DEPOSITIONAL SYSTEMS, URANIUM OCCURRENCE AND POSTULATED GROUND-WATER HISTORY OF THE TRIASSIC DOCKUM GROUP, TEXAS PANHANDLE-EASTERN NEW MEXICO

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CONTENTS

FIGURES

TABLES

ABSTRACT

Late Triassic (Dockum Group) rocks accumulated in a relict Paleozoic basin defined, in Texas, by the Amarillo Uplift to the north and the Glass Mountains to the south. This basin was reactivated during Late Paleozoic or Early Mesozoic by tectonic activity that probably was related to the opening-up of the Gulf of Mexico. The basin subsided, some relict positive elements were uplifted, and sediments began to accumulate in the basin.

More than 2,000 feet of terrigenous clastics, derived mostly from older sedimentary rocks, accumulated within the basin. Source areas were in Texas, Oklahoma, and New Mexico; sediment transport was from the south, east, north, and west. The Dockum Group accumulated in a variety of depositional systems including: (1) braided and meandering streams; (2) alluvial fans and fan deltas; (3) distributary-type lacustrine deltas (highly constructive lobate deltas); (4) lacustrine systems including ephemeral and relatively long-lived lakes; and (5) mud flats.

Dockum sedimentation was cyclic. Underlying cause of cyclicity was alternation of humid and arid climate; tectonism most likely was the climatic trigger. During humid climatic conditions lake level was relatively stable (lake area and depth were maximum); meandering streams supplied sediment to high-constructive lobate deltas in the central basin area (Texas and New Mexico) whereas braided streams and fan deltas were dominant depositional elements within southern and northern basin areas. Lake area and depth decreased during arid climatic conditions, base level was lowered, valleys were cut into older Dockum deposits, and relatively small fan deltas were constructed along margins of ephemeral lakes; evaporites, calcretes, silcretes, and soils developed upon floors of ephemeral lakes and on delta platforms.

Occurrence of uranium in the Dockum Group has been known for years. Association between depositional facies and uranium occurrence was first documented through research by the Bureau of Economic Geology. Twenty-five distinct depositional facies have been recognized in the Dockum; each of these facies contains uranium. Highest uranium values are in lacustrine facies which developed under arid climatic conditions; however, only a few areas exhibited high values. Channel-lag facies of meanderbelt systems generally exhibit consistently higher uranium values than other depositional facies. Crevasse channel and crevasse splay deposits associated with meandering streams and delta distributaries locally contain carbonized wood some of which contains uranium. Facies of high-constructive lobate deltas contain uranium; highest values are exhibited by delta front sandstones. Some valley-fill deposits are mineralized; radioactive minerals mostly are within conglomeratic parts of the sequence.

Uranium deposits within the Dockum Group are, for the most part, epigenetic and generally occur within sandstone bodies. Four sources of uranium for Dockum mineralization are possible: (1) Triassic volcanics; (2) igneous rocks in Oklahoma; (3) Cretaceous volcanics; and (4) Tertiary volcanics.

Although there is a relationship between uranium occurrence and depositional facies, prediction of areas of uranium occurrence is difficult because of a rather complex ground-water history. Ground-water flow was for the most part basinward (down depositional slope) during deposition and shallow burial of the Dockum. Erosion during Jurassic and Early Cretaceous influenced local ground-water flow which would have been toward erosional lows. Ground-water chemistry was probably affected by marine transgression during Cretaceous. Following accumulation of Cretaceous sediments, erosion again dominated the area of the Dockum basin; erosion prevailed until sometime during the

Pliocene. Pliocene (Ogallala Formation) wet alluvial fan deposits accumulated upon a highly dissected surface underlain in part by Cretaceous rocks, but most of the area was underlain by the Dockum Group. During and subsequent to Pliocene deposition ground-water flow was to the east in both the Ogallala Formation and the upper part of the Dockum Group.

At present, there are two favorable areas for uranium exploration in outcrop: (1) Tule Canyon-Palo Duro Canyon area, and (2) from southern Dickens County southward through Mitchell County. Within the subsurface a widespread radiometric anomaly occurs at the top of the lowermost progradational sequence; this anomaly is a few hundred to more than 1,000 feet below ground surface. A fourth favorable area for uranium exploration is the uppermost Dockum which has been dissected and is immediately overlain by the volcanic ash-bearing Pliocene Ogallala Formation.

INTRODUCTION

The Dockum Group in northwestern Texas and eastern New Mexico was studied in outcrop and subsurface in cooperation with the U. S. Geological Survey (Grant Number 14-08-0001-G-410) for the purpose of: (1) determining the depositional systems within the Dockum, (2) establishing relationships between uranium occurrence and depositional facies, and (3) deriving a model which may be employed in uranium exploration.

A first report on the Dockum Group, submitted to U. S. Geological Survey in February, 1978, concerned the lower half of the Dockum Group (in outcrop and subsurface) in Texas and New Mexico south of the Matador Arch. The first report described the depositional framework for the lower half of the Dockum Group. Most conclusions contained in the first report were derived from reconnaissance and detailed outcrop studies. Initial subsurface analyses south of the Matador Arch indicated that depositional facies recognizable in outcrop could be identified and mapped in the subsurface. The first report emphasized a combination of tectonic and climatic controls on Late Triassic fluvial, deltaic, and lacustrine sedimentation. It tentatively concluded that opening-up of the Gulf of Mexico strongly influenced the style of Dockum deposition. It was also postulated that volcanic activity that accompanied horst and graben development was a possible source of uranium-bearing detritus from which radioactive materials contained within parts of the Dockum were derived.

Subsurface work, throughout the Dockum basin in Texas and New Mexico, was performed contemporaneously with outcrop work. Each phase, outcrop and subsurface analysis, was compared with the other to verify the validity of the environmental interpretations. There is general agreement between facies interpretations made from outcrop studies and sandstone trends and gamma-ray log characteristics for the subsurface Dockum.

This report emphasizes the subsurface Dockum Group in 51 counties in Texas and eight counties in New Mexico and selected outcrop areas in Texas and New Mexico. The entire Dockum Group was investigated for the purpose of determining: (1) the depositional history of the southwestern Triassic basin, (2) depositional systems operative during accumulation of the Dockum Group, and (3) the subsurface distribution of radioactive anomalies and the association (if any) of those anomalies with depositional facies.

Sections of this report were written by McGowen, Granata, and Seni. The following sections were written by McGowen: (1) abstract, (2) introduction, (3) parts of the section on outcrop geology (part of the Northeastern New Mexico area, and all of the Canadian River Valley, Tule Canyon, Dicken-Mitchell County area, Depositional Systems, Modern Analogues for the Dockum), (4) Dockum Depositional Systems: A Summary, (5) Uranium Occurrence in Dockum Outcrop Facies, (6) Depositional and Erosional Events that Affected the Dockum Ground-Water System, (7) Hypothetical Evolution of Ground-Water Systems, (8) Possible Uranium Sources, Mechanisms and Timing of Emplacement, and (9) Conclusions. Granata's primary responsibility was the Dockum subsurface. Granata wrote the following sections: (1) Regional Geology of the Dockum Group, (2) part of the section on outcrop geology (the major part of Northeastern New Mexico area), and (3) Radioactive Anomalies from Subsurface and Radiometric Data, Dockum Group. Seni's primary responsibility was outcrop work in Palo Duro Canyon. Seni also participated in part of the regional outcrop reconnaissance work, and detailed outcrop work in Garza County. The section on outcrop geology of Palo Duro Canyon was written by Seni.

More than 2,000 gamma-ray logs from oil well boreholes were used in the subsurface study. Rock cuttings from several boreholes were described; lithic descriptions were used as a means to check lithic interpretations made from gamma-ray log patterns.

General Setting

The Upper Triassic Dockum Group accumulated in a basin that underlies 96,000 square miles (249,600 km^2), parts of Texas, New Mexico, Colorado, Kansas and Oklahoma (fig. 1). The area of investigation in Texas and eastern New Mexico covers 73,000 square miles (189,800 km^2). Location and geometry of the basin appear to be related to Paleozoic structural elements (fig. 2) which probably originated in Late Mississippian (Nicholson, 1960). In the northern part of the area relict structural elements are the Amarillo Uplift and Bravo Dome. Structure in the southern part of the basin is partially obscured by evaporite solution resulting from Cenozoic surface drainage (Miller, 1955; Hills, 1972). The Matador Arch apparently was inactive during Late Triassic and exerted little influence on sedimentation. Sandstone depositional patterns in the lower half of the Dockum were unaffected by the Central Basin Platform (fig. 3).

Dockum and underlying Permian Strata are red, but Dockum facies, which accumulated in fluvial, deltaic, and lacustrine environments are in marked contrast with Permian evaporites and terrigenous clastics 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 sedimentation appears to have been continuous from Permian into Late Triassic time. Lower and Middle Triassic deposits are perhaps represented by such Upper Permian deposits as Pierce Canyon redbeds (Lang, 1935) and Dewey Lake redbeds (Page and Adams, 1940).

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.

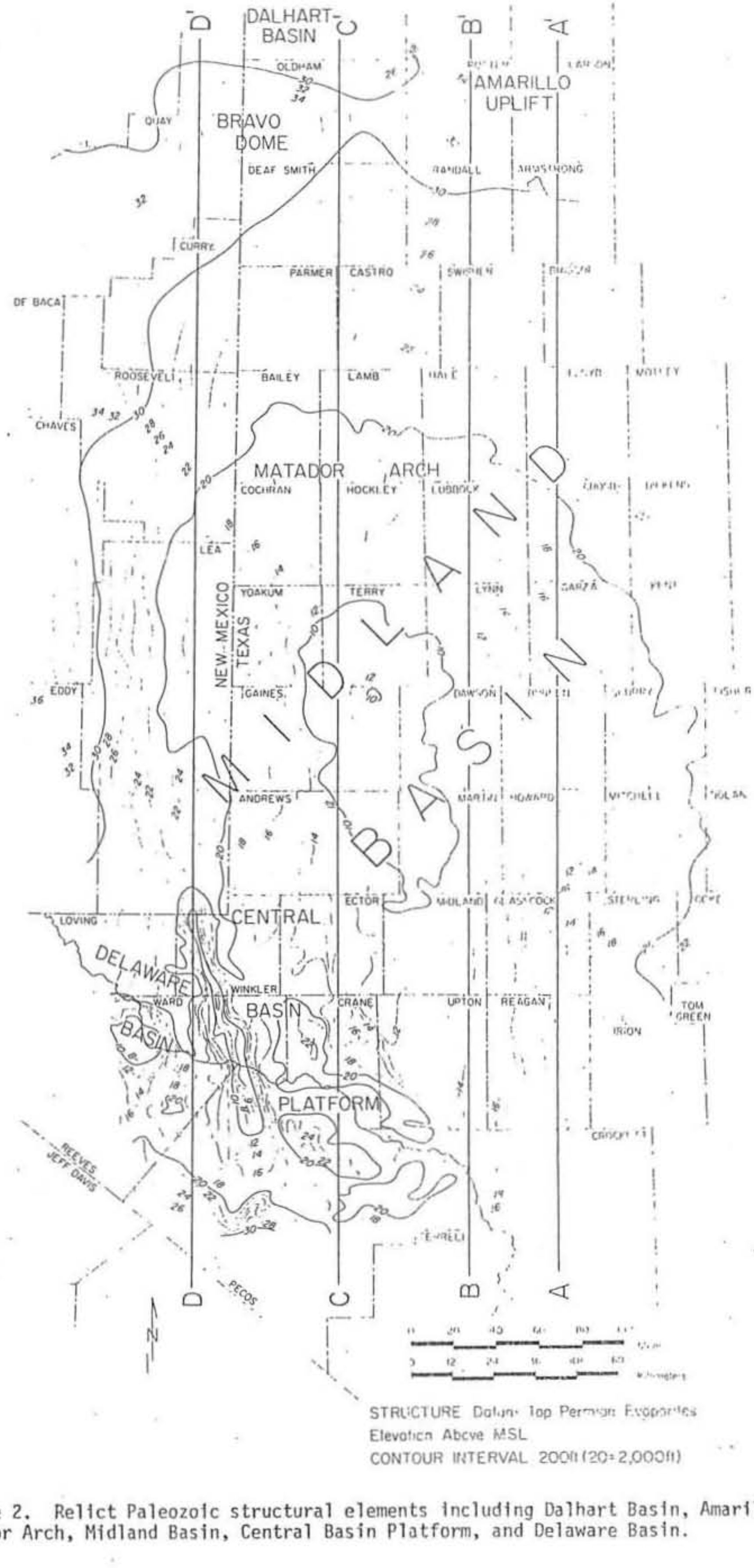

Figure 2. Relict Paleozoic structural elements including Dalhart Basin, Amarillo Uplift, Matador Arch, Midland Basin, Central Basin Platform, and Delaware Basin.

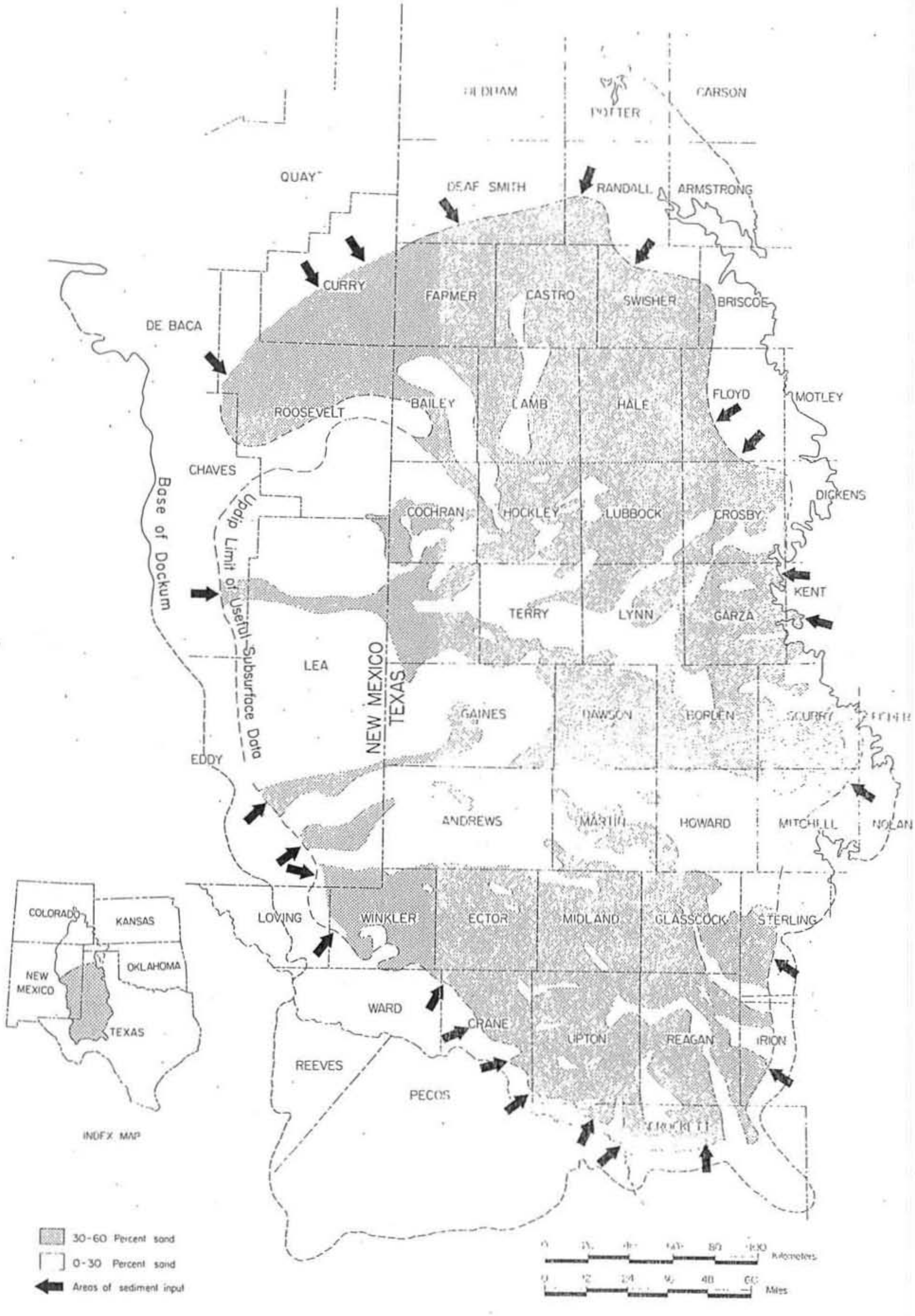

Figure 3. Generalized sandstone trends for the lower half of the Dockum Group in Texas and New Mexico, and inferred direction of sediment input.

The Dockum basin received sediment from the east, south, west, and north. 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.

In this report, Triassic strata are analyzed in terms of genetic facies that compose depositional systems, and Dockum Group is the only formal stratigraphic term applied.

Previous Studies

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-alluvial fan setting.

Several dissertations and theses have dealt with specific stratigraphic, paleontologic, and sedimentologic aspects of the Dockum Group (Green, 1954; Kiatta, 1960; Cazeau, 1962; and 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.

Subsurface Procedures

Approximately 2,000 gamma-ray logs compose the data base of the subsurface study. Few electric logs that penetrate the Dockum section are available, and most of these are of poor quality because of low contrast between the salinity of borehole fluids and formation fluids. Also, for purposes of mapping sand facies, data from electric logs were found to be incompatible with that from gamma-ray logs. The SP curve, for example, responds somewhat to porosity and thus responds to "sandstones" by a textural definition. Thus, an SP log might show as "sandstone" a rock composed of sand-sized clasts of mudstone. Gamma-ray logs, on the other hand, measure the natural radioactivity of rocks. 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. Thus, gamma-ray logs respond to "sandstone" of a mineralogical definition. In this study, therefore, we are mapping "sandstone" facies composed of relatively clean quartz sandstones and siltstones. This general relationship between gamma-curve response and lithology was verified by comparing lithic composition from well cuttings with gamma log properties.

By mapping clean quartz sandstones and siltstones, we are mostly looking at sediments derived from outside the immediate basin of deposition and deposited by processes conducive to good sorting of sediment (e.g., longer duration, lower intensity). Such processes were operative during high base level stands (documented by outcrop studies). High base level stands were dominant early within the two major Dockum cycles (discussed in sections on Dockum Stratigraphy) and became less common later in these cycles. Sediments that compose low stand deposits (documented in outcrop studies) 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 fine-grained deposits on gamma-ray logs. Hence, sand percentage maps probably reflect principally depositional systems operating during high stand.

An additional limitation is inherent in interpretations based on gamma-ray logs alone. Sandstones with a high content of uranium or potassium-bearing mica may appear on gamma curves as mudstones. Though probably significant on a smaller scale it was assumed that these errors did not affect regional sandstone distribution patterns.

It was observed that for a given gamma-ray log, the net thickness of low-gamma-ray-level response within the Dockum section was relatively low. The net thickness of intermediate-gamma-ray-level responses was relatively high. In tabulating sandstone thickness data, a vertical line was drawn on the log, far enough to the left (low on the radioactivity scale) to exclude the bulk of the intermediate-gamma-ray-level responses. The parts of the curve to the left of this line were counted as sandstone (fig. 4).

The terrigenous clastic section immediately below the Dockum is known as the Pierce Canyon redbeds (Lang, 1935) in the Delaware Basin and is called

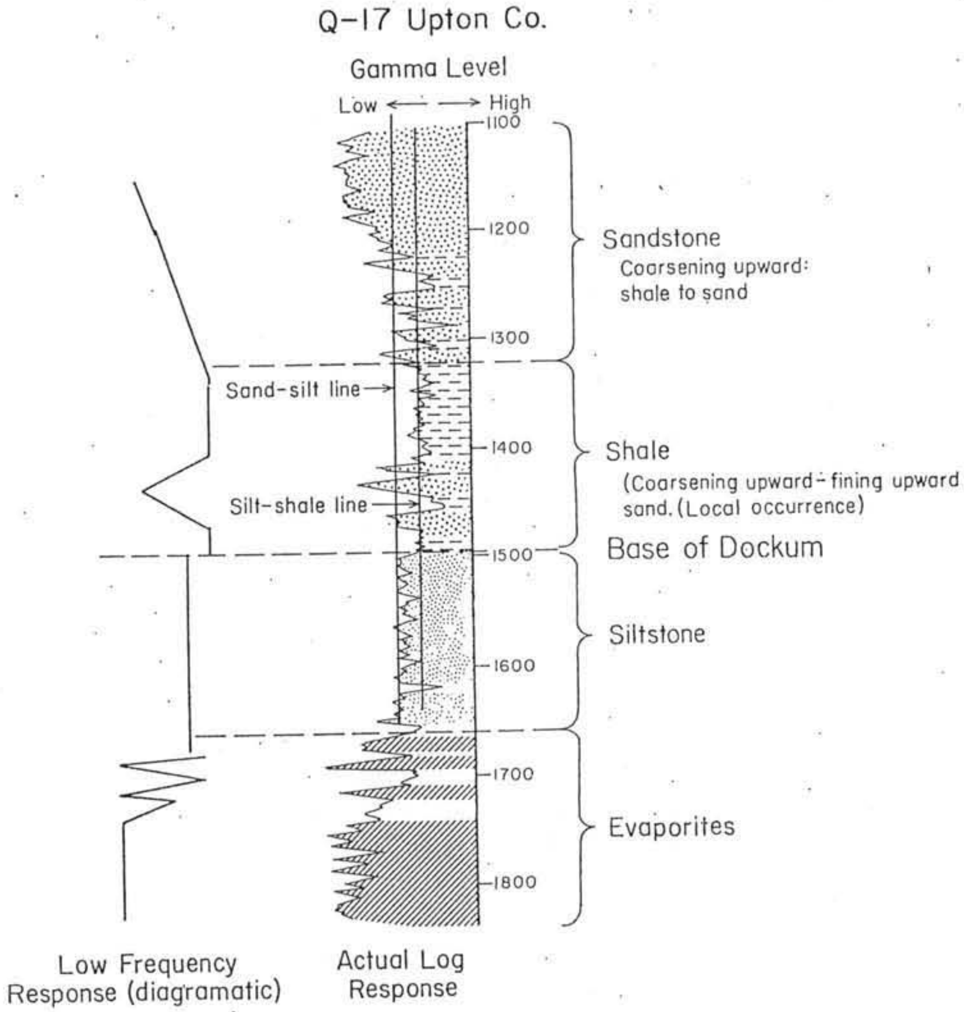

Figure 4. Gamma-ray log characteristics and corresponding terrigenous clastic rocks.

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. Subsurface data generated during this investigation suggests that this clastic interval maintains this uniform lithology over a wide part of the Dockum basin, thereby producing a reference section of known lithology on each log. Placement of the "sand line" on logs was always made so as to exclude the Dewey Lake siltstones. This procedure served to guard against variability in logging tools and in amplification (scales) among logs.

Limited interpretation of vertical textural trends were also made from individual gamma-ray logs. 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.

Outcrop Methods

Rocks were studied in outcrop (both reconnaissance and detailed field work) by measuring and describing sections and by making photomosaics where extensive lateral exposures were present. Rock color, lithology, vertical and lateral variations in scale, and type of primary sedimentary structures, textural trends, biological constituents (body fossils and ichnofossils), and accessory or minor rock types or mineral components (for example, chert, gypsum, and salt casts) were recorded for each outcrop area.

Depositional facies were determined in the field at each outcrop. Cross-sections and fence diagrams were constructed from outcrop descriptions; photomosaics were also utilized for facies mapping, particularly where outcrops were inaccessible.

At each outcrop directional features (axes of trough-fill cross-strata, dip direction of foreset cross-strata, direction of ripple migration, and parting lineation) were measured if exposed on a bedding surface where there was no doubt as to the type of sedimentary structure being measured. Directional features in conjunction with sand-body geometry were used to determine sediment transport direction.

Samples were collected at all outcrops for analysis of uranium content. The objective was to determine the uranium-bearing potential of each depositional facies. Thin sections and clay mineral slides were made from representative samples from the entire Dockum outcrop.

Acknowledgments

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REGIONAL GEOLOGY OF THE DOCKUM GROUP

Structural and Stratigraphic Framework

The major structural features of the Dockum depositional basin are shown in figure 5, which shows present structural relief on the base of the Dockum. Study of Dockum depositional facies indicates that basin configuration during Dockum deposition was approximately the same as that preserved today. The regional structural setting of the Dockum Group is characterized by a series of interconnected basins separated to varying degrees and locally bounded by structurally positive features. These basins and highs, active during Permian deposition, appear overall to have exerted less influence on Dockum than on Permian sedimentation. Basinward stratigraphic thickening within the Dockum is typically five feet per mile (1 m/km). Observed in outcrop, rock sequences from individual (not vertically stacked) depositional systems are generally less than 100 feet (30 m) thick. Depositional facies suggest that both differential structural movement and topographic relief were low within the Dockum basin. Effect of individual structural features on different attributes of the Dockum are discussed with those attributes.

Figure 6 shows the position of cross sections used in this report. Cross sections and the thickness map for the lower part of the Dockum (fig. 7) indicate that the center of the Dockum depositional basin lay close to the center of the Midland Basin in Late Permian time. Therefore, an erosional unconformity between Dockum and underlying units is unlikely at least at basin center. Figure 8 (isopach of Dewey Lake interval) exhibits areas of pre-Dockum erosion. In Texas these areas coincide with the crests of three structurally high features: (1) the Central Basin Platform, (2) an unnamed arch in and northwest of Sterling County, and (3) the Bravo Dome. In New

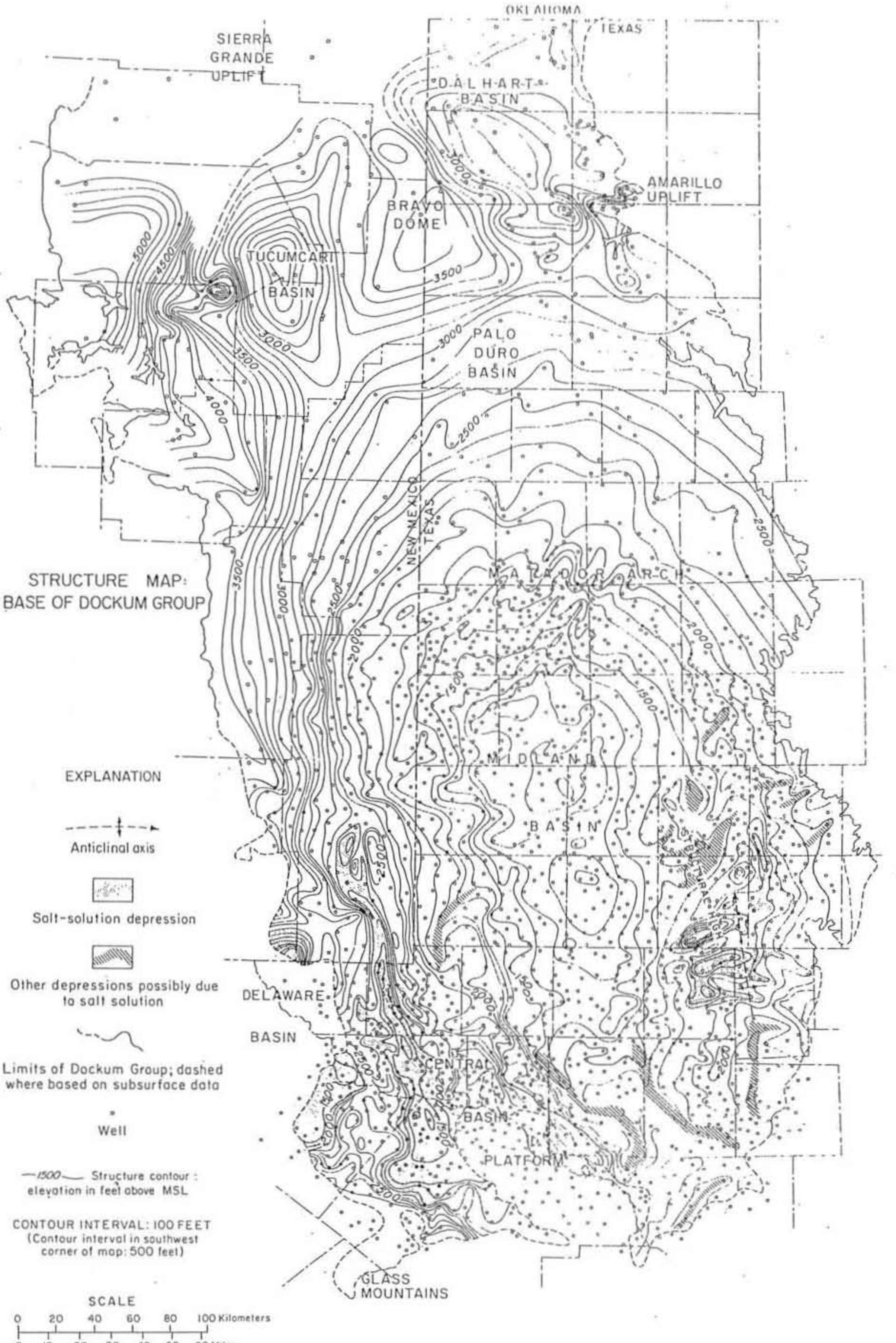


Figure 5. Structure map, base of Dockum Group. Elevation, in feet, above mean sea level. Principal relief Permian structures are labeled. Structural elements had varying influence on Dockum sedimentation. Subsidence caused by solution of Permian salt occurred after Dockum deposition and resulted in local preservation (from erosion) of thicker Dockum sections.

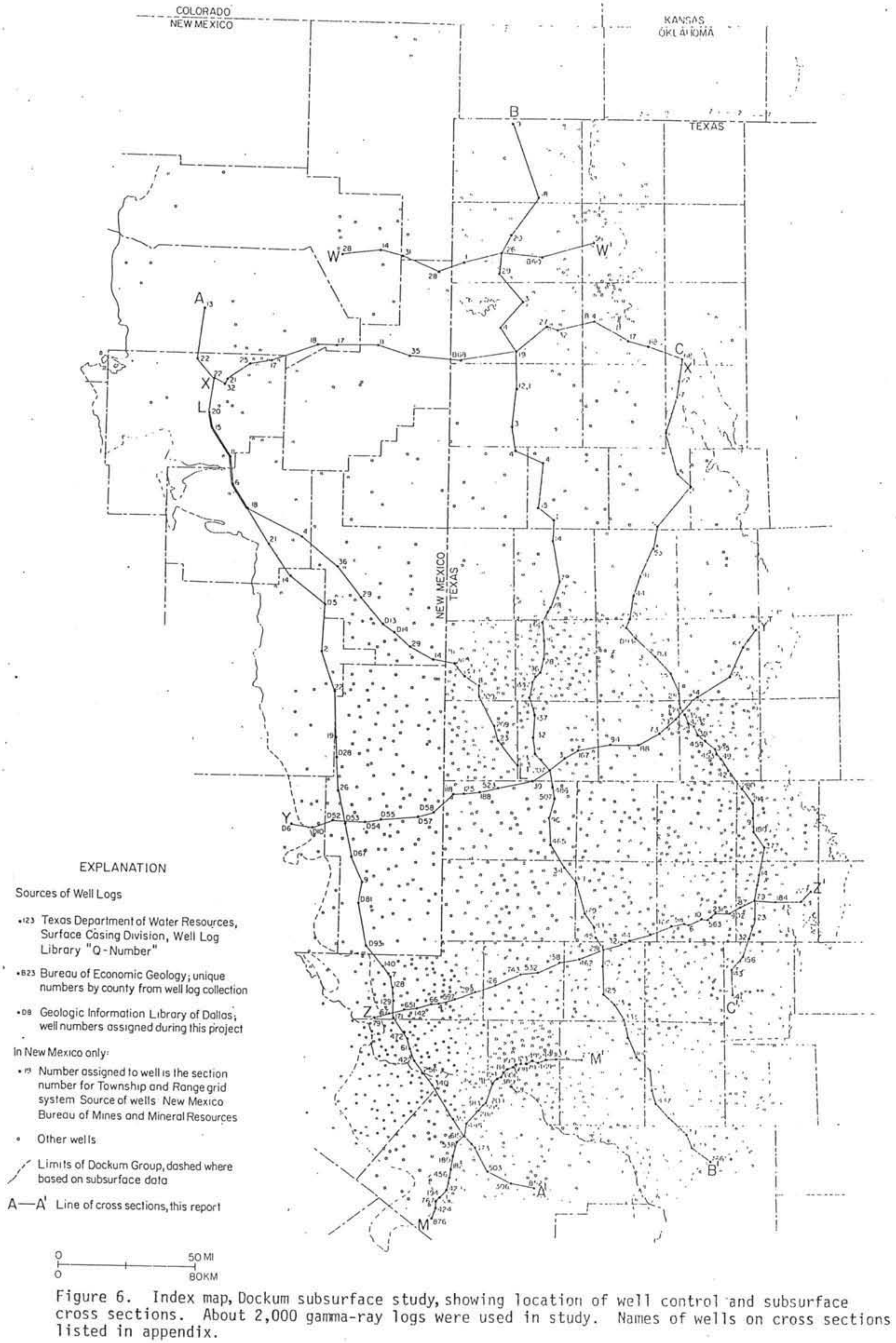


Figure 6. Index map, Dockum subsurface study, showing location of well control and subsurface cross sections. About 2,000 gamma-ray logs were used in study. Names of wells on cross sections listed in appendix.

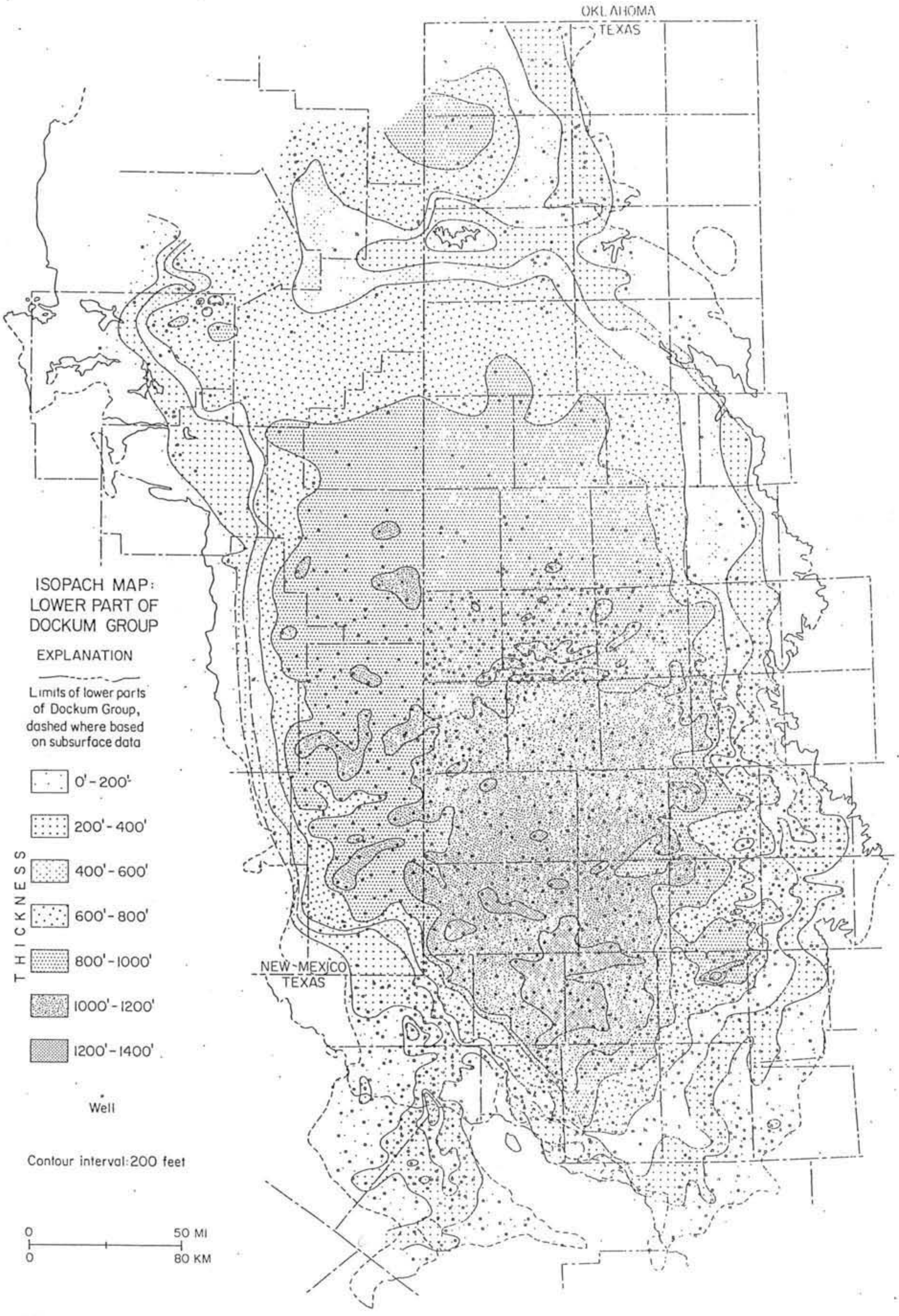


Figure 7. Isopach map, lower part of Dockum Group. Where not eroded (overlain by younger Dockum deposits) lower unit thickens southward at about 4 feet per mile (.75/km).

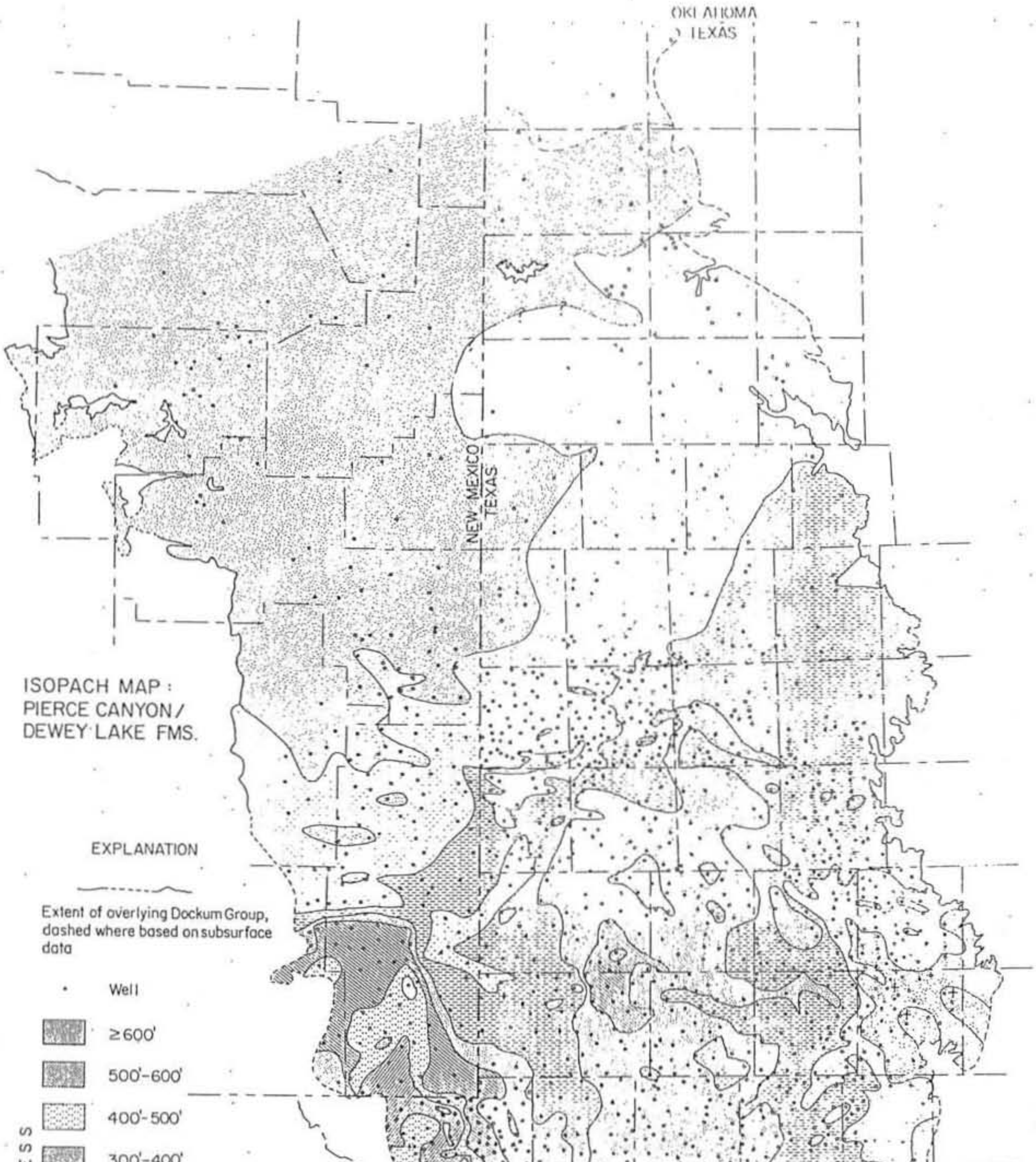


Figure 8. Isopach map, Pierce Canyon/Dewey Lake Formations and equivalent pre-Dockum clastic deposits. This map unit thins southward from a southern source area. Where this unit is absent or partially truncated, Dockum rocks rest unconformably on older sediments. In the southern part of study area, unconformable contacts are limited to margins of Central Basin Platform and crest of an unnamed structural arch in Mitchell County area.

Mexico along a northwest trend across the northwest part of the study area, rocks of the Dockum Group lie on progressively older Permian rocks. In southeastern Colfax County, New Mexico, McKee and others (1959) report rocks of Pennsylvanian and Precambrian age immediately beneath the Dockum. Throughout most of the study area Dockum rocks are underlain by a continuous terrigenous clastic interval known as Dewey Lake redbeds in the Midland Basin and as Pierce Canyon redbeds in the Delaware Basin. Paleontological evidence for the age of the Pierce Canyon/Dewey Lake interval is lacking. However, cross section MM' (fig. 9) suggests a direct correlation between the Pierce Canyon of the Delaware Basin and the Bissett Conglomerate outcrops of the Glass Mountains. King (1935) concluded that physical and paleontological evidence favor an Early Triassic age for the Bissett. Thus, the Pierce Canyon/Dewey Lake interval may represent the "missing" sediment interval between the Permian and the continuously deposited Late Triassic Dockum Group.

The base of the Dockum is defined on gamma logs for the purpose of this study as the base of any muds (high radioactivity response) immediately underlying lowest Dockum sandstone (see fig. 10 wells 96, 486 Gaines County), or conversely as the top of the siltstone interval (intermediate radioactivity response) immediately overlying the Permian evaporite section. This definition holds over most of the Midland and Delaware Basin, over the western part of the Central Basin Platform, and over parts of the Palo Duro Basin. Around the margins of the basins where units thin somewhat and where there is considerable vertical and lateral lithologic variation both within the Dockum and the Upper Permian, the base-of-Dockum pick is correlated from well to well.

In the extreme southern part of the Midland Basin a 25-200-foot, progradational (coarsening upward) sequence of sediment lies between what is

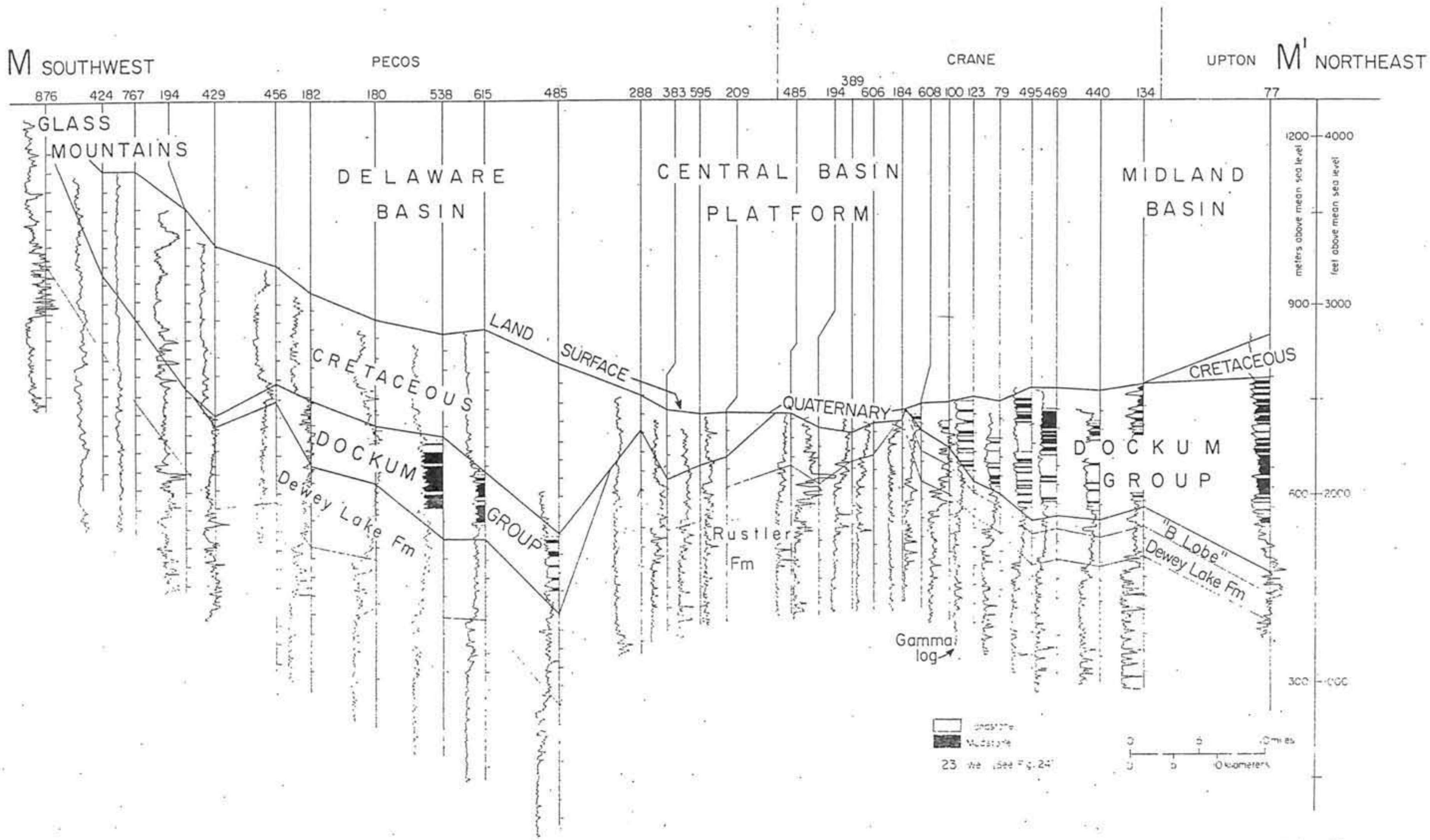


Figure 9. Cross section M-M'. This section extends from Midland Basin, across Central Basin Platform and Delaware Basin to within 1-3 miles of outcrops of Bisset Conglomerate in Glass Mountains. Up to 600 ft of Bisset Conglomerate are overlain by Cretaceous in outcrop. Cross section M-M' demonstrates a close correlation between Bisset Conglomerate and Pierce Canyon Formation.

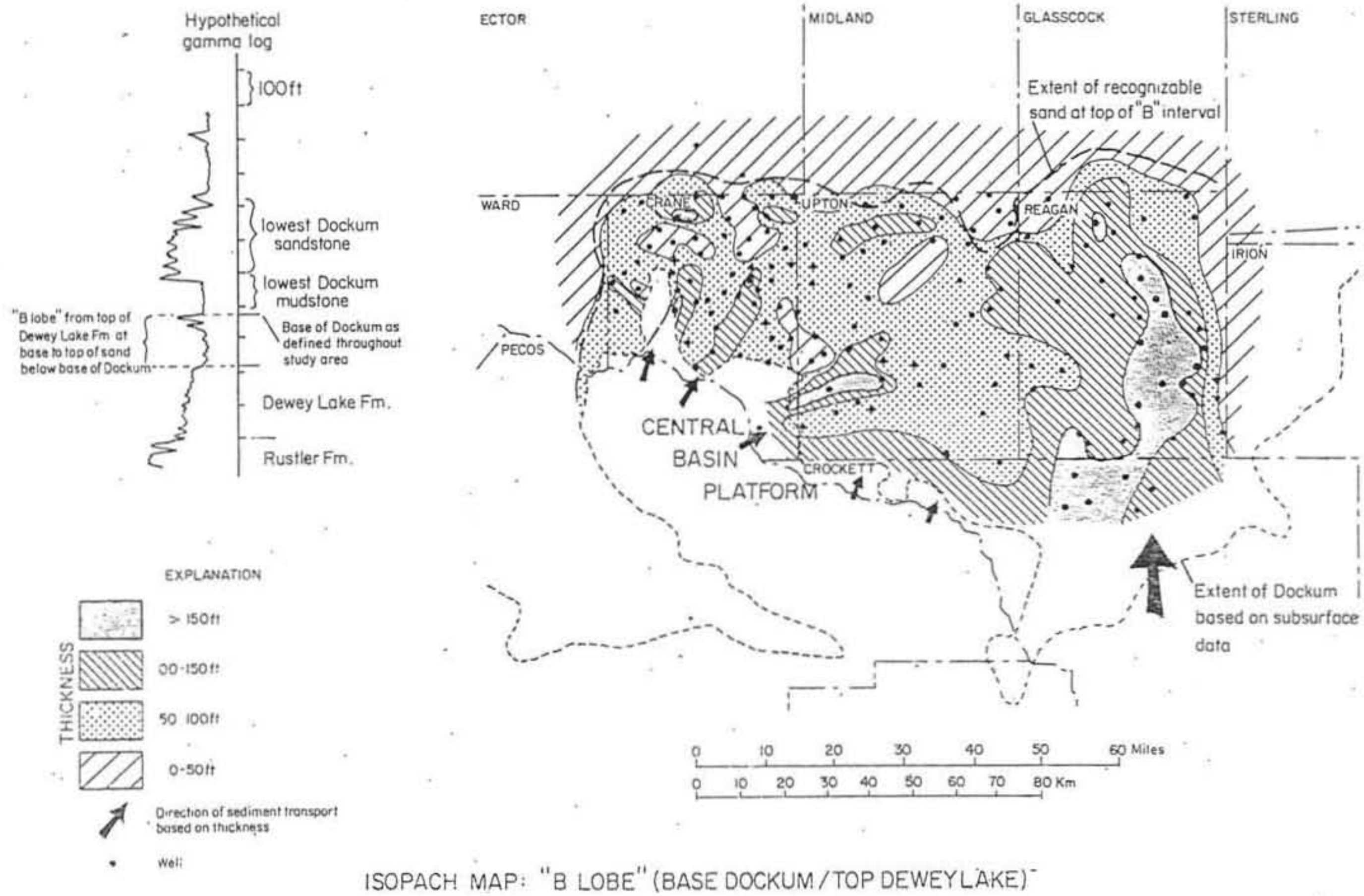


Figure 11. Isopach map "B Lobe". This progradational unit is mapped where a sandy facies is developed at the top, allowing distinction of the unit from overlying Dockum mudstone (see Fig. 13).

defined as top of the Dewey Lake and base of the Dockum. This lobe (labeled "B Lobe" on cross sections BB', fig. 10, and MM', fig. 9) of sediment is mapped in figure 11. B Lobe is lithologically similar on gamma-ray logs and has a direction of transport similar to overlying lowest Dockum sediment. Whether or not this early pulse of sediment from the relatively active southern source area is equivalent to any of Bissett Conglomerate/Pierce Canyon section in the Delaware Basin is not known due to truncation of the Dockum section over the Central Basin Platform.

The sub-Dockum unconformity in and west and northwest of Quay County (cross section LL', fig. 12), New Mexico is of extremely low angle over much of its extent. In outcrops along the Pecos River north and south of Santa Rosa, erosional relief was found to be less than one foot (.3 m) over the distance of single exposures. This hiatus is considered to represent a period of gentle erosion or nondeposition. The lower sandstone member of the Santa Rosa Sandstone (informal stratigraphic members mapped by Gorman and Robeck, 1946) appears on gamma-ray logs as a mudstone interval. This mineralogically dirty sandstone thus appears on the map of the lowest Dockum mudstone (fig. 13) as a southeasterly directed lobe. The outcrop equivalent of this sandstone accumulated as a low gradient fan. It differs in depositional style and lithology from overlying sandstones which are the lowest sandstones that are correlatives of the rest of the Dockum basin. Thus, this sandstone (lower member) may represent deposition during part of the missing interval below the Dockum.

The Dockum Group is overlain by Jurassic sediments in northeastern New Mexico (figs. 14 and 15). The original extent of Jurassic deposition is not known. Prior to deposition of Cretaceous strata Jurassic deposits were removed in basin margin areas and upper Dockum rocks were eroded. Present

Figure 13. Generalized isopach map, lowest Dockum mudstone unit. Mudstone unit (lake bottom and prodelta) represents initial Dockum lacustrine transgression and subsequent deltaic progradation, respectively.

This lowest mudstone facies (and by inference, the initial lacustrine environment) is absent north of Midland Basin, except in Tucumcari Basin. North of Midland Basin lowest Dockum fluvial sandstones rest directly on pre-Dockum rocks. Large lobes that occur in northwestern and northeastern parts of map area are clay-bearing sandstones which, on gamma-ray logs, appear to be mudstones. These two clay-bearing sandstone bodies are equivalent to alluvial fan deposits in outcrop.

The area of greatest thickness in the southeastern Midland Basin represents muddy prodelta facies where fan deltas entered the basin from the south.

An earlier, lowest Dockum or pre-Dockum, deposit also prograded into the basin from the south. This unit is informally called "B-Lobe" (Fig. 11). Where sands do not occur in the "B-Lobe," it cannot be distinguished from the overlying Dockum mudstone unit; consequently, thickest values represent an undivided "B-Lobe" and lowest Dockum mudstone unit.

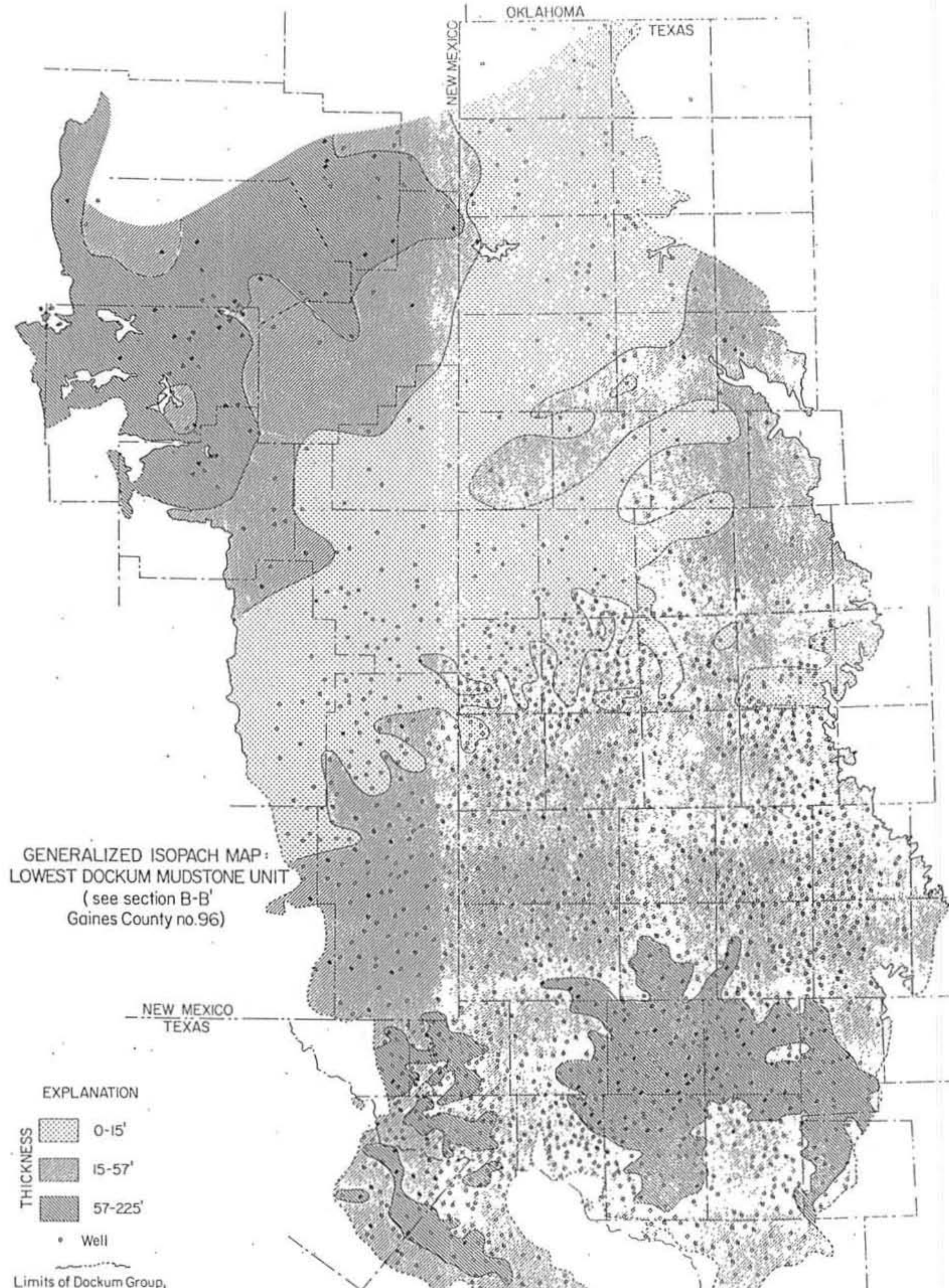

OKLAHOMA
TEXAS
NEW MEXICO
GENERALIZED ISOPACH MAP:
LOWEST DOCKUM MUDSTONE UNIT
(see section B-B'
Gaines County no.96)
NEW MEXICO
TEXAS
EXPLANATION
THICKNESS
0-15'
15-57'
57-225'
Well
Limits of Dockum Group, dashed where based on subsurface data
0
50 MI
0
80 KM

Figure 13.

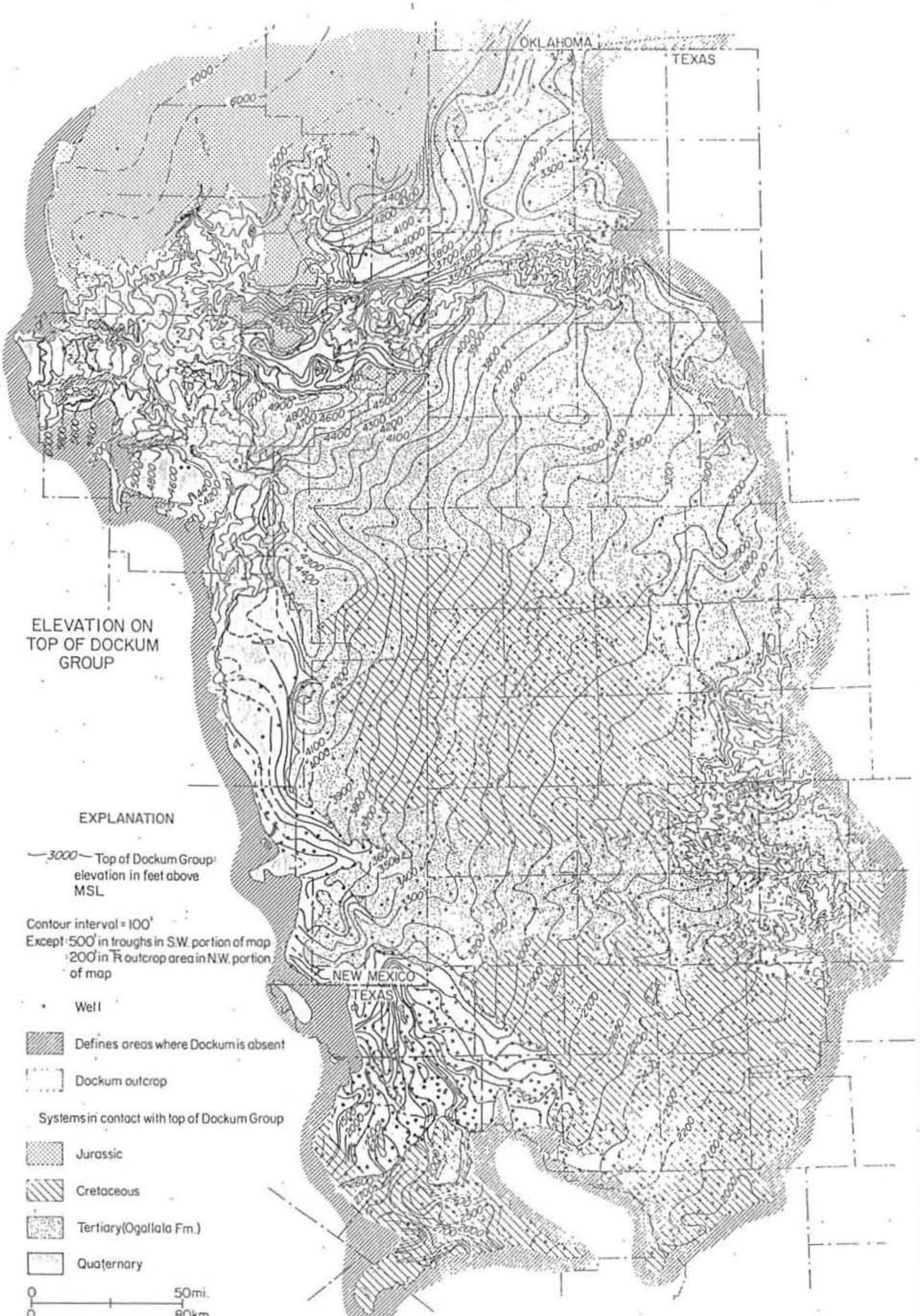


Figure 14. Elevation on top of Dockum Group in feet above mean sea level. Age and distribution of rocks directly overlying Dockum rocks. Though modified by many periods of erosion, the upper surface of the Dockum Group shows effect of eastward structural tilt produced by Early Tertiary uplift of the Rocky Mountains.

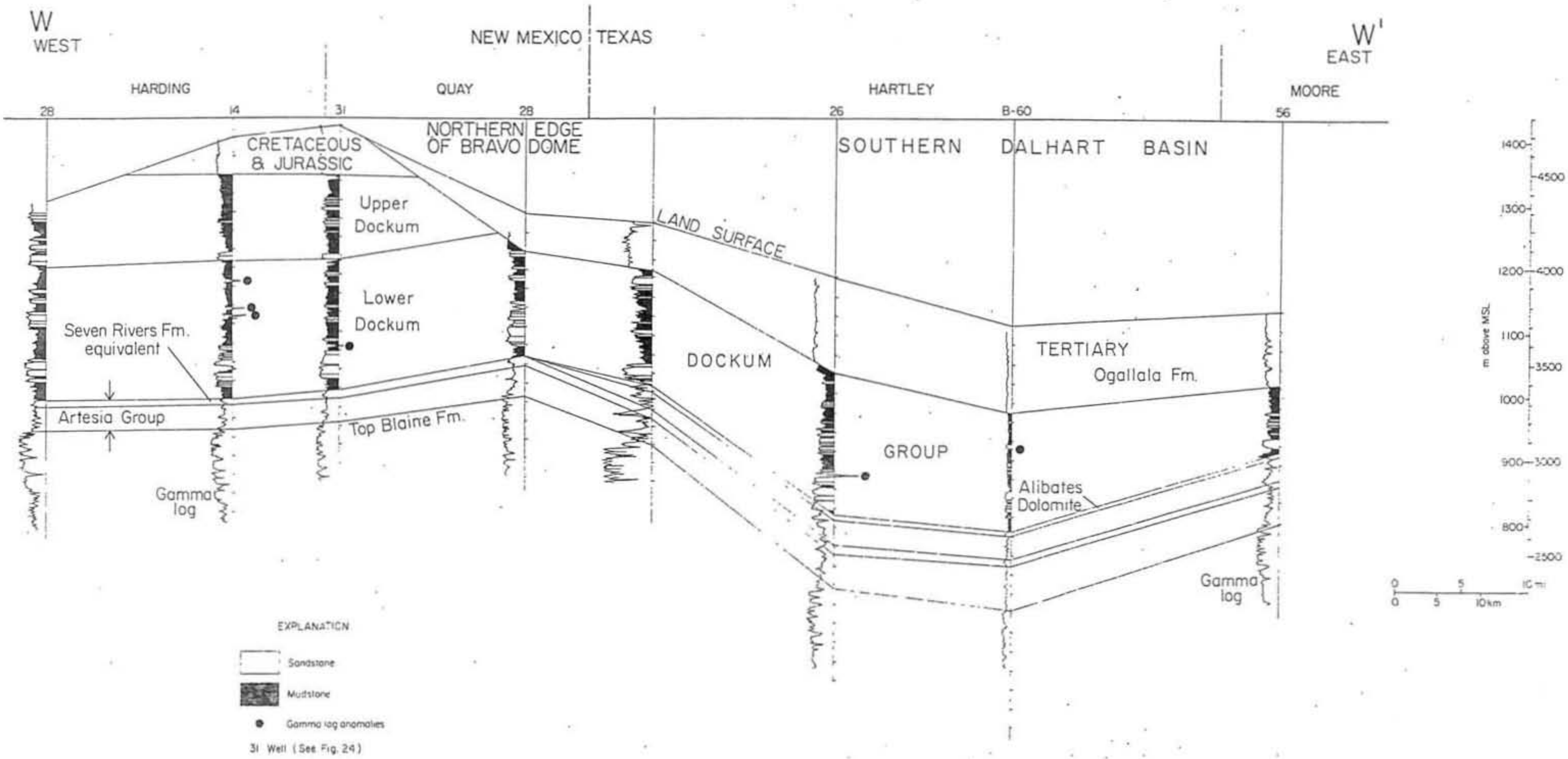


Figure 15. Cross section W-W' (E-W) north of Amarillo Uplift - Bravo Dome trend.

distribution of Cretaceous rocks suggests that the entire area presently underlain by Dockum rocks was covered by the Cretaceous. Both Cretaceous and Dockum rocks were subjected to erosion prior to deposition of the Tertiary Ogallala Formation. Cretaceous strata were removed from most of the Dalhart Basin-Amarillo Uplift trend-Palo Duro Basin area and from a strip trending east-west across the southern Midland Basin. This strip appears to have been the stream valley for an eastward-flowing Early Tertiary (pre-Ogallala) stream. Most of the area underlain by Dockum rocks was covered by the Pliocene Ogallala Formation, largely wet alluvial fan deposits shed from the rising Rocky Mountains to the west. Subsequent to Ogallala deposition, erosion of Dockum rocks has been active along the eastern escarpment of the High Plains, along the Canadian and Pecos River valleys, in the structurally elevated northwestern part of the study area, and over the Central Basin Platform. The upper surface of the body of Dockum rocks, though apparently largely erosional, is dominated by a structural tilt to the southeast of 10 to 15 feet per mile (.5 to .75 m/km).

Deposition of the Dockum Group

Maximum preserved thickness of Dockum rocks, 2,000 feet (600 m), occurs slightly west of the center of the Midland Basin (fig. 16). In order to map more accurately sand facies within the Dockum it was necessary to subdivide the Dockum into thinner intervals. Dockum rocks are characterized by a complexity of localized genetic units whose sand facies show very little lateral continuity. Continuous or correlatable individual beds are nonexistent on the scale used in this study. In order to find correlatable cycles of lithology useful for subdividing the section, it was necessary to look at "average vertical sections" derived from several closely spaced

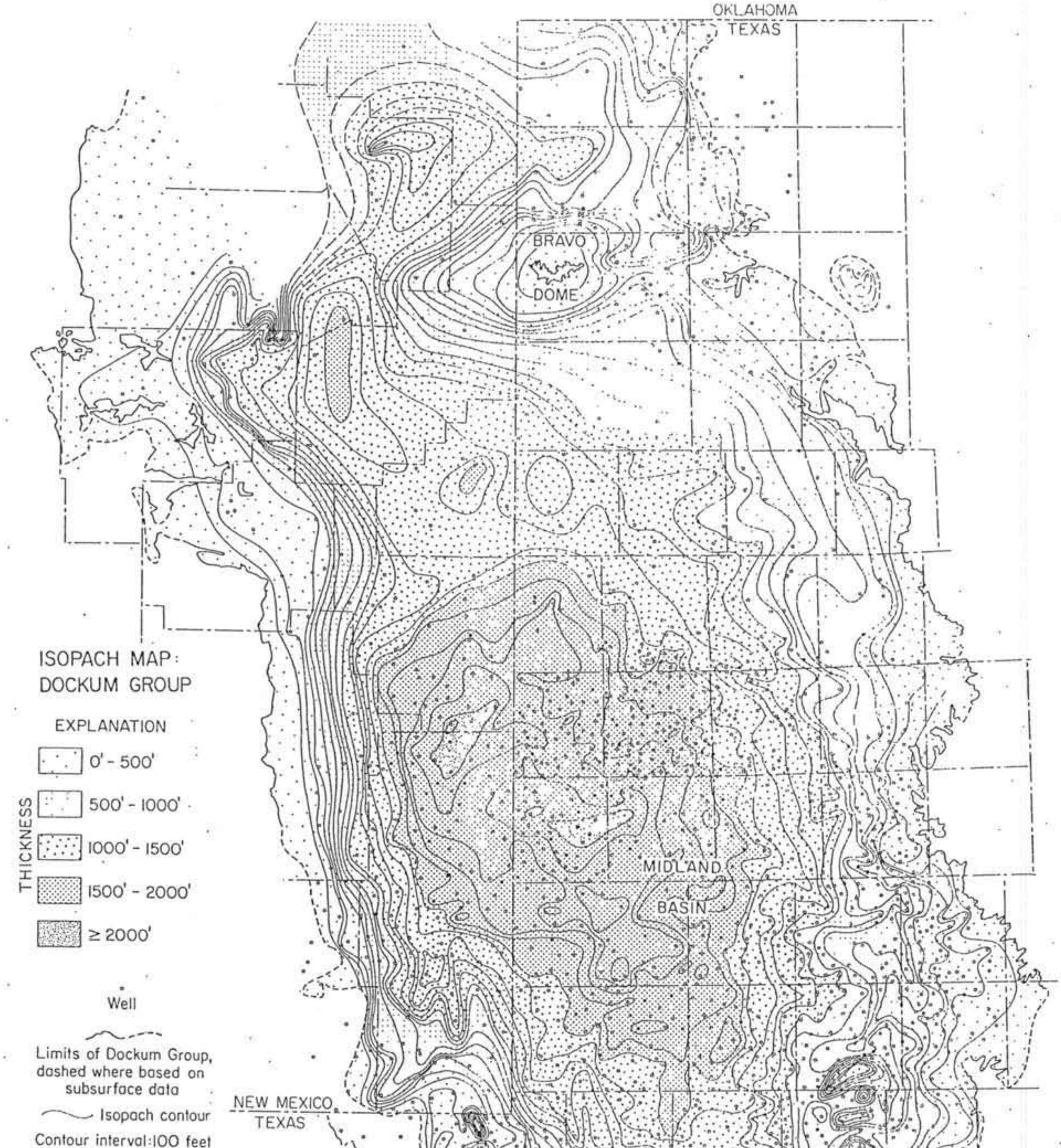


Figure 16. Isopach map, Dockum Group. Thickness variations result about equally from differential rates of subsidence during deposition and from post-depositional erosion of upper Dockum sediments. Isolated thick areas in the Delaware Basin and in Mitchell and Howard counties caused by post-depositional subsidence into salt solution troughs.

wells. Average vertical sections from different parts of the basin were then correlated. Two low frequency cycles of lithology were found to exist throughout the study area upon which higher frequency lithic changes are superimposed. The lower cycle is characterized as having a sandy lower segment which gives way to an increasingly muddy upper part. The upper cycle consists of a similar overall fining upward sequence in outcrops in the northwestern part of the study area. However, a fining-upward character is not typical of this cycle farther south in the northwestern Midland Basin. Here, sand from an eastern source was deposited throughout the preserved part of the upper Dockum cycle. Since the two Dockum lithic cycles are recognizable throughout the basin despite differing source areas, they are inferred to be due to climatic and/or tectonic variations.

Deposition of the Lower Cycle

The preserved extent of the lower Dockum cycle coincides with the maximum preserved extent of Dockum sediments. It obtains a maximum thickness of about 1400 feet (420 m) south of the center of the Midland Basin. Two hundred miles (320 km) north in Quay County, New Mexico, the equivalent section is 600 feet (180 m) thick.

The lowest part of the Dockum section is a mudstone (fig. 10, section BB', well #96 Gaines County) which varies from a few feet to about 200 feet (60 m) thick (fig. 7). This interval is made up of lacustrine and prodelta muds composing the basinward mudstone facies of both the initial lacustrine transgression and the subsequent delta progradations.

The lowest Dockum sandstone (fig. 10, section BB', well #486 Gaines County) represents the updip sandy facies of the initial progradational sequence. It was derived from many different source rocks surrounding the basin. This sand has been mapped in New Mexico as the Santa Rosa Formation and has been informally called the Santa Rosa Sandstone throughout the entire Midland Basin. Gorman and Robeck (1946) subdivided the Santa Rosa Formation in north-central Guadalupe County, New Mexico, into four informal members, a lower sandstone, a middle sandstone, a shale member, and an upper sandstone. Subsurface cross section XX' (fig. 17) is extended to the surface (fig. 18) north of Santa Rosa, New Mexico in an area where the upper three members crop out. The upper two sandstone members are not individually mappable units in the subsurface. The lowest member, as mentioned previously, appears as a mudstone on gamma-ray logs and is mapped in figure 13.

An indication of the regional distribution of depositional systems is given by a map of the vertical sequence of lithologies at the base of the lowest Dockum sandstone (fig. 19). A clearcut progradational (coarsening upward) sequence is preserved only toward the center of the Midland Basin, suggesting that the Early Dockum lacustrine environment was confined to the Midland Basin. The original extent of the lowest Dockum progradational sequence was modified by subsequent scouring through the progradational sequence by fluvial systems.

Sand percentage maps suggest cumulative geometry of mineralogically clean quartz sand bodies for the interval mapped. Geometry of a high-percentage sand area is determined by: (1) the distribution of sandstone within a depositional systems, (2) the interrelation of sandstone bodies with sandstone bodies of adjacent systems, and (3) the amount of vertical stacking of a single system or overlapping of adjacent systems through time. Subdivision of the Dockum Group into upper and lower parts for sandstone mapping was intended to reduce number 3 above as much as possible. However, within the lower part of the Dockum Group, sandstones near the base consist of vertical stacking of 1 to 4 progradational cycles. This type of stacking preserves paleoslope-

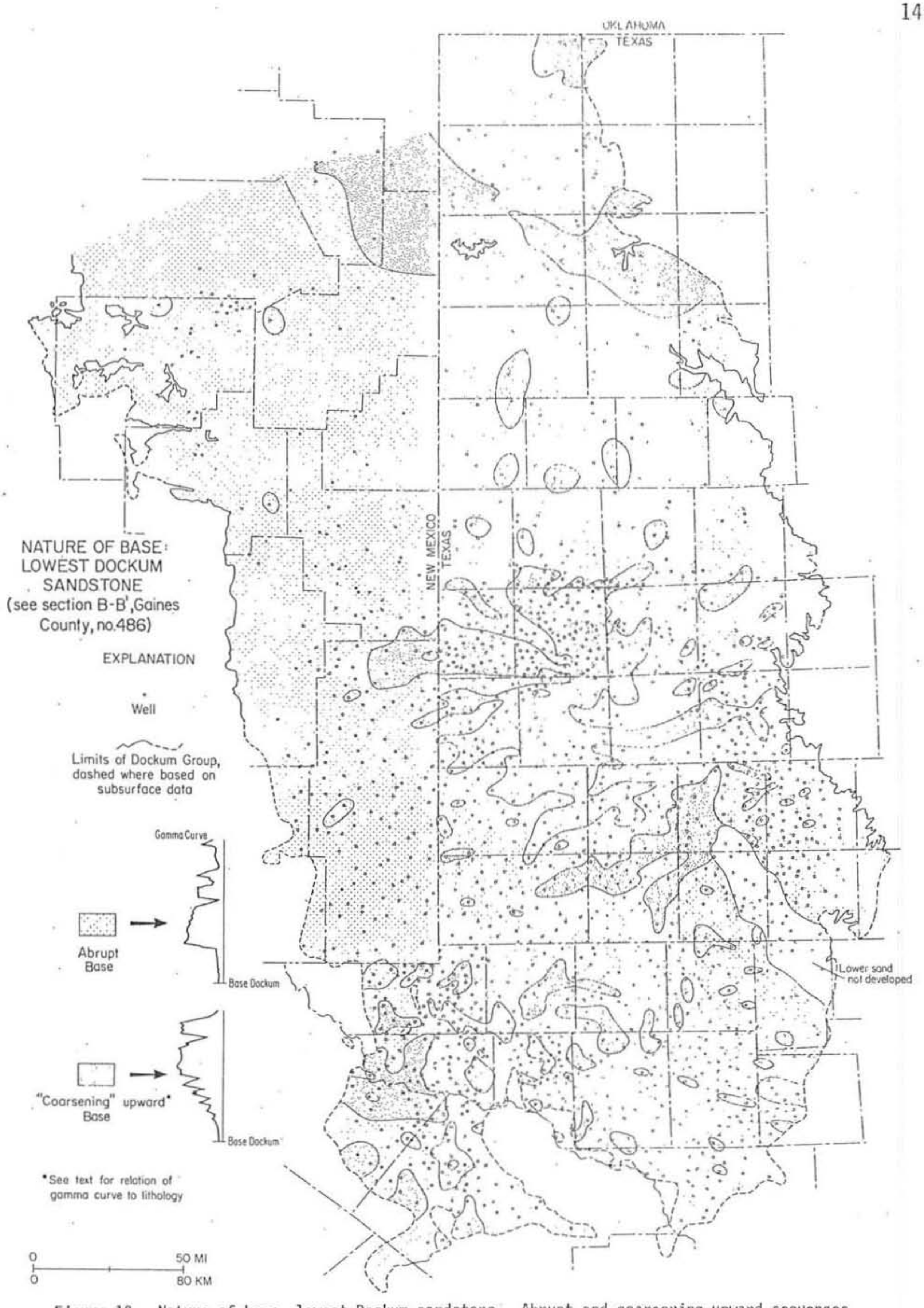


Figure 19. Nature of base, lowest Dockum sandstone. Abrupt and coarsening-upward sequences are mapped throughout the basin. Definition of abrupt vs. coarsening-upward is not applicable south of Andrews, Martin and Howard counties where alluvial-fan or fan-delta deposits typically exhibit an abrupt base, followed by a coarsening-upward sandstone sequence.

indicative patterns but obliterates detailed sand patterns of single systems. Overlapping through time of adjacent systems occurs toward the basin center and where adjacent basin margins meet at higher angles, as in Cochran County, Texas. This overlapping tends to obscure even primary paleoslope trends.

The Midland Basin is rimmed on its western, northern, and eastern sides by dip-oriented sand-percentage highs which bifurcate basinward (fig. 20). In the subsurface adjacent to outcrops in the eastern Midland Basin, a westerly direction of transport indicated by subsurface sandstone trends corroborates with directional data interpreted from outcrop. In the Garza County area where outcrops have been extensively studied, it is empirically known that subsurface sandstone percentage patterns indicate fluvial and lobate-delta sedimentation, though it is doubtful whether individual distributary patterns would appear on a map of this scale. Vertical textural (lithology) trends on individual logs (fig. 21, cross section CC') and when mapped (fig. 19) indicate an increased proportion of deltaic over fluvial deposits downdip from outcrop exposures. One distinct delta is visible on cross section CC' (fig. 21) as a laterally continuous coarsening-upward sequence capped by mudstone and bound laterally by mudstones.

The inference, by analogy, that similar depositional systems rimmed the northern and western Midland Basin is consistent with other aspects of our understanding of Dockum sedimentation. Vertical textural trends on individual logs (figs. 22 and 23, cross sections AA' and YY') also suggest similar fluvial-deltaic sedimentation along the northern and western margins of the Midland Basin.

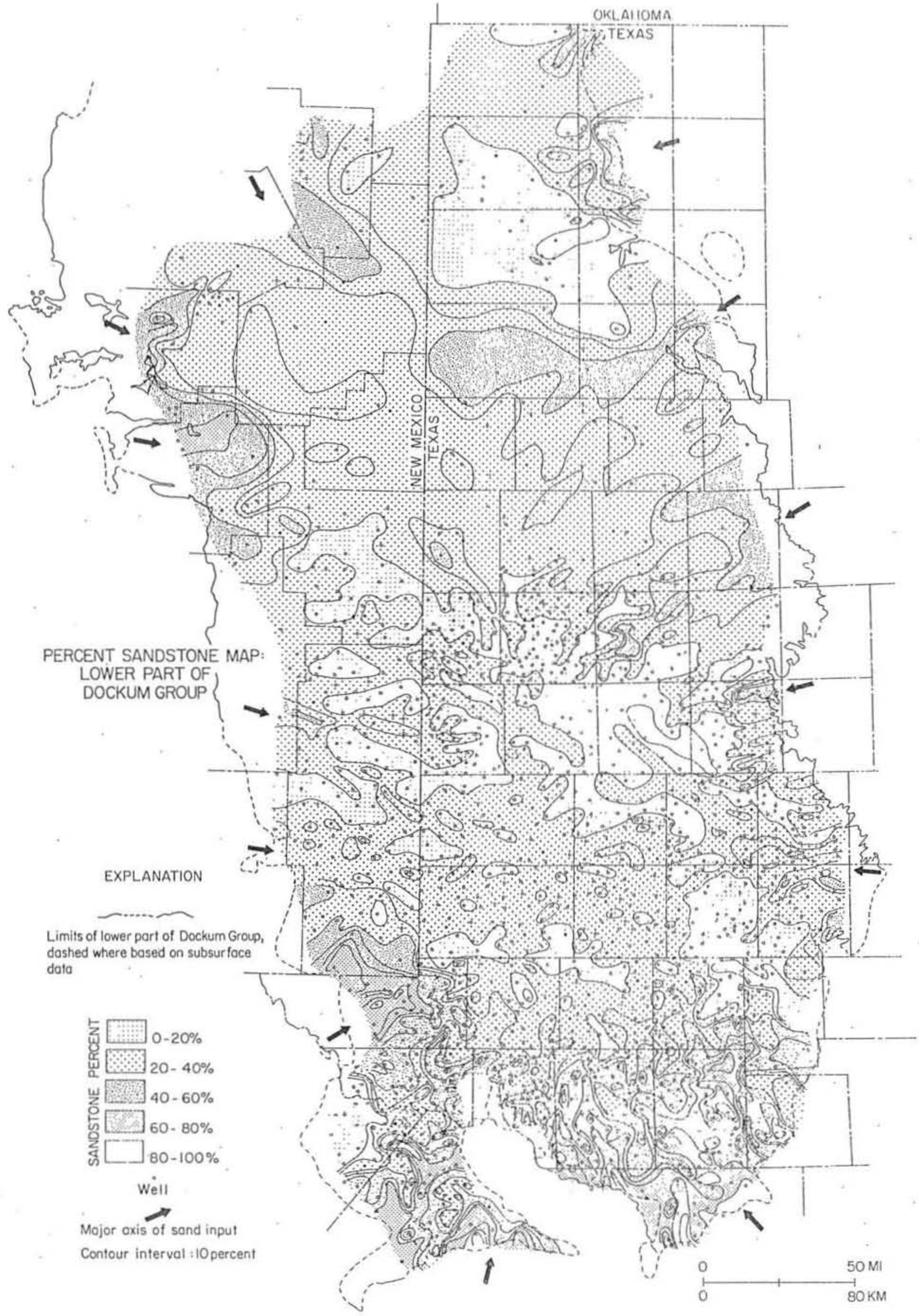


Figure 20. Percent sandstone map, lower part of the Dockum Group. Sandstone distribution patterns (high sand-percentage trends) are considered first order paleoslope (paleocurrent) indicators. Percent sand trends indicate multiple source areas with peripheral filling of the basin by prograding deltas and fan-deltas.

The broader percent-sandstone patterns developed north of the Matador Arch are probably due to: (1) the higher proportion of fluvial sedimentation north of the arch, and (2) the decrease in density of well control north of the arch. Outcrops in Palo Duro Canyon, Texas and in the Santa Rosa area, New Mexico indicate that the Dockum Group consists of fluvial sands overlain respectively by lobate-deltaic sandstones and fan-delta sandstones.

In the Delaware Basin and southernmost Midland Basin, broadly coalesced, high percent-sandstone patterns define the extent of fan and fan-delta systems shed from source rocks to the south. Greater than 90 percent sandstone and up to 600 feet (180 m) gross sandstone thickness is indicated on gamma-ray logs in parts of this system. Gamma curves typically show a scoured (abrupt) base and a general coarsening upward trend through the lower part and a generally fining upward trend through the upper part of this sandstone sequence. This fan/fan delta system is separated from delta systems to the north by an unnamed structural arch (fig. 5). The Dockum section overlying the arch is characterized by a low sand percentage (figs. 20 and 24).

Deposition within the Upper Cycle

Considerably less is preserved of the upper Dockum cycle than of the lower Dockum. Figure 25 shows the preserved thickness of this unit. Maximum thickness of about 1,200 feet (360 m) occurs west of the center of the Midland Basin. In New Mexico, the base of the upper Dockum cycle corresponds to the base of sandstones mapped in outcrop as the Cuervo or Middle Sandstone Member of the Chinle Formation (Kelley, 1972a). In Texas, along the Canadian River valley, the base of the upper cycle approximately coincides with the base of the Trujillo Formation as mapped in Texas.

Sediment (rocks) of the upper cycle had a western source along the western side of the Midland Basin (fig. 26). Minor sediment sources to the

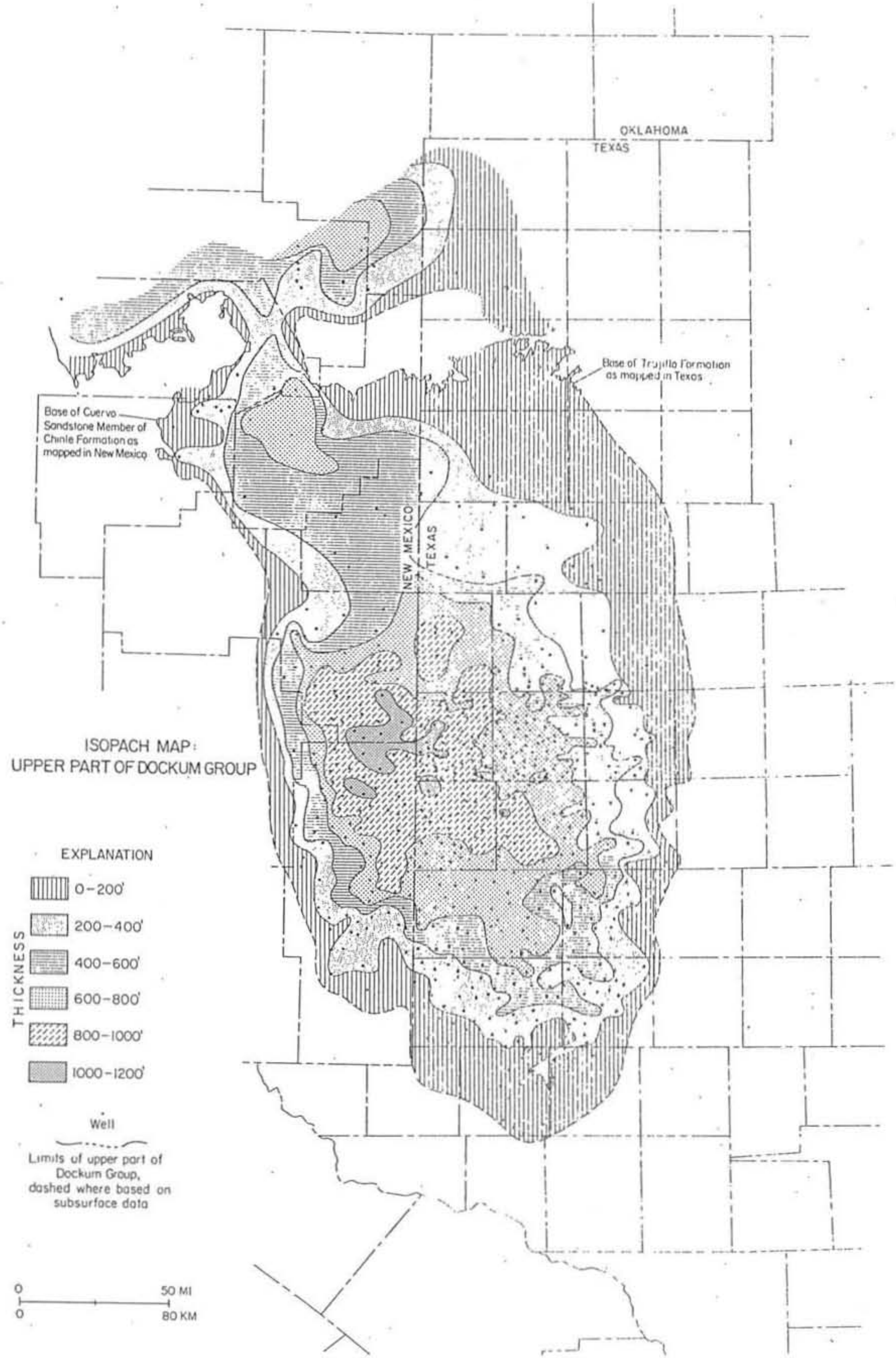


Figure 25. Isopach map, upper part of Dockum Group. Precise correlation of the base of this map unit and base of Trujillo Formation in northeastern part of this map is questionable.

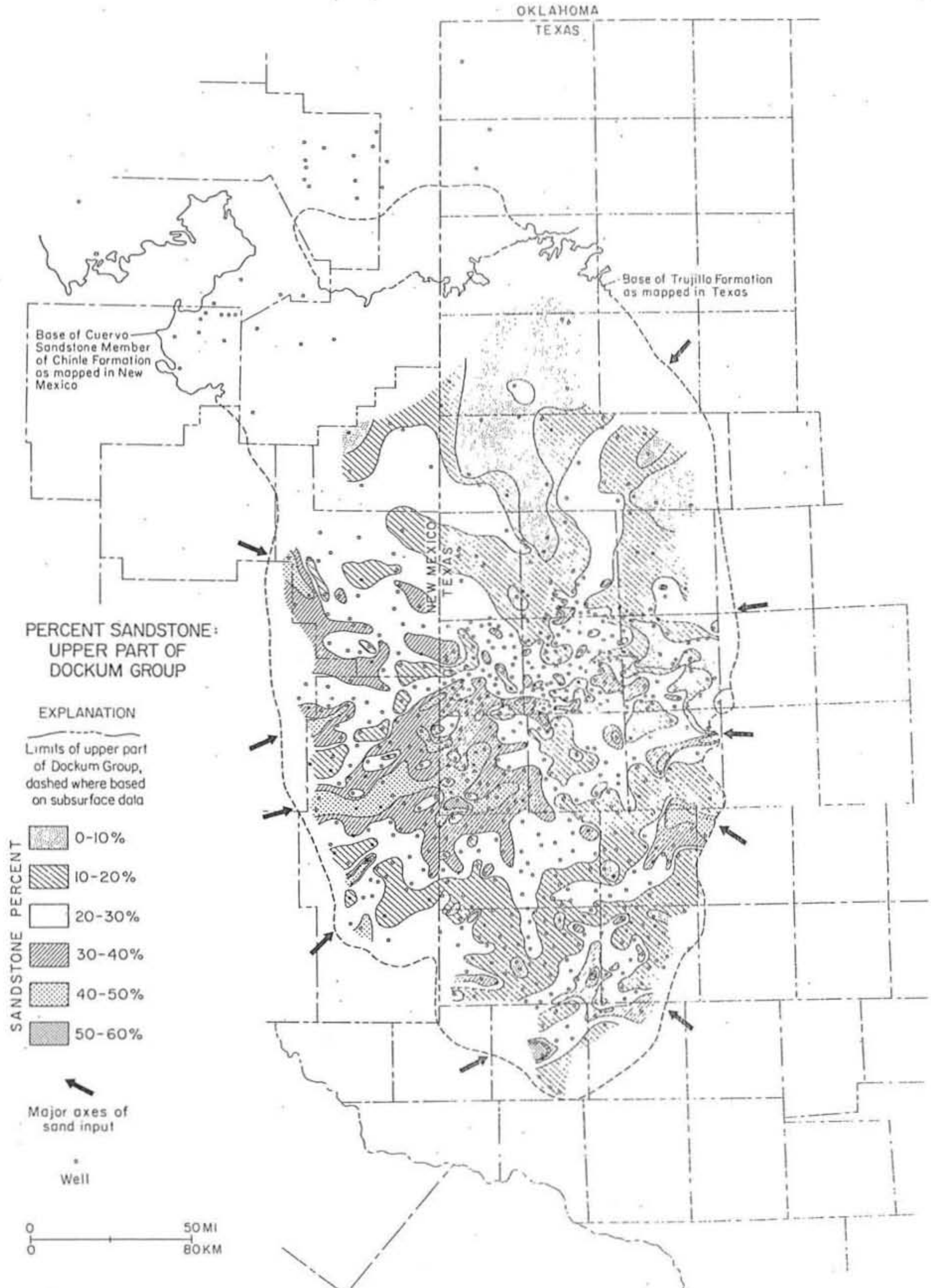


Figure 26. Percent sandstone map, upper part of Dockum Group. Sandstone distribution patterns (high sand-percentage trends) indicate paleoslope. Fluvial-deltaic depositional systems carried sediment eastward from central Lea County, New Mexico, while smaller systems carried sediment basinward from other margins of Dockum basin.

east contributed sediment to the eastern part of the basin. Rocks of the upper cycle do not crop out in the southern part of the basin. In San Miguel County, New Mexico, outcrops of sandstones at the base of the upper cycle show a progradational sequence of thin overlapping delta lobes overlain by fluvial sandstones. Individual delta lobes are typically 15 to 30 feet (5-10 m) thick and contain at their base considerable quantities of rip-up clasts of lacustrine limestone nodules and mudstone. These observations indicate that these deltas prograded into a shallow body of water.

GEOLOGY OF SELECTED OUTCROP AREAS

Most of the concepts relative to depositional framework of the Dockum, tectonic and climatic imprint on sedimentation, and fluctuation of base level during accumulation of the Dockum Group were developed from outcrop observations. Interpretation of the subsurface data was influenced by interpretations of outcrop geology, and subsurface work completed subsequent to the outcrop work tends to strengthen depositional facies interpretations of the Dockum in outcrop.

Reconnaissance and detailed outcrop work was conducted throughout Texas and in northeastern New Mexico (McGowen, Granata, and Seni, in press). Outcrop data from northeastern New Mexico, Canadian River valley (Texas), Palo Duro Canyon, Tule Canyon, and Dickens-Mitchell County area are summarized in this paper, which emphasizes the regional subsurface distribution of the Dockum.

Northeast New Mexico Area

Dockum rocks are exposed in a wide outcrop belt along the Pecos and Canadian Rivers in DeBaca, Guadalupe, San Miguel, and Quay Counties, New

Mexico. The exposed section includes perhaps the oldest and the youngest preserved Dockum rocks.

The sandstone at the base of the Dockum is well developed in this area and is mapped as the Santa Rosa Sandstone. The Santa Rosa has been subdivided in outcrop (Gorman and Robeck, 1946; Finch and Wright, 1975) into a lower sandstone member, a middle sandstone member, a shale member, and an upper sandstone member (fig. 27).

The lower sandstone is characterized by a few feet to 100 feet (30 m) of intrabasinal conglomerate and medium-grained sandstone at the base, fining upward to fine sandstone. Typical exposures include one to three incomplete sequences at the base and local rejuvenations of the sequence in the upper part.

An idealized vertical section consists of: (1) massive sand and conglomerate channel fill, (2) 2 to 4 feet of crossbedded sandstone resulting from lateral migration of broad shallow channels, and (3) thin bedded (1.0 feet, or 0.3 m) medium sandstone, becoming very thin bedded (1.0 inch, or 2.0 cm) upward. The lower sandstone is interpreted as a low-gradient alluvial fan or fan delta deposit. Subsurface mapping and correlation indicate that the lower sandstone may predate most of the lower Dockum rocks.

The middle sandstone member, 60 to 130 feet (18-40 m) thick, is interpreted to be a coarse-grained meanderbelt system. The lower part typically consists of 1 to 3 incomplete vertical sequences of abandoned channel fill and lateral channel fill (point bar) deposits recording multiple channel migrations. A complete vertical sequence of about 40 feet (12 m) from scour pool through upper point bar facies is preserved at the top of the middle member. The sequence consists of: (1) about 5 feet (1.5 m) of conglomeratic medium-grained sandstone, (2) from 4 to 6 feet (1.2 to 1.8 m) of parallel laminated

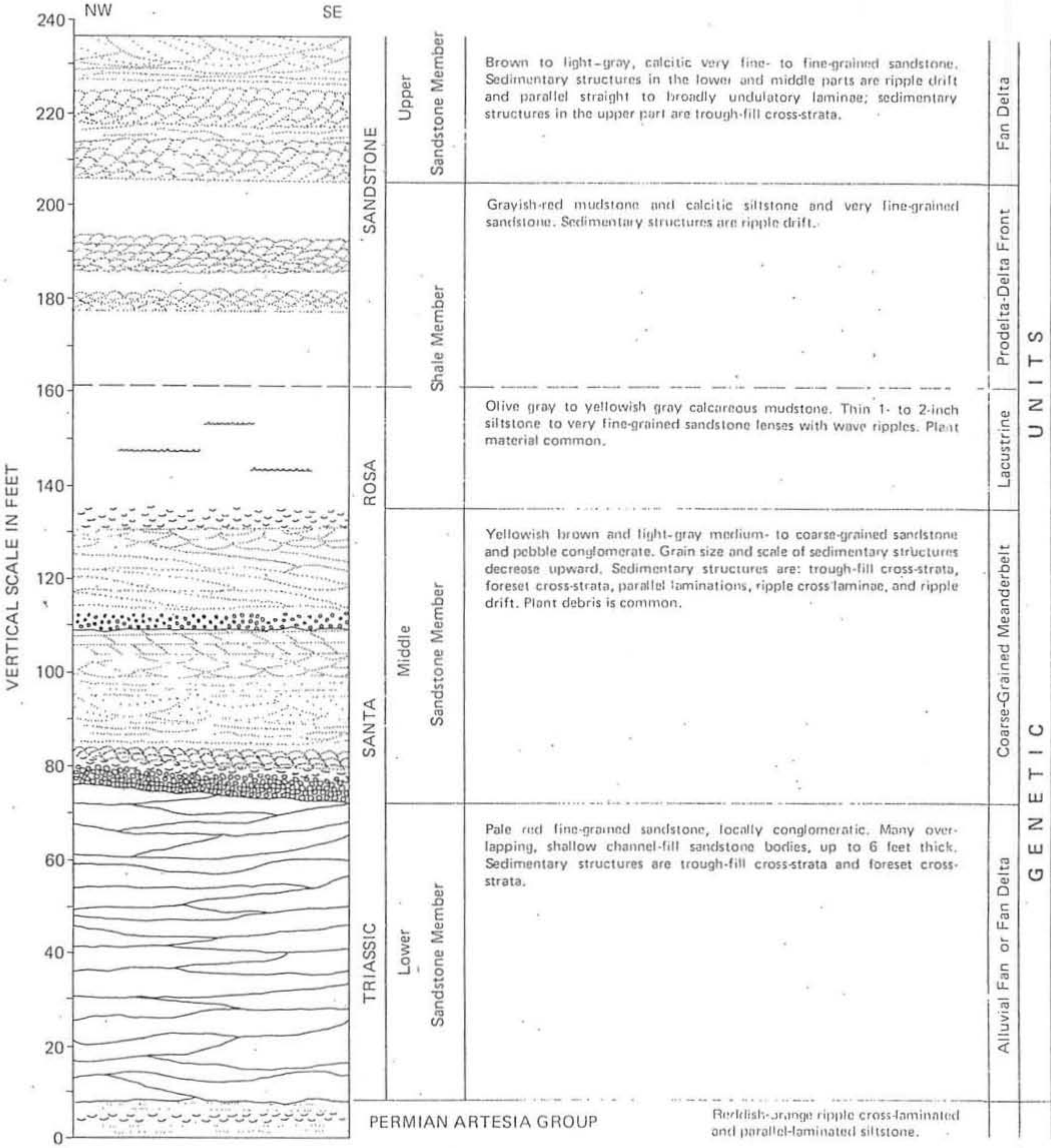


Figure 27. Generalized section of Santa Rosa Sandstone (principal reference section of Finch and Wright, 1975) Guadalupe County, New Mexico. Informal stratigraphic units after Finch and Wright.

medium-grained sandstone containing some large scale trough-fill cross-strata, (3) approximately 20 feet (6 m) of moderately well-sorted medium-grained sandstone consisting of small trough-fill cross-strata, and (4) about 5 feet (1.5 m) of ripple cross-laminated fine- to medium-grained sandstone in one-inch to one-foot beds.

Lacustrine mudstone overlies the middle sandstone member. Burrows, plant material, and carbonate nodules are locally common in the mudstone. Where overlain by an upper sandstone member, the mudstone ranges from a few feet to 50 feet (15 m) thick. Lacustrine mudstone grades upward into progradational deltaic deposits.

The upper sandstone is interpreted as a progradational/transgressive fan-delta sequence. The underlying lacustrine mudstone grades upward into alternating mudstone and thin (1 inch, or 2 cm) sandstone beds. Mudstone is characterized by soft-sediment slumps. Sedimentation units within delta foresets increase in thickness upward (up to 6 inches, or 15 cm). Broad (200 feet, or 60 m) scour channels truncate the upper parts of foresets. Some scour channel fill and foresets lateral to distributary channels consist of alternating thin beds (1 foot, or .3 m) of ripple cross laminated medium sandstone and thin (6 inches, or 15 cm) mudstone beds. Channel fill also includes some lateral accretionary beds (alternate bars) and some 3 to 5 feet (1 to 1.5 m) foreset crossbeds. Up to 80 feet (24 m) of 4-inch to 1-foot (10 cm to 0.3 m) beds of ripple cross-laminated sandstone represent a vertically-stacked and somewhat transgressive sequence of distal fan-delta facies. Small (50 feet, or 15 m wide) mud-filled abandoned channels occur in the upper part of of the sandstone sequence. At the top of the sequence, sandstones grade by interbedding into lacustrine mudstones.

The upper three members of the Santa Rosa are interpreted to represent deposition within a single fluvial-deltaic-lacustrine system. Outcrop and subsurface data indicate that the coarse-grained meanderbelt system was the most widespread. During the initial progradational episode of the Dockum, fluvial systems covered the entire San Miguel-Quay-Guadalupe and northern DeBaca County outcrop area. The number of fluvial systems operative at this time is not known. Subsurface data indicate that the fluvial environment extended (figs. 13 and 19) to the Matador Arch, which is a step marking the northwest margin of the Midland Basin. Midland and Tucumcari Basins probably were the first sites of Dockum deltation. Expansion of the lacustrine environment shifted deltation northwest into the outcrop area. Fluvial-deltaic progradations are localized, and sandstone deposits exhibit limited lateral continuity above lacustrine transgression in the Dockum section. Lake level fluctuations and changes in volume of sediment transported by streams probably caused shifting in sites of fluvial-deltaic sedimentation. The 500 feet (152 m) of lacustrine mudstone that lies above Santa Rosa sandstones are mapped as the lower part of the Chinle Formation in New Mexico.

Cuervo Sandstone Member (Kelley, 1972b) of the Chinle Formation records an episode of fluvial-deltaic progradation into a shallow lake. The Cuervo progradational sequence is 300 to 350 feet (91 to 107 m) thick. The lower part comprises overlapping small (10 to 30 feet, or 3 to 9 m thick and a few hundred feet wide) delta lobes interspersed with 30 to 60 foot (9 to 18 m) intervals of lacustrine mudstone. Two to five delta lobes are stacked in a typical vertical section. The ratio of quartz sand grains to intrabasinal clasts increases from lower to upper delta units.

Delta foresets consist of conglomeratic sandstone containing intrabasinal lacustrine mudstone and limestone-nodule clasts. Channel fill, made up of intrabasinal or quartz sandstone, truncates the tops of foreset beds. From base to top, stratification of channel-fill deposits consists of massive, trough cross-bedded, and horizontal beds. Foreset cross-bedded units near the top of delta sequences may represent splay deposits. The uppermost sandstones of a delta sequence are typically thick, horizontally bedded or ripple cross-laminated. The uppermost beds of a delta sequence are burrowed and contain rare crustacean tracks. These biological structures record slow deposition following delta abandonment and foundering.

The upper 30 to 50 feet (9 to 15 m) of the Cuervo Sandstone Member is fluvial sandstone that scoured through most of the underlying progradational sequence. Textural properties and sequence of primary sedimentary structures of the upper Cuervo Sandstone Member are analogous to those of the middle sandstone member of the Santa Rosa Formation and are indicative of a coarse-grained meanderbelt system.

About 300 feet (91 m) of Chinle Formation overlies the Cuervo Sandstone Member. This part of the Chinle is mostly lacustrine mudstone, but locally there are 10 to 30 foot (3 to 9 m) thick sequence of deltaic sediment. The upper surface of the Chinle is variagated purple, red, and light green, suggesting a weathered surface.

The Redonda Formation crops out within the Tucumcari Basin. Its southeastern subsurface extent is unknown. Redonda is interpreted as a shoreface-lacustrine facies tract. Fluctuations in lake level resulted in interbedding of those facies. The overall vertical sequence represents an initial expansion of the lake across Chinle deposits followed by a progradation of shoreface deposits through the lower half of the Redonda followed by gradual lake expansion and lacustrine sedimentation through the upper part of the Redonda. Bedding and lithology of the Redonda are laterally continuous. From offshore (lacustrine) through shoreface the rock types are: (1) extensively burrowed clayey siltstone, (2) burrowed sandy siltstone with some horizontal bedding and wave ripples, (3) slightly bioturbated horizontally bedded silty fine sandstone, and (4) horizontally bedded well-sorted fine sandstone with fore-set cross-beds up to 1 foot (.3 m) thick. Some of the well-sorted fine-grained sandstones contain beds of curled (desiccation) mud chips. Primary gypsum crystals occur as blades and rosettes within some of the sandstone beds. Redonda sediments probably accumulated under relatively stable lake-level conditions when climate was arid and sedimentation rates were slow.

Canadian River Valley

Within the Canadian River Valley (in Texas) a lower mudstone sequence was not investigated. A section west of Tascosa (south of the Canadian River) was investigated. Here, sandstone sequences consist of overlapping, broad sand-stone bodies from 10 to 30 feet thick (fig. 28). Some sandstone bodies are convex upward and have low-angle foresets along lateral margins that are characterized by interbedded sandstone, siltstone, and mudstone. 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 sandstone sequences. Channel-fill is fine-grained sandstone consisting chiefly of trough-fill cross-strata with some ripple cross laminae and mud drapes.

Reddish-brown mudstone and siltstone that underlie and interfinger with sandstone beds record multiple depositional events. Most of these sedi-mentary sequences begin with coarse-grained siltstone or fine-grained sand-stone characterized by parallel laminae, or massive mudstone. Soft sediment deformation is common to this facies.

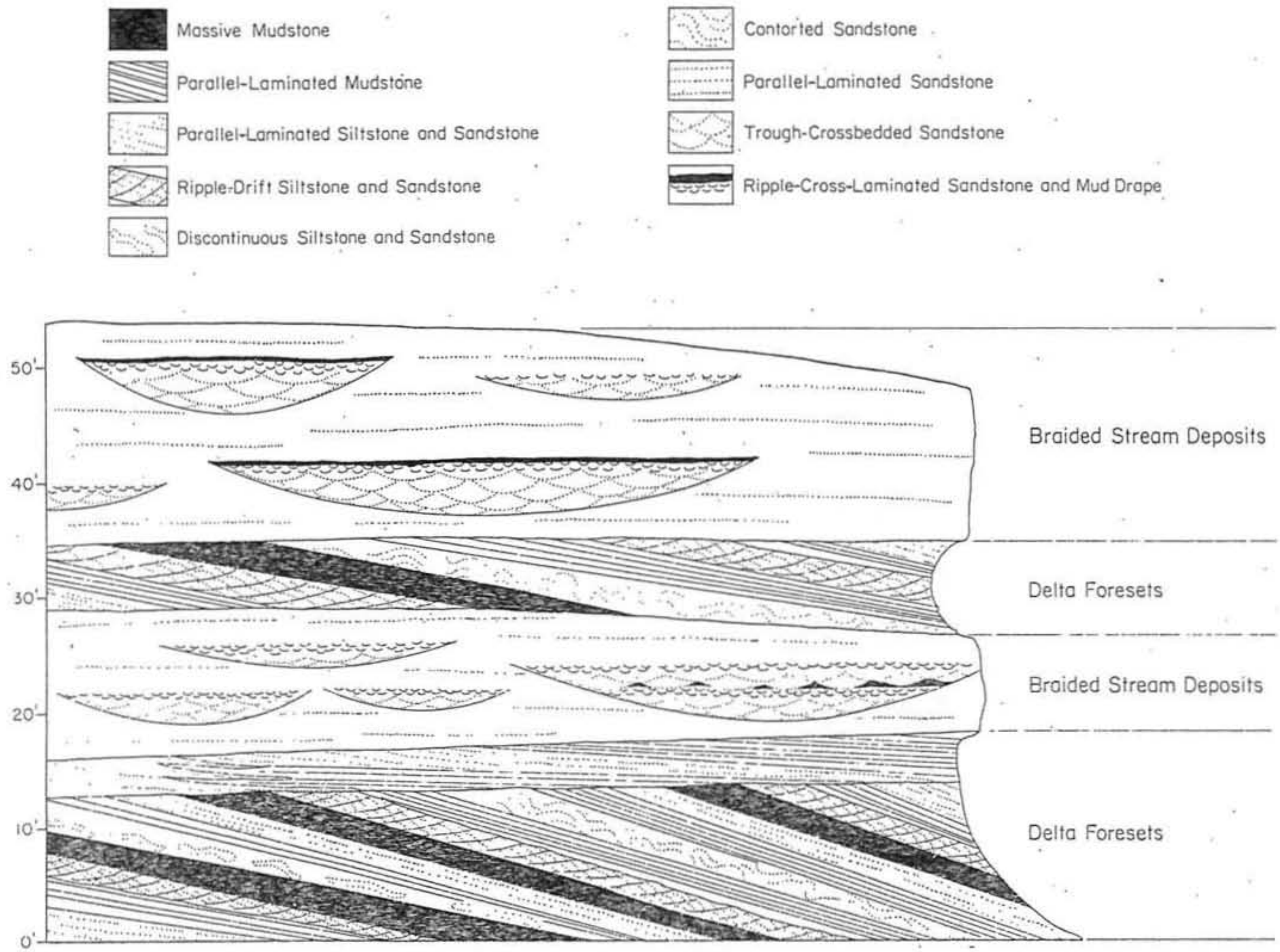


Figure 28. Schematic of fan delta deposits in Oldham County, Texas (Boys Ranch West 7.5-minute quadrangle), along right bank of Canadian River, west of U.S. Route 385, and south of Fort Worth and Denver Railroad. Shown here are: (1) delta foresets consisting of (a) massive and parallel laminated mudstone, (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 cross bedded 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).

Straight channels up to 40 feet deep were scoured through sandstone bodies into underlying siltstone and mudstone. Channel-fill is symmetrical and asymmetrical indicating that currents at times flowed both parallel and oblique to channel axes. Grain size of channel-fill deposits ranges from intrabasinal conglomerate (clasts were derived from older Dockum deposits) to mudstone.

Stratification of channel-fill consists of 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 to channel banks where foresets dip toward channel axes. Most trough-fill cross-strata occurs in conglomerate and sandstone that occupy basal parts of the channel fill. The most abundant stratification types within lower channel-fill are parallel laminated and ripple cross laminated siltstone and very fine-grained sandstone that conform to the channel perimeter. As a general rule, coarser sediment occupies channel banks, and finer sediment was deposited near channel axes.

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

A detailed outcrop study was made of the western part of Palo Duro Canyon during parts of the summers of 1976-77 (fig. 29). This area and the Canadian River Valley area (Texas and New Mexico) serve as tie points (outcrop and subsurface) for the Texas and New Mexico Dockum sections.

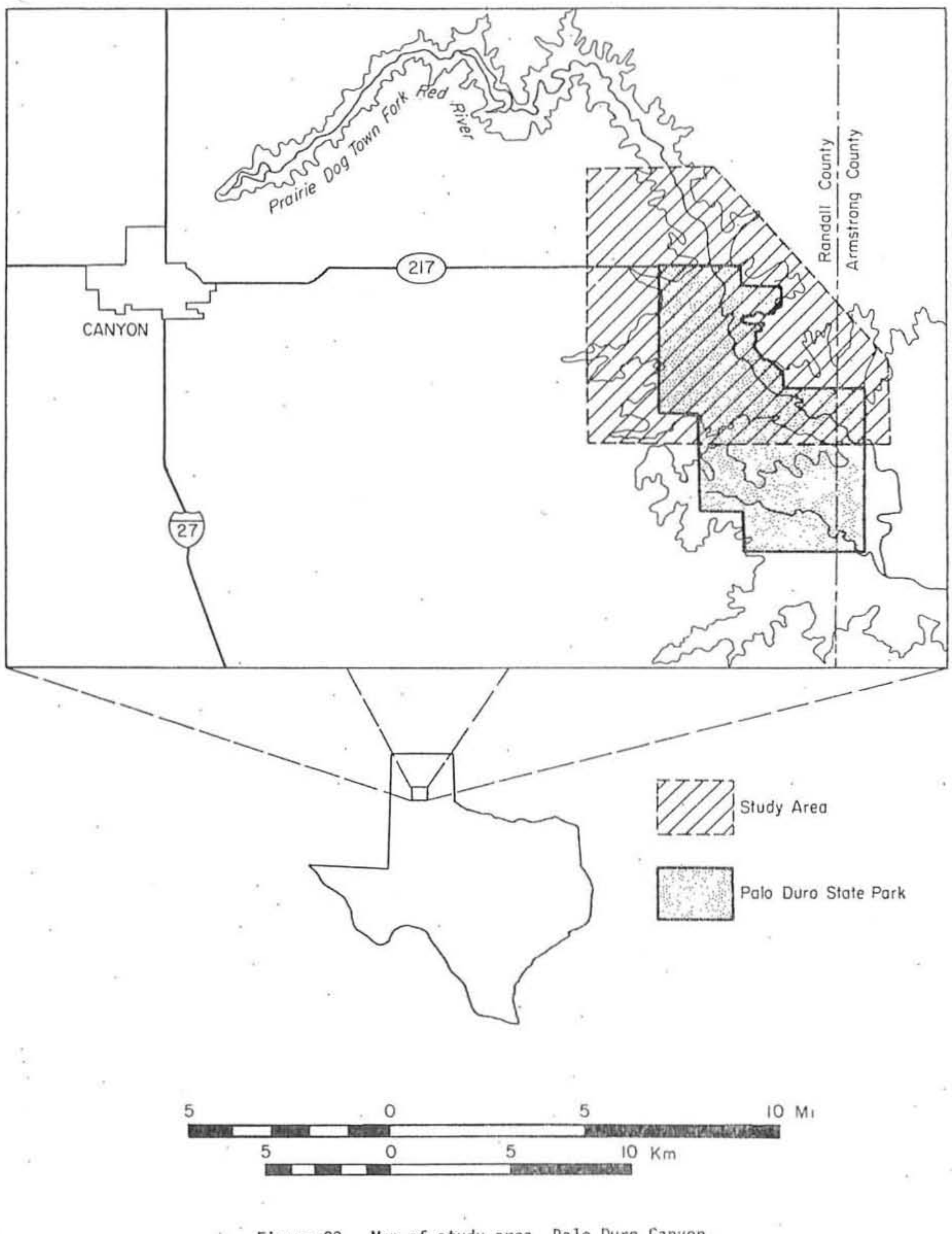


Figure 29. Map of study area, Palo Duro Canyon.

From 300-400 feet (90 to 120 m) of Dockum are exposed in Palo Duro Canyon. Within this area the Dockum records a complex depositional and erosional history. Fluvial, deltaic, and lacustrine systems were dominant when the Dockum was laid down. Fluctuations between humid and arid climatic conditions, oscillations in lake area and depth, soil and evaporite development, and scouring of narrow and relatively deep canyons all transpired during the time the Dockum Group was accumulating.

Fluvial, deltaic, and lacustrine depositional systems comprise three main progradational sequences in Triassic rocks exposed in Palo Duro Canyon. Interpretations of depositional environments are based on data from: (1) thirty-three measured sections, and (2) forty-seven photo mosaics (fig. 30) which were used to determine vertical and lateral facies relationships.

In the Palo Duro Canyon area the combination of fluvial, deltaic, and lacustrine systems are genetically linked to produce progradational sequences. One transgressive valley-fill sequence was observed in this area. Three vertically superposed progradational sequences characteristically begin with lacustrine mudstone and end with fluvial-deltaic sandstone-conglomerate. This reflects a minimum of three complete cycles beginning with lacustrine deposition and ending with fluvial-deltaic progradation.

Lacustrine rocks are composed of two lithologies: (1) varicolored burrowed mudstones, and (2) calcareous zones. Burrowed mudstones make up more than 90 percent of the lacustrine section. Mudstones accumulated in lake center environments.

Calcareous nodules consisting of microspar calcite, sparry calcite, and minor dolomite are paleocaliche horizons that separate mudstone units. Caliche formed in intermittently dry mudflats or possibly within a shallow subsurface diagenetic environment. Textural trends are not obvious within

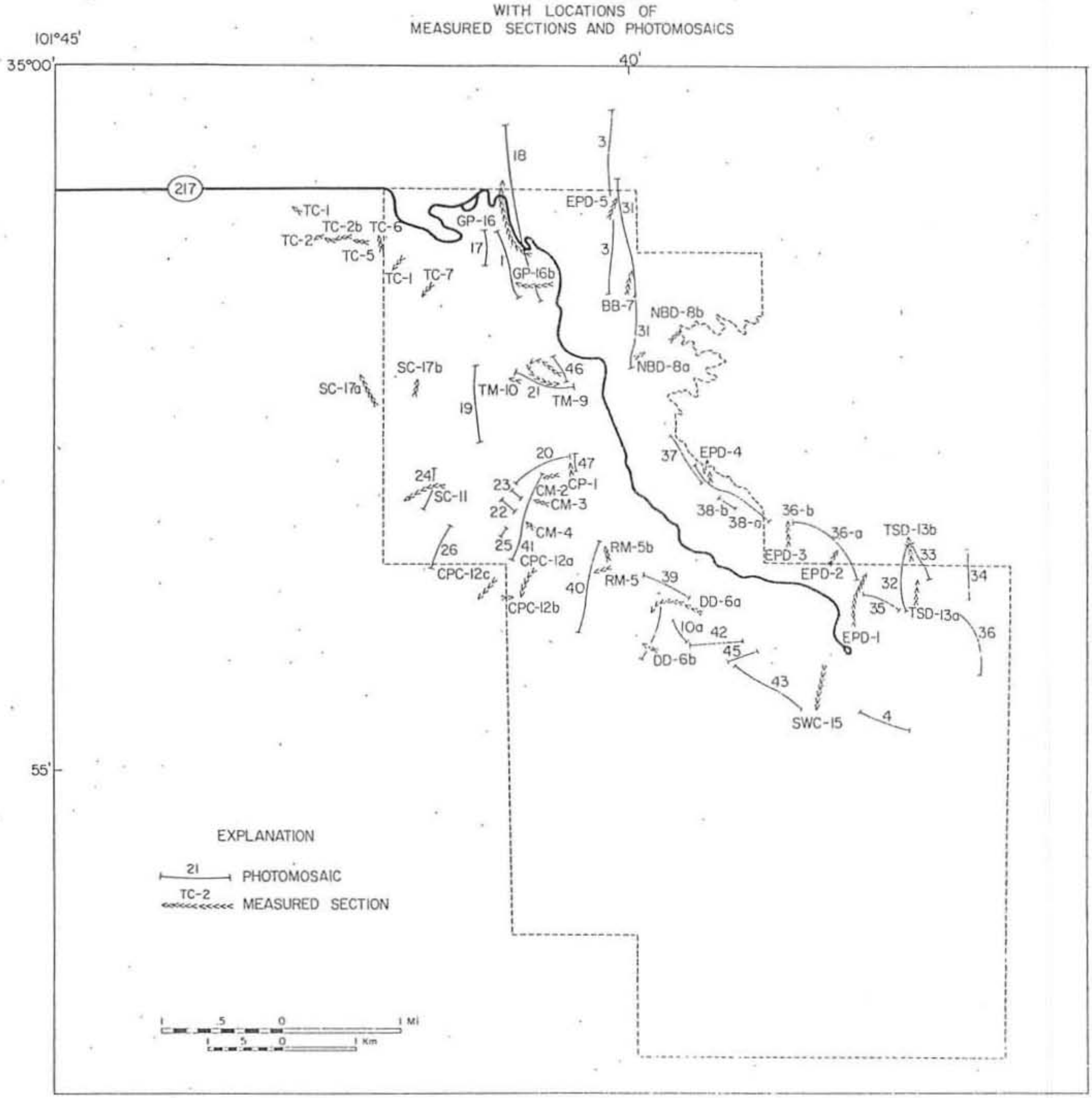


Figure 30. Location of measured sections and photomosaics.

vertical sequences of lacustrine rocks. Characteristics of the lacustrine deposits are illustrated in figure 31.

Delta system rocks are texturally diverse depositional units that can be categorized as shallow-water and deep-water lacustrine deltas.

Shallow-water lacustrine deltas overlie lacustrine mudstones and are capped by fluvial sandstone-conglomerate sheets deposited on fan delta platforms. Shallow-water lacustrine deltas are characterized by this sedimentary package that accumulated in delta front, distributary channel, and channel mouth bar environments. Slump structures are common to this sequence. The characteristics of shallow-water lacustrine deltas which prograded into water 1 to 10 m (3 to 30 feet) deep are illustrated in figure 32.

A common attribute of deep-water lacustrine deltas is thick sequences of delta front foresets. Foresets are 8 to 15 m (25 to 50 feet) thick indicating that deposition occurred in a lake basin at least 8 to 15 m deep. Features of deep-water lacustrine deltas are exhibited in figure 33.

Fluvial sandstone-conglomerate bodies occur in two distinct geometries: (1) sheets, and (2) linear belts. Delta systems are capped by sandstone-conglomerate sheets that represent deposition on fan delta platforms by coarse-grained braided streams. One fluvial sandstone-conglomerate body comprises a linear belt of valley-fill. This sequence is represented by thick channel-fill lenses, some of which are composed of chert pebble conglomerate. Properties of valley-fill deposits are shown in figure 34.

Eight lithofacies have been identified in the Palo Duro Canyon area (table 1). Lithofacies are defined on texture, mineralogy, sedimentary structures, and vertical and lateral relationships of component depositional units.

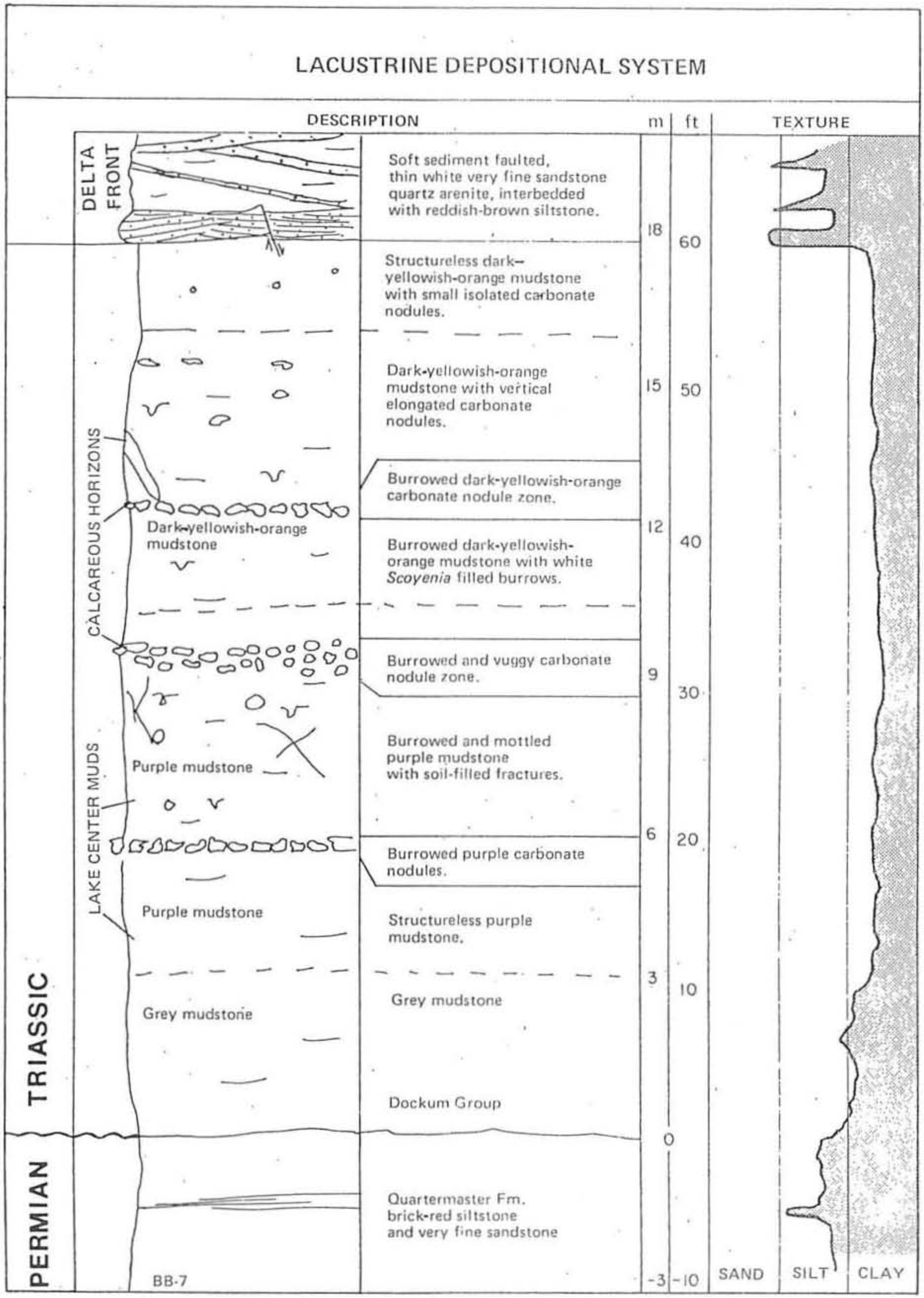


Figure 31. Lacustrine system deposits are characterized by fine-grained mudstones bearing Scoyenia and Teichichnus, and caliche horizons.

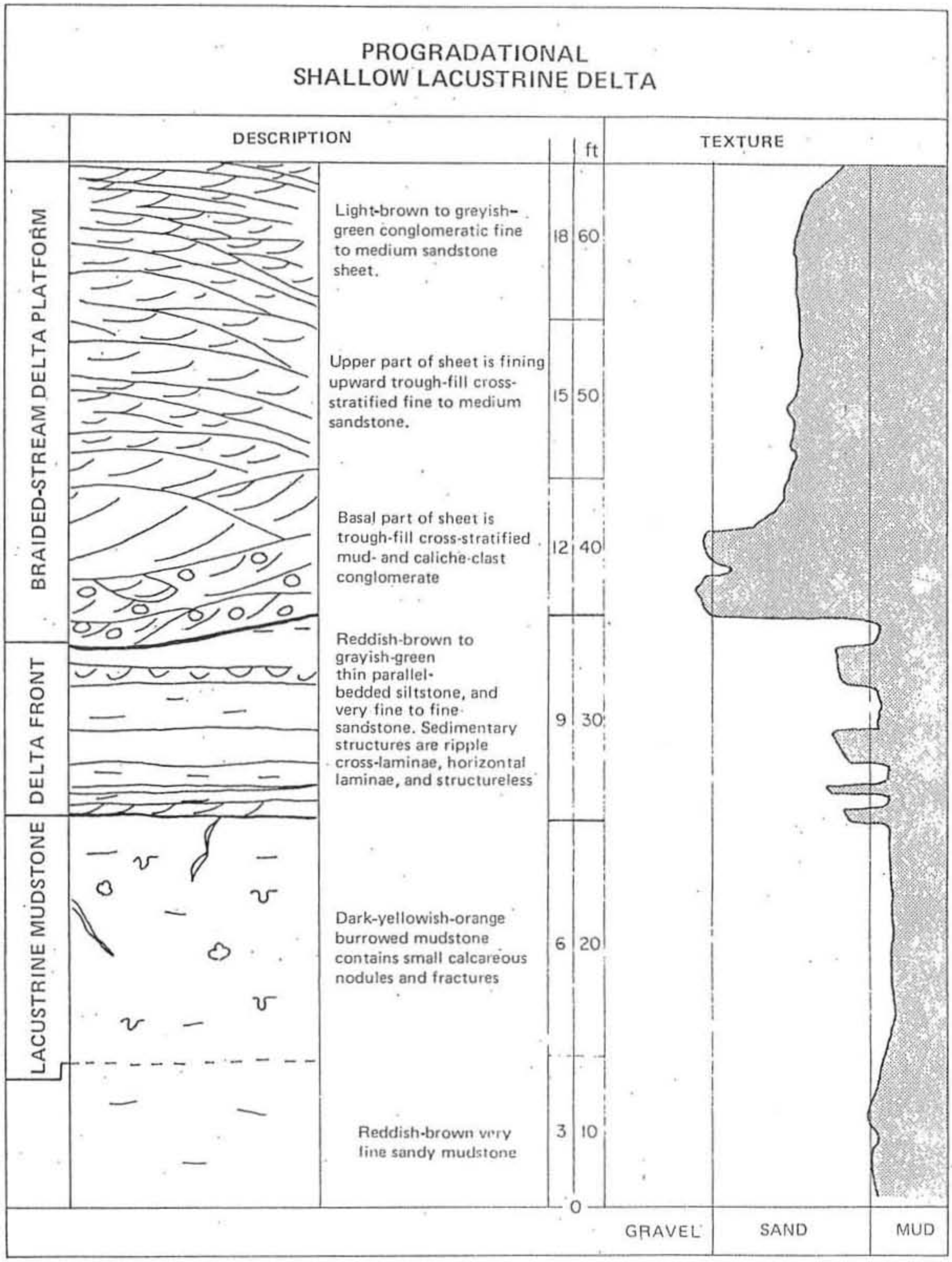


Figure 32. Shallow-water lacustrine deltas are characterized by coarse-grained delta platform sandstone-conglomerate sheets that overlie progradational coarsening-upward lacustrine and thin delta front sequences.

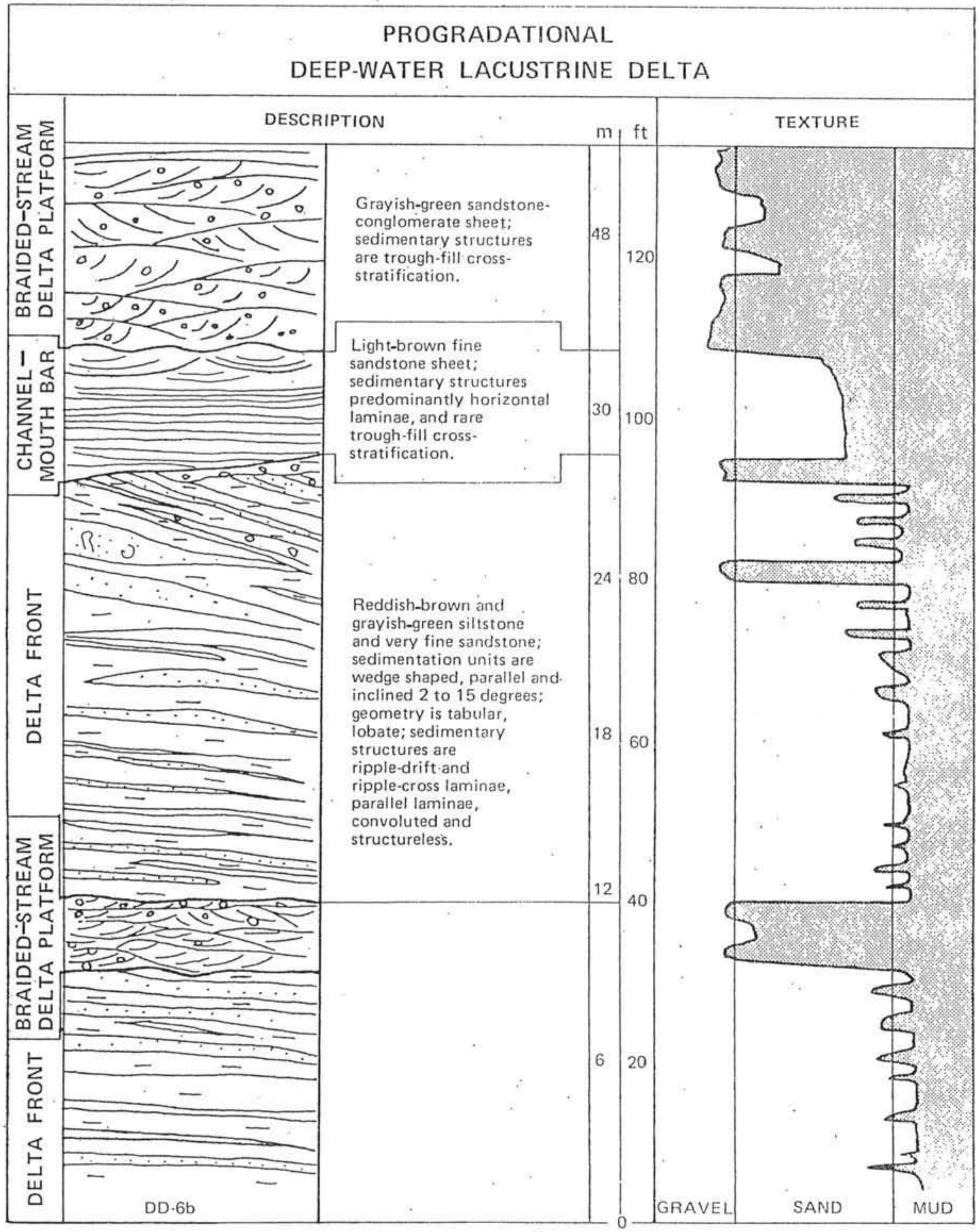


Figure 33. Deep-water lacustrine deltas are characterized by thin, coarse-grained delta platform sandstone-conglomerate sheets that overlie thick, progradational foreset inclined delta front deposits.

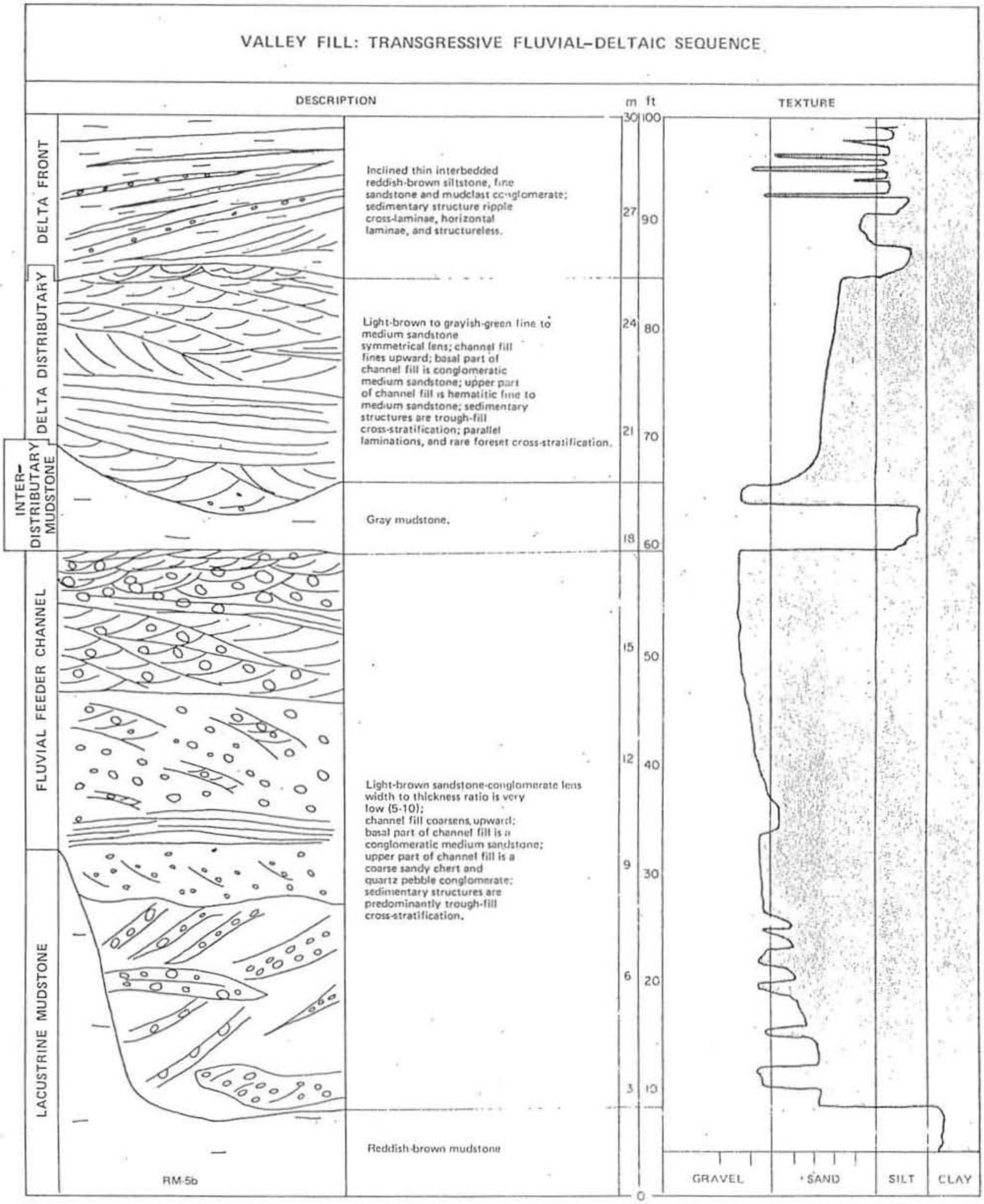
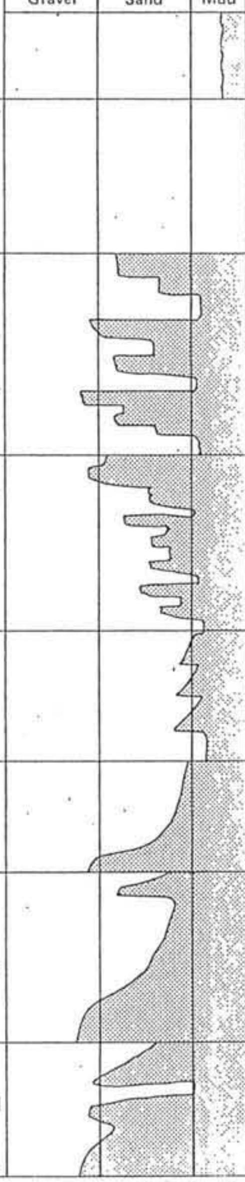


Figure 34. Valley-fill system comprises a transgressive fluvial-deltaic-lacustrine system that is composed of a basal fluvial chert pebble conglomerate, overlain by delta distributary, and delta front deposits that are capped by lacustrine mudstones.

Table 1. Characteristics of fluvial, deltaic, and lacustrine facies, Dockum Group, Palo Duro Canyon area.

LITHOFACIES	ENVIRONMENT	TEXTURAL TREND			STRUCTURES	THICKNESS
		Gravel	Sand	Mud		
Lacustrine (1) Burrowed mudstone	Lake center, lake margin				Burrowed sandy mudstone, desiccated and brecciated, popcorn weathering surface	Total 20 to 50 m, genetic units 1 to 10 m
(2) Calcareous zones	Lake margin mudflat				Calcareous zones are discrete pisolitic and burrowed nodules; clay and quartz sand normally in microspar calcite matrix; sparry calcite, dolomite and opal also present	Total less than 1 to 3 m, individual zones 0.1 to 1 m
Deltaic (3) Parallel bedded, horizontal, sheet, siltstone-sandstone-conglomerate	Lacustrine fan delta front, shallow water 1 to 5 m deep				Parallel laminae, ripple drift, contorted laminae, and soft-sediment slumps and faults; trough-fill cross-stratification is rare	Total 5 to 15 m, individual units 1 to 7 m
(4) Parallel bedded, inclined, lobate, siltstone-sandstone-conglomerate	Lacustrine delta front foresets, deep water 5 to greater than 15 m deep				Ripple-cross laminae, ripple drift, parallel laminae; trough-fill cross-stratification and soft-sediment faults and slumps are rare; sedimentation units are inclined and wedge shaped	Total 15 to 35 m, genetic units 5 to 15 m
(5) Mudclast siltstone-sandstone	Interdeltaic mudflat, embayment				Ripple drift is the primary sedimentary structure; contorted laminae is common	Total less than 1 to 10 m, genetic units 0.05 to 0.4 m
(6) Symmetrical channel-fill sandstone	Distributary channel				Trough-fill cross-stratification; texture fines upward, ripple-cross laminae and parallel laminae at top	Lenses 2 to 13 m thick
Fluvial (7) Sheet sandstone-conglomerate	Fan delta - delta platform				Trough-fill cross-stratification is the most abundant sedimentary structure; ripple cross-laminae and parallel laminae at top; accretionary grain and curved bed set boundaries are common	Total 10 to 30 m, individual sheets 2 to 20 m
(8) Stacked channel-fill sandstone-conglomerate	Fluvial valley fill				Multiple channel-fill scours; trough-fill cross-stratification occurs at base of channels; cross strata fines upward; parallel laminae occurs at top	Total 20 to 45 m, individual channel-fills 7 to 20 m



Lacustrine System

Lacustrine system rocks accumulated in two environments--lake center and intermittently dry mudflats. These environments coincide with two distinct lithofacies--burrowed mudstones and calcareous mudstones respectively. Varicolored, burrowed lacustrine mudstones make up more than 90 percent of the lacustrine section and as much as 20 percent of the total Dockum section. Caliche horizons, which constitute less than one percent of the Dockum, formed on intermittently dry lacustrine mudflats.

Lacustrine Mudstones

Varicolored lacustrine burrowed mudstones occur in four to seven genetic packages concentrated in the lower 70 m of the Dockum. Mudstone units are 1 to 10 m thick and are distinguished by color ranging from purple, reddish purple, reddish brown, to dark yellowish orange.

Mudstone geometry ranges from horizontal blankets to broad lenses. Mudstone thickness decreases toward the southwest. Although the total thickness of the Dockum increases to the west beneath the High Plains, sub-basins may have been locally important areas of sediment accumulation.

Small-scale structures in lacustrine mudstones are predominantly burrows and desiccation fractures associated with caliche horizons. Primary sedimentary structures have been destroyed by intense burrowing which produced Scoyenia (Hantzchel, 1962). Cross sections through Scoyenia reveal arcuate back-fill structures or spreite.

The texture and mineralogy of lacustrine mudstones is uniform. Silt-and sand-sized quartz grains are rare to common. Smectite and illite are the common clay minerals. Complex suites of diagenetic carbonate and siliceous minerals associated with caliche horizons formed within subaerially exposed lacustrine mudstones.

Caliche Horizons

Paleocaliche occurs as thin layers of calcareous mudstone nodules comprising microspar, sparry calcite-filled fractures and some dolomite. Silicified evaporite nodules are rare. Paleocaliches are interbedded with lake center muds indicating that lake fluctuations subaerially exposed broad areas of lake muds.

Silcretes situated in the lower 5 to 20 m (16 to 65 feet) of the Dockum at Wayside Crossing in Armstrong County and near Silverton in Briscoe County might have formed contemporaneously with paleocaliches. Calcareous zones and nodules similar to those in the Dockum are described by Nagtegaal (1969) in Permian and Triassic paleocaliches in Spain.

Summary

Lacustrine mudstones were deposited in the lake center environment by sedimentation from suspension. The fine grain size indicates that low-energy conditions prevailed during deposition. Stratification was destroyed by ubiquitous and thorough burrowing which indicates that bottom waters were oxygenated and that the lake system was not highly stratified as postulated for the lacustrine environment in which the Eocene Green River Formation accumulated (Bradley, 1964; Picard and High, 1968; Eugster and Bradley, 1969).

Caliche horizons developed on lake center mudstones suggest that lake level fluctuations subjected lacustrine muds to arid climate conditions. Ephemeral Lake Eyre, Australia is a possible Modern analogue for part of the Dockum (Bonython and Mason, 1953).

Deltaic System

Deltaic rocks comprise central parts of three major progradational sequences. Seven westward prograding delta lobes were identified within these three major sequences. One lobe prograded southward. Lacustrine mudstones underlie deltaic siltstone-sandstone-conglomerate, and fluvial sandstone-conglomerate sheets overlie deltaic rocks and mark upper limits of progradational sequences.

Delta components are delta front, delta foreset, interdeltaic mudflat, and distributary channel. Burrowed lacustrine mudstones grade laterally and upwards into distal delta front siltstone. Delta platforms comprise coarse-grained sandstone-conglomerate sheets. Two lacustrine delta models, (1) shallow-water delta, and (2) deep-water delta, are proposed for Dockum deltaic deposits.

Thin-bedded delta front deposits of shallow-water deltas contain mudclast and caliche granule conglomerate interbedded with texturally mature, horizontally-laminated very fine-grained sandstone. Interbedding of mature very fine sandstone and immature sedimentary rock fragment conglomerate is typical of delta-front deposits of shallow-water deltas. Soft sediment slump structures are common to delta front deposits.

Within the lower 70 m of the Dockum, shallow-water lacustrine deltas were developed in 1 to 10 m (3 to 30 feet) of water as base level fluctuated during arid climate conditions. Coarse debris, eroded from older Dockum deposits, was transported across delta platforms by braided streams and was deposited as frontal splays. Lacustrine expansion flooded and buried deltaic deposits beneath lacustrine mudstones.

Deep-water lacustrine deltas display thick "Gilbert-type" delta foresets. Delta foresets are wedge-shaped, thin at the toe, thicken toward the top, and are inclined 4-15 degrees. Grain size and scale of sedimentary structures increase from the base upward. Delta foresets, 8 to 15 m (25 to 50 feet) thick, developed in part from slip face accretion and in part from grainfall (suspension of silt and sand). Thickness of individual foresets indicates water depths of 8 to 15 m. The high angle of repose of delta foresets is preserved under conditions of rapid sedimentation, minimal soft sediment movement, and low-physical energy within the basin of deposition.

Both delta types were lobate in plan and were fed by braided streams. Deltaic deposits comprise 20-45 percent of the Dockum section. Shallow-water delta progradational sequences are thinner (15 to 30 m, 50 to 100 feet) than deep-water delta progradational sequences (20 to 70 m, 65 to 230 feet).

Fluvial System

Two fluvial systems, braided streams and incised streams, were operable during accumulation of the Dockum. Sediment deposited on braided-stream delta platforms caps three major progradational sequences in Palo Duro Canyon. The valley-fill system, floored by linear fluvial sandstone-conglomerate, is terminated with a transgressive fluvial-deltaic-lacustrine sequence.

Three fluvial sandstone-conglomerate horizons are composed of seven individual lobate sheets. Small sheets are one to three km (0.6 to 1.8 miles) wide; large sheets are greater than 3 km (1.8 miles) wide. Deltaic facies are laterally equivalent with fluvial lithofacies. Fluvial sheets are overlain by lacustrine mudstones that are genetically related to the next progradational sequence. Texture and scale of sedimentation units of sandstone-conglomerate sheets decrease upward. Trough-fill cross-stratification is the predominant sedimentary structure. Sediment that makes up delta platforms moved downstream as dune bedforms within braided channels.

Two laterally equivalent valley-fill units are situated in the northern and southern sectors of Palo Duro Canyon and occupy part of the central 50 m (160 feet) of the Dockum. Asymmetrical and symmetrical sandstone-conglomerate lenses accumulated at the base of a valley-fill sequence. Most of the valley-fill deposits fine upward. One unit within the valley-fill comprises an upward coarsening lens of chert pebble conglomerate 18 m (60 feet) thick. Trough-fill cross-stratification is the predominant sedimentary structure. Fluvial lenses within the valley-fill are overlain by deltaic and lacustrine deposits that accumulated during a rise in lake level.

Braided streams were operative in delta platform and valley floor environments; braided stream facies are equivalent to downdip lacustrine and deltaic facies. Fluvial deposits constitute 10-50 percent of the Dockum section. Multilateral sheet geometry, texture, and sedimentary structures indicate that sediment was transported across delta platforms by braided streams.

Depositional Summary

Lacustrine, deltaic, and fluvial depositional systems comprise three major upward-coarsening, progradational sequences in Palo Duro Canyon. A single transgressive valley-fill sequence displays an upward-fining, fluvial, deltaic, lacustrine sequence. Lacustrine mudstones underlie the progradational deltaic sequences which accumulated in delta front, delta foreset, interdeltaic mudflat, and distributary channel environments. Shallow-water lacustrine deltas are typified by thin texturally and mineralogically variable delta front deposits that contain abundant slump structures. Deep-water lacustrine deltas typically exhibit "Gilbert-type" delta foresets.

Both shallow- and deep-water lacustrine delta platforms were constructed by braided-stream processes. During a low-level lake stand, one progradational sequence was cut by a headwardly eroding valley which constructed a small fan delta at its mouth. The valley was finally filled by fluvial-deltaic-lacustrine deposits during a lacustrine transgression.

Genetic Sequences

Three progradational sequences, each composed of genetically-related lacustrine, deltaic, and fluvial rocks, comprise the Dockum Group in Palo Duro Canyon. Interpretation of genetic sequences is based on data derived from contour maps, fence diagrams, cross sections, paleocurrent analysis, and petrographic studies.

Lower Progradational Sequence

An upward coarsening sequence of lacustrine and fluvial-deltaic sediments characterize the first progradational sequence of the Dockum Group in the study area (fig. 35). Basal sandstone of the lower unit contains medium to coarse and well-rounded quartz and chert sand grains probably derived from Permo-Triassic dunes to the east. Sandstones of the upper unit are mostly very fine quartzarenites, and their source also may have been Permo-Triassic dune fields. Interbedding of lacustrine mudstones and paleocaliches in the middle unit indicate that the climate alternated between arid and humid cycles. A vertical profile of shallow-water lacustrine deposits which characterize the first progradational sequence is shown in figure 32.

Middle Progradational Sequence

The second progradational sequence comprises much of the sandstone-conglomerate-rich central 30 to 50 m (100 to 165 feet) of the Dockum in the study area (fig. 36). A westward prograding lacustrine delta system was the dominant depositional element in the second progradational sequence. This delta system was eroded in the northern and southern sectors by two laterally equivalent valley-fill sequences. Small fan deltas were constructed west of the valley mouth. Subsequent expansion of lake area produced flooding in the valley which was finally filled by a transgressive fluvial-deltaic-lacustrine sequence. A decrease in sandstone percentage occurs in the direction of progradation (to the west).

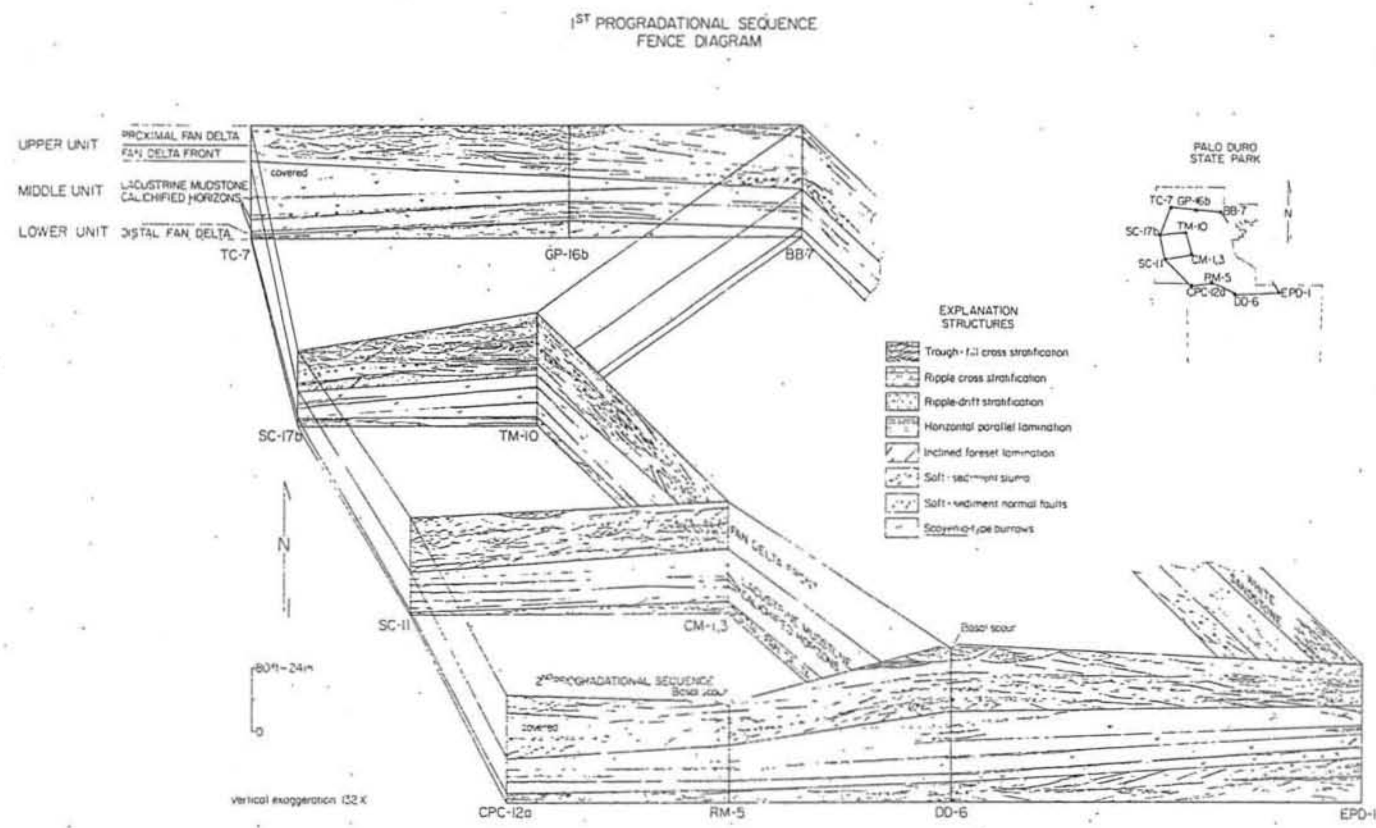


Figure 35. First progradational sequence fence diagram illustrates sedimentary structures and depositional facies.

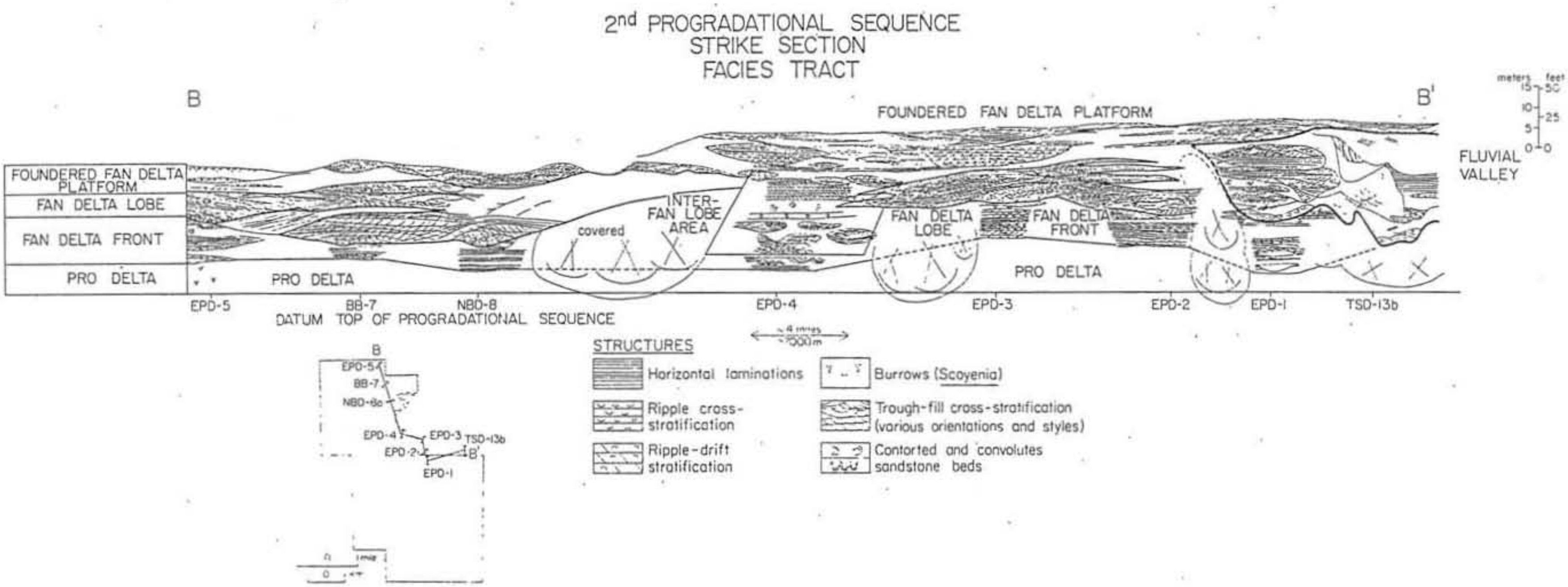


Figure 36. Second progradational sequence strike section is exposed along the eastern margin of Palo Duro State Park. This figure illustrates the facies tract and sedimentary structures. Two nearly continuous sandstone-conglomerate sheets, which cap the second progradational sequence, were deposited in sandstone-rich delta platform braided stream and distributary channel environments. The progradational sequence is composed in ascending order of: lacustrine burrowed mudstone (prodelta), and delta front siltstone-sandstone-conglomerate. The two laterally and temporally equivalent lacustrine fan deltas were separated by finer grained interdeltaic mudflat or embayment. The southern flank of the southern lacustrine delta is truncated by a thick valley-fill sequence which formed in response to diminished lake depth and area. The valley-fill sequence is composed of basal braided stream and delta distributary sandstone-conglomerate. The valley-fill sequence comprises a transgressive sequence encased within an overall progradational sequence. A subsequent expansion of lake area caused the lacustrine deltas to founder. Fine-grained lacustrine mudstones of the third progradational sequence overlie the second progradational sequence. Vertical exaggeration is 128x.

Upper Progradational Sequence

The third progradational sequence comprises two vertically superposed, deep-water lacustrine delta cycles (fig. 37). A vertical profile through sequence three contains, in ascending order: lacustrine burrowed mudstones, inclined delta foreset, siltstone-sandstone-conglomerate, and fluvial-delta platform sandstone-conglomerate. This vertical sequence is repeated resulting in two superposed progradational cycles. The third progradational sequence displays westward progradation of two delta lobes.

Lacustrine mudstones, although not well exposed, thicken to the west where they comprise one or two burrowed horizons that are 2 to 10 m thick.

Deltaic deposits, the thickest facies in the third progradational sequence, are composed chiefly of parallel-bedded, inclined wedge-shaped delta foresets. Some foreset units are 8 to 15 m (26 to 50 feet) thick, suggesting that lacustrine deltas were deposited in a water body 8 to 15 m deep.

Apparent dip direction of delta foresets varies widely. Factors which influence apparent dip direction as observed on an outcrop face include true dip direction and the strike of the outcrop face. Measurements taken from sedimentary structures exposed in two-dimensional vertical outcrops are not valid paleocurrent indicators. Facies geometry and trends in sandstone percentage were used as a means to determine the westward deltaic progradation.

Two lacustrine delta lobes were fed by westward-flowing streams. The lower delta lobe prograded to the west across the study area. An increase in lake area and depth, or an upstream river avulsion and continued basin subsidence, caused the lower delta to founder. Lacustrine mudstones accumulated on the lower delta platform. Dockum deposition ceased in Palo Duro Canyon with another cycle of western deltaic progradation into water 10 to 20 m (33 to 66 feet) deep.

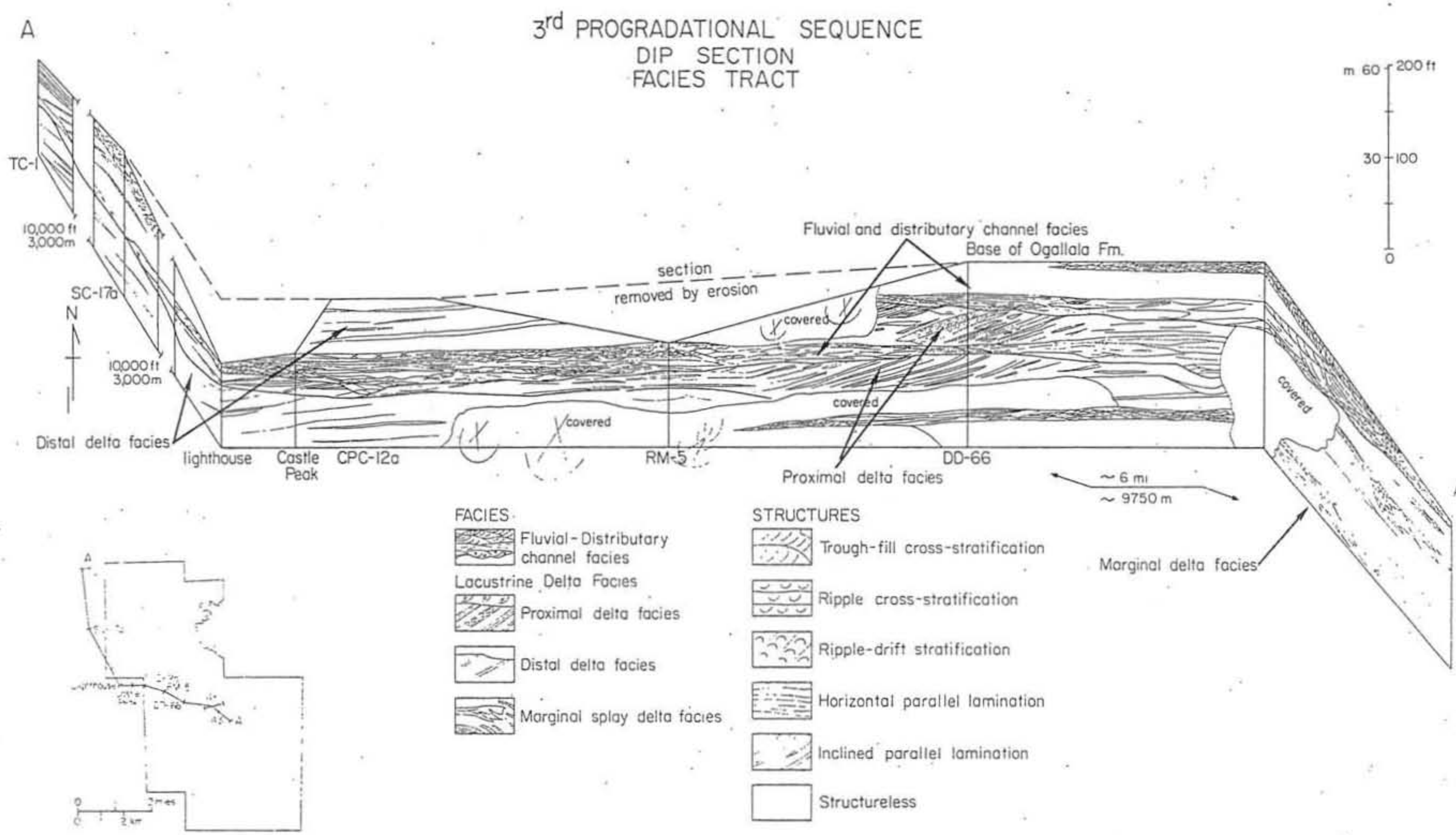


Figure 37. Fence diagram of the third progradational sequence exposed in the central and western portions of the study area. This figure illustrates sedimentary structures and depositional facies. Two superposed lacustrine deltas prograded to the west across the study area. Each lacustrine delta is composed in ascending order of: lacustrine mudstone, deltaic siltstone-sandstone-conglomerate. Parallel, foreset inclined, wedge-shaped sedimentation units that were deposited proximal delta (delta front) facies are highly characteristic of deltaic deposits of the third progradational sequence. The thickness of these delta foresets is from 8 to 15 m, indicating that deposition occurred in water at least 8 to 15 m deep. Vertical exaggeration is 44x.

Tule Canyon

Triassic Dockum Group exposed in Tule Canyon is interpreted to have accumulated under conditions almost identical to those that prevailed in the Palo Duro Canyon area to the north (Boone, in progress).

Dockum Group is approximately 130 m (425 feet) of mudstone, siltstone, sandstone and conglomerate, which displays an overall fining-upward texture. Sandstone and conglomerate constitute about 62 percent of the Dockum exposed in Tule Canyon.

Depositional systems identified in Tule Canyon (Boone, in progress) are from the base upward: (1) alluvial fan-fan delta (approximately 40 m, 130 feet thick); (2) valley-fill (more than 60 m, 197 feet thick); (3) meanderbelt (more than 30 m, 100 feet thick); and (4) lobate delta (more than 60 m, 200 feet thick).

Fan-Delta System

A continuous, tabular sandstone body, an alluvial fan or fan-delta system, marks the base of the Dockum in Tule Canyon. This is a high-sand system and contains small amounts of siltstone and mudstone. The base of the system is relatively flat and uniform. Maximum thickness of the system is about 40 m (130 feet). Erosion by the overlying valley-fill system scoured completely through the fan-delta sandstone into underlying Permian mudstone. Sedimentary structures within the alluvial fan-fan delta sandstone are dominated by medium to large scale trough-fill and foreset cross-strata, parallel lamination, and some ripple cross-lamination and ripple drift. This section, which exhibits a local basal progradational sequence and lake-basin association, closely resembles the fan-delta sequence in some areas (McGowen, 1971a; McGowen and Scott, 1974).

Valley-Fill System

A distinctive feature of the Dockum Group in Tule Canyon is a valley-fill sequence of conglomerate and sandstone. A large drop in base level is postulated to explain deep scouring and narrow incision of this valley and coarse texture of basal fill. Chert pebble conglomerate characterized by large-scale trough-fill cross-strata forms the lower two-thirds of the valley-fill. Base of the valley is lined with angular sandstone boulders up to 2 m (6 feet) in maximum dimension. Valley-fill system is about 1.3 km (0.75 mile) wide and with maximum thickness of 64 m (210 feet).

Meanderbelt System

Fluvial meanderbelt facies are exposed in the western part of Tule Canyon. The fluvial system comprises a complex of point bar and channel deposits. Overbank mudstone and siltstone make up a small volume of the system. Meanderbelt facies overlie the valley-fill system and grade northward into contemporaneous deltaic facies. Maximum thickness of the fluvial zone is approximately 25 m (80 feet).

Delta System

Delta systems comprise most of the Dockum Group in the Tule Canyon area. Lobate lacustrine deltaic systems occupy the upper part of this section and are distinct from the lower fan delta system in that framework sandstone units are lenticular, and are variable in geometry. Deltaic sandstones are associated with locally thick prodelta and delta-front mudstone and siltstone. Sandstone bodies range in geometry from small, isolated lenses to thick, stacked units extending over large areas. Maximum lateral extent of individual units appears to be on the order of 5 to 10 km (3 to 6 miles). Deltaic systems are stacked or imbricated suggesting that subsidence and/or lake level rise kept pace with sediment input to the lake basin. Total thickness of individual deltaic systems is indicative of relative water depth. Maximum depth was interpreted to be about 30 m (100 feet); depths were generally less than 30 m.

Detailed study in the upper part of the canyon resulted in recognition of a variety of components of delta systems including prodelta, delta front, distributary mouth bar, distributary channel, crevasse splay, and delta plain environments.

Dickens-Mitchell County Area

The first Dockum report, Depositional Framework of the Lower Dockum Group (Triassic), Texas Panhandle, submitted to the U.S. Geological Survey in February, 1978, emphasized the interpretation of the Dockum in outcrop in the area defined by Dickens, Crosby, Kent, Garza, Scurry, Borden, Mitchell and Howard Counties. Only a summary of conclusions of that report are included herein (for details see the first report).

The Dockum Group changes southward in the vicinity of northern Dickens County, from here southward there is more mudstone than contained in equivalent strata to the north. Within the eight-county outcrop belt the Dockum is characterized by cyclic sedimentation. At least five sedimentary cycles, each more than 100 feet thick, have been recognized in Dickens, Crosby, Kent and Garza Counties. Three cycles were identified in Palo Duro Canyon area (Seni, 1978) where detailed field study was carried out.

Cyclic Sedimentation

Sedimentary cycles began after accumulation of the basal Dockum, which is a progradational sequence, recognizable in outcrop and traceable westward in the subsurface to the vicinity of the Texas-New Mexico border. Basal

Dockum deposits, which accumulated during expansion of the Dockum lake environment, consist from bottom upward of a basal lacustrine and deltaic mudstone and siltstone sequence, a thin deltaic sequence and an uppermost thick fluvial sandstone.

Cyclic deposits that accumulated upon the basal Dockum progradational sequence are red beds which grade upward into grayish-green, yellowish-brown and orange siltstone, sandstone and conglomerate. Red beds constitute 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 deposits are termed intrabasinal. Siltstones, sandstones and conglomerates that overlie red beds were derived, for the most part, from outside the basin of deposition; these deposits are extrabasinal.

Sediment properties (e.g., color, texture, composition, sequences of sedimentary structures, geometry, cross-cutting relationships, and biological constituents) indicate that climatic fluctuations produced depositional cycles. Tectonic activity, however, could have been the prime factor that triggered climatic fluctuations. It is postulated that most of the red beds are products of arid cycles and that extrabasinal sediments were transported to the Dockum depositional basin when the climate was humid.

High-Stand, Humid Phase

Dockum sedimentation ensued with the advent of humid climatic conditions. Base level was relatively stable and sediment was transported to the basin by meandering streams. High constructive lobate deltas were the dominant lake margin depositional system during the high-stand (lake level) part of a cycle (fig. 38).

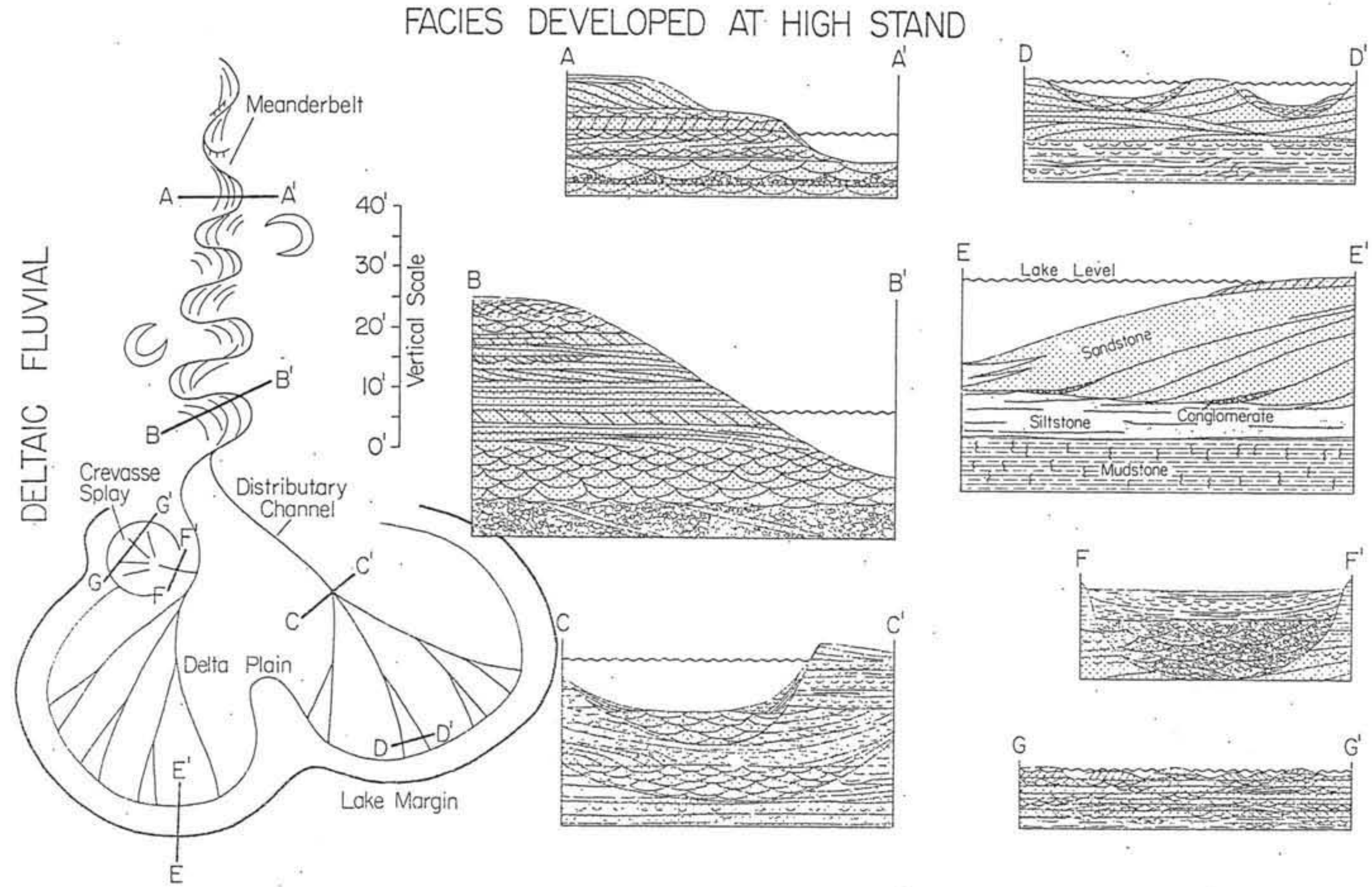


Figure 38. Major depositional elements during the high-stand, humid phase: meandering streams, distributary deltas, and shallow lakes. Facies tract and cross sections generalized from field observations. Cross section A-A' represents coarse-grained meanderbelt sequence, and B-B' is fine-grained meanderbelt 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.

A vertical (upward) sequence of strata deposited during high stand in Triassic lakes commonly begins with reddish-brown, massive to parallel laminated lacustrine or prodelta mudstone. Grayish-green siltstone and very fine-grained delta front sandstone overlies lacustrine and prodelta facies. Delta front facies (sandstones) are mostly parallel and ripple cross laminated and contain a few small washout channel-fill deposits. Distributary channel-fill sequences (mostly sandstone) 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. Fining upward fluvial sandstones are products of 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 (15 m) thick are commonly the only sandstone facies present in an outcrop area. Delta front and distributary channel-fill sandstone facies are poorly preserved as a consequence of down-cutting and lateral migration of 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 (15 m) deep to small fan delta systems at the basin margin (fig. 39).

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 mudstones are desiccated and contain gypsum crystals and salt hoppers. Most siltstone units are components of fan deltas; they are mostly 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 (3 to 9 m). Valleys that were eroded into the Dockum were filled with sediment ranging in texture from clay to boulder 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, siltstone, 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.

Depositional Systems

The Dockum Group accumulated within a variety of depositional systems influenced by base level oscillations. Red beds mostly accumulated when lake area and depth were restricted. Low-stand facies consist of valley-fill, fan delta and lacustrine deposits. Meandering streams and associated high con-

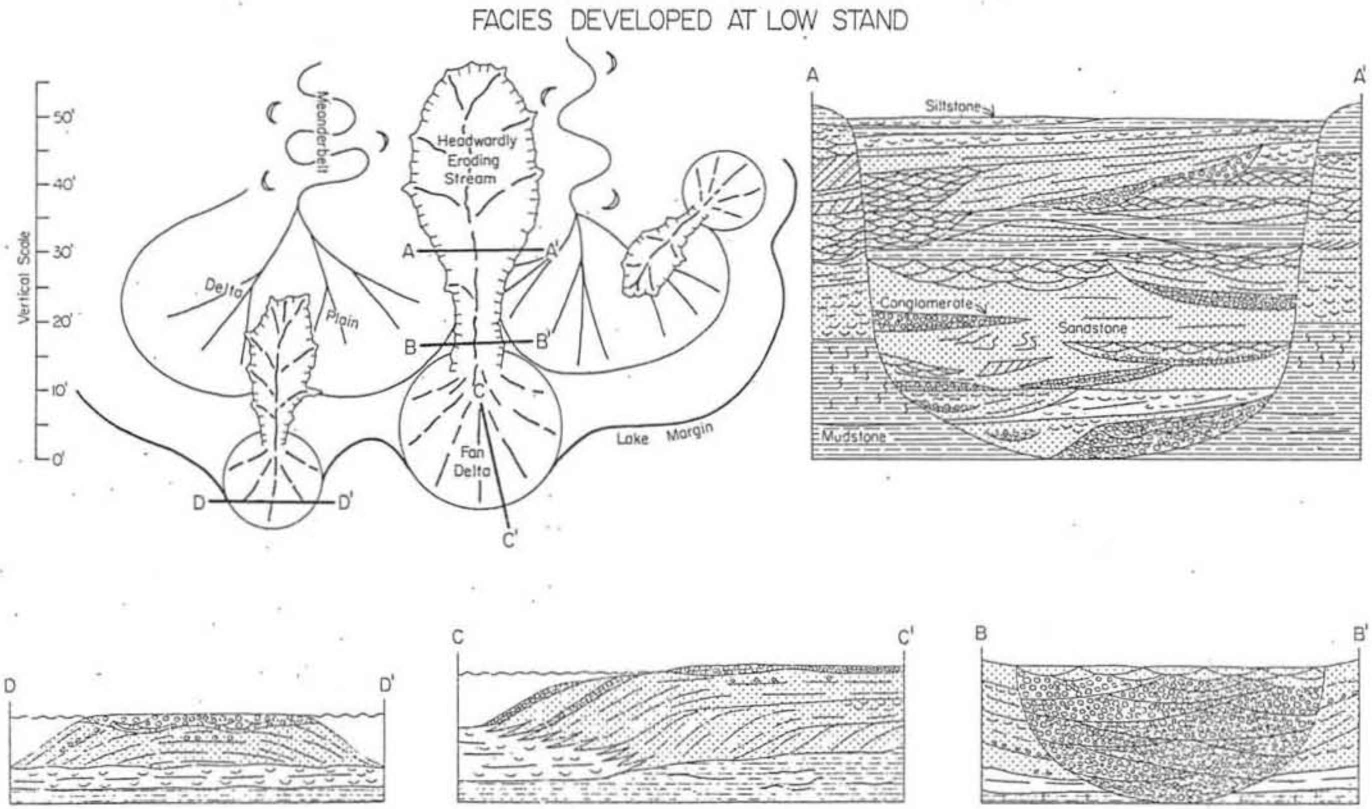


Figure 39. Major depositional elements during low-stand, arid phase: headward-eroding streams, braided streams, small fan deltas, and small ephemeral lakes. Facies tract and cross sections generalized from field observations. Cross section A-A' is valley-fill sequence consisting of braided and meandering 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 cross bedded 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.

structive lobate deltas developed under humid climatic conditions when lake area and level were at a maximum.

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 (fig. 40).

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 (3 m) thick. Lacustrine and prodelta facies are generally thin (5 to 10 feet, 1.5 to 3 m thick) and valley-fill fluvial deposits range from a few to about 50 feet (15 m). Figure 41 exhibits some of the low-stand facies.

Modern Analogues for the Dockum

The Dockum Group in Texas and New Mexico accumulated in an inland fluvial-lacustrine basin. In outcrop fluvial and deltaic facies are dominant. Subsidence within the basin, in concert with a change from arid climatic conditions of the Permian to more fluvial conditions of the Triassic,

Figure 40. 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, unit 1 and upper part of unit 2 are delta foresets consisting of reddish brown mudstone, siltstone, very fine sandstone and intrabasinal conglomerate; primary sedimentary structures are parallel inclined laminae, ripple cross-laminae, trough 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, 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.

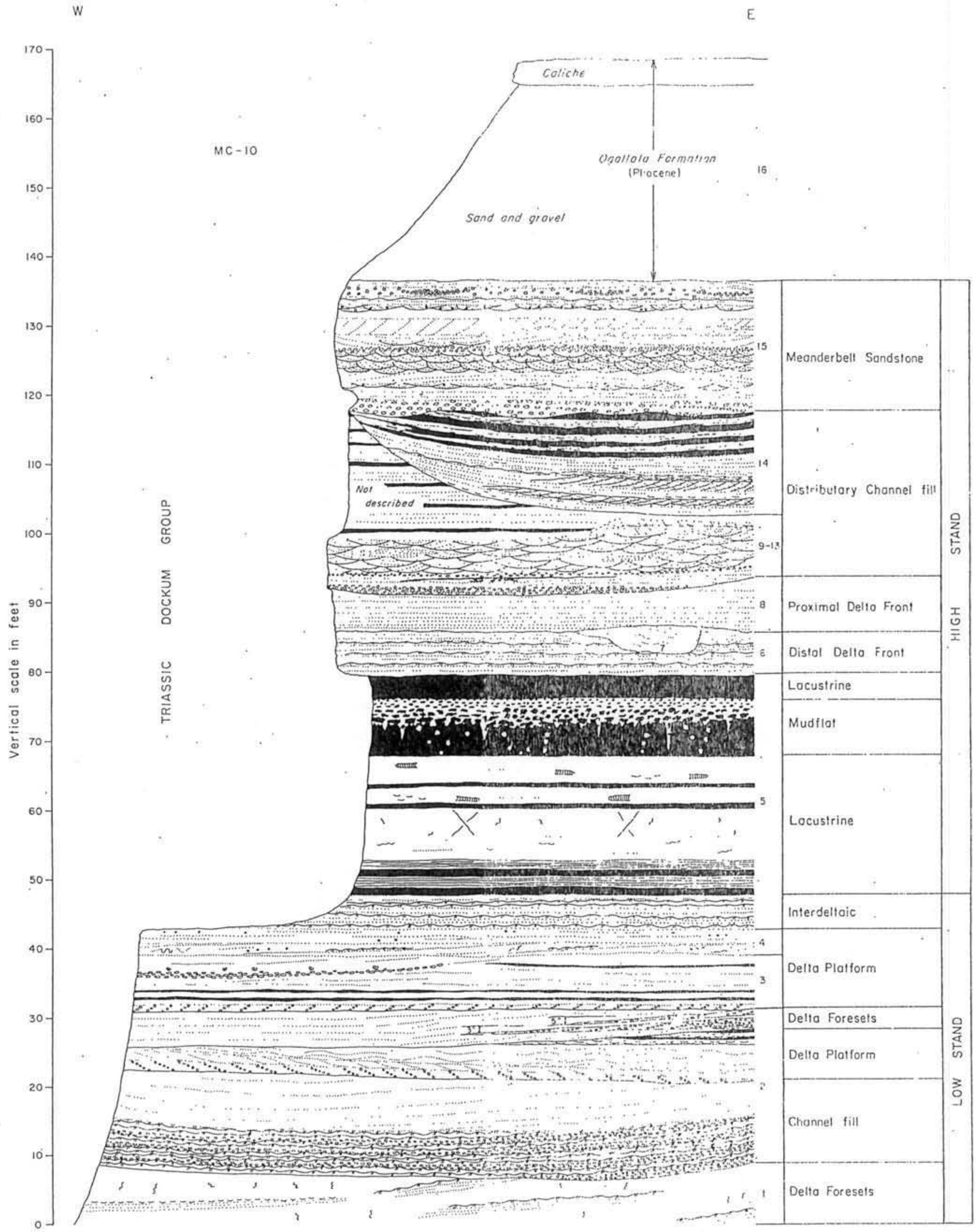

W
E
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Vertical scale in feet
MC-10
TRIASSIC DOCKUM GROUP
Caliche
Ogallala Formation
(Pliocene)
16
Sand and gravel
Not described
15
14
9-13
8
6
5
4
3
2
1
Meanderbelt Sandstone
Distributary Channel fill
Proximal Delta Front
Distal Delta Front
Lacustrine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

Figure 40.

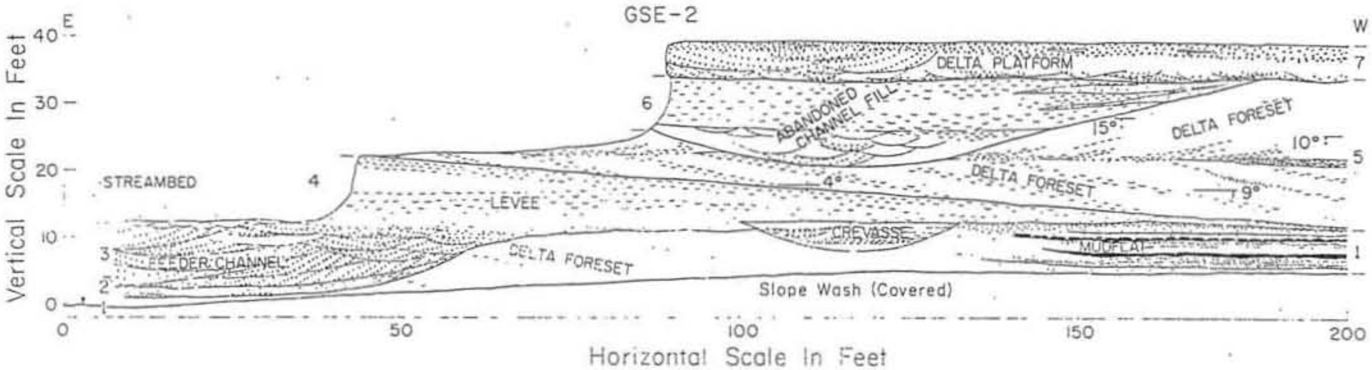


Figure 41. Facies developed during low-stand, southeastern Garza County (Macy Ranch, Grassland Southeast 7.5 minute quadrangle). Seven facies depicted in outcrop sketch: delta foresets; mudflat; feeder channel; crevasse channel; levee; abandoned channel-fill; and delta platform. Delta foresets have apparent dips of 9°-15° and consist of parallel laminated mudstone, siltstone, very fine sandstone, and granule conglomerate. Lateral to upper parts of some foresets are mudflat deposits consisting of burrowed, ripple cross laminated, contorted, and desiccated claystone, siltstone, and very fine sandstone. Feeder channels are filled at base (see unit 2) with parallel laminated, contorted foreset cross-beds 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.

was perhaps related to the opening of the Gulf of Mexico and reactivation of some relict Paleozoic structural elements. 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 accumulation 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. 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 (9.6 miles) 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 (4 m) 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.

DOCKUM DEPOSITIONAL SYSTEMS: A SUMMARY

Subsurface work by McKee and others (1959), and substantiated by the present study, indicates that the Dockum basin was supplied with sediment by streams flowing from east, south and west (fig. 42). 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 tidal flat and sabkha environments were replaced by expanding lacustrine and fluvial-deltaic environments.

Regional and local detailed outcrop studies, supplemented by subsurface data, indicate that meandering streams and distributary deltas were dominant in the east central part of the basin. Log character and subsurface sand distribution patterns in the west-central part of the basin suggest that similar depositional environments existed throughout that part of the basin. Log character and distribution pattern of the predominantly sand sequences south of Sterling, Glasscock, Midland, Ector and Winkler Counties, Texas, are interpreted to represent coalescing fan deltas.

Fan or fan delta facies are covered in the southern part of the basin by Quaternary alluvium and dune sands. In the Glass Mountains there is a complex

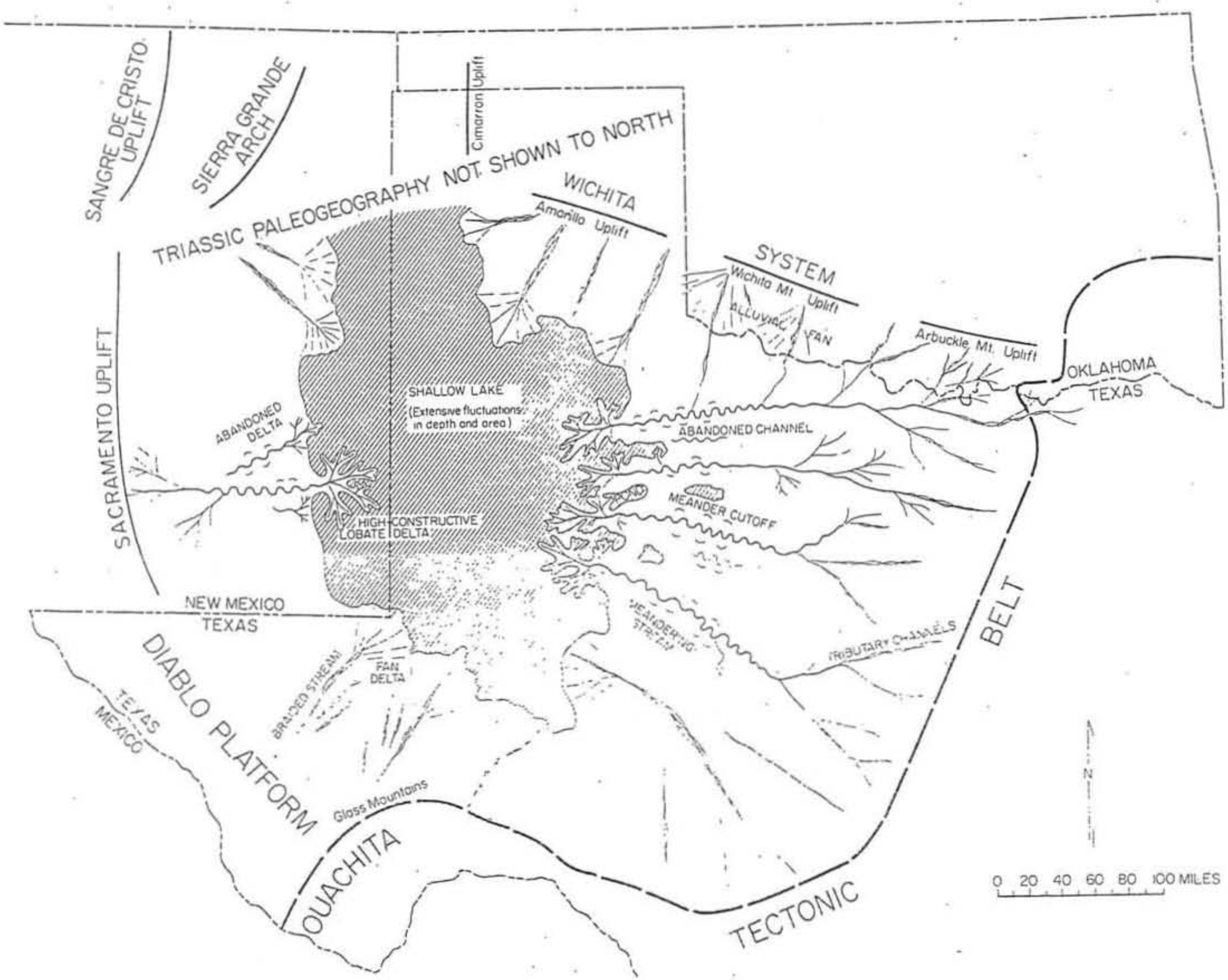


Figure 42. Inferred paleogeography during the initial stage of Dockum sedimentation in area south of Amarillo Uplift-Bravo Dome. Depositional elements are braided streams, alluvial fans, fan deltas, meandering streams, distributary deltas, and shallow lakes.

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). Paleontological data indicate that the Bissett is older than the Dockum. 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. 3), and reconnaissance and local detailed 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.

Fluvial 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 fluvial periods. Maximum depth attained in the outcrop area, based on thicknesses of progradational sequences, was about thirty feet to the south and about 60 feet to the north (Seni, 1978).

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. Small fan deltas were constructed where braided streams debouched from valleys into small lakes. Many of the 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.

URANIUM OCCURRENCE IN DOCKUM OUTCROP FACIES

Depositional systems that constitute the Dockum Group are fluvial, deltaic, lacustrine, valley fill and beach. Some of the depositional facies that comprise these systems were altered through soil forming processes; however, most of these facies are readily identified. Underlying Permian deposits are chiefly components of a tidal flat system. Dockum Group rocks that crop out in Texas and New Mexico accumulated in 25 distinct depositional environments (table 2).

There are 7 fluvial facies, 11 deltaic facies, and 4 lacustrine facies. Individual facies of valley fill systems are not shown on table 2 (these are

Table 2. Depositional systems and depositional environments operative during accumulation of the Dockum Group.

Depositional System	Depositional Environment
Fluvial	Meanderbelt Point Bar Channel Lag Levee Crevasse Splay Flood Plain Abandoned Channel Fill
Deltaic	Distributary Channel Abandoned Distributary Channel Mouth Bar Delta Front Frontal Splay Interdistributary Lacustrine-Interdistributary Interdeltaic Delta Platform Delta Foresets Crevasse Splay-Splay Delta
Lacustrine	Lacustrine Lacustrine-Mud Flat Mud Flat Lacustrine-Deltaic
Valley Fill	Valley Fill
Soil (Paleosols)	Soil
Beach	Beach

enumerated in that part of the text that deals with depositional systems). Paleosols, although not considered depositional facies, are common in Dockum outcrops. Beach deposits were recognized in only one exposure of Dockum rocks.

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

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

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

Four facies make up the lacustrine system. Lacustrine facies were interpreted through association with other facies. Some 87 percent of rocks of the lacustrine system were categorized as "lacustrine" facies and probably represent sediment that accumulated toward the center of Dockum lakes. Mud flat facies constitute a little more than 4.0 percent of the lacustrine system, whereas lacustrine-mud flat deposits make up about 3.0 percent. Lacustrine-deltaic facies constitute about 6 percent of the lacustrine system.

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

Based on frequency of occurrence of the numerous fluvial, deltaic, and lacustrine facies within the Dockum Group (fluvial deposits are most abundant in outcrop, with deltaic deposits occurring only slightly less frequently), uranium should occur mostly within fluvial facies. This assumption is not correct with respect to either frequency of occurrence or highest ppm U_3O_8 (fig. 43, table 3).

An attempt was made to evaluate uranium-bearing potential of the many different depositional facies of the Dockum Group exposed in outcrop. In order to do this we tried to: (1) identify, in outcrop, the depositional systems and component facies, and (2) collect samples that exhibited the total range of textures and stratification types of each depositional facies. These samples were analyzed at the Bureau of Economic Geology Mineral Studies Laboratory for U_3O_8. To date, more than 400 samples have been analyzed (table 3). Approximately 10 percent of these samples contained U_3O_8 in excess of 5 ppm; 90 percent of the samples contained less than 5 ppm U_3O_8.

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

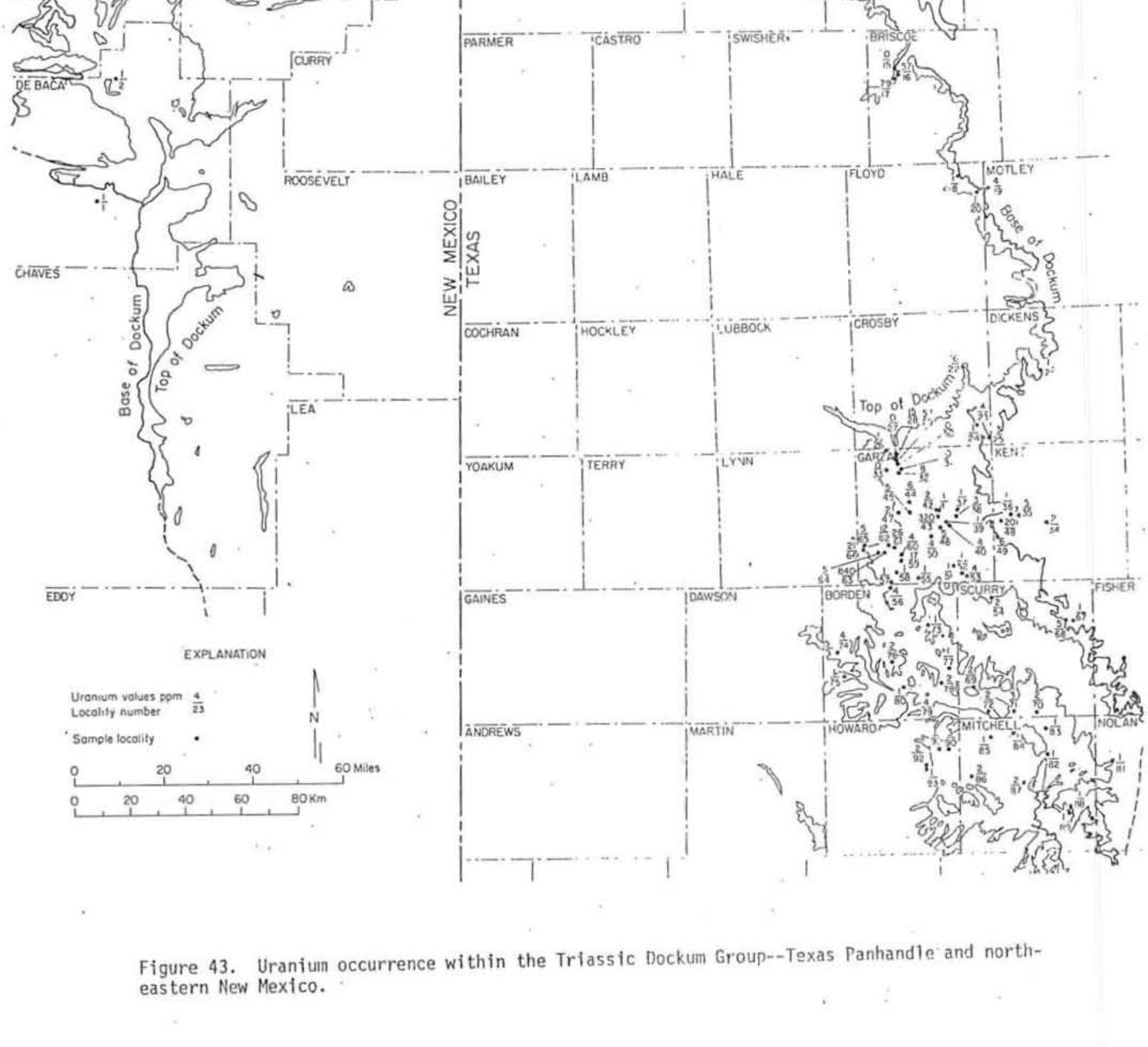


Figure 43. Uranium occurrence within the Triassic Dockum Group--Texas Panhandle and northeastern New Mexico.

Table 3. Associations among rock type, depositional environment (facies), and U_3O_8 content as determined from samples from 93 outcrop localities in Texas and New Mexico.

LOCALITY NO.	ROCK TYPE	ENVIRONMENT (FACIES)	U_3O_8 ppm
1	siltstone (Permian)	tidal flat	< 1
2	sandstone	braided stream	1
3.i	medium sandstone	braided stream	< 1
h	very fine sandstone	delta front	< 1
g	very fine sandstone	delta front	< 1
f	mudstone	lacustrine	< 1
e	fine sandstone	upper point bar	1
d	medium sandstone	lower point bar	< 1
c	sandy conglomerate	channel lag	2
b	medium sandstone	braided stream	1
a	intrabasinal conglomerate	braided stream	< 1
4	fine sandstone	delta front	1
5	fine-medium sandstone	braided stream	2
6	chert pebble conglomerate	braided stream	2
7	limestone	lacustrine	< 1
8	chert pebble conglomerate	channel lag	2
9.d	mudstone	distributary channel	< 1
c	mudstone	distributary channel	3
b	mudstone	distributary channel	< 1
a	conglomerate	distributary channel	3
10.d	sandstone	splay	1
c	sandstone	splay	< 1
b	sandstone	splay	< 1
a	mudstone	splay	2

LOCALITY NO.	ROCK TYPE	ENVIRONMENT (FACIES)	U_3O_8 ppm
11.q	mudstone	interdistributary	4
p	mudstone	interdistributary	2
o	mudstone	interdistributary	3
n	mudstone	interdistributary	< 1
m	sandstone	distributary channel	1
l	sandstone	distributary channel	1
k	sandstone	distributary channel	< 1
j	mineralized log	distributary channel	14
i	carbonized log	distributary channel (base)	40
h	sandstone	distributary channel (base)	< 1
g	mudstone	lacustrine	< 1
f	mudstone	lacustrine-interdistributary	1
e	mudstone	lacustrine-interdistributary	1
d	conglomerate	splay	2
c	mudstone	interdistributary	2
b	conglomerate	splay	1
a	mudstone	lacustrine-interdistributary	1
12.r	sandstone	fluvial channel fill	< 1
q	sandstone	delta front	< 1
p	sandstone	distributary channel	< 1
o	sandstone	delta front	2
n	mudstone	delta front	1
m	mudstone	interdistributary	< 1
l	mudstone	interdistributary	1
k	conglomerate	fluvial channel fill	1

LOCALITY NO.	ROCK TYPE	ENVIRONMENT (FACIES)	U_3O_8 ppm
12.j	conglomerate	fluvial channel fill	< 1
i	sandstone	fluvial channel fill	2
h	sandstone	fluvial channel fill	2
g	mudstone	interdistributary	3
f	conglomerate	splay	1
e	conglomerate	splay	3
d	mudstone	lacustrine	< 1
c	mudstone	lacustrine	< 1
b	mudstone	lacustrine	< 1
a	mudstone	lacustrine	2
13.h	conglomerate	delta platform	7
g	sandstone	delta front - splay	1
f	sandstone	delta front - splay	2
e	mudstone	delta front - splay	2
d	mudstone	lacustrine	2
c	mudstone	lacustrine	< 1
b	mudstone	lacustrine	3
a	mudstone	lacustrine	1
14.b	quartz geode	paleosol	< 1
a	quartz geode	paleosol	1
15	siltstone	floodplain	< 1
16	carbonized log	valley fill	57
17.c	carbonized log	channel lag	79
b	carbonized log	channel lag	15
a	carbonized log	channel lag	18

LOCALITY NO.	ROCK TYPE	ENVIRONMENT (FACIES)	U_3O_8 ppm
18	conglomeratic sandstone	braided stream	< 1
19.b	conglomeratic sandstone	lower point bar	< 1
a.	chert conglomerate	channel lag	4
20.e	sandstone	braided stream	1
d	conglomerate	braided stream	1
c	conglomerate	braided stream	1
b	sandstone	upper point bar	< 1
a	sandstone	upper point bar	1
21.f	conglomerate	abandoned channel fill	1
a	very fine sandstone	beach	< 1
22.e	alternating mudstone and sandstone	lacustrine	1
d	sandstone	lacustrine	4
c	mudstone-siltstone	lacustrine	3
b	mudstone	lacustrine	16
a	mudstone	lacustrine	5
23.g	conglomerate	braided stream	4
e	medium sandstone	delta front	< 1
d	fine sandstone	delta front	< 1
b	conglomerate	braided stream	1
a	siltstone	tidal flat (Permian)	2
24.e	mudstone and sandstone	abandoned channel fill	< 1
d	conglomerate	abandoned channel fill	1
c	very fine sand	delta front	< 1
b	fine sand	delta front	< 1
a	mudstone and sandstone	tidal flat (Permian)	1

LOCALITY NO.	ROCK TYPE	ENVIRONMENT (FACIES)	U_3O_8 ppm
25.d	conglomerate	channel lag	1
c	sandstone	delta front	< 1
b	fine sand	delta front	1
a	mudstone and sandstone	tidal flat (Permian)	3
26.g_3	conglomerate	distributary channel fill	1
g_2	sandstone	distributary channel fill	1
g_1	mudstone	distributary channel fill	< 1
b_2	red mudstone	lacustrine	< 1
b_1	green mudstone	lacustrine	1
27	mudstone-conglomerate	lacustrine-deltaic	not reported
28.c	fine sandstone	point bar	15
29.h	fine sandstone	delta front	23
e	mudstone	lacustrine	9
d	very fine sandstone	distal delta front	57
30	mudstone-sandstone	lacustrine-deltaic	not reported
31	conglomeratic sandstone	meanderbelt	not reported
32.q	fine sandstone	abandoned channel fill	< 1
p	very fine sandstone	abandoned channel fill	< 1
o	siltstone-sandstone	abandoned channel fill	1
n	sandstone	braided stream	< 1
m	sandstone	braided stream	< 1
l	sandstone	braided stream	1
k	sandstone	braided stream	2
j	sandstone	braided stream	< 1

LOCALITY NO.	ROCK TYPE	ENVIRONMENT (FACIES)	U_3O_8 ppm
32.i	sandstone	braided stream	1
h	sandstone	distributary channel fill	6
g	sandstone	distributary channel fill	1
f	conglomeratic sandstone	distributary channel fill	7
e	sandstone-conglomerate	delta front	4
d	sandstone	delta front	1
c	sandstone	delta front	4
b	mudstone-siltstone	lacustrine	8
a	mudstone-siltstone	lacustrine	2
33	mudstone-conglomerate	crevasse splay splay delta	not reported
34.e	mudstone	tidal flat (Permian)	2
d	siltstone-mudstone	tidal flat (Permian)	2
c	siltstone	tidal flat (Permian)	1
b	sandstone-siltstone	tidal flat (Permian)	< 1
a	very fine sandstone	tidal flat (Permian)	< 1
35.b	conglomeratic sandstone	channel lag	1
a	conglomeratic sandstone	channel lag	2
36.d_4	conglomeratic sandstone	abandoned channel fill	< 1
b_2	medium sandstone	abandoned channel fill	< 1
b_1	medium sandstone	abandoned channel fill	< 1
37.c	coarse sandstone	distributary channel	< 1
b	medium sandstone	delta front	2
a	mudstone	lacustrine	1
38	gray mudstone	abandoned channel fill	3
39.k	fine sandstone	point bar	1
f	conglomeratic sandstone	point bar	1

LOCALITY NO.	ROCK TYPE	ENVIRONMENT (FACIES)	U_3O_8 ppm
39.e	medium sandstone	point bar	1
40	carbonized log	point bar	4
	carbonized log	point bar	1
	carbonized log	point bar	< 1
	carbonized log	point bar	< 1
41.b	conglomerate	channel lag	1
a	sandstone	point bar	1
42.o	fine sandstone	point bar	1
h	fine sandstone	point bar	< 1
g	medium sandstone	distributary channel	< 1
f	conglomerate	distributary channel	1
e	fine-medium sandstone	delta front	< 1
c_2	conglomeratic sandstone	channel-mouth bar	< 1
c_1	fine sandstone	channel-mouth bar	< 1
b	very fine sand	delta front	1
43	mineralized calcite nodule in burrowed mudstone	lacustrine	320
44.i	muddy sandstone	floodplain	1
h	sandstone	point bar	< 1
g	sandstone	point bar	< 1
f	sandstone	point bar	< 1
d	conglomerate	channel lag	1
c	fine sandstone	point bar	2
a	mudstone	floodplain	6
45.d	conglomerate	crevasse splay	1
c	mudstone	floodplain	5

LOCALITY NO.	ROCK TYPE	ENVIRONMENT (FACIES)	U_3O_8 ppm
45.a	mudstone	floodplain	3
46.e_2	siltstone-sandstone	delta foresets	1
c_2	sandstone	splay delta	1
c_1	conglomerate	splay delta	3
a_8	mudstone	lacustrine	1
a_7	mudstone (burrowed)	lacustrine	1
a_6	mudstone (burrowed)	lacustrine	1
a_5	mudstone (burrowed)	lacustrine	2
a_4	mudstone (desiccated)	mudflat	5
a_3	mudstone	lacustrine	2
a_2	mudstone	soil horizon	1
a_1	mudstone	floodplain	1
47.f	sandstone	channel-mouth bar	< 1
e_2	sandstone (burrowed)	abandoned distributary	< 1
e_1	sandstone (burrowed)	abandoned distributary	< 1
d	conglomerate	distributary channel	2
c	mudstone	abandoned distributary	1
b	sandstone	distributary channel	1
a_2	sandstone	delta front	1
a_1	sandstone	delta front	1
48.d	fine sand	point bar	2
c	chert conglomerate	channel lag	20
49.m	conglomeratic sandstone	channel lag	6
l_6	sandstone	point bar	1
l_5	medium sandstone	point bar	< 1

LOCALITY NO.	ROCK TYPE	ENVIRONMENT (FACIES)	U_3O_8 ppm
49.1_4	sandstone-conglomerate	channel lag	1
k	mudstone-siltstone	lacustrine	2
f	mudstone	lacustrine	1
e	fine-medium sandstone	floodplain	1
d	mudstone-siltstone	tidal flat (Permian)	2
50.e	sandstone	braided stream	4
d	sandstone	braided stream	2
c	sandstone	braided stream	2
b	sandstone	braided stream	3
a	sandstone	braided stream	< 1
51.b	siltstone	delta foresets	1
52.b	fine sandstone	crevasse splay	1
a	fine sandstone	crevasse splay	< 1
53.c	mudstone-siltstone	floodplain	1
a	sandstone	meanderbelt	4
54.b	mudstone	lacustrine	1
a	mudstone	lacustrine	2
$55.b_5$	mudstone (burrowed)	lacustrine	1
$56.e_3$	mudstone-siltstone	lacustrine	2
e_2	mudstone-siltstone	lacustrine	2
e_1	mudstone-siltstone	abandoned channel fill	2
d	conglomerate	abandoned channel fill	4
c	mudstone-siltstone	abandoned channel fill	2
b_2	sandstone	abandoned channel fill	2
b_1	conglomerate	abandoned channel fill	4

LOCALITY NO.	ROCK TYPE	ENVIRONMENT (FACIES)	U_3O_8 ppm
56.a	mudstone	abandoned channel fill	3
57.j_2	manganese	point bar	1
j_1	limonitic log	point bar	2
i	sandstone	point bar	1
g	mudstone-sandstone	abandoned channel fill	2
e	mudstone	abandoned channel fill	2
d	sandstone	abandoned channel fill	1
c	sandstone	upper point bar	1
b	sandstone	upper point bar	1
a	sandstone	lower point bar	1
58.h	sandstone	channel-mouth bar	< 1
f	mudstone	lacustrine	1
e	mudstone	abandoned distributary	< 1
d	sandstone	distributary channel	< 1
b	mudstone	lacustrine	1
a	sandstone	delta front	< 1
59.g_3	mudstone-siltstone	delta foresets	2
e_3	mudstone-siltstone	delta foresets	5
e_2	mudstone-siltstone	delta foresets	< 1
e_1	mudstone-siltstone	delta foresets	16
d_2	mudstone-siltstone	delta foresets	< 1
d_1	mudstone-siltstone	delta foresets	17
c	conglomerate	splay	11
b	mudstone	lacustrine	< 1
a	mudstone	lacustrine	1
60.x_2	siltstone	paleosol	4

LOCALITY NO.	ROCK TYPE	ENVIRONMENT (FACIES)	U_3O_8 ppm
60.x_1	mudstone	paleosol	1
w_3	siltstone	lacustrine	1
w_2	mudstone	lacustrine	1
w_1	mudstone	lacustrine	1
v	mudstone-sandstone	lacustrine	< 1
t	mudstone	lacustrine	1
r	siltstone-sandstone	valley fill	1
p	siltstone	valley fill	< 1
h_2	siltstone	valley fill	< 1
h_1	siltstone	valley fill	1
c	mudstone-conglomerate	valley fill	< 1
b	siltstone-sandstone	valley fill	1
61.1	sandstone	delta front	1
i_3	sandstone	point bar	2
i_1	siltstone-sandstone	point bar	2
h_6	fine sandstone	delta front	15
h_4	conglomerate	frontal splay	26
h_1	fine sandstone	delta front	7
g	mudstone	lacustrine	3
f_4	conglomerate	frontal splay	6
f_3	siltstone-sandstone	delta front	3
f_1	fine sandstone	abandoned channel fill	3
c	siltstone-sandstone	delta front	5
a_4	conglomerate	frontal splay	5
a_3	siltstone	delta foresets	3

LOCALITY NO.	ROCK TYPE	ENVIRONMENT (FACIES)	U_3O_8 ppm
61.a_2	siltstone	delta foresets	6
a_1	siltstone	delta foresets	6
62.o_4	conglomeratic sandstone	point bar	1
o_3	sandstone	point bar	2
o_1	conglomerate	channel lag	2
n_2	mudstone-sandstone	abandoned distributary channel	< 1
m	sandstone	distributary channel	< 1
k_1	siltstone	abandoned distributary channel	1
j	sandstone	distributary channel	1
i	conglomerate	distributary channel	2
h	sandstone	proximal delta front	1
g	sandstone	distal delta front	1
e_{12}	mudstone	mudflat	12
e_8	mudstone breccia	mudflat	12
e_5	siltstone (burrowed)	lacustrine	2
e_4	siltstone (burrowed)	lacustrine	< 1
e_3	claystone-mudstone	lacustrine	1
e_2	siltstone-sandstone	interdeltaic	1
e_1	siltstone-sandstone	interdeltaic	< 1
d	conglomeratic sandstone	delta platform	< 1
c	mudstone-sandstone	delta platform	< 1
b_7	siltstone-conglomerate	delta foresets	< 1
b_6	mudstone-sandstone	delta foresets	1
b_5	sandstone	delta platform	1

LOCALITY NO.	ROCK TYPE	ENVIRONMENT (FACIES)	U_3O_8 ppm
62.b_4	sandstone	delta platform	1
b_3	conglomerate	delta platform	2
b_2	sandstone	channel fill	2
b_1	sandstone-conglomerate	channel fill	6
a	mudstone-sandstone	delta foresets	3
63.v_3u	sandstone	abandoned channel fill	2
v_3l	mudstone-sandstone	abandoned channel fill	2
v_2	siltstone	abandoned channel fill	2
v_1	siltstone	abandoned channel fill	2
t_2	mudstone-sandstone	abandoned channel fill	1
r	conglomerate	channel lag	2
p	mudstone-siltstone	paleosol	1
n_3	siltstone-sandstone	delta foresets	1
m_1	sandstone	splay	3
l	conglomerate	splay	4
k_{12}	siltstone	lacustrine	2
k_7	siltstone	lacustrine	2
j	sandstone	delta foresets	2
g_2	siltstone-sandstone	splay	5
d_4u	siltstone (burrowed)	lacustrine	840
d_4l	siltstone (burrowed)	lacustrine	1
64.o_3	mudstone	floodplain	2
o_2	sandstone	floodplain	< 1
l	conglomerate	channel lag	2

LOCALITY NO.	ROCK TYPE	ENVIRONMENT (FACIES)	U_3O_8 ppm
64.j	conglomeratic sandstone	channel lag	1
h_4	sandstone	point bar	< 1
h_3	conglomeratic sandstone	point bar	4
g	mudstone-siltstone	lacustrine	1
f_3	siltstone	delta foresets	1
65.s	sandstone	splay	2
r	mudstone	floodplain	1
q_2	sandstone	splay	2
q_1	sandstone-conglomerate	splay	< 1
p_2	sandstone	point bar	2
p_1	sandstone	point bar	1
n_4	mudstone-siltstone	floodplain	1
n_3	sandstone	point bar	1
n_2	sandstone	point bar	2
n_1	sandstone-conglomerate	channel lag	3
m	sandstone	delta front	2
l_4	mudstone (dessication-cracked)	lacustrine-mudflat	1
l_3	mudstone-siltstone	delta front	1
l_2	sandstone-conglomerate	splay	1
l_1	mudstone-siltstone	delta front	3
k_2	siltstone-sandstone	delta platform	1
k_1	sandstone-conglomerate	delta platform	1
j_3	siltstone	delta front	2
j_2	sandstone	delta front	< 1
j_1	sandstone	delta front	1

LOCALITY NO.	ROCK TYPE	ENVIRONMENT (FACIES)	U_3O_8 ppm
65.i	siltstone	delta front	2
h	mudstone-siltstone	lacustrine	1
g	siltstone	lacustrine	2
f	siltstone	lacustrine	5
e	siltstone	lacustrine	2
d_3	sandstone	splay	1
d_2	sandstone	splay	1
d_1	sandstone	splay	1
c	conglomerate	splay	3
b	conglomerate	braided stream	5
a	sandstone	channel fill	2
66a.b	sandstone-conglomerate	splay	3
a	siltstone-sandstone	delta foresets	1
66b.e	sandstone-conglomerate	delta platform	< 1
d_2	mudstone-sandstone	abandoned channel fill	< 1
d_1	sandstone-conglomerate	abandoned channel fill	3
b_1	siltstone-sandstone	levee	1
66b.a	sandstone-conglomerate	channel fill	4
66c.k_{1c}	siltstone-mudstone	levee	2
k_{1b}	siltstone-sandstone	floodplain	2
k_{1a}	sandstone	splay	< 1
j	mudstone	floodplain	2
i	sandstone	splay	21
g_{3b}	sandstone-conglomerate	point bar	1
g_{3a}	conglomerate	channel lag	1
g_2	sandstone	distributary channel	1

LOCALITY NO.	ROCK TYPE	ENVIRONMENT (FACIES)	U_3O_8 ppm
66c.g_1	sandstone	channel-mouth bar	1
f	conglomeratic sandstone	channel lag	1
e	sandstone	delta front	1
c	mudstone-breccia	lacustrine-mudflat	1
b	mudstone-sandstone	lacustrine	1
67	siltstone	tidal flat (Permian)	< 1
68	sandstone	meanderbelt	5
69.c	conglomerate	splay	2
b	siltstone (burrowed)	lacustrine-delta front	2
70	conglomerate	channel lag	2
71.h_{2b}	sandstone	splay	1
h_{2a}	conglomerate	splay	3
f	siltstone	splay	2
c	siltstone	levee	1
a_7	sandstone	point bar	2
a_4	sandstone	point bar	< 1
72	sandstone	meanderbelt	2
73	sandstone	delta front	1
74	mudstone-sandstone	abandoned channel fill	4
75	sandstone	crevasse channel	1
76.b	sandstone	braided stream	2
a	sandstone	braided stream	< 1
77	sandstone	point bar	< 1
78.a	sandstone	channel mouth bar	2
79.b	siltstone-sandstone	distributary channel	4
a	siltstone-sandstone	distributary channel	1

LOCALITY NO.	ROCK TYPE	ENVIRONMENT (FACIES)	U_3O_8 ppm
80.b	sandstone	meanderbelt	< 1
a	sandstone	meanderbelt	< 1
81	sandstone	meanderbelt	< 1
82	sandstone-conglomerate	meanderbelt	< 1
83	sandstone	meanderbelt	1
84.b	sandstone	meanderbelt	1
85	sandstone	braided stream	< 1
86.c	caliche	paleosol	1
b	gypsiferous mudstone	lacustrine	2
a	mudstone	lacustrine	2
87.d	sandstone	point bar	2
b_2	sandstone	point bar	< 1
88	conglomeratic sandstone	meanderbelt	1
89	siltstone-sandstone	tidal flat (Permian)	< 1
90.c	sandstone	delta front - lacustrine	1
b	sandstone	distributary channel	2
a	conglomerate	distributary channel	3
91.a	sandstone	channel fill	1
92	sandstone	distributary channel	< 1
93.eu	mudstone	floodplain	< 1
el	mudstone-siltstone	levee	1
d	siltstone	upper point bar	< 1
c	sandstone	upper point bar	< 1
b	sandstone	point bar (lateral bar)	1
a	sandstone	channel lag	1

Deltaic facies yielded 21 samples with U_3O_8 content in excess of 5 ppm. All of these samples were derived from six deltaic facies which, in order of decreasing numbers, are: (1) delta foresets (5 samples, range 5-17 ppm); (2) distributary channel and delta front (4 samples each, range 5-57 ppm); and (3) frontal splay and crevasse splay (3 samples each, range 5-26 ppm).

Ten samples collected from facies of the lacustrine system had U_3O_8 content in excess of 5 ppm. Two facies contained all these samples. "Lacustrine" facies yielded seven of these samples and exhibited U_3O_8 range of 5 to 840 ppm. Mud flat deposits (3 samples) had U_3O_8 range of 5-12 ppm.

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

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

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

RADIOACTIVE ANOMALIES FROM SUBSURFACE AND RADIOMETRIC DATA, DOCKUM GROUP

Within the subsurface, the Dockum Group exhibits some high, anomalous gamma-ray values. Units in which anomalous gamma log readings have been observed are assumed to contain concentrations of radioactive minerals adjacent to the borehole at that depth. Radioactivity peaks on gamma-ray logs were counted by visual estimate if their magnitude on the radioactivity scale was about two standard deviations greater than normal. A quantitative evaluation of radioactive anomalies is prohibited by the large number of non-standardized logging tools employed and the unknown value of variables associated with each logging run.

Anomalously high gamma-ray peaks were mapped for the total Dockum section and for stratigraphic subdivisions within the Dockum. The map for total Dockum includes, in addition to gamma-ray log data, published chemical analyses of outcrop samples and published aerial radiometric survey data. (Specific localities and references are recorded in Bureau of Economic Geology Open File Report.) Chemical analyses are included if the indicated uranium concentration is 20 ppm or above. Aerial radiometric data consist of $^{214}Bi/^{208}Tl$ and ^{214}Bi readings. Levels were considered anomalous if their magnitude was two or more standard deviations above normal. Groupings of two or more anomalies along a flight path are shown on the map. Concentrations of gamma log anomalies in and adjacent to Garza County, Texas correlate closely with anomalies from aerial and chemical data.

Areal distribution of anomalies within the upper Dockum cycle appears to be very uniform except around the margins of the upper Dockum sediment body (fig. 44). Where the thickness of the upper Dockum is less than 500 feet, the concentration of gamma log anomalies decreases toward zero. A uniform distribution of anomalies is consistent with a syngenetic concentration of uranium.

Distribution of anomalies is not uniform within the lower Dockum cycle (fig. 45). Areal clusters of anomalies are associated with lower Dockum sandstones (fig. 46). Of particular interest are the radioactive anomalies in the vicinity of Garza County, where known low-tonnage, near-surface concentrations of uranium have been prospected and mined (Finch, 1975b; Butler, et al., 1962). A high concentration of radioactive minerals (25 areas suggested by anomalous gamma-ray log peaks) consistently occur at the top of the lowest Dockum sandstone bodies. These sandstone bodies are interpreted as progradational deltaic sequences, and high radioactive values are inferred to occur within delta plain deposits. The association of radioactive anomalies and depositional facies suggests a syngenetic mode of emplacement. Another area of radioactive anomalies within the lower Dockum sandstones is Lubbock and adjacent counties. Distribution of these anomalies is associated with an area within the lower Dockum made up of a high sand percent (fig. 46). Anomalies occur in muddy facies near the top of the lowest Dockum sand sequence. The mode of emplacement probably is the same as for the Garza County area.

Two other areas that are characterized by high radioactive anomalies are: (1) Crane, Upton, and southern Midland Counties, and (2) Andrews, Martin, Dawson, and Gaines Counties. The southern area (area 1) lies within the high sand fan or fan delta system. The northern area (area 2) contains

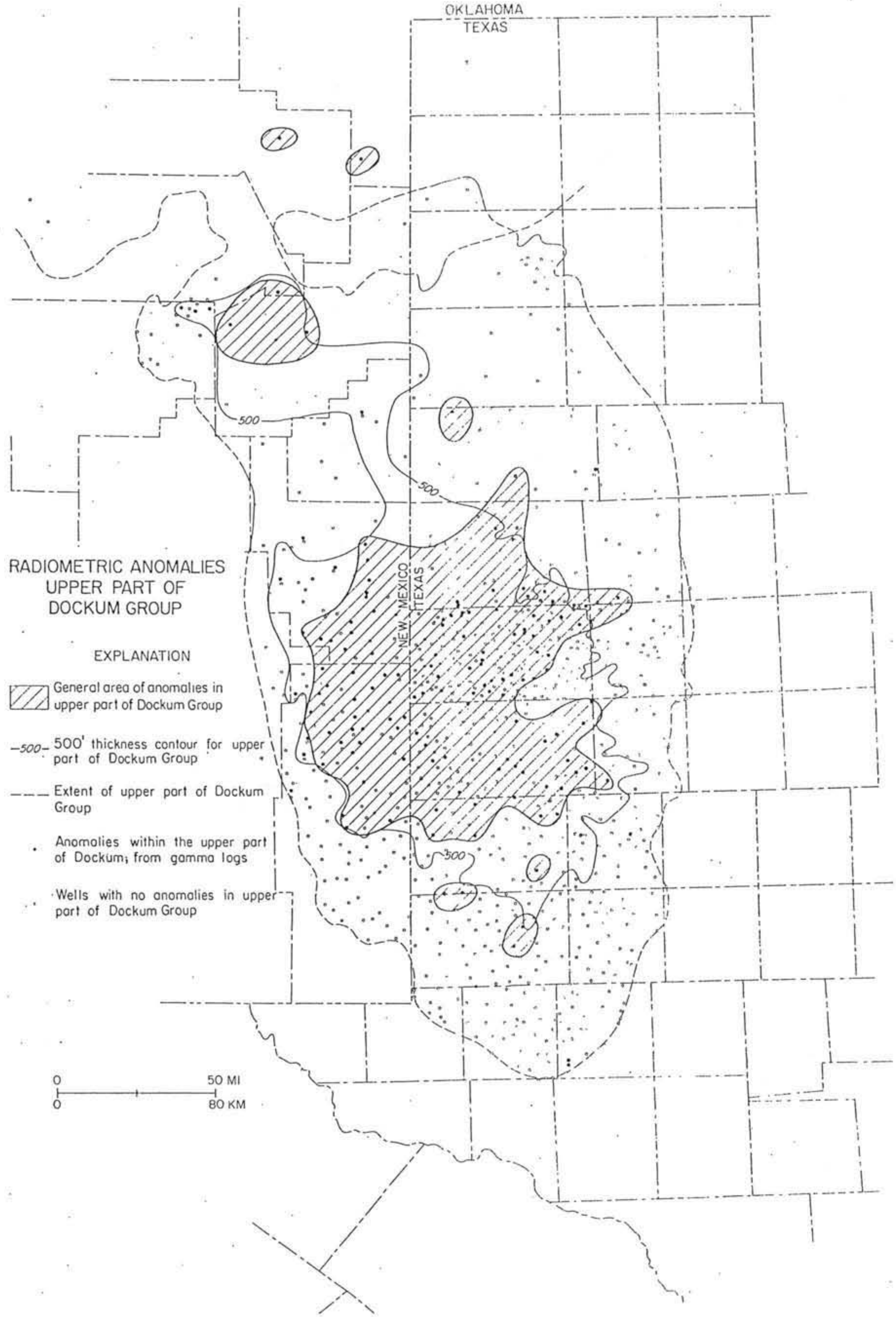


Figure 44. Radiometric anomalies (gamma log) within the upper part of the Dockum Group.

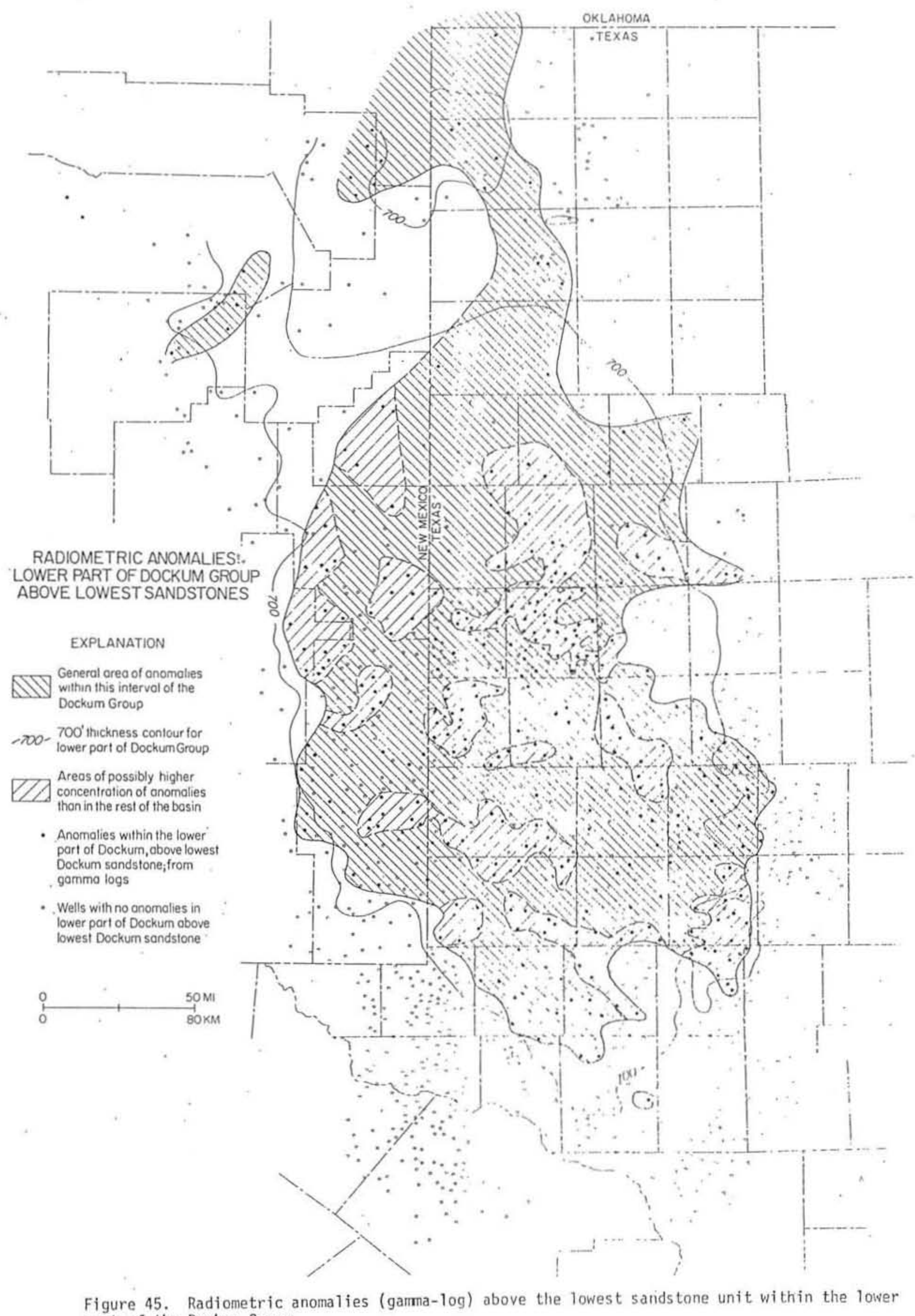


Figure 45. Radiometric anomalies (gamma-log) above the lowest sandstone unit within the lower part of the Dockum Group.

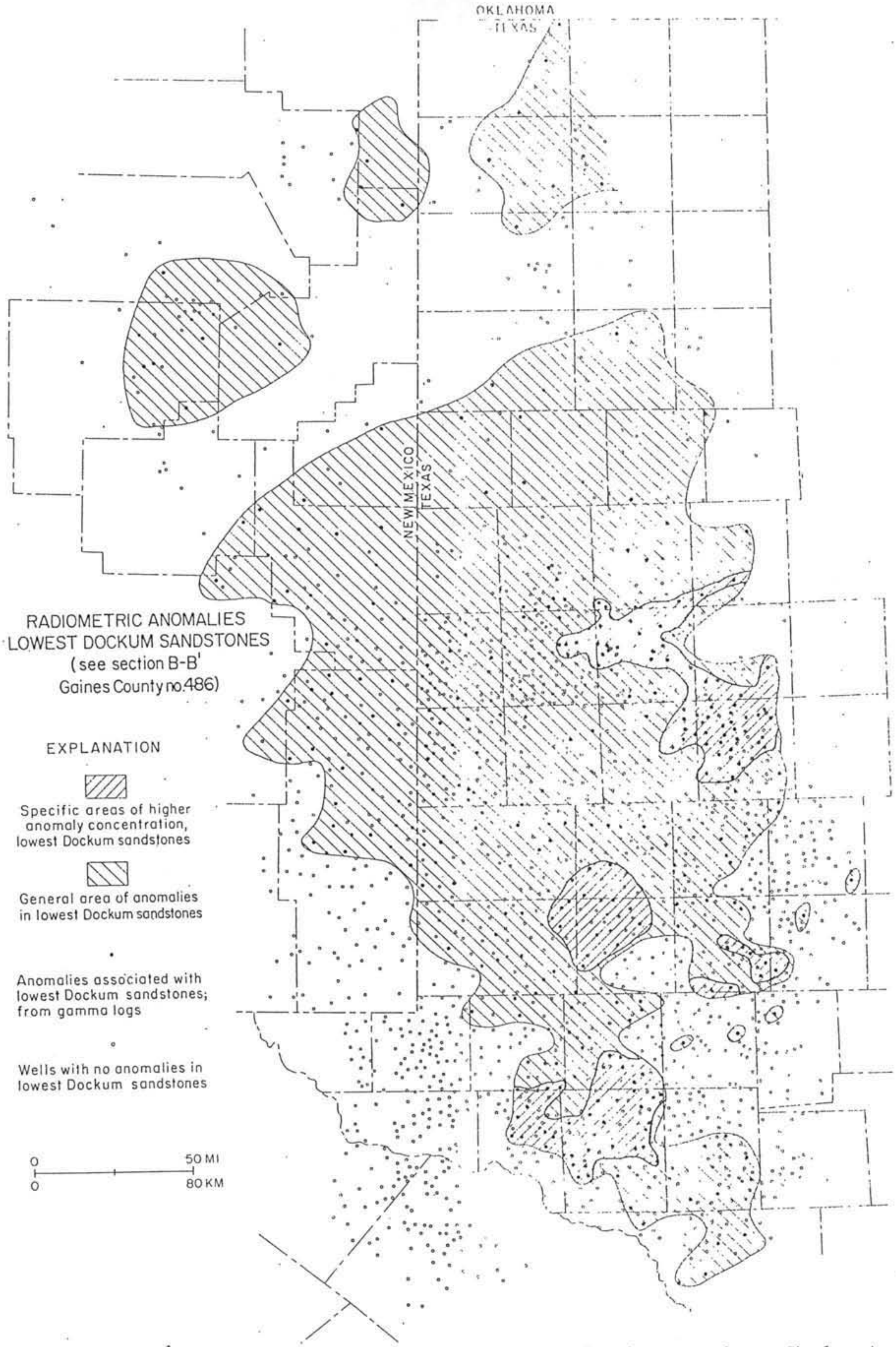


Figure 46. Radiometric anomalies, lowest Dockum sandstone, based on gamma logs. The lowest sandstones of the Dockum Group are facies of fluvial, deltaic or fan-delta depositional systems. This sandy section is composed of many laterally discontinuous sandstone bodies. For the purpose of this map "lowest sandstone" includes any continuous sandstone sequence extending upward from the base of the Dockum to the first major (40 ft) mudstone sequence.

anomalies within the mudstone facies overlying the lowest Dockum sandstone; this low percent sand coincides with the center of the Midland Basin. These two areas of radioactive anomalies and associated sedimentary rocks are known to occur only in the subsurface, therefore the specific nature of uranium occurrence is not known.

Several possible groupings of anomalies are contained within the upper part of the lower Dockum (fig. 45). Some groupings on this map probably arise from a random sampling of uniformly distributed anomalies; other groupings may be significant. One radioactive anomaly group in Yoakum County and another in Hockley County coincide with the downdip extent of two high sand systems that enter the Midland Basin respectively from the west and the northeast. Two other possible groupings (one in northwestern Lea, eastern Chaves, and southwestern Roosevelt Counties, New Mexico) and one in Howard and northern Glasscock Counties, Texas) are situated in low sand areas between areas of major sediment input.

Radioactive anomalies are absent over two positive structural features, the Central Basin Platform and an unnamed structural high along the southeastern edge of the Midland Basin (fig. 47). These areas may have served as ground-water recharge sites during and after Dockum deposition; consequently, uranium was flushed downdip. Another possibility is that these highs could have provided an elevated, oxidizing depositional environment which could have been unfavorable to syngenetic deposition of uranium.

The 600 feet (183 m) of Dockum strata in the Delaware Basin exhibit no radioactive anomalies. Geometry of the Delaware Basin and rocks contained herein has been greatly altered by up to 1500 feet (457 m) of subsidence into salt-solution troughs. Ground-water history of the Delaware Basin is complex and probably is responsible for the absence of radioactive anomalies. A

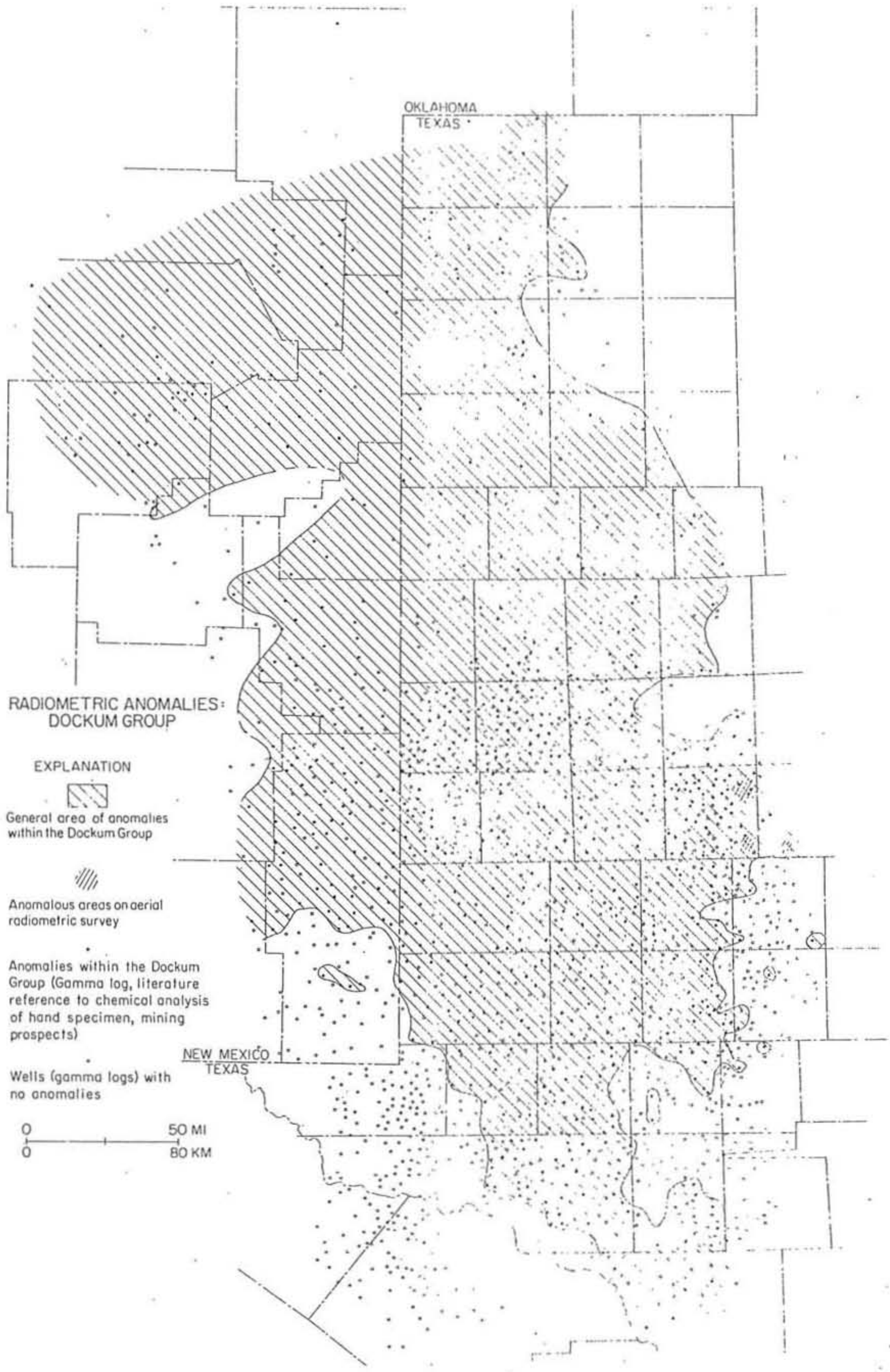


Figure 47. Radiometric anomalies, Dockum Group. Criteria for designating anomalies for gamma-ray logs discussed in text. Specific references for and locations of anomalies other than gamma-ray logs are listed in open file report at the Bureau of Economic Geology. Chemical anomalies based on greater than 20 ppm uranium. Aerial radiometric anomalies based on magnitude and density of standard deviations for both $^{214}Bi/^{208}Tl$ and ^{214}Bi along a flight path.

source of uranium possibly was absent for the Delaware Basin during Dockum deposition and/or during subsequent episodes of ground-water activity.

DEPOSITIONAL AND EROSIONAL EVENTS THAT AFFECTED THE DOCKUM GROUND-WATER SYSTEM

Triassic Events

An erosional unconformity exists between Permian and Triassic rocks in the northern part of the Texas Panhandle and in northeastern New Mexico. Elsewhere, sedimentation was continuous from Permian time through Triassic. Depositional style and setting changed from Permian into Triassic from tidal flat (sabkha) to fluvial-deltaic-lacustrine as a consequence of increased precipitation that was probably related to creation of the Gulf of Mexico by block faulting.

Sedimentary sequences preserved in the Dockum Group indicate alternating humid and arid climatic conditions; the cause of climatic fluctuations probably was tectonic events that created the Gulf of Mexico. Lake level and area were at a maximum during high rainfall periods. At this time, meandering fluvial systems and associated lobate deltas dominated the landscape in the central basin area of Texas and New Mexico; braided streams and fan deltas were major depositional elements in southern and northern basin areas. Arid cycles caused a considerable decrease in lake area and depth; this resulted in lowering of base level, scouring of valleys, cannibalization of older Triassic deposits, and construction of small fan deltas at margins of ephemeral lakes.

More than 2,000 feet of sediment, deposited under alternating humid and arid conditions, are preserved in the central part of the Dockum basin in

Texas and New Mexico. Sediment sources for the Dockum were mostly older sedimentary rocks exposed in New Mexico, Texas, and Oklahoma. These source areas are indicated by outcrop and subsurface sandstone trends, outcrop directional features, and composition of fluvial sandstones. Sandstone composition is different in outcrop areas around the basin; for example, (1) a coarse-grained sandstone from the Bissett Formation in Pecos County, Texas is an immature calclithite, (2) in Scurry County, Texas a very fine to fine-grained fluvial sandstone is a feldspathic litharenite with calcite and kaolin cement, and (3) the Santa Rosa sandstone in Guadalupe County, New Mexico is a medium grained quartz arenite with limonite cement. Within the outcrop belt in Texas there is a northward increase in feldspar content in fluvial sandstones; some fluvial sandstones in the Palo Duro Canyon area are subarkoses (Seni, 1978), suggesting some contribution from the Wichita Mountains in Oklahoma. Also, in outcrop within the Texas area, sandstones locally contain abundant biotite (some grains are hexagonal), suggesting a volcanic source to the south and southeast in the region now occupied by the Gulf of Mexico.

Post-Triassic Events

It is assumed that the Dockum lacustrine basin was filled prior to beginning of the Jurassic Period. Outcrop mapping by Eifler (1967, 1968, 1969, 1974) and subsurface work (this report) indicate that the Dockum Group is unconformably overlain in some areas by Lower Cretaceous strata and in other areas by the Pliocene Ogallala Formation. Following is the sequence of events subsequent to deposition of the Dockum Group: (1) Erosion of the Dockum during Jurassic and part of Early Cretaceous. (2) Deposition of Lower Cretaceous rocks. (3) Erosion during Late Cretaceous and Tertiary periods up to the Pliocene. (4) Deposition of an extensive wet alluvial fan system (the Pliocene Ogallala Formation) upon a highly dissected surface underlain by Lower Cretaceous and Triassic sedimentary rocks. (5) Development of extensive calcrete at the top of the Ogallala. (6) Development of Pleistocene lakes in which volcanic ash accumulated. Deposition of extensive aeolian cover sands. (7) Development of modern drainage.

HYPOTHETICAL EVOLUTION OF GROUND-WATER SYSTEMS

Triassic Depositional Stage

During early deposition of the Dockum Group ground water was, for the most part, unconfined. Surface water moved from drainage basins during humid cycles through meandering streams and delta distributaries into the lake or lakes. Part of the fresh water was trapped within newly deposited fluvial and deltaic sands, and some water moved by infiltration process into fluvial and deltaic sands. Sands of the fan deltas at the north and south ends of the basin also contained ground water. Ground water moved down depositional slope through fan delta deposits (north and south basin areas), meanderbelt and lobate delta sands (central basin areas). Some ground water was discharged at or near the lake surface. Ground-water flow during early deposition of a humid cycle was from north, east, south, and west down depositional slope toward the lake or lakes.

Arid climatic conditions caused a decrease in lake size and depth, a lowering of base level, and creation of stream valleys. Surface water flow was down depositional slope from drainage basin, through stream valleys, across fan deltas, and into shallow ephemeral lakes. Surface water and ground-water flow were somewhat different from flow during humid climatic conditions. Rainfall was probably intense and of short duration during this time. Vegetation was sparse and consequently there was short lag between precipitation and runoff. Discharge was flashy and infiltration was minimal. Since valleys were cut as much as 200 feet into the older Dockum deposits which contained ground water, it is possible that (at least during early stages of erosion) ground water flowed from the older Dockum sandstones toward, and perhaps into, the valleys. Ground water contained within fan delta deposits was probably discharged near the transition between delta foresets and lake bottom sediment, onto the floor of ephemeral lakes.

Because of the continually changing climatic conditions that were accompanied by fluctuating base level there should have been a tendency for ground water to continually transport materials in solution toward ephemeral lakes. Materials contained in solution in ephemeral lake and adjacent "low-stand" fan deltas should have been concentrated further through evaporation processes. Evidence that evaporative processes were operative during Dockum time are exhibited as silcrete, chert modules, caliche nodules and lenses, thin dolomite beds, salt casts, and gypsum crystals.

Triassic Shallow Burial

As deposition continued within the Dockum basin, the older water-bearing strata were buried beneath younger deposits, some of which were mud that formed an aquitard, which presumably was impermeable and prevented vertical movement of ground water from one sediment type into another. During this phase of development, ground-water flow was confined or semiconfined (fig. 48). Flow was still down depositional slope from all sides of the basin. It is possible that there was vertical movement (either upward or downward) of ground water from less permeable strata into more permeable strata. In this

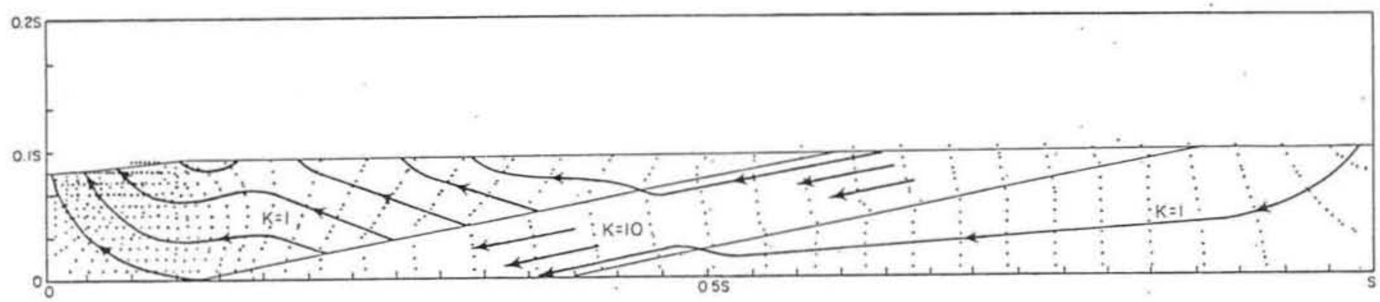


Figure 48. Possible ground-water flow in Dockum strata during early deposition-shallow burial stage. High permeability (K=10) dipping unit. Major movement is down the high-K unit with some discharge into the overlying low-K unit (after Kreitler, 1978).

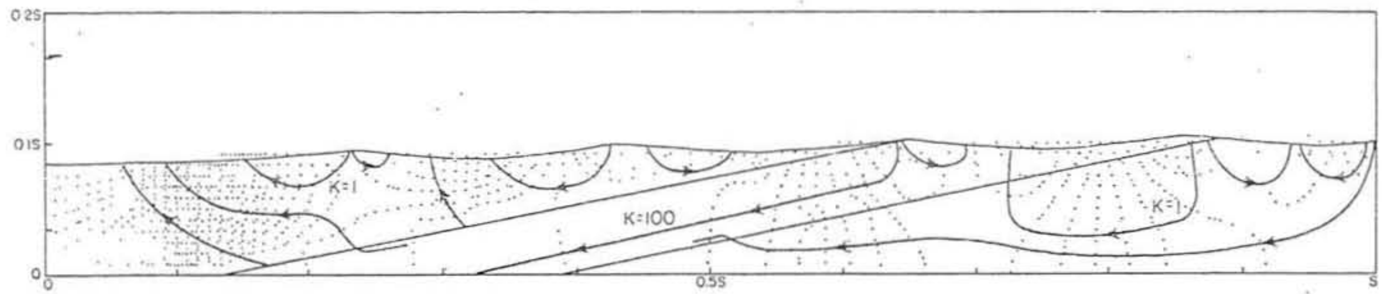


Figure 49. Possible ground-water flow in Dockum strata following deposition during Triassic and erosion during Jurassic and Cretaceous. Topography affects near-surface flow. It reduces flow down the aquifer, but does not, in general, affect regional ground-water flow (after Kreitler, 1978).

situation materials in solution in waters of mudstones or siltstones could move upward or downward into reducing ground water contained within sandstones.

Post-Dockum Erosion

Stream erosion into the Dockum during Jurassic and Early Cretaceous probably affected ground-water flow in the recharge zone but had little effect on the deeper parts of the ground-water system. Valleys were eroded into the Dockum at this time, and it is assumed that by this time regional surface drainage had changed from a general westward flow (in Texas) to eastward or Gulfward flowing streams. Valleys that existed during Jurassic and Cretaceous time probably received some water from Dockum aquifers. Whatever materials that were contained in solution in the ground water contributed to Jurassic and Cretaceous streams moved eastward beyond the outcrop limits of the Dockum.

Cretaceous Deposition--Burial of the Dockum

Dockum ground-water chemistry and flow direction probably were altered during the Cretaceous as a consequence of sedimentation and marine transgression. Fluvial, deltaic, and shelf environments migrated across Texas into New Mexico during initial transgression. With these changes in environment the recharge areas of the Dockum, both in Texas and New Mexico, were affected first by fresh water from streams, next by a mixing of fresh and marine water, and finally by marine waters. Depth of invasion of marine water is not known, but certainly there must have been a salinity and chemical gradient in the ground-water system similar to that shown by Kreitler (1978). Because of the timing of the marine transgression and direction of dip of Dockum strata (to the west in Texas and to the east in New Mexico) the gradient could have been more pronounced along the east side of the Dockum basin.

Post-Cretaceous Erosion

Much of the Cretaceous cover was stripped from the underlying Dockum Group sometime between Cretaceous and Pliocene time. Valleys were incised across Cretaceous and Triassic strata by streams flowing eastward from the Rocky Mountains. Local ground-water flow was most likely influenced by erosional topography; ground-water flow within Cretaceous and Triassic aquifers was toward erosional valleys (fig. 49).

Pliocene Deposition

Local and regional ground-water flow pattern, at least in the upper part of the Dockum Group, probably was altered as a consequence of widespread deposition of gravel and sand during the Pliocene as a wet alluvial fan. Depositional slope of the Ogallala (Pliocene) alluvial fan was generally to the east; this direction of slope coincides with slope of the Dockum in New Mexico, but is opposed to the westward dip of the Dockum in Texas.

Wet alluvial fans are constructed entirely by fluvial processes that operate at high intensity over relatively short periods of time. Discharge of some streams that construct Modern wet alluvial fans is in the range of the Mississippi River during flood stage (Gole and Chitale, 1966). A significant volume of that discharge is lost by infiltration into the underlying porous and permeable alluvial fan deposits. The volume of ground water that moves from apex to toe, where it is discharged, is tremendous. Flooding of rivers that build the large wet fans occurs each year but lasts about three months. During the remainder of the year the streams are virtually dry and the zone of saturation moves downward in the fan deposits; the oxidation zone increases in thickness until the onset of the next flood.

Sand bodies of the Ogallala wet alluvial fan and the upper part of the older Dockum Group are juxtaposed (they are in contact) as a result of stream incision. During and after deposition of the Ogallala an integrated aquifer system comprising Ogallala and Dockum sands (sandstones) was developed.

Because of this integrated ground-water system, the large volume of water that moved through the Ogallala fan and the direction of movement of ground water, generally toward the east, it is postulated that regional flow in the upper part of the Dockum was dramatically changed in the eastern part of the basin. Flow direction on the western side of Dockum basin was to the east and down depositional slope in both the Ogallala and Dockum. Ground-water flow in Ogallala and Dockum on the east side of the basin was also to the east; this would be down depositional slope in the Ogallala, but up depositional slope in the Dockum (fig. 50).

Post-Pliocene Erosion

The gently dipping surface of the Ogallala wet alluvial fan has been altered considerably since Pliocene time. Erosion in New Mexico, Colorado, and elsewhere along the eastern front of the Rocky Mountains, has severed the Ogallala from its recharge area. The Ogallala in Texas occupies or forms the Llano-Estacado which is being dissected by headwardly eroding streams. Recharge of the Ogallala is now very slight and results from downward percolation of water that is trapped in soils, wind-blown sand, and solution lakes. Natural ground-water movement is most likely controlled by topography; flow is toward streams and valleys.

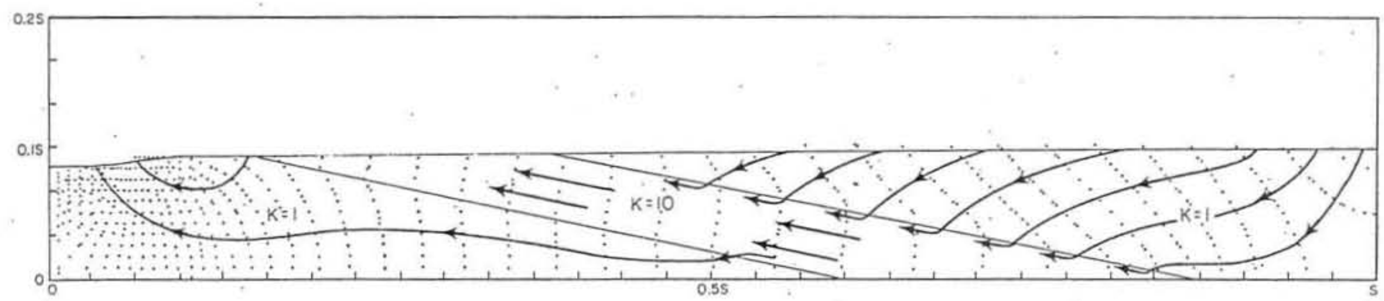


Figure 50. Dip of hydraulic gradient is opposite that of stratigraphic dip. Flow is up stratigraphic dip, and ground-water discharges into what would be considered a classic recharge zone. This situation is postulated for flow in the Dockum Group on the east side of the basin subsequent to accumulation of the Pliocene Ogallala wet alluvial fan (after Kreitler, 1978).

POSSIBLE URANIUM SOURCES, MECHANISM AND TIMING OF EMPLACEMENT

Granitic and volcanic rocks (mostly ash) are the common source materials of uranium that occur in sedimentary rocks. Granitic rocks occur in the Wichita Mountains of Oklahoma. Triassic volcanic rocks: (1) are associated with horst and graben that are now buried beneath the Gulf coastal plain, (2) occur in northern Mexico, and (3) occur in southwestern New Mexico and southeastern Arizona. These granitic and volcanic sources could have supplied sediment to the Dockum basin. Volcanic activity was widespread during Cretaceous time, and ash might have been incorporated with the terrigenous clastics that accumulated above the Dockum in Texas and New Mexico. Ash deposits are contained in the Pliocene Ogallala Formation. Each of these sources could have contributed uranium to the Dockum.

Feldspar content is greater in fluvial sandstones of the Palo Duro-Tule Canyon area than in fluvial sandstones in Texas to the south or in northeastern New Mexico. Uranium content of sandstones in Palo Duro-Tule Canyon area is higher than in comparable rocks in northeastern New Mexico or in Texas southward to the Matador Arch area. Relatively high uranium content coincident with an increase in feldspar content suggests that granitic rocks of the Wichita Tectonic System could be a source of uranium. Uranium in this area is epigenetic, is contained in sandstone hosts, and was emplaced by ground water that flowed from east to west. It is postulated that uranium was emplaced during the Triassic. One can speculate that, because of continuously fluctuating lake level, uranium was precipitated and remobilized repeatedly during the Triassic. Therefore, it is possible that only small uranium deposits will be found in outcrop and shallow subsurface.

Relatively high uranium values are widely distributed in Dockum strata that crop out in an area defined by southern Crosby County southward to

Mitchell County. Within this area sandstones and siltstones contain a significant amount of biotite which is assumed to be derived from a volcanic source. It is possible that the source of ash and biotite was Triassic volcanics in Texas and northern Mexico. Although ash or tuff have not been recognized in Dockum deposits indirect evidence, volcanic biotite and montmorillonite, suggest that volcanic activity transpired during the filling of the Dockum basin. It is unlikely that ash blanketed the basin. Most likely ash and tuff accumulated in the upland areas east and south of the basin where they weathered to form montmorillonite which was subsequently eroded and transported by streams to lake margin areas. Uranium was probably released from ash and tuff in the uplands and transported basinward through meandering streams. Uranium emplacement was early (probably prior to cementation of sandstones and dewatering of mud and silt); a syngenetic origin of the deposits is possible.

Uranium mineralization in the Dockum directly beneath Cretaceous and Pliocene sandstones and conglomerates is most likely related to ash contained within these younger rocks and to Cretaceous and Pliocene aquifers. Chemistry of Ogallala and upper Dockum ground water (Seni, 1977) substantiates the idea that Ogallala and upper Dockum ground-water systems are interconnected. Uranium that was released from ash in the Ogallala probably moved downward through the Ogallala then into underlying upper Dockum. Movement of ground water through both Ogallala and Dockum strata was from west to east. During early phases of uranium mobilization and ground-water movement, funneling of flow probably occurred within erosional lows that were scoured into the Dockum. It is postulated that as ground water moved eastward through these erosional conduits that water migrated laterally (through valley walls) and downward into the Dockum; since the Dockum was virtually blanketed by Ogallala there was downward movement of ground water everywhere into the Dockum, particularly into the sandstones. Most of the uranium in the upper Dockum was probably derived from leaching of ash within the Ogallala; some uranium may be related to enrichment during Triassic and Cretaceous time. It is possible that flow of ground water through the Ogallala and upper Dockum accounts for low values observed in the Dockum in New Mexico but relatively high values in outcrop on the Texas side of the basin. Ground-water flow through the Ogallala might have caused enrichment in the upper Dockum in some areas, whereas uranium was possibly remobilized and moved out of the Dockum in other areas. It is postulated, however, that enrichment of the upper part of the Dockum is of epigenetic origin related to eastward movement of ground water through the Ogallala.

Since the Pleistocene there has been an ever-decreasing amount of ground-water movement through the Ogallala. The Ogallala has been dissected, and natural flow is mostly toward modern streams and valleys. Upward ground-water movement and evaporation have resulted in development of extensive caliche within the Ogallala. This evaporative process should have served to concentrate uranium in the caliche.

CONCLUSIONS

Dockum Group (Late Triassic) is the product of a continental regime. Dockum sediment accumulated in a fluvial-lacustrine basin that was in marked contrast with the "restricted sea" of the Late Permian-Early Triassic whose deposits were typified by alternating terrigenous clastics, evaporites, and carbonates which accumulated in a shallow hypersaline sea in tidal flat and sabkha environments.

Initiation of Dockum sedimentation began with the opening-up of the Gulf of Mexico, a tectonic event that produced block faulting in the area of the present Gulf coastal plain, reactivated (uplifted) relict Paleozoic structural elements, produced a change in atmospheric conditions sufficient to cause a transition from arid "Permian" conditions to humid "Triassic" conditions and was accompanied by volcanic activity. Sediment was delivered to the Dockum basin by streams that headed in Texas, New Mexico, and Oklahoma. Older sedimentary rocks were the major sediment sources. Granitic rock fragments were transported from the Wichita Tectonic System in Oklahoma south and southwestward to the Dockum basin. Volcanic debris, derived from the block-faulted area, accumulated to the south and east of the basin where it was weathered (possibly under humid climatic conditions) then was transported by streams to the Dockum basin.

Uranium occurs in the Dockum in amounts ranging from a few parts per million to several hundred parts per million. Sources of uranium are indicated to be granitic rocks in Oklahoma, Triassic volcanic rocks in Mexico and Texas (now buried beneath the coastal plain), and volcanic ash contained within the Pliocene Ogallala Formation. Uranium occurrence and depositional facies are closely allied, but this association has been somewhat modified by a complex ground-water history. Since the depositional history of the Dockum Group was one of fluctuating lake level (alternating humid and arid climatic conditions), any early (syngenetic) uranium deposits would have had short residence time; uranium was repeatedly oxidized, mobilized, transported by the ground-water system, and re-precipitated in a new locale in successively more basinward positions. Ground-water flow paths were altered by erosion during Jurassic and Cretaceous time, and ground-water chemistry was altered as Cretaceous seas transgressed the area; redistribution of shallow subsurface uranium deposits resulted from these changes in ground-water flow and chemistry. A reversal in direction of ground-water flow within the upper part of the Dockum in Texas came about with deposition of the Ogallala wet alluvial fan systems; flow on the east side of the basin was to the west until the eastward flow was established within the Ogallala. Uranium occurrence within the Dockum has been influenced by: (1) sources of uranium, (2) depositional facies which provided the sedimentary hosts and requisite reductants, and (3) a complex of ground-water systems ranging in age from Triassic through Recent times during which man has altered the system. Uranium occurrence in outcrop and shallow subsurface bears the imprint of perhaps the youngest major ground-water system; this would be the Ogallala system at the time its recharge area was adjacent to the Rocky Mountains. Only the deeper uranium occurrence (regional radiometric anomaly) at the top of the lowest progradational sequence possibly escaped redistribution by changing flow patterns and water chemistry.

Possible uranium prospecting areas and/or stratigraphic horizons are: (1) Palo Duro-Tule Canyon area, (2) southern Dickens to Mitchell County area, (3) the regional radiometric anomaly at the top of the lowermost progradational sequence, and (4) Dockum rocks immediately below the Ogallala Formation. Sediment transport in the Palo Duro-Tule Canyon area was to the west and southwest; granitic detritus was derived from the Oklahoma area; ground-water flow was for the most part down depositional slope; trends within uranium-bearing strata should be to the west and southwest. Sediment transport within the Dickens-Mitchell County area was to the west and northwest; uranium-bearing volcanic debris was derived from an area now buried beneath the Gulf coastal plain; ground-water flow during Triassic was down depositional slope; trends within uranium-bearing strata should be to the west and northwest. Regional radiometric anomaly within the subsurface above the lowermost progradational sequence, if proven to be uranium-bearing, would have to be produced by a leaching process; uranium emplacement and concentration were probably during Triassic time through an evaporative and/or soil-forming mechanism. Trends of uranium-bearing deposits within the Dockum beneath the Ogallala should parallel the paleotopographic lows cut into the Dockum, the trends of Dockum sandstone bodies, and the direction of Pliocene-Pleistocene ground-water flow.

Additional research that would aid the understanding of uranium distribution and enhance the possibility of discovering uranium deposits within the Dockum would be: (1) a petrographic-geochemical study of soils (calcrete, silcrete, etc.) in the Palo Duro-Tule Canyon area, (2) continued investigation of ground-water flow history, and (3) a coring program designed to test select areas of the Dockum beneath the Ogallala Formation.

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Cross Section A'-A

Pecos	
852	H. Hunt, 4, Wimberly
306	Phillips, A-1, Harral
503	El Paso Nat. Gas, D-1 Winfield
473	Gulf, ST-1, Warnock
615	H.O.R., 10, Wilbanks
312	J. Grim, 1, Neal
Reeves	
340	Sinclair, 2, Fidelity Trust
256	Sinclair, 1, Ligon
Ward	
422	Dixilyn Drlg., 1, Kimbell
61	Argo A., 1, Wilson et al.
472	L. Crumleg, 1, O.P.A.
Loving	
171	Penzoil, 26-1, University
129	F. Chapman, 1, Haley
128	Sinclair, 2, Gills
7	Argo, O., 1, Linberg
140	Redfern & Herd, 1, Brunson
Lea, N.M.	
26S, 33____, (D93)	Hill and Meeker, 1, Hall Fed.
23S, 33____, (D81)	Conoco, 1, Levick Ford.
22S, 33 9	Dral Prod. Co., 1, Hudson Fed.
20S, 33____, (D67)	El Cinco O., 1, Shell Fed.
18S, 33____, (D53)	Hudson & Hudson, 2, Inverson Fed.
16S, 33, 26	Conoco, 1, Williams Ranch
14S, 32, ____, (D28)	Texaco, 1, State AU
13S, 32, 19	Superior, 1-335, State

Cross Section A'-A (Cont'd)

Chaves, N.M.	
10S, 31, 22	Hall, 1-G, State
8S, 30, 2	MWJ Prod., 1, Cato St.
Roosevelt, N.M.	
5S, 30, ____, (D5)	Tidewater, 1, Boone
Chaves, N.M.	
3, 27, 14	Sunray Dx, AK-1, State
1S, 26, 21	Sandefer, 1, Vaugn
De Baca, N.M.	
2N, 25, 18	Twentieth Century, O, 1, Myrick
3N, 24, 6	General Crude, 1-A, Fed.
Guadalupe, N.M.	
5N, 23, 11	Felmant O., 1-A, Whitaker
7N, 22, 15	Baker and Taylor, 1, Smith
8N, 22, 20	Thompson, et. al., 1, Tucumcari Nat. Bank
10N, 22, 22	General Crude, 1, Spires
11N, 21, 22	Cities, 1, Driggers
14N, 21, 13	H.O.R. 6-34-13, Core lab.

Cross Section B-B'

Dallam, Tx

9	Shell O, 1-2, Simms
18	Standard, 1, Hill

Hartley, Tx

20	Sinclair, 1, Reynolds
26	Standard, 1, Buzzard
29	Bridwell O, 2-A, Hougetan

Oldham, Tx

3	Shell, 80-1, Fulton
4	Superior, 3, Matador
19	Pan Am Pef. 1, Whales

Deaf Smith, Tx

12	L. P. Oil Comp, 1, Morgan Jones
3	Honolulu, 1, Ponder

Parmer, Tx

4	Gulf Oil Corp., A-1, Keliehot

Castro, Tx

4	Skelly O.C., 1, S. Wilson
15	Amarillo Oil Co., 1, L. C. Boothe
1	Sun Oil Co., 1, W. C. Vselton

Lamb, Tx

14	Anderson Prichard O. Corp., 1, E. M. Getty
78	Sinclair Oil & Gas Co., 1, Roy Gilbert
28	L. C. Hewitt Trustee, 1, Cunningham

Hockley, Tx

136	De Kalb Argicultural Ass. Inc., 1, R. M. Smith
16	Delfern O.C., 1, Mitchell
28	Stanolind O & G, 1, W. J. Powell
96	Amerada Pet. Corp., 2, Brown

Cross Section B-B' (Cont'd)

Hockley, Tx

347	S & W Richardson, 33, S. A. Slaughter
21	Gulf Oil, 26, Malleh Ld & Co.

Terry, Tx

137	H. W. Baxter & Great Western Drilling Co., 1, Pool
132	Sun Oil Corp., 1, Laura Winn
130	Phillips Pieta Co., E-1, John
207	Placid Oil Co., 1, Von Rosenberg

Gaines, Tx

486	Texaco, 1, Hudson
507	Anderson Prichard, 1, Boldin
96	McDaniels & Beechel, 1, Radford Grocery Co.
465	Cities Service, A-1, Pruett

Andrews, Tx

34	Pan-Am Pet., CU-1, V.St.

Martin, Tx

101	Texaco, X-1, Univ.
179	Leland Davison, 1, Mabee
89	Gulf, B-3, Glass
45	Blackwood & Nichols, 1, Stimson

Midland, Tx

281	Ashum & Hilliard O, et al., 1, Jones
121	Moore Expl., 1, Dowler-Houpt
125	York & Harper, A-1, TXL
23	T.X.L. Oil, A-1, Bryant
333	J. Connally O., 44-1, Shackelford

Upton, Tx

104	Amerada, 1-44, Tippett
180	Humble, 12, Pembrook

Cross Section B-B' (Cont'd)

Reagan, Tx

231	Blackwood & Nichols
109	Humble, N-1, V.St.
437	Sunray, Dx, 25-2, U.St.
9	W. Bakke, 1, Gulf, Vist

Crockett, Tx

39	Hydro Drlg., 2, Neal
678	M. Bryant, 1, Shannon
766	Conoco, A-24, Shannon

Cross Section C-C'

Carson, Tx

68	Pure Oil, 1, Reed

Armstrong, Tx

22	Suray, SP 13, E. Palo Duro
17	Suray, C.D.H, 3, E. Palo Duro
1	Burdell O, 1, McGehee

Swisher, Tx

5	Standard O.C., 1, Johnson

Briscoe, Tx

1	Gulf, D-1, S. A. Rogers

Swisher, Tx

9	Frankfort O. C., 1, Sweatt

Hale, Tx

53	Ed Ogles Worth, 2, Biers
41	Permian Basin O. C., 1, T. A. Shipp
44	Russell O Magire, 1, Wherley
20	Honolulu O. Corp, 1, Martha Schultz

Lubbock, Tx

24	Standard Oil & Gas Co., 1, G. G. Flinn
93	Roden O., 1, Bozeman
81	Miles Kernaghan, 1, Sherrod
39	DOB Oil Properties, Inc., 1, Boyd

Crobsy, Tx

28	Stephens Petr. Co., 1, Forrest

Garza, Tx

139	Garret Oil, 1, Stulle
135	K. E. Parr et al, 1, Ray Collins
423	Honolulu Oil Corp., 6, Richardson Unit

Cross Section C-C' (Cont'd)

Garza, Tx (Cont'd)

264	Sinclair O & G., 2, Jones
397	D. J. Stonir Oil & Gas Operations, 5-1, Post estate
458	Duncan Drlg., 1-A, Kirkpatrick
395	D. J. Stone Oil & Gas Operations, 1, Moore-Connel
453	R. S. Anderson, 1, Connell
49	R. S. Anderson, 5, Standlind-Stoker
42	R. S. Anderson, 1, Miller "D"

Scurry, Tx

280	Bright & Schiff, 1, Clawson
214	Humble Oil & Rfg., 11, Shannon
9	Sun Oil Co., B-4, Randals
180	Lone Star Prsd. Co., 1, McLaughlin
377	Robinson Drlg. Co., 1, C. H. Toombs

Mitchell, Tx

14	Theiss Drlg., C3, Strain
79	Pan Am, 1, Barber
23	Humble, 1, Cooper
32	Conoco, 1, Ellwood

Sterling, Tx

156	Great Western Drlg., 1, McCube
143	Monsanto, 1, Lea
141	HMH Operators, 2A, Ray

Cross Section L-L'

Guadalupe, N.M.	
8N, 22, 20	Thompson, et al., 1, Tucumcari Nat. BAnk
7N, 22, 15	Baker and Taylor, 1, Smith
5N, 23, 11	Felmont O., 1-A, Whitaker
DeBaca, N.M.	
3N, 24, 6	General Crude, 1-A, Fed.
2N, 25, 18	Twentieth Century O., 1, Myrick
Chaves, N.M.	
1S, 28, 4	McAdams, 1, White
Roosevelt, N.M.	
2S, 30, 36	Baker & Taylor, 1, State
4S, 32, 29	Austral O., 1, Sadler
6S, 34, ___(D13)	Sunray Dx, 1, N.Mex. St. "FF"
7S, 36, 29	Pam Am, A-1, Peterson Fed.
8S, 37, 14	Shell, 1, Bluitt
Cochran	
260	Texas Pac. Oil Co., 1, H. B. Robb, Jr.
149	Monterey Oil Co., 1, F. O. Masten
8	Great Western Procedures, 22-2, Starries
209	J. M. Huber & J. P. Wagner, 1, M. E. Daniel
Yoakum	
209	Cabot Carbon, 1-4, Walser
23	Paul Musslewhite, 1, Bob Lackey
Terry	
103	Phillips Pieta. Co., E-1, John

Cross Section M-M'

Pecos, Tx

876	HOR-, B-1A, Elsinore
424	Hunt, 20, Elsinore
767	HOR, D-2, Pike's Peak
194	Hunt, 2, Elsinore
429	Great Western, 1, Oates
182	Stanolind, A-1, State
180	J. Meriwether, 1, Leon Farms
538	Humble, 1606, Ft. Stockton Unit
615	HOR, 10, Wilbanks
485	Amerada Petroleum Corp, A-1, E. O. Reed
288	Texaco, 1, Athins
383	El Paso, 1, Athins
595	J. C. Barnes, 1 or Unit 8, Jackson
209	Thornbury-Gas et al., 1, Pecos

Crane, Tx

485	Southland Log, 2, Evdaly
194	Texaco, 1, Evdaly
389	Asell, 1, Adams
606	Moran Bros., 1, Reed
184	Gulf, 855-E, Waddell
608	Atlantic, 36, Barnsley
100	Ohio Oil, A-2, Barnsle
123	Gulf, 3E, Lea
79	Magnolin, 43, Lea
495	Phillips, W-1, University
469	Gulf, My-1-D, State University
440	R. Wood Et al, 1, University
134	Kewanee Oil, E-7-Ohio

Upton, Tx

77	Wilshire Oil, 14-117, McElroy

Cross Section W-W'

Harding, N.M.	
18N, 30, 28	SEC. Corp., 15, Mitchell
18N, 32, 14	H.O.R., CM-1, State
Union, N.M.	
18N, 34, 31	H.O.R., CK-1, State
Quay, N.M.	
17N, 36, 28	H.O.R., Co-1, State
Hartley, Tx	
1	Skelly, 1, Castleberry
26	Standard, 1, Buzzard
B-60	Michigan-Wisconsin Pipeline, 1, Collins
Moore, Tx	
56	Phillips, 2, Ellis

Cross Section X-X'

Guadalupe, N.M.	
10N, 22, 22	General Crude, 1, Spires
10N, 23, 32	General Crude, A-2, Simpson
10N, 23, 21	LaMance Drlg., 1, Simpson
11N, 24, 25	H.O.R., 6-43-25, Core Test
11N, 26, 17	H.O.R., 6-14-17, Core Test
San Miguel, N. M.	
12N, 29, 18	Miami Pet, 2, Hoover
12N, 30, 17	Puretex, 2, Chappel
12N, 32, 11	O. Ledgerwood, 1, Kimes
12N, 34, 35	Penrose, 1, Tippin
Oldham, Tx	
B-68	Livermore, 1, Moser
19	Pan Am Pet., 1, Whales
27	Shell, 2-58, Strat Test
37	Shell, 1-60, Alamosa
Potler, Tx	
B-14	H.O.R., 1, Emeny
17	J. Brown, 1, Hill
88	Asarco, WOW-1-29, Amarillo field
Carson, Tx	
68	Pure O., 1, Read

Cross Section Y-Y'

Eddy, N.M.	
18S, 29, ___(D6)	Leonard O., 1, Fed. Parcell
19S, 31, ___(D10)	Cherry Bros., 3, Featherstone Fed.
Lea, N.M.	
18s, 32, ___(D52)	Shell, 1, Querecho Plains
18S, 34, ___(D54)	Conoco, 1, Tonto Deep
18S, 35, ___(D55)	Sinclair, 1, State Lea 403
18S, 37, ___(D57)	Conoco, 1, North Hobbs Unit
18S, 39, ___(D58)	Bishop Canyon Uranium Corp., 1, Gule Tomlinson
Gaines, Tx	
118	Anderson Prichard O., 4, Jones
125	Shell, 16, Leaverton
188	Amerada, 1, Riley
523	Childress Royalty O., 1, O.D.C.
39	Osmonds, 1, Morris
Terry, Tx	
207	Placid Oil Col, 1, Von Rosenberg
3	Fullitation Oil Col, 1, Taylor
167	Greenbriel Oil Co., 1, Johnson
Lynn, Tx	
94	McAlester Drlg., 1, Edwards
B8	Argo O., 1, Edwards
73	Dekalb Ag. Assoc. & Balbon O., 1, Terry
29	Roland S. Bond, 1, H. V. Wheeler
Crosby, Tx	
34	Sinclair O & G., 1, Guy Price
66	H. L. Hunt, 1, Jones
63	Morris R. Antweil, E-A1, English
13	Tidewater Assoc. O. C., 1, Hickman

Cross Section Z-Z'

Loving, Tx	
79	Sinclair, 1, Bailey
67	LeBland et al., 1, University
Winkler, Tx	
651	Healey & LeBlond, 1-23, University
142	Shell, 21-A-1, University
66	Noel & Rodman, C-3, Hendricks
4	Hudson & Hudson, 7, Halley
597	J. Champlin, 1, Mitchell
299	Stanolind, A-1, Wight
Ector, Tx	
1126	Texaco, B-4, T. Thomas
743	Texas Pacific Coal & Oil & Eastland Oil, C-1, Johnson
532	Sinclair, B-41, Johnson
158	Felmont, 1, Parks
Midland, Tx	
462	Texaco, 1-B, Bryant
281	Ashum & Hilliard O., et al., 1, Jones
321	F. Holbrook & Brennard, 1, McAlister
Martin, Tx	
44	Union Sulphur, 1, Snyder Arnett
71	Stanolind, A-2, Mulkey
Howard, Tx	
466	National Associated Pet., 1, Quinn
88	Ibex, 6, Velma
6	Cosden Pet., B-4, PeHerson
10	Stanolind, D-1, T.X.L.
229	J. Williamson & J. Barnes, 1, Wade
231	R. Smith, 1, Barber
402	Sunoco, 1, Snyder

Cross Section Z-Z' (Cont'd)

Mitchell, Tx	
87	Robinson Drlg., 2, Waston
79	Pan Am, 1, Barber
184	Seaboard, 1, Thompson
24	Flour Bluff O., 1, Girvin
207	Great Western Drlg., 1, Bauman