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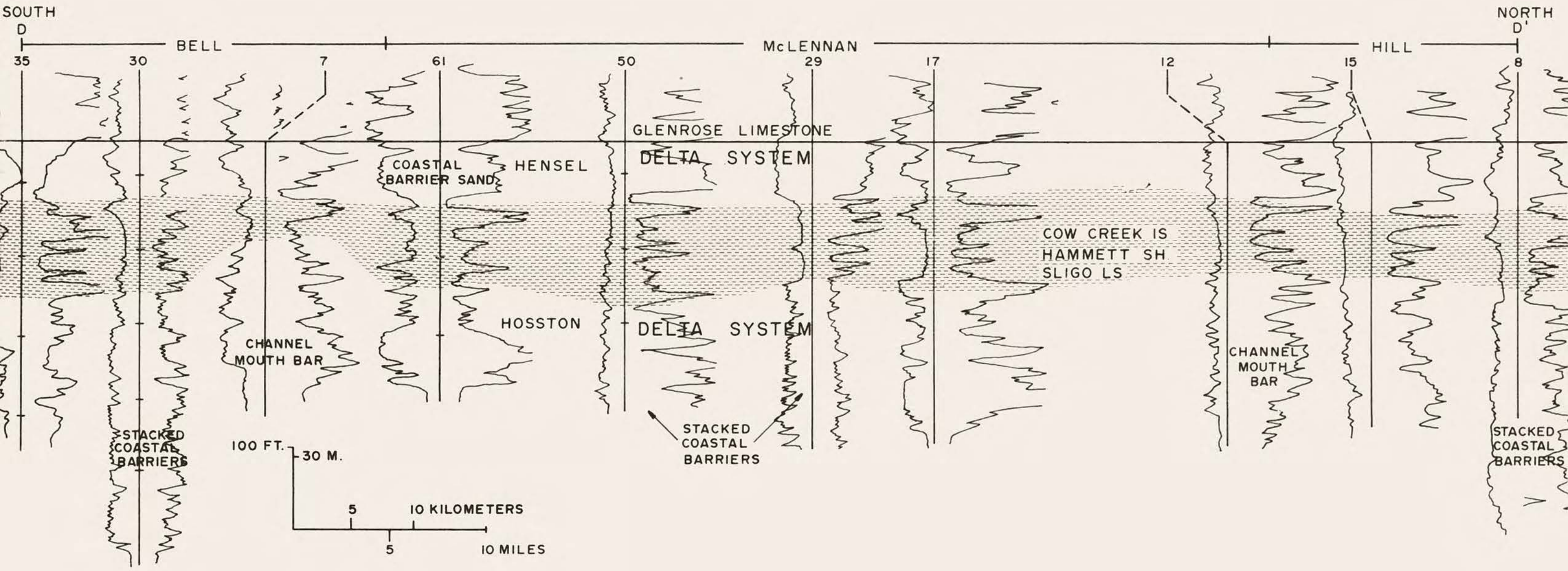
W. DOUGLAS HALL



BUREAU OF ECONOMIC GEOLOGY
THE UNIVERSITY OF TEXAS AT AUSTIN
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HYDROGEOLOGIC SIGNIFICANCE OF DEPOSITIONAL SYSTEMS AND FACIES IN LOWER CRETACEOUS SANDSTONES, NORTH-CENTRAL TEXAS

W. Douglas Hall[1]

ABSTRACT

The Lower Cretaceous Hosston and Hensel Sandstones are important sources of ground water in North-Central Texas. Delineation of major depositional systems and their component facies within these formations provides a method for predicting the quantity, movement, and chemical composition of water in the aquifers.

The Hosston and Hensel Sandstones were deposited during minor reversals of marine transgression onto the Texas craton by Comanchean (Lower Cretaceous) seas. A net sandstone map of the Hosston Formation shows two major depositional trends: (1) a dip-oriented (west-east) meanderbelt fluvial system, strongly influenced in the west by relief on the underlying Wichita paleoplain, which supplied sediment to (2) a strike-oriented (north-south) high-destructive, wave-dominated delta system overlying the Ouachita foldbelt in the east. The Hensel deposits prograded eastward across the relatively featureless upper surface of the Pearsall Formation, forming two depositional systems similar to those of the Hosston.

The meanderbelt sandstone facies of the fluvial systems and the coastal barrier facies of the delta systems are thick, laterally persistent sandstone bodies capable of supplying greater amounts of ground water than the flood basin, lagoon-marsh-embayment, or prodelta-shelf facies, which are composed principally of mudstone and siltstone. Regional ground-water movement in both formations is to the southeast with hydraulic gradients of 10 to 15 feet per mile (2 to 3 meters/kilometers). Transmissivity averages 8,000 gallons per day per foot (1.2 liters/second/meter) in the Hosston and 5,000 gallons per day per foot (0.7 liters/second/meter) in the Hensel.

Hydrochemical facies of water in the Hosston and Hensel Sandstones coincide with the principal lithogenetic facies of the two depositional systems. Ground water is dominantly of the calcium magnesium bicarbonate type in the fluvial system but changes downdip to sodium sulfate and sodium bicarbonate types in the delta systems, indicating a change in conditions of chemical equilibrium.

INTRODUCTION

The Lower Cretaceous Hosston and Hensel Sandstones are the most important sources of ground water in North-Central Texas. These sandstones, locally known as the "Trinity sands" or "basement sands," provide water of suitable quantity and quality for municipal supply, irrigation, and industrial use throughout most of the area.

OBJECTIVES AND METHODS

The principal objectives of this study are: (1) to determine the hydrogeologic significance of facies within depositional systems that compose the Hosston and Hensel Sandstones in North-Central Texas, and (2) to investigate the possible relationships between the depositional framework and chemical water types. The Travis Peak Formation, a complex braided-stream and fan-delta system flanking the Llano uplift southeast of the study area, was not included in this investigation.

The study integrated geologic surface and subsurface information with hydrogeologic data. Electric and gamma-ray logs (fig. 1) supplemented by driller's logs, borehole cuttings, and outcrop studies provided data for the geologic investigation (Index to Subsurface Electric Log Control, from Hall, 1974, is on open file at the Bureau of Economic Geology, The University of Texas at Austin).

Sand trends, thickness distribution, and lateral and vertical facies relationships were

[1]Dames and Moore, Boca Raton, Florida.

delineated on net sandstone maps of the two formations and on cross sections. These characteristics of the sedimentary framework were then compared with published descriptions of Holocene and ancient depositional systems to interpret and reconstruct Hosston and Hensel depositional environments.

Pumping test information, water-level records, and laboratory analyses of well water samples were the principal hydrogeologic data. Maps of potentiometric surfaces were constructed and related to sandstone distribution and thickness within each aquifer. Hydrochemical facies, based on relative concentrations of major ions, were delineated and superimposed on the depositional framework. Regional variations in the chemical composition, quantity, and movement of ground water were related to individual depositional systems or component facies within each aquifer.

LOCATION

The study area, about 11,000 square miles (28,500 km^2) in North-Central Texas, includes Bell, Bosque, Comanche, Coryell, Eastland, Erath, Falls, Hamilton, Hill, Hood, Johnson, McLennan, and Somervell Counties (fig. 1). Waco, with a population of about 100,000 in 1970 (Arbingast, 1973), is the largest city in the area.

The Hosston and Hensel Sandstones crop out in Comanche, Eastland, Erath, and Hood Counties. The pre-Glen Rose Trinity outcrop belt constitutes the Western Cross Timbers, a major physiographic province in Texas. In outcrop, the two sandstones and the Pearsall Shale have been collectively designated the Twin Mountains Formation (Fisher and Rodda, 1966). The major land uses in the outcrop area are ranching and agriculture.

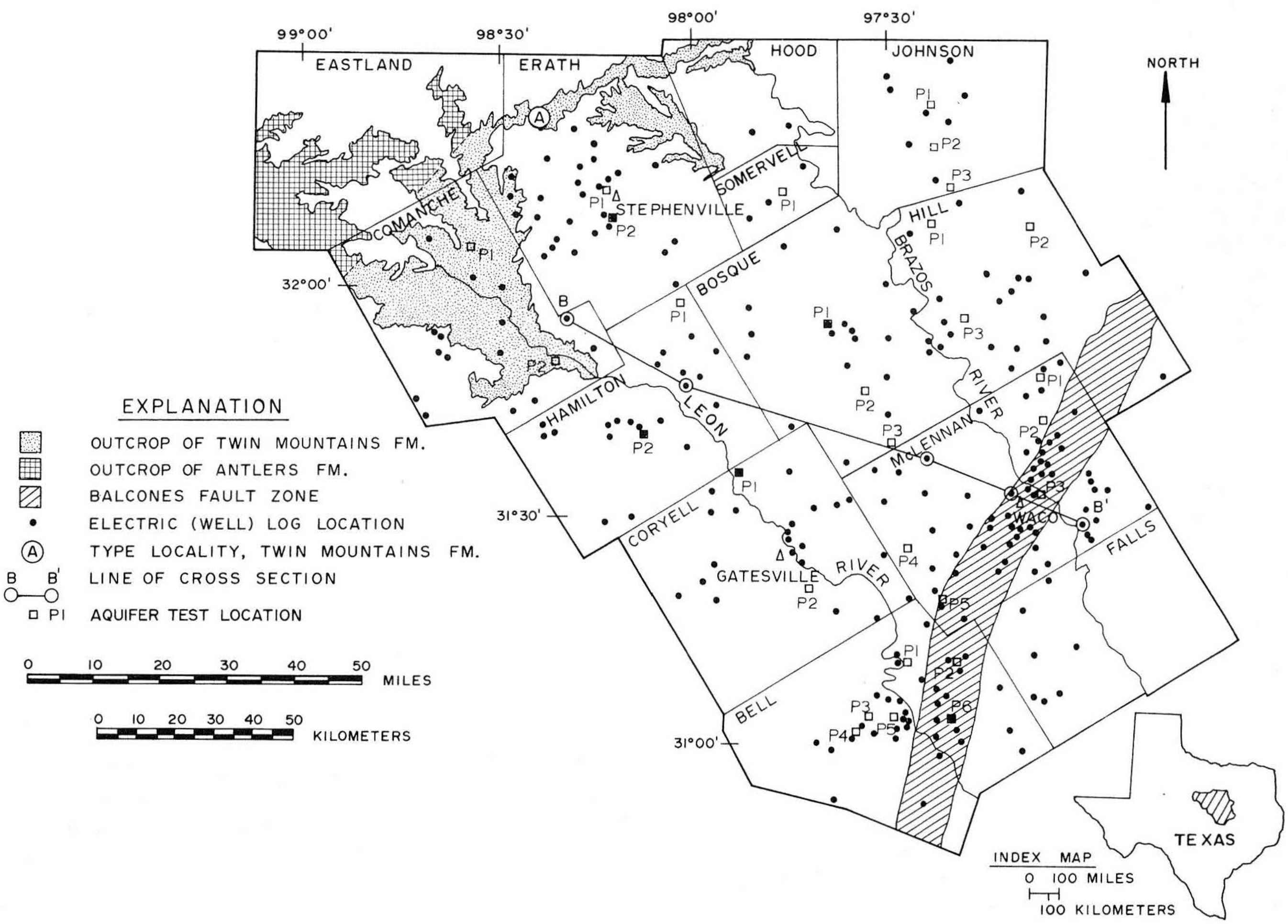


Figure 1. Location map.

The mean annual precipitation is 28 to 36 inches (71 to 91 cm), and mean annual temperature is 64 to 68 degrees Fahrenheit (18 to 20 degrees Centigrade) (Arbingast, 1973).

STRUCTURAL FRAMEWORK

Comanchean (Lower Cretaceous) rocks in North-Central Texas were deposited in a region composed of two major structural provinces—the East Texas basin and the Texas craton. The East Texas basin was an area of active subsidence throughout much of the Mesozoic and Cenozoic Eras, and the Texas craton was a relatively stable structural platform. The boundary between these two distinctive structural provinces is marked in Paleozoic rocks by the Ouachita foldbelt and in the Cretaceous section by the Balcones and Mexia-Luling fault zones.

The Ouachita foldbelt, inactive since late Paleozoic time, apparently served as a hinge between the subsiding East Texas basin and the relatively stable platform to the west (Hayward and Brown, 1967). During Cretaceous deposition, the basin subsided south and east of the study area, resulting in an eastward increase in dip and thickness of the Cretaceous rocks (Holloway, 1961).

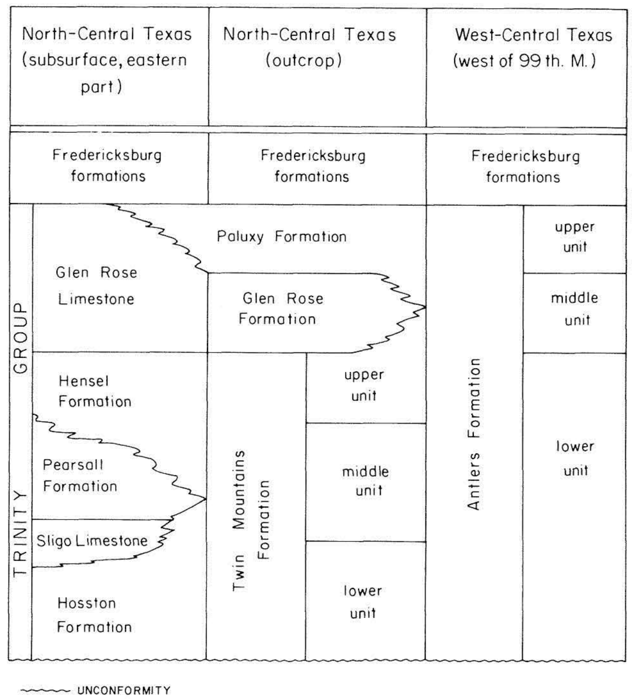
The Balcones fault zone, which trends north-south through the eastern part of the study area, is the innermost zone of faulting in the Gulf coastal plain and consists of predominantly down-to-the-coast, somewhat en echelon faults. Displacements as great as 400 feet (122 m) have been recognized in Comanchean and Gulfian rocks in McLennan County (Holloway, 1961).

The sub-Cretaceous surface, known as the Wichita paleoplain (Hill, 1901), was developed upon westward-dipping Paleozoic rocks in the craton region and on truncated metamorphic rocks of the Ouachita foldbelt (Flawn, 1961). Structural contours of this paleosurface (Boone, 1968; Bain, 1973) indicate considerable topographic relief in the form of major drainage valleys and divides (fig. 2). This paleotopography is also reflected in the thickness patterns of the overlying Hosston Sandstone which filled the valleys. The average dip of this paleosurface increases from 15 feet per mile (2.8 m/km) in the west to more than 80 feet per mile (15 m/km) in the east.

PREVIOUS INVESTIGATIONS

The Hosston and Hensel Sandstones and the genetically related rocks of the Twin Mountains Formation in North-Central Texas were described by Fisher and Rodda (1966; see table 1). The nomenclatural history has been summarized by several workers (Boone, 1968; Stricklin and others, 1971; Bain, 1973) and, although interesting, is not relevant to this study.

Table 1. Nomenclature and correlation of Lower Cretaceous rocks of North-Central and West-Central Texas (modified from Fisher and Rodda, 1966).



Recent reports concerning the geology and hydrogeology of the area include those of Holloway (1961), Hayward and Brown (1967), Stricklin and others (1971), Bain (1973), and Klemt and others (in press). The work of Boone (1968) provided valuable background information; his lithic descriptions and subsurface correlations aided in the interpretation of stratigraphic relationships and depositional history. Henningsen (1962) delineated chemical water masses within the Trinity aquifers of Central Texas and also furnished an excellent summary of geochemical factors influencing water diagenesis. His study, one of the earliest of its type, demonstrated the usefulness of geochemistry in regional ground water studies.

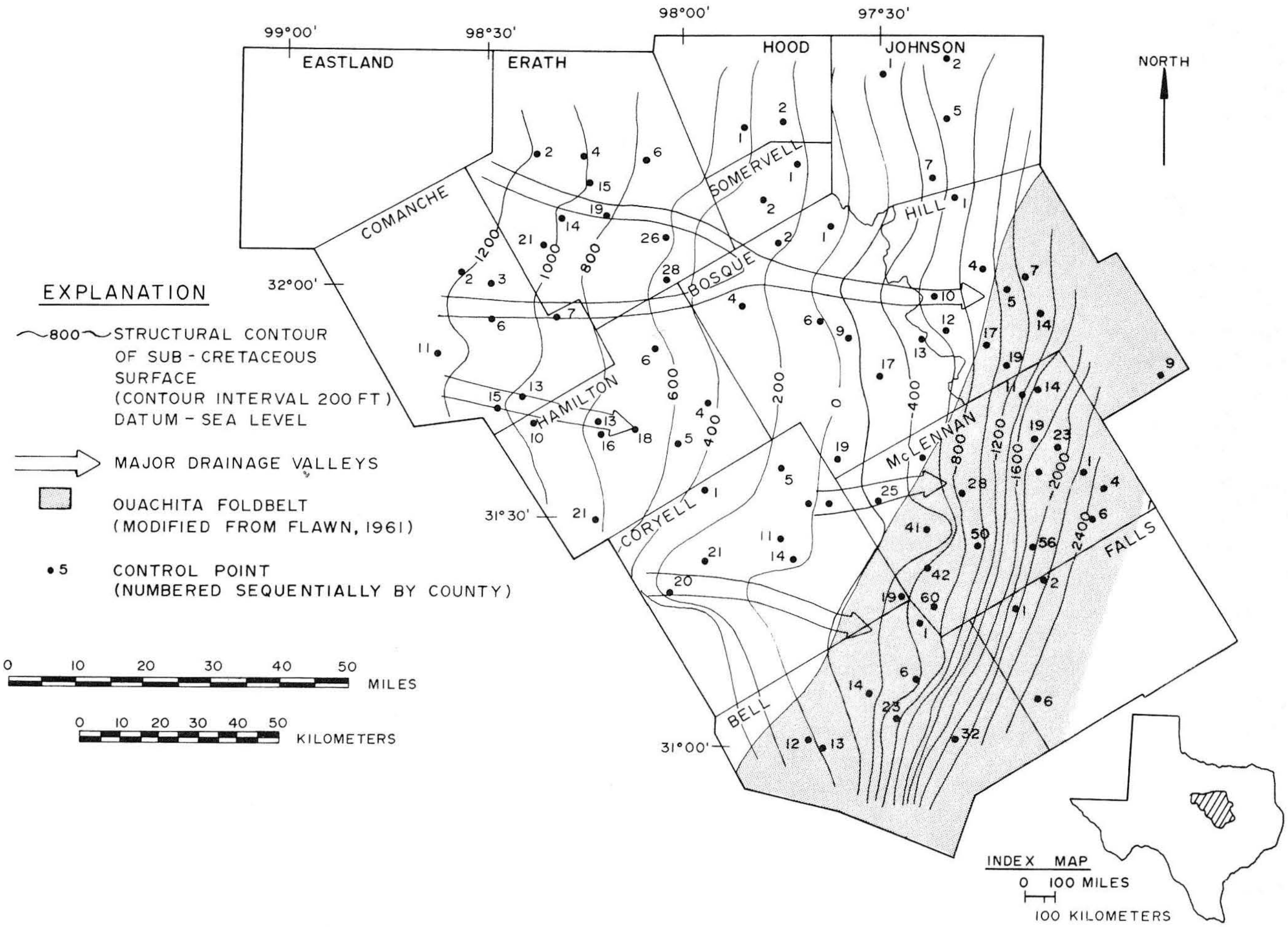


Figure 2. Paleotopography of sub-Cretaceous surface, North-Central Texas. Arrows indicate major drainage valleys (modified from Boone, 1968).

ACKNOWLEDGMENTS

This report is based on a Master's thesis at The University of Texas at Austin. The reviews and criticisms of Dr. L. J. Turk, supervising professor, Department of Geological Sciences, The University of Texas at Austin, Dr. L. F. Brown, Jr., Bureau of Economic Geology, and Dr. L. S. Land, Department of Geological Sciences, are much appreciated. Steven D. Hulke edited the thesis and provided helpful suggestions.

A. Wayne Wyatt, William B. Klemt, and Phillip L. Nordstrum, of the Texas Water Development Board, willingly shared their knowledge of the area and provided necessary hydrogeologic data. Jimmie N. Russell, also of the Texas Water Development Board, provided access to the extensive log library.

Thesis work was financed by a research grant from the Mobil Oil Corporation in the spring of 1973 and by the Mr. and Mrs. L. F. McCollum Groundwater Fellowship for 1973-74. These grants were furnished through the Geology Foundation, The University of Texas at Austin. In addition, summer field support was provided by the Texas Bureau of Economic Geology in 1973.

STRATIGRAPHY

REGIONAL STRATIGRAPHIC RELATIONSHIPS

The stratigraphic interval investigated in this study consists of rocks of the Trinity Group above the Paleozoic surface of the Texas craton and below the base of the Cretaceous Glen Rose Limestone. The thickness of this interval within the study area is less than 100 feet (30 m) in the northwest and more than 500 feet (150 m) in the east (fig. 3).

The pre-Glen Rose Cretaceous interval from base to top consists of the Hosston Sandstone, the Sligo Limestone, the Hammett Shale and Cow Creek Limestone Members of the Pearsall Formation, and the Hensel Sandstone. This section is most complete in the subsurface in the eastern part of the study area. West of McLennan County, the carbonate facies of the Sligo Limestone and Pearsall Formation are not recognizable on electric logs. Updip and in outcrop, the Hosston and Pearsall coalesce with the Hensel Sandstone and collectively are designated the Twin Mountains Formation (Fisher and Rodda, 1966).

Farther to the west, the Glen Rose Limestone pinches out. Where this occurs, the underlying Twin Mountains Formation becomes indistinguishable from and merges with the overlying Paluxy Sandstone. This basal Cretaceous sequence of rocks, which cannot be subdivided adequately, has been called the Antlers Formation. The Antlers Formation in North Texas is composed of Cretaceous sands and clays below the Walnut Formation and updip beyond the Glen Rose pinch-out (Fisher and Rodda, 1966).

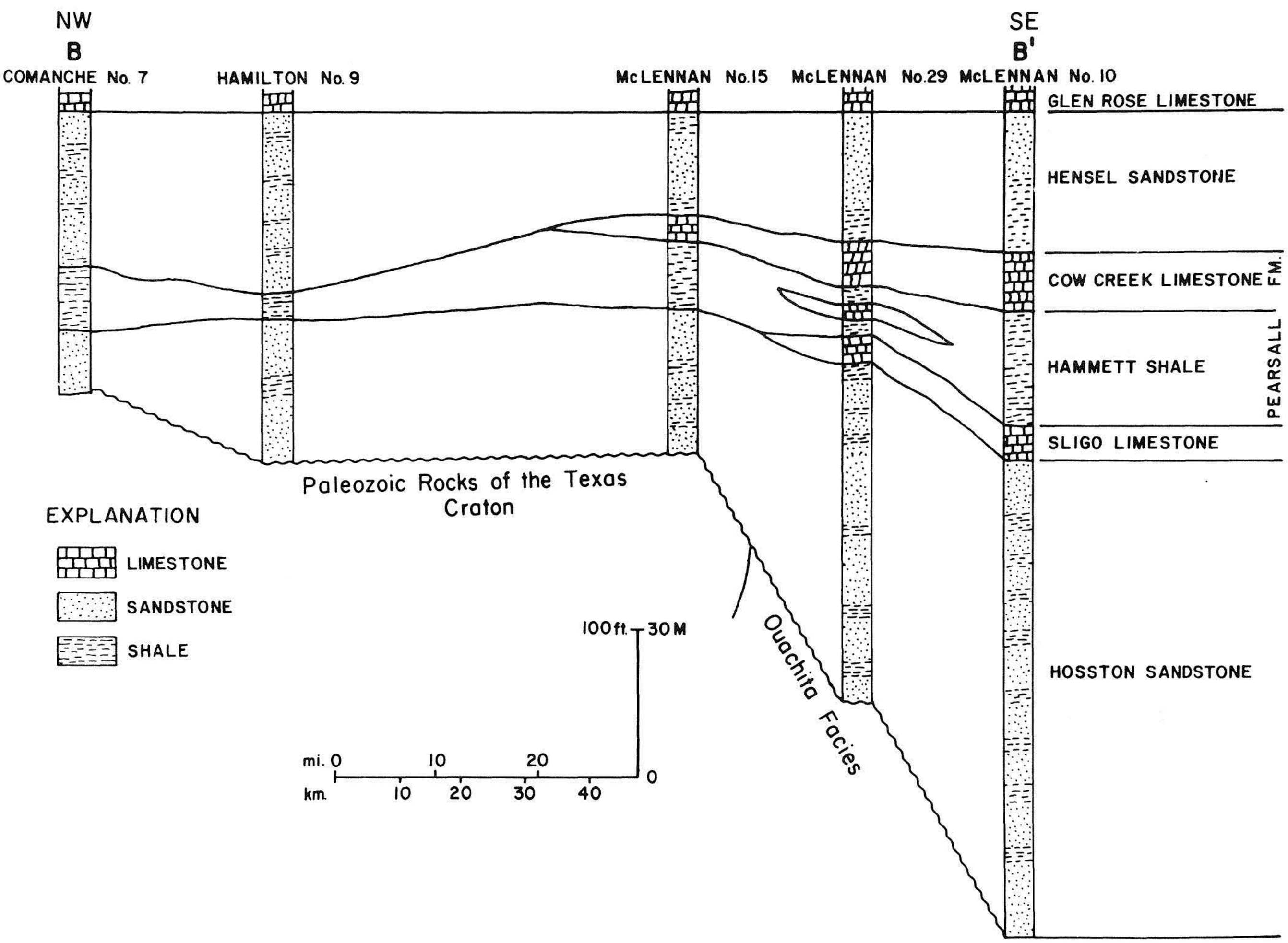


Figure 3. Stratigraphic dip section B-B′, North-Central Texas. Refer to figure 1 for location of section.

PRINCIPAL STRATIGRAPHIC UNITS

HOSSTON SANDSTONE

The basal Cretaceous stratigraphic unit in the subsurface of the study area is the Hosston Sandstone, which is equivalent to the lower unit of the Twin Mountains Formation in outcrop. At the type locality of the Twin Mountains Formation on the north side of Twin Mountains in northern Erath County (location A, fig. 1), the lower unit consists of medium- to coarse-grained, moderately well-sorted sand; gray, silty clay; and siliceous conglomerate composed of well-rounded pebbles, chiefly chert and quartz (Fisher and Rodda, 1966). In outcrop, the sands are thin to massively bedded, and crossbedding is commonly associated with the conglomeratic parts of the unit (Boone, 1968). The tan to gray or red-brown sandstones may be friable or compact, commonly cemented by silica cement, with minor amounts of green and yellow-brown sandy muds.

In the subsurface of McLennan County, the Hosston Sandstone is commonly fine to coarse, red to white, silty, porous sand, locally cemented with calcite and interbedded with variegated shale (Holloway, 1961). The Hosston is present throughout the study area except in the subsurface near the city of McGregor in McLennan County, where it was not deposited over a prominent paleotopographic high on the Wichita paleoplain.

Thickness of the Hosston Sandstone ranges from less than 40 feet (12 m) in the west to more than 240 feet (73 m) in the east (fig. 4). The east-west-trending axes of maximum net sandstone thickness over the Texas craton correspond to the major valleys on the sub-Cretaceous surface. The Hosston Sandstone thickens over the Ouachita foldbelt in the east and continues to thicken into the East Texas basin where sandstone and siltstone beds of the Hosston interfinger with carbonate facies of the Sligo Limestone.

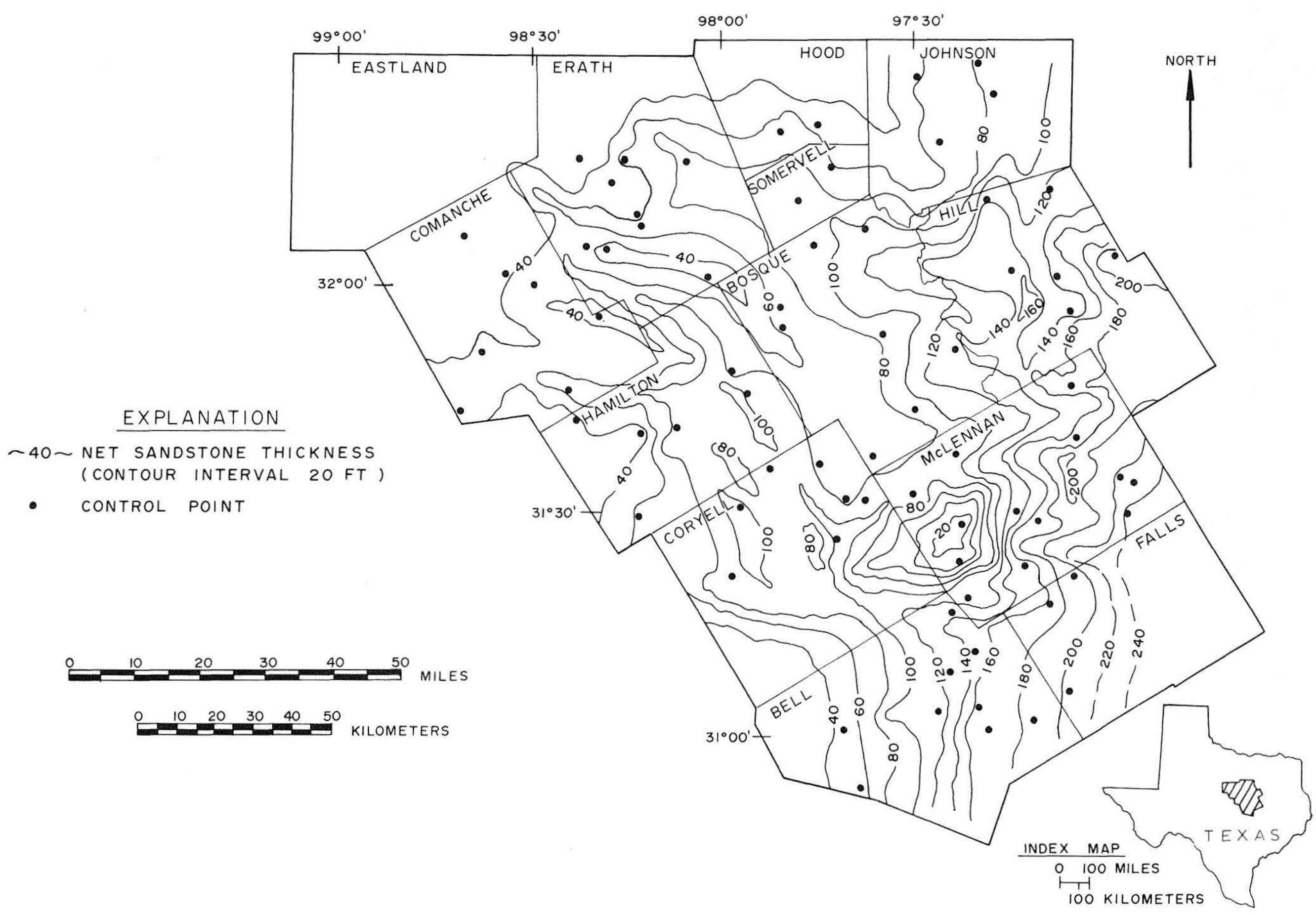


Figure 4. Net sandstone map of the Hosston Formation, North-Central Texas. Note the northwest-southeast sand trend in the west and the north-south trend in the east.

SLIGO LIMESTONE

The Sligo Limestone, present only in the eastern part of the study area, consists of gray to brown, oölitic to pseudo-oölitic, sometimes crystalline to chalky, generally fossiliferous limestones and interbedded shales (Murray, 1961). West of Waco, the Sligo grades into sandstone and shales indistinguishable from the underlying Hosston Sandstone. The Sligo Limestone is about 50 feet (15 m) thick in the study area.

PEARSALL FORMATION

The Pearsall Formation in North-Central Texas overlies the Sligo Limestone in the east and the Hosston Sandstone in the west. The Pearsall consists of a lower member, the Hammett Shale, and an upper member, the Cow Creek Limestone.

At Waco, the Hammett Shale Member is composed of about 50 feet (15 m) of gray, slightly sandy shales intercalated with a few cream-colored, slightly oölitic limestone beds. The Cow Creek Limestone is developed best in the western part of the East Texas basin, where it consists of about 50 feet (15 m) of cream to tan, finely sucrosic to oölitic, crystalline limestone beds (Holloway, 1961).

West of Waco, the Hammett and Cow Creek members grade into calcareous sand and shale and the entire Pearsall Formation resembles the Hammett Shale Member in electrical log characteristics (Hayward and Brown, 1967). In outcrop, the Pearsall is equivalent to the middle unit of the Twin Mountains Formation and consists of calcareous mudstone and red-brown, green, and tan silty claystone.

HENSEL SANDSTONE

The Hensel Sandstone overlies the Pearsall Formation throughout the study area. In outcrop, the Hensel is equivalent to the upper unit of the Twin Mountains Formation. The Hensel consists of fine- to medium-grained, light-gray to buff, well-sorted sandstone. The sandstone is crossbedded and contains siliceous pebbles similar to those in the Hosston (Fisher and Rodda, 1966).

In the subsurface of McLennan County, the Hensel Formation is a white, fine- to coarse-grained, subrounded to subangular, unconsolidated sand (Holloway, 1961). The Hensel, interbedded with minor green to red shale beds on the craton, grades eastward into finer sand and eventually into shale and limestone in the East Texas basin (Hayward and Brown, 1967).

The Hensel Sandstone, which in this report includes the Bluff Dale Sand of Rodgers (1967) and Boone (1968), is distributed as a series of east-west-trending sand bodies in the west and north-south-trending sand bodies in the east (fig. 5). Net sandstone in the Hensel is 140 feet (42 m) thick in the northern part of the area.

The Hensel is conformably overlain by shale, siltstone, and limestone beds of the Glen Rose Formation, except in the far western part of the area where the Glen Rose pinches out and the Hensel grades into the lower part of the Antlers Formation.

DEPOSITIONAL SYSTEMS

TERMINOLOGY

The terminology used to describe lithogenetic facies within the Hosston and Hensel Sandstones is derived largely from the depositional systems approach to stratigraphy described by Fisher and McGowen (1969) and Fisher (1969). Modern depositional systems are assemblages of related facies, environments, and associated processes; such systems include delta, fluvial, barrier, and slope systems which are readily recognized by their physiographic character. Ancient depositional systems are three-dimensional assemblages of sedimentary facies linked genetically by inferred sedimentary environments and depositional processes. Ancient systems deposited within fluvial, delta, strandplain, and barrier-bar systems are analogous to and interpreted from the character of their modern counterparts. They are the stratigraphic counterparts of modern depositional systems.

The fundamental unit of a system is a lithogenetic facies which is defined as a body of sedimentary rock deposited within a unique

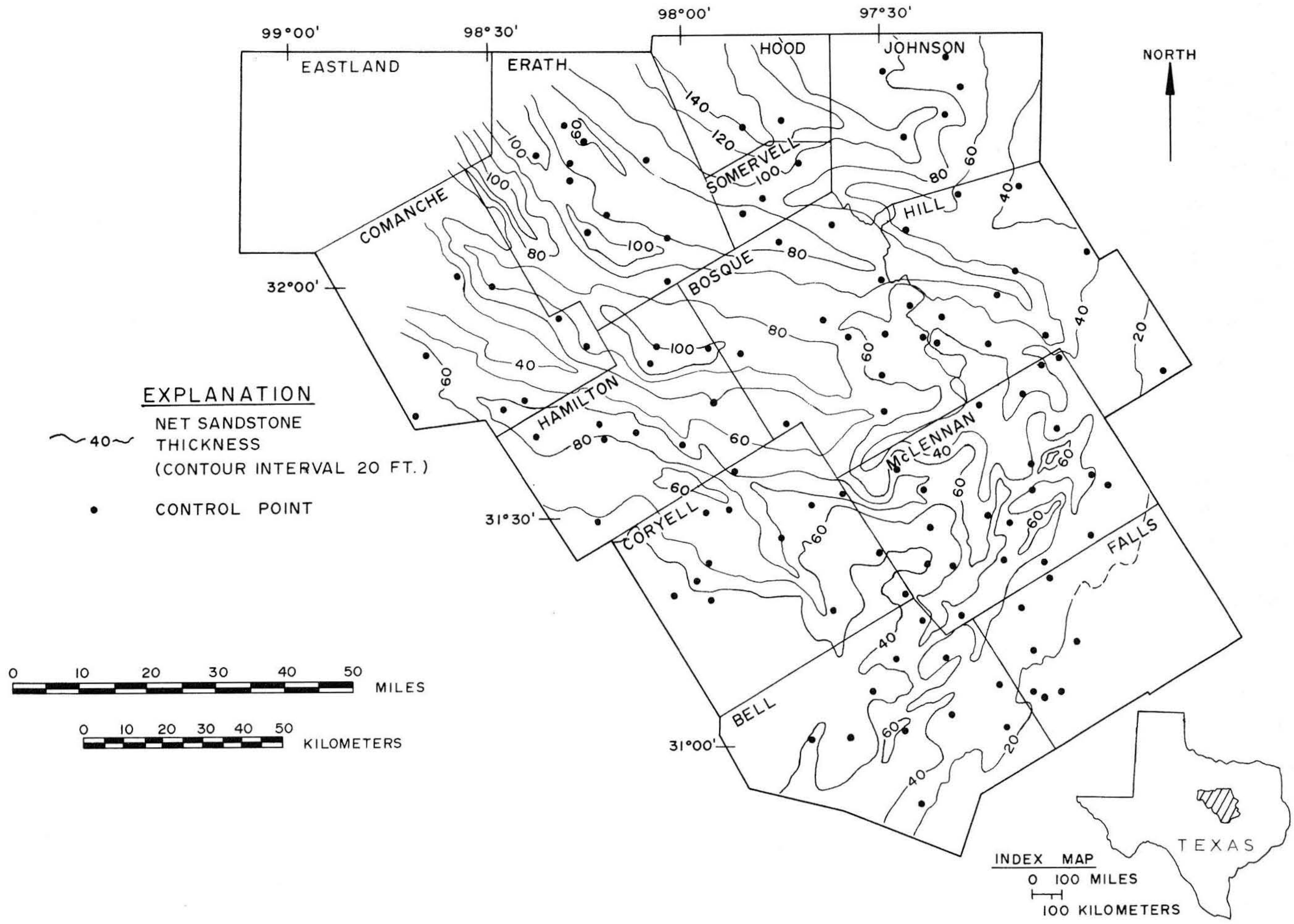


Figure 5. Net sandstone map of the Hensel Formation, North-Central Texas. Note the northwest-southeast sand trend in the west and the north-south trend in the east.

environment and characterized by unique physical, biologic, and/or sedimentary characteristics. A fluvial system, for example, includes channel-lag and point-bar sandstone facies, levee siltstone facies, and overbank mudstone facies.

A spectral series of depositional systems develops in different tectonic, oceanic, and geomorphic settings. For example, deltas may assume different forms depending on the amount and nature of sediment input, depth of water into which the delta is prograding, and magnitude and form of reservoir energy (waves, currents, tides) especially in relation to the amount of fluvial discharge. Sand bodies within fluvial systems may be coarse grained and multilateral or predominantly fine grained and multistory. Because these variations in the nature and geometry of facies greatly affect the physical characteristics of an aquifer, an attempt has been made to identify the specific nature of systems within the Hosston and Hensel Formations. This permits a better understanding of physical properties and spatial relationships of the lithic components of each aquifer.

HOSSTON DEPOSITIONAL SYSTEMS

The Hosston Formation in North-Central Texas is composed of two major depositional systems: (1) a meanderbelt fluvial system in the western part of the study area and (2) a high-destructive, wave-dominated delta system in the east (fig. 6). Sediment supplied from source areas in the west, northwest, and north was transported southeastward towards the East Texas basin by Hosston rivers which were initially confined within major drainage valleys on the Wichita paleoplain

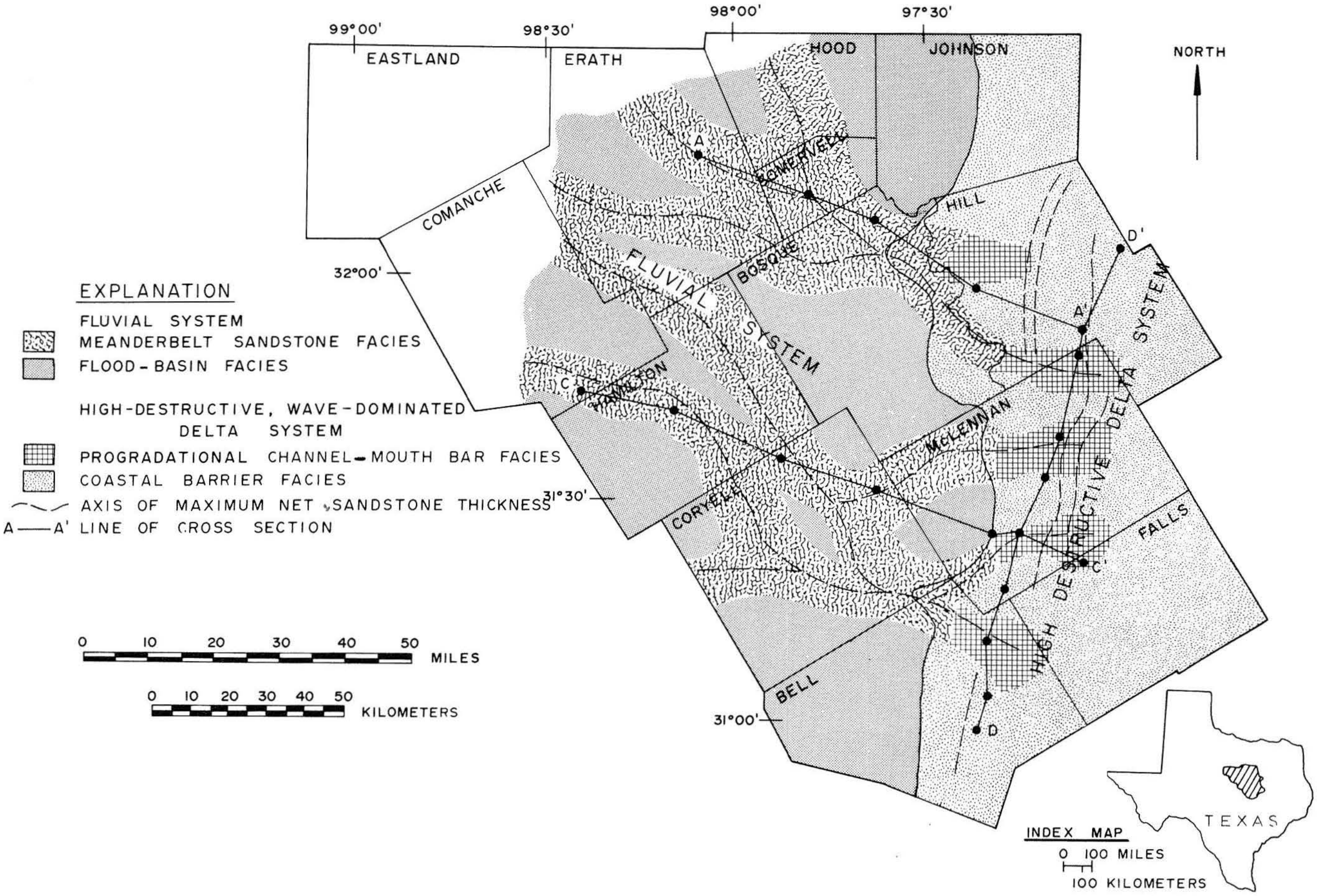


Figure 6. Depositional systems and component facies, Hosston Formation, North-Central Texas.

(Boone, 1968). As these valleys filled with both fluvial and estuarine sediment during transgression of the Comanchean marine facies, the rivers began to meander on the alluvial plain. Braided-stream and fan-delta deposits, which compose the equivalent Travis Peak Formation southeast of the study area, were derived from source areas on the Llano uplift. The Travis Peak Formation is not included in this report.

Discharge of clastic, fluvial sediment into open-marine water resulted in basinward progradation of the shoreline. This progradation was countered by high and/or persistent wave energy and longshore currents which caused most of the fluvial sediment to be transported and deposited along regional strike. Net sandstone trends, associated facies, and electric log patterns suggest that the shoreline consisted of a series of individual high-destructive, wave-dominated deltas. Further investigation beyond the eastern limits of the study area will be required, however, to fully determine the nature of Hosston lithogenetic facies in the East Texas basin.

FLUVIAL SYSTEM

The Hosston fluvial system is located in Comanche, Erath, Hood, Somervell, Hamilton, Coryell, and the western parts of Johnson, Bosque, McLennan, and Bell Counties (fig. 6). The fluvial system grades downdip to the east into the coastal barrier and channel-mouth bar facies of the Hosston delta system (figs. 7, 8, 9). Sandstone, the dominant lithic type in the system, composes practically the entire Hosston in some areas. Interchannel deposits of overbank mudstone are not well developed.

The Hosston fluvial system is a dip-oriented, laterally persistent sandstone which is thicker in areas occupied by the major valleys of the sub-Cretaceous surface. Pettijohn and others (1965) proposed the term multilateral for this type of sand geometry. Two sedimentary facies within the fluvial system are recognized on the basis of net sandstone trends, sand/mud ratios, and electric log patterns: a meanderbelt sandstone facies and a flood-basin facies.

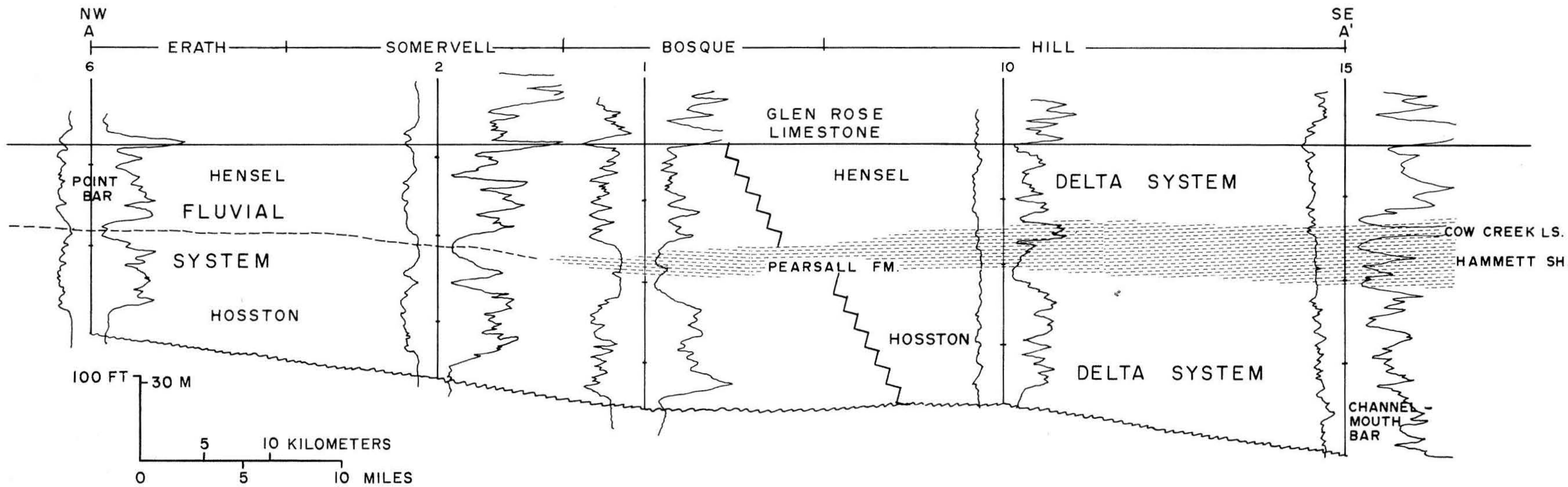


Figure 7. Stratigraphic dip section A-A′, North-Central Texas, showing downdip change from Hosston and Hensel fluvial systems to high-destructive, wave-dominated delta systems. Refer to figure 6 for location of sections.

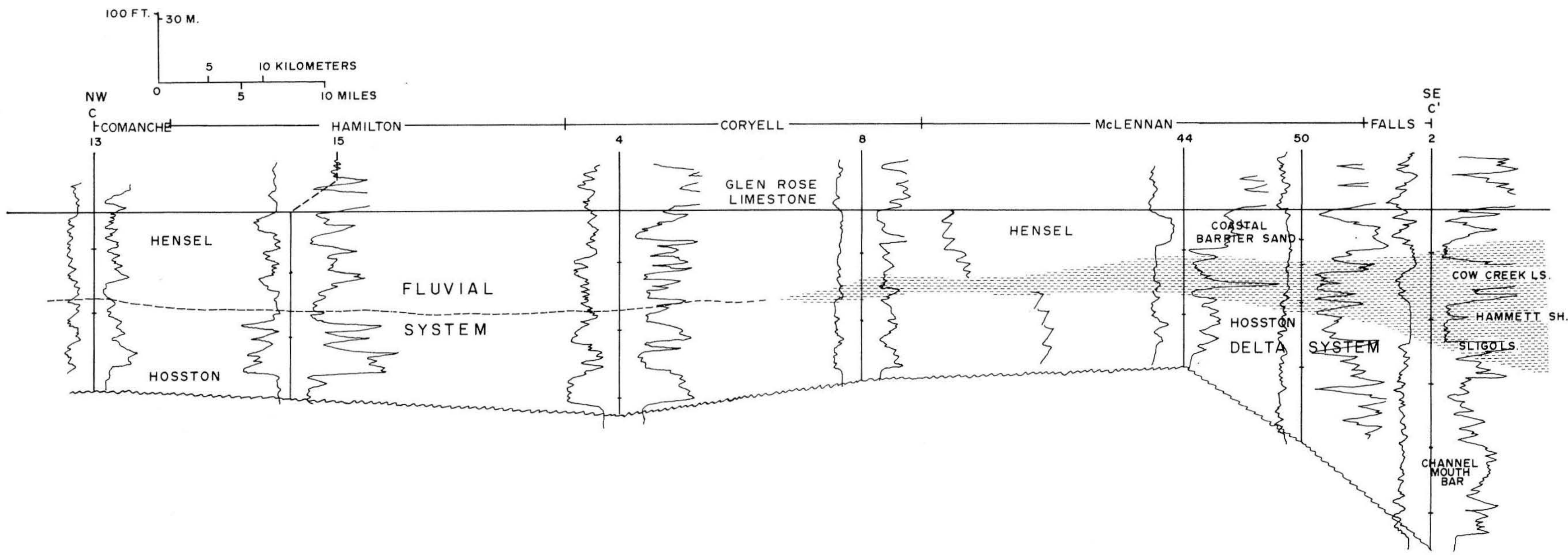


Figure 8. Stratigraphic dip section C-C′, North-Central Texas, showing downdip change from Hosston and Hensel fluvial systems to high-destructive, wave-dominated delta systems. Refer to figure 6 for location of sections.

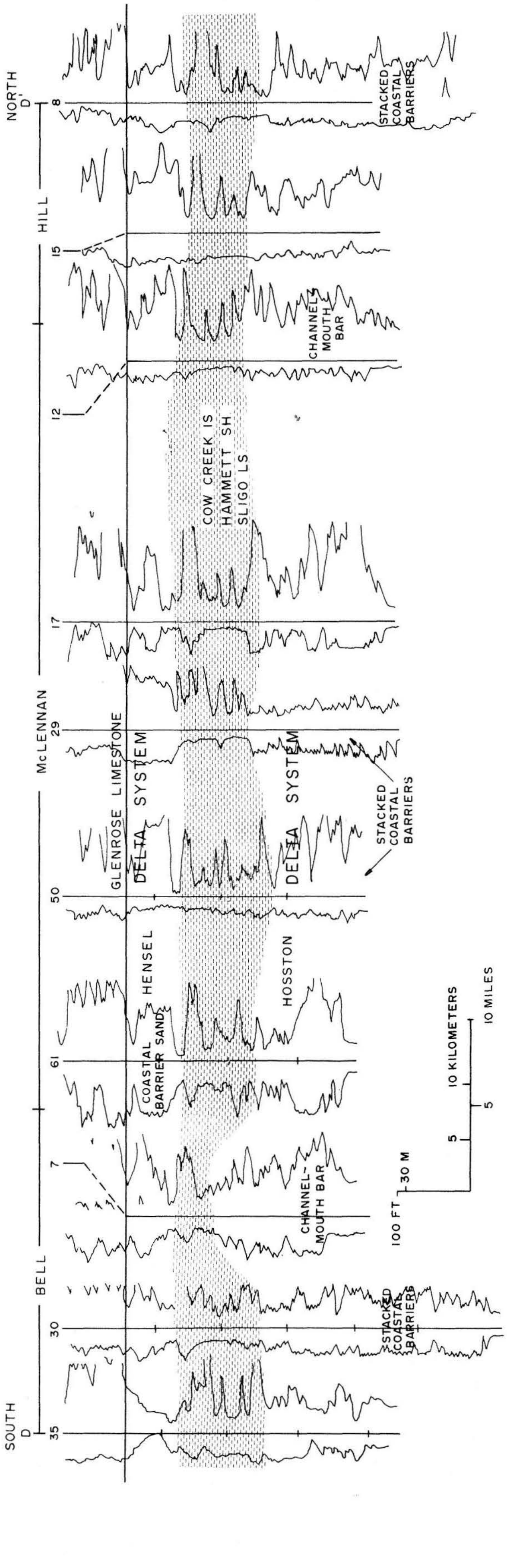


Figure 9. Stratigraphic strike section D-D', North-Central Texas. Facies of Hosston and Hensel high-destructive, wave-dominated delta systems. Refer to figure 6 for location of section.

Meanderbelt sandstone facies.—The meanderbelt sandstone facies consists of dip-oriented, multilateral sandstone deposits composed principally of medium- to coarse-grained, moderately well-sorted sand. The thickest accumulations of sandstone within this facies occur in west-east-trending and northwest-southeast-trending belts (fig. 4) which coincide with the major drainage valleys on the Wichita paleoplain (fig. 2). Within these areas, fluvial valley-fill and possibly estuarine sediments underlie the meanderbelt sandstones. Total thickness of this facies is approximately 100 feet (30 m) in Coryell, Hamilton, and Bosque Counties. Individual fluvial sandstone bodies are 20 to 70 feet (6 to 21 m). These individual sand bodies are characterized by erosional contacts with underlying units and consist of channel-lag and lower point-bar deposits.

On electric logs, these sandstone units may be characterized by abrupt basal contacts and abbreviated upward-fining sequences (fig. 10); vertical stacking of these deposits is common. In outcrop, these facies are characterized by large-scale, trough-filled (festoon) crossbeds and channel-lag gravels overlain by moderate- to small-scale trough-filled and tabular crossbeds.

Flood-basin facies.—The flood-basin facies is composed of overbank siltstones and mudstones which are adjacent to and merge laterally with the principal meanderbelt sandstone deposits (fig. 6). This facies is neither thick nor laterally extensive, indicating a paucity of mud and silt within the fluvial system. Some thin sandstone units alternating with mudstones are occasionally recognized and may represent crevasse-splay deposits.

Coarse-grained meanderbelt fluvial model.—Sandstone distribution, textural and sedimentary structural characteristics, and relationships to surrounding deposits suggest that the Hosston represents a variety of the coarse-grained meanderbelt fluvial system described by McGowen and Garner (1970).

Coarse-grained meanderbelt systems are about midway in the spectrum of fluvial types between braided and fine-grained meanderbelts (fig. 11). The Hosston rivers were probably moderate to high bed-load dispersal systems controlled by moderate gradients. The fluvial deposits are characterized by (1) medium- to coarse-grained sandstone, (2) incomplete (lower-middle) point-bar sequences,

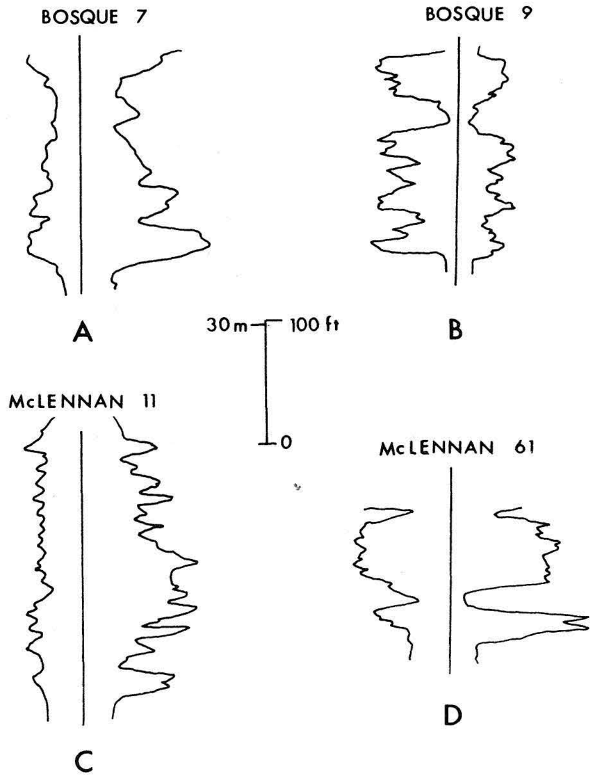


Figure 10. Characteristic electric log patterns. A. Abrupt erosional contact and complete fining-upward point-bar sequence; B. Sandstone sequence showing abrupt erosional lower contacts and abbreviated fining-upward sequences; C. Sequence of coarsening-upward channel-mouth bar deposits; D. Box-like pattern typical of coastal barrier sands.

(3) wedge-set crossbeds (chute bars), and (4) multilateral sand-body geometry.

A depositional model of an idealized, coarse-grained meanderbelt system is composed of partly developed point bars which coalesce to form multilateral sand bodies (fig. 12). Complete fining-upward point-bar sequences are rarely developed because upper point-bar facies are commonly eroded and replaced by chute channel-fill and chute bar deposits. Chute bars form only under rapid-flow conditions of extreme flooding (McGowen and Garner, 1970). During extreme floods, high bed-load streams with poorly developed levees tend to straighten their courses by scouring the chutes and swales along the inside, convex bank. Some of the coarsest bed-load material passes through these chutes and accumulates as steep-front, lobate gravel or sand bodies (McGowen and Garner, 1970). Thus, the upper point-bar sequence is replaced by the coarse bed-load material of the chute bar.

The small volume of mud and silt in these systems precludes development of significant levee deposits, permitting channels to meander across the sandy alluvial plain forming multilateral sand bodies.

Lateral persistence and high permeability of sandstones within coarse-grained meanderbelts make this type of fluvial system an important aquifer. Hydrogeologic characteristics such as porosity, permeability, and flow direction within the aquifer are influenced by the distribution of sedimentary facies in the meanderbelt system. For example, larger quantities of flow moving at higher rates should be associated with the dip-oriented axes of maximum net sandstone thickness of the meanderbelt sandstone facies rather than in the adjacent flood-basin facies which contain a higher percentage of mudstones and siltstones.

HIGH-DESTRUCTIVE, WAVE-DOMINATED DELTA SYSTEM

The Hosston high-destructive, wave-dominated delta system is located in Hill, Falls, and the eastern parts of Johnson, Bosque, McLennan, and Bell Counties (figs. 6, 9). This depositional system, which is composed of a series of individual deltas, is continuous with and immediately downdip from the Hosston fluvial system (figs. 7, 8). Only part of the delta complex is within the limits of the study area; thus, the nature of facies and boundaries farther downdip in the East Texas basin is not known. North-south-trending, strike-oriented sandstone bodies, composed principally of fine- to coarse-grained sand, are the most prominent features within the study area.

High-destructive, wave-dominated delta systems develop when marine processes in the form of waves and longshore currents are more significant than the fluvial discharge of water and sediment (Fisher, 1969). As a result, shoreline progradation is not as extensive in this type of delta system as in a high-constructive or fluvially dominated delta. Principal accumulation of sediment is in a series of coastal barriers flanking the river mouth, giving a cuspate or arcuate trend to the sand body (Fisher, 1969; see also fig. 13A).

Examples of coastal barrier facies associated with high-destructive delta systems are the Pleistocene Apalachicola delta system, northwestern Florida (Fisher, 1969), Pleistocene deposits on the coast of Surinam (Fisher, 1969), and the Rhone delta system (Oömkens, 1967; see also fig. 13B).

Fisher (1969) summarized high-destructive deltas in terms of a number of characteristic features which appear analogous to the nature and development of the Hosston delta complex: (1) relatively local source areas are drained by numerous small to moderate, braided or meandering channels, which are generally less than 200 miles (322 km) long and are relatively uniformly spaced along basin margins; (2) volume of sediment input of fluvial systems is moderate and the bed-load/suspended-load ratio is high; (3) coastal progradation is slight to moderate compared with high-constructive systems; (4) fluvial channels in the delta plain are commonly meandering types in which lateral shifting of streams and paucity of

	Braided	Coarse-grained Meanderbelt	Fine-grained Meanderbelt	Straight Distributary
Gradient	High →			Low
Channel flow	Unconfined →			Confined
Discharge rate	Flashy →			Continuous
Bed-load / suspended load	High →			Low
Sand/mud (deposit)	High →			Low
Sand body (deposit)	Wide →	Multilateral →	Multistoried →	Narrow
Levees	Slight →			Prominent

Figure 11. Spectrum of features in fluvial systems (Brown and others, 1973).

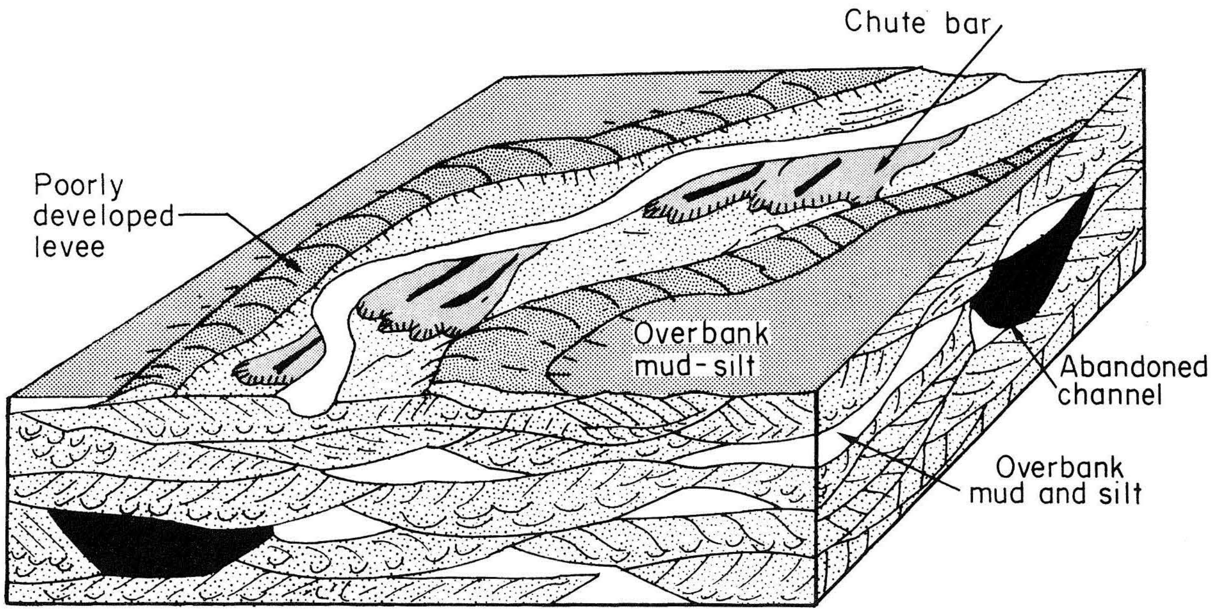
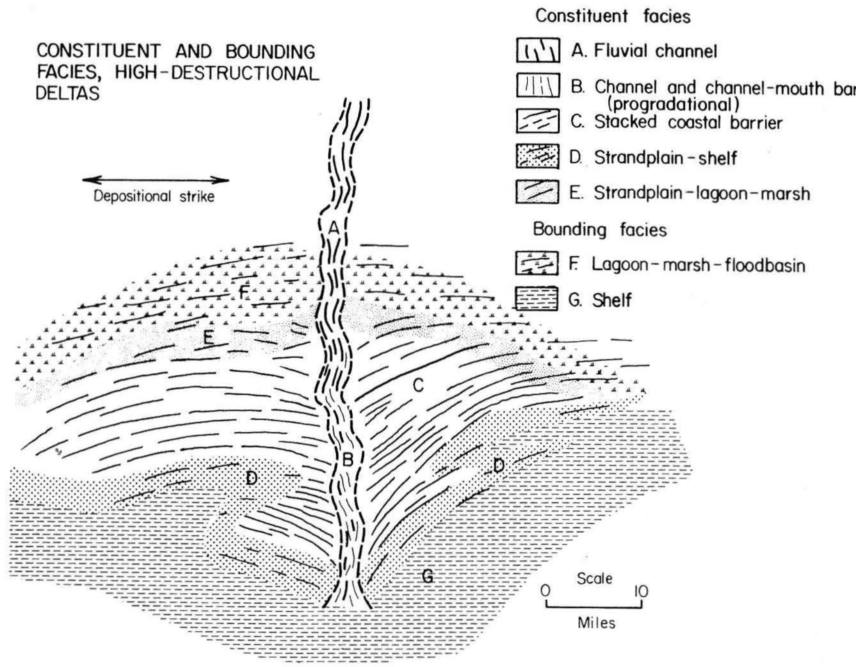
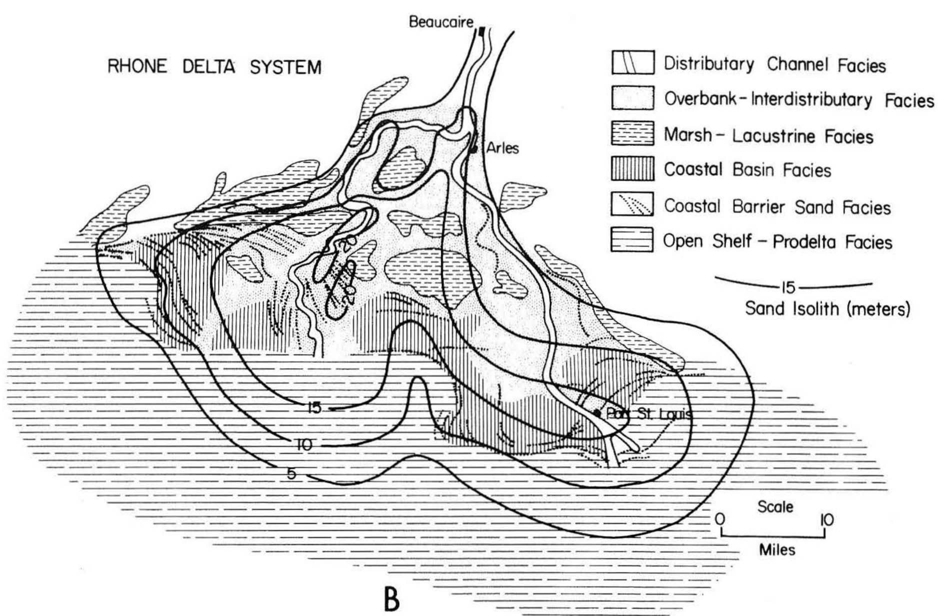


Figure 12. Depositional model of an idealized coarse-grained meanderbelt fluvial system showing bedforms, sedimentary structures, and multilateral sand geometry (Brown and others, 1973; after McGowen and Garner, 1970).



A



B

Figure 13. A. Principal facies, high-destructive, wave-dominated delta systems, Gulf coast basin (from Fisher, 1969).
B. Principal depositional environments, Rhone delta system, southern France (from Fisher, 1969, adapted from Kruit, 1955, and Oömkens, 1967).

mud result in poorly developed delta-plain facies; and (5) destructional marine facies such as coastal barriers are extensive and principally developed contemporaneously with constructional facies.

Two distinct component facies of the Hosston delta system are recognized: (1) channel-mouth bar sandstone and (2) coastal barrier sandstones developed laterally to the channel mouth. Criteria for delineating these facies include external geometry of facies, position relative to other facies within the system, lithic composition, sequences of lithology and stratification, and nature of bounding relationships.

Channel-mouth bar facies.—Rivers supplying sediment to high-destructive deltas are normally meandering; hence, their deposits on the delta plain are similar to updip facies of the associated fluvial system. Point-bar facies may be closely associated with channel-mouth bar deposits and barrier-bar/strandplain facies.

The progradational, channel-mouth bar facies is characterized by a progressive upward coarsening of sediment grain size from clay-size material to fine- and medium-grained sandstone. This coarsening-upward sequence is the result of progradational deposition of bed-load material over progressively finer material previously deposited seaward of the river mouth (Oömkens, 1967).

Channel-mouth bar facies gradationally overlie muds of the prodelta-shelf facies and are, in turn, overridden by channel sands of the meanderbelt fluvial system (fig. 9). Laterally associated facies are extensive, commonly cuspate-shaped coastal barrier sands. The areal pattern of channel-mouth bar facies in wave-dominated deltas may be difficult to delineate accurately because the bar is transitional with laterally flanking coastal barrier sandstones. The channel-mouth bar is an elongate sandstone body approximately the width of the delta-plain meanderbelt.

Within the study area, progradational sequences in the Hosston that are interpreted to be channel-mouth bar deposits occur only in the subsurface. These facies are recognized on electric logs by the coarsening-upward pattern of the resistivity curve (fig. 10). Initial deflection of the curve is weak and irregular, reflecting thin sandstone beds and considerable mudstone in basal portions of the sequence. Resistivity deflections become progressively greater upward in the sequence in response to increasing proportions of relatively clean sandstone beds.

Coastal barrier facies.—Laterally adjacent to the channel-mouth bar facies of a high-destructive, wave-dominated delta are extensive, strike-oriented, coastal barrier sandstone facies. Maximum net sandstone trends are oriented perpendicular to the maximum sandstone trends of the major fluvial system (fig. 13). Coastal barriers, which are strike-fed and aligned parallel to the coast, accumulate by marine processes. Sandstones composing this facies are fine to medium grained and very well sorted.

Individual sand bodies within the Hosston delta system are normally less than 50 feet (15 m) thick and are separated vertically by shale units. Aggregate thickness of superposed coastal barrier facies of the Hosston Formation exceeds 200 feet (60 m) within the study area. The interbedding of relatively thin, discrete, coastal barrier sandstones with shale tongues (fig. 9) is a distinguishing feature (Fisher, 1969). Shale interbeds may vary from shelf to lagoonal along the facies tract of the system (fig. 13). Sandstones deposited as barrier bars or islands are interbedded seaward with prodelta-shelf mudstones. Landward, these barriers are interbedded with lagoonal or marsh mudstones (Oömkens, 1967). Strandplain sandstones are similar, but without the distinctive lagoonal facies that occur landward of barrier islands. The coastal barriers are the dominant facies within the high-destructive, wave-dominated delta system (fig. 13).

The coastal barrier facies within the Hosston do not crop out within the study area. These facies are typified by distinctive electric log patterns (fig. 10). Numerous discrete box-shaped deflections of the spontaneous potential and resistivity curves depict the vertically stacked, individual coastal barrier sandstone bodies and interstratified shale beds. Individual sandstone units are relatively thin and evenly spaced vertically within the sequence; basal spontaneous potential and resistivity deflections are normally sharp.

The thick sequence of clean, well-sorted coastal barrier sandstones of the Hosston Formation provides most of the ground water used in the eastern part of the study area. The coastal barrier and the channel-mouth bar sandstones are laterally continuous facies hydraulically connected with the updip fluvial system by the meanderbelt sandstone facies. The abrupt change in net sand trends between the fluvial and deltaic systems results in a change in ground-water flow direction from principally west-east to north-south. Lateral permeability should be high and fairly uniform within the coastal barrier facies, whereas vertical permeability is reduced by the thin interbedded mudstones.

HENSEL DEPOSITIONAL SYSTEMS

The Hensel Formation in North-Central Texas is similar to the Hosston inasmuch as it is composed of a meanderbelt fluvial system in the western part of the area and a high-destructive, wave-dominated delta system in the east. Sediment supplied from the north and northwest was carried eastward in meandering streams and rivers and eventually deposited in a series of high-destructive, wave-dominated deltas developed along the western edge of the East Texas basin.

FLUVIAL SYSTEM

The Hensel Sandstone in Comanche, Eastland, Erath, Hamilton, and the western parts of Hood, Somervell, Bosque, and Coryell Counties is principally composed of fluvial facies (fig. 14). These fluvial facies of meanderbelt origin grade downdip to the east into the mixed channel-mouth bar and coastal barrier facies of the Hensel high-destructive, wave-dominated delta system (figs. 7, 8). Medium- to coarse-grained sandstone is the dominant lithic type in the fluvial system. However, siltstone and mudstone constitute a significant part of the Hensel in some areas.

The Hensel fluvial system is a dip-oriented, multilateral sandstone body characterized by two important kinds of facies—a meanderbelt sandstone facies and a flood-basin facies—which are delineated on the basis of net sandstone thickness distribution, sand/mud ratios, and electric log patterns.

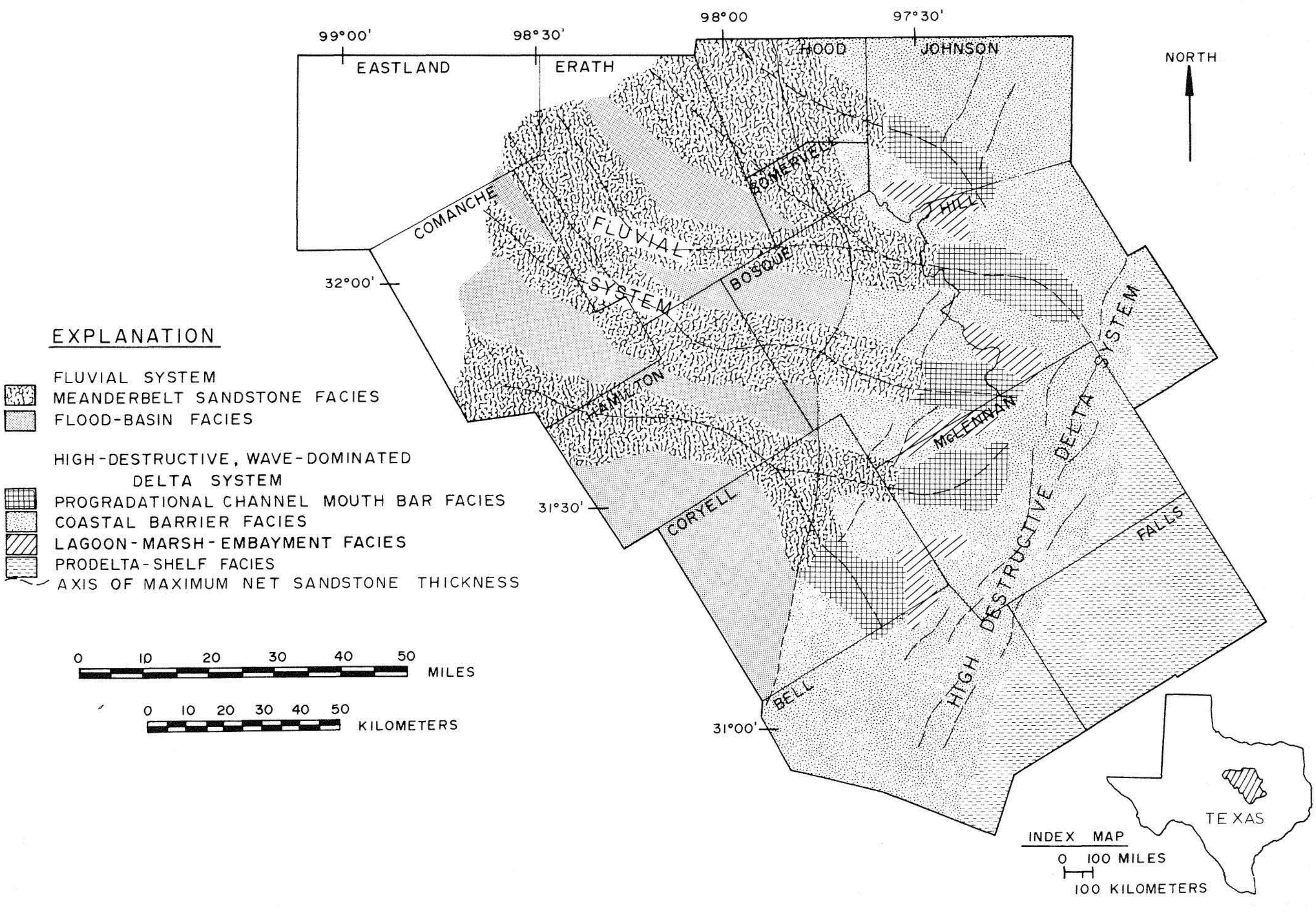


Figure 14. Depositional systems and component facies, Hensel Formation, North-Central Texas.

Meanderbelt sandstone facies.—The meanderbelt sandstone facies is a multilateral sand body composed principally of point-bar deposits. Although individual meanderbelt facies are poorly defined, maximum net sandstone axes within the multilateral sandstone body are oriented subparallel to paleoslope (fig. 14). These west-east-trending and northwest-southeast-trending sandstone bodies are separated by less sandy facies containing a greater amount of overbank deposits.

Maximum net sandstone thickness in the meanderbelt facies is approximately 140 feet (40 m) in the northern part of the study area. Individual meanderbelt deposits range in thickness from 10 to 40 feet (3 to 12 m) and are characterized on electric logs by abrupt, probably erosional, basal contacts and, in several places, by well-developed, upward-fining sequences (fig. 10).

In outcrop, these facies are characterized by trough-fill (festoon) crossbeds and channel lag overlain by smaller trough-fill and tabular crossbeds. These crossbeds, in turn, are overlain by finer grained sandstone and siltstone with plane beds and current ripple cross-laminations, which may grade into mottled levee deposits and overbank laminated mudstone beds.

Flood-basin facies.—The flood-basin facies of the Hensel fluvial system are overbank mudstones and siltstones that are adjacent to and merge laterally with meanderbelt sandstone deposits. The flood-basin facies are thicker and more extensive in the Hensel than in the Hosston and, as a result, the Hensel has characteristics of both coarse- and fine-grained meanderbelt systems (fig. 11).

Mixed coarse-grained/fine-grained meanderbelt fluvial model.—Models of fine-grained or mud-rich fluvial meanderbelt deposition have been studied by Bernard and others (1970) and Allen (1965) who proposed models of point-bar deposition characterized by sequences of upward-fining textures. These models contrast with the coarse-grained meanderbelt (McGowen and Garner, 1970) which lacks consistent upward grain-size trends and has a high sand/mud ratio.

Although the Hensel fluvial system is not analogous to all the characteristics of the fine-grained meanderbelts as summarized by Brown and others (1973), it exhibits some similarities. Complete upward-fining point-bar sequences in the Hensel are preserved and recognizable in the subsurface. Overbank muds are extensive and in some areas constitute a major part of the system. Areas of thickest net sandstone accumulation are relatively narrow and elongate parallel to paleoslope, suggesting some multistorying of sandstone bodies. Similarities between the Hensel and the coarse-grained models include its general multilateral geometry and the recognition of some abbreviated, upward-fining sequences.

HIGH-DESTRUCTIVE, WAVE-DOMINATED DELTA SYSTEM

The Hensel Sandstone was deposited as a high-destructive, wave-dominated delta system in Bell, Falls, McLennan, Hill, Johnson, and eastern parts of Hood, Somervell, Bosque, and Coryell Counties (fig. 14). This depositional system is downdip from the Hensel meanderbelt fluvial system. Sandstone is the dominant lithic component and axes of maximum net sandstone are oriented north-south, subparallel to regional strike.

The Hensel delta system is thinner than the Hosston delta system. Maximum net sandstone thickness is only 80 feet (24 m) and thickness of individual sandstone bodies is limited to 10 to 40 feet (3 to 12 m). Progradational, channel-mouth bar and coastal barrier deposits are the dominant sandstone facies within the system. In addition, the lower sand/mud ratio of the Hensel fluvial system is compatible with the presence of more distinct marsh-lagoon-embayment muddy facies on the delta plain and with thicker prodelta-shelf deposits.

Channel-mouth bar facies.—Rivers that supplied sediment to the Hensel high-destructive, wave-dominated delta system meandered, and hence, delta-plain fluvial distributary deposits are similar to facies of the updip meanderbelt fluvial system. The progradation of channel-mouth bar facies is marked by a progressive upward coarsening of sediment from mudstone to fine- and medium-grained sandstone (fig. 10). This upward-coarsening sequence is the result of deposition of bed-load material on channel-mouth bars that built progressively basinward over finer grained sediment previously deposited seaward from the river mouth (Oömkens, 1967).

Hensel progradational sequences are similar to those of the Hosston both areally and vertically with respect to bounding facies. Channel-mouth bar facies gradationally overlie mudstones of the prodelta-shelf facies and are in places overridden by fluvial sandstone facies of the meanderbelt fluvial system. Channel-mouth bar deposits are transitional with laterally flanking coastal barrier sands (fig. 9).

Channel-mouth bar deposits in the Hensel Formation, which occur only in subsurface within the study area, are characterized on electric logs by an upward increase in the deflection of the resistivity curve (fig. 10).

Coastal barrier facies.—Along depositional strike and laterally adjacent to the channel-mouth bar facies is the coastal barrier facies of the high-destructive, wave-dominated delta system. Maximum net sandstone thickness axes of the barrier facies are oriented perpendicular to the major fluvial net sandstone axes (fig. 14). Coastal barriers are strike-fed bodies parallel to the coast, accumulated under the influence of marine processes. As a result, the facies are principally marine sandstone, dominantly very well-sorted quartz.

Individual barrier sandstone units are generally less than 50 feet (15 m) thick and are separated by shale units; aggregate thickness of the superposed sandstone bodies of the coastal barrier facies of the Hensel rarely exceeds 60 feet (18 m) within the study area. The interbedding of coastal barrier sandstone beds with prodelta-shelf or lagoonal shale beds is a distinctive feature of the system (fig. 9). The relationship of coastal barrier sands to associated facies within an individual high-destructive delta lobe is illustrated by a model developed from the Rhone delta (fig. 13B).

The coastal barrier facies of the Hensel delta system do not crop out within the study area. In the subsurface, these facies are recognized by distinctive box-shaped deflections of the SP and resistivity curves. Individual coastal barrier sands are interstratified with prodelta-shelf or lagoonal shale units.

Marsh-lagoon-embayment facies.—Landward of the coastal barrier sandstone trend is a strike-oriented belt characterized by thin sandstone and relatively thick mud sequences (fig. 14). This sequence is interpreted to be a marsh-lagoon-embayment facies related to the high-destructive Hensel delta system. These mud facies are neither thick nor laterally extensive because of the lateral shifting of meandering fluvial channels.

In a high-destructive, wave-dominated delta, the strike-oriented coastal barrier sands receive the brunt of marine wave energy. Fine-grained sand, silt, and mud deposits resulting from fluvial overbank deposition accumulate locally on the delta plain in flood basins, lakes, lagoons, and marsh. These fine-grained deposits may later be scoured by meandering channels or receive sand from crevasse splays, bayhead deltas, tidal channels, or storm transport. Muds also accumulate in isolated lagoons landward of the coastal barriers and in swales between beach ridges on the barriers or strandplains. During subsequent abandonment of the delta lobe, mud will continue to accumulate as the delta subsides and marine destructional processes attack the foundering lobe. The mud facies of a high-destructive delta are neither thick nor extensive, and carbonaceous material is uncommon.

Prodelta-shelf facies.—Underlying and interfingering shoreward with the coastal barrier and channel-mouth bar sandstones are relatively thin prodelta-shelf facies which represent the most basinward deposition of the Hensel delta system in the study area. Thickness of the dominantly mud facies increases to the east. Studies of modern high-destructive, wave-dominated deltas (Oömkens, 1967; Kruit, 1955) indicate that rates of prodelta deposition are moderate to low in these high bed-load systems. Similarly, the high wave energy sweeps the suspended load away from the channel mouth and distributes it over the adjacent innermost shelf. Low rates of prodelta deposition permit extensive bioturbation of the facies; consequently, prodelta and shelf facies are difficult to distinguish in high-destructive, wave-dominated systems.

The Hensel prodelta-shelf facies is characterized by a thickness generally equal to the on-delta barrier-bar/fluvial deposits, a feature which typifies wave-dominated systems.

HYDROGEOLOGY

The second phase of this study was an analysis of the hydrogeologic characteristics of the Hosston and Hensel aquifer systems and their relationship to the depositional framework presented in the preceding section of this report.

RECHARGE AND REGIONAL FLOW PATTERNS

Recharge of ground water to the Hosston and Hensel aquifers is from infiltration of precipitation in the outcrop area of the Twin Mountains Formation (fig. 1) and from seepage from streams within the drainage networks of the Leon, Bosque, and Brazos Rivers.

Maps of the potentiometric surface in both aquifers were constructed by using measurements of water level in March and April of 1970 by the Texas Water Development Board (figs. 15, 16; list of water-level measurements, from Hall, 1974, is on open file at the Bureau of Economic Geology). These maps show that regional ground-water movement in the Hosston and Hensel Sandstones is to the southeast with hydraulic gradients averaging 10 to 15 feet per mile (1.9 to 2.8 m/km).

Flow lines were sketched orthogonally to equipotential contours to determine flow conditions within the aquifers. The flow lines are equally spaced along the 900-foot contour line on each map (figs. 15, 16) to allow comparison of flow patterns. In order to derive useful information from this procedure, two assumptions are necessary: (1) equal amounts of flow occur between the flow lines, thus closely spaced flow lines indicate more discharge through an area than do widely spaced flow lines; and (2) the quantity of ground-

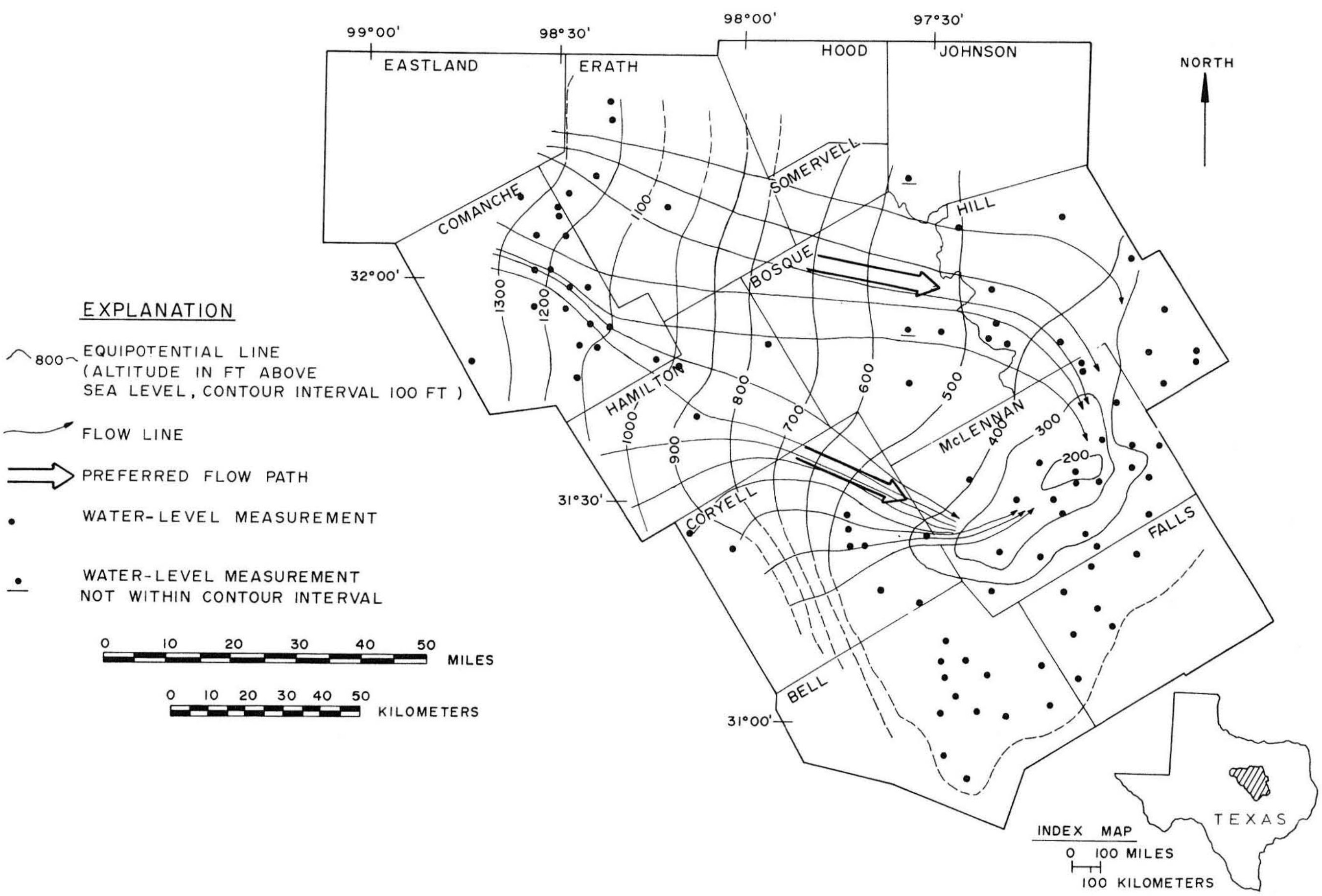


Figure 15. Hosston potentiometric surface, North-Central Texas. Large arrows indicate preferred flow paths.

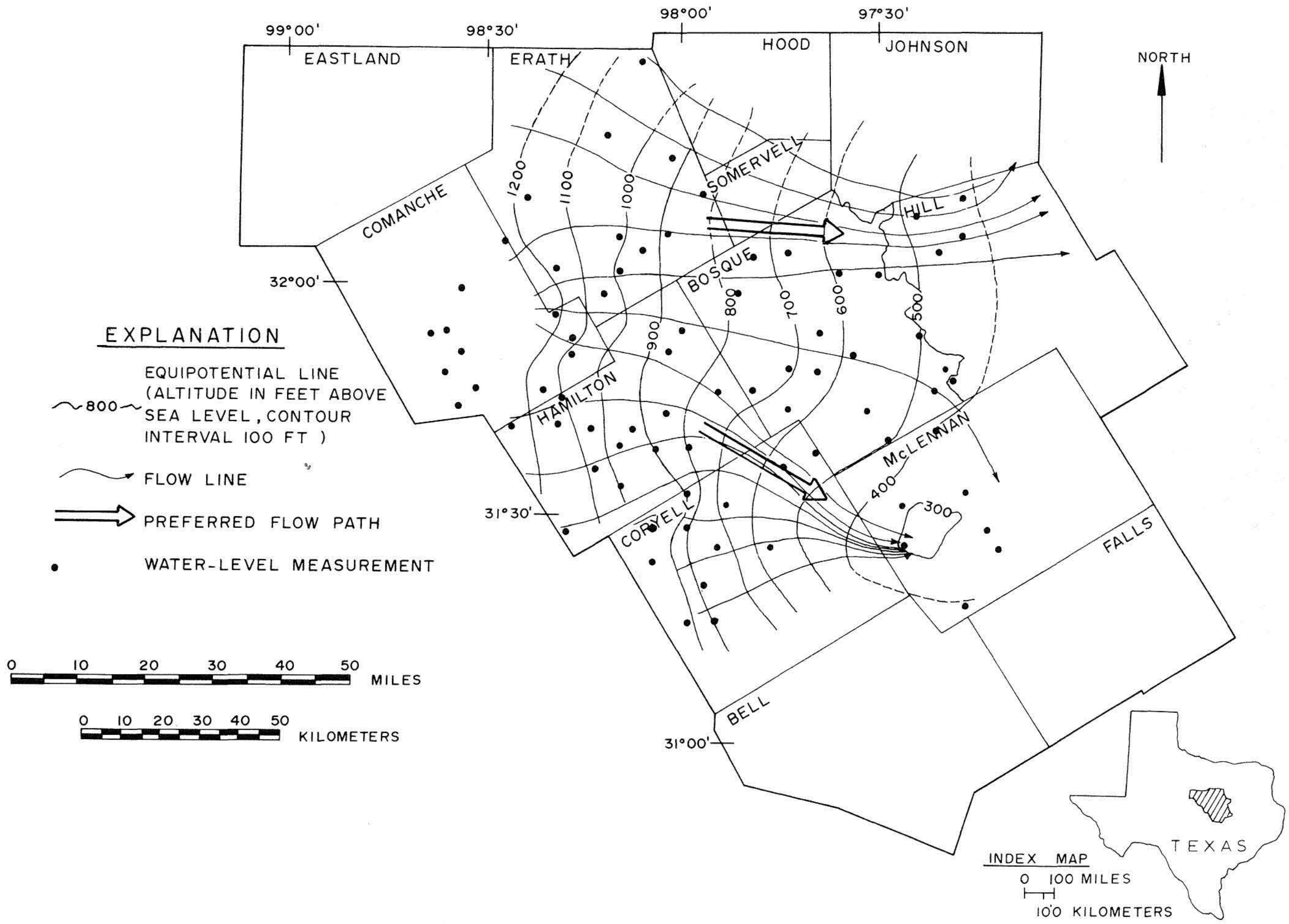


Figure 16. Hensel potentiometric surface, North-Central Texas. Large arrows indicate preferred flow paths.

water flow across each equipotential line is constant. Both assumptions are required because aquifer boundaries are unknown. Use of these maps for quantitative studies of water supply and flow rates is prevented by lack of boundary information (Casagrande, 1937). Neither assumption allows for recharge to the system along flow paths, which obviously does occur, particularly in the outcrop area. The recharge accounts for certain irregularities in the flow net. Quantitative flow data in the recharge zone cannot be obtained from such a modified flow net. However, general features such as major flow directions and most favorable areas for drilling can be inferred.

A bunching or high number of closely spaced flow lines indicates the preferred ground-water flow paths (figs. 15, 16). Water flows through these areas at a higher rate and in larger quantity than in adjacent areas. These paths, trending northwest-southeast through Somervell and Bosque Counties in the north and through Hamilton and Coryell Counties in the south, coincide with the dip-oriented trends of maximum net sandstone thickness within the Hosston and Hensel fluvial systems (figs. 6, 14). In the east, the flow lines begin to disperse and trend either north or south. This change in direction corresponds to a change in sand-body orientation from fluvial to barrier bar in both aquifers (figs. 4, 5).

Although this application of the flow net departs somewhat from theory, it appears to be a useful method for determining areal variation of water quantity and flow directions within an aquifer. An exception to this method can be found in Comanche County (fig. 15), where the high number of flow lines is probably caused by large quantities of recharge rather than higher flow rates within the aquifer.

GROUND-WATER AVAILABILITY AND EVALUATION

AQUIFER PARAMETERS

The value of an aquifer as a source of ground water depends upon the capacity of the aquifer to store and transmit water. These two characteristics, referred to as the coefficients of storage and transmissivity, generally provide the foundation on which quantitative subsurface hydrologic studies are constructed (Ferris and others, 1962).

The coefficient of transmissivity indicates the capacity of the aquifer as a whole to transmit water and is equal to the product of the hydraulic conductivity and the saturated thickness of the aquifer (Theis, 1935). The United States Geological Survey uses the meinzer unit to measure hydraulic conductivity. The meinzer unit is defined as the flow of water in gallons per day through a cross sectional area of 1 square foot under a hydraulic gradient of 1 foot per foot (Davis and DeWiest, 1966). Transmissivity, therefore, is a measure of the volume of water which will flow each day through a vertical strip of the aquifer 1 foot wide and extending the full saturated thickness, under a hydraulic gradient of unity (100 percent).

The storage coefficient is a dimensionless term defined as the volume of water that the aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface (Walton, 1962). For an artesian aquifer, water released from or taken into storage, in response to a change in hydraulic head, is attributed to the compressibility of the aquifer material and the water. For a water-table aquifer, the water released from or taken into storage is attributed partly to gravity drainage or refilling of the zone through which the water table moves and partly to the compressibility of the water and aquifer material in the saturated zone (Ferris and others, 1962). Although rigid limits cannot be established, the storage coefficients of artesian aquifers are commonly from 0.00001 to 0.001, whereas in water-table aquifers they are 0.05 to 0.30 (Ferris and others, 1962).

Storage and transmissivity are commonly determined by pumping tests in aquifers. A test well is pumped at a known constant rate and water levels are measured in the pumping well and in observation wells which penetrate the aquifer. Graphs of drawdown versus time after pumping started, and/or of drawdown versus distance from the pumped well, are used to solve mathematical formulas which express the relation between the hydraulic properties of an aquifer and its confining bed, if present, and the lowering of water levels in the vicinity of the pumped well (Walton, 1962).

Table 2 lists results of pumping tests in the Hosston and Hensel Sandstones in North-Central Texas. Transmissivity averages 8,000 gallons per day per foot (1.2 l/s/m) in the Hosston and 5,000 gallons per day per foot (0.7 l/s/m) in the Hensel. Hydraulic conductivity is 17 to 222 gallons per day per square foot (8×10^{-4} to 1×10^{-2} cm/s) in the Hosston and 26 to 126 gallons per day per square foot (1×10^{-3} to 6×10^{-3} cm/s) in the Hensel. Representative storage coefficients for the Hensel are unavailable but in the Hosston are 0.015 to 0.000028. The higher coefficient, 0.015, indicates water-table conditions measured in a well in Comanche County where the aquifer crops out and is recharged by precipitation and seepage from the Leon River. The lower coefficient, 0.000028, indicating artesian conditions, is from a well in Hill County where the Hosston Sandstone is confined by the overlying Pearsall Formation.

AQUIFER PROPERTIES RELATED TO DEPOSITIONAL FACIES

The mathematical models used to determine the hydraulic properties of aquifers and confining beds generally assume a homogeneous, isotropic aquifer of infinite areal extent (Ferris and others, 1962). The hydrologic characteristics of an aquifer, however, may vary considerably in short distances, depending upon changes in lithic composition and texture and aquifer thickness. A single aquifer test therefore measures the hydraulic properties in only a small part of the total aquifer.

Delineation of major depositional systems and, more specifically, delineation of component facies within an aquifer can be useful in the prediction of regional aquifer properties. If sufficient subsurface lithic control is available to define and delineate these facies, an aquifer system can be subdivided into components that should exhibit similar physical and, thus, hydrologic characteristics. For example, a knowledge of sand-

Table 2. Results of pumping tests in Hosston and Hensel Sandstones, North-Central Texas*

Map Index Number+	State Well Number	Aquifer**	Transmissivity (gpd/ft)	Hydraulic Conductivity (gpd/ft^2)	Storage
BELL COUNTY					
1.	4053505	Ho	8100	85	–––
2.	4054501	He, Ho	14100	–––	–––
3.	4060601	He, Ho	10300	69	0.00009
4.	4060801	He, Ho	8700	97	0.000043
5.	4061402	Ho	20000	–––	0.0003
6.	4062401	Ho	48000	–––	–––
BOSQUE COUNTY					
1.	4003603	Ho	7300	73	–––
2.	4012803	He	6700	126	–––
3.	4021701	He, Ho	7200	–––	–––
COMANCHE COUNTY					
1.	3160220	Ho	12200	222	0.015
2.	4114106	Ho	3800	–––	–––
CORYELL COUNTY					
1.	4026102	Ho	4800	92	–––
2.	4043206	He, Ho	9400	103	0.000084
ERATH COUNTY					
1.	3155107	He, Ho	6000	87	0.00023
2.	3155801	He, Ho	11500	93	–––
HAMILTON COUNTY					
1.	4108302	He, Ho	11600	–––	0.0008
2.	4124403	He	3800	68	–––
HILL COUNTY					
1.	3253902	He	5200	71	–––
2.	3255904	Ho	1500	17	–––
3.	4006501	Ho	2800	–––	0.000028
JOHNSON COUNTY					
1.	3237901	He, Ho	4600	19	–––
2.	3245601	He, Ho	7660	31	–––
3.	3254101	Ho	3200	48	–––
McLENNAN COUNTY					
1.	4016404	Ho	1950	18	–––
2.	4024102	Ho	2500	32	–––
3.	4032403	Ho	4500	32	–––
4.	4037501	He	1100	26	–––
5.	4046403	Ho	8200	71	0.000028
SOMERVELL COUNTY					
1.	3250303	Ho	13500	–––	–––

* - Data obtained from Texas Water Development Board.

+ - For locations, see Texas Well Numbering System, from Hall, 1974, on open file at the Bureau of Economic Geology.

** - Ho, Hosston; He, Hensel.

stone thickness distribution, dominant lithic character, sedimentary textures, and nature and spatial distribution of facies boundaries would enable aquifer parameters determined from a few well-placed aquifer tests to be extrapolated to estimate values for the parameters at other locations in the same facies.

Meanderbelt sandstone facies.—The preferred paths of ground-water flow occur within the principal meanderbelt sandstone facies (compare figures 6 and 14 with figures 15 and 16). The thick, widespread, dip-oriented deposits of coarse sand offer less resistance to flow than the thinner, less permeable mudstone and siltstone deposits that are more prevalent in the flood-basin facies. In the western part of the study area, transmissivities are highest in the meanderbelt facies, and hydraulic conductivity measured within the meanderbelt sandstone deposits should be fairly uniform because there is relatively little variation in sand texture.

Flood-basin facies.—The flood-basin mudstone and siltstone deposits are neither thick nor laterally extensive. Where present, lower permeabilities exhibited by flood-basin facies affect the hydrologic regime by retarding ground-water flow. Alternating thin, discontinuous sandstone and mudstone deposits restrict both lateral and vertical permeability and reduce transmissivity.

Channel-mouth bar and coastal barrier facies.—The channel-mouth bar and coastal barrier facies within the Hosston and Hensel delta systems are hydrologically connected and are also tied to the updip fluvial system by the meanderbelt sandstone facies.

The coastal barrier facies is bounded in the west (updip) by lagoon-marsh and fluvial flood-basin deposits and in the east (downdip) and at its base by prodelta-shelf siltstones and mudstones. The downdip boundary is abrupt and the updip boundary is gradational. The effectiveness of the lateral facies boundaries as barriers to ground-water flow is indicated on figure 15 where the drawdown cone of the Hosston potentiometric surface in the eastern part of the area is elongate rather than circular and is parallel to the north-south-trending coastal barrier sandstone body.

Transmissivities tend to be higher in coastal barrier facies than in other delta facies because of the thick, widespread, and laterally continuous sequences of well-sorted marine sands. Vertical permeability, however, is adversely affected by the interbedded prodelta-shelf or lagoonal mudstones and siltstones. Hydraulic conductivity within this facies should be fairly constant because of the uniform sand textures within individual barrier units. The individual channel-mouth bar deposits exhibit some internal variation of permeability owing to the upward coarsening of grain size; thus, greater hydraulic conductivities should be expected in the upper parts of these units.

Marsh-lagoon-embayment facies.—The marsh-lagoon-embayment facies, landward of the coastal barrier sandstone trend, has relatively little importance as an aquifer when compared with the channel-mouth bar and coastal barrier facies. The thick mud sequences have very low hydraulic conductivities and ground water is confined to thin, isolated sandstone bodies.

Prodelta-shelf facies.—The prodelta-shelf facies is dominantly mudstone and siltstone and therefore provides very little ground water. The fine-grained deposits within this facies constitute an abrupt, downdip, impermeable boundary for the coastal barrier facies and, where intercalated, tend to reduce vertical permeability within the stacked barrier sequences.

HYDROCHEMISTRY

DISTRIBUTION OF MAJOR CHEMICAL CONSTITUENTS

Chemical constituents in the ground water within the study area are derived principally from the soluble materials in the soil and rock through which the water has moved. The chemical types of water in the Hosston are similar to those in the Hensel (fig. 17; results of water analyses, from Hall, 1974, are on open file at the Bureau of Economic Geology). The dissolved solids in the waters in the updip western part of the area are dominantly calcium magnesium bicarbonate ($CaMgHCO_3$). In the eastern downdip area, the waters are mainly of the sodium bicarbonate ($NaHCO_3$) or sodium sulfate ($NaSO_4$) types.

Total dissolved solids in the Hensel waters range from 314 milligrams per liter in Comanche County to 976 milligrams per liter in McLennan

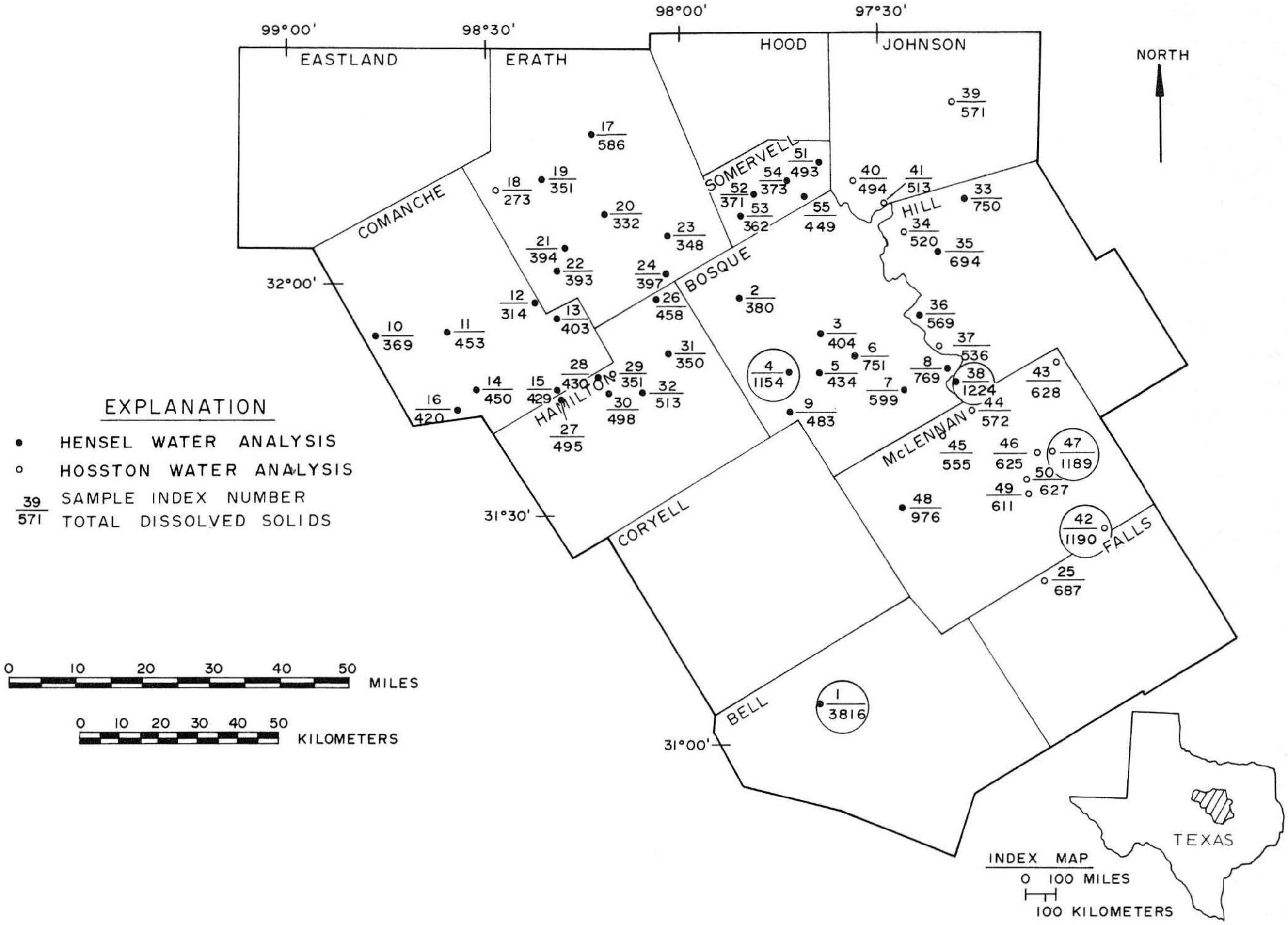


Figure 17. Total dissolved solids, Hosston and Hensel aquifers, North-Central Texas.

County. Hosston waters range from 273 milligrams per liter in Erath County to 687 milligrams in Falls County. Total dissolved solids within the Hosston and Hensel generally increase with increasing depth and distance from the recharge area.

The values of dissolved solids at locations 1, 4, 38, 42, and 47 on figure 17 appear abnormally high and mainly result from sulfate concentrations that are higher than normal. With the exception of well 4 in Bosque County, these wells are in the vicinity of the Balcones fault zone. Henningsen (1962) noted that the overlying Glen Rose waters contain large concentrations of sulfate and suggested that mixing of waters occurred along fault displacements. Sampling irregularities and faulty casing are possible explanations for the high concentrations of dissolved solids in well 4.

HYDROCHEMICAL FACIES

The previously discussed correlation between hydrogeologic characteristics and sedimentary facies suggests that the delineation of depositional systems and component facies within an aquifer may also prove useful in understanding the distribution of chemical types of water.

Trilinear diagrams developed by Piper (1944) were used to delineate and classify major chemical water types or hydrochemical facies within the Hosston and Hensel aquifers. The hydrochemical facies classification was developed by Back (1966). Water analyses were converted from parts per million to milequivalents per liter and checked for accuracy by using a computer program developed by Holland (1973). The resulting milequivalents per liter are plotted on the Piper diagram (fig. 18).

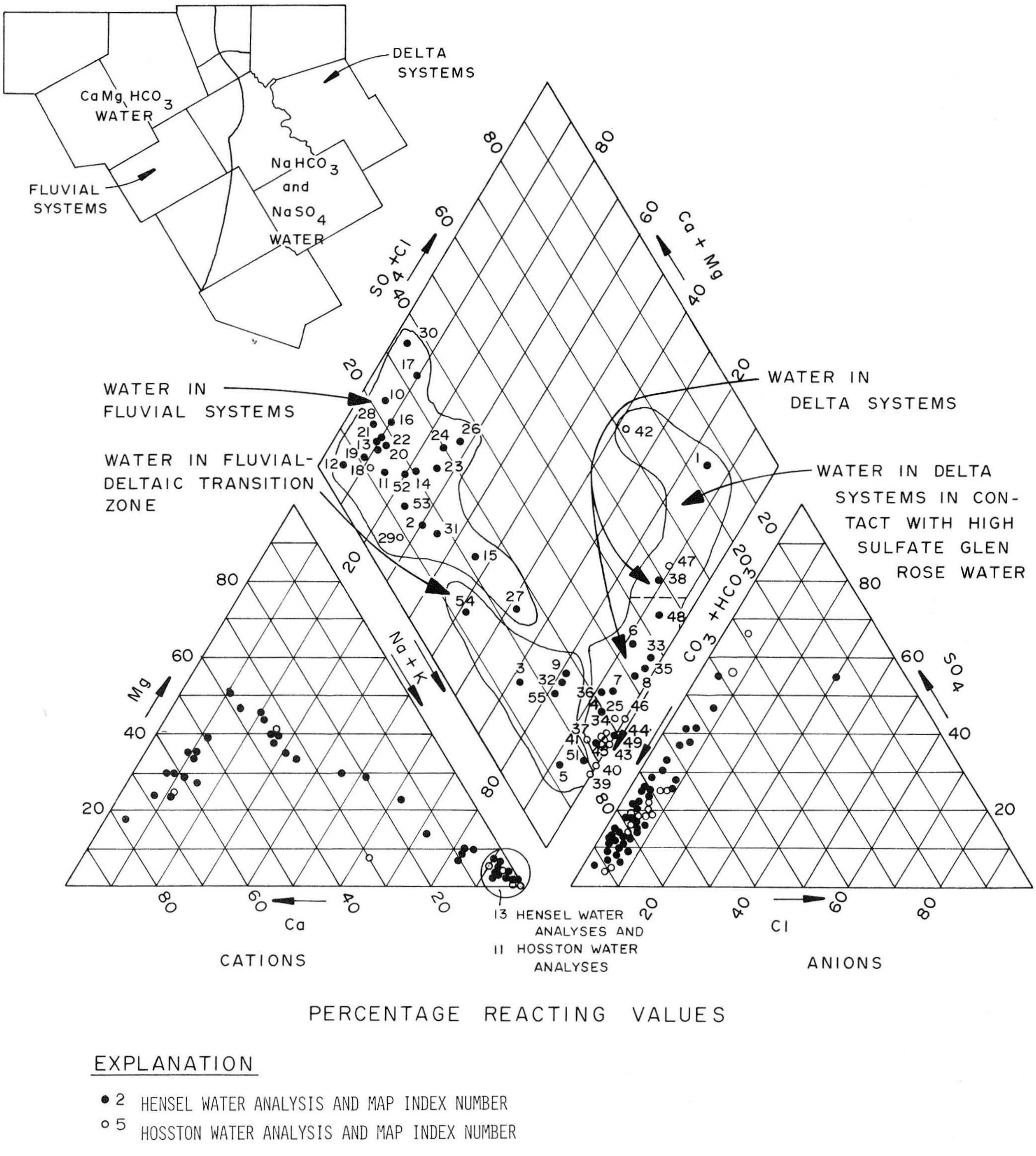
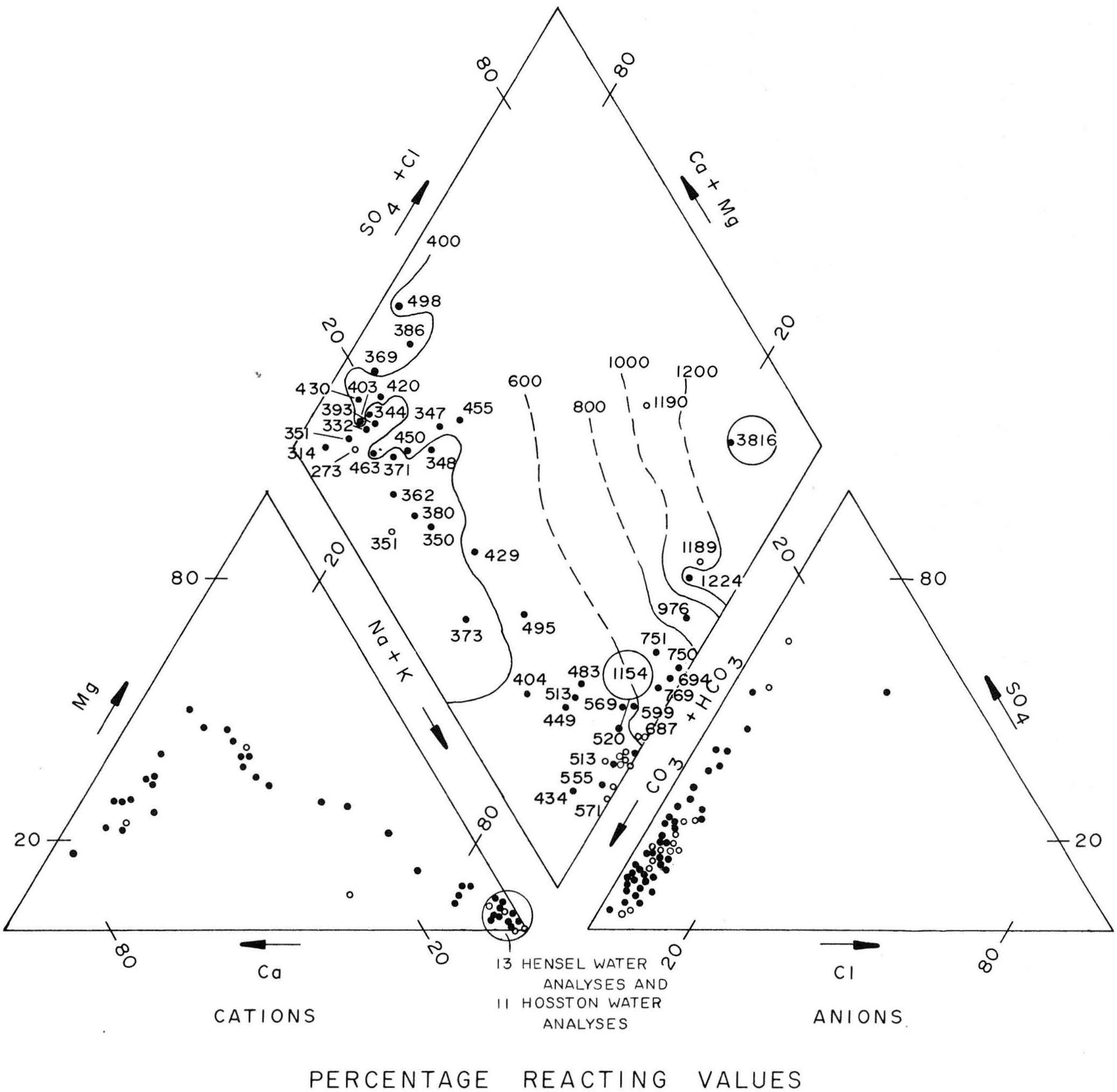


Figure 18. Trilinear diagram showing relative chemical composition of Hosston and Hensel waters, North-Central Texas.



EXPLANATION

- • 351 HENSEL WATER ANALYSIS, TOTAL DISSOLVED SOLIDS
- o 463 HOSSTON WATER ANALYSIS, TOTAL DISSOLVED SOLIDS
- CONTOUR OF EQUAL TDS--INTERVAL = 200 MG/L (CIRCLED VALUES DO NOT FIT WITHIN CONTOUR INTERVAL)

Figure 19. Trilinear diagram showing relationship between total dissolved solids and chemical composition of waters in Hosston and Hensel aquifers, North-Central Texas. Analyses are plotted in same positions as on figure 18.

Reacting values of the three cation groups are plotted as a single point according to conventional trilinear coordinates. The same is done for the anion group. The central diamond-shaped field shows the overall chemical character of the ground water by a third single point plotting, which is at the intersection of rays projected from the cation and anion fields (Walton, 1970).

The Piper diagram (fig. 18) shows the overall chemical character of water in the Hosston and Hensel aquifers. The combined plottings form a pattern which suggests possible correlation between dissolved solids content and depositional facies. Water samples taken from within the previously delineated fluvial depositional facies in both aquifers (figs. 6, 14) are principally of the calcium magnesium bicarbonate ($CaMgHCO_3$) type. Samples from the deltaic depositional facies within the Hosston and Hensel consist mainly of sodium bicarbonate ($NaHCO_3$) and sodium sulfate ($NaSO_4$) ions.

The chemical character of water in the updip fluvial system probably results from the interaction of meteoric water and sedimentary carbonate units in the recharge area. Percolating waters leach calcium, magnesium, and bicarbonate from the limestone and dolomite beds in the overlying Glen Rose Limestone. Because calcite dissolves more rapidly than dolomite, the water is initially calcium-rich. With increasing distance downdip and longer residence time, the waters in the fluvial system reach equilibrium with dolomite. Total dissolved solids remain fairly uniform in the fluvial system (fig. 19) because the calcium magnesium bicarbonate waters are saturated with respect to the available ions in the host rock.

A change in equilibrium conditions is indicated as the dolomite-saturated waters enter the marginally marine deltaic sediments. This change is reflected by an increase in dissolved solids, primarily sulfate and sodium (fig. 19). The increase of dissolved solids may result from the interaction of the calcium magnesium bicarbonate waters with an extremely soluble material such as gypsum. This reaction would result in the release of sulfate and calcium ions. But inasmuch as concentrations of calcium do not increase in waters of the delta facies, the calcium ions probably are exchanged for sodium in the deltaic marine clays.

A reduction of the pH of the waters may also cause an increase in dissolved solids. The oxidation of iron minerals, such as pyrite, within the lagoonal environments, would increase the acidity of the water and allow dissolution of more mineral solids, particularly sulfate. However, data concerning mineralogy of the marine sediments and of the availability of dissolved oxygen in the waters are not adequate to prove either hypothesis.

The restriction of marine waters in lagoon or embayment areas landward of the coastal barriers may have resulted in local sebkha and evaporite deposits in the delta plain. Waters percolating through these deposits would be higher in sodium and bicarbonate concentration, as observed in figures 18 and 19.

Although several hypotheses have been offered for the downdip change in water types, further geochemical work involving detailed mineralogical examination and the determination of dissolved oxygen concentrations in waters of the deltaic facies is necessary in order to better determine the relationship between rock and hydrochemical facies.

CONCLUSIONS

1. The Hosston and Hensel Sandstones of the Trinity Group in North-Central Texas were deposited during minor regressions of the Comanchean (Lower Cretaceous) seas.
2. Paleotopography on the sub-Cretaceous surface in North-Central Texas influenced sediment accumulation in both the Hosston and Hensel Sandstones. Axes of maximum net sandstone thickness of both units generally correspond with valleys on the Wichita paleoplain.
3. Both sandstone units are characterized by a meanderbelt fluvial system in the west and a high-destructive, wave-dominated delta system in the east.
4. Multilateral sandstone bodies, abbreviated point-bar sequences, and absence of wide-spread flood-basin muds suggest that the Hosston fluvial system is of the coarse-grained meanderbelt type.
5. Some complete point-bar sequences, more extensive overbank deposits, and locally well-

developed flood-basin mud facies suggest a lower bed-load/suspended-load ratio for the Hensel meanderbelt fluvial system than for the Hosston.

6. Regional ground-water flow in the Hosston and Hensel aquifers is to the southeast with hydraulic gradients averaging 10 to 15 feet per mile (1.9 to 2.8 m/km).
7. Delineation of major depositional systems and their component facies within an aquifer is useful in the prediction of regional aquifer properties such as permeability boundaries and high-permeability trends. Once the facies are delineated, the aquifer can be subdivided into components exhibiting similar hydrogeologic characteristics such as thickness, lateral and vertical hydraulic conductivity, and storage.
8. Hydrochemical facies of the water and major depositional systems in the Hosston and Hensel coincide within the study area.
9. Calcium, magnesium, and bicarbonate are the dominant ions in waters of the fluvial system because meteoric water dissolves sedimentary carbonate units in the recharge zone. Higher concentrations of dissolved solids, primarily sulfate and sodium, in waters of the delta facies are caused by a change in equilibrium conditions probably resulting from the interaction of dolomite-saturated waters from the fluvial facies with an extremely soluble material such as gypsum, or an increase in acidity due to oxidation of pyrite in lagoonal facies within the high-destructive, wave-dominated delta system. The increase of sodium may result from ion exchange of calcium for sodium in marine clays within the delta system.

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