Geological Circular 84-5

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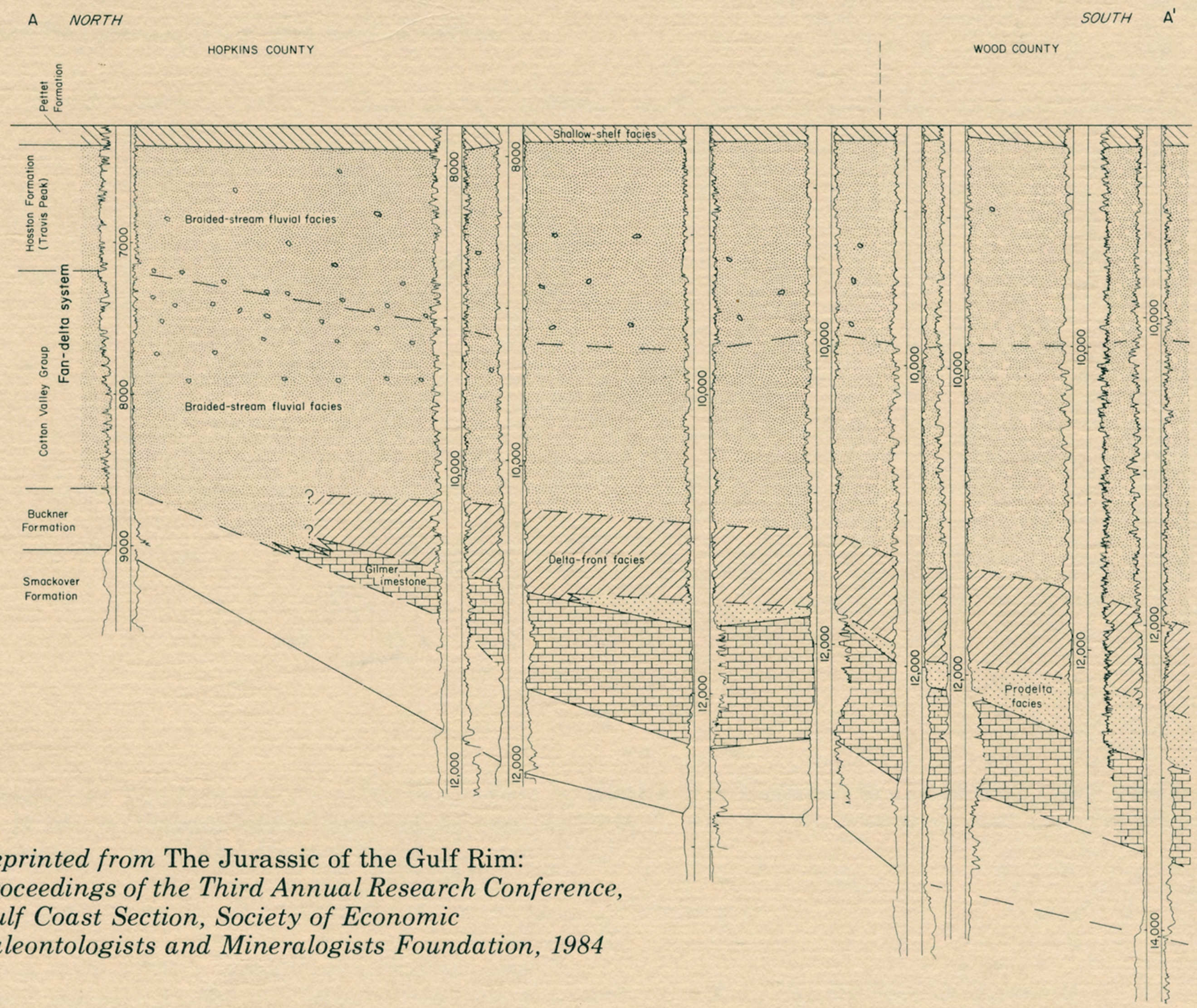

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COTTON VALLEY (UPPER JURASSIC) AND HOSSTON (LOWER CRETACEOUS) DEPOSITIONAL SYSTEMS AND THEIR INFLUENCE ON SALT TECTONICS IN THE EAST TEXAS BASIN

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ABSTRACT

Correct interpretation of the effect of basin infilling on salt mobilization is critical to understanding salt dome growth and stability. The size of salt structures in the East Texas Basin is determined by the original thickness of the underlying Louann Salt (Middle Jurassic): that is, salt structures distinctly increase in size toward the interior of the basin. Initial movement of salt apparently occurred in the marginal areas of the basin during Smackover (Late Jurassic) deposition. This movement seems to have resulted from downward creep that was induced by loading of carbonate units and was enhanced by basinward tilting.

During a major shift from carbonate to clastic sedimentation in the Late Jurassic, salt movement became more extensive. This salt migration was caused by uneven sediment loading of fluvial-deltaic systems in the Cotton Valley Group (Upper Jurassic) and the Hosston Formation (Lower Cretaceous). Terrigenous source areas to the west and north persisted throughout Cotton Valley and Hosston time. Clastics were delivered to the East Texas Basin by many small streams, rather than by one major stream, because a mature drainage system had not yet formed.

The Cotton Valley Group, which is thought to be a fan-delta system, can be subdivided into three types of facies: prodelta deposits, delta-front deposits, and braided fluvial deposits. Fan deltas, supplied by braided streams, prograded from the north, northwest, and west. Dip-oriented sandstone trends dominate in the northwestern part of the basin and change basinward to northeast to southwest strike-oriented trends.

During Hosston time, sedimentation in the northwestern part of the basin was dominantly fluvial. The depositional characteristics of sediments in this area are typical of braided streams. In the study area, parallel net-sandstone and sediment thicks are clearly defined in the distal part of the Cotton Valley but are not as well defined in the Hosston. This suggests that most deltaic sedimentation during Hosston time occurred basinward of the study area. A major transgression at the end of Hosston time resulted in deposition of the Pettet Limestone.

Apparently, the location of salt domes and salt anticlines was controlled by the position of the Smackover-Gilmer carbonate platform. This platform impeded local subsidence to the extent that fan-delta sediments

of the Cotton Valley Group spread laterally across the shelf rather than stacked vertically. Sediment depocenters formed preferentially basinward of the platform, resulting in migration of the underlying salt into ridges that fronted the prograding sediment wedge. As the salt was depleted under these depocenters, subsidence slowed and thereby allowed the fan deltas to override the salt ridges. This resulted in a basinward progradation of deltaic depocenters and produced younger depocenters toward the interior of the basin. Further salt migration and differentiation of salt ridges produced the present complex array of salt domes and anticlines of the East Texas Basin. Seismic and gravity data clearly demonstrate the existence of these salt ridges and intervening sediment thicks.

INTRODUCTION

The Cotton Valley Group (Upper Jurassic) and Hosston Formation (Lower Cretaceous) were studied as part of the East Texas Waste Isolation project being conducted by the Bureau of Economic Geology for the U. S. Department of Energy. The purpose of the project is to assess the suitability of salt domes in the East Texas Basin as potential repositories for nuclear waste; this suitability is contingent on the tectonic stability of the domes. The objective of the present analysis was to investigate the effect of early basin infilling on salt mobilization in the East Texas Basin. Understanding the mechanisms responsible for early salt movement is essential to predicting domal growth evolution and ultimate stability.

An area in the northwestern part of the East Texas Basin consisting of seven counties--Hunt, Hopkins, Wood, Rains, Kaufman, Van Zandt, and Henderson--was selected for the study of the relationship between salt movement and the influx of Upper Jurassic terrigenous clastic sediment. The study area was chosen for two reasons: first, because preliminary studies indicated the presence of a fan-delta system prograding from the northwest and north into the basin (McGowen and Harris, 1981) and second, because deep-well-control, seismic, and gravity data were available.

Salt movement began at different times in different parts of the basin. The earliest movement occurred around the margins of the basin during Smackover deposition (Jackson and Harris, 1981). At that time, increased subsidence toward the center of the basin caused basinward tilting that, induced by downward creep, mobilized salt.

More extensive salt movement occurred after the influx of Cotton Valley clastic sediment during the Late Jurassic (Fig. 1). Before that time, deposition in the East Texas Basin was dominated by carbonates, evaporites, and marine mudstones and claystones. Salt movement apparently was controlled by differential loading of Upper Jurassic and Lower Cretaceous fluvial-deltaic systems, as well as by the position of the subjacent Smackover-Gilmer carbonate shelf complex (Jackson and Harris, 1981; McGowen and Harris, 1981).

Data Base

Electric logs from 232 wells (Fig. 2), supplemented by Bouguer residual gravity maps and two dip-oriented, six-fold conventional CDP seismic profiles, served as a data base for this study. When possible, well data were integrated with seismic data by using velocity conversion tables. Five seismic reflectors within the Mesozoic were used, including the base of the Louann Salt, the top of the Louann Salt, the top of the Gilmer Limestone (Cotton Valley Limestone)(Forgotson and Forgotson, 1976), and the top of the Pettet Limestone (Table 1). The fifth reflector, which we believe is the top of the Massive Anhydrite, was used in the northern part of the basin, where the Pettet Formation changes lithologically from a limestone facies to a sandy facies and thereby loses its character as a distinct seismic reflector. The Louann Salt is characterized by prominent boundary reflections (Jackson and Harris, 1981). Its inferred thickness, based on

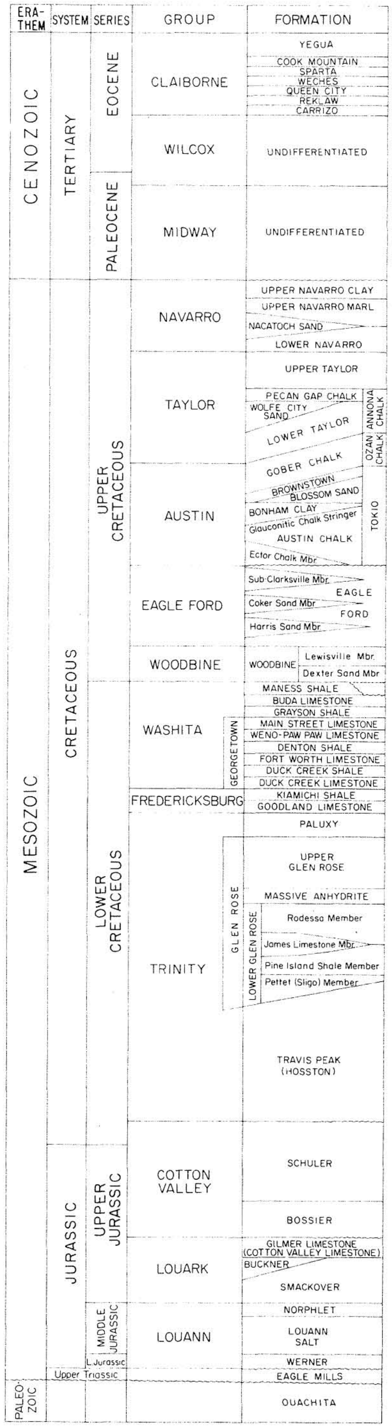


Figure 1. Stratigraphic succession and nomenclature in the East Texas Basin (Wood, 1981).

seismic interpretation, was correlated with

Table 1. Seismic Reflectors and Seismic Units In the Northwestern Part Of the East Texas Basin

SEISMIC REFLECTOR	SEISMIC UNIT
Upper Navarro Marl	
Top of the Pecan Gap Chalk	
Top of the Austin Chalk	
Top of the Buda Limestone	
*Top of the Massive Anhydrite?	
*Top of the Pettet Limestone	D
*Top of the Gilmer Limestone	C
*Top of the Louann Salt	B
*Base of the Louann Salt	A

*Seismic reflectors used in this study.

gravity data. Zones of thicker salt generally coincide with gravity lows, whereas areas of thinner salt correspond to gravity highs (Jackson and Harris, 1981) (Fig. 3).

Isopach, net-sandstone, and sandstone-percent maps of the Cotton Valley Group and the Hosston Formation were prepared. The boundary between the two was based on scout card information and regional correlations within the East Texas Basin. Using the Pettet Limestone as a datum, nine stratigraphic cross sections were constructed within the study area; selected sections are included in this report (Fig. 2).

Limitations of this data base include the following: First, although well spacing within individual oil and gas fields is good, overall spacing is poor, precluding detailed mapping of the Cotton Valley Group and Hosston Formation on a regional scale. Second, because conventional-core data were not available to verify environmental interpretations, facies designations were based entirely on electric log response and on sand-body geometry determined from net-sandstone maps, sandstone-percent maps, and textural and compositional features observed in well cuttings. And third, because Jurassic formations in northeast Texas are restricted to the subsurface, facies relationships of surface exposures could not be examined.

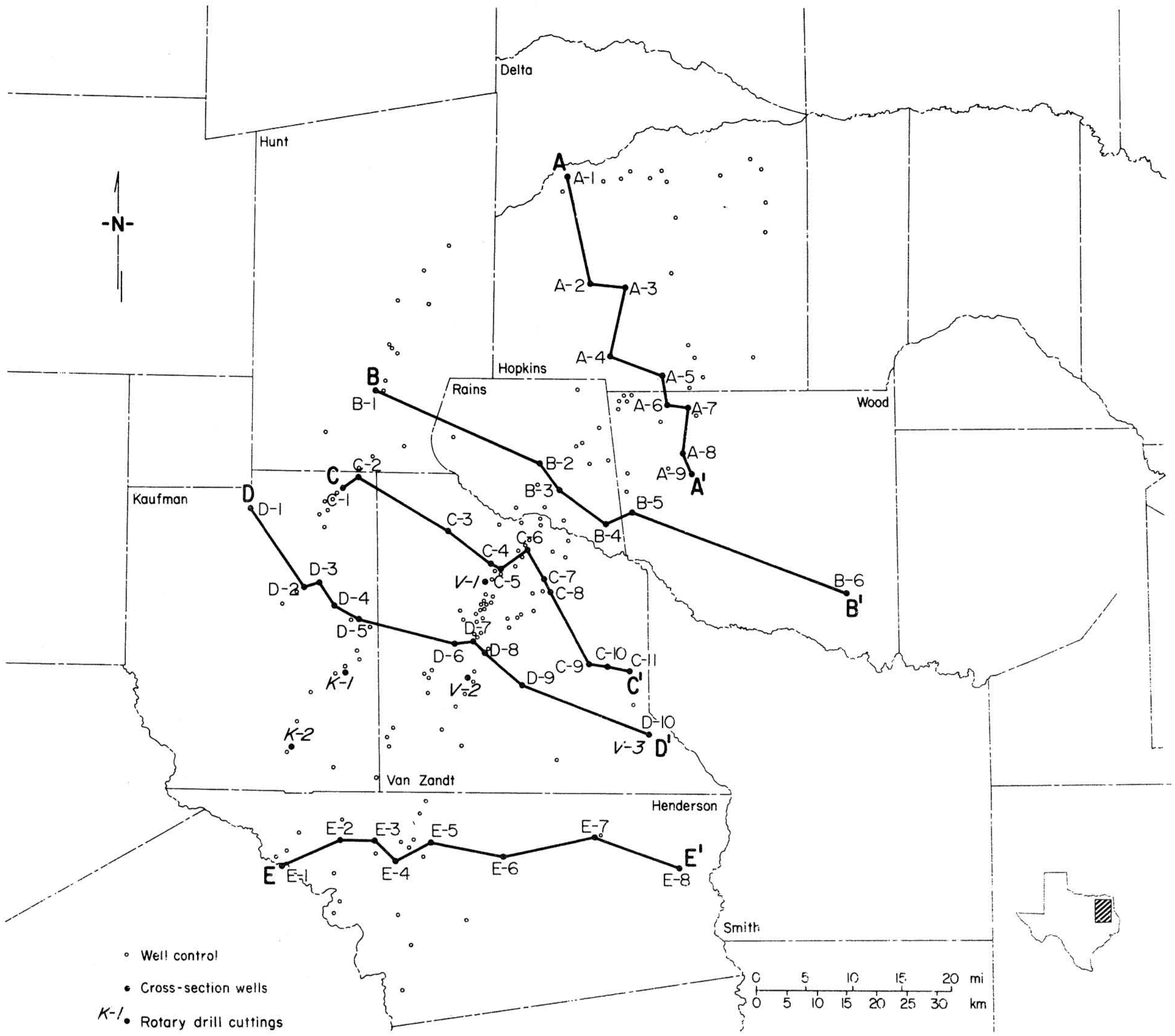


Figure 2. Index map showing well control, well cuttings, and location of stratigraphic cross sections.

Previous Work

Early work on the Cotton Valley Group (Upper Jurassic) and the Hosston Formation (Lower Cretaceous) in the East Texas Basin emphasized regional stratigraphic and environmental synthesis; the limited number of wells penetrating the Jurassic section precluded more detailed studies. Regional studies that provide excellent background material include Imlay (1943), Swain (1949), Forgotson (1954), Bushaw (1968), Dickinson (1968), Nichols *et al.*, (1968), and Newkirk (1971). Todd and Mitchum (1977) were the first to present seismic data on the Jurassic section in East Texas and identified several distinct seismic sequences within the section by integrating seismic data with lithologic, environmental facies, biostratigraphic, radiometric, and well-log information.

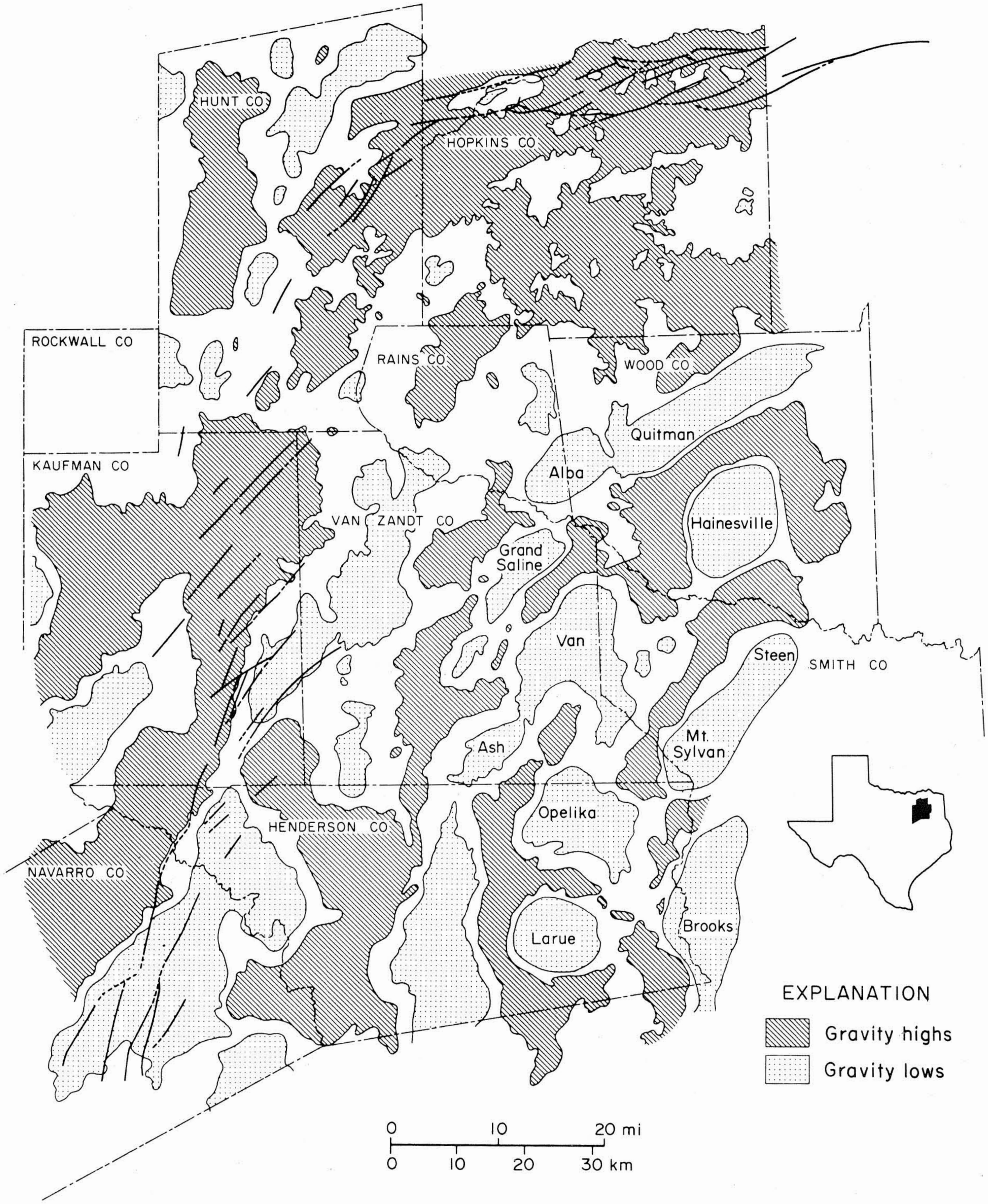


Figure 3. Generalized residual gravity map (modified from map done by Exploration Techniques, Inc.).

TECTONIC FRAMEWORK

The East Texas Basin is recognized as a subbasin, or reentrant, of the larger Gulf Coast Basin (Wood and Walper, 1974; Walper, 1980). Most researchers agree that the East Texas Basin was formed from one of either the megashear zones, the rift grabens, or the aulacogens that formed along the margins of the Gulf of Mexico, probably coincident with the breakup of Pangea and the separation of North and South America during the Triassic (Kehle, 1971; Burke and Dewey, 1973; Moore and Del Castillo, 1974; Wood and Walper, 1974; Beall, 1975; Salvador and Green, 1980). Kehle (1971) suggested that the interior salt basins of Mississippi and northern Louisiana also are foundered grabens that are marginal to the ancestral Gulf Coast Basin. Major tectonic elements in and around the East Texas Basin are shown in Figure 4.

Tectonic History

Kehle (1971) and Wood and Walper (1974) maintained that the development of the interior salt basins resulted from the opening of the Gulf of Mexico. They described the history of these interior salt basins as follows: The interior salt basins (Mississippi, North Louisiana, East Texas, and Salinas Basins) represent the most marginal grabens that are associated with continental rifting. These grabens were initially filled with alluvial-fan deposits of the Eagle Mills Formation. With prolonged spreading, however, the interior grabens continued to founder. The southern margin of the East Texas Basin may have been elevated, thereby restricting circulation of sea water between the basin and the Gulf of Mexico. Evaporites of the Werner Anhydrite and Louann Salt were precipitated, possibly by the brine-mixing process (Fig. 7 of Raup, 1970).

Continued subsidence resulted in open marine conditions; this is evidenced in the widespread occurrence of carbonates in the Smackover and Gilmer Formations. One of the characteristics of rifting is that during the early stages the bounding crustal blocks tilt away from the incipient rift, allowing large quantities of terrigenous clastics to enter the basin only when the dip of the rift margin reverses. The major influx of terrigenous clastics into the East Texas Basin during the Late Jurassic (Cotton Valley) and Early Cretaceous (Hosston) may reflect this dip reversal.

Salt Tectonics

Two general observations about salt structures in the East Texas Basin can be made: First, the size and type of salt-related structures seem to be directly controlled by the thickness of the underlying salt. This relationship was also observed in the interior Mississippi salt basin by Hughes (1968). Second, salt apparently migrated at different times in different parts of the East Texas Basin through several mechanisms: faulting (common in the marginal areas of the basin) (Parker and McDowell, 1955; Rosenkrans and Marr, 1967; Hughes, 1968); gravity gliding of post-Louann strata, which was caused by basinward tilting (Kehle, 1971; Jackson and Harris, 1981); and mass imbalance caused by uneven sediment loading (Rogers, 1967; Turk, Kehle, and Associates, 1978; McGowen and Harris, 1981).

Dome Growth Mechanisms. Kehle(1971) maintained that uneven sediment loading is the dominant mechanism responsible for salt dome initiation. He observed that the density inversion caused by uneven sediment loading is accentuated in the resulting salt flow because the viscosity of salt is highly sensitive to shear stress. Kehle concluded that the unequal pressure gradient set up within a salt mass because of uneven sediment loading is dependent on the slope of the overlying sediment, which in the present study is a deltaic lobe.

Loocke (1978) applied this principle to the East Texas Basin, suggesting that the growth of the Hainesville salt dome (south-central Wood County) was initiated by mass imbalance caused by the progradation of Cotton Valley deltas into that part of the ba-

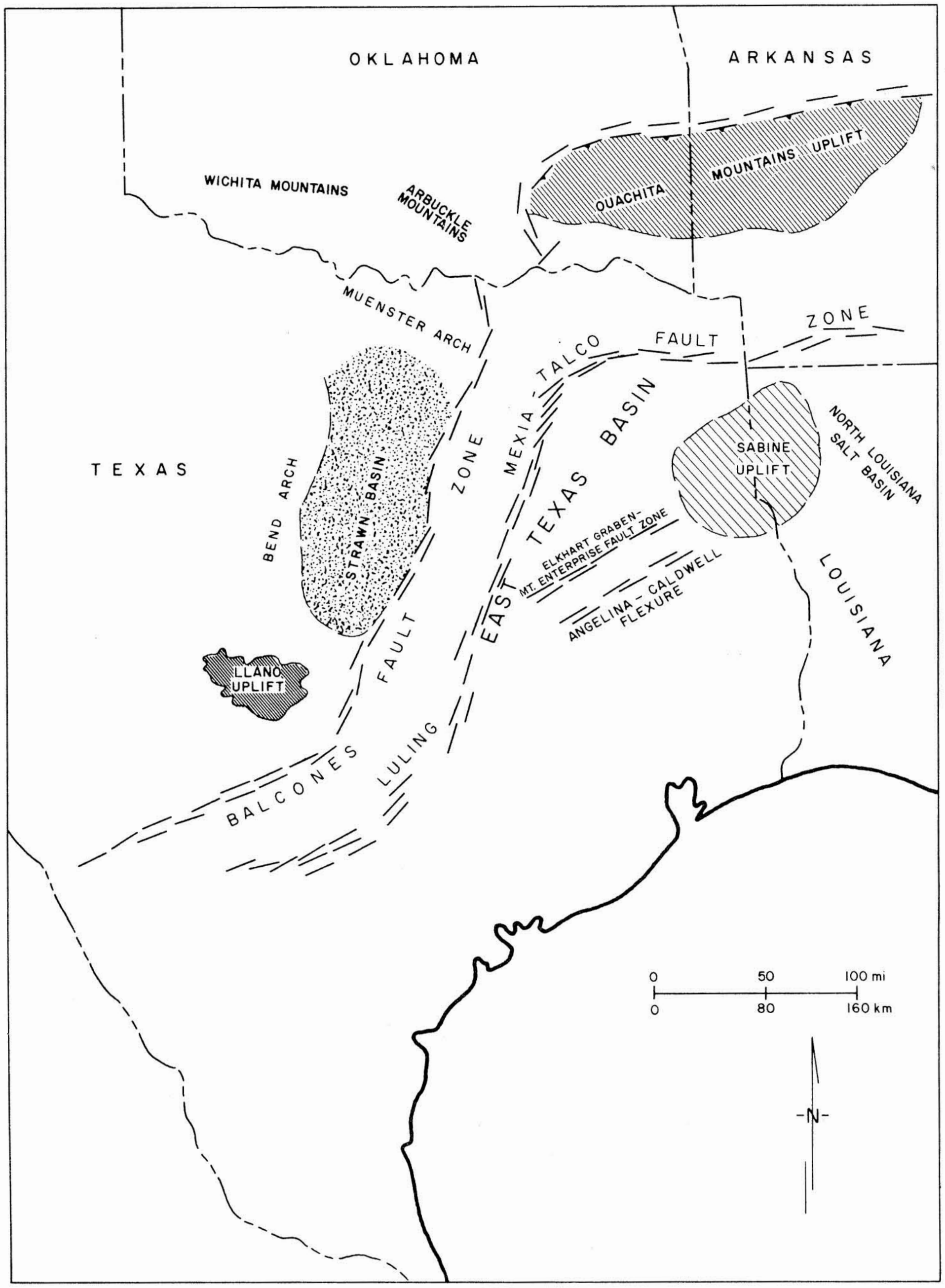


Figure 4. Tectonic elements in and around the East Texas Basin.

sin. By the end of Hosston (Early Cretaceous) sedimentation, the structure had grown into a topographically high salt pillow, or anticline (Loocke, 1978). The evolution of initial salt anticlines into salt domes depends on continued sediment loading (Kehle, 1971) as well as on the thickness of the underlying salt, which controls the supply of salt for continued growth.

Timing of Initial Salt Movement. Two seismic profiles available in the study area document the timing of salt mobilization (Figs. 5 and 6). Profile S-1 extends northwest to

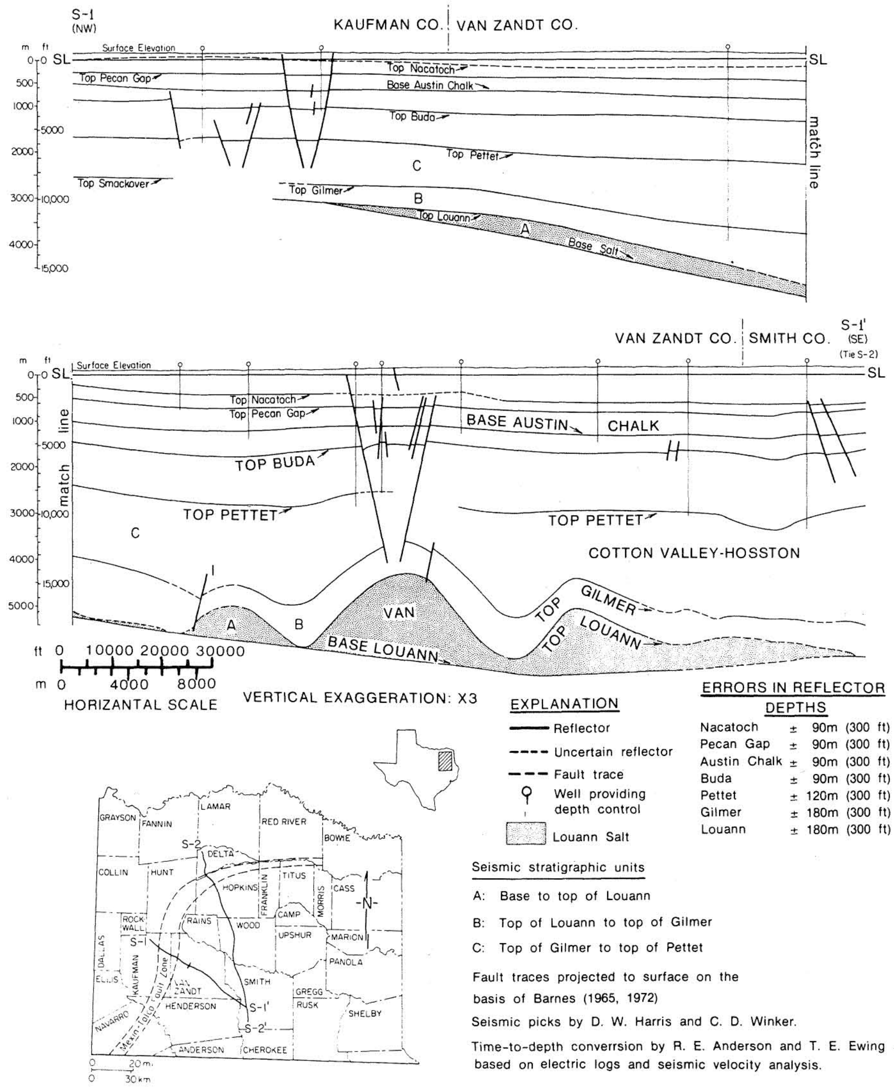


Figure 5. Time-to-depth conversion section S-1. Seismic units A, B, and C refer to Table 1. Southeastern end of line shows salt-withdrawal feature associated with Mount Sylvan salt dome.

southeast through Kaufman, Van Zandt, northeastern Henderson, and western Smith Counties; profile S-2 trends north to south through Delta, Hopkins, Wood, and Smith Counties.

Seismic data suggest that salt movement was both pre-Gilmer and coeval with Cotton Valley-Hosston deposition (Jackson and Harris, 1981; McGowen and Harris, 1981). Pre-Gilmer salt migration occurred in an area north and west of a line through central Wood, eastern Rains, central Van Zandt, and central Henderson Counties (Figs. 5 and 6). Time-thickness variations are apparent between reflections at the top of the Louann Salt and the top of the Gilmer Limestone (seismic unit B, Table 1). No thickness variations caused by salt movement were observed in the seismic interval between the top of the Gilmer Limestone and the top of the Pettet Limestone (seismic Unit C, Fig. 5) or between the top of the Gilmer Limestone and the top of the Massive Anhydrite (seismic unit D, Fig. 6). Thus, it can be concluded that salt

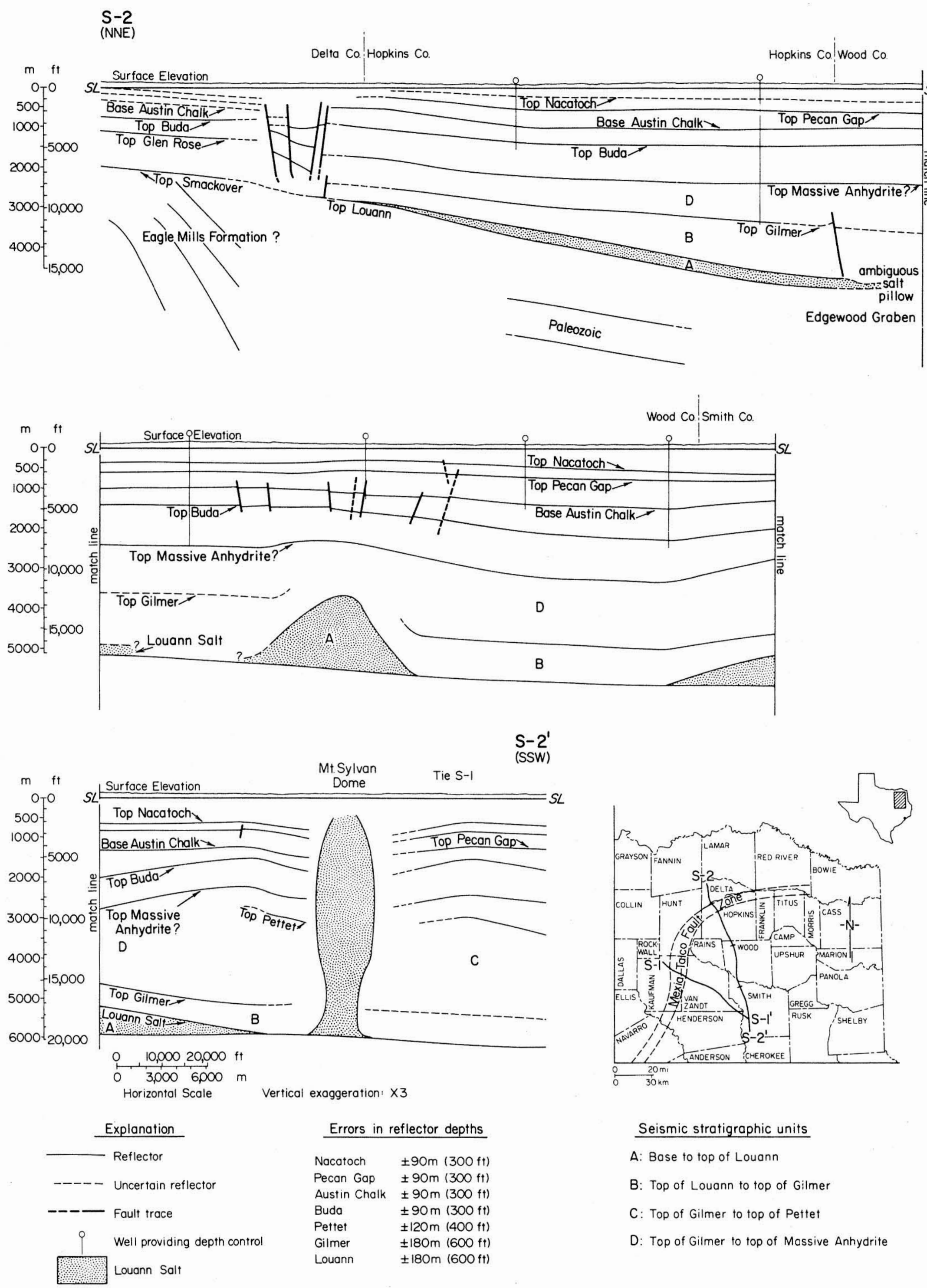


Figure 6. Time-to-depth conversion section S-2. Seismic units A, B, C, and D refer to Table 1. Fault traces projected to surface on the basis of Barnes (1965, 1966). Seismic picks by D.W. Harris and C.D. Winker. Time-to-depth conversion by R.E. Anderson and T.E. Ewing based on electric logs and seismic velocity analysis.

moved during Smackover deposition, which preceded Cotton Valley-Hosston deposition.

During Cotton Valley-Hosston deposition, salt moved south and east of a line through central Wood, eastern Rains, central Van Zandt, and central Henderson Counties. The seismic interval between the top of the Gilmer Limestone and the top of the Pettet Limestone (seismic unit C, Fig. 5) apparently thins over salt structures and thickens within synclines caused by salt withdrawal. In contrast, the seismic interval between the reflections at the top of the Louann Salt and top of the Gilmer Limestone (seismic unit B, Fig. 5) appears to be planar. This relationship is not as discernible on profile S-1 (Fig. 5) as on profile S-2 (Fig. 6) because seismic resolution is poor on the deep stratigraphic horizons in southern Wood County.

Structural Styles

Structural styles within the East Texas Basin can be grouped into four general categories: a peripheral graben system; a deformation-free zone; low- to intermediate-amplitude salt structures, which show pre-Cotton Valley salt movement; and salt anticlines and domes, which show movement coincident with Cotton Valley-Hosston deposition. These features have been discussed by Kehle (1971) and Jackson and Harris (1981), and similar structures have been observed in the Mississippi (Hughes, 1968) and the North Louisiana (Kehle, 1971) salt basins.

Peripheral Graben System. The Mexia-Talco fault zone bounds the study area on the north and west. The position of the fault system marks the updip depositional limit of the Louann Salt (Kehle, 1971; Agagu *et al.*, 1980; Jackson and Harris, 1981). The fault zone is a series of en echelon normal faults and grabens that formed early in the history of the basin. However, there is no evidence on seismic lines observed during this study that the peripheral faults extend into the basement. Rather, evidence suggests that the grabens are based in the Louann Salt (Jackson, 1982). Turk, Kehle, and Associates (1978) maintained that major displacement along the fault zone was largely caused by downdip creep of the Louann Salt. Jackson and Harris (1981) suggested that fault displacement was also caused, in part, by basinward creep of clastic strata above the Louann decollement zone. Movement along the fault affected strata of Mesozoic through early Tertiary age.

Basinward of the Mexia-Talco fault zone, a second graben system (the Edgewood Graben) developed parallel to the Mexia-Talco trend (Rosenkrans and Marr, 1967) (Fig. 7). These faults were active during the Jurassic and became inactive during the Early Cretaceous before deposition of the Pettet Limestone (Fig. 6). These faults and related structures are discussed in more detail in the section titled "Low- to Intermediate-Amplitude Salt Structures."

Deformation-Free Zone. On both seismic profiles S-1 and S-2, a deformation-free zone between the peripheral graben system and the first occurrence of low-amplitude salt swells (Figs. 5 and 6) underlies Delta and Hopkins Counties to the north and Kaufman and western Van Zandt Counties to the west. The Louann Salt is recognized by prominent boundary reflections and lack of internal reflections (Jackson and Harris, 1981). Within the deformation-free zone, boundary reflections are planar and diverge basinward, indicating a thickening of the salt wedge (approximately 1,020 to 1,920 feet, or 340 to 640 m) (Jackson *et al.*, 1982). Existence of the deformation-free zone suggests that a critical thickness of salt (approximately 1,500 feet, or 500 m) must be present to initiate flow (Jackson *et al.*, 1982). Kehle (1971) maintained that the deformation-free zone is discontinuous along the full length of the basin margin.

Low- to Intermediate-Amplitude Salt Structures. Low-amplitude salt structures occur basinward of the deformation-free zone in southern Hopkins, southern Rains, and western Van Zandt Counties. Amplitudes, indicated by relief on the top of the salt anticlines, in-

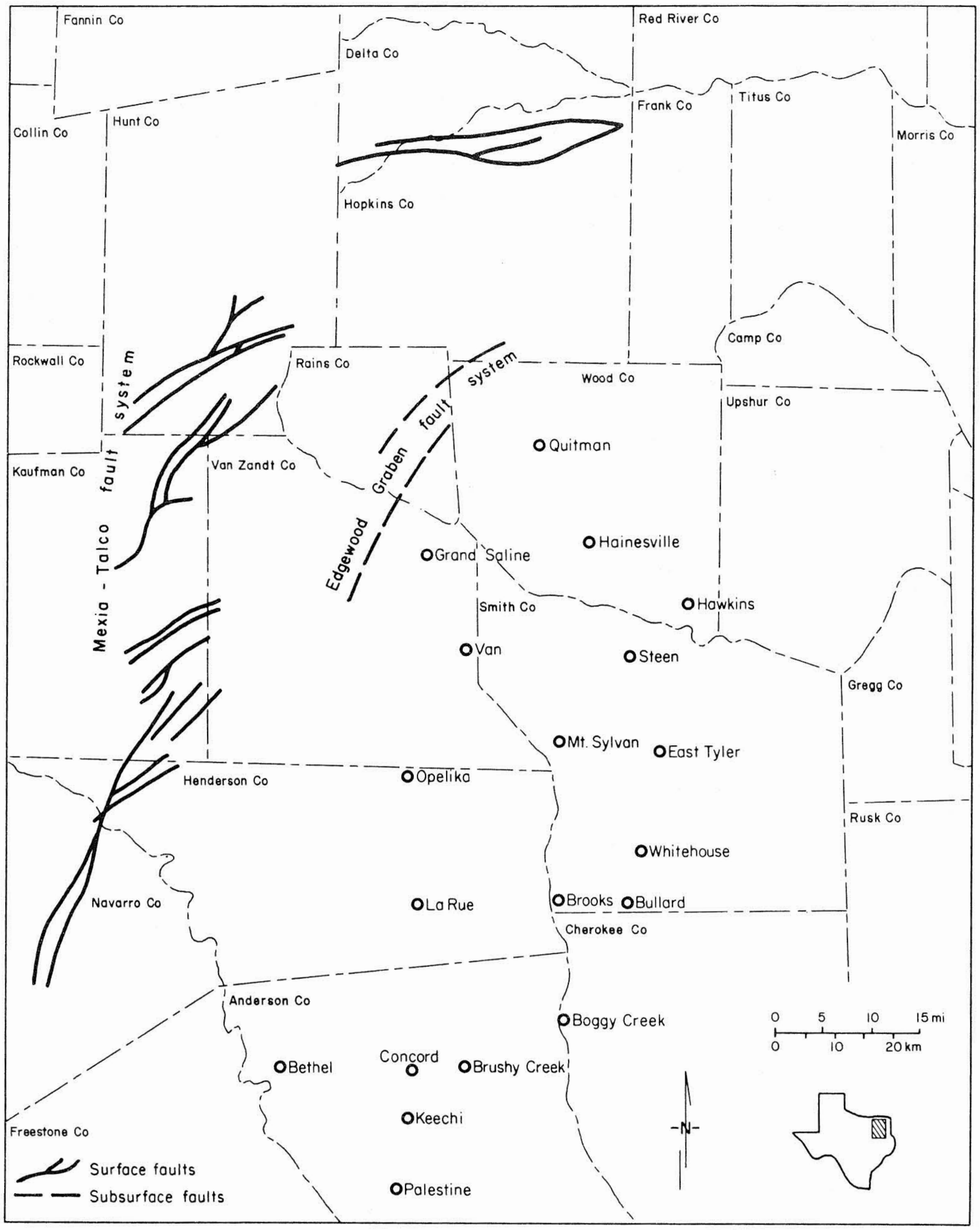


Figure 7. Salt domes and major fault systems, northwestern part of the East Texas Basin.

crease basinward as the salt wedge thickens. Basinward, folds are commonly tighter and salt has pierced some anticlines (Hughes, 1968; Kehle, 1971). Seismic profiles indicate that these low- to intermediate-amplitude structures formed early in the development of the basin. Salt movement began during deposition of the Smackover Formation; this is evidenced by time-thickness variations between reflections on the top of the Louann Salt and the top of the Gilmer Limestone (Figs. 5 and 6). Salt migration was probably initiated by downward creep that was induced by sedimentary loading of carbonate deposits

(Rogers, 1967) and was enhanced by basinward tilting. Residual gravity maps suggest that these initial salt structures are aligned roughly parallel to the Mexia-Talco fault zone (Figs. 3 and 4). Hughes (1968) deduced that salt movement occurred as early as deposition of the Norphlet in the Mississippi salt basin. He also observed that low-amplitude salt structures in marginal areas of the basin are commonly arranged in ridges that parallel the peripheral faults.

Most growth of low-amplitude salt structures apparently occurred before deposition of Cotton Valley clastic sediment. This is evidenced on seismic profiles, which show little variation in time-thickness between the reflections at the top of the Gilmer Limestone and the top of the overlying Pettet Limestone. The low-amplitude salt features exhibit little to no structural expression above the Gilmer Limestone. The thin underlying salt wedge appears to have largely controlled the size of the structures that formed in this part of the basin.

Near the Edgewood Graben (Fig. 7), salt structures of intermediate size are truncated by the fault system. Rosenkrans and Marr (1967) maintained that the salt structures were generated by faulting, and Jackson and Harris (1981) concluded that salt withdrawal by downdip creep, coincident with sediment loading within the graben, may have caused the faults. Fault movement along the system displaced strata of Late Jurassic and Early Cretaceous age but ended in the Early Cretaceous. Seismic profile S-2(Fig. 6) indicates that faulting was contemporaneous with deposition of Cotton Valley clastic sediment.

Seismic profile S-2 (Fig. 6) also shows evidence of displaced reflections along the Edgewood graben during deposition of the Cotton Valley-Hosston strata. The following relationships were observed: First, a salt structure underlies the Edgewood fault, but the exact relationship of the structure to the fault is not clear on the seismic profile. Second, reflection of the Gilmer Limestone is offset down to the basin without appreciable time-thickness variations within seismic unit B (Table 1), indicating that most of the movement occurred after deposition of the Gilmer Limestone. And third, seismic unit D thickens on the downthrown side of the fault, not on the upthrown side, indicating that movement along the fault was contemporaneous with deposition of the Cotton Valley Group. The fault terminates within seismic unit D (Hosston Formation).

Evidence of faults that were active northwest of Van Dome during Cotton Valley-Hosston deposition is shown on seismic profiles S-1 (top structure, Fig. 5). First, updip of the fault, seismic unit A (Table 1) is distorted, and the configuration of the Louann Salt cannot be discerned. Second, seismic unit B thickens slightly basinward of the fault, suggesting that salt movement occurred during Smackover deposition. Third, the Gilmer Limestone reflection is clearly offset at the fault. Fourth, seismic unit C thickens appreciably on the downthrown side of the fault, indicating movement contemporaneous with deposition of Cotton Valley clastic sediment. And fifth, the fault terminates either in the upper part of the Cotton Valley or in the Hosston below the Pettet reflection, which is planar.

Salt Anticlines and Domes. Within the study area, salt anticlines and domes occur south and east of a line through southern Hopkins, eastern Rains, central Van Zandt, and central Henderson Counties (Fig. 8). The location of salt anticlines and domes in the basin appears to have been controlled largely by the location of the Smackover-Gilmer carbonate platform, particularly where Gilmer carbonate shelf-edge strata overlie Smackover deposits. Rogers (1967) maintained that a carbonate shelf-edge facies began to form during Smackover deposition and continued in some areas during Gilmer deposition, reaching a maximum combined thickness of 3,500 feet (1,166 m) (Fig. 9). A carbonate shelf of this thickness could provide a stable platform, upon which fan-delta sediments of the Cotton Valley Formation would tend to spread laterally rather than to stack vertically. The isopach map of the Cotton Valley Group indicates a close correlation between the position of the

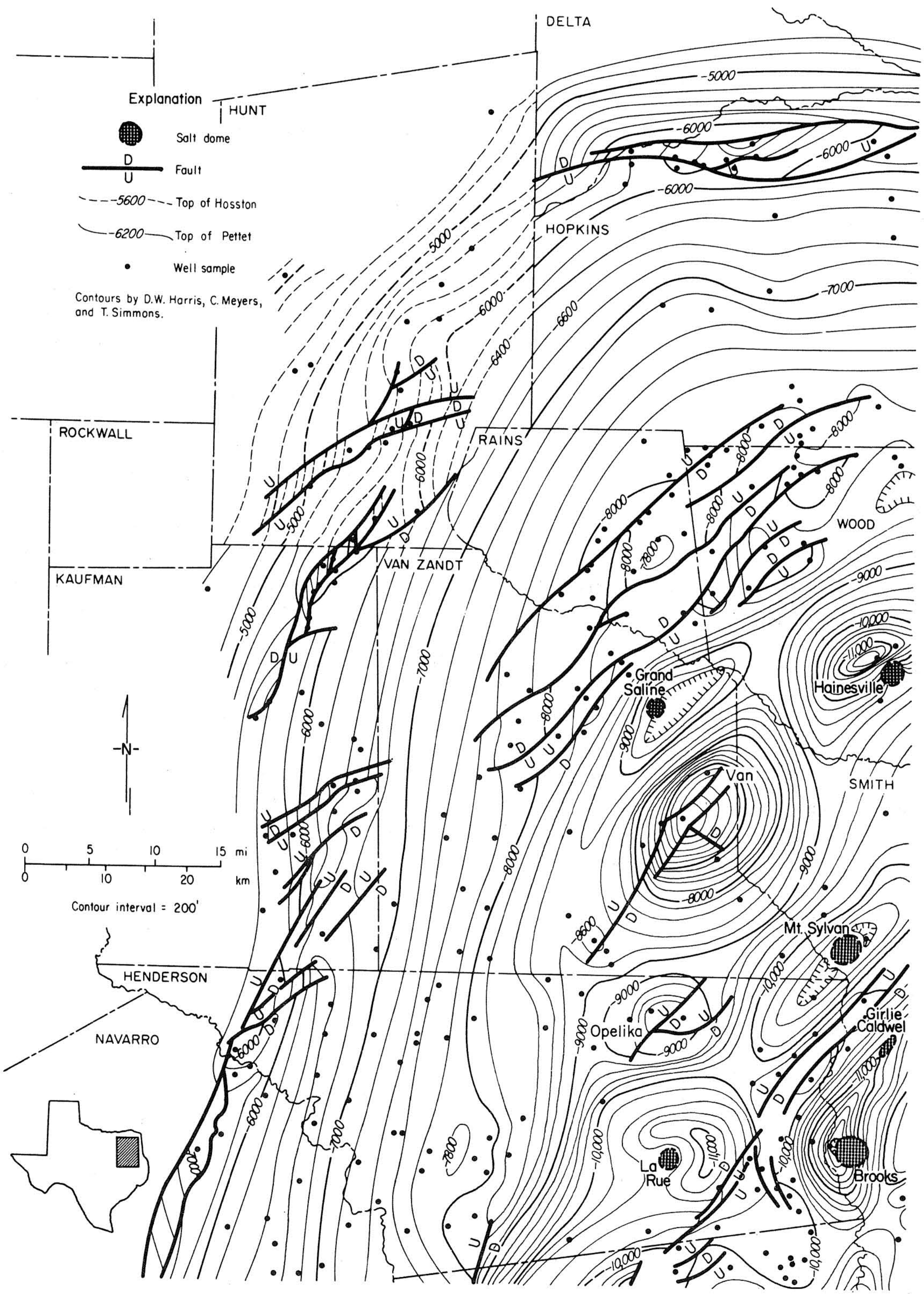


Figure 8. Structure map of the top of the Pettet Formation and the top of the Hosston Formation (Hunt County only).

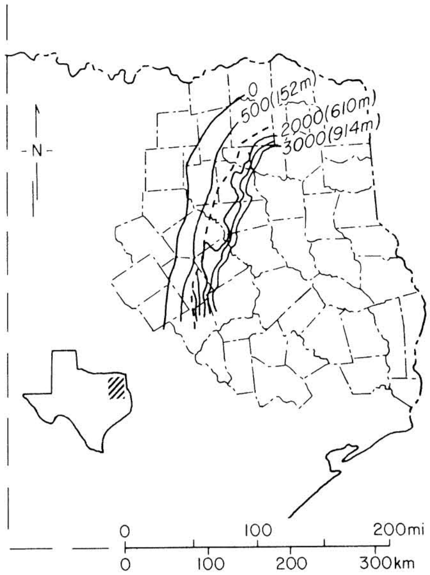


Figure 9. Isopach map of Smackover-Gilmer carbonate shelf facies (Rogers, 1967). Isopach of Smackover northwest of dashed line, combined isopach of Smackover and Gilmer southeast of dashed line.

Smackover carbonate shelf edge, as mapped by Eaton (1961) and Rogers (1967), and the occurrence of Cotton Valley deltaic depocenters (Fig. 10). Superposition of deltaic sediments occurred in synclines that were located between salt ridges and were immediately basinward of the older carbonate wedge. Salt mobilization was initiated by basinward migration of the salt into ridges that fronted the progradational fan-delta system. The salt ridges probably were bathymetric highs that acted as effective sediment dams to perpetuate the synclines as depocenters until either the underlying salt was depleted or the rate of sedimentation was greater than the rate of subsidence. This allowed the delta to overrun the salt ridge.

During continued progradation, the fan-delta complex probably overran the initial syncline and salt ridge and established a new depocenter basinward of and parallel to the original salt ridges. Consequently, sediments in depocenters should be progressively younger toward the center of the basin. Initial salt ridges that developed during the Late Jurassic and Early Cretaceous were later modified by continued salt flow, which resulted from uneven sediment loading by younger sedimentary units. Johnson (1980) showed that a preexisting salt ridge on the outer continental shelf and upper slope of the Gulf Basin evolved into individual salt domes when buried by an influx of fluvial-deltaic sediments during the Pliocene.

A residual gravity map of the study area indicates a parallel arrangement of lows and highs (Fig. 3). A comparison of the Cotton Valley isopach map (Fig. 10) with the residual gravity map shows that sediment thicks generally coincide with gravity highs and salt thins, whereas sediment thins coincide with gravity lows and areas of thicker salt. The approximate parallel alignment of residual gravity lows again suggests that the original salt structures may have been a series of parallel salt ridges that evolved through time into salt anticlines and domes.

Seismic lines across the salt anticlines and domes in the study area indicate that in most cases, salt moved after deposition of the Gilmer Limestone, whereas low-amplitude structures located in the marginal areas indicate pre-Gilmer movement. Deeper seismic reflections near Quitman Dome (Wood County) are distorted, and thus obscure the relationship between the salt structure and the overlying sedimentary units. However, a seismic survey profile across Mount Sylvan Dome (Smith County) shows virtually no evidence of pre-Cotton Valley salt movement (Fig. 6). West Tyler, to the southeast of Mount Sylvan Dome, and Boynton Field, to the northwest, are turtle structures created by early salt withdrawal that started coeval with Cotton Valley deposition (Jackson *et al.,* 1982). Turtle structures are anticlinal structures without salt cores that were created by sediment thicks in primary withdrawal basins formed by early salt withdrawal (Trusheim, 1960; Kehle, 1971; Wood, 1981). Turtle structures probably were depocenters during deltaic sedimentation of the Late Jurassic.

Seismic profile S-1 passes to the south of Grand Saline and Van Domes but crosses two parallel, lateral salt ridges that extend southeastward from Van Dome (Figs. 3 and 5)

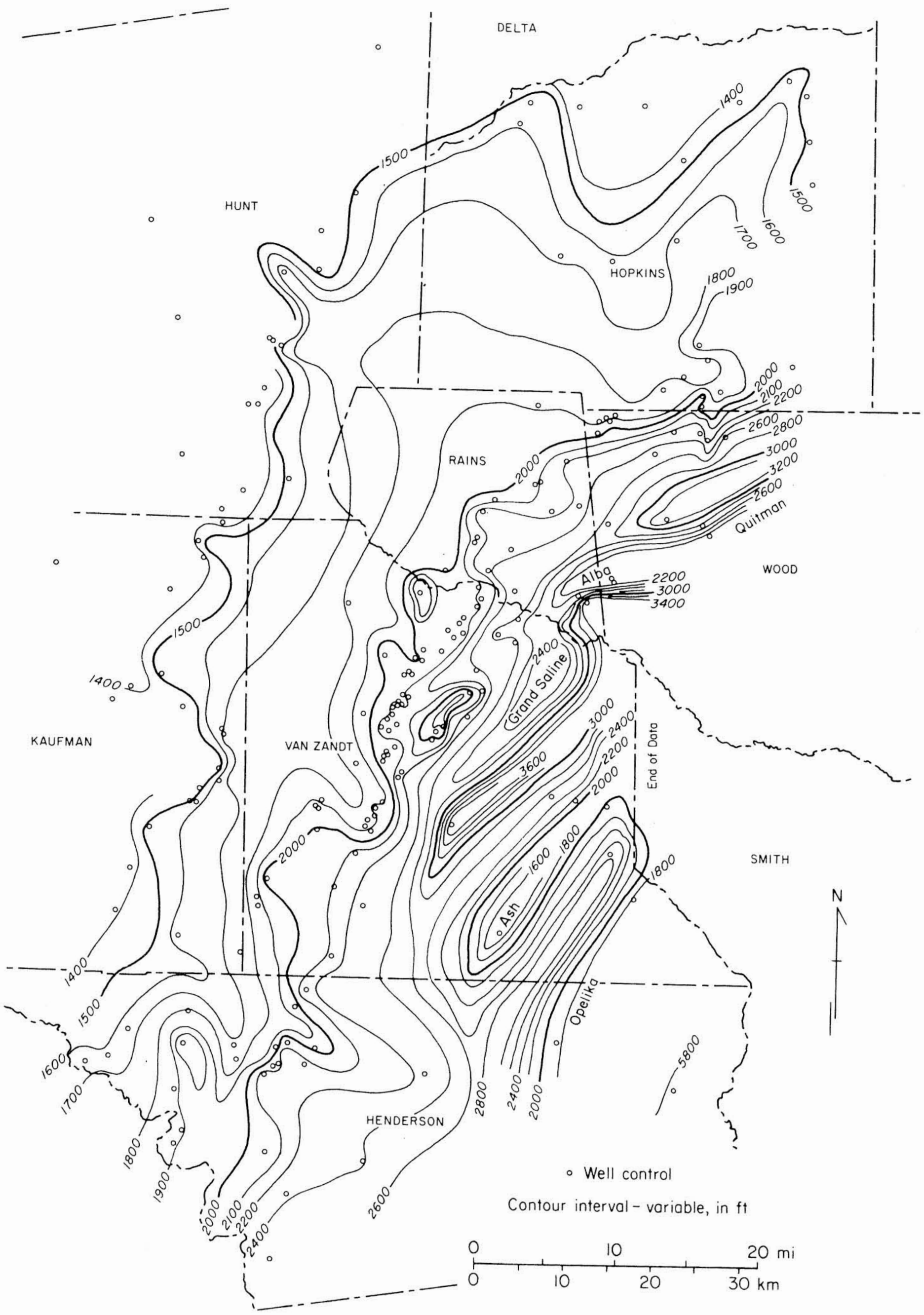


Figure 10. Isopach map of the Cotton Valley Group.

(Jackson and Harris, 1981). The seismic survey across the western ridge indicates that some pre-Gilmer salt movement occurred (seismic unit B, Fig. 5). Major movement, however, was coincident with deposition of Cotton Valley deltaic sediments (seismic unit C, Fig. 5). Basinward of the western ridge, no pre-Gilmer salt movement apparently occurred.

SUMMARY

Seismic profiles indicate that salt movement occurred at different times in different parts of the East Texas Basin and demonstrate that more than one mechanism caused movement. Within marginal parts of the basin, low-amplitude salt structures formed during Smackover (pre-Gilmer) time. Salt migration was caused by loading of the Smackover carbonate deposits in conjunction with basinward tilting. Time-thickness variations caused by low-amplitude salt structures are not indicated on Cotton Valley-Hosston isopach maps. The sizes of salt structures increase basinward, coincident with thickening of the underlying salt wedge.

Basinward of a line running through central Henderson, Van Zandt, and Wood Counties, salt movement occurred later than it did in the marginal parts of the basin. Salt migrated during deposition of Cotton Valley-Hosston strata as a result of mass imbalance, which was caused by uneven sediment loading. Time-thickness variations (divergence) are evident between seismic reflections at the top of the Gilmer Limestone and the top of the Pettet Limestone. In contrast, reflections at the top of the Louann Salt and the top of the Gilmer Limestone are parallel, suggesting that salt did not move in this part of the basin until Cotton Valley time.

SEDIMENTOLOGIC FRAMEWORK

Methodology

Early Jurassic sedimentation was dominated by the deposition of carbonate, evaporite, and mudstone facies. The first major influx of terrigenous clastic sediment into the East Texas Basin occurred during the Late Jurassic (Cotton Valley) and continued into the Early Cretaceous (Hosston).

Basin infilling during the Late Jurassic and Early Cretaceous produced a variety of complexly distributed facies in the East Texas Basin and the adjacent North Louisiana Basin. As a result, a complex nomenlature has evolved to describe these deposits. Because this study deals primarily with sedimentation during the Late Jurassic and Early Cretaceous, a rock-stratigraphic classification restricted to those times has been used. No attempt has been made to classify the Cotton Valley Group in the northwestern part of the basin using the stratigraphic nomenclature that has been applied to the eastern part of the basin and to Louisiana.

In this study, the boundary between the Cotton Valley Group and the Hosston Formation is arbitrary, based on regional correlations and information of geologic picks from scout cards. In the northwestern part of the East Texas Basin, the top of the upper Cotton Valley Group is difficult to pick on electric logs and seismic profiles because Hosston sandstones overlie upper Cotton Valley sandstones. Nichols *et al.* (1968) maintained that deposition was continuous through Late Jurassic and Early Cretaceous time except around the western and northern margins of the basin, where an erosional contact was recognized. In these marginal areas, a basal Hosston conglomerate, ranging in thickness from 50 to 100 feet (16 to 33 m), separates the two formations (Nichols *et al.*, 1968). It has not been determined whether this conglomerate bed occurs regionally or whether it consists of unrelated local facies, such as proximal alluvial-fan deposits or braided-stream channel-fill deposits. On the basis of seismic interpretations, Todd and Mitchem (1977) recognized a major unconformity between the Cotton Valley Group (Upper Jurassic) and the Hosston Formation (Lower Cretaceous) in the East Texas Basin. However, we did not recognize a major unconformity on seismic sections in the northwestern part of the basin. The depositional sequence between either the Gilmer Limestone (Cotton Valley Limestone) or the base of the Buckner Anhydrite and the top of the Hosston Formation is thought to represent one regressive sequence with minor interruptions. The regression was terminated by a major transgression, which is evidenced by the transition of the uppermost Hosston Formation into the Pettet Limestone.

The volume, texture, and composition of sediment, the nature of the sediment-dispersal system, and the geometry of sands of the Cotton Valley Group and Hosston Formation were studied using sandstone-percent and net-sandstone maps. These were supplemented by regional stratigraphic cross sections, electric logs, isopach maps, and well cuttings. A sandstone-percent map is an effective way to reveal sand-body geometry because it minimizes the effect of thickness variations within a mappable unit (Krumbien and Sloss, 1959; Kaiser *et al.*, 1978). Stratigraphic markers are virtually absent in the Cotton Valley Group and Hosston Formation within the northwestern part of the basin; therefore, sandstone maps represent the composite sandstone thickness of superposed facies. The cumulative values do not reflect the geometry of individual sand bodies, so interpretation of individual depositional systems from these maps should be done cautiously. Brown (1969) observed that some depositional systems appear to remain in approximately the same geographic position through time; when this occurs, similar systems would tend to stack vertically and thus be revealed in a gross lithologic map.

Source Area

The same source area supplied terrigenous clastics to the East Texas Basin during both the Late Jurassic (Cotton Valley) and the Early Cretaceous (Hosston). Deposition of Cotton Valley terrigenous clastics in the East Texas Basin suggests that a reactivation of this source area along the northern and western margins of the basin began as early as the Late Jurassic. The Central Mineral Region and the Ouachita, Arbuckle, and Wichita Mountains were all highlands during the Late Jurassic and Early Cretaceous (Imlay, 1943)(Fig. 4).

Patterns of the net-sandstone and sandstone-percent maps (Figs. 19 and 20) suggest that during the Late Jurassic, terrigenous clastics were delivered to the East Texas Basin by many small streams and rivers. This differs from the major river and tributary system in Louisiana and Mississippi, where an ancestral Mississippi River was the principal fluvial system entering the North Louisiana Basin (Thomas and Mann, 1966).

Tongues of quartz conglomerate along the northwestern and northern margins of the basin in the Cotton Valley Group and throughout the Hosston Formation were probably derived from the Ouachita, Arbuckle, and Wichita highlands. Textural maturity and the dominance of very fine grained to fine-grained sandstone suggest that older sedimentary rock surrounding the basin during the Late Jurassic and Early Cretaceous was also an important source of terrigenous clastic sediment for the East Texas Basin. Most of the sandstone is quartzarenite and subarkose.

Depositional Systems

Fan-Delta Processes and Environments. The Cotton Valley Group and the Hosston Formation are thought to be a large fan-delta depositional system. A fan delta is an alluvial fan that progrades into a body of water from an adjacent highland (Holmes, 1965; McGowen, 1970). Fan-delta deposits exhibit a higher ratio of coarse-grained to fine-grained sediment than either lobate or elongate deltas (Erxleben, 1975). Characteristically, fan deltas have relatively small drainage areas and flashy runoff, and they are supplied by bed-load streams braided to the toe of the delta (McGowen, 1970). Aggradation and progradation occur only during periods of high discharge (McGowen, 1970).

Rates of progradation are controlled by sediment supply, by discharge rates of the fluvial system supplying the fan delta with sediment, by intensity of marine processes (whether the fan delta is debouching into a low-energy or high-energy marine environment), and by depth of water. Heavy seasonal rains or floods are essential to providing discharge rates capable of transporting large quantities of sand-size sediment to the toe of the fan delta. Sediment is stored in channels during periods of low rainfall, whereas sediment is entrained during floods, when rapid progradation occurs (Casey, 1980).

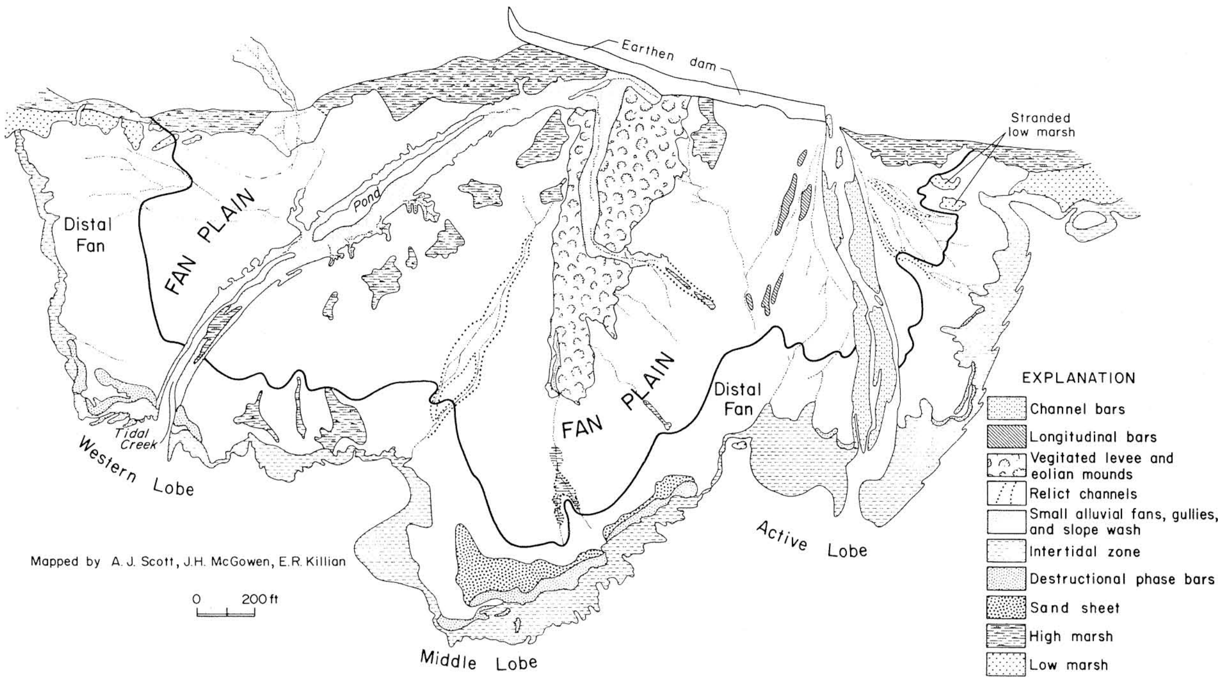


Figure 11. Gum Hollow fan-delta model (McGowen, 1970).

McGowen (1970) attributed major growth of the Gum Hollow fan delta to three principal depositional events: The heavy spring rains of 1966 and the heavy rains associated with Hurricane Beulah in 1967 and with Tropical Storm Candy in 1968. During periods of low fluvial discharge, distal parts of the active fan deltas are modified by marine processes. Inactive lobes are subject to destructional processes year round. The greatest rates of progradation occur when fan deltas debouch into shallow-water low-energy environments. Progration is accomplished by lateral shifts in sites of deposition, resulting in a complex overlapping of fan-delta lobes (Casey, 1980).

McGowen (1970) subdivided fan deltas into two subenvironments--fan plains and distal fans--based on their dominant sedimentary process (Fig. 11). The fan plain includes the subaerial part of the fan delta and is dominated by braided-stream fluvial processes. A braided stream is defined by Leopold *et al.* (1964) as a channel divided into several channels that successively meet and redivide. A braided-stream system is composed of bed-load streams with rapid discharge fluctuations. Finer sediment is transported through the system without accumulating; constructional features include both longitudinal and transverse bars. With the absence of muddy levees and top strata, the channel banks are easily eroded; thus, bars tend to laterally coalesce, forming continuous and extensive sand sheets (Walker and Cant, 1979)(Fig. 12).

The distal fan includes the transitional zone between the subaerial fan plain and the subaqueous part of the fan delta (McGowen, 1970). Fluvial and marine interaction produces a complex environment. Marine processes dominate this part of the fan delta except during periods of high discharge, when fluvial influence is evident. During periods of low discharge, delta-front sediments are reworked into bars, spits, and shoals (Lucchi *et al.*, 1981)(Fig. 13). Inactive fan delta lobes are continuously modified. Characteristic environments include marshes, destructional bars, intertidal zones, and eolian mounds (McGowen, 1970). Benthic fauna may migrate into the delta front and the aban-

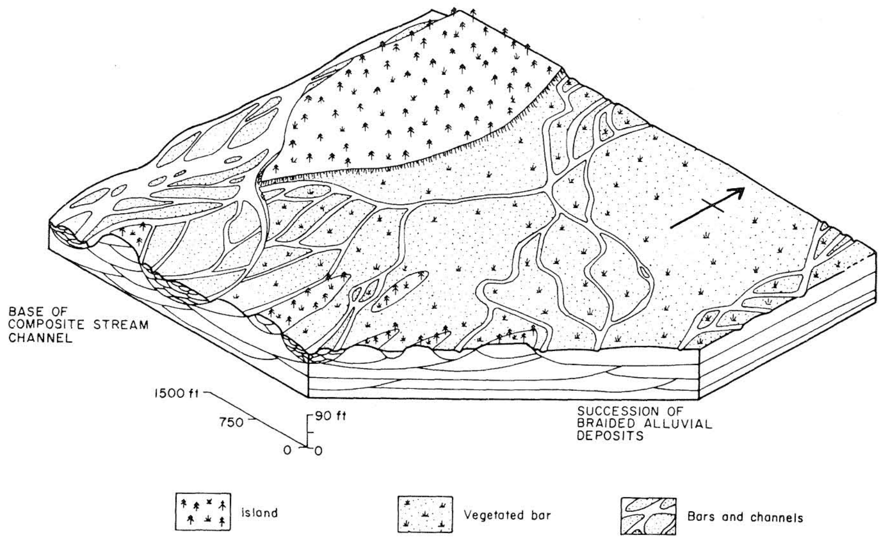


Figure 12. Braided-stream model (Rust, 1978).

doned channel areas (Casey, 1980).

Wescott and Ethridge (1980) presented an excellent synopsis of modern and ancient deposits that are thought to be fan delta systems. Examples of modern fan deltas that debouch into marine environments include the Gum Hollow fan delta (McGowen, 1970), the Yallahs fan delta (Wescott and Ethridge, 1980), and the fan deltas associated with glacial outwash along the coast of Iceland (Ward *et al.*, 1976; Boothroyd and Nummendal, 1978) and the coast of Alaska (Boothroyd and Ashley, 1975; Boothroyd, 1976; Galloway, 1976; Boothroyd and Nummedal, 1978). Temperatures vary considerably between these geographic areas; the intensity of marine processes affecting the distal margins of the fan deltas also varies. However, many of the processes controlling sedimentation are similar. For example, the fan deltas are fed by braided-stream fluvial systems that exhibit rapidly fluctuating discharge rates, which are controlled by seasonal events; most of the fans prograde into relatively shallow water (the width of the shelf varies with each geographic location).

Cotton Valley-Hosston Fan-Delta System. Deposits of the Cotton Valley Group and Hosston Formation are thought to be a system of coalescing fan deltas that prograded from the west, northwest, and north. Facies interpretations are based on sandstone-percent values, sandstone distribution, electric log re-

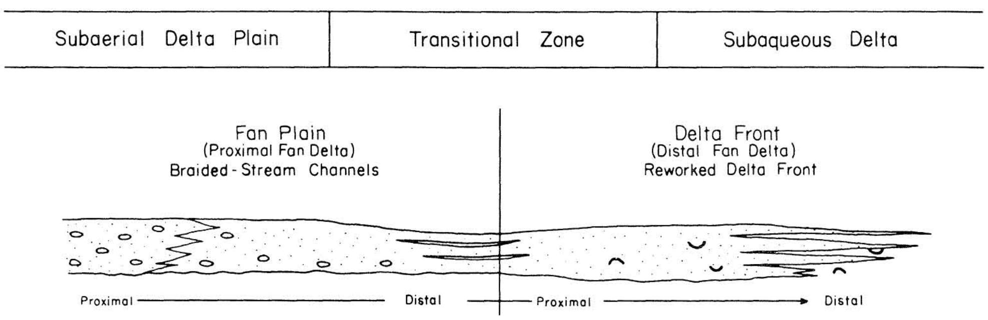


Figure 13. Diagrammatic cross section of fan-delta subenvironments (after Lucchi *et al.*, 1981).

sponse patterns, descriptions of well cuttings (appendix A), and lithologic descriptions from other studies. Lack of core data precludes the study both of sedimentary structures and of detailed relationships among vertical sequences of facies within the Cotton Valley Group and Hosston Formation.

Cotton Valley Group. *Facies.*--Facies of the Cotton Valley Group can be divided into three general categories: prodelta deposits, delta-front deposits, and braided stream deposits, all components of a fan-delta system (Figs. 2, 14 through 18). Prodelta deposits compose a thin subordinate facies in the study area; however, the facies thickens basinward. It consists of black or green calcareous, fossiliferous mudstone interbedded with light-gray to light-brown crystalline limestone and shelly, sandy limestone. Minor amounts of very fine-grained sandstone and siltstone occur within the facies.

Delta-front deposits consist of alternating beds of sandstone and mudstone and a few thin beds of sandy limestone. Sandstone, the dominant lithology, is white to light gray and very fine-grained to fine-grained, containing glauconite, shells, and finely disseminated carbonized plant fragments. Interbedded mudstone is dark gray to black to green. Thick beds of conglomeratic sandstone occur in the proximal areas.

Braided-stream fluvial deposits consist of white to light red, very fine-grained to fine-grained sandstone, conglomeratic sandstone, and chert-gravel quartz and conglomerate. Thin beds of red and green mudstone occur as a subordinate lithology. Conglomerate is more common updip, extending basinward as tongues (Newkirk, 1971). This facies exhibits blocky electric log patterns with sharp (erosional) bases and tops, characteristic of braided-stream deposits (Erxleben, 1975; Galloway *et al.*, 1979). Well-developed upward-coarsening or upward-fining sections are rare to absent.

Sandstone Distribution.--Sandstone distribution in the Cotton Valley Group is indicated on the sandstone-percent map (Fig. 19). Higher sandstone-percent values are restricted to the basin margin, and values decrease basinward. Many dip-oriented sandstone-rich belts extend across Kaufman, Hunt, Hopkins, and northwestern Van Zandt Counties, suggesting the presence of many smaller streams in this part of the study area. Basinward, the dip-oriented sandstone geometry appears to change into a northeast to southwest strike-oriented trend. The change in orientation of sandstone trends marks the fluvial-marine interface. Seaward of this area, dominant marine processes had reworked sandstones into strike-oriented facies. This change in orientation seems to coincide with the position of an older Smackover-Gilmer carbonate shelf described by Eaton (1961) and Rogers (1967) (Fig 9).

The Cotton Valley Group gradually thickens basinward toward a line that runs through central Henderson, central Van Zandt, and north-central Wood Counties (Fig. 10). Basinward of this line, the isopach contours outline parallel-aligned, strike-oriented thicks and thins. When compared with the residual gravity map (Fig. 3), sediment thicks correspond to salt-poor (gravity highs), and sediment thins overlie salt structures (gravity lows). Parallel sandstone thicks indicate successive seaward depocenters of prograding fan deltas.

The area where the Cotton Valley Group gradually thickens basinward is coincident with subjacent Smackover-Gilmer carbonate shelf facies. The combined thickness of the Smackover-Gilmer deposits is approximately 3,500 feet (1,067 m). The isopach map of the Cotton Valley suggests that the Smackover-Gilmer shelf was a stable platform over which the advancing Cotton Valley fan deltas prograded both laterally and basinward. Superposition of deltaic sediments occurred in synclines that were located between salt ridges immediately basinward of the Smackover-Gilmer carbonate shelf edge. The thickness of the Louann Salt, which directly determined the amount of salt available for the formation of salt structures, also controlled the rate and amount of subsidence that occurred coeval with sedimentation.

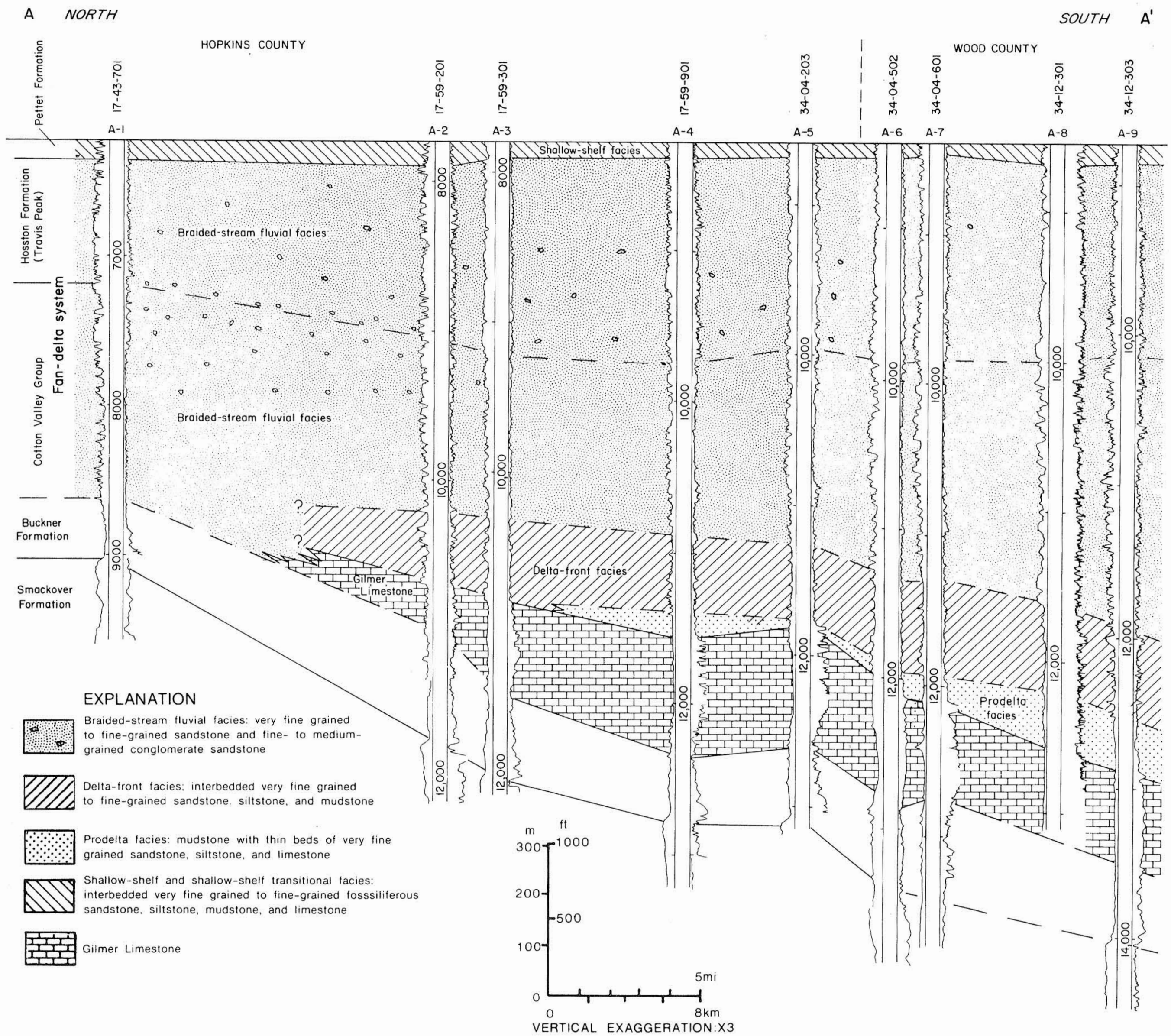


Figure 14. Stratigraphic cross section A-A' through Hopkins and Wood Counties.

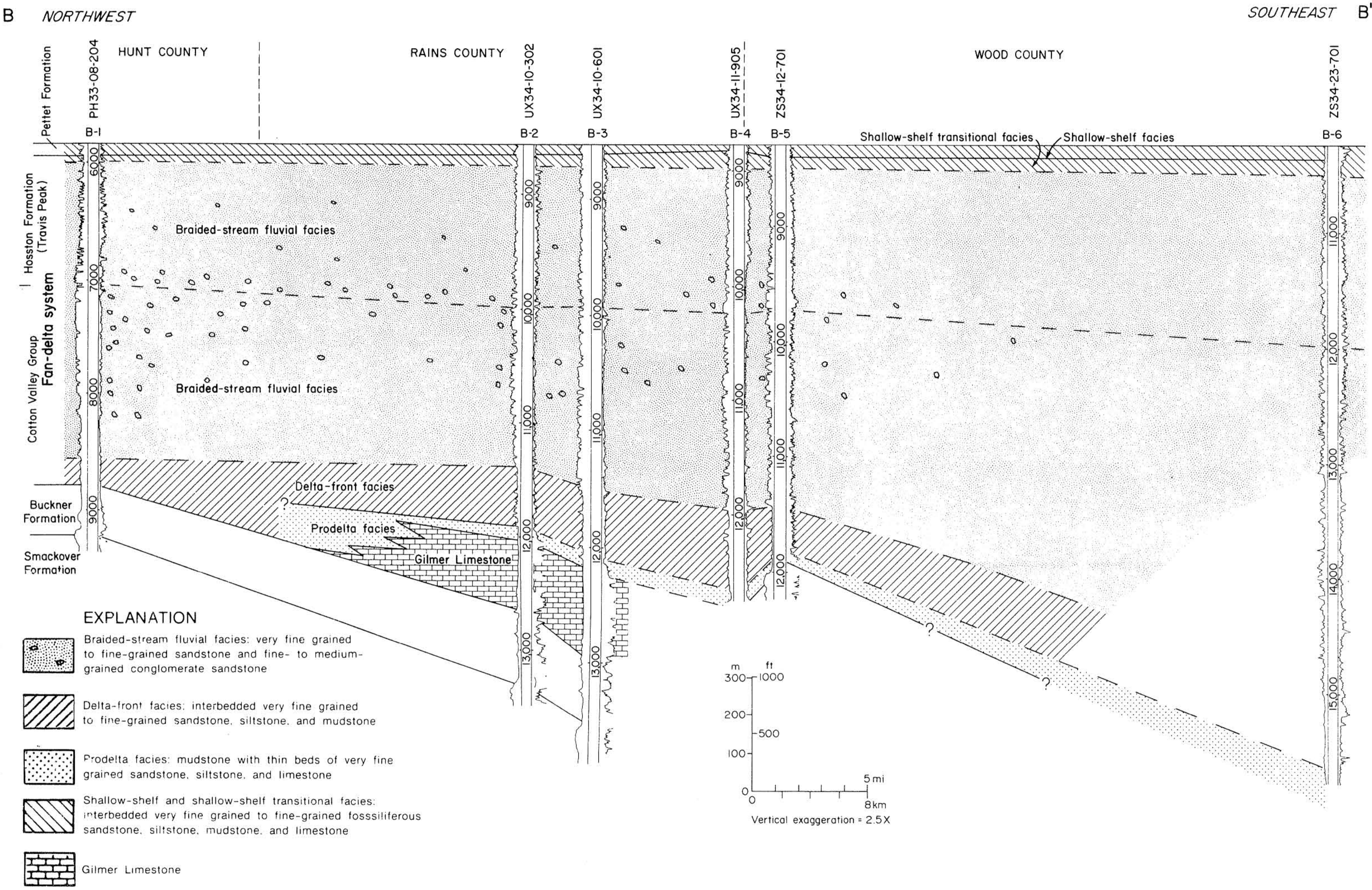


Figure 15. Stratigraphic cross section B-B' through Hunt, Rains, and Wood Counties.

The net-sandstone map indicates that sandstone-rich belts coincide with thick isopach trends of the Cotton Valley Group (Fig. 20). Net-sandstone values increase gradually across the Smackover-Gilmer shelf; beyond the shelf edge, net-sandstone highs correspond to sediment thicks indicated on the Cotton Valley isopach map (Fig. 10). Net-sandstone thicks coincide with salt-poor areas (Fig. 3).

Sediment accumulation around the northern and western margins of the basin appears to have been controlled, in part, by contemporaneous faulting in the Mexia-Talco fault zone. In Kaufman County, for example, massive sandstone units in the upper Cotton Valley Group are up to 600 feet (183 m) thick. These units are thought to be superposed braided-stream deposits that accumulated early in grabens of the Mexia-Talco fault zone. Subsidence was accelerated by accumulation of thick braided-stream deposits composed of quartz and pebble conglomerate and fine- to medium-grained sandstone.

Hosston Formation. *Facies.*--Two facies constitute the Hosston Formation: a braided-stream facies, which is dominant, and a transitional shallow marine facies, which is subordinate. The braided-stream deposits represent the subaerial fan-plain facies, a component facies of the larger fan-delta system (Figs. 11 through 13). Fluvial sedimentation ended with a major transgression reflected by a transitional shallow marine facies restricted to the upper 100 to 200 feet (33 to 67 m) of the Hosston Formation. The transitional deposits grade into the overlying Pettet Formation (Limestone).

The fluvial facies is composed of conglomeratic sandstone and white to light-red, fine- to medium-grained sandstone; light-gray to red muddy sandstone; white to pale-red siltstone; and thin beds of red and grayish-green mudstone. Carbonaceous and lignitic material occurs in some sandstone units. Quartz and pebble conglomerate beds occur throughout the section but are more common in the lower part of the formation (Bushaw, 1968; Nichols *et al.*, 1968) (Appendix A). Electric log patterns of individual sand beds are blocky and have sharp (erosional) lower and upper boundaries. Upward-fining and upward-coarsening log responses are rare. Superposition of braided-stream deposits, occurring contemporaneous with faulting, is not as apparent here as it is in the Cotton Valley Group.

The upper 100 to 200 feet (33 to 67 m) of the Hosston Formation consists of interbedded white to light-red, very fine-grained to fine-grained sandstone; gray mudstone; and gray to light-tan sandy, fossiliferous, oolitic limestone. Uppermost Hosston deposits reflect a decrease in the sediment supply to the East Texas Basin because of a shift from dominantly fluvial deposits to dominantly marine deposits.

Sandstone Distribution.--Sandstone distribution within the Hosston Formation is characterized by dip-oriented sandstone-rich belts in proximal areas (Fig. 21). There is, however, a change from many dip-oriented high-sandstone-percent trends in the Cotton Valley to a single dominant dip-oriented sandstone trend in the Hosston centered in Hunt County (Figs. 19 and 21). Narrower sandstone-percent trends in the Hosston occur around the northern margin of the basin (Fig. 22). The sandstone-percent map suggests that the Cotton Valley drainage system had evolved, by Hosston time, from an immature fluvial complex made up of many smaller streams into a more mature system, the principal drainage system being located in the northwestern part of the study area.

In general, net-sandstone and isopach trends in the Hosston Formation (Figs. 22 and 23) resemble those of the Cotton Valley Group. Thickness and net-sandstone values of the Hosston Formation gradually increase basinward across the subjacent Smackover-Gilmer stable carbonate platform. Basinward of the platform, the parallel high-net-sandstone trends and sediment thicks in the Cotton Valley Group coincide with those of the Hosston Formation. Thickness variations, however, are not as great within the Hosston, suggesting that most of the Hosston deltaic sedimen-

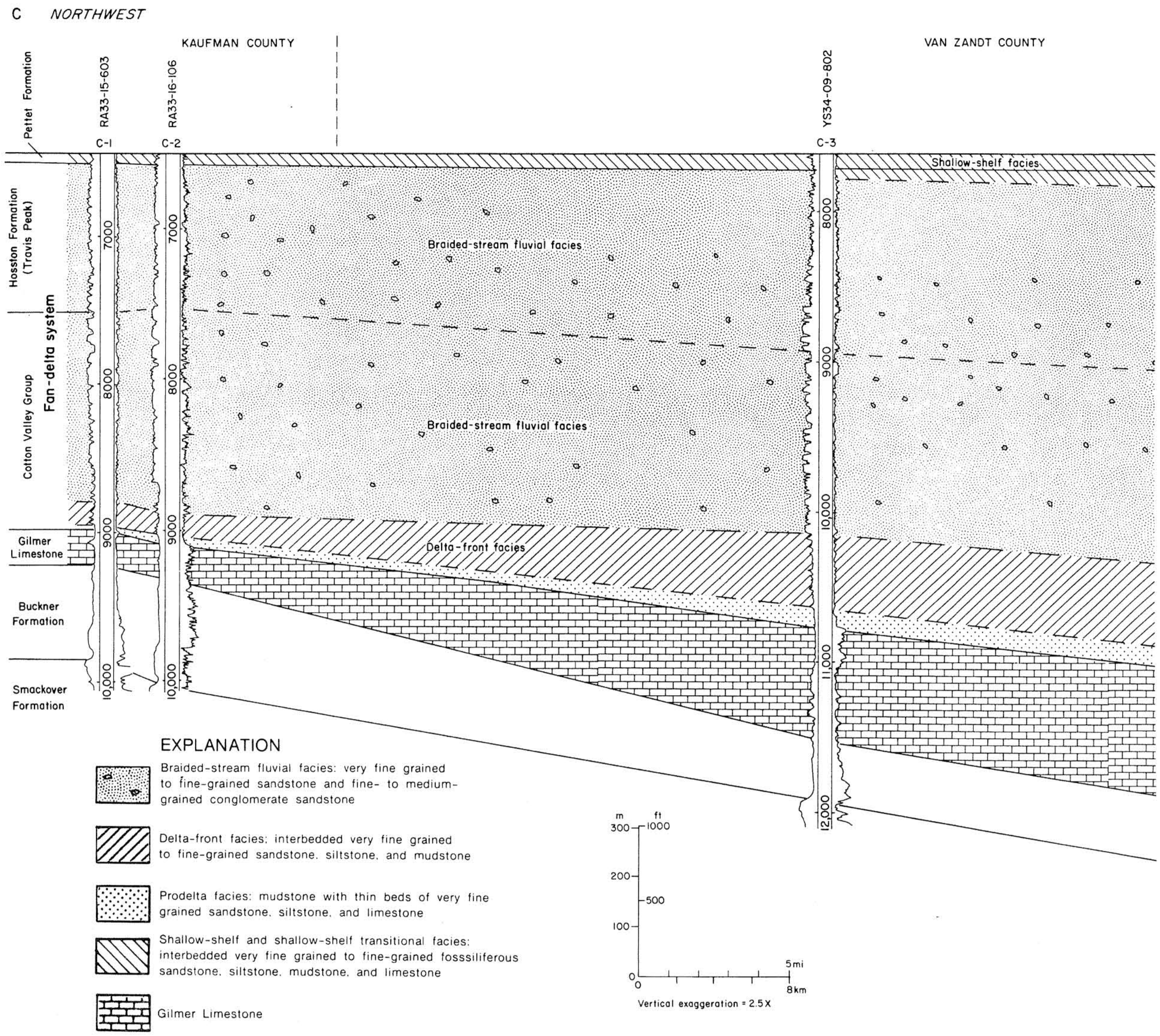
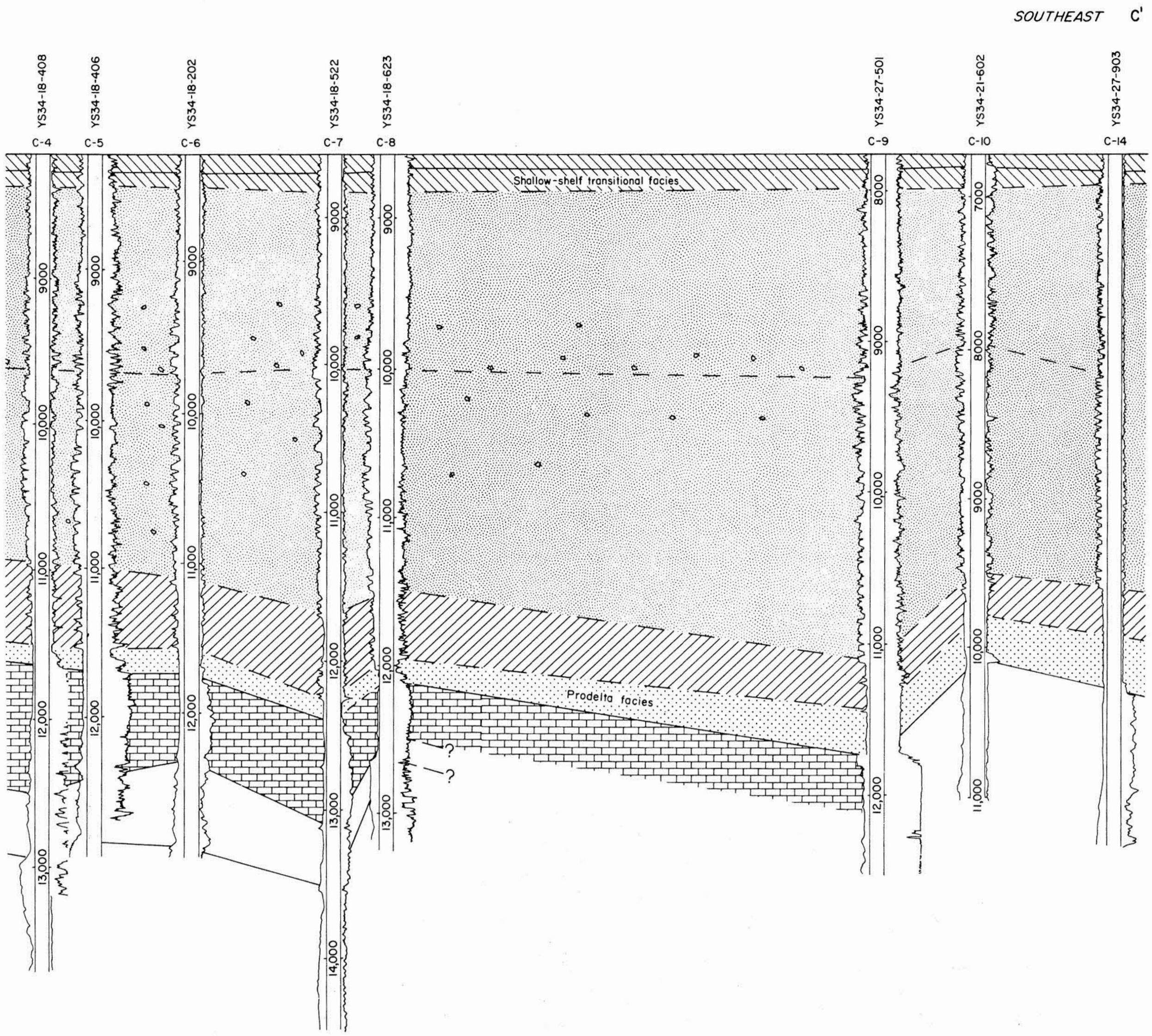


Figure 16. Stratigraphic cross section C-C'



through Kaufman and Van Zandt Counties.

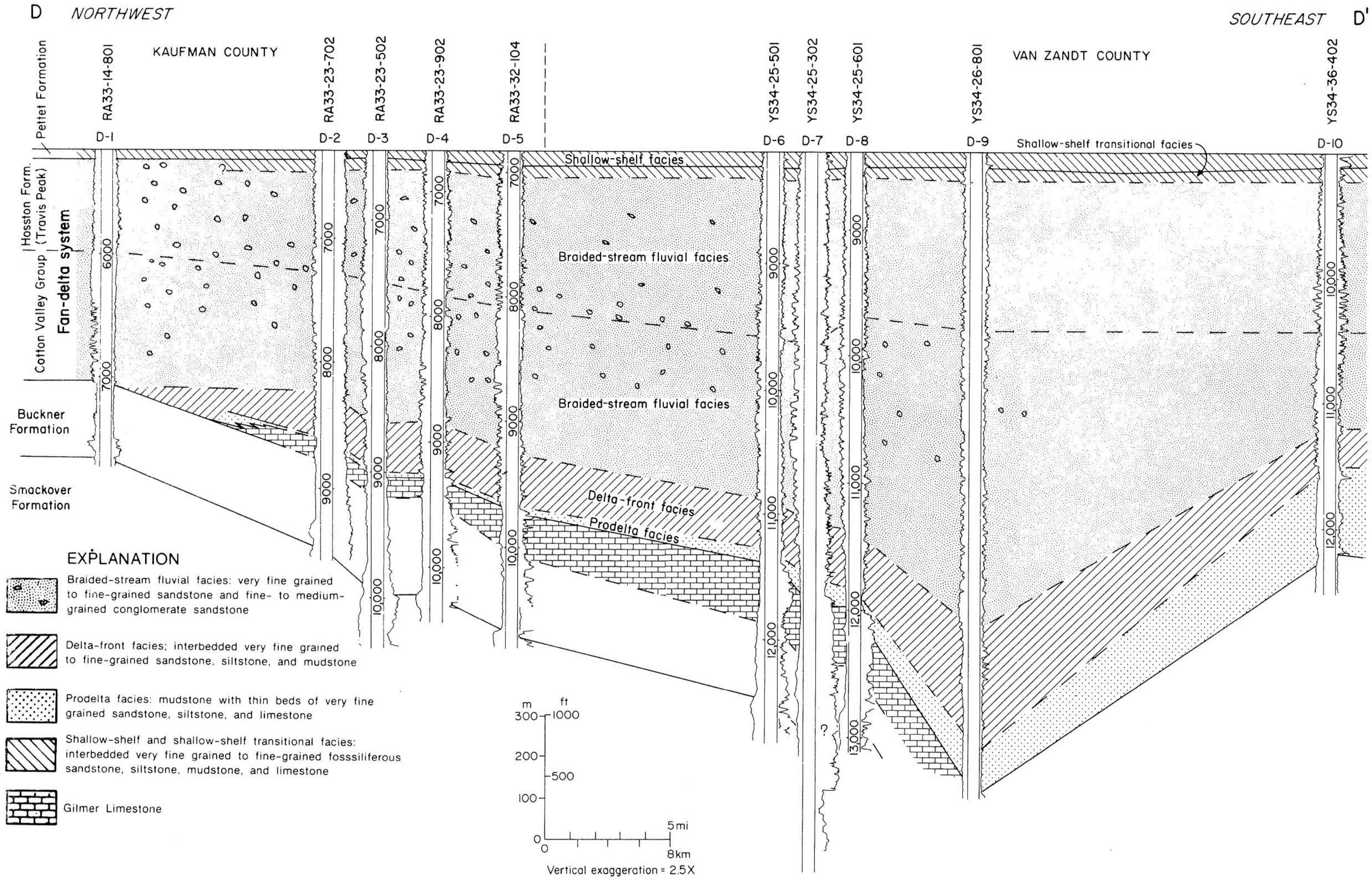


Figure 17. Stratigraphic cross section D-D' through Kaufman and Van Zandt Counties.

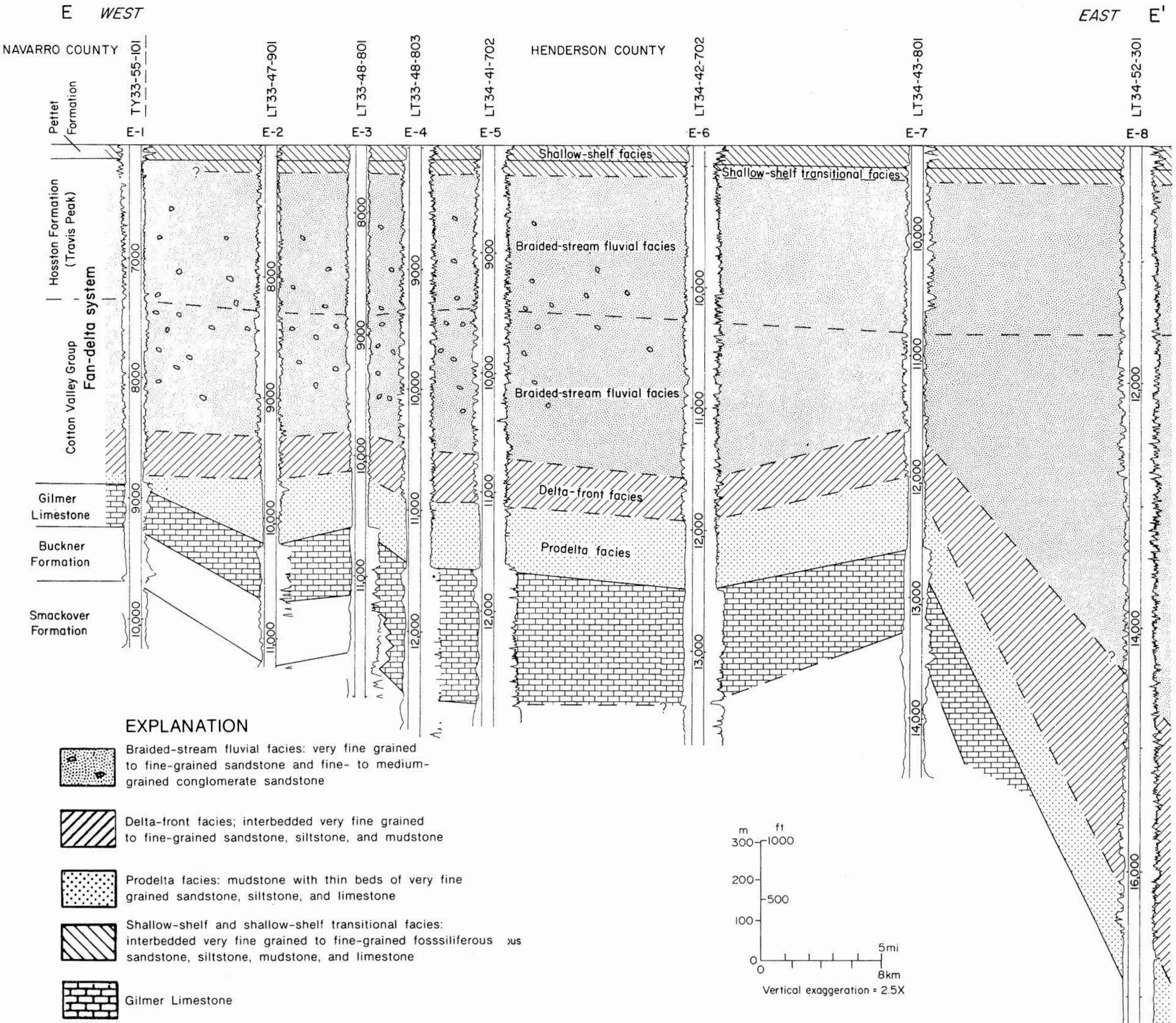


Figure 18. Stratigraphic cross section E-E' through Henderson County.

tation was basinward of the study area. A map showing depositional environments during middle Hosston time indicates a similar trend (Fig. 8 of Bushaw, 1968). Basinward, the Hosston Formation increases in thickness from 800 to 1,350 feet (244 to 412 m); the Cotton Valley Group exhibits a similar increase, from 1,400 to 5,800 feet (427 to 1,700 m).

DEPOSITIONAL AND STRUCTURAL MODEL

The model selected for use in this study was proposed by Kehle (1971) to explain the initiation of salt movement on an originally flat salt surface. Kehle suggested that mass imbalance, resulting from uneven sediment loading, has greater impact on initial salt migration than any other mechanism. He attributed uneven sediment loading to several sedimentary processes, such as reef development, formation of submarine fans at the base of a continental slope, and progradation of deltaic and strandline systems. According to this model, the underlying salt flows laterally away from the sedimentary anomaly, thereby forming an initial withdrawal basin. With continued accumulation of sediment, the withdrawal basin enlarges so that salt ridges

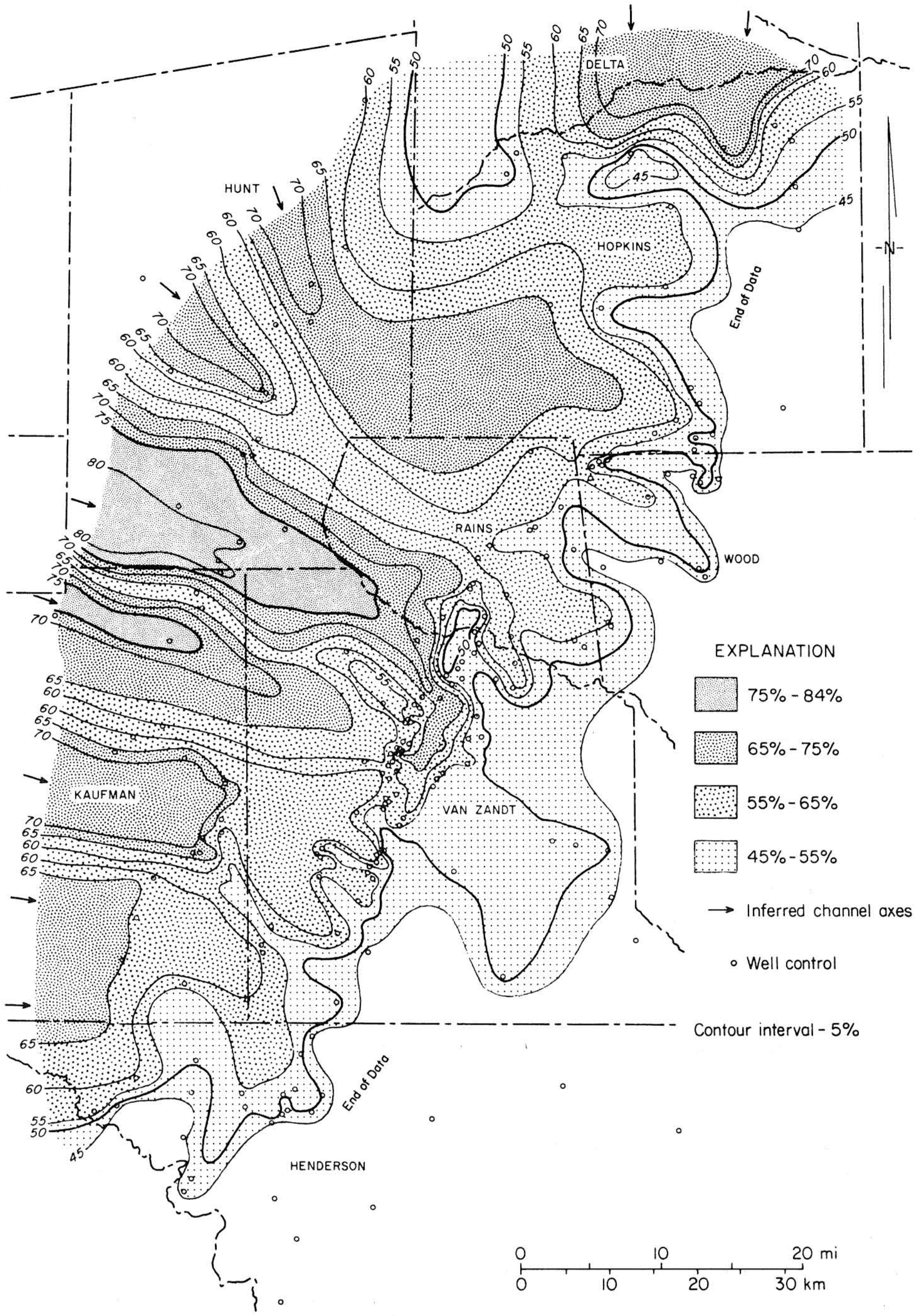


Figure 19. Sandstone-percent map of the Cotton Valley Group.

are formed basinward of the sediment thicks. Lehner (1969) and Martin (1973) documented the presence of analogous features on the abyssal plain and lower continental slope in the northern Gulf of Mexico.

Bishop (1978) proposed a similar model to explain the emplacement of piercement diapirs. His model emphasized the importance of uneven sediment loading but also suggested additional factors that might contribute to

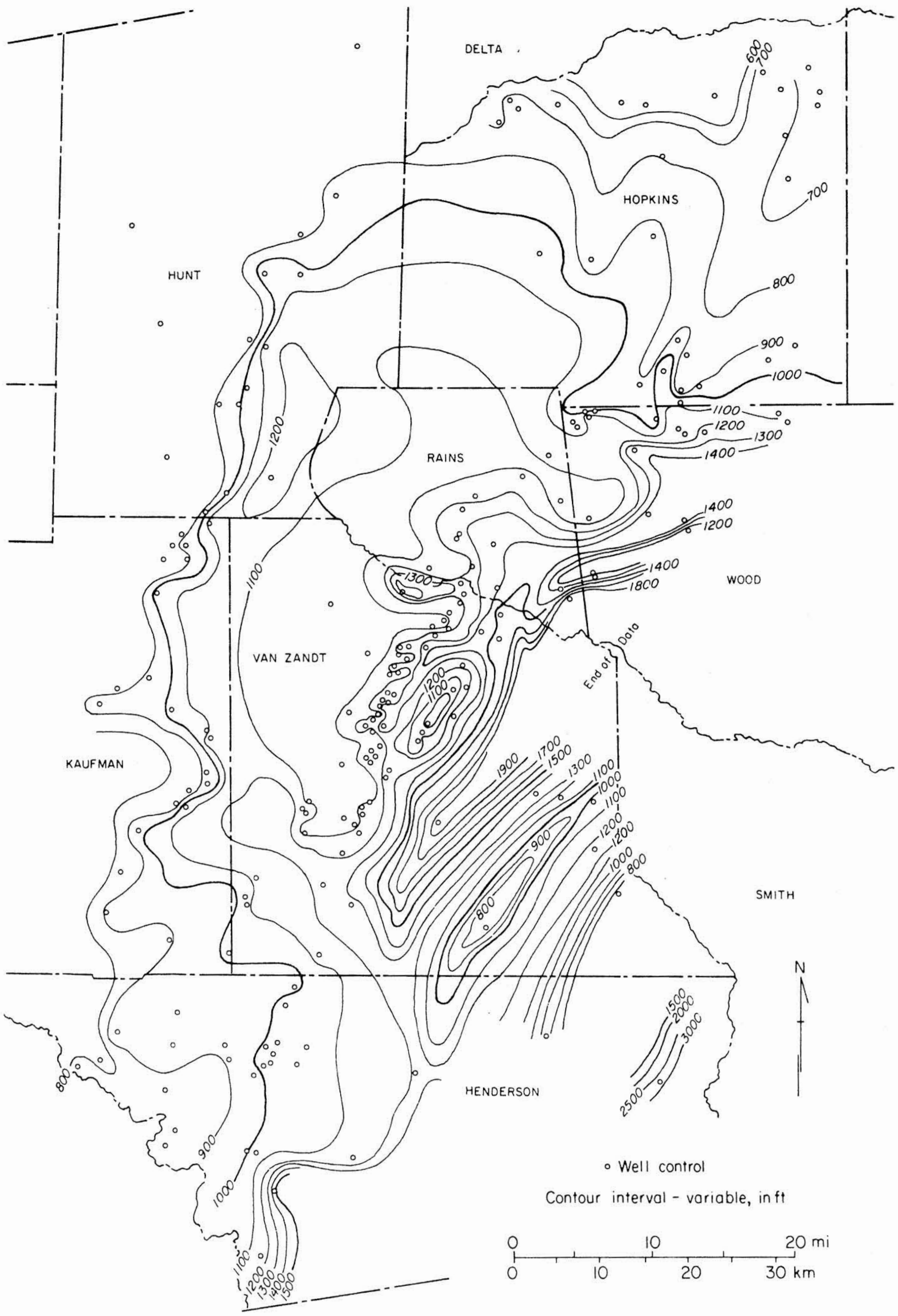


Figure 20. Net-sandstone map of the Cotton Valley Group.

the formation of incipient salt structures; these include regional dip, sedimentation rate, progradation rate, sediment density, thickness of overburden, and thickness of the underlying salt.

Fisher (1973) proposed a direct relationship between sedimentation and salt tectonics in the western Gulf Basin. He distinguished two main types of sedimentation styles and their related salt structures. In the first type, high-constructive lobate deltaic systems initiate mobilization of salt

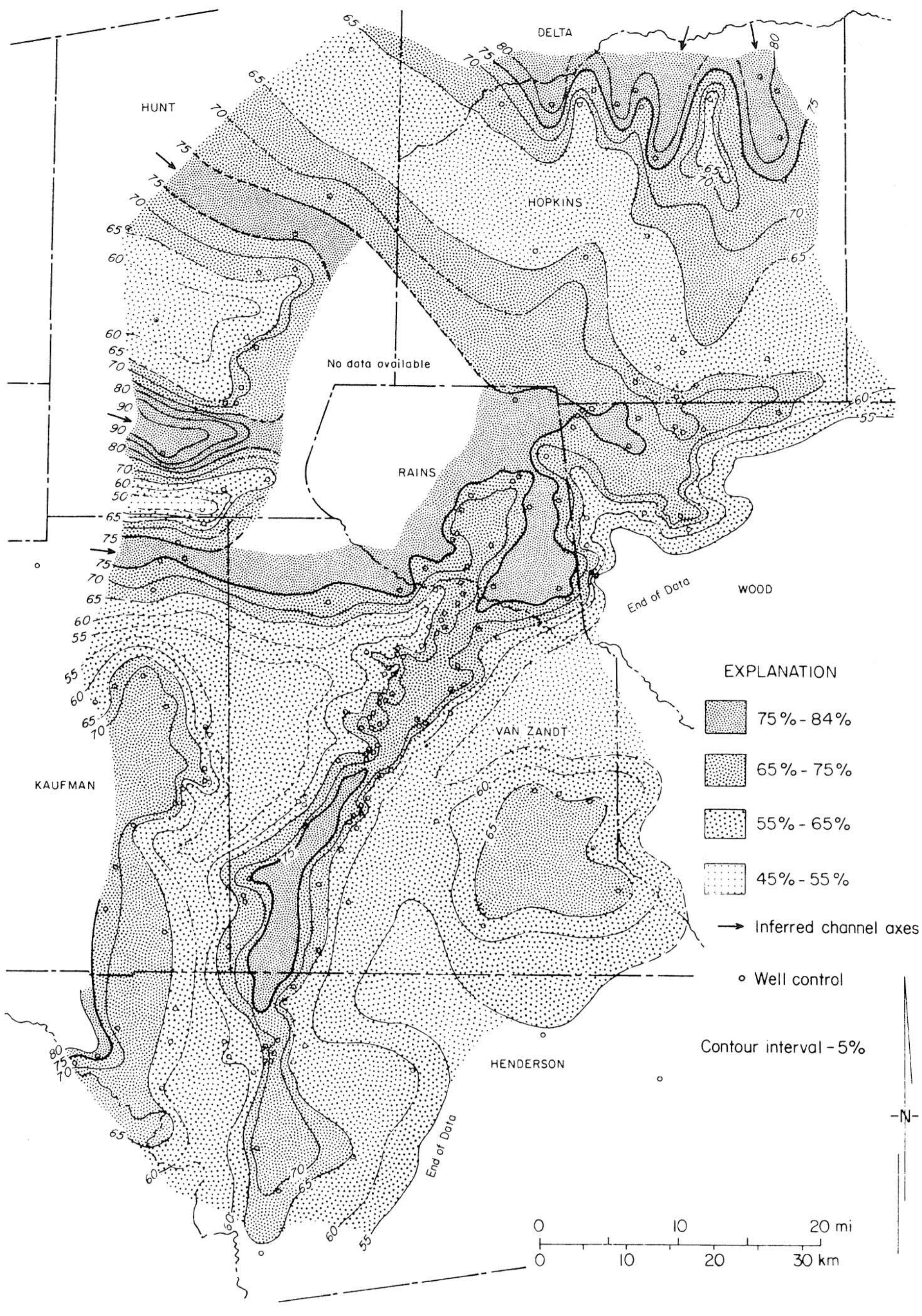


Figure 21. Sandstone-percent map of the Hosston Formation.

and the salt migrates laterally into interdeltaic areas, resulting in the formation of diapirs between the major deltaic lobes. In the second type, strike depositional systems generally induce broad salt ridges, rather than discrete salt structures, in the incipient stages. The second type is closer than the first to the salt structures that are thought to have formed during deposition of the Late Jurassic fan delta system.

In using these two models to explain how Late Jurassic depositional systems effected

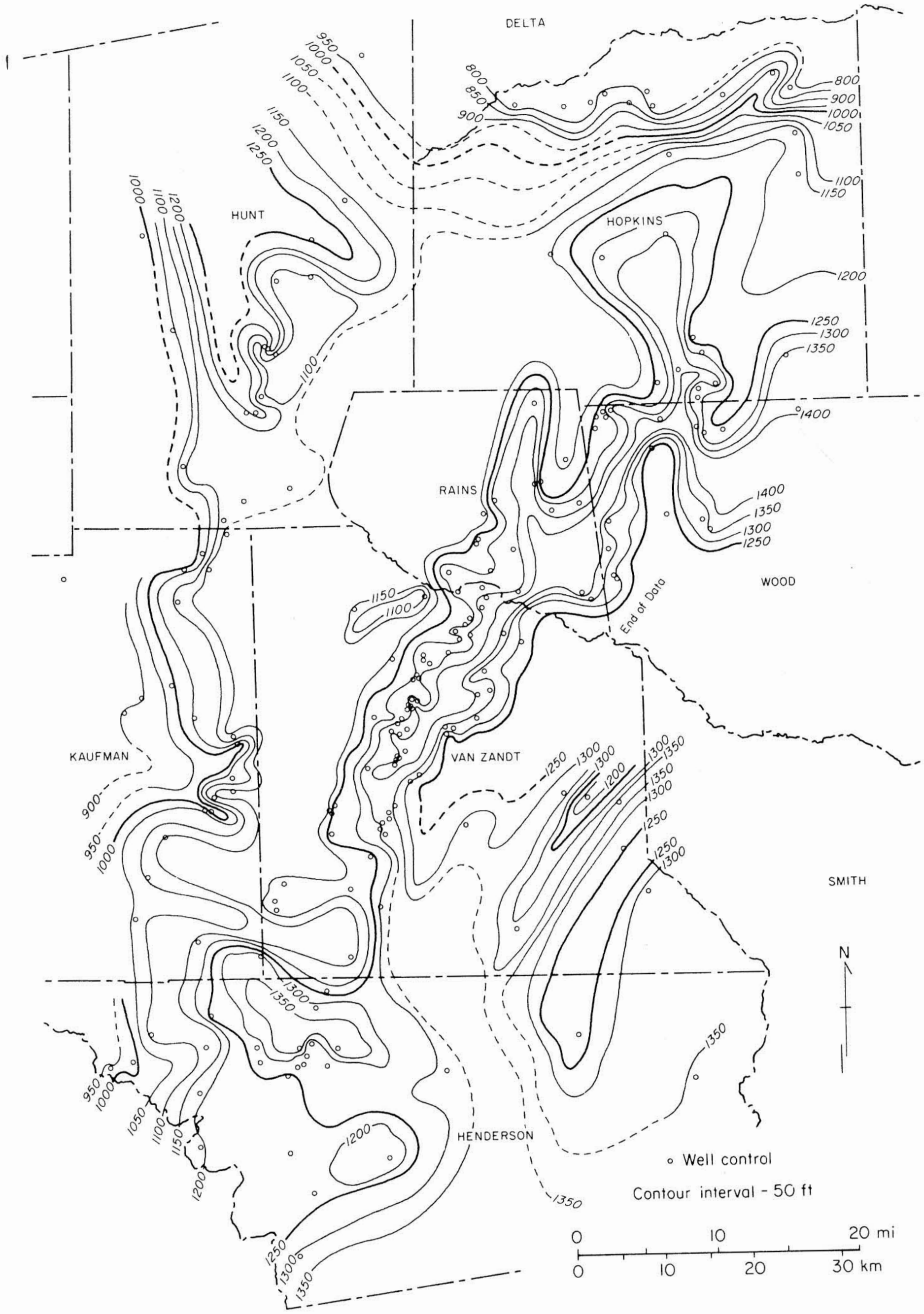


Figure 22. Isopach map of the Hosston Formation.

salt migration, the following sequence of events is suggested: Reversal of dip along the rift margin allowed an influx of terrigenous clastics into the East Texas Basin during the Late Jurassic and Early Cretaceous. Before that time, main drainage along the western margins of the basin flowed into the Triassic basins to the west. The Ouachita Mountains to the north were low-lying and thus supplied only a small quantity of terrigenous clastic sediment, which was limited mostly to the northern periphery of the basin.

As the supply of terrigenous clastic

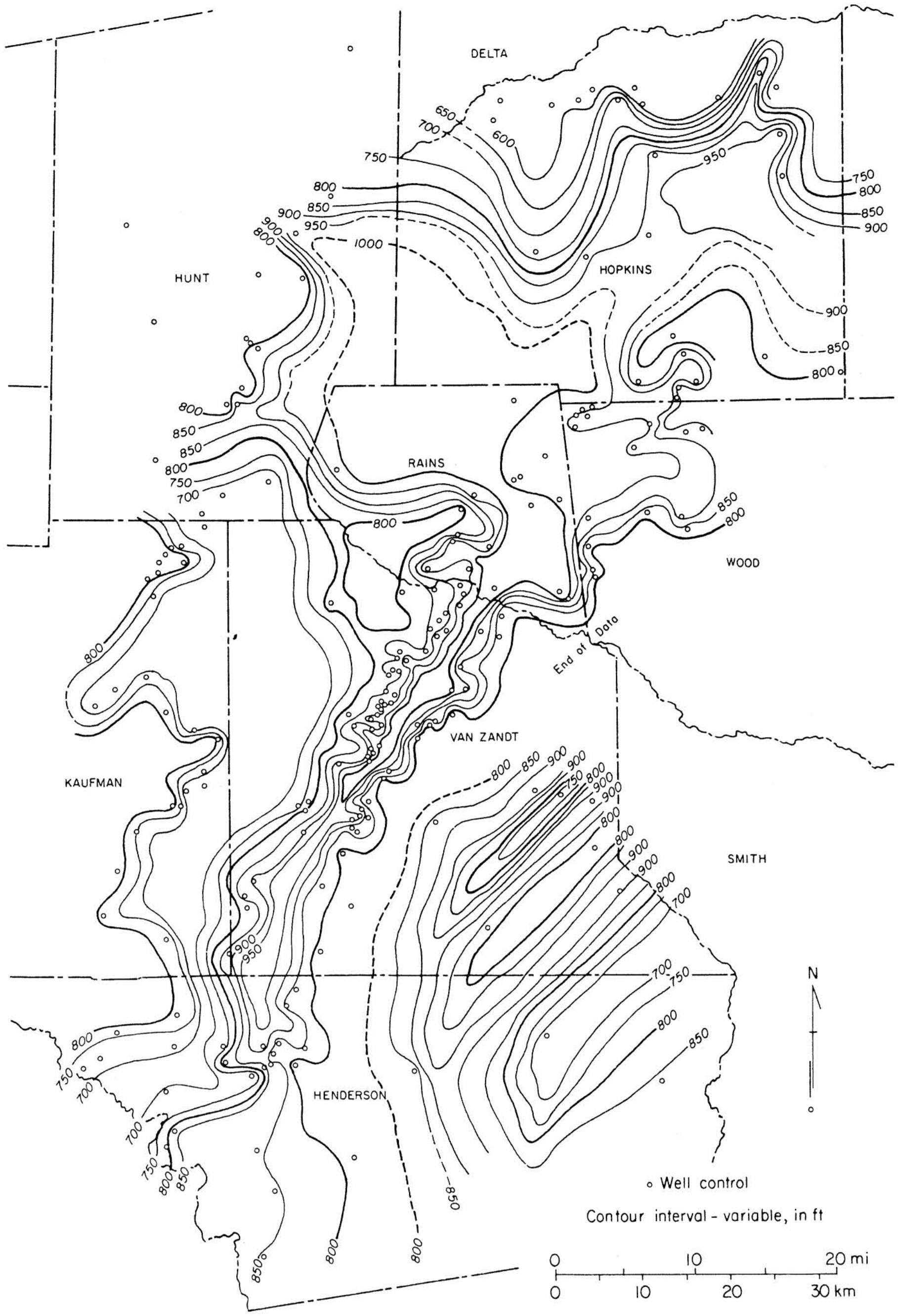


Figure 23. Net-sandstone map of the Hosston Formation.

sediment increased, Cotton Valley and Hosston fan-delta systems, which were advancing southward and eastward and were supplied by a braided-stream complex, began prograding across the Smackover-Gilmer carbonate shelf in the East Texas Basin (Fig. 24). The shelf was a stable platform, and although regional subsidence occurred, it impeded the formation of local depocenters. Most likely, the seas over the carbonate platform were shallow and the rate of progradation of the advancing deltaic complex was rapid. Low-amplitude

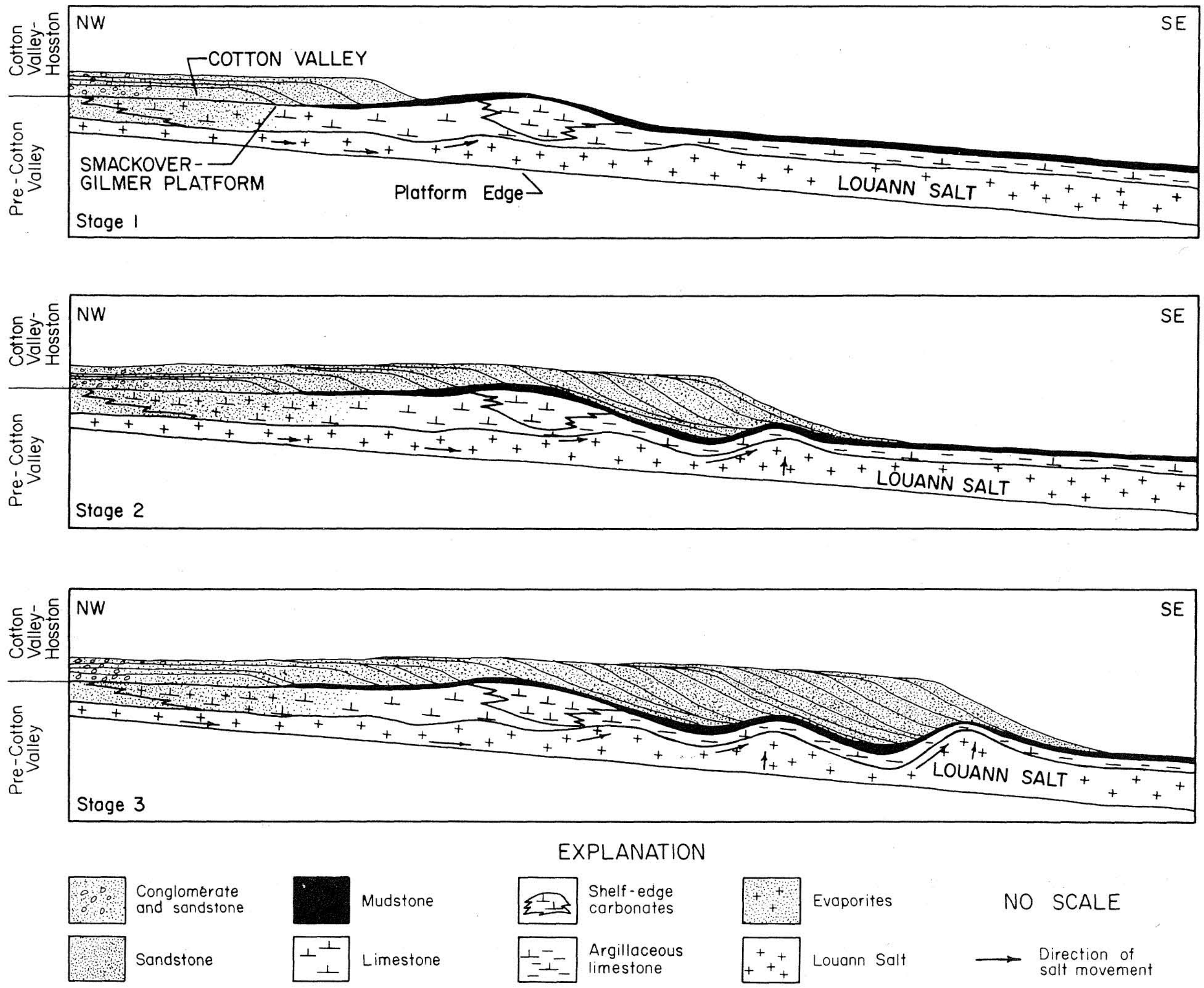


Figure 24. Structural and depositional model of salt migration in the northwestern part of the East Texas Basin during Late Jurassic and Early Cretaceous time.

salt structures occur under the Smackover-Gilmer shelf complex, apparently the result of downward creep that was caused by loading of carbonate deposits (Rogers, 1967; Jackson and Harris, 1981). These low-amplitude salt swells are not evident in the overlying Cotton Valley-Hosston sediments.

Basinward of the ancient Jurassic shelf edge, the rate of progradation slowed, while subsidence caused by salt migration and increased water depth allowed the fan delta complex to stack up, forming elongate depocenters. Salt migrated basinward, forming a salt ridge in front of the sediment wedge. This ridge acted as a dam and thereby enhanced the effectiveness of the syncline as a sediment trap. As the Louann Salt became depleted through basinward migration, subsidence slowed and allowed aggradation to surpass it. Consequently, each subsequent depocenter and associated salt ridge shifted basinward, resulting in a series of parallel salt ridges and sediment thicks. As the older salt ridges became buried, continued salt migration evolved the original salt ridges into separate salt structures, such as salt anticlines and domes.

Toward the end of Early Cretaceous time, the volume of terrigenous clastic sediment entering the East Texas Basin decreased. The transitional nature of the uppermost Hosston and marine deposits in overlying units indicate that a marine transgression occurred.

CONCLUSIONS

Subsurface mapping of the Cotton Valley and Hosston depositional systems and subjacent salt structures leads to four major conclusions regarding the role of basin infilling in the initiation of salt movement within the northwestern part of the East Texas Basin. Absence of data in the central part of the basin, however, precludes delineation of the basinward extent of the proposed depositional systems.

First, a prograding fan delta system comprises the Cotton Valley-Hosston stratigraphic units. The strata between the Gilmer and Pettet Limestones were deposited during a period of regression that was ended by a major post-Hosston transgression. The transgression is evidenced by transitional shallow marine strata in the upper 100 to 200 feet (33 to 66 m) of the Hosston Formation and by upward gradation into the overlying Pettet Limestone.

Second, the initial movement of salt that occurred in the proximal parts of the East Texas Basin during Smackover deposition was the result of downward creep that was induced by loading of carbonates and was enhanced by basinward tilting (Jackson and Harris, 1981). The resulting salt movement produced small salt structures. Relief on the salt structures increased basinward, coincident with thickening of the salt wedge.

Third, salt mobilized by mass imbalance was induced by Cotton Valley and Hosston deltaic deposition. Uneven sediment loading was controlled by the position of the underlying Smackover-Gilmer carbonate shelf. The Smackover-Gilmer carbonate shelf comprised a stable platform that impeded local subsidence and vertical aggradation of deltaic deposits. Therefore, advancing Cotton Valley-Hosston fan deltas spread laterally and basinward, depositing a fairly uniform wedge of sediments that gradually thickened basinward. Mass imbalance became a viable mechanism to initiate salt movement only when the advancing fan deltas prograded basinward of the stable carbonate platform. Salt migrated basinward of the prograding sediment wedge, forming a proximal incipient withdrawal basin and distal salt ridge. Subsequent depocenters and salt ridges shifted basinward, forming parallel sediment thicks and salt ridges.

Fourth, parallel salt ridges that formed during deposition of the Cotton Valley and Hosston apparently were the initial stage in the development of salt anticlines and domes. Through continued loading, the salt ridges evolved into discrete salt structures. Domal growth appears to depend directly on continued sediment loading, which occurs during periods of major deltaic deposition where the underlying salt wedge is adequately thick.

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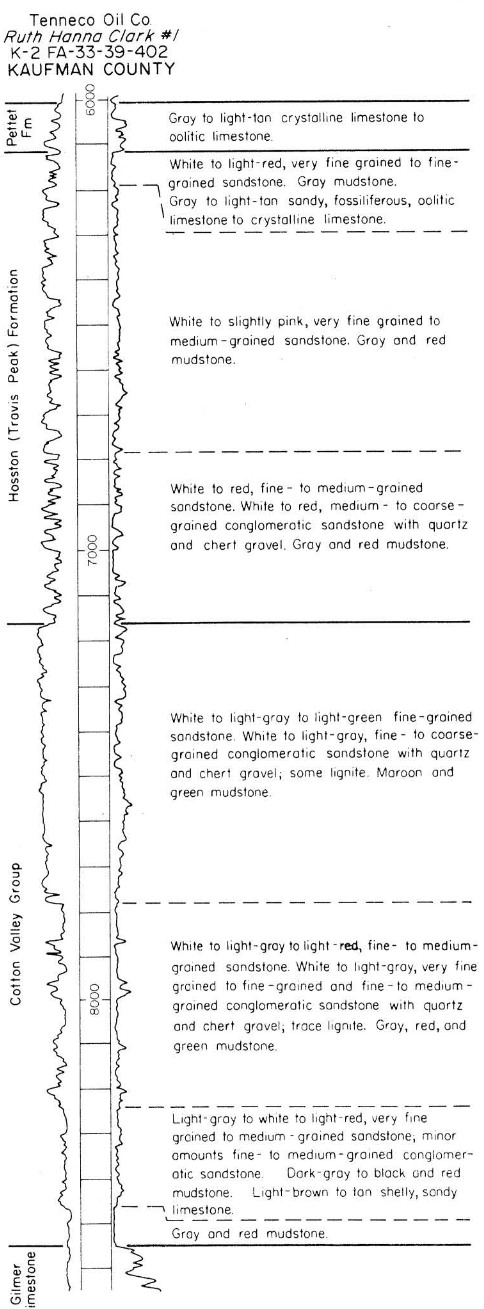
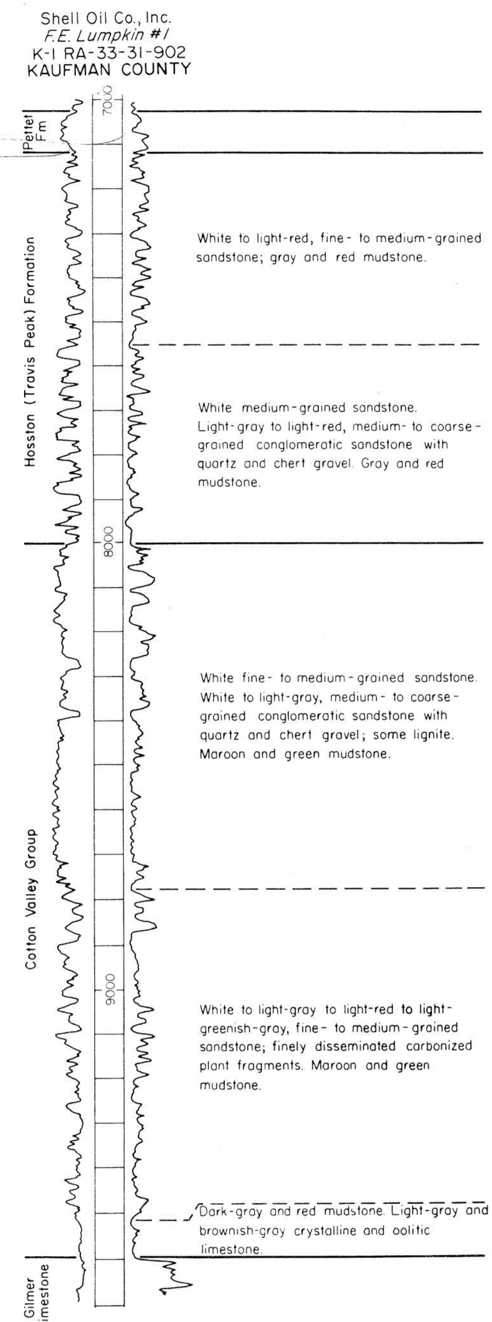
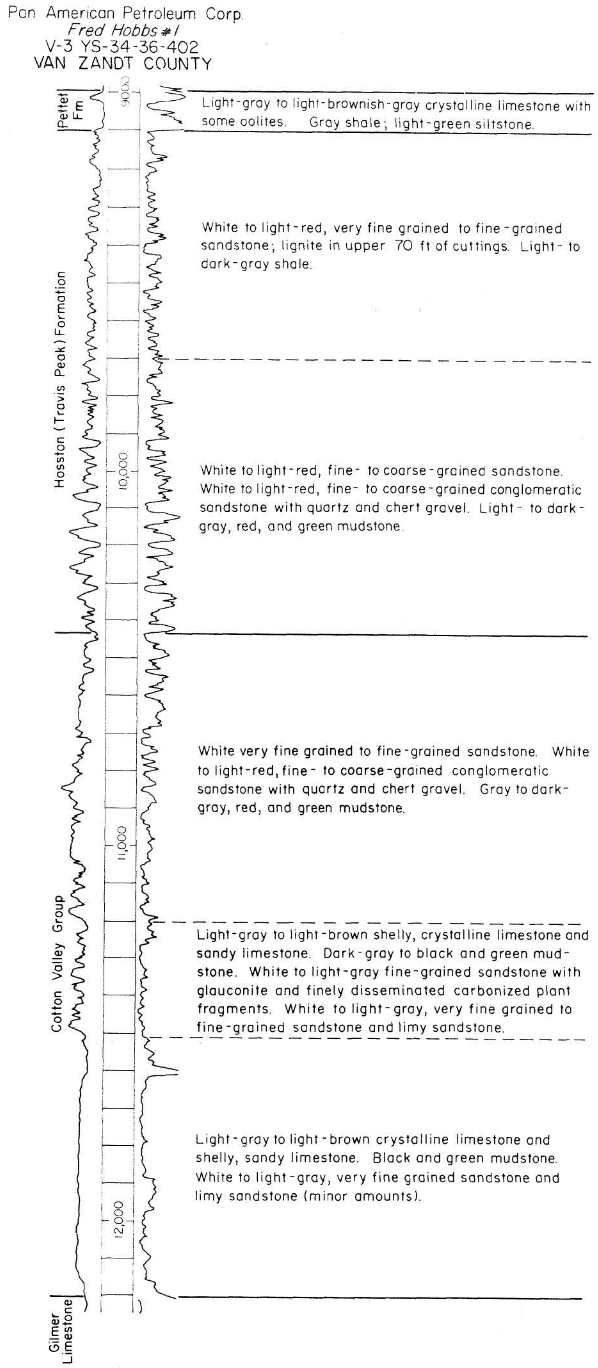
APPENDIX A

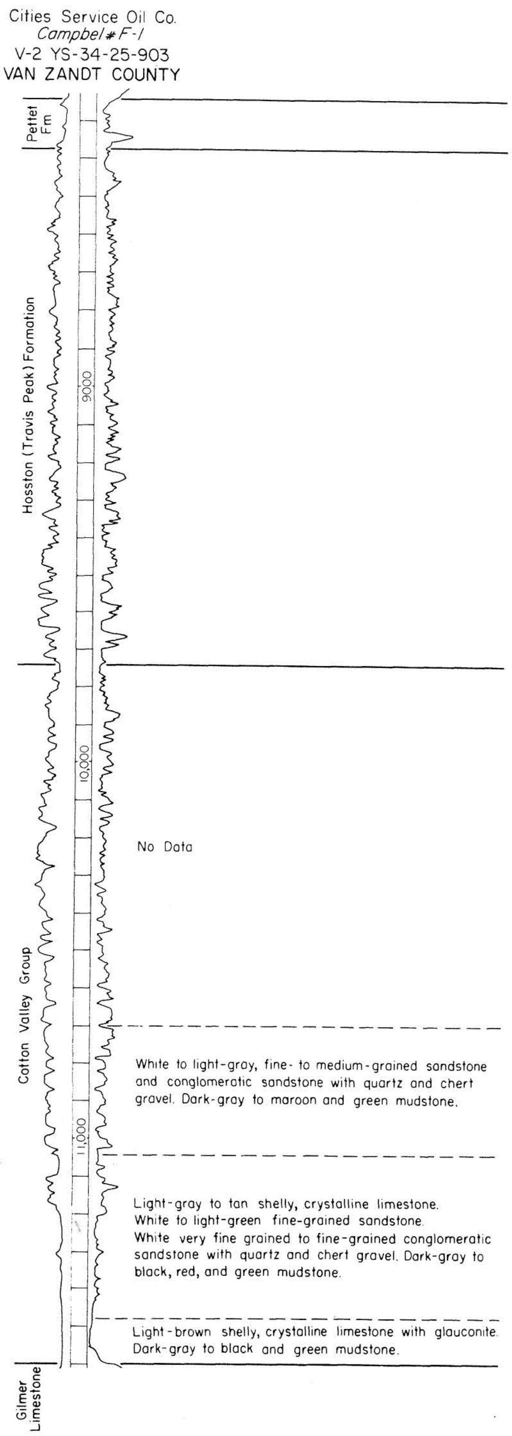
Electric log tracings and descriptions of rotary well cuttings (refer to Fig. 2 for location).



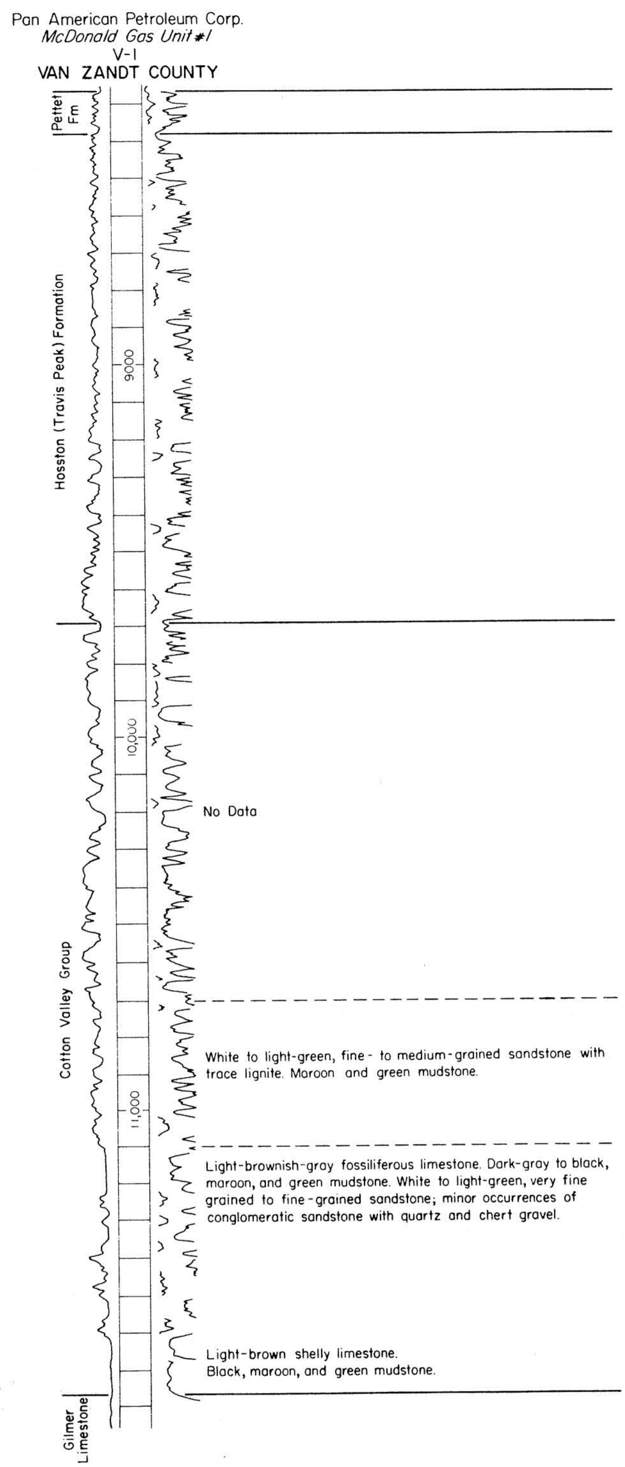


APPENDIX A - Continued





APPENDIX A - Continued



APPENDIX B

Cross-section wells

Well No.	Well Name	County
Line A-A'		
A-1 LZ 17-43-701	Humble Oil & Refining Co. No. 1 Dunham	Hopkins
A-2 LZ 17-59-201	Sunray Dx Oil Co. No. 1 Seaman	Hopkins
A-3 LZ 17-59-301	North Central Oil Co. No. 1 Moseley	Hopkins
A-4 LZ 17-59-901	Hinton No. 1 Walker	Hopkins
A-5 ZS 34-04-203	Forest Oil Corp. No. 1 Asher	Hopkins
A-6 ZS 34-04-502	Hughley Operating Co. and No. Am. Expl. Co.	Wood
A-7 ZS 34-04-601	Humble Oil & Refining Co. No. 1 Allen	Wood
A-8 ZS 34-12-301	Getty Oil No. 1 Blalock	Wood
A-9 ZS 34-12-303	Shell Oil Co. No. 1 Wright	Wood
Line B-B'		
B-1 PH 33-08-204	Ohio Oil Co. No. 1 Popper	Hunt
B-2 UX 34-10-302	Texaco, Inc. Irvine Gas Unit No. 1	Rains
B-3 UX 34-10-601	Delta Drilling No. 1 Hare	Rains
B-4 UX 34-11-905	Caraway & Smith No. 1 Gilley	Rains
B-5 ZS 34-12-701	Samedan Oil Corp. Buchanan No. 1	Wood
B-6 ZS 34-23-701	Humble Oil & Refining Co. NW Hawkin No. 1	Wood
Line C-C'		
C-1 RA 33-15-603	Schneider and Murray No. 1 Jones Estate	Kaufman
C-2 RA 33-16-106	Santa Fe Minerals, Inc. No. 1 Barrow Estate	Kaufman
C-3 YS 34-09-802	E. C. Johnston Co. No. 1 Martin Gas Unit	Van Zandt
C-4 YS 34-18-408	Pan American Petr. Corp. Brown Gas Unit B-1	Van Zandt
C-5 YS 34-18-406	Pan American Petr. Corp. No.1 Nichols Gas U.	Van Zandt
C-6 YS 34-18-202	Caraway and Smith Parker Gas Unit No. 2	Van Zandt
C-7 YS 34-18-522	R. J. Caraway No. 1 Stone (Fruitvale GU)	Van Zandt
C-8 YS 34-18-623	Continental Oil Co. No. 1 Elliot	Van Zandt
C-9 YS 34-27-501	Halbouty No. 1 Rowan	Van Zandt
C-10 YS 34-27-602	Midwest et al. No. 1 Clark	Van Zandt
C-11 YS 34-27-903	Pure Oil Co. D-8 Swain No. 11	Van Zandt
Line D-D'		
D-1 RA 33-14-801	Rockwall Exploration Co. No. 1 Wallace	Kaufman
D-2 RA 33-23-702	W. M. Hughes No. 1 Billings	Kaufman
D-3 RA 33-23-502	The T x 1 Oil Corp. No. 1 Liston	Kaufman
D-4 RA 33-23-902	Southland Royalty Co. No. 1 Frosch Unit	Kaufman
D-5 RA 33-32-104	Union Tex. Pet.-Lacal Pet. No. 1 Phillips	Kaufman
D-6 YS 34-25-501	R. J. Caraway No. 1 Yates	Van Zandt
D-7 YS 34-25-302	Superior Oil Co. No. 1 Porter	Van Zandt
D-8 YS 34-25-601	R. J. Caraway No. 1 Parker	Van Zandt
D-9 YS 34-26-801	R. J. Caraway No. 1 Gilmore	Van Zandt
D-10 YS 34-36-402	Pan American Petr. Corp. No. 1 Hobbs	Van Zandt
Line E-E'		
E-1 TY 33-55-101	Humble Oil & Refining Co.	Navarro
E-2 LT 33-47-0-1	Max Pray No. 1 Carter	Henderson
E-3 LT 33-48-801	Pan American Petr. Corp. No. 1 Sorrell	Henderson
E-4 LT 33-48-803	Rudman Resources, Inc. No. 1 Hammock	Henderson
E-5 LT 34-41-702	Lake Ronel Oil Co.-Bill Ross No. 1 Shaver	Henderson
E-6 LT 34-42-702	B. Smith, G. Lehnertz, W. Perryman No. 1 Lee	Henderson
E-7 LT 34-43-801	Lone Star Producing Co. 1-B Allyn	Henderson
E-8 LT 34-57-301	Texas Interstate Oil & Gas Co. No. 1 Cotton	Henderson