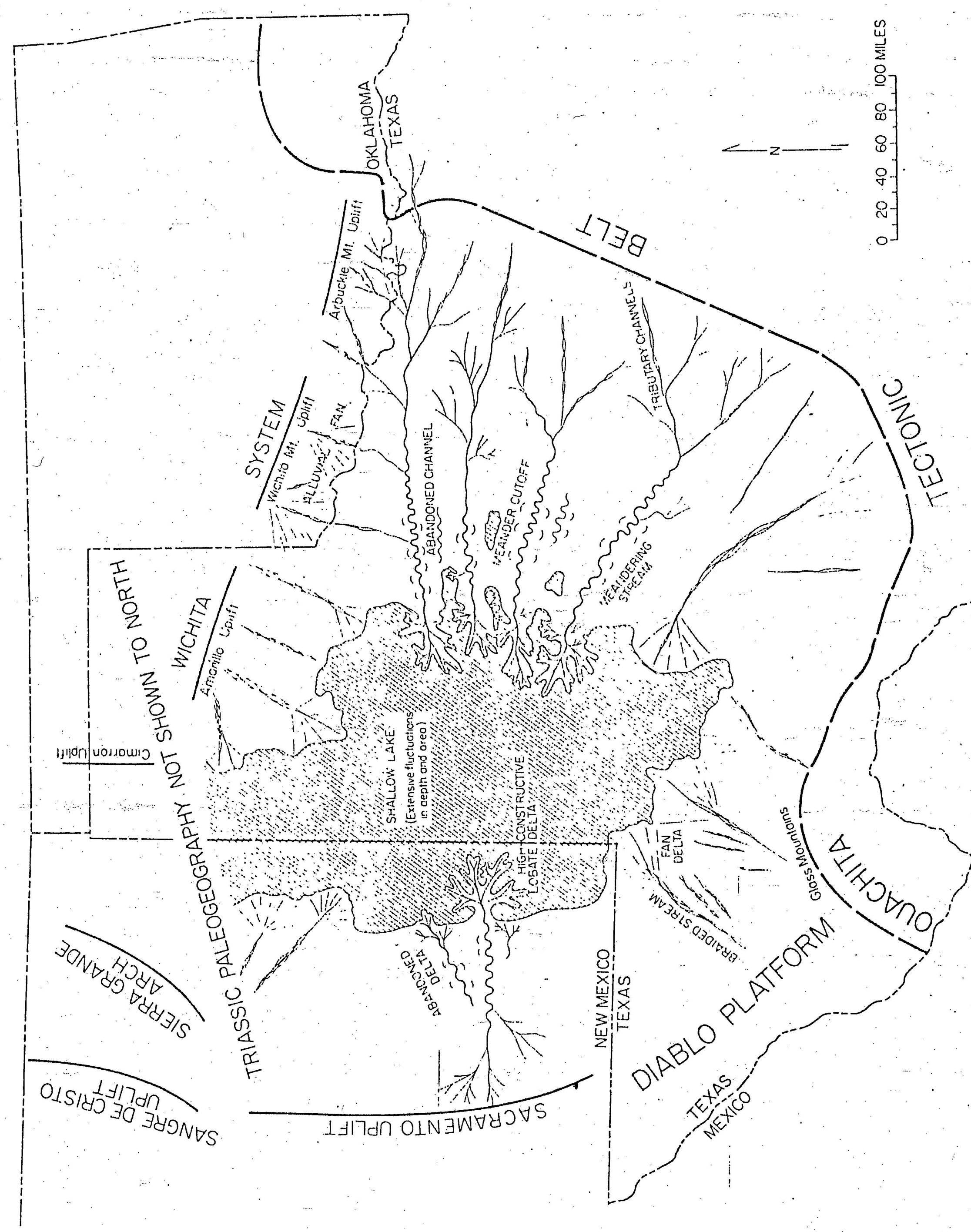
DOCKUM GROUP: FLUVIAL, DELTAIC, AND LACUSTRINE SYSTEMS

Subsurface work by McKee and others (1959), and substantiated by the present study, indicate 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.

Initiation of Dockum sedimentation resulted from two apparent changes: (1) a shift from 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

Figure 5.

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



TRIASSIC PALEOGEOGRAPHY NOT SHOWN TO NORTH
Cimarron Uplift
WICHITA
Amarillo Uplift
SYSTEM
Wichita Mt. Uplift
ALLUVIAL
FAN
Arbuckle Mt. Uplift
OKLAHOMA
TEXAS
BELT
TECTONIC
OUACHITA
TRIBUTARY CHANNELS
ABANDONED CHANNEL
MEANDER CUTOFF
MEANDERING STREAM
SHALLOW LAKE
(Extensive fluctuations in depth and area)
HIGH-CONSTRUCTIVE LOBATE DELTA
ABANDONED DELTA
FAN DELTA
BRAIDED STREAM
Glass Mountains
DIABLO PLATFORM
NEW MEXICO
TEXAS
TEXAS
MEXICO
SACRAMENTO UPLIFT
SANGRE DE CRISTO UPLIFT
SIERRA GRANDE ARCH
N
0 20 40 60 80 100 MILES

Figure 5.

sabkha environments were replaced by expanding lacustrine and fluvial-deltaic environments.

Early during Dockum deposition, 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 Dockum time. 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 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 attained in the outcrop area, based on thicknesses of progradational sequences, was about thirty 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 systems. 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 flood events. Fan deltas were consequently 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.

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 pattern of the predominantly sand

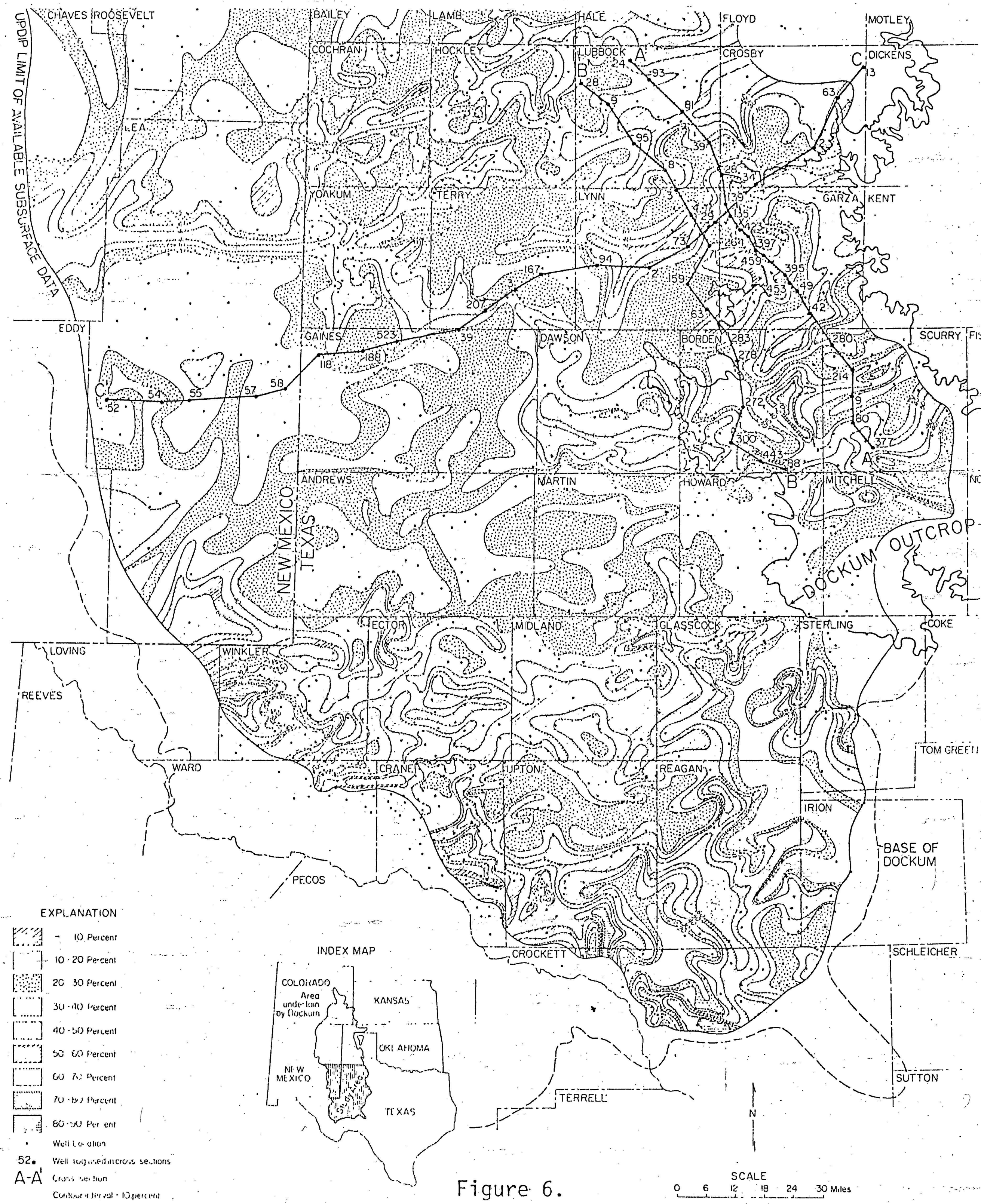


Figure 6.

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 on figures 34, 35, and 36.

sequences south of Sterling, Glasscock, Midland, Ector and Winkler Counties, Texas are interpreted to represent 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, occurs a complex of Triassic limestone and chert conglomerate, sandstone, reddish-brown mudstone, and thin limestone and dolomite beds that comprise 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 Conglomorate 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) 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 fold belt, shown by various sandstone maps, is interpreted to be 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 Debaca 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, flood plain, and lake environments. Four 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) the 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 fan delta system. An unconformity separates the lower and middle sandstone members.

A middle sandstone member, interpreted to be a coarse grained meanderbelt sequence (McGowen and Garner, 1970; Levey, 1976), records multiple channel migrations and the basal 10-15 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

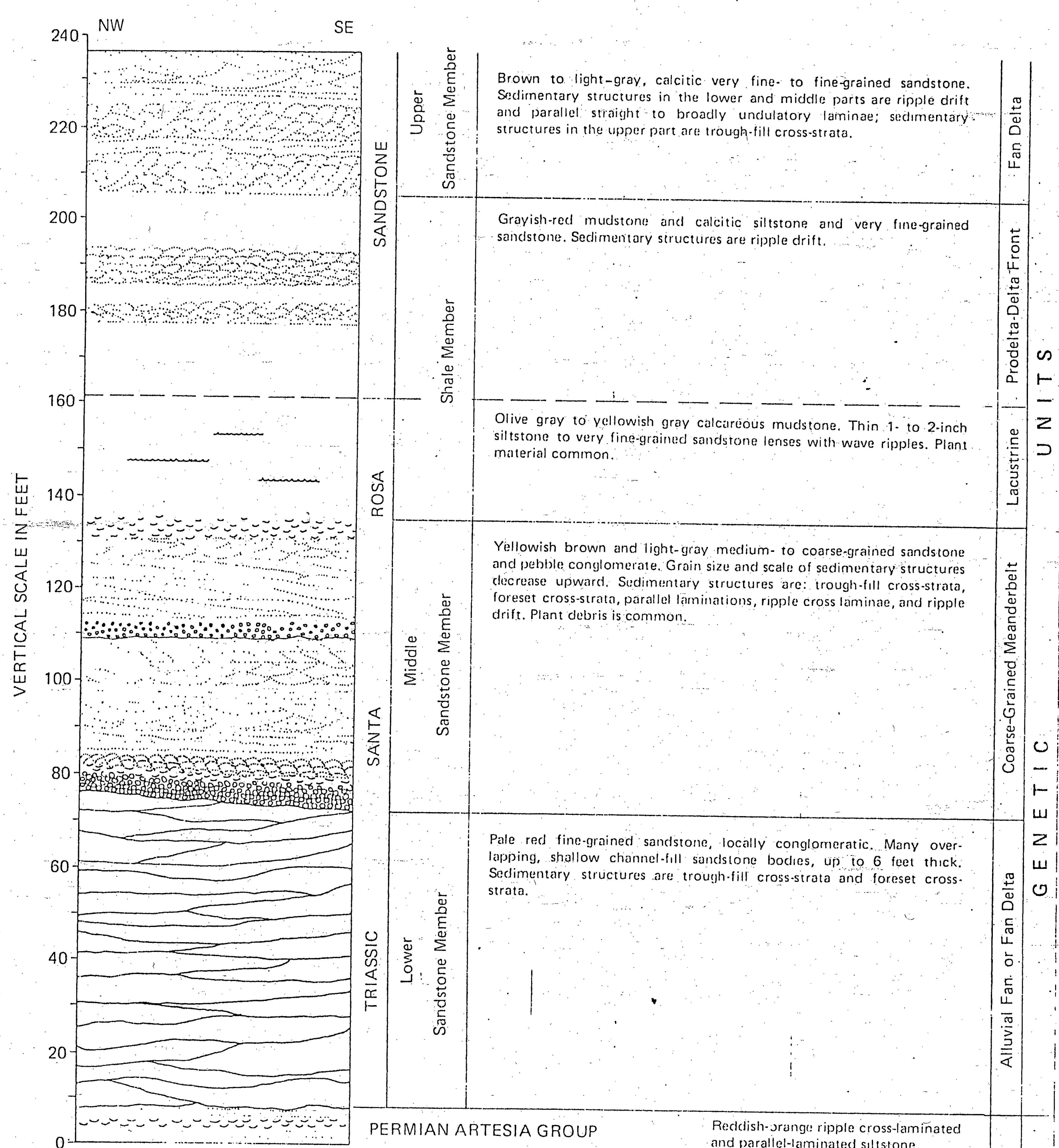


Figure 7. Generalized section of Santa Rosa Sandstone (principal reference section of Finch and Wright, 1975) Guadalupe County, New Mexico. Informal stratigraphic units after Finch and Wright. Refer to figures 10, 13, and 14 for explanation of sedimentary structure.

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 one-inch to one-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 10-15 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- 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 distal 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 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, minor 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

Figure 8.

Schematic of fan delta deposits in Oldham County, Texas (Boys Ranch West 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 crossbedded 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, 1971).

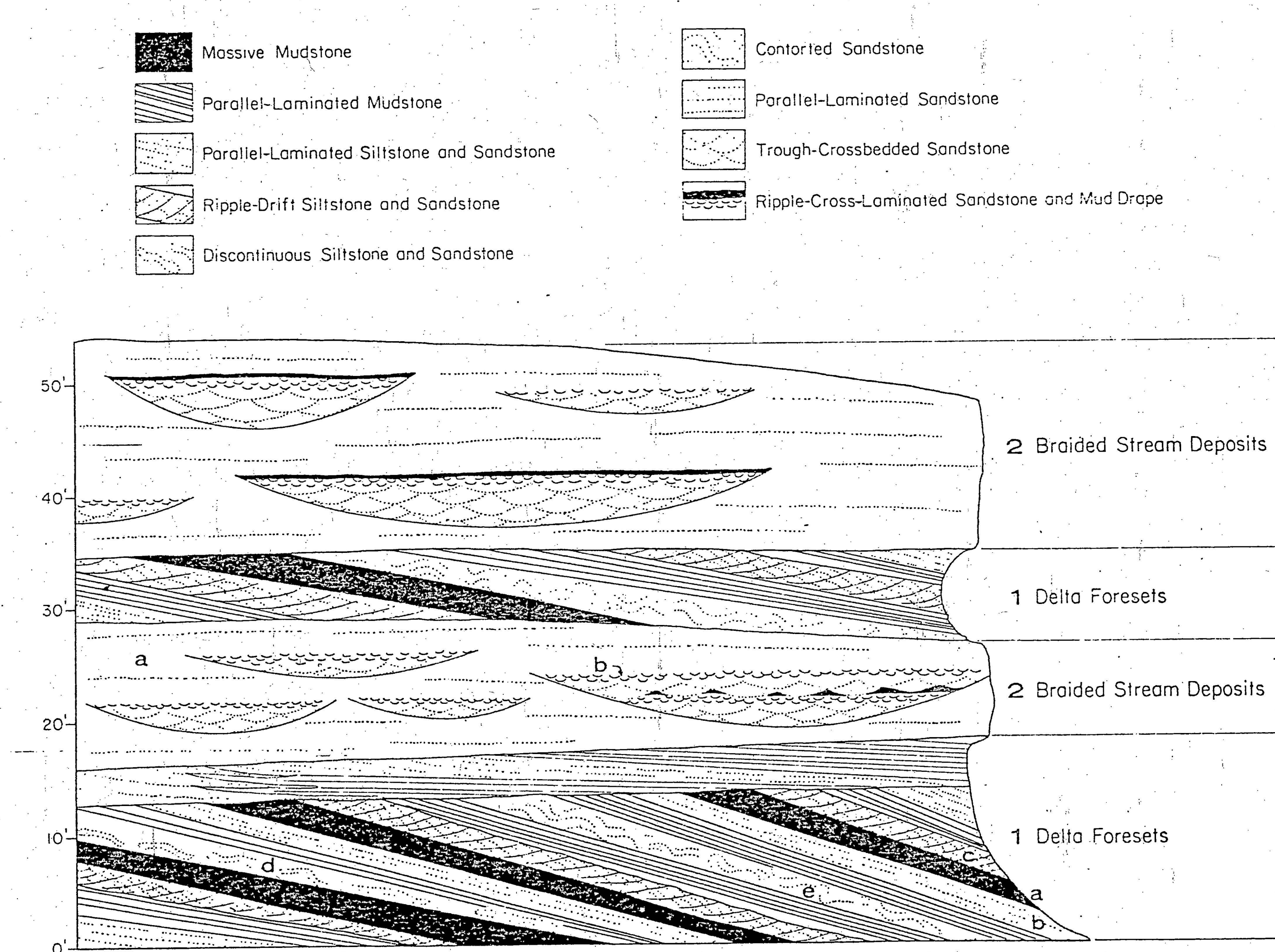

Massive Mudstone
Parallel-Laminated Mudstone
Parallel-Laminated Siltstone and Sandstone
Ripple-Drift Siltstone and Sandstone
Discontinuous Siltstone and Sandstone
Contorted Sandstone
Parallel-Laminated Sandstone
Trough-Crossbedded Sandstone
Ripple-Cross-Laminated Sandstone and Mud Drape
50'
40'
30'
20'
10'
0'
a
b
c
d
e
2 Braided Stream Deposits
1 Delta Foresets
2 Braided Stream Deposits
1 Delta Foresets

Figure 8.

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 were 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 structures are massive conglomerate, and parallel laminae, trough-fill cross-strata and low-angle foreset cross-strata in sandstones. Valley-fill deposits, shown on the sketch consist in ascending order of: (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, for the most part, of quartz; these beds are about 3-7 inches thick, and are ripple cross laminated (apparent transport direction S-SW). Reddish-brown, coarse siltstone to fine sandstone consists almost entirely of mud clasts; these beds are about 4-6 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 2-4 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-size conglomerate at the base; granule- and sand-size 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 stain) 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 photo 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 0.5-1.0 inch thick. Siltstone and sandstone comprise 1.0 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 0.12-0.25 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, give a false impression of foreset cross-strata. (6) Eight units (not all are shown on this figure) make up sedimentary sequence number 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 2.0 feet of light brown, slightly calcitic, very fine sandstone; grains are quartz and mud clasts; contains a few reddish-brown, cobble-size, mud clasts that are elongate parallel to bedding. Sedimentary structures are predominantly parallel laminae; upper 2.0-6.0 inches are ripple cross laminae, some of which have been deformed by soft sediment movement. (d) A few inches to 1.0 foot of brown, clayey siltstone. Massive with parallel inclined laminae at the top of the thicker part of the unit. (e) One 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 and 5.0 feet wide) that are filled with parallel laminae and ripple cross laminae. (f) Lower 5.0 inches comprise greenish-gray, massive, calcitic, very fine sandstone. Upper 7.0 inches consists of greenish-gray, massive, calcitic, sandy pebble conglomerate; clasts are mostly caliche, other clasts are siltstone and mudstone. (g) 0.5 to 1.0 foot of olive green, massive, friable, sandy, granule to pebble intrabasinal conglomerate (clasts were derived from mudstone). Carbonized plant debris is locally abundant. (h) 5.0 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.

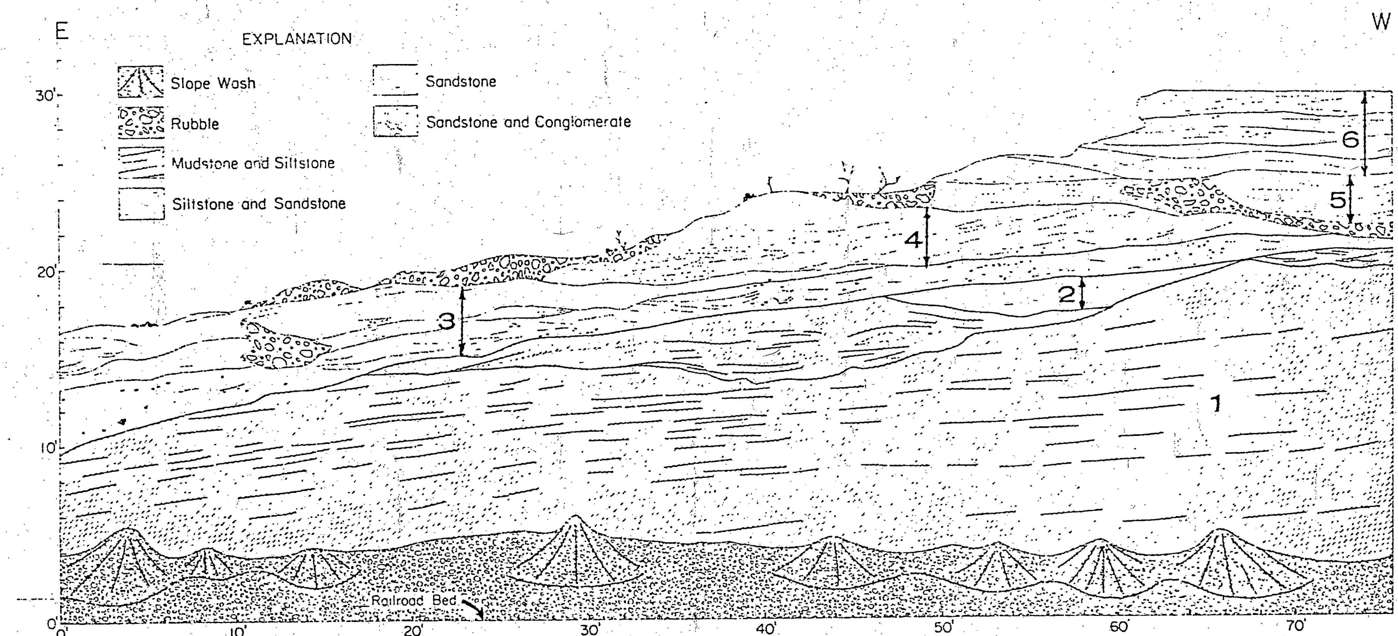

E
W
EXPLANATION
Slope Wash
Rubble
Mudstone and Siltstone
Siltstone and Sandstone
Sandstone
Sandstone and Conglomerate
30'
20'
10'
0'
0'
10'
20'
30'
40'
50'
60'
70'
1
2
3
4
5
6
Railroad Bed

Figure 9.

flowed both parallel and oblique to channel axes. Textural types comprising 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 which consists for the most part 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 was deposited 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, whose sedimentary structures are parallel laminae, ripple cross laminae, and soft-sediment deformation, accumulated either during low-flow conditions associated with a major flood event or during lesser floods when depth of flow was shallow.

Lower Dockum strata near Tascosa in the Canadian river valley are interpreted to be a lacustrine-fan delta couple. Mudstone and siltstone accumulated in lacustrine and fan delta front environments. Sandstones were deposited on fan delta plains (McGowen, 1971a, 1971b; McGowen and Scott, 1974). Channels were scoured and filled when lake level was lowered.

Palo Duro Canyon Area

From 300 to 400 feet of Dockum strata are 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 2-8).

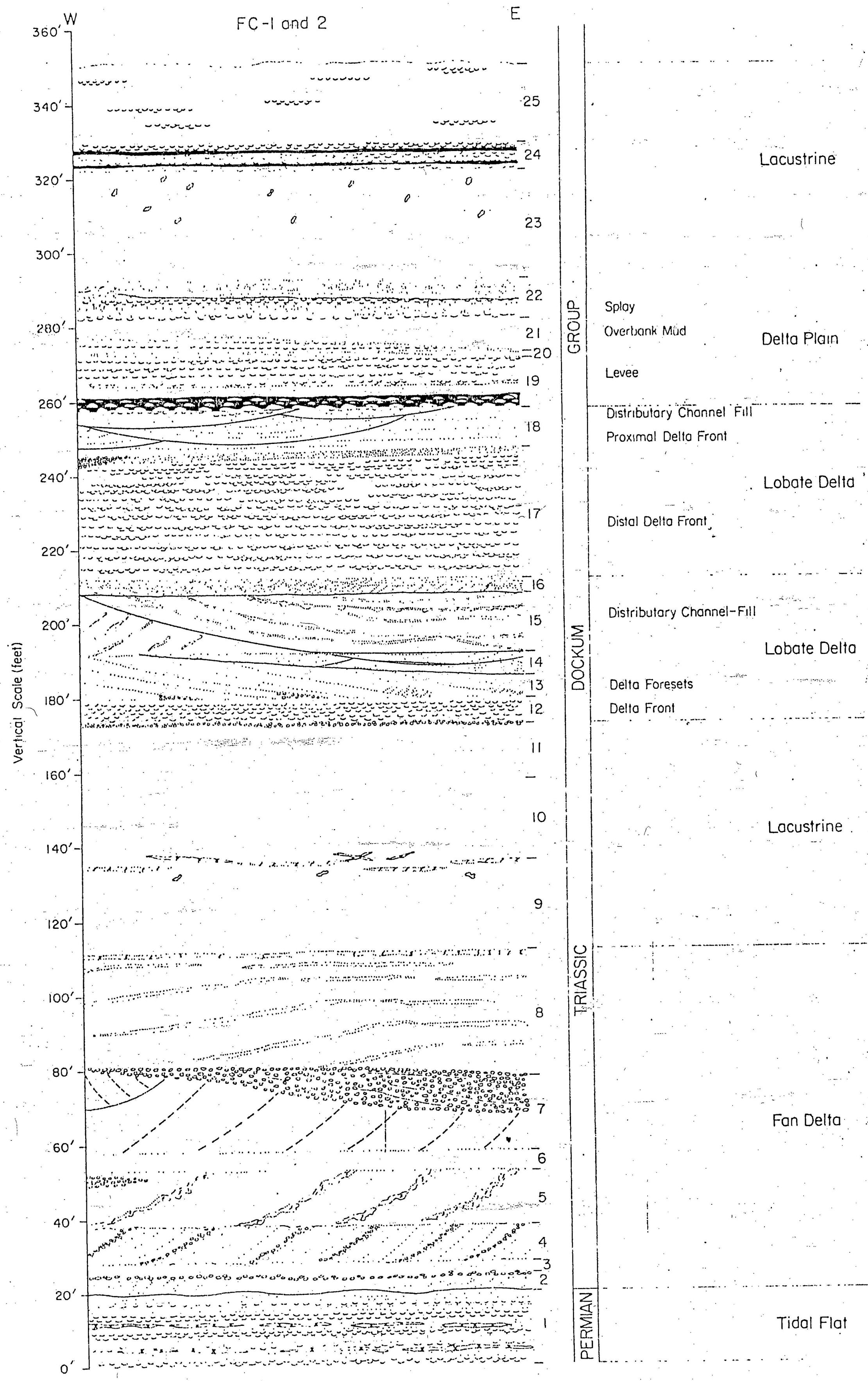
Delta foreset beds are similar to those reported by Gilbert (1890) for Pleistocene deltas in Lake Bonneville. Foresets are composed of (1) massive mudstone, (2) siltstone containing parallel inclined laminae and ripple cross-laminae, (3) bioturbated and soft sediment-deformed siltstone and very fine-grained sandstone, and (4) lenses of intrabasinal conglomerate. Intrabasinal conglomerate consists of clasts that were 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

Figure 10.

Composite section near east end of Palo Duro Canyon State Park, north of turn-around 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 2-11 are probably equivalent to Tecovas Formation, Dockum Group, and units 12-25 are probably equivalent to Trujillo Formation, Dockum Group. Units 2-8 are fan-delta facies comprising conglomerate, sandstone, siltstone, and mudstone foresets (units 2-6); 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 9-11) consist of thick, massive, yellow, medium gray, reddish brown and purple mudstone with lenses of impure silty dolomite and satinspar veins. Units 12-25 are probably equivalent to Trujillo Formation. Two progradational deltaic sequences are defined by lower units 12-16, 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 mud clast 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 14-16); channels were alternately active and abandoned. Upper

Figure 10 continued

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 crossbedded and ripple cross-laminated fine sandstone, respectively. Overbank, delta plain deposits (units 19-22) are greenish-gray parallel laminated, ripple cross-laminated, and trough crossbedded siltstone and very fine sandstone; and massive brown, green, yellow, and maroon mudstone. Lacustrine deposits (units 23-25) that cap sequence are brown and reddish brown mudstone with lenses of greenish-gray ripple cross-laminated siltstone and very fine sandstone.



FC-1 and 2
W
E
Vertical Scale (feet)
360'
340'
320'
300'
280'
260'
240'
220'
200'
180'
160'
140'
120'
100'
80'
60'
40'
20'
0'
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
DOCKUM GROUP
TRIASSIC
PERMIAN
Lacustrine
Splay
Overbank Mud
Delta Plain
Levee
Distributary Channel Fill
Proximal Delta Front
Lobate Delta
Distal Delta Front
Distributary Channel-Fill
Lobate Delta
Delta Foresets
Delta Front
Lacustrine
Fan Delta
Tidal Flat

Figure 10.

deltas constructed of very fine- to fine-grained sand, which accumulated in extremely shallow water, did not develop foresets. This mudstone-conglomerate 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 12-20) are components of high constructive lobate delta, meanderbelt, and valley-fill systems (meanderbelt and valley-fill deposits are not shown on Fig. 10). Distal delta front facies are comprised 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 19-22) accumulated in levee and delta plain environments. Lacustrine mud deposition followed delta abandonment and foundering (Fig. 10, units 23-25). 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 70-80 feet of the Dockum are similar to the lower mudstone (bed numbers 2-11, fig. 10) in Palo Duro Canyon State Park. There are some differences, however, particularly with respect to the contact between Permian and Triassic strata, and the presence of probable paleosols in the lower 10-15 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 five 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 five to seven feet of Dockum consists of two, massive, mottled, purple, yellow and brown, slightly silicic, very fine sandstone separated by mottled, purple, yellow and gray mudclast breccia. Chert lenses, about 0.06 to 2.0 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 the complex sodium silicate presently forming in Lake Magadii (Eugster, 1967, 1969; Eugster and Jones, 1968) and in Alkali Lake, Oregon (Rooney, et al, 1969). The complex sodium silicate, magadiite, converts with age to chert. (2) The other possibility is that the chert in the Dockum is a silcrete resulting from deposition of silica by evapotranspiration from surficial and shallow subsurface waters (Stephens, 1971). Immediately above the chert horizon there are about six feet of alternating purple and greenish-gray mudstone and reddish-brown and light gray, massive, very well rounded, medium to very coarse sandstone; this sequence comprises foresets that have an apparent dip to the south. The next 40 feet, or so, is covered and is assumed to be predominantly mudstone. Overlying the mudstone section are 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 which 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; this is recorded as abandoned channel-fill consisting of approximately 15 feet of reddish-brown, ripple cross laminated, siltstone and very fine sandstone. Stratigraphically above the abandone channel-fill are three symetrically-filled channels; these were inaccessible for description, but appear to be about 15-20 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-size sediment was emplaced by bed-load streams during flood events; 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 have been reported by Butzer and others (1969) from late Cenozoic strata in the Omo Basin.

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 to have accumulated in a fluvial environment and the upper 200 feet are 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 one-half-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 succeed 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 were measured. Here, the Permian comprises reddish-brown mudstone, siltstone, and very fine sandstone (predominantly sandstone) that accumulated in shallow, meandering, tidal channels (channels were 5.0 to 15.0 feet deep; based on thicknesses of preserved channel-fill deposits). Where complete channel sequences are preserved, the deposits exhibit fining upward textural and sedimentary structure trends. Basal channel-fill comprises trough-fill and foreset cross-stratified sandstone, followed by parallel (horizontal) laminated and parallel inclined (some are wedge sets) laminated sandstone and siltstone, and an uppermost mudstone-siltstone sequence consists of combined-flow ripples with flasers and parallel laminae.

There is an abrupt change in sandstone texture and composition, and in depositional style between the Permian and Triassic. Overlying the Permian there are 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-size clasts comprise granule to pebble chert, quartz, and quartzite. Depositional packages average 7.0 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 (bed load streams used in this report synonymously with braided streams). There is slight erosional relief along the upper surface of the lowermost Dockum.

Approximately 30 feet of sandstone, muddy sandstone, mudstone, and chert overlie the braided stream deposits; a massive chert bed a few inches to more than three feet thick caps these deposits. The lower 18-20 feet consists, for the most part, of reddish-brown and greenish-gray, poorly sorted, angular to very well rounded, fine to medium sandstone having local occurrences of granule to pebble-size chert, quartz, and quartzite. Sedimentary structures are predominantly foreset cross-strata that range in thickness from a few inches to about six 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 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 three 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-size quartz grains. Chert grades westward into massive, friable to silica-cemented, fine to medium 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 to medium sandstone. Two sandstone bodies occupy this interval. The lower sandstone is a few inches to about 8.0 feet thick, and the upper one is up to 25.0 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 pinchout into brown and reddish-brown mudstone. Sandstones are products of a braided stream process, and claystones, mudstones and siltstones accumulated in a lacustrine environment. The uppermost sandstone of this sequence was removed, to the east, by erosion which cut downward to within a few feet of the paleosoil. Erosion created a valley; at least 50 feet of valley-fill deposits are exposed in the road cut.

Well exposed outcrops of the Dockum Group are limited between Silverton and Dickens County. 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 meanderbelt system (McGowen and Garner, 1970; Levey, 1976). Uppermost exposures of Triassic strata in eastern Floyd County are characterized by braided stream deposits which grade westward into delta foresets composed of alternating mudstone and sandstone. Rocks that underlie braided stream deposits are, in ascending order, (1) massive mudstone which 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 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, is characterized upward by a basal lacustrine and deltaic mudstone and siltstone sequence, a thin deltaic sequence and an uppermost thick fluvial sandstone.

Cyclic deposits that overlie the basal Dockum progradational sequence consist of red beds which 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 re-sedimentation of older Dockum deposits; these sediments are termed <u>intrabasinal</u> in this report. Silstones, sandstones and conglomerates that overlie the red beds were derived, for the most part, from outside the basin of deposition; these sediments have been labeled <u>extrabasinal</u>.

Sediment properties (e.g. color, texture, composition, sequences of sedimentary structures, geometry, cross-cutting relationships, and biological constituents) indicate that depositional cycles were produced principally by 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 climatic conditions.

A vertical (upward) sequence of strata deposited during high stand

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.

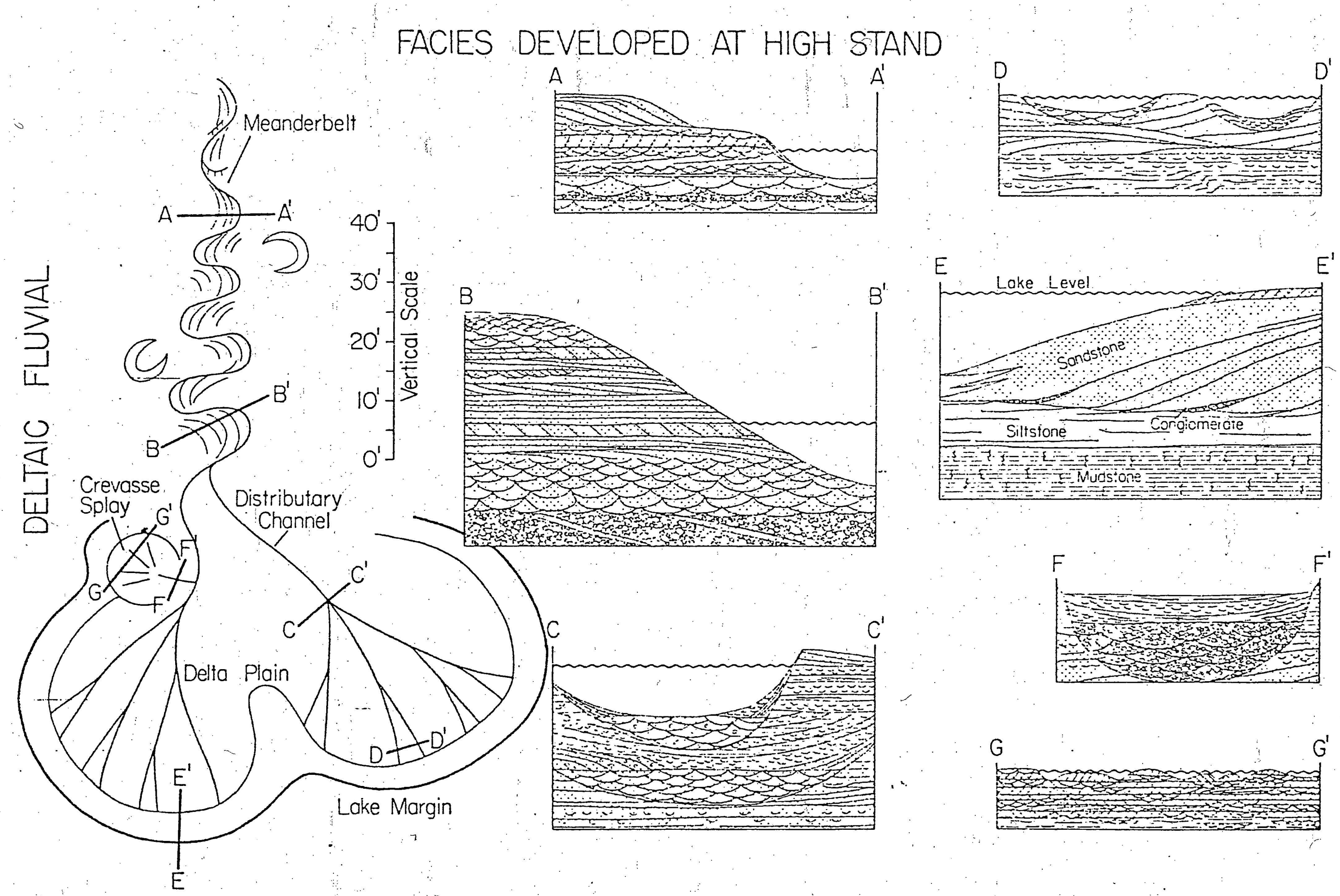

FACIES DEVELOPED AT HIGH STAND
DELTAIC FLUVIAL
Meanderbelt
A
A'
B
B'
C
C'
D
D'
E
E'
F
F'
G
G'
Crevasse Splay
Distributary Channel
Delta Plain
Lake Margin
40'
30'
20'
10'
0'
Vertical Scale
Lake Level
Sandstone
Siltstone
Conglomerate
Mudstone

Figure 11.

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 and ripple cross laminated containing 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 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 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 as a result of down-cutting 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 to represent sedimentation under arid or semi-arid 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 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 eroded 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 from suspension (settle-out within ponded water bodies).

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

Figure 12.

Major depositional elements during 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, slope-wash, 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 crossbedded intrabasinal conglomerate. Delta platform, delta margin, and delta foresets 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.

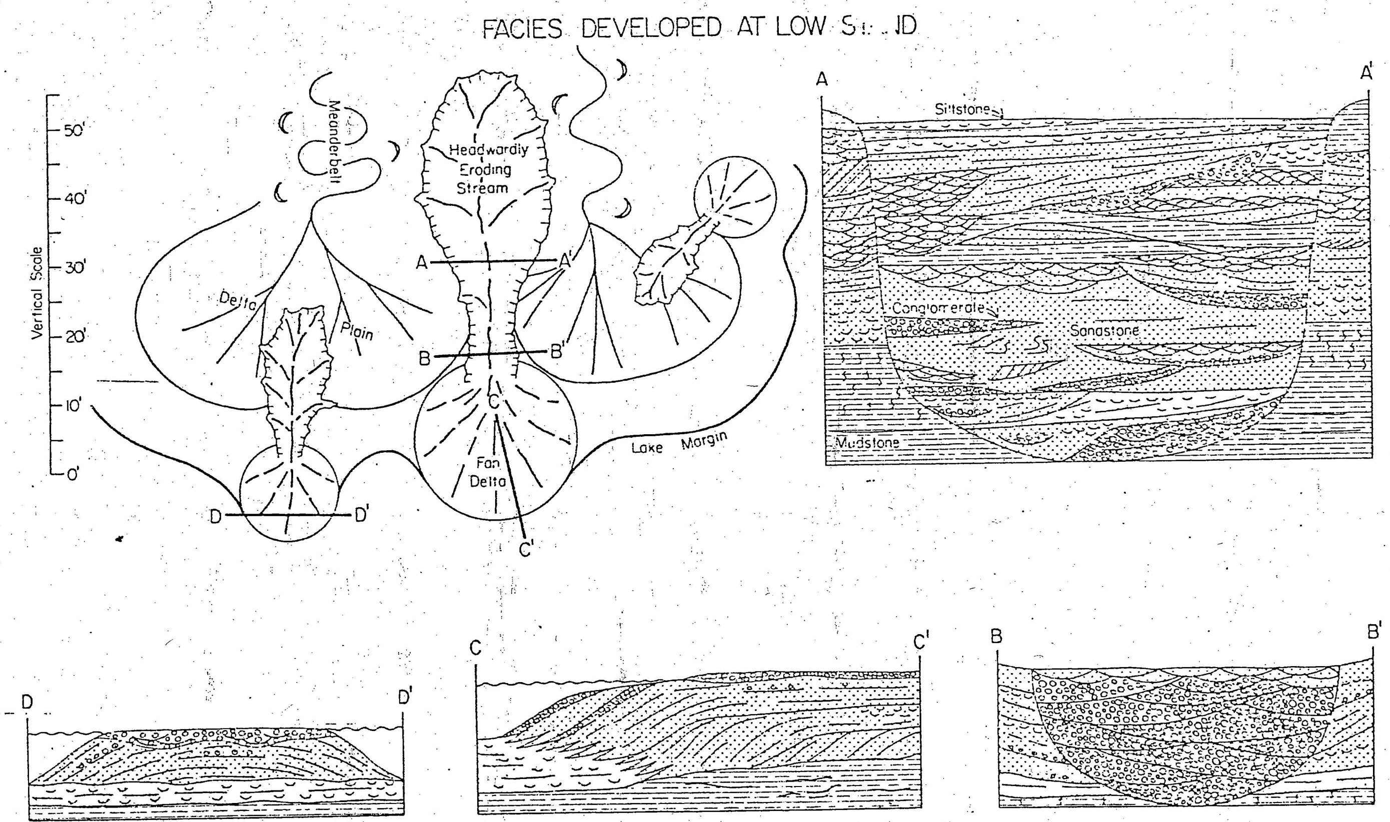

FACIES DEVELOPED AT LOW S... ID
Vertical Scale
50'
40'
30'
20'
10'
0'
Meanderbelt
Delta
Plain
Headwardly Eroding Stream
Fan Delta
Lake Margin
A
A'
B
B'
C
C'
D
D'
Siltstone
Conglomerate
Sandstone
Mudstone

Figure 12.

DEPOSITIONAL SYSTEMS

The Dockum Group was deposited 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 area and level was at a 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 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.

Figure 13.

Progradational sequence, Slaughter ranch, southwestern Garza County (Middle Creek 7.5 minute quadrangle). High-stand and low-stand deposits represented in section. Units 1-4 are low-stand deposits; and units 5-15 are high-stand deposits; a transition occurs from low-stand to high-stand facies. Low-stand deposits (units 1-4) components of fan deltas. For example, units 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 crossbeds, and low-angle delta foresets; also small diameter (0.06 to 0.12 inch) burrow. 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 and 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 9-14) comprises greenish gray granule to pebble intrabasinal conglomerate,

Figure 13 continued

conglomeratic fine sandstone, and fine sandstone, and moderate brown to reddish brown mudstone, siltstone, and very fine sandstone; primary sedimentary structures are trough crossbeds, 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 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, shallow trough crossbeds, parallel inclined laminae, medium scale trough crossbeds, high-angle foreset cross-strata, and wavy parallel laminae.

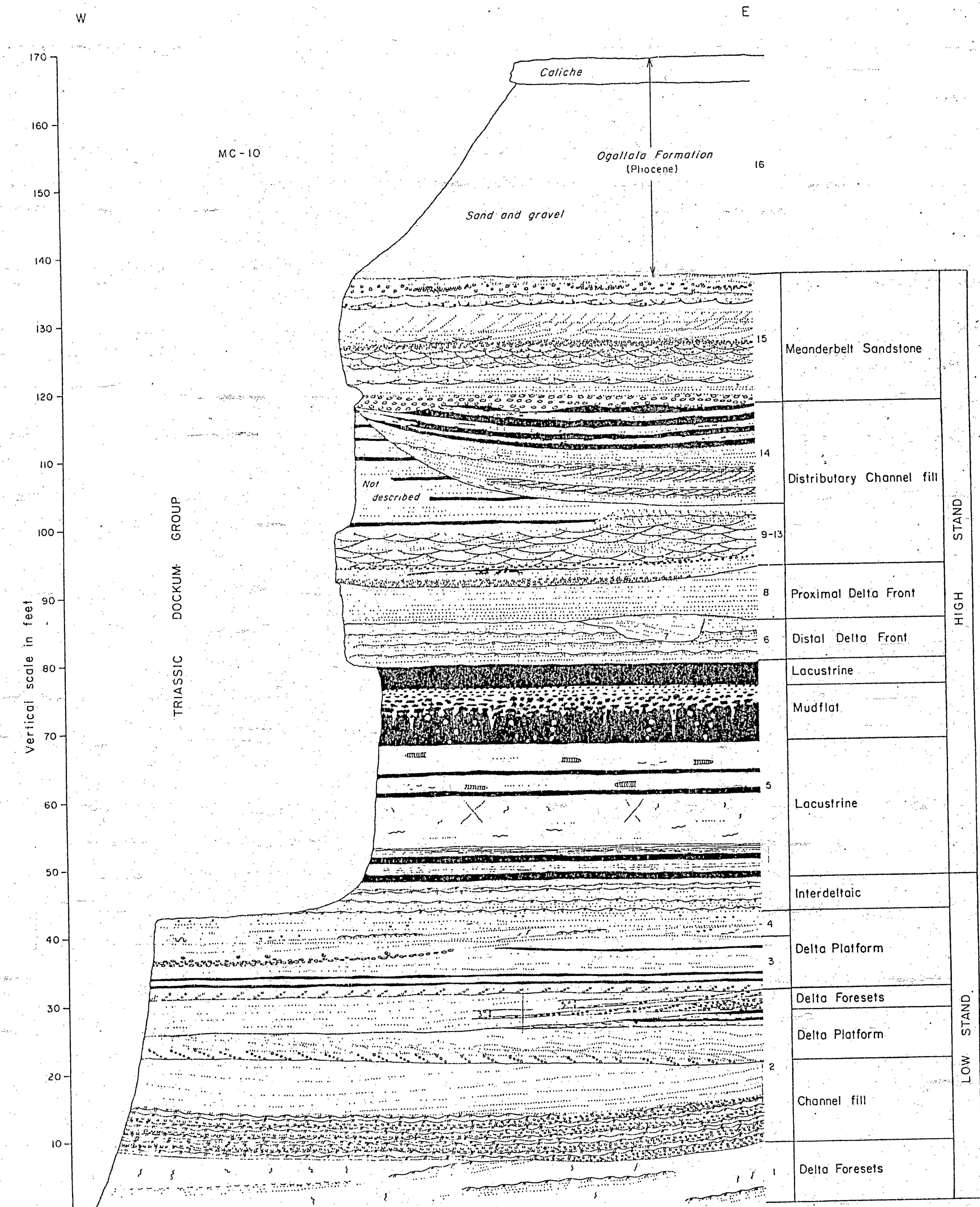

W
E
Caliche
MC-10
Ogallala Formation
(Pliocene)
16
Sand and gravel
Vertical scale in feet
TRIASSIC DOCKUM GROUP
Not described
15
Meanderbelt Sandstone
14
Distributary Channel fill
9-13
8
Proximal Delta Front
7
6
Distal Delta Front
Lacustrine
Mudflat
5
Lacustrine
Interdeltaic
4
Delta Platform
3
Delta Foresets
Delta Platform
2
Channel fill
1
Delta Foresets
HIGH STAND
LOW STAND
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170

Figure 13.

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 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

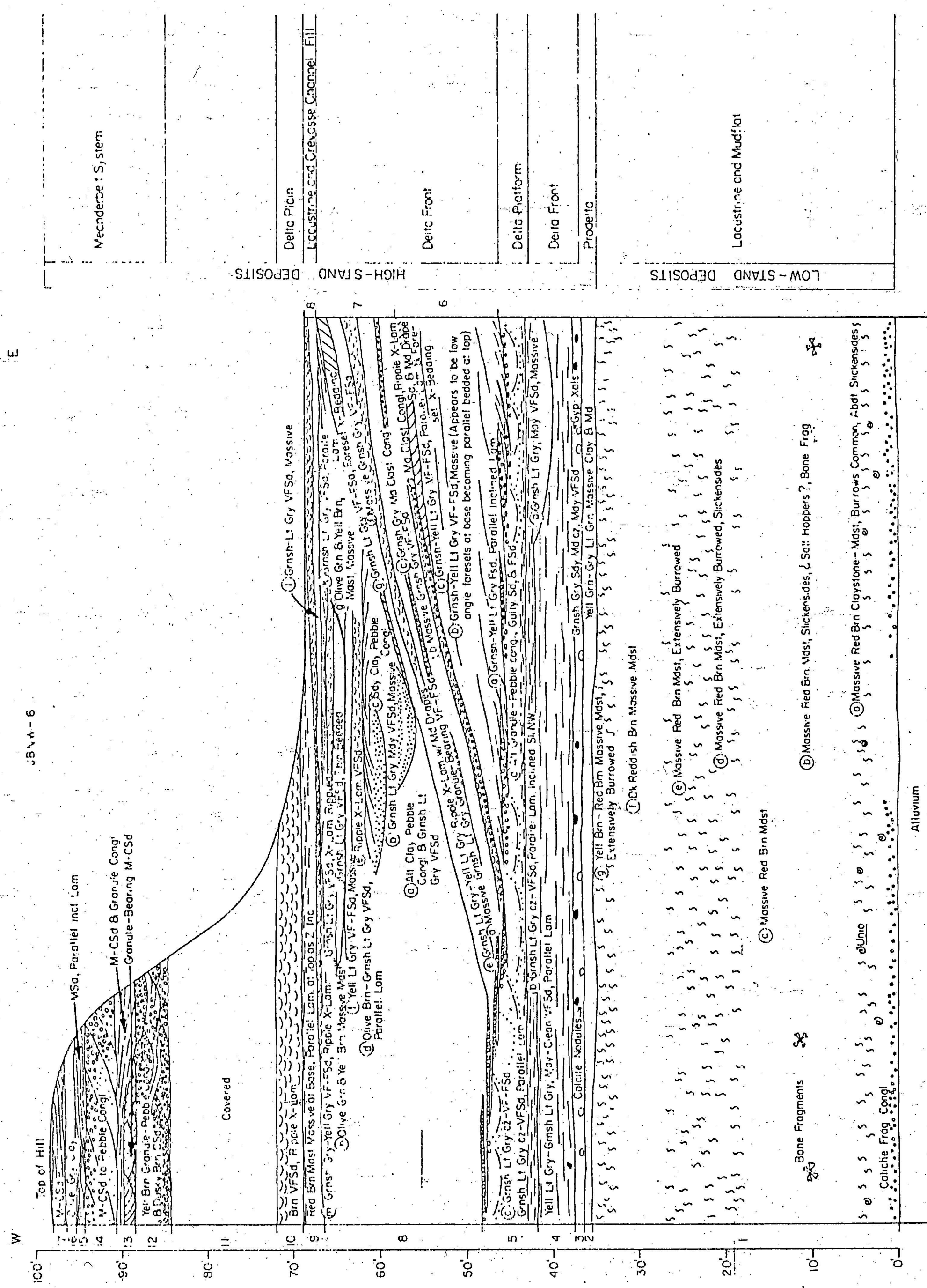
Delta front siltstone and sandstone facies are mostly grayish-green with reddish-brown being dominant in the lower few feet of the unit. Bedding may be approximately horizontal or inclined in the direction of sediment transport (Fig. 14). Sedimentation units thin and grain size decreases in a downcurrent 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 wash-out channels are rare to common (Fig. 13). Channels, one to two 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 diameter (0.25 inch), and oriented both perpendicular and parallel to bedding. _Ophiomorpha_ are rare.

Figure 14.

14. Delta front facies associated with high-stand lobate delta, Dalby ranch, Garza County (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* (fresh water clam) suggest alternating hypersaline and fresh-water environment; bone fragments and abundant *Scoyenia* (poly-chaaete worm burrows). High-stand deposits (units 2-17) accumulated under varying water-level conditions. Thin coarsening-upward sequence represented by units 2-5; 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 about 5^{o} west (unit 6) and about 7^{o} 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 12-17).



W
E
Top of Hill
Covered
Alluvium
Bone Fragments
Caliche Frag Congl
HIGH-STAND DEPOSITS
LOW-STAND DEPOSITS
Delta Plain
Delta Front
Delta Platform
Prodelta
Lacustrine and Mudflat

Figure 14.

Other biological constituents are bone fragments and unidentified molluscan calcite shell fragments.

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- 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- to fine-grained sandstone comprising 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

Figure 15.

Thin progradational sequence, approximately 9 feet thick, on Dalby ranch, Garza County (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^{o} northwest and southeast. (c) Greenish gray, mud clast-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.

Figure 15.

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 which parallel transport direction of the thicker channel-fill sequences. Reactivation surfaces are common in the large sigmoidal foresets. Reactivation surfaces are analogous to those reported by Harms (1975, p. 50-51).

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 display limited distribution

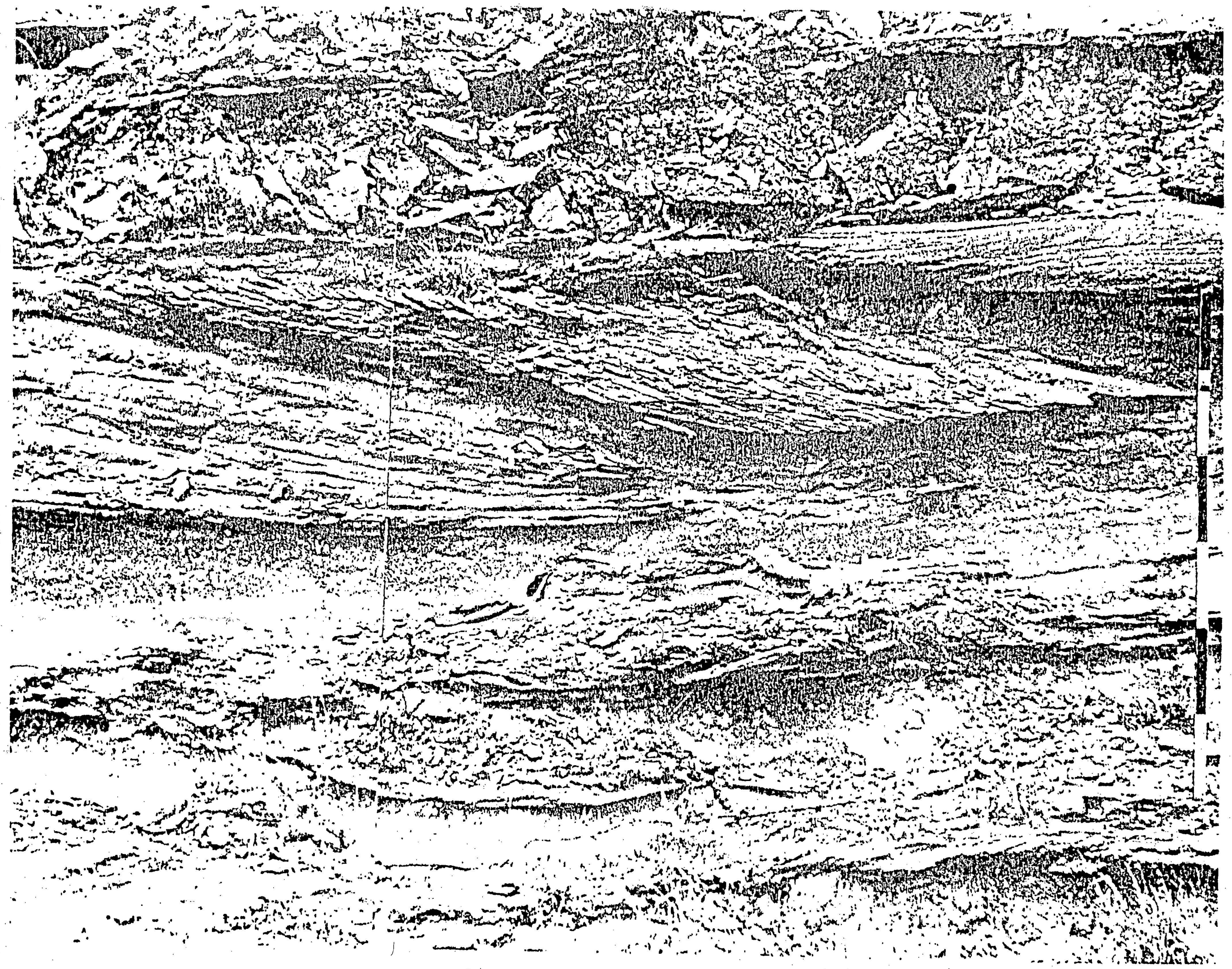


Figure 16.

Large sigmoidal foreset crossbeds in lower part of distributary channel-fill, road cut, Farm Road 669, south of Double Mountain Fork of Brazos River, southwest Garza County (Middle Creek 7.5 minute quadrangle). View west. Apparent transport direction north. Reactivation surfaces common in sequence. Jacob's staff 6.0 feet long.

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, bone fragments and plant debris are rare to abundant. Some plant debris has been carbonized. Locally, relatively thick plano-convex sandstone bodies that display dominant parallel laminae and subordinate trough-fill cross-strata, overlie conglomerate-filled crevasse channels.

Crevasse Splay Facies

Conglomerate-filled crevasse channels grade down current into sheetlike conglomerate and sandstone bodies that constitute the splay facies. Splay conglomerate and sandstone were emplaced by braided stream processes whose modern counterparts have been observed on the Omo Delta (Butzer, 1971). Since splays are products of unconfined flow, paleocurrent indicators exhibit a wide directional variation similar to those of fans and fan deltas (McGowen, 1971a; McGowen 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 derived 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 three 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 flood plain deposits) or thick meander belt 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 and width of meandering fluvial sandstone bodies are approximately 85 feet and six miles, respectively. 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 multi-depositional events, and (2) sandstone bodies that represent a single fluvial sandstone body; these normally occur near meanderbelt margins. Single sandstone bodies range in thickness from 20 to 40 feet.

Accretionary grain, a feature that results from point bar accretion, is exhibited by some point bar sandstones that crop out over broad areas that are approximately perpendicular to sand-body trend.

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) 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 (e.g. in Kent and Crosby Counties) is mostly granule- to pebble-size chert, quartz and quartzite (Fig. 17). Bone material and large plant fragments (e.g. 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 in ascending order of (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)

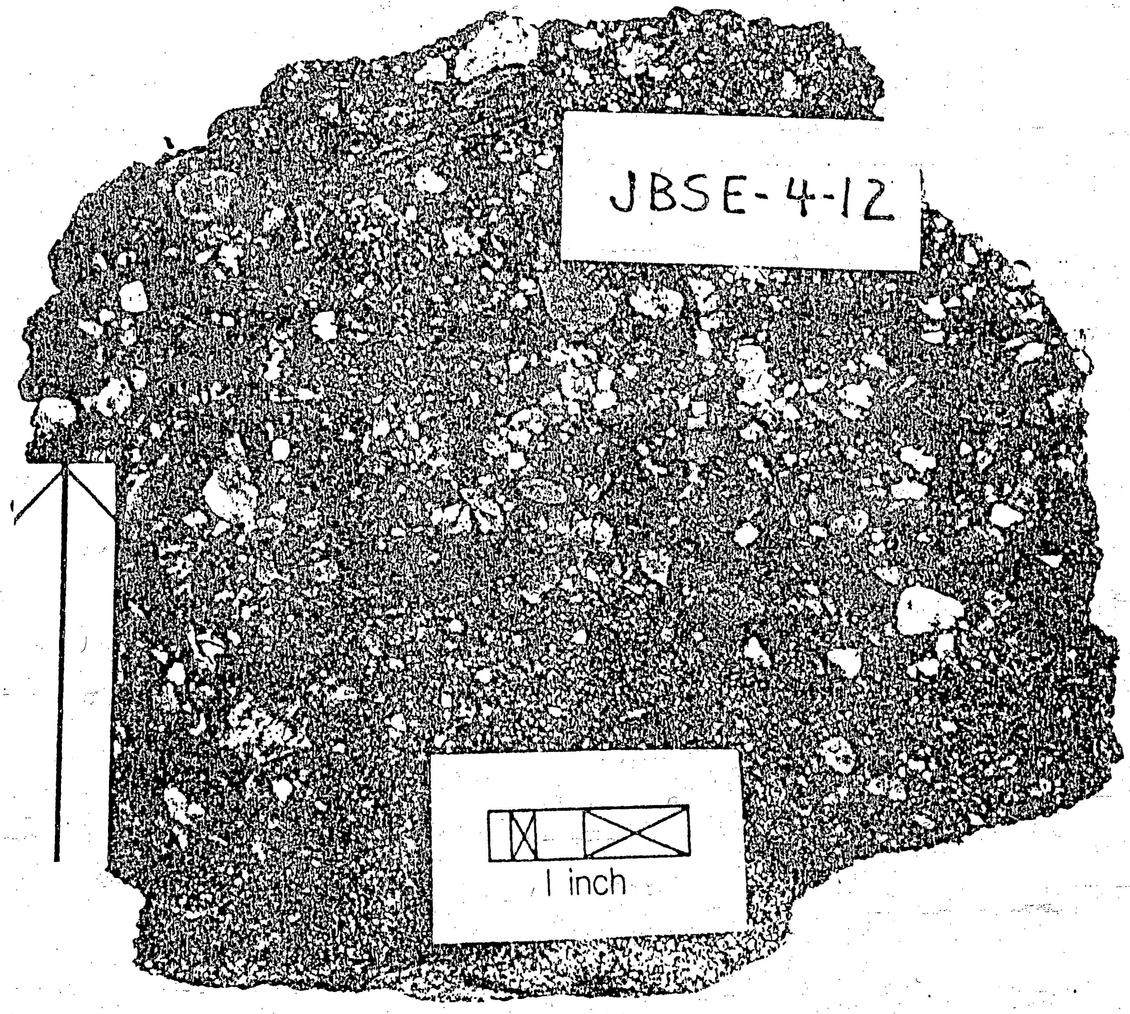


Figure 17.

Channel-lag conglomerate, Johnson ranch, Kent County (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.

either simple low angle foresets that are 5 to 9 feet thick or an interval of compound foresets of comparable thickness, and finally (4) parallel and ripple cross laminated siltstone and very fine-grained sandstone that alternate with parallel laminated or massive mudstone (Fig. 18).

The analogy between Modern coarse-grained meanderbelt seqeunces 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 bed-load and mixed-load to distinguish between ancient fluvial deposits. This procedure dispenses with the problem of variance 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- 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 cut-offs and abandoned stream courses are components of meanderbelt systems (Fig. 11). Abandoned channels are filled with mud-

Figure 18.

Coarse-grained meanderbelt sequence, Dalby ranch, central Garza County (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 5-8, 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 sandstone. Overbank deposits (units 6, 7, 8) consist of ripple cross-laminated coarse siltstone to very fine sandstone and massive sandy mudstone.

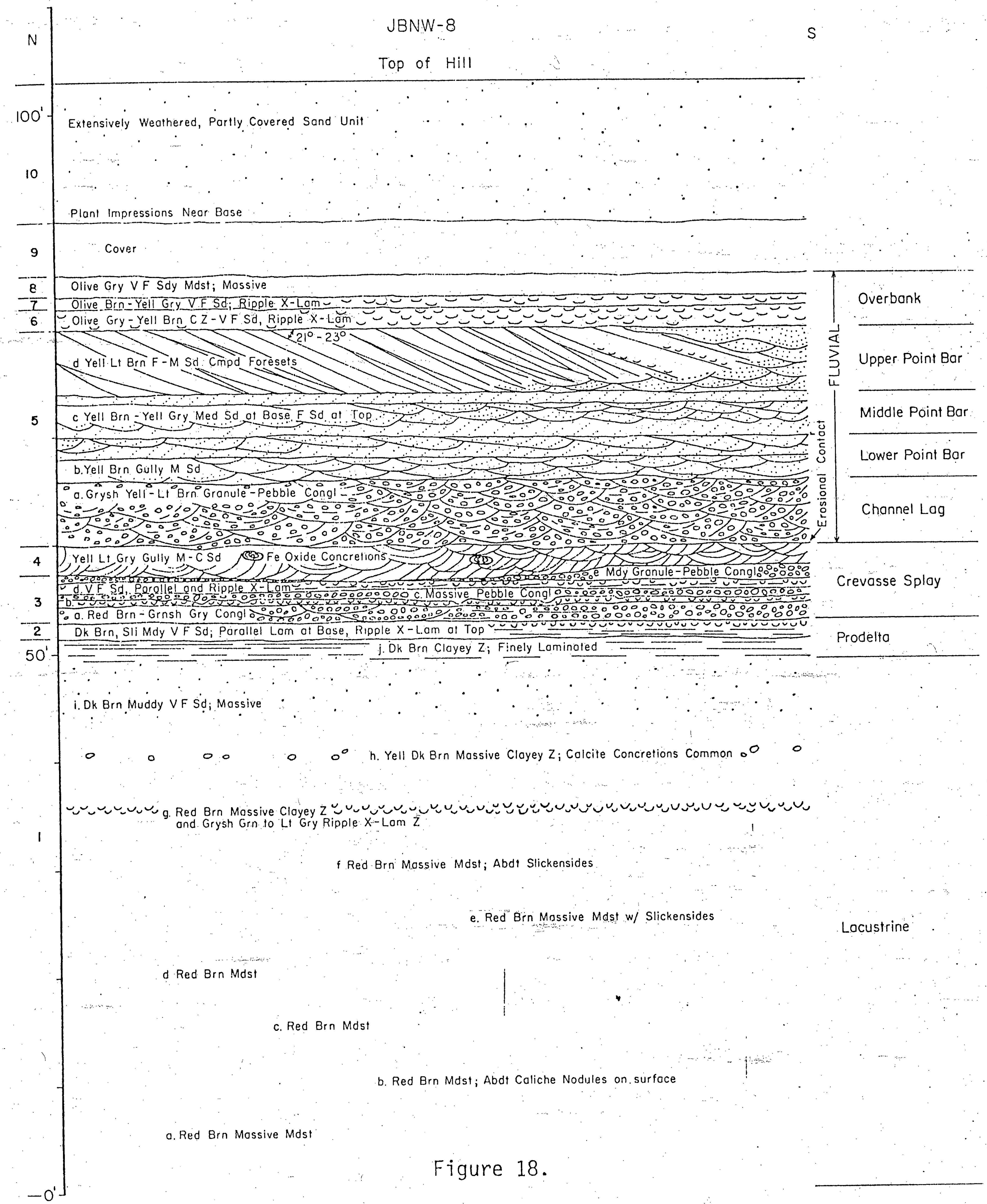
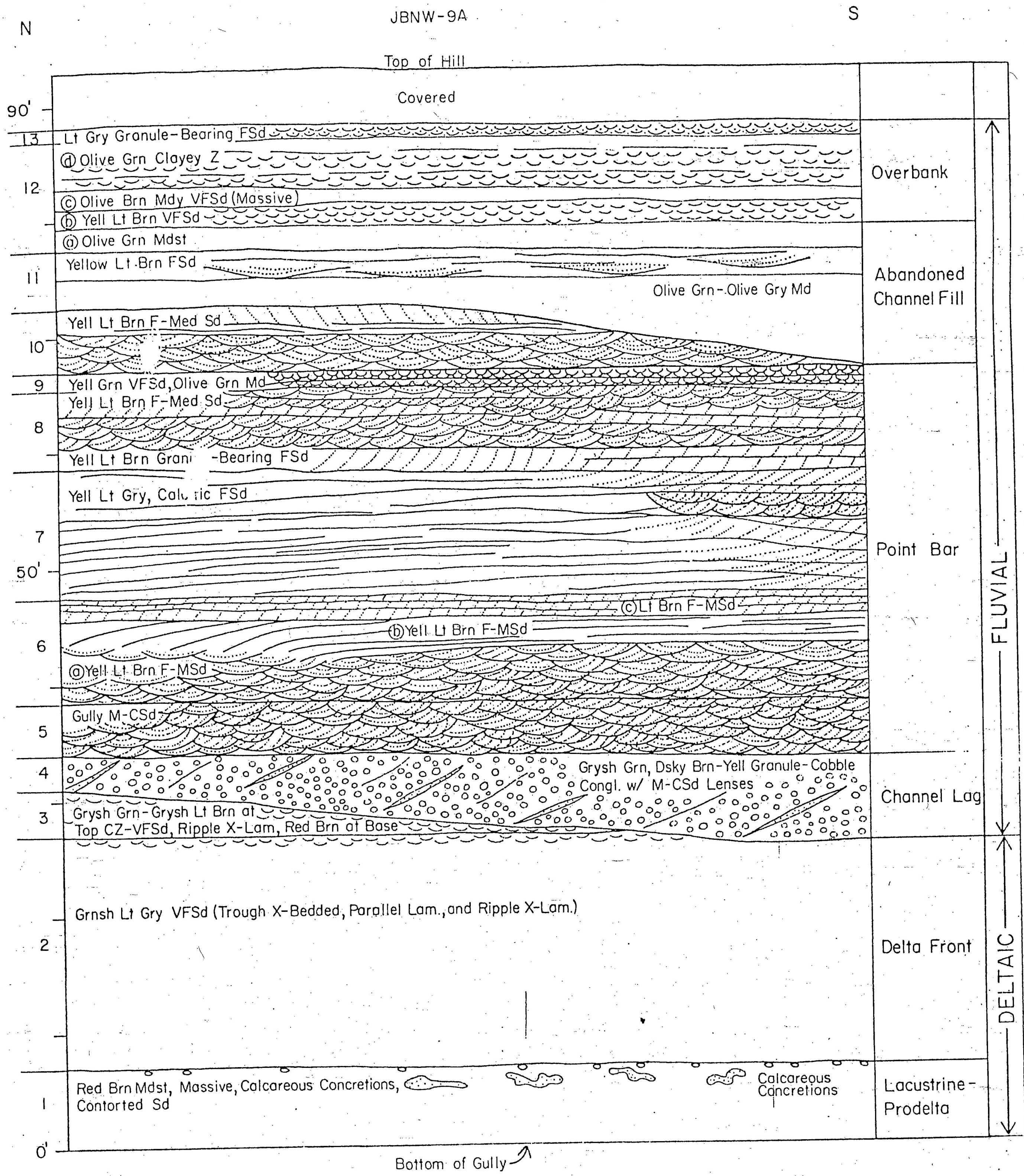

JBNW-8
N
S
Top of Hill
100'
10
Extensively Weathered, Partly Covered Sand Unit
Plant Impressions Near Base
9
Cover
8
Olive Gry V F Sdy Mdst; Massive
7
Olive Brn-Yell Gry V F Sd; Ripple X-Lam
6
Olive Gry-Yell Brn C Z-V F Sd, Ripple X-Lam
21° - 23°
d Yell Lt Brn F-M Sd Cmpd Foresets
5
c Yell Brn-Yell Gry Med Sd at Base F Sd at Top
b. Yell Brn Gully M Sd
a. Grysh Yell-Lt Brn Granule-Pebble Congl
4
Yell Lt Gry Gully M-C Sd
Fe Oxide Concretions
e Mdy Granule-Pebble Congl
3
d. V F Sd, Parallel and Ripple X-Lam
b.
c. Massive Pebble Congl
a. Red Brn-Grnsh Gry Congl
2
Dk Brn, Sli Mdy V F Sd; Parallel Lam at Base, Ripple X-Lam at Top
50'
j. Dk Brn Clayey Z; Finely Laminated
i. Dk Brn Muddy V F Sd; Massive
h. Yell Dk Brn Massive Clayey Z; Calcite Concretions Common
g. Red Brn Massive Clayey Z and Grysh Grn to Lt Gry Ripple X-Lam Z
1
f Red Brn Massive Mdst; Abdt Slickensides
e. Red Brn Massive Mdst w/ Slickensides
d Red Brn Mdst
c. Red Brn Mdst
b. Red Brn Mdst; Abdt Caliche Nodules on surface
a. Red Brn Massive Mdst
0'
FLUVIAL
Erosional Contact
Overbank
Upper Point Bar
Middle Point Bar
Lower Point Bar
Channel Lag
Crevasse Splay
Prodelta
Lacustrine

Figure 18.

Figure 19.

Fine-grained meanderbelt sequence, Dalby ranch, central Garza County (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 2-8 (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.



JBNW-9A
N
S
Top of Hill
Covered
90'
13
Lt Gry Granule-Bearing FSd
ⓓ Olive Grn Clayey Z
12
ⓒ Olive Brn Mdy VFSd (Massive)
ⓑ Yell Lt Brn VFSd
ⓐ Olive Grn Mdst
Overbank
Yellow Lt Brn FSd
11
Olive Grn-Olive Gry Md
Abandoned Channel Fill
Yell Lt Brn F-Med Sd
10
9
Yell Grn VFSd, Olive Grn Md
Yell Lt Brn F-Med Sd
8
Yell Lt Brn Grani -Bearing FSd
Yell Lt Gry, Calc ric FSd
7
50'
Point Bar
ⓒ Lt Brn F-MSd
ⓑ Yell Lt Brn F-MSd
6
ⓐ Yell Lt Brn F-MSd
Gully M-CSd
5
4
Grysh Grn, Dsky Brn-Yell Granule-Cobble Congl. w/ M-CSd Lenses
Channel Lag
3
Grysh Grn-Grysh Lt Brn at Top CZ-VFSd, Ripple X-Lam, Red Brn at Base
FLUVIAL
Grnsh Lt Gry VFSd (Trough X-Bedded, Parallel Lam., and Ripple X-Lam.)
2
Delta Front
DELTAIC
Red Brn Mdst, Massive, Calcareous Concretions, Contorted Sd
Calcareous Concretions
1
Lacustrine-Prodelta
0'
Bottom of Gully

Figure 19.

stone 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 cut-offs. 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; indications are that 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.

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 foresets, (3) delta platform, (4) mudflat, and (5) valley-fill fluvial deposits. Single deltaic sequences comprising foresets and delta platform are on the order of 10 feet thick. Lacustrine and prodelta facies are generally thin (5 to 10 feet thick) and valley-fill fluvial deposits range from a few 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 wherein flow was confined. 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 accumulated along the foresets from suspension. Sediment was emplaced on the lake floor by bottom currents and from suspension.

Lacustrine and Prodelta Facies

Reddish-brown mudstone and siltstone comprise lacustrine and prodelta deposits. Several mudstone and siltstone types make up these deposits, which represent the lowest 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 exhibites 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 (0.1-0.2 inch diameter); (2) burrow-fill with a ropy texture (0.2-0.5 inch diameter); and (3) spreite, meaning something spread between two supports (0.5-0.7 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

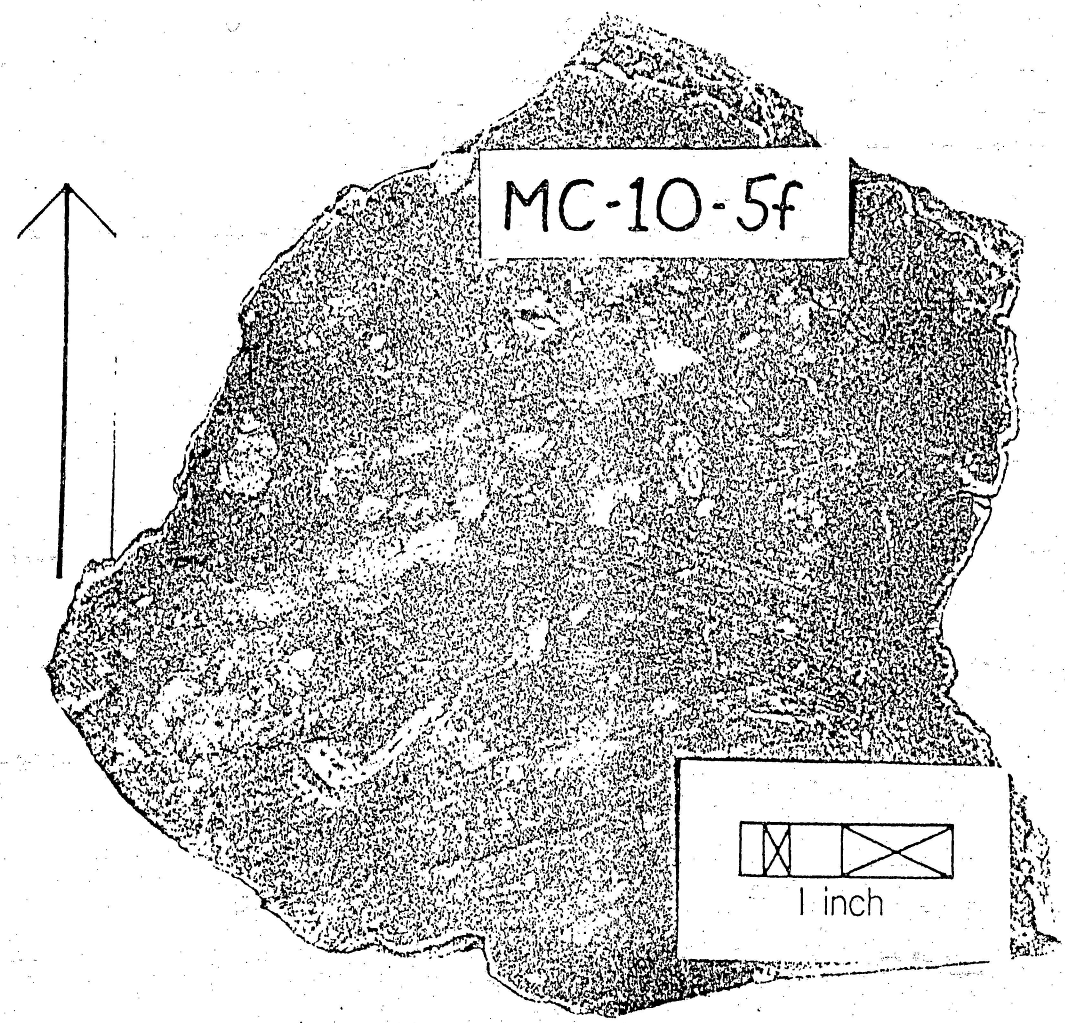


Figure 20.

Pale reddish brown (10R5/4) massive mudstone with greenish gray (5G 6/1) reduction patches, Slaughter ranch, southwest Garza County (Middle Creek 7.5 minute quadrangle). Sample from mudstone that grades vertically and laterally into burrowed mudstone with well preserved _Teichichnus_. Scale at bottom right is one inch.

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 in close proximity 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 composed of horizontal, inclined, straight or wavy, 0.5- to 2.0-mm laminae. Parallel-laminated mudstones are normally associated with ripple cross-laminated siltstone which 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 there is an increase in silt content and stratification produced by bottom currents. 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 2.0-inch lenses of intrabasinal and extrabasinal materials. This lithic type is situated lateral to massive and burrowed mudstones, 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, delta foresets, and

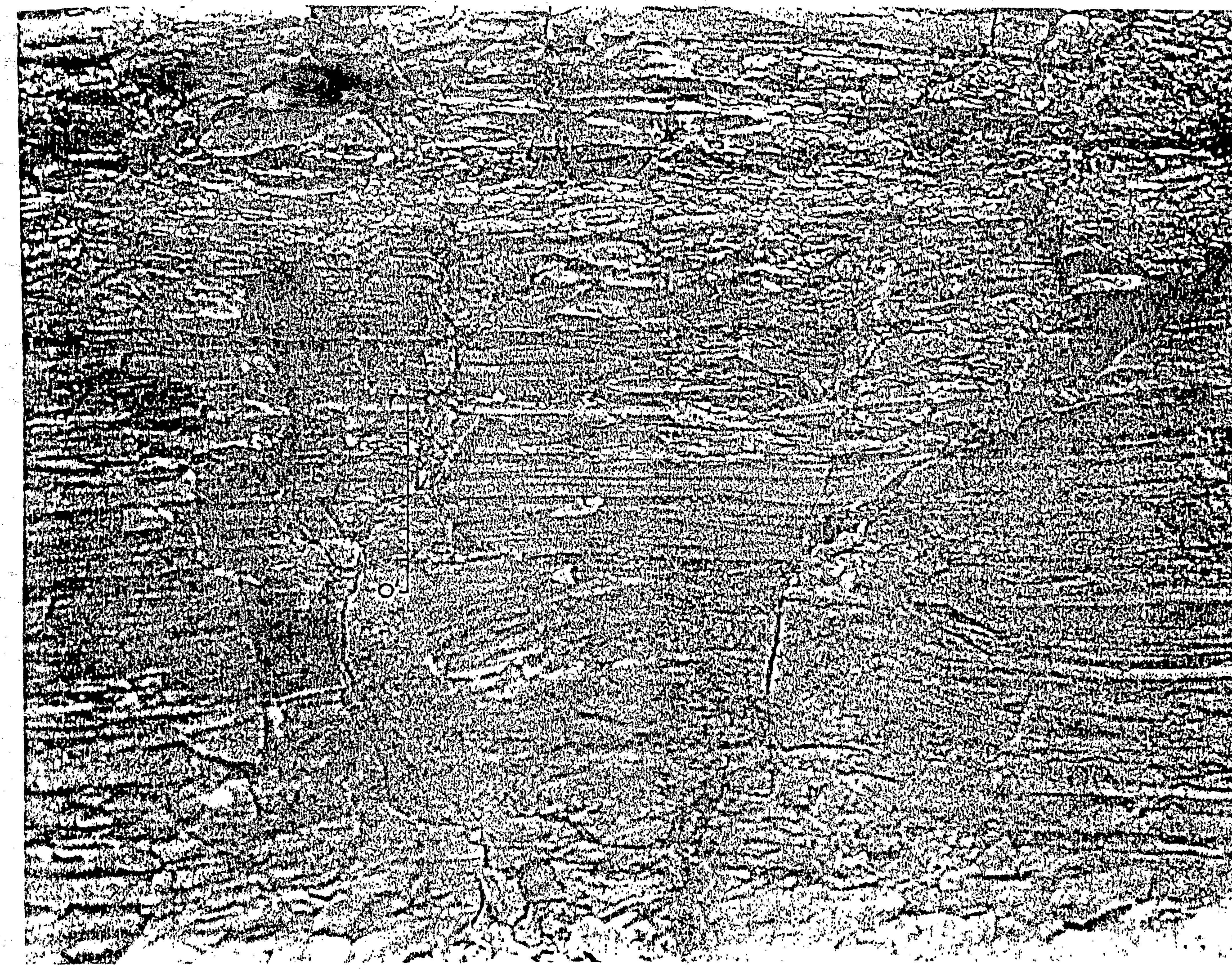


Figure 21.

Lacustrine mudstone and siltstone, Johnson ranch, Kent County (Justiceburg Southeast 7.5 minute quadrangle). View north. Vertical scale: 1.0 foot. Alternating moderate brown parallel laminated mudstone and light brown wavy laminated calcitic siltstone.

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 comprise the foresets. Foresets range in thickness from about 2 to 10 feet. Multiple foresets, consisting of as many as 4 units, are up to 30 feet thick. Dips of foresets range from 9^{0} to 16^{0}. Outcrops that are 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 bedforms that migrated up foreset slopes (the ripple bedforms produced ripple drift stratification), intrabasinal conglomerate foresets, and erosional surfaces and discordance in dip between depositional units.

Most foreset sequences display (1) a downcurrent decrease in dip angle and bedding thickness, (2) conglomerate lenses that are thickest near tops of foresets but generally pinchout 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) one to six inch beds of granule to pebble intrabasinal conglom-

Figure 22.

Delta foresets associated with small fan deltas, Macy ranch, southwest Garza County (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^{o}-9^{o} north. (b) Light brown to moderate brown, parallel inclined laminated and ripple cross-laminated very fine to fine sandstone; foresets dip 6^{o}-8^{o} north. (c) Light to moderate brown, ripple cross laminated very fine sandstone, and moderate brown, parallel inclined laminated coarse siltstone; foresets dip about 4^{o} north. (d) Moderate brown to reddish brown, parallel laminated, clayey siltstone, and grayish green, ripple cross laminated very fine sandstone; foresets dip about 3^{o} north.

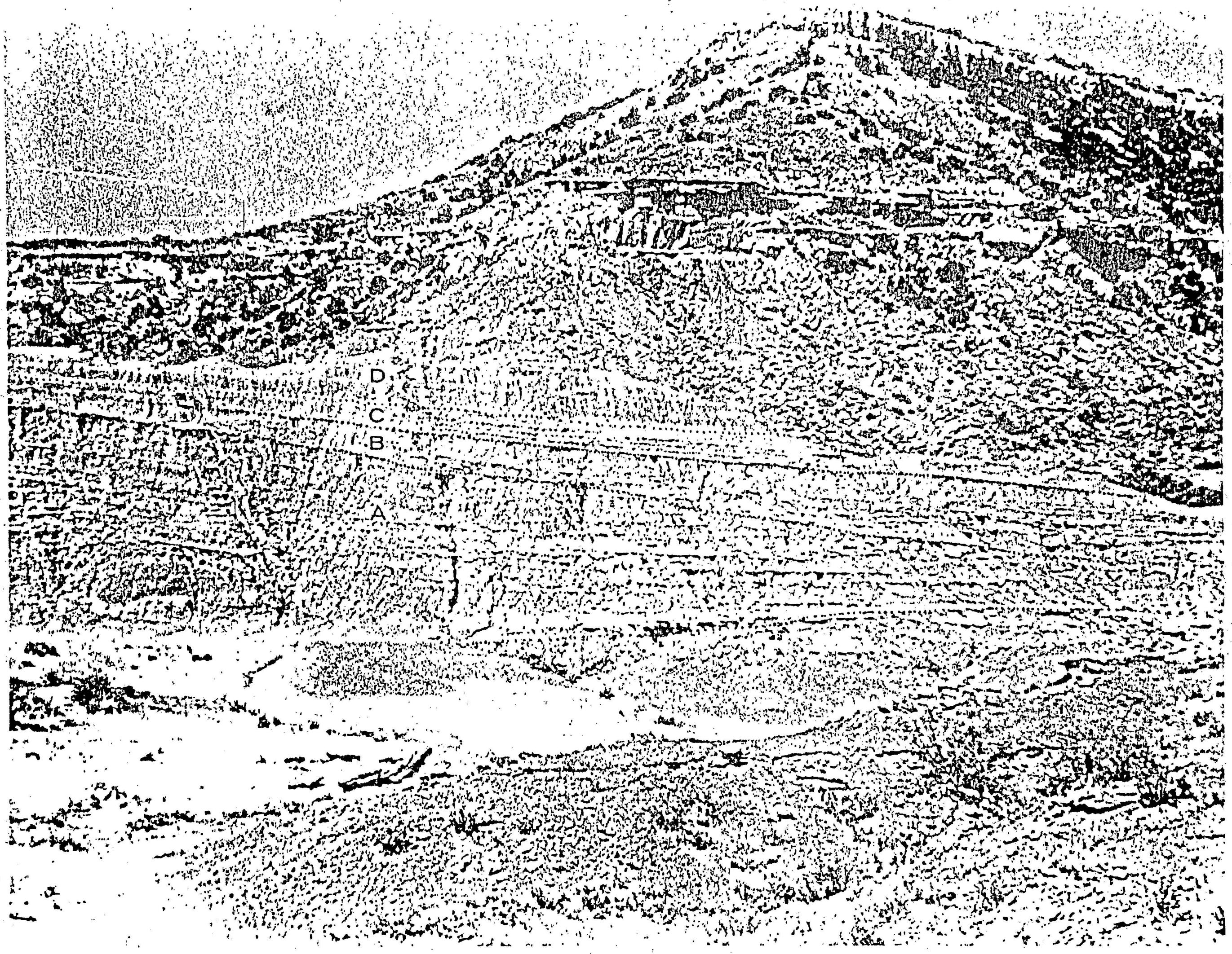


Figure 22.

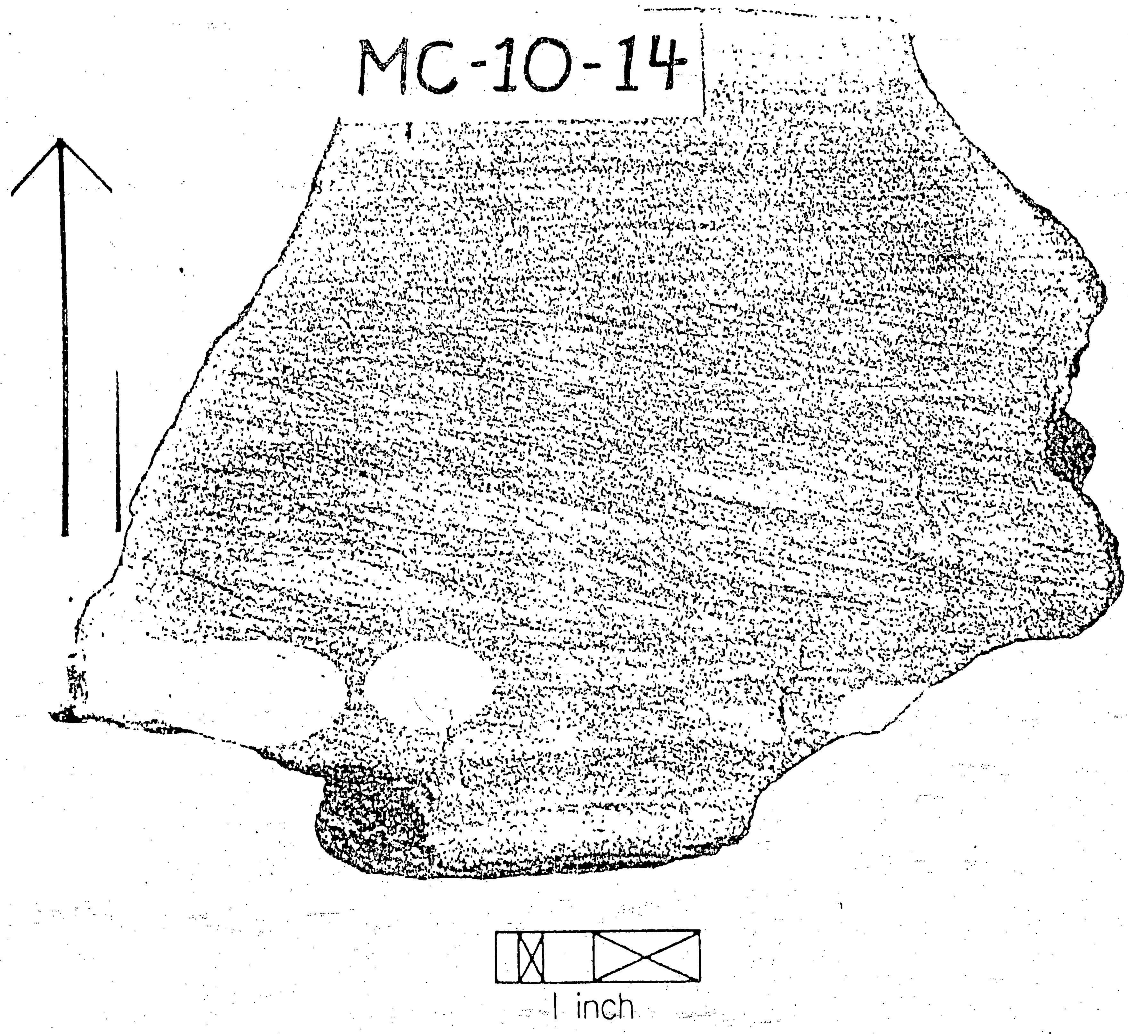


Figure 23.

Ripple drift siltstone and sandstone, Slaughter ranch, southwest Garza County (Middle Creek 7.5 minute quadrangle). Pale red (5R 6/2) coarse siltstone to very fine sandstone with light greenish gray (5G 6/1) reduction patches. Ripple drift (migration from left to right) grades upward into parallel laminae. Scale at bottom is 1.0 inch.

erate (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-size 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, one to five 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- 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 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*.

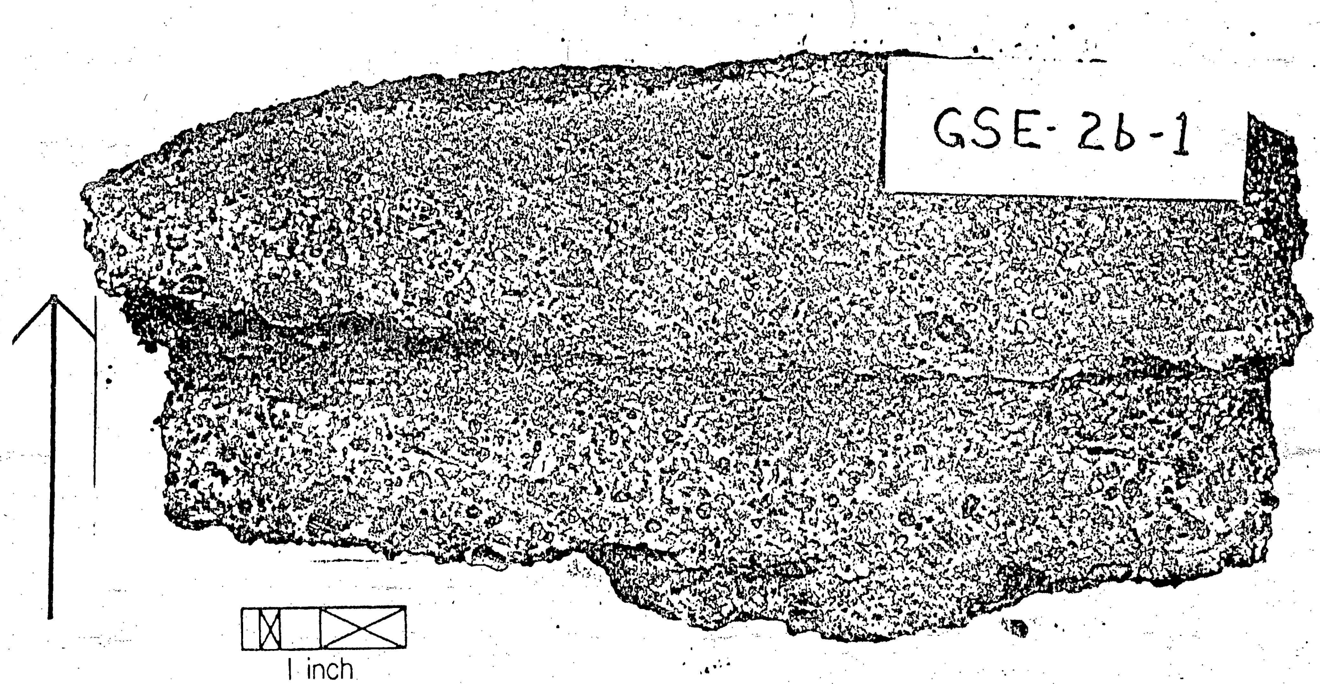


Figure 24.

Intrabasinal conglomerate, Macy ranch, southwest Garza County (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. Scale at lower right is 1.0 inch.

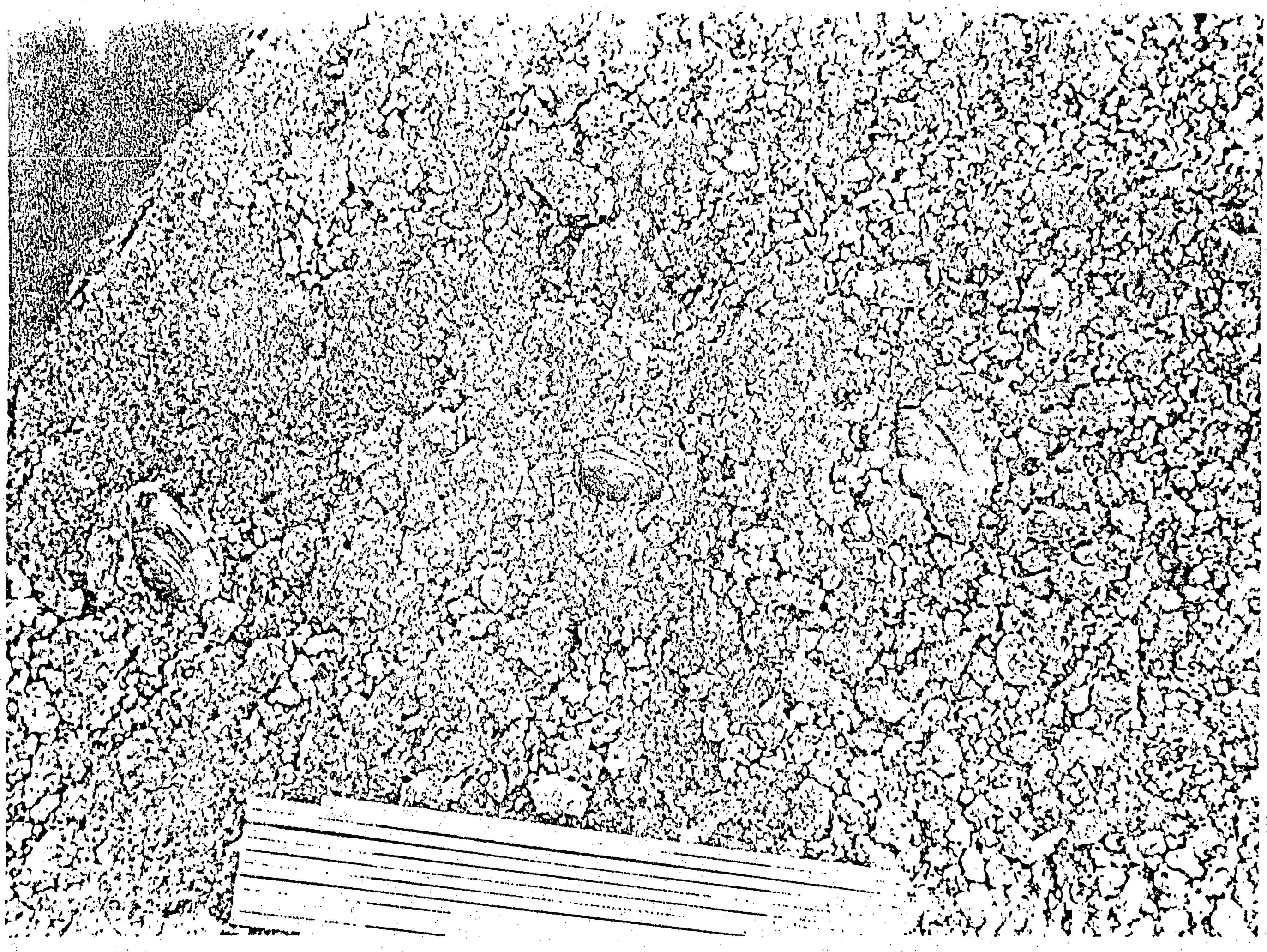


Figure 25.

Freshwater clam, Unio, on upper surface of delta platform, Slaughter ranch, southwest Garza County (Cooper Creek 7.5 minute quadrangle). Carpenter's rule 6 inches long, 1.7 inches wide.

Channel-fill conglomerates are of two types. The first type of channel-fill is represented by thin granule to pebble lenses that floor 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 three 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 25:1 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 believed that chert initially accumulated as a complex sodium silicate (such as magadiite) which 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

Figure 26.

Facies developed during low-stand, southeastern Garza County (Macy ranch, Grassland Southest 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^{0}-15^{0} 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 corssbeds and ripple drift siltstone to granule conglomerate. Most feeder channel 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 comprised 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.

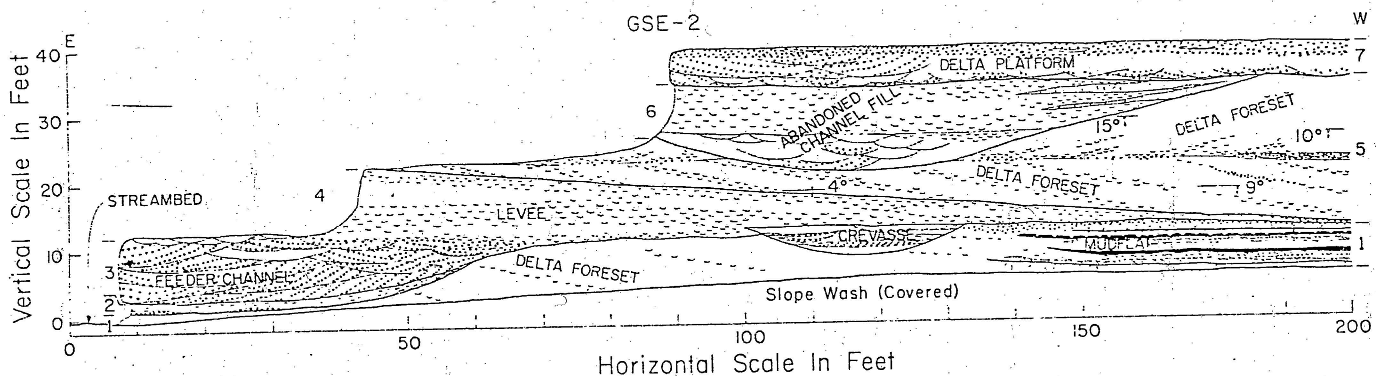

GSE-2
W
E
DELTA PLATFORM
ABANDONED CHANNEL FILL
DELTA FORESET
15°
10°
9°
4°
DELTA FORESET
LEVEE
CREVASSE
MUDFLAT
STREAMBED
FEEDER CHANNEL
DELTA FORESET
Slope Wash (Covered)
1
2
3
4
5
6
7
Vertical Scale In Feet
0
10
20
30
40
Horizontal Scale In Feet
0
50
100
150
200

Figure 26.

Figure 27.

Feeder channel for small fan delta system, Macy ranch, southwest Garza County (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 crossbeds. In the lower part of channel-fill, trough crossbeds are 15 to 30 feet wide and 1 to 3 feet thick. In the upper part of channel-fill trough crossbeds 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.

mudstones are reddish brown. Some desiccation cracks are calcite-filled. Zoning (about 1.0 foot thick) is evident in the more intensely desiccated mudstones. In lower parts of mudstones, cracks are filled with sand- to pebble-size mud clasts. The middle zone comprises many small cracks which created a pebble to cobble breccia (clasts do not appear to have been transported). Angular to round, sand- to pebble-size mud clasts (indicating some transport) characterize the upper part of the zone (Fig. 28). Desiccated mudstones commonly overlie massive or burrowed lacustrine and prodelta mudstone, and may be overlain by lacustrine and prodelta mudstone or delta foresets.

Valley-Fill Fluvial System

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 whose maximum depths, 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 ranging in texture from mudstone to cobble conglomerate, which records many depositional and erosional events. Valleys were filled with debris 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 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.

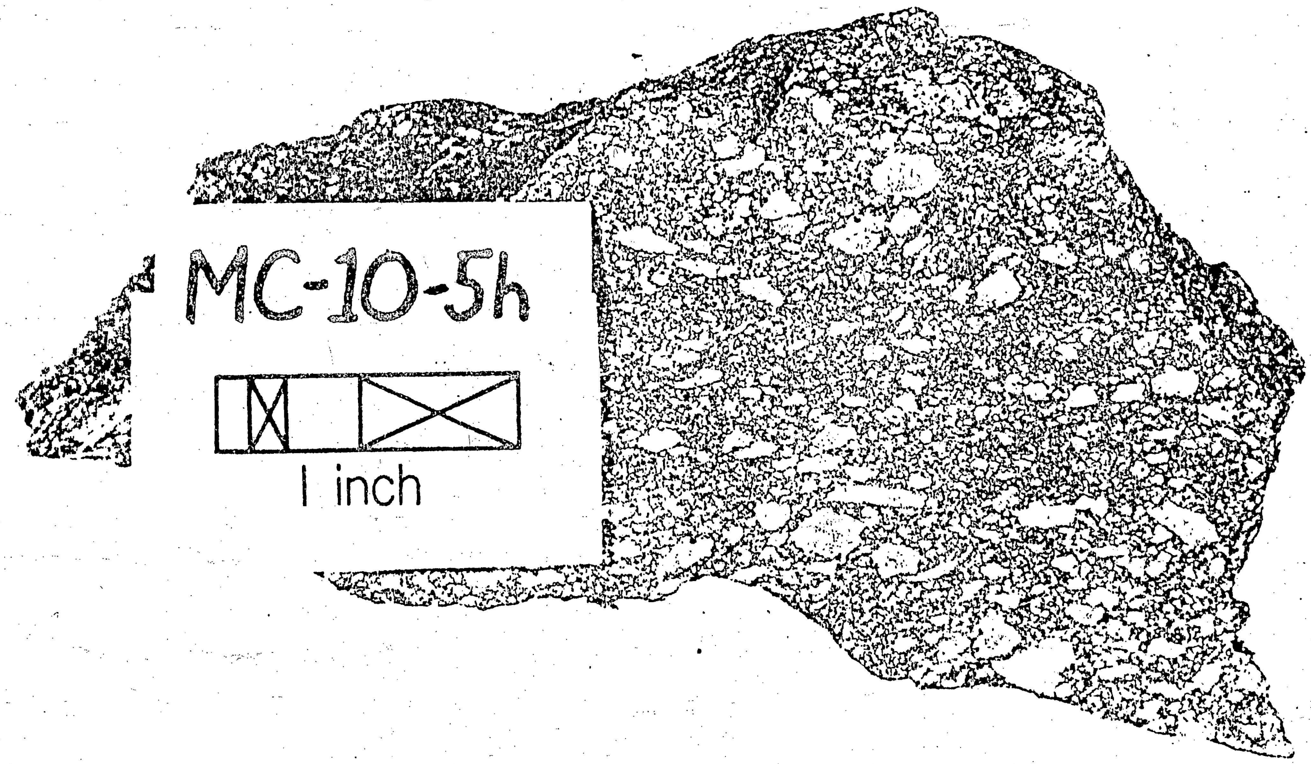
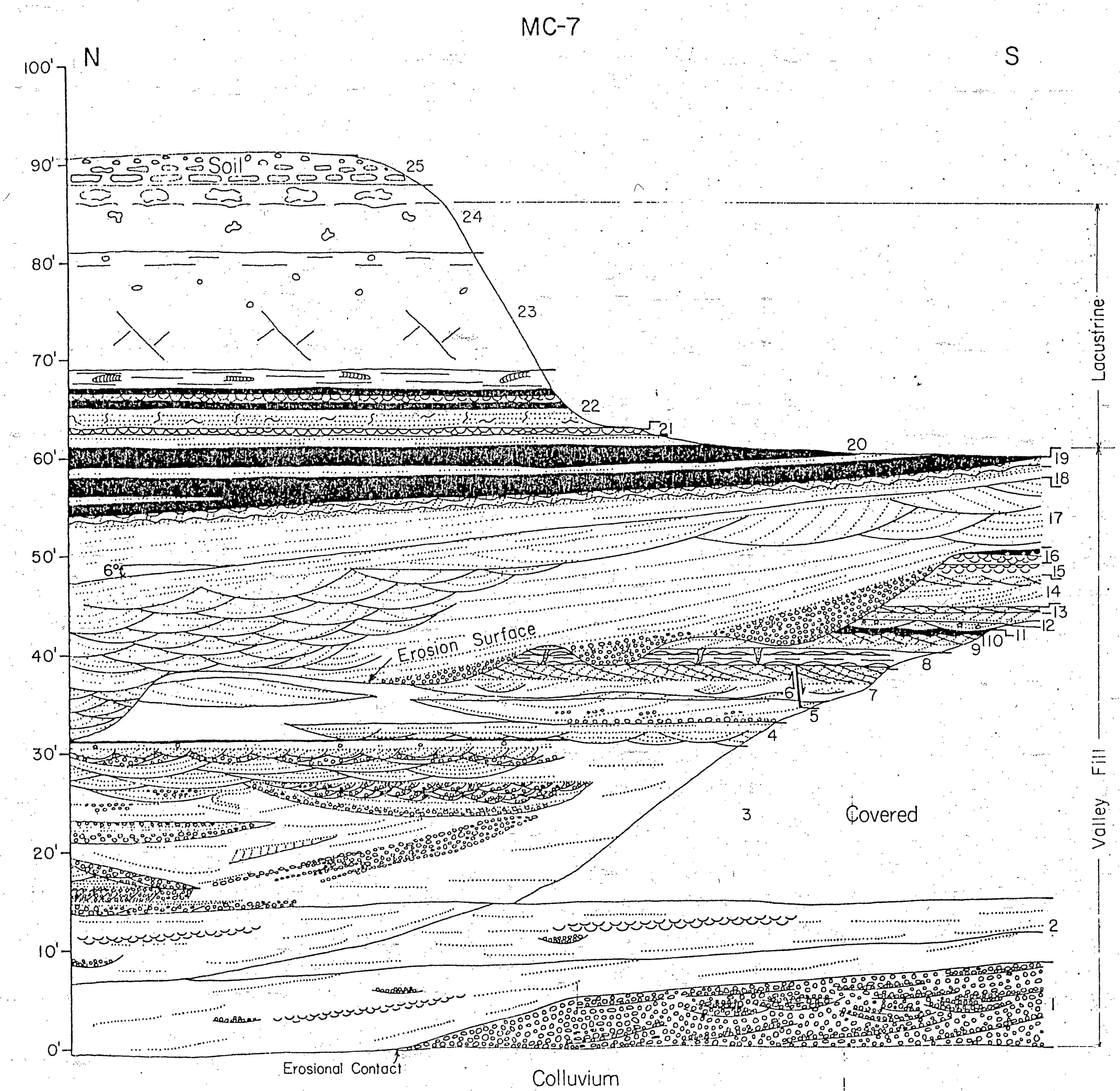


Figure 28.

Desiccation breccia (Slaughter ranch, southwest Garza County, Middle Creek 7.5 minute quadrangle). Grayish red purple (5RP 4/2) granule breccia. Clasts are greenish gray mudstone that are floating 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 (Middle Creek 7.5 minute quadrangle). Represented in outcrop sketch are valley-fill deposits (units 1-19), lacustrine deposits (units 20-24), and soil (top unit 24 and unit 25). At least 3 sedimentary sequences 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 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 small-displacement faults. 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 20-24) 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). Post depositional features in mudstones (units 23 and 24) are slickensides, reduction patches, and pyrite-filled fractures. Top of unit 24 and unit 25 comprise soil.



MC-7
N
S
100'
90'
80'
70'
60'
50'
40'
30'
20'
10'
0'
Soil
25
24
23
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18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
6°
Erosion Surface
Covered
Lacustrine
Valley Fill
Erosional Contact
Colluvium

Figure 29.

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 occurs 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 that contain abundant carbonized plant debris.

Dolomite has been recognized 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 one- to three-inch dolomite beds are restricted to a three-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

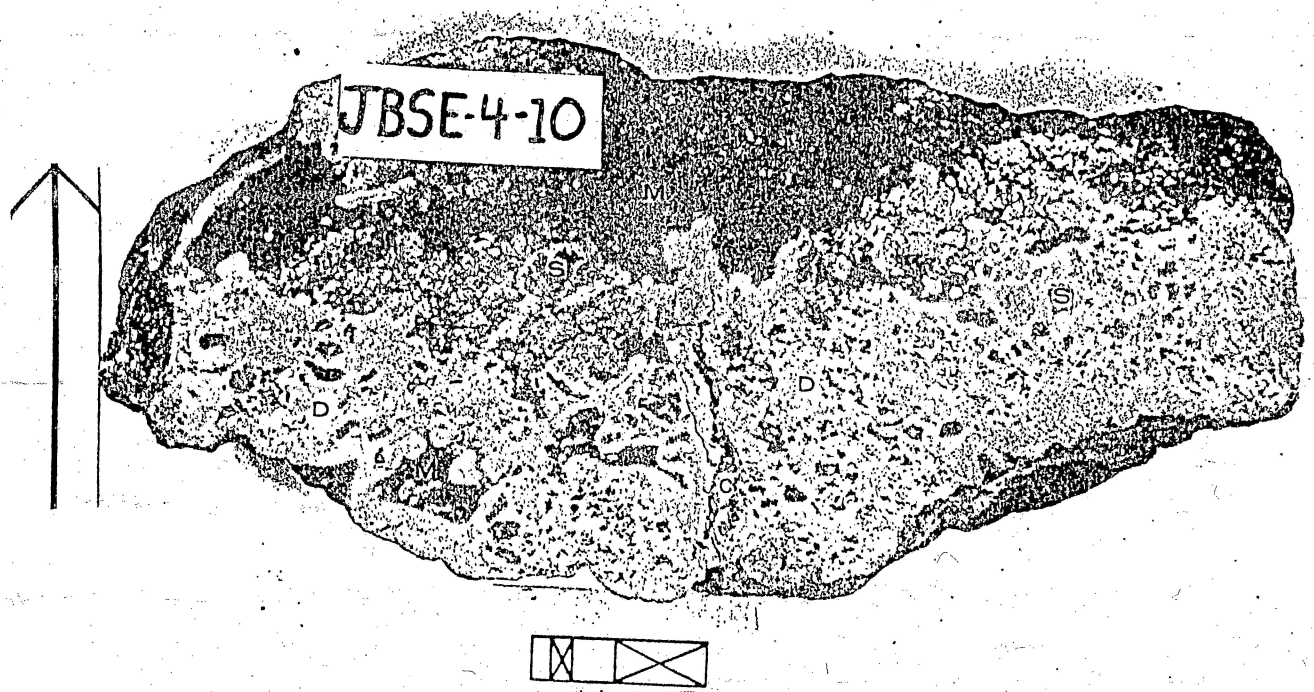


Figure 30.

Lacustrine dolomite from lower 70 feet of Dockum Group, Johnson ranch, Kent County (Justiceburg Southeast 7.5 minute quadrangle). Mottled pale red dolomite (10R 6/2), pale reddish brown dolomitic mudstone (10R 5/4), and light gray sparry calcite and limpid dolomite (N7). Rock is thoroughly bioturbated and comprises dolomite (D), vugs and fractures filled with sparry calcite (C), and limpid dolomite, and dolomitic mudstone.

suddenly and drastically changed to almost fresh water by fresh-water flooding or through 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 crystallization rate is slow. Dolomite in the lower part of the Dockum Group is inferred to be 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 5.0 feet above the Permian-Triassic boundary in Armstrong County, 60-65 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 3.0 feet thick directly overlies lacustrine deposits, the upper 5.0-10.0 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 is commonly known as "billy" in Australia (Stephens, 1971). 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 are the result of largely Pliocene deposition of silica by evapotranspiration from surficial and shallow subsurface waters which arose in a very large sub-continental zone occupied predominantly by lateritic soils. These waters then traversed adjoining but somewhat smaller and drier zone 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 is a silcrete whose origin was analogous to silcrete in Australia (Stephens, 1971). There is a possibility that 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, et.al., 1969).

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

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

SUBSURFACE DISTRIBUTION OF LOWER DOCKUM DEPOSITIONAL SYSTEMS

An area of approximately 60,000 square miles is underlain by the Triassic Dockum Group, or its equivalent, in Texas and eastern New Mexico. 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 three counties in New Mexico. Included in this report are subsurface strata that are equivalent to outcropping Dockum deposits 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 groundwater properties. In this report, the first two objectives are addressed for the lower part of the Dockum Group. Future reports will consider the subsurface aspects of the upper half of the Dockum, as well as specific considerations of the interrelationship between 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 (e.g. illite) have higher gamma radiation levels than 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 coarse-grained rocks (siltstones and sandstones). This assumption was verified by comparing lithic composition from well cuttings with gamma-ray log properties. Clear-cut distinction cannot be made, however, between siltstone and sandstone 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 in the interpretation of depositional environments of terrigenous clastic deposits that underlie parts of the North Sea (Selley, 1976), and the sedimentology of petroleum-bearing strata in the Niger Delta area (Weber, 1971). In these two studies gamma-ray logs were used, in the manner that SP curves are used, to determine textural trends.

For purposes of interpretation, an arbitrary base line was used consistently to define sandstone, siltstone, and mudstone on each gamma log. 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 to be the youngest Permian sequence in the Texas-New Mexico area by some workers (Miller, 1955), is known as the

Pierce Canyon redbeds (Lang, 1935) in the Delaware Basin, and is called Dewey Lake redbeds (Page and Adams, 1940) in the Midland Basin. According to Miller (1955) the Pierce Canyon and Dewey Lake redbeds 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 in amplification (scales) exist among logs. Base of the Dockum Group in this study was selected to agree with the top of the Dewey Lake. A lithic change was chosen (see Figs. 32 and 33; well from Upton County) which is recognizable over a large part of the Midland Basin.

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 mid-point. 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 which 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 net sand maps. Furthermore sand percentage emphasizes dip orientation of sand trends by eliminating effects of

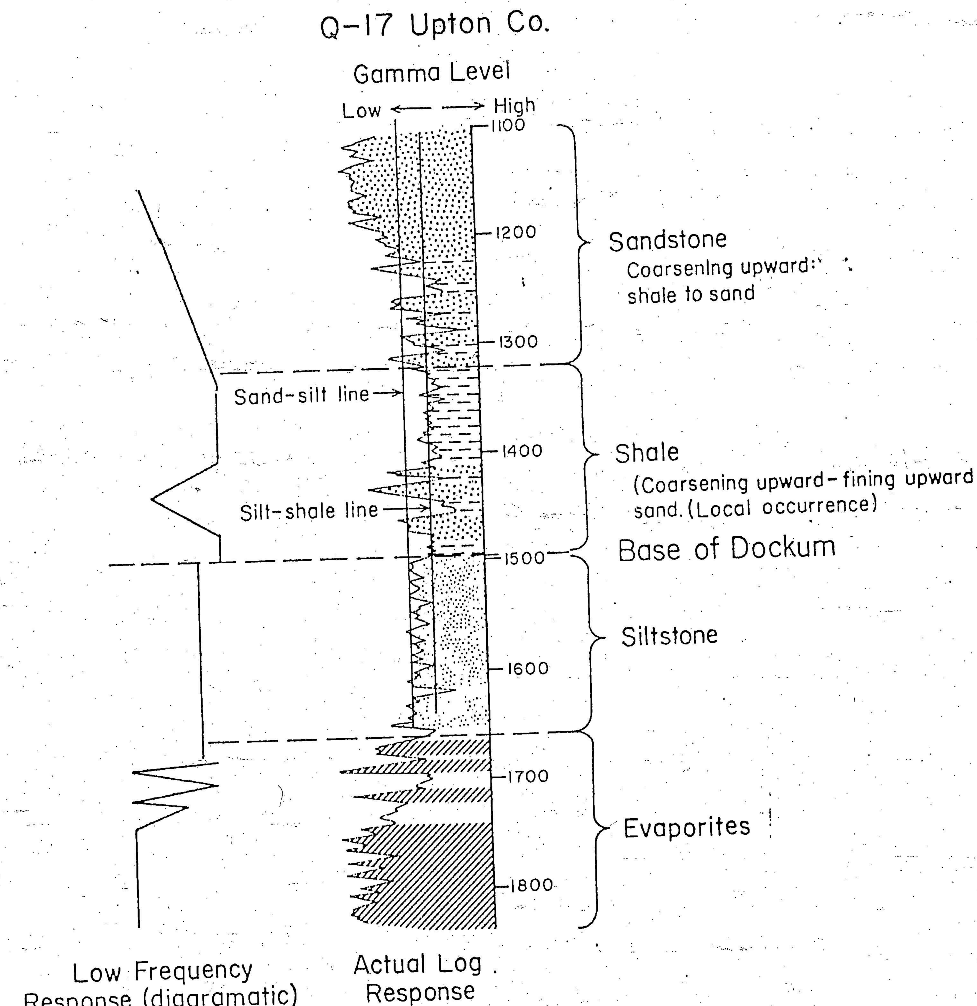


Figure 32.

Gamma-ray log characteristics and corresponding terrigenous clastic rocks.

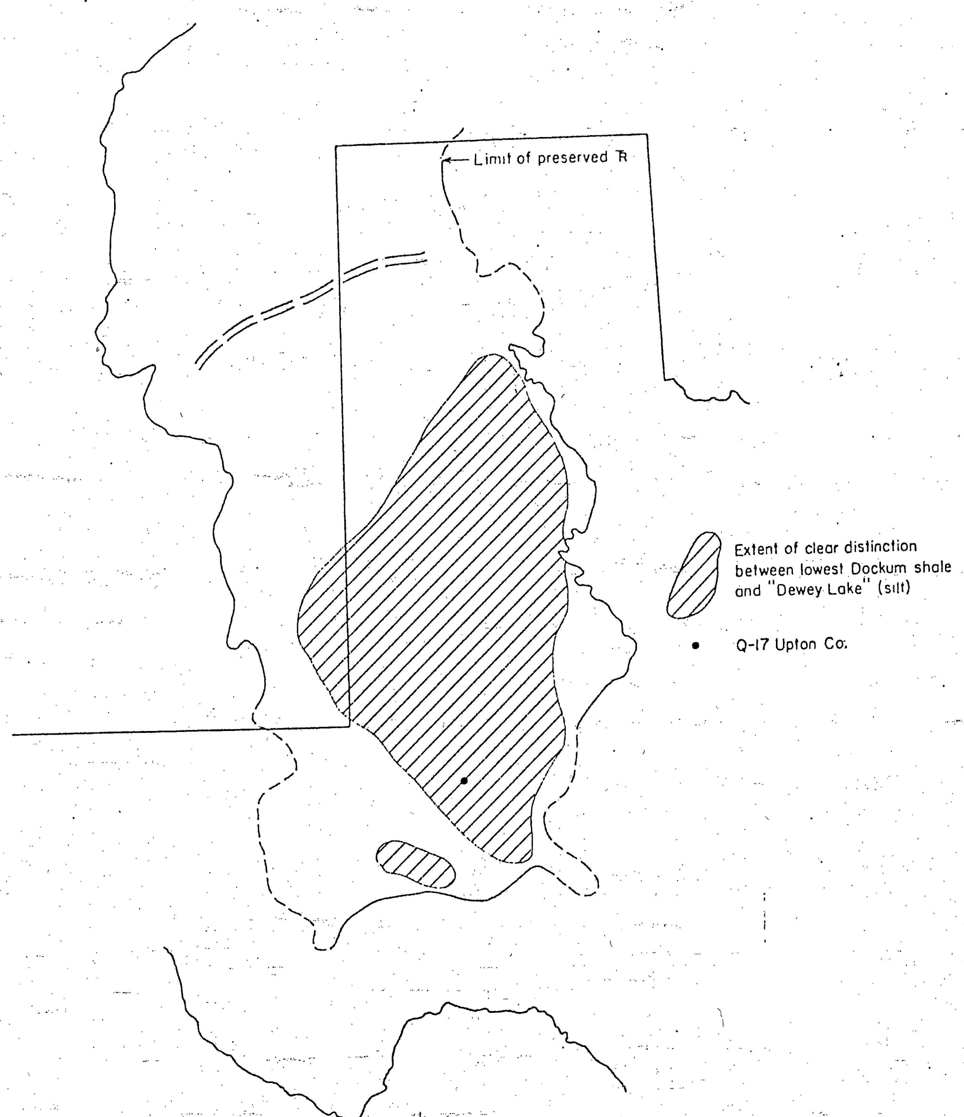


Figure 33.

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

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). Both 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, across Lea County, and into Yoakum County, Texas, where it defines a distributary pattern. This pattern is inferred to be 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. 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 two to eight 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-size clasts undoubtedly are 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 operative during high-stand conditions were favorable for grain-size sorting. Hence, well-sorted (cleaner) sands and silts are principally restricted 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 occupies much of Mitchell, Howard, Martin and Andrews Counties, Texas and extends into southeastern Lea County, New Mexico. High mud deposition persisted in this area 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 e-log patterns are: (1) fluvial channel-fill; (2) delta plain; (3) delta front, including channel mouth bars; and (4) prodelta facies. Erxleben (1975) demonstrated that fan deltas may also exhibit diagnostic e-log patterns. Most terrigenous clastic deposits display vertical changes in grain size and such changes may be recorded by the self-potential and/or resistivity curves. Contacts between superposed terrigenous clastic facies may be gradational or abrupt (e.g. erosional contact). These boundary relationships may be displayed by specific, distinctive e-log patterns. Response to texture and/or composition should also be exhibited by gamma-logs (Weber, 1971; Selley, 1976). At this time, however it is possible to make only general interpretations of genetic facies within the Dockum from gamma-logs. Extensive investigation and correlation of gamma-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 outcrop areas that have been studied (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 inferred arbitrarily within areas comprising 40 percent, or greater, sand within a stratigraphic interval of 200 to 1050 feet.

Lacustrine and prodelta mud and silt 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). On Figure 35, multiple, coarsening-upward sequences characterize the Garza fluvial-deltaic system. Individual coarsening upward sequences are 25-100 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 no. 423, Garza County). The Garza fluvial-deltaic system thins to the west in Lynn County (Fig. 35), where multiple fining-upward sequences attain thicknesses of 90 feet, the average is 50 feet thick.

In addition to coarsening-upward sequences, the Lubbock fluvial-deltaic system exhibits gamma-log patterns that display abrupt lower and

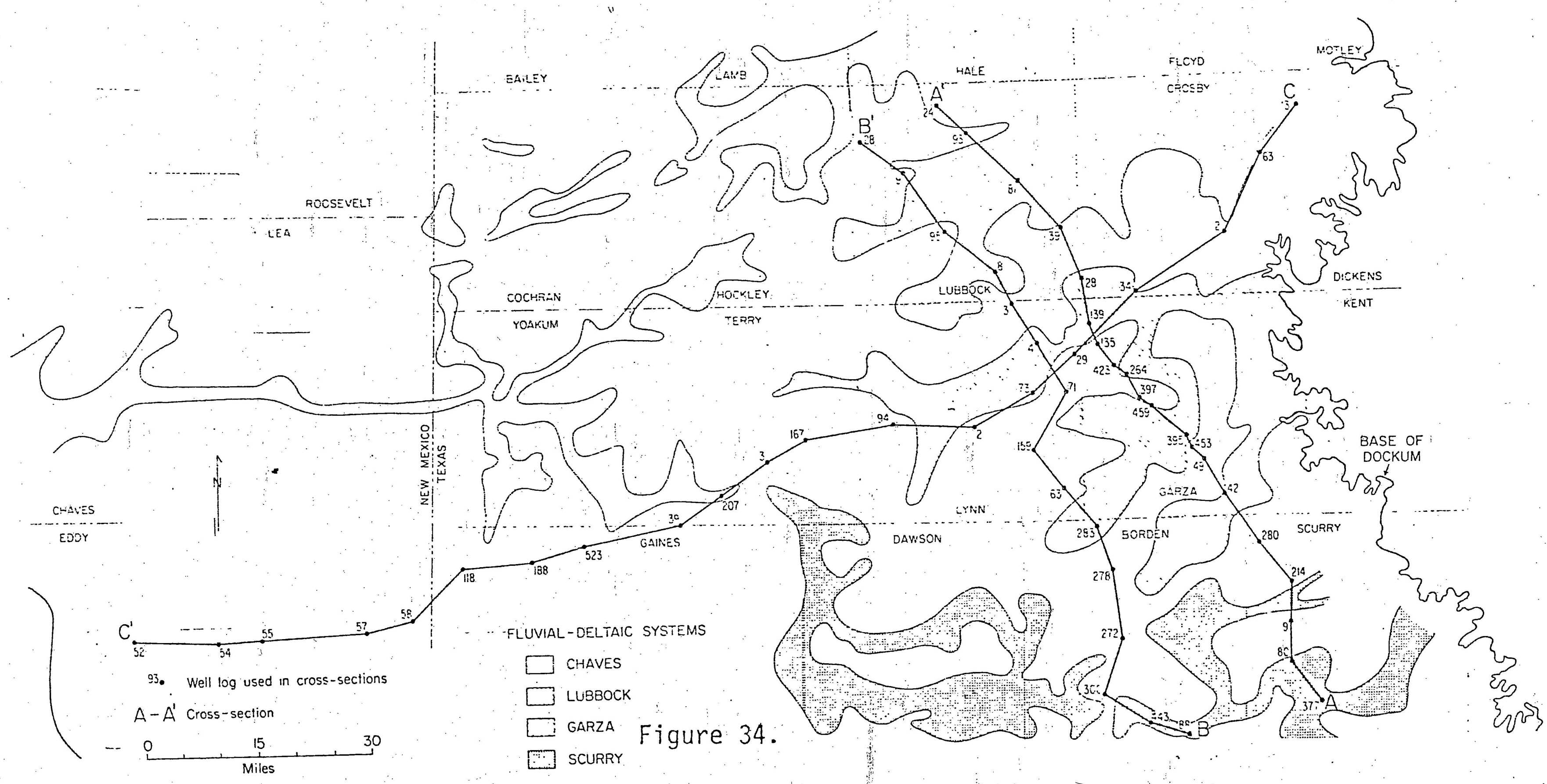


Figure 34.

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 on figures 35 and 36.

Figure 35.

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

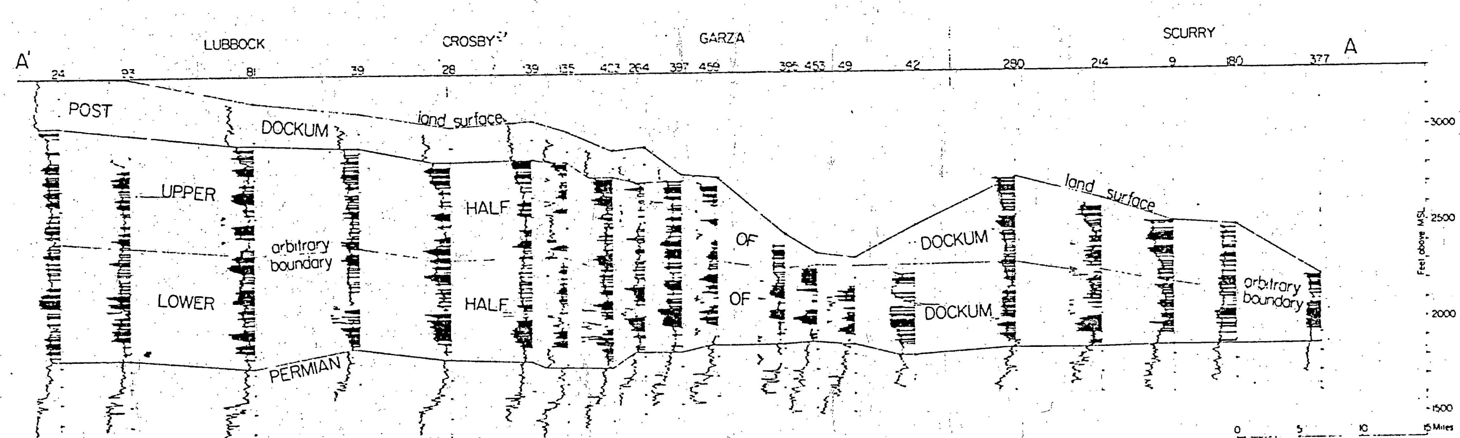

A'
A
LUBBOCK
CROSBY
GARZA
SCURRY
24
93
81
39
28
39
135
423
264
397
459
395
453
49
42
290
214
9
180
377
POST
DOCKUM
land surface
UPPER
LOWER
arbitrary boundary
HALF
HALF
OF
OF
DOCKUM
DOCKUM
PERMIAN
Feet above MSL
3000
2500
2000
1500
0
5
10
15 Miles

Figure 35A.

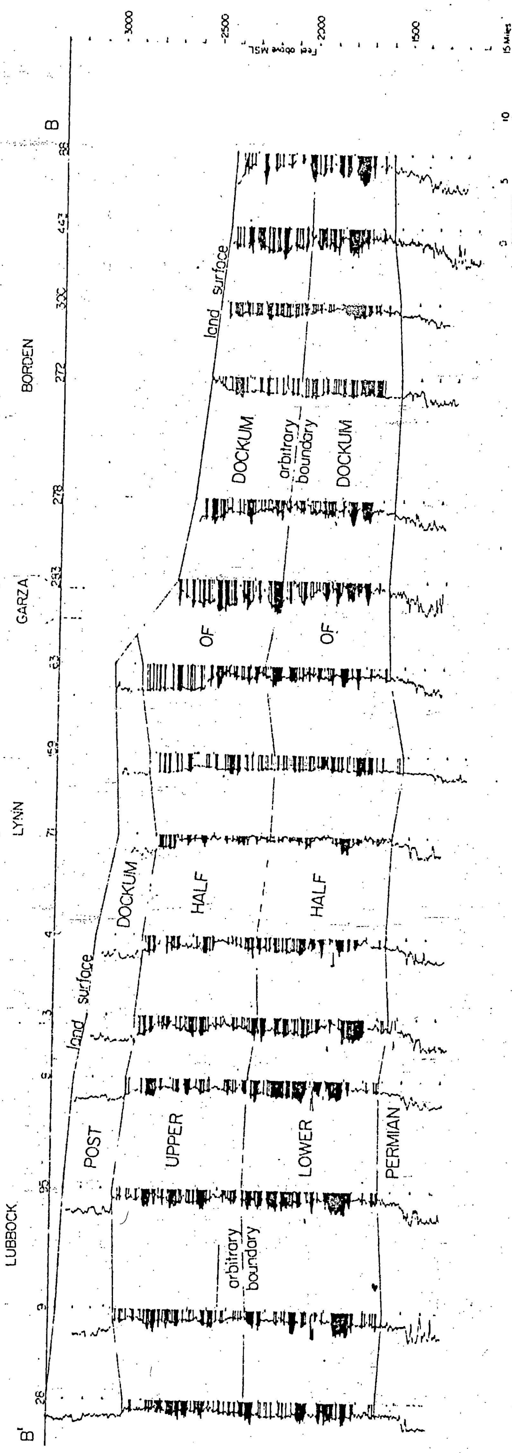
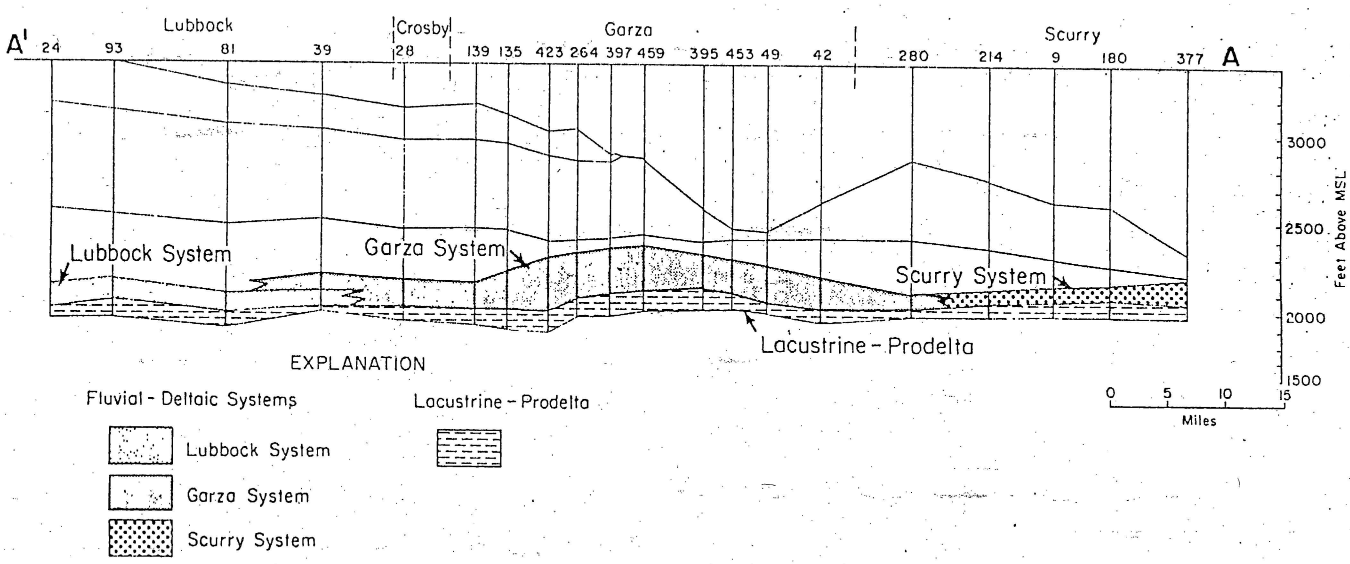

B
B'
LUBBOCK
LYNN
GARZA
BORDEN
land surface
POST
UPPER
LOWER
PERMIAN
DOCKUM
HALF
OF
arbitrary boundary
Feet above MSL
3000
2500
2000
1500
0
5
10
15 Miles

Figure 35B.

Figure 35C.


A'
A
Lubbock
Crosby
Garza
Scurry
24 93 81 39 28 139 135 423 264 397 459 395 453 49 42 280 214 9 180 377
3000
2500
2000
1500
Feet Above MSL
Lubbock System
Garza System
Scurry System
Lacustrine - Prodelta
EXPLANATION
Fluvial - Deltaic Systems
Lubbock System
Garza System
Scurry System
Lacustrine - Prodelta
0 5 10 15
Miles

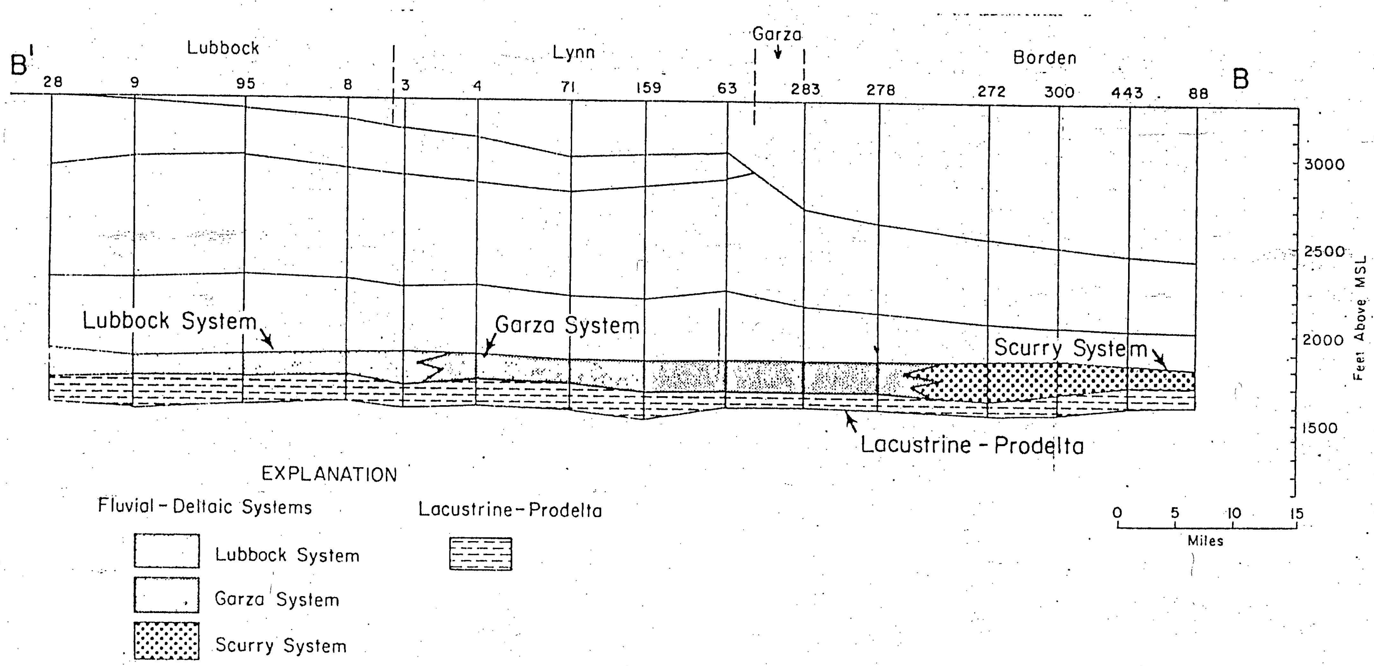

B'
B
Lubbock
Lynn
Garza
Borden
28 9 95 8 3 4 71 159 63 283 278 272 300 443 88
3000
2500
2000
1500
Feet Above MSL
Lubbock System
Garza System
Scurry System
Lacustrine - Prodelta
EXPLANATION
Fluvial - Deltaic Systems
Lubbock System
Garza System
Scurry System
Lacustrine - Prodelta
0 5 10 15
Miles

Figure 36.

Dip cross-section across parts of Lubbock, Garza, and Chaves fluvial-deltaic systems. Section shows gamma-log profile, lithic interpretation (sandstone--black; shale/siltstone--white; A), and boundaries of principal depositional systems (B). Line of section shown on fig. 34 .

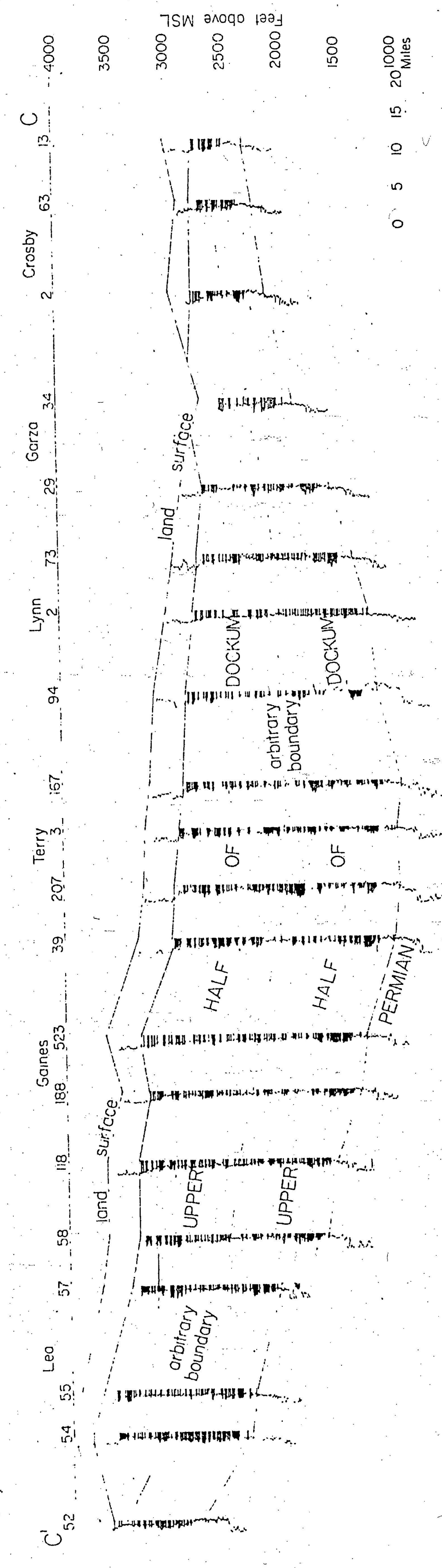

C
C'
Crosby
Garza
Lynn
Terry
Gaines
Lea
13
63
2
34
29
73
2
94
167
3
207
39
523
188
118
58
57
55
54
52
Feet above MSL
4000
3500
3000
2500
2000
1500
1000
0 5 10 15 20
Miles
land surface
land surface
DOCKUM
DOCKUM
arbitrary boundary
arbitrary boundary
OF
OF
HALF
HALF
UPPER
UPPER
PERMIAN

Figure 36A.

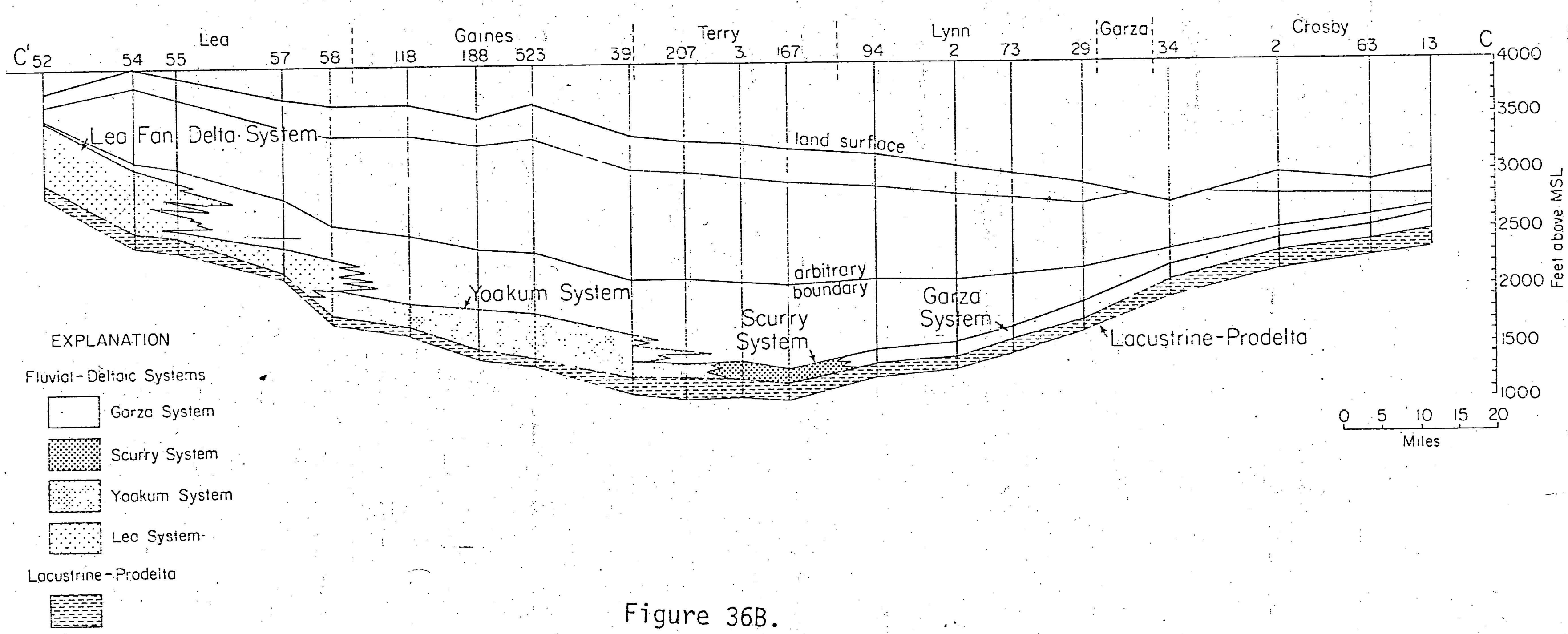

C'
C
Lea
Gaines
Terry
Lynn
Garza
Crosby
52
54
55
57
58
118
188
523
39
207
3
167
94
2
73
29
34
2
63
13
4000
3500
3000
2500
2000
1500
1000
Feet above MSL
0 5 10 15 20
Miles
Lea Fan Delta System
land surface
arbitrary boundary
Yoakum System
Scurry System
Garza System
Lacustrine-Prodelta
EXPLANATION
Fluvial-Deltaic Systems
Garza System
Scurry System
Yoakum System
Lea System
Lacustrine-Prodelta

Figure 36B.

upper contacts similar to e-log patterns of the Pennsylvanian Henrietta fan delta system of north-central Texas (Erxleben, 1975). Although coarsening upward sequences characterize the southeastern part of Lubbock fluvial-deltaic system, it was dominated by braided stream and fan delta systems interpreted from sandstones that exhibit gamma-log patterns with abrupt bases and tops.

The Garza fluvial-deltaic system extends southwestward from Garza through Lynn and into Terry County (Figs. 34 and 36), where it coalesces with 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 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 workers to determine dispersal trends of terrigenous clastic rocks. Among these 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 structures. During the past two 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 County, 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 N45°W to S45°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 percentage 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 of Curray (1956).

Directional readings from selected outcrops of Santa Rosa Sandstone in Guadalupe and DeBaca Counties, New Mexico (Fig. 37) suggest transport directions to the east and south. In Guadalupe County, crossbed orientation within the Santa Rosa Sandstone also were 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, indicates westerly flowing paleocurrents. Differences in apparent transport direction between Guadalupe and San Miguel Counties may be attributed to deposition in adjacent sub-basins (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

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.

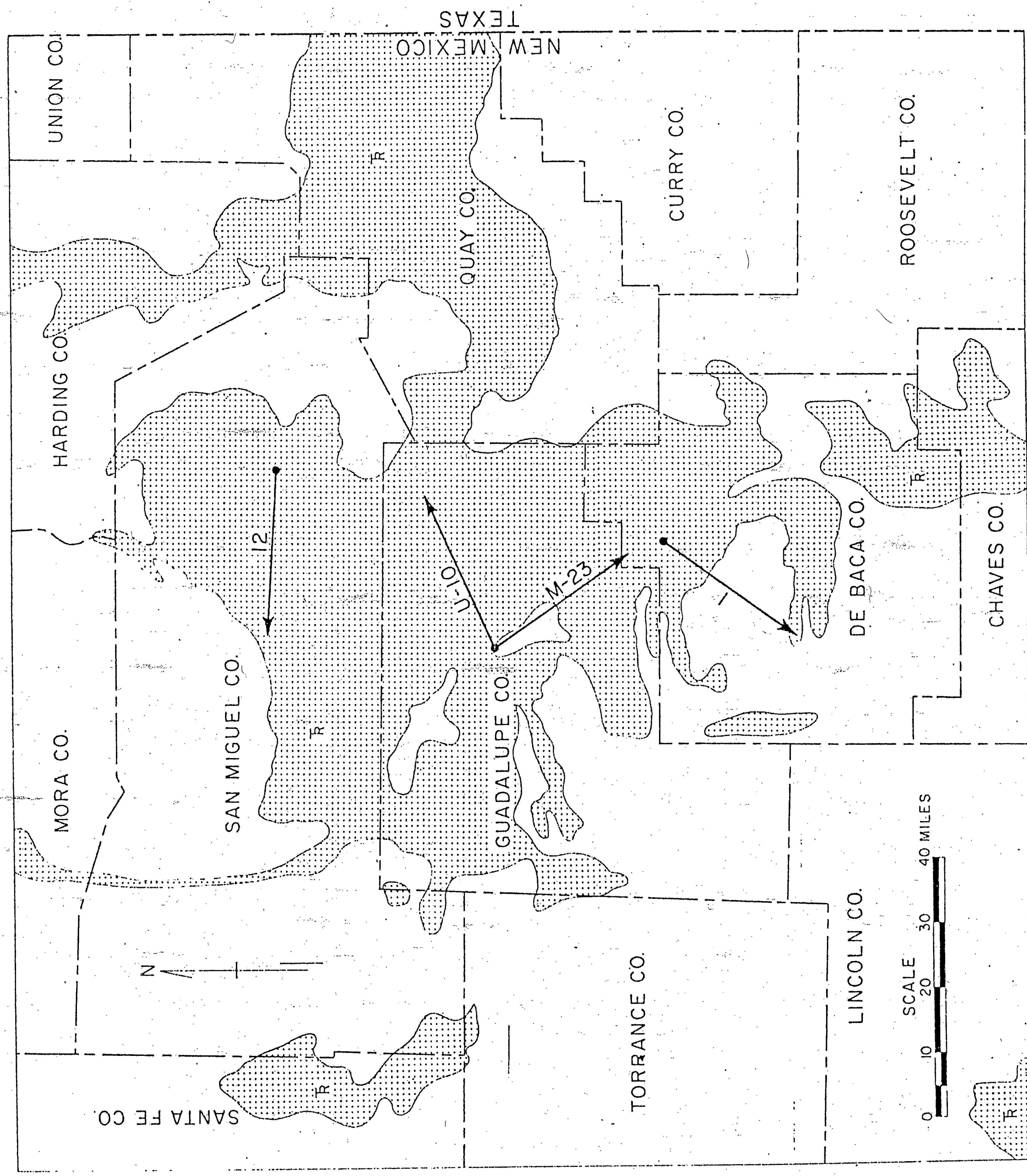

NEW MEXICO
TEXAS
UNION CO.
HARDING CO.
MORA CO.
SAN MIGUEL CO.
SANTA FE CO.
QUAY CO.
GUADALUPE CO.
TORRANCE CO.
CURRY CO.
ROOSEVELT CO.
DE BACA CO.
CHAVES CO.
LINCOLN CO.
I2
U-10
M-23
I
N
SCALE
0 10 20 30 40 MILES

Figure 37.

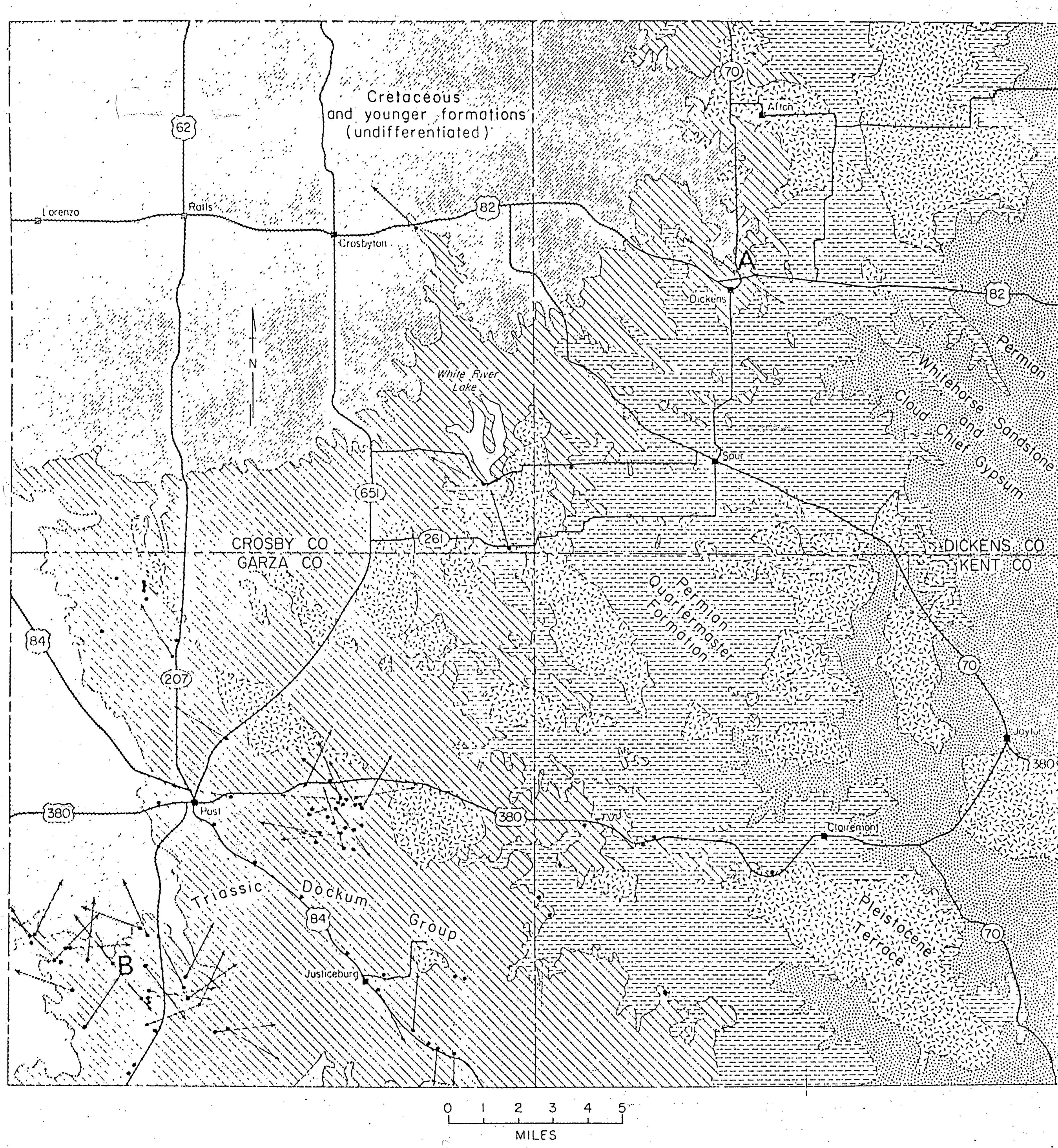


Figure 38.

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

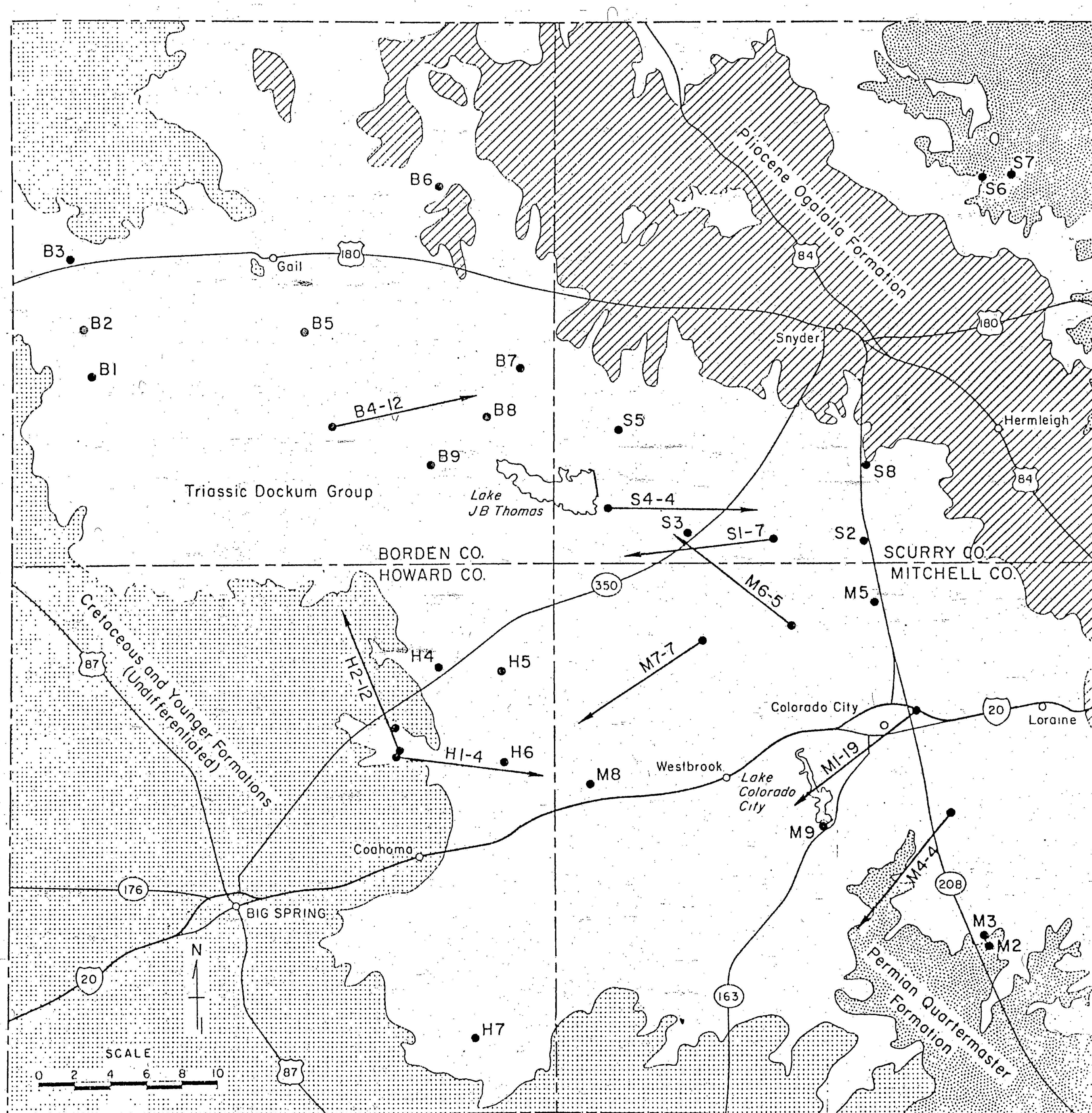


Figure 39.

Current directional features, Dockum Group, Scurry, Mitchell, Borden, and Howard Counties. Resultant vector azimuth and number of readings given for each locality.

definitely could 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, are helpful in delineating genetically related depositional sequences. Two examples from the Dockum of southwest Garza County are presented 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, are 50 feet of reddish-brown mudstone and siltstone, greenish-gray sandstone and reddish-brown intrabasinal conglomerate that compose 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.

Figure 40.

Sandstone body trend and current directional features, Dockum Group, southwest Garza County (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^{0} from trend of sandstone body.

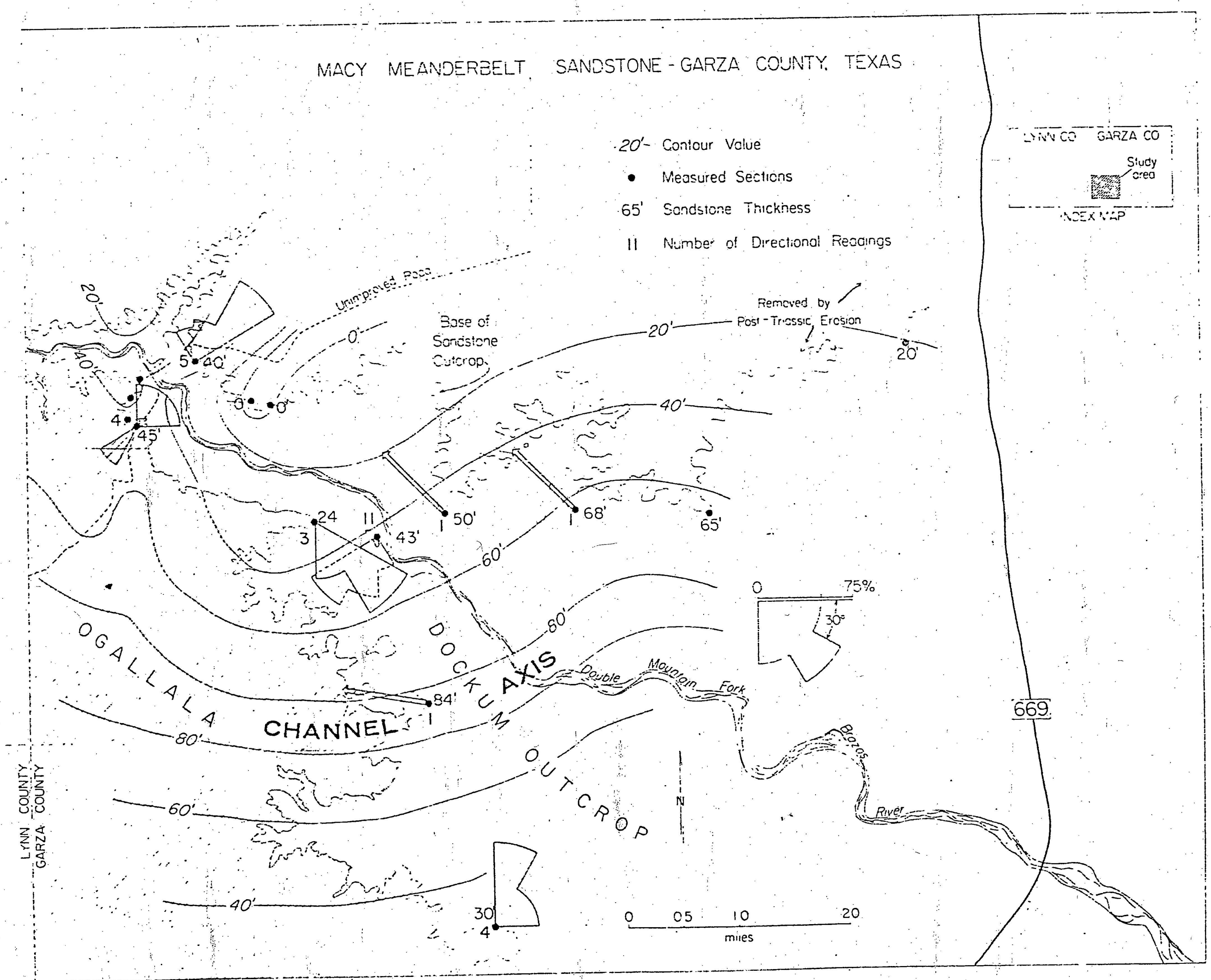

MACY MEANDERBELT SANDSTONE - GARZA COUNTY, TEXAS
20' Contour Value
Measured Sections
65' Sandstone Thickness
11 Number of Directional Readings
LYNN CO
GARZA CO
Study area
INDEX MAP
Unimproved Road
Base of Sandstone Outcrop
Removed by Post-Triassic Erosion
OGALLALA CHANNEL AXIS
DOCKUM OUTCROP
Double Mountain Fork
Brazos River
669
LYNN COUNTY
GARZA COUNTY
N
0 05 10 20
miles
75%
30°

Figure 40.

Figure 41.

Paleocurrent direction from three stratigraphically different crevasse splay and delta foreset units, Macy ranch, southwest Garza County (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 crossbedded fine sandstone with some intrabasinal clasts. Map B shows paleocurrent measurements in a crevasse spaly sequence consisting of ripple cross laminated and parallel laminated siltstone, massive claystone and mudstone, ripple cross laminated siltstone, parallel laminated very fine sandstone, trough crossbedded fine sandstone, and foreset and trough crossbedded 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 crossbedded sandstone of splay unit A (Map A), currents flowed from north to southeast. Map A shows spatial distribution of trough axes on bedding surface of crevasse splay A. Paleocurrents during deposition of trough crossbedded conglomerate at top of crevasse splay B (Map B) were to west and northwest. Delta foresets (Map C) were deposited by surrents that flowed northwestward. Rose diagram (upper part of Map C) utilizing all directional readings shows a bimodal paleocurrent distribution.

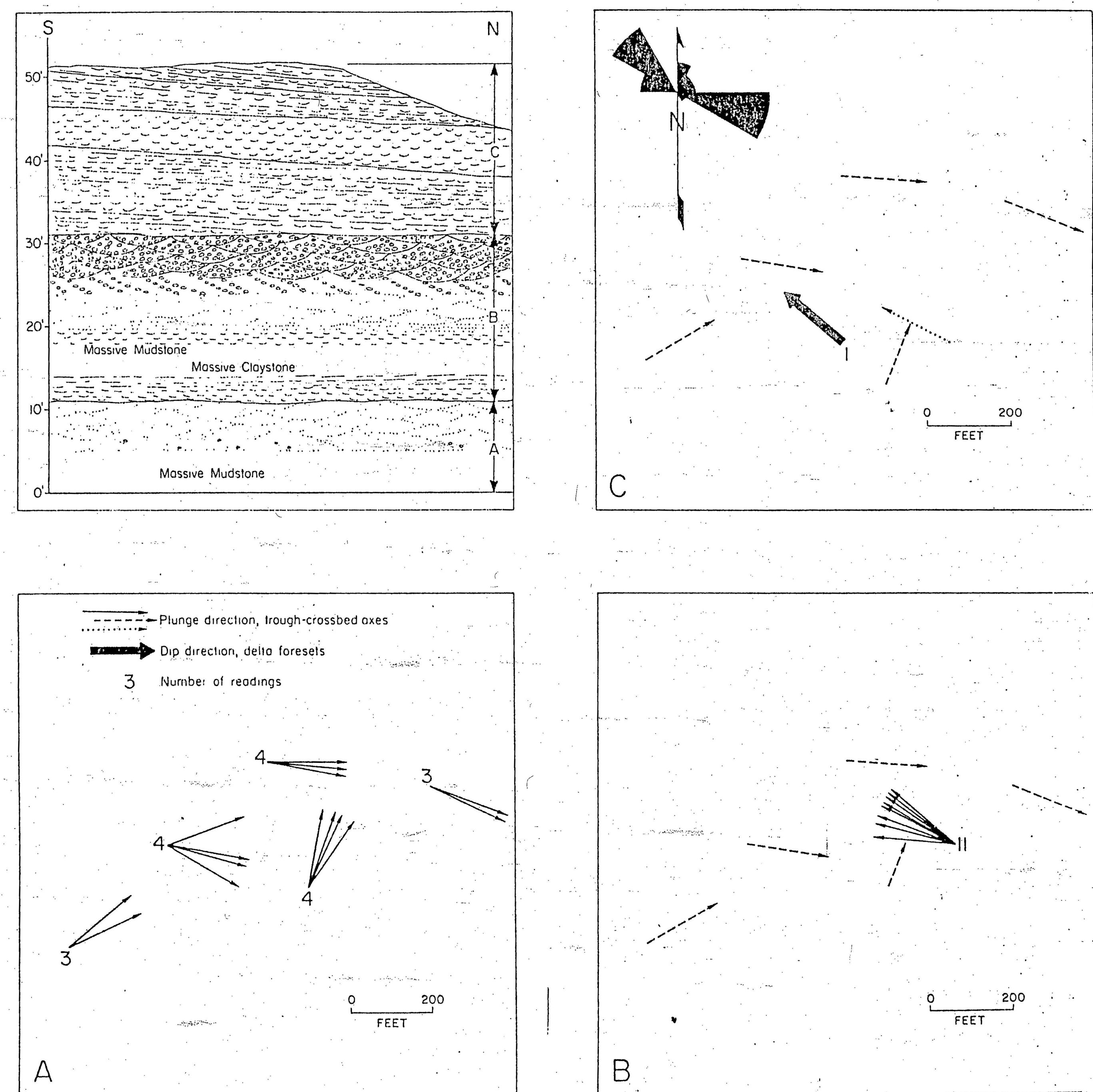

S
N
50'
40'
30'
20'
10'
0'
C
B
A
Massive Mudstone
Massive Claystone
Massive Mudstone
N
0
200
FEET
I
C
Plunge direction, trough-crossbed axes
Dip direction, delta foresets
3
Number of readings
4
3
4
4
3
0
200
FEET
A
II
0
200
FEET
B

Figure 41.

During construction of the oldest splay (Fig. 41A), current direction was from north to east. Westward flowing currents prevailed while the second splay was active (Fig. 41B), and dip direction of delta foresets (Fig. 41C) indicate a northwest flow direction. When directional data of these three stratigraphically <u>unrelated facies</u> are treated indiscriminately, a 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 foresets and plunge directions of trough crossbed axes are perhaps the second most reliable paleocurrent indicators (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 percent 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 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.

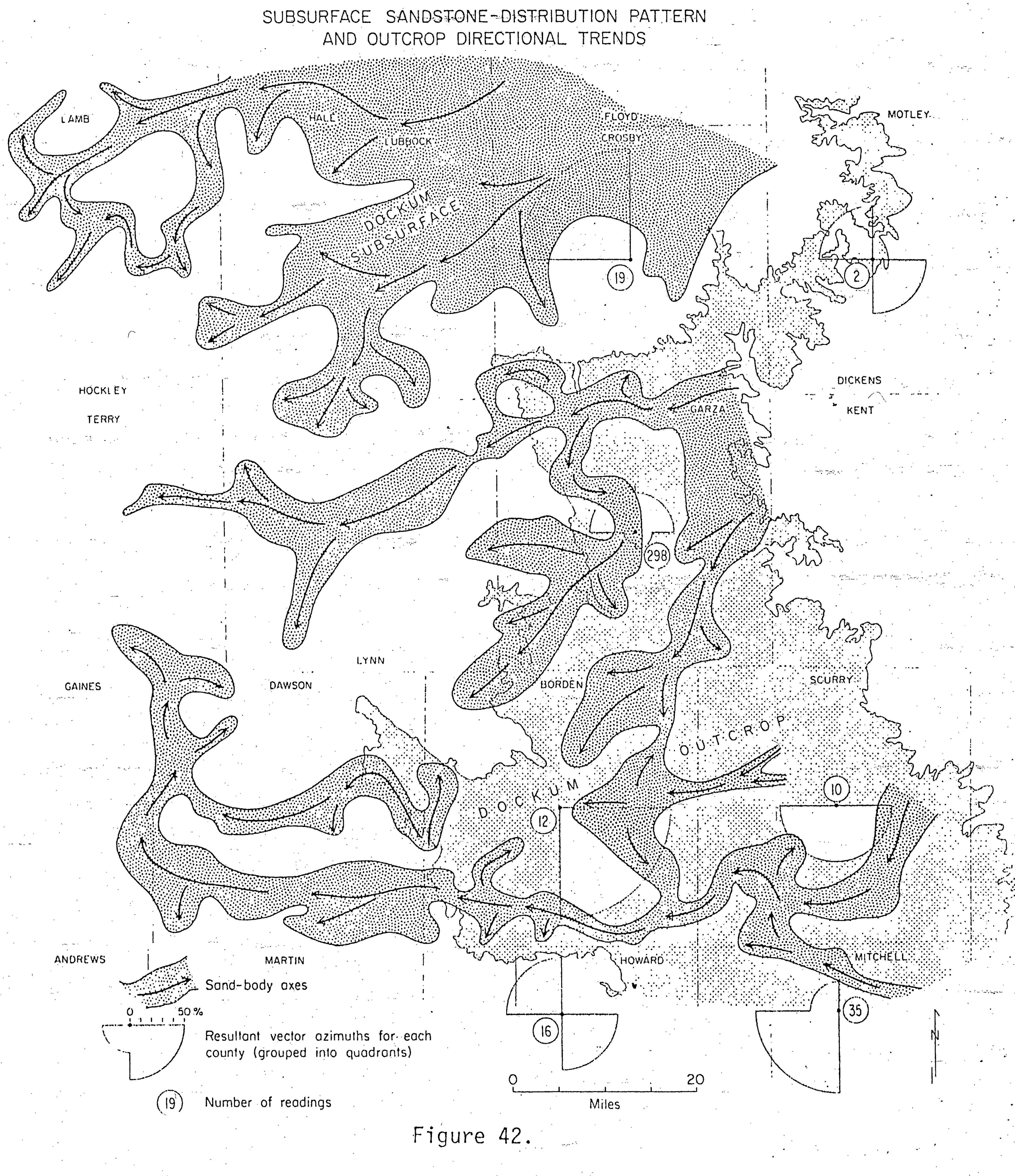

SUBSURFACE SANDSTONE-DISTRIBUTION PATTERN
AND OUTCROP DIRECTIONAL TRENDS
LAMB
HALE
LUBBOCK
FLOYD
CROSBY
MOTLEY
DOCKUM SUBSURFACE
19
2
HOCKLEY
TERRY
DICKENS
KENT
GARZA
298
LYNN
GAINES
DAWSON
BORDEN
SCURRY
OUTCROP
DOCKUM
10
12
ANDREWS
MARTIN
HOWARD
MITCHELL
Sand-body axes
0
50%
Resultant vector azimuths for each county (grouped into quadrants)
16
35
N
0
20
Miles
19
Number of readings

Figure 42.

CONCLUSIONS

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

Several dissertations and theses have dealt with specific stratigraphic, paleontologic, and sedimentologic aspects of the Dockum Group (Green, 1954; Kiatta, 1962; 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 times became more humid and at other times shifted toward aridity. Kiatta (1960) believed the Tecovas was deposited on a flood plain and the Trujillo accumulated in stream channels. Cazeau (1962) stated that early deposition of the Dockum Group was chiefly on flood plains, 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 as braided alluvial sheets.

Finch (1975) reported on 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 conclude that the 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 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 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 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 which constructed lobate deltas along lake margins. Alternating arid climatic conditions were accompanied by small ephemeral lakes, a lowering of base level, erosion of valleys, some of which attained depths of 200 feet, and small braided streams that 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 of Australia (Bonython and Mason, 1953). The Omo delta is a distributary delta characterized by a delta plain that is virtually a barren mud flat across which the shoreline of Lake Rudolph transgresses and regresses about 16 kilometers each year. Climate in the headwaters of the Omo river is humid; the climate becomes progressively drier toward the delta. On the delta plain vegetation is restricted, for the most part, to the area adjacent to distributaries.

Lake Eyre, in South Australia, is a normally dry basin. Large 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 occurs 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 workers. This report attempts to integrate relationships between geologic setting, climatic conditions, and depositional facies.

REFERENCES

Allen, J. R. L., 1966, On bedforms and paleocurrents: Sedimentology, v. 6, p. 153-190.

Asquith, G. B., and Cramer, S. L., 1975, Source and depositional environment of the upper Triassic of the Texas high plains (abst.): Geol. Soc. America, South-Central Sec. 9th Ann. Mtg., p. 142.

Axelsson, V., 1967, The Laiture Delta, a study of deltaic morphology and processes: Geogr. Annaler, v. 49, p. 1-127.

Bates, C. C., 1953, Rational theory of delta formation: Amer. Assoc. Petrol. Geol., v. 37, p. 2119-2162.

Bernard, H. A., Major, C. F., Parrott, B. S., and LeBlanc, R. J., Sr., 1970, Recent sediments of southeast Texas: Univ. Texas, Austin, Bur. Econ. Geology Guidebook 11, 132 p.

Bonython, C. W., and Mason, B., 1953, The filling and drying of Lake Eyre: Geog. Jour., v. 199, p. 321-330.

Born, S. M., 1972, Late Quaternary history, deltaic sedimentation, and mudlump formation at Pyramid Lake, Nevada: Univ. Nev. System, Center for Water Resources Research, Desert Research Institute, 97 p.

Brown, L. F., Jr., 1969, Geometry and distribution of fluvial and deltaic sandstones (Pennsylvanian and Permian), North-Central Texas: Gulf Coast Assoc. Geol. Soc. Trans., v. 19, p. 23-47.

Butzer, K. W., 1971, Recent history of an Ethiopian delta: Univ. Chicago, Dept. Geography, Res. Paper No. 136, 184 p.

________, Brown, F. H., and Thurber, D. L., 1969, Horizontal sediments XI, p. 15-30.

Cazeau, C. J., 1962, Upper Triassic deposits of west Texas and northeastern New Mexico: Univ. North Carolina, Ph.D. dissertation, 94 p.

Church, M., 1972, Baffin Island sandunes; a study of arctic fluvial processes; Canada Dept. Energy, Mines and Resources Bull. 216, 208 p.

Cleaves, A. W., II, 1975, Upper Desmoinesian-lower Missourian depositional systems (Pennsylvanian), north-central Texas: Univ. Texas, Austin, Ph.D. dissertation, 256 p.

Cramer, S. L., 1973, Paleocurrent study of the upper Triassic sandstones, Texas high plains: West Texas State Univ., MS thesis, 31 p.

Curray, J. R., 1956, The analysis of two dimensional orientation data: Journal Geology, v. 64, p. 117-131.

Cummins, W. F., 1889, The Permian of Texas and its overlying beds: First Ann. Rept., Geol. Survey Texas, p. 424-430.

Erxleben, A. W., 1975, Depositional systems in Canyon Group (Pennsylvanian System), north-central Texas: Univ. Texas, Austin, Bur. Econ. Geology Rept. Inv. 82, 75 p.

Eugster, H. P., 1967, Hydrous sodium silicates from Lake Magadi, Kenya: precursors of bedded chert: Science, v. 157, p. 1177-1180.

________ 1969, Inorganic bedded cherts from the Magadi area, Kenya: Contr. Mineralogy and Petrology, v. 22, p. 1-31.

________, and Jones, B. F., 1968, Gels composed of sodium-aluminum silicate, Lake Magadi, Kenya: Science, v. 161, p. 160-163.

Finch, W. I., 1975, Uranium in west Texas--paper delivered June 3, 1975, AAPG-SEPM Rocky Mountain Sec. Meeting, Albuquerque, New Mexico: U. S. Dept. Interior, Geological Survey, Open-file Rept. 75-356, 20 p.

________, and Wright, J. C., 1975, Unedited measured stratigraphic sections of uranium-bearing late Triassic rocks in eastern New Mexico, west Texas and the Oklahoma panhandle showing provisionary stratigraphic nomenclature: United States Geological Survey, Open-file report 75-March, 1975.

Fisher, W. L., 1969, Facies characterization of Gulf Coast basin delta systems, with some Holocene analogues: Gulf Coast Assoc. Geol. Soc. Trans., v. 19, p. 239-261.

________, Brown, L. F., Jr., Scott, A. J., and McGowen, J. H., 1969, Delta systems in the exploration of oil and gas: a research colloquium: Univ. Texas, Austin, Bur. Econ. Geology Spec. Pub., 212 p.

________, and Brown, L. F., Jr., 1972, Clastic depositional systems - a genetic approach to faccies analysis: Univ. Texas, Austin, Bur. Econ. Geology, 211 p.

Folk, R. L., 1974, Petrology of sedimentary rocks: Hemphill Publishing Co., Austin, Texas, 182 p.

________, and Siedlecka, A., 1974, The "schizohaline" environment: its sedimentary and diagenetic fabrics as exemplified by late Paleozoic rocks of Bear Island, Svalbard: Sed. Geology, v. 11, p. 1-15.

________, and Land, L. S., 1975, Mg/Ca ratio and salinity; two controls over crystallization of dolomite: Am. Assoc. Petroleum Geologists Bull., v. 59, no. 1, p. 60-68.

Galloway, W. E., 1970, Depositional systems and shelf-slope relationships in upper Pennsylvanian rocks, north-central Texas: Univ. Texas, Austin, Ph.D., dissertation, 115 p.

________ 1977, Catahoula Formation of the Texas coastal plain: depositional systems, composition, structural development, ground-water flow history, and uranium distribution: Univ. Texas, Austin, Bur. Econ. Geology Rept. Inv. 87, 59 p.

Glibert, G. K., 1890, Lake Bonneville: United States Geological Survey, Monograph I, 438 p.

Gottschalk, L. C., 1964, Reservoir sedimentation, in V. E. Chow, editor, Handbook of Applied Hydrology: McGraw-Hill Book Company, p. 17-1 through 17-34.

Gould, C. N., 1906, The geology and water resources of the eastern portion of the Panhandle of Texas: U. S. Geol. Survey Water-Supply Paper 154, 64 p.

________ 1907, The geology and water resources of the western portion of the Panhandle of Texas: U. S. Geol. Survey Water-Supply Paper 191, 70 p.

H. R. ________ 1960, Turbidity currents, in Smith, et. al., Comprehensive study of sedimentation in Lake Mead 1948-1949: United States Geological Survey Prof. Paper 295, p. 201-207.

Green, F. E., 1954, The Triassic deposits of northwestern Texas: Texas Technological College, Ph.D. dissertion, 196 p.

Harms, J. C., 1969, Hydraulic significance of some sand ripples: Geol. Soc. America, v. 80, p. 363-396.

________ 1975, Stratification produced by migrating bed forms: in depositional environments as interpreted from primary sedimentary structures and stratification sequences: Soc. Econ. Paleontologists and Mineralogists Short Course No. 2, Dallas 1975, p. 45-61.

________, and Fahnestock, R. K., 1965, Stratification, bed forms, and flow phenomena (with an example from the Rio Grande), in Primary sedimentary structures and their hydrodynamic interpretation: Soc. Econ. Paleont. Mineral. Spec. Pub. No. 12, p. 85-115.

Hayes, M. O., and Kana, T. W., editors, 1976, Terrigenous clastic depositional environments, some modern examples: Coastal Research Division, Dept. Geol., Univ. South Carolina, Tech. Rept. No. 11-CRD.

Hills, J. M., 1972, Late Paleozoic sedimentation in west Texas Permian basin: Am. Assoc. Petroleum Geologists Bull., v. 13, p. 2303-2322.

Jopling, A. V., 1961, Origin of regressive ripples explained in terms of fluid-mechanic processes: U. S. Geol. Survey Prof. Paper 424-D, p. 15-17.

Kehle, R. O., 1972, Gulf coast structure: origin of the Gulf of Mexico: Univ. Texas, Austin, Dept. Geol. Sci. Lecture Notes, 152 p.

Kiatta, H. W., 1960, A provenance study of the Triassic deposits of northwestern Texas: Texas Technological College, MS thesis, 63 p.

King, P. B., 1930, The geology of the Glass Mountains, Texas, pt. I, descriptive geology: Univ. Texas Bull. 3038, p. 84-89.

________ 1935, Age of Bissett Conglomerate: Am. Assoc. Petroleum Geologists Bull., v. 19, p. 1544-1546.

________ 1937, Geology of the Marathon region, Texas: U. S. Geol. Survey Prof. Paper 187, 148 p.

Lang, W. B., 1935, Upper Permian formation of Delaware Basin of Texas and New Mexico: Am. Assoc. Petroleum Geologists Bull., v. 19, p. 262-270.

Langbein, W. B., 1961, Salinity and hydrology of closed lakes: U. S. Geol. Survey Prof. Paper 412, 20 p.

Lentz, R. C., 1976, Relation of Eocene depositional environments to sulfur content and quality of surface waters at lignite strip mines near Fairfield, Texas: Univ. Texas, Austin, MA thesis, 147 p.

Levey, R. A., 1976, Characteristics of coarse-grained point bars, upper Congaree River, South Carolina: in Hayes, M. O., and Kana T. W., editors, Terrigenous clastic depositional environments: Coastal Research Division, Dept. Geol., Univ. South Carolina, Tech. Rept. No. 11-CRD, p. II-38 to II-51.

Lupe, R., 1977, Depositional history of the Triassic Santa Rosa Sandstone, Santa Rosa, New Mexico: Geol. Soc. Am., South-Central Section, 11th Annual Meeting, March 17-18, 1977, El Paso, Texas, p. 61.

McGowen, J. H., 1971a, Gum Hollow delta, Nueces Bay, Texas: Univ. Texas, Austin, Bur. Econ. Geology Rept. Inv. 69, 91 p.

________ 1971b, Alluvail fans and fan deltas: depositional models of some terrigenous clastic wedges (abst.): Southwest Sec., Am. Assoc. Petroleum Geologists 13th Ann. Mtg., p. 11-13.

________, and Garner, L. E., 1970, Physiographic features and stratification types of coarse-grained point bars: modern and ancient examples: Sedimentology, v. 14, p. 77-111. Reprinted as Univ. Texas, Austin, Bur. Econ. Geology Geol. Circ. 75-9.

________, and Groat, C. G., 1971, Van Horn Sandstone, West Texas; an alluvial fan model for mineral exploration: Univ. Texas, Austin, Bur. Econ. Geology Rept. Inv. 72, 57 p.

________, and Scott, A. J., 1974, Fan-delta deposition: processes, facies and stratigraphic analogues (abst.): AAPG-SEPM, Ann. Meetings Abstracts, v. 1, p. 60-61.

McKee, E. D., Oriel, S. S., Ketner, K. B., MacLacklan, M. E., Goldsmith, J. W., MacLacklan, J. C., and Mudge, M. R., 1959, Paleotectonic maps of the Triassic system: U. S. Geol. Survey Misc. Geol. Inv. Map I-300.

Miller, D. N., Jr., 1955, Petrology of Pierce Canyon redbeds Delaware basin Texas and New Mexico: Univ. Texas, Austin, Ph.D. dissertation, 148 p.

Nicholson, J. H., 1960, Geology of the Texas panhandle; in Aspects of the geology of Texas; A symposium: Univ. Texas, Austin, Bur. Econ. Geology Pub. 6017, p. 51-64.

Ore, H. T., 1964, The braided stream depositional environment: Univ. Wyoming, Ph.D. dissertation, 205 p.

Oriel, S. S., and Mudge, M. R., 1956, Problems of lower Mesozoic stratigraphy in southeastern Colorado: Rocky Mountain Association Geologists Guidebook, Geology of the Raton Basin, Colorado, p. 19-24.

Page, L. R., and Adams, J. E., 1940, Stratigraphy, eastern Midland Basin, Texas: Am. Assoc. Petroleum Geologists Bull., v. 24, p. 52-64.

Pezzetta, J. M., 1973, The St. Clair river delta: sedimentary characteristics and depositional environments: Jour. Sed. Petrology, v. 43, p. 168-187.

Pirson, S. J., 1963, Handbook of well log analysis for oil and gas formation evaluation: Prentice-Hall, Inc., 326 p.

Rooney, T. P., Jones, B. F., and Neal, J. T., 1969, Magadiite from Alkali Lake, Oregon: Am. Min., v. 54, p. 1034-1043.

Selley, R. C., 1976, Subsurface environmental analysis of North Sea sediments: Am. Assoc. of Petroleum Geologists, v. 60, p. 184-195.

Smith, N. D., 1970, The braided stream depositional environment: comparison of the Platte River with some Silurian clastic rocks, north-central Appalachians: Geol. Soc. America Bull., v. 81, p. 2993-3014.

Stephens, C. G., 1971, Laterite and silcrete in Australia: Geoderma, v. 5, p. 5-52.

Teichert, C., editor, 1975, Treaties on invertebrate paleontology, pt. W. miscellanea, supplement 1, trace fossils and problematic, 2d ed.: Geol. Soc. America, Inc. and Univ. Kansas, 269 p.

Weber, K. J., 1971, Sedimentological aspects of oil fields in the Niger Delta: Geologie en Mijnbouw, v. 50, p. 559-576.