TIDALLY INFLUENCED DEPOSITS OF THE HICKORY SANDSTONE, CAMBRIAN, CENTRAL TEXAS

FRANK GARY CORNISH

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by

FRANK GARY CORNISH, B.S.

THESIS

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APPROVED:

Alan J Scott

Earle F McBride

Douglas Smith

PREFACE

My interest in Cambrian sandstones was sparked during my undergraduate years by Dr. Donald Lowe of Louisiana State University in his field investigation of the Sawatch Sandstone of Colorado. Dr. Alan J. Scott, my thesis supervisor, suggested the Hickory Sandstone as the subject of my thesis. I am most grateful to him for his contributions to this project, my development as a geologist, and particularly to his culinary guidance. The other members of my committee were Dr. E. F. McBride and Dr. Doug Smith to whom I extend my thanks for critically reviewing the manuscript. Paul Smith acted as student editor.

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I am thankful for the many cooperative land owners of Central Texas and to Pennsylvania Glass Sand Co., for allowing me access to their properties. I would like especially to thank Mr. Mather Dorbandt for allowing me a roof and a bed for one field week. I am grateful to Mr. Doug Ratcliff and his assistants for their extended efforts in helping me with core and other subsurface materials.

Mr. Francis Shepherd of the Geological Information Library of Dallas and Mr. Richard Preston of the Texas Water Development Board were helpful in supplying electric logs, cores, and other subsurface data.

I am deeply grateful to my field assistant and wife, Judi, for her continued encouragement, financial support, and typing.

This thesis was submitted to the committee in October, 1975.

Frank G. Cornish

November 1975

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A B S T R A C T

The Hickory Sandstone Member of the Riley Formation is dominantly quartz sandstone up to 167 m thick which crops out in the Llano Uplift region of central Texas and dips away in all directions. It lies unconformably upon the irregular surface of the Precambrian Texas craton. The association of isopach thicks and thins over cratonic lows and highs demonstrates topographic control of Hickory deposition. Regional subsurface studies delineate the extent of the overlying Cap Mountain Limestone. Beyond the limits of the Cap Mountain, the Hickory grades into the Lion Mountain Sandstone laterally and vertically so that regional correlations are difficult.

The six lithofacies of the Hickory Sandstone were deposited as nonbarred tidally-influenced or estuarine-related equivalents to deposits of Holocene environments. Outer estuarine tidal channel-shoal deposits display abundant channel fills of large-scale foresets,

parallel bedded sandstone, and minor siltstone. Trilobite trackways (Cruziana) and resting traces (Rusophycus) occur in these deposits, associated with U-shape burrows (Diplocraterion and Corophioides). Deposits of open coast sandy tidal flats display upward-fining character, medium-to large-scale festoon crossbedding, abundant small-scale ripple bedforms of all types, and mudcracks. These deposits include the U-shape burrows, Corophioides, and the trackway, Climactichnites. Deposits of inner estuarine tidal channels and tidal flats display upward-fining character, wavy-lenticular bedding, bimodal paleocurrent patterns, and the resting trace, Pelecypodichnus. All of these deposits prograded as a unit until sea level rise shut off sediment supply. Progradation of tidal channel and shoal sediments was renewed. These deposits are festoon crossbedded hematitic sandstone with wavy-lenticular bedding and abundant fossil debris. Storm energy funneled through tidal channels deposited crossbedded sandstone onto the nearshore inlet-influenced shelf. Final Hickory deposits and initial Cap Mountain deposits were storm-dominated, burrowed and laminated calcitic shelf sands.

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INTRODUCTION

The Hickory Sandstone is one of the many lower Paleozoic cratonic sandstones of North America. These deposits have caught the interest of numerous geologists. Their study has been primarily limited to stratigraphic, petrographic, and paleocurrent analysis. The depositional environments of these deposits (including the Hickory Sandstone) have been largely defined as transgressive or shallow marine (Pettijohn et al., 1973, p. 227). 'Shallow marine' has taken on a rather ambiguous meaning with the development of modern concepts and theories of depositional systems. Depending upon the reader, shallow marine sands may represent delta front, shoreface, barrier, intertidal or shelf environments.

The main purpose of this study is the identification of the specific depositional environments of the deposits of the Hickory Sandstone. In particular, it is the objective of this work to identify facies, their composition and texture, their relationships to each other, their sedimentary structures and vertical sequence, and their body fossils and lebenspurren. Further, Holocene examples are used to explain the distribution and occurrence of the various facies and their geologic history.

Study Area

The Hickory Sandstone crops out along northeast-southwest trending fault blocks of the Llano uplift area of central Texas (fig. 1). This seven county area is entirely within the drainage basins of the Llano and Colorado rivers. Elevations range from 210 m to 610 m with local relief of up to 150 m. Natural exposure of the basal lithofacies are abundant, but the remaining lithofacies are poorly exposed except along river bluffs, in quarries, and on roadcuts.

The Hickory dips away from the uplift in all directions. The subsurface extent of the study area is limited by depositional pinchout of the Cap Mountain Limestone to the west, north, and northwest of the outcrop area (fig. 6). Regional subsurface correlation sections include the area shown in Figure 1. The Ouachita structural trend forms the limit of study to the east and south. Structural elements affecting Hickory deposition are discussed in a subsequent section of this study.

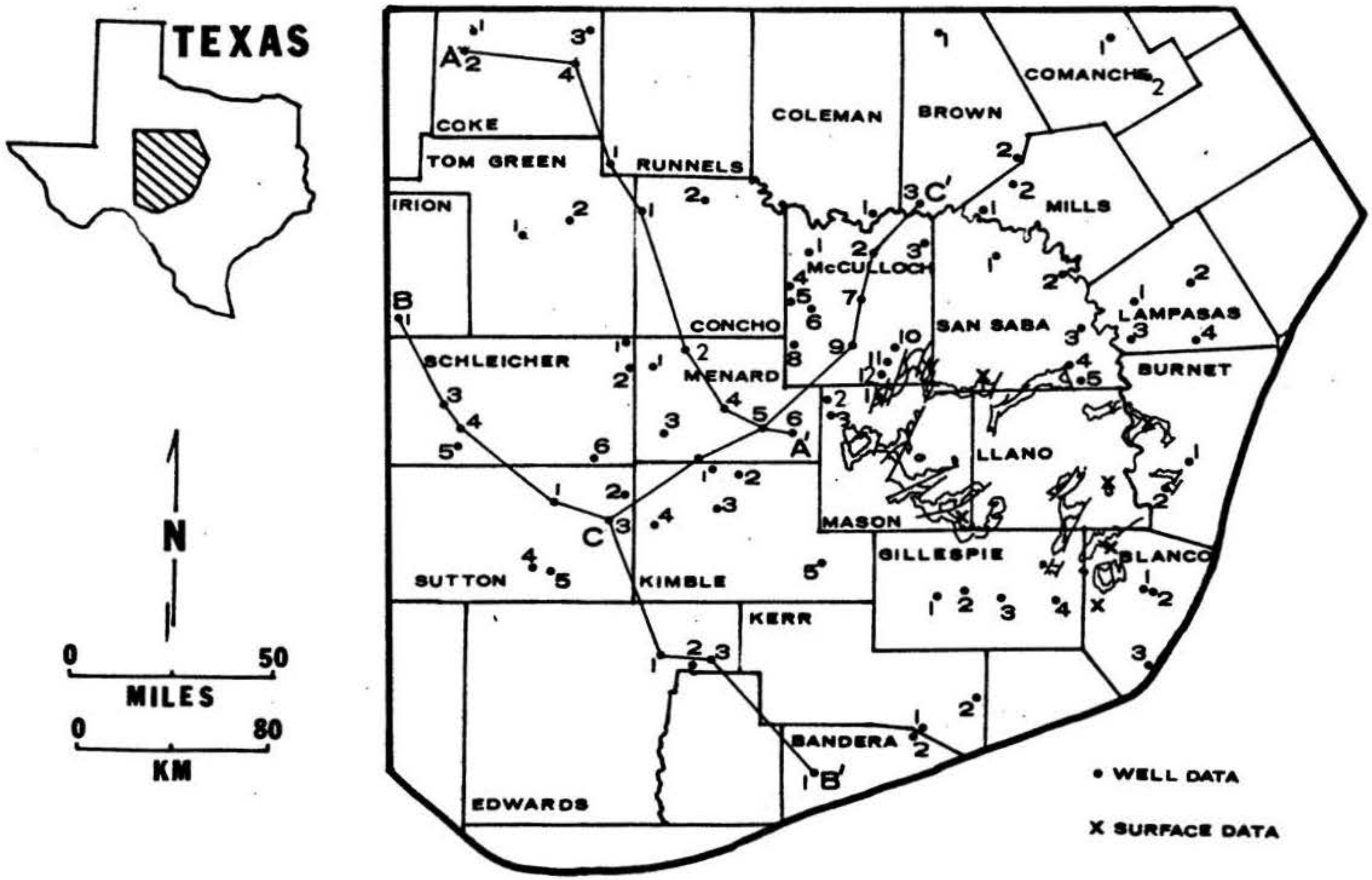


Figure 1. Location map showing the study area and control for regional stratigraphic sections (Figures 4, 5, and 6) and isopach maps (Figures 8 and 9 includes data from Barnes et al., 1959) Well names listed in Appendix V. Figure 10 shows locations of measured sections.

Stratigraphy

A brief discussion of the stratigraphic relationships of the Hickory Sandstone follows. The reader is referred to Wilmarth (1938) and to Bridge _et al_. (1947) for a more detailed account of the history of stratigraphic nomenclature.

The Hickory Sandstone lies unconformably upon a Precambrian igneous and metamorphic complex and was deposited on a surface of high relief. The Hickory was given status as the basal member of the Riley Formation by Cloud _et al_.(1945). Bridge _et al_. (1947), defined the three gradational members of the Riley Formation: the Hickory Sandstone, the Cap Mountain Limestone, and the Lion Mountain Sandstone (fig. 2).

The Hickory grades laterally and vertically upward into the Cap Mountain Limestone member as seen in surface exposures in the study area. The Cap Mountain pinches out to the northwest of the outcrop area and the Hickory becomes virtually indistinguishable from the Lion Mountain Sandstone (Barnes _et al_., 1959).

Palmer (1954) described trilobite assemblages that zone the Riley Formation. The Hickory lay within

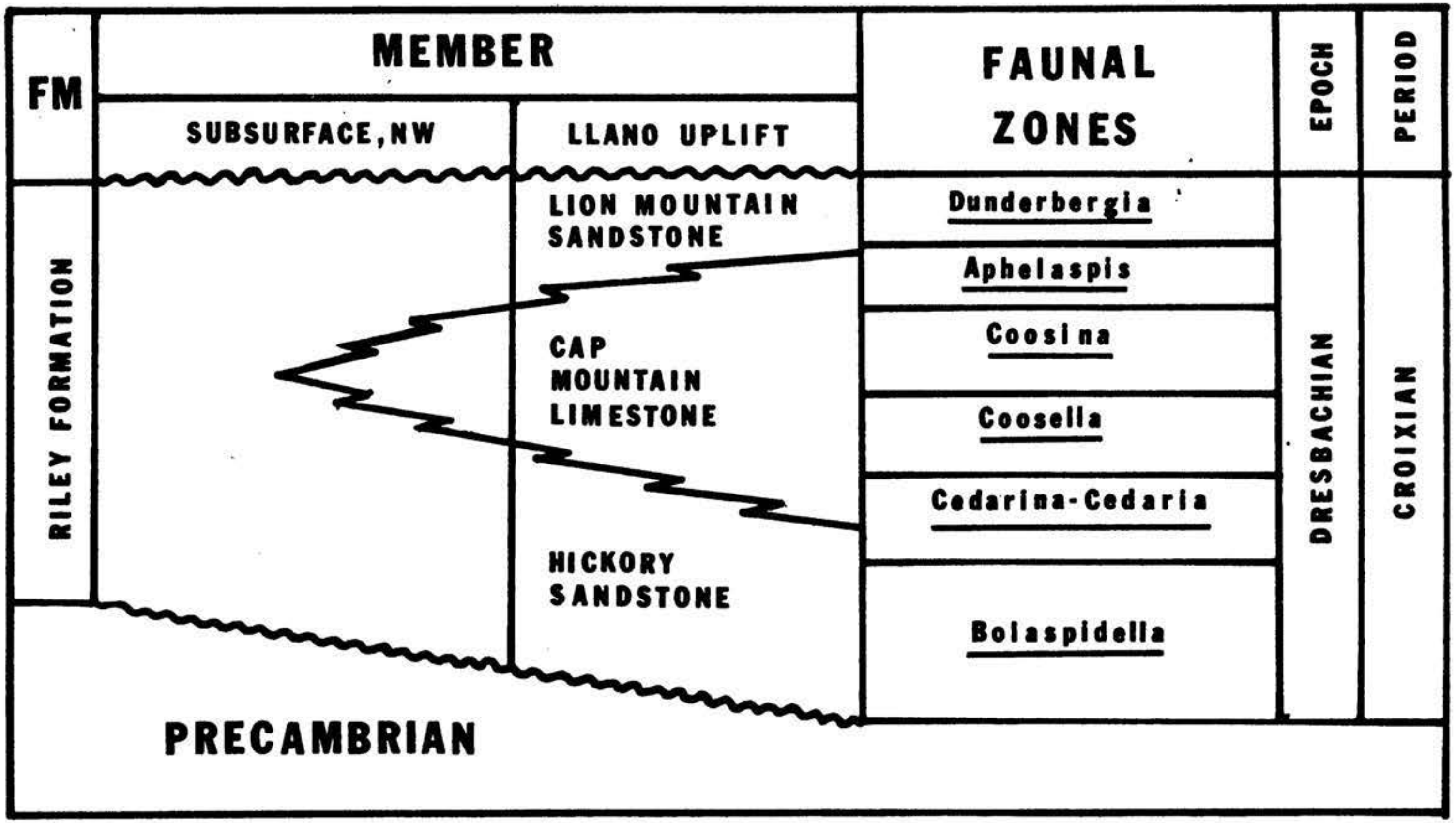


Figure 2. Stratigraphic and biostratigraphic relationships of the Riley Formation, modified from Barnes et al. (1959) and Bell and Barnes (1961)

his *Bolaspidella* and *Cedarina-Cedaria* zones (fig. 2). He and previous workers (Bridge, 1937; Lochman, 1938) noted that this faunal zone occurred in both the Hickory and Cap Mountain members of the Riley Formation. The Hickory was considered Dresbachian in age on the basis of the trilobite assemblages. Palmer reported that some samples from the middle and upper portions of the Hickory contained transitional Middle-Late Cambrian fossils and suggested that the lower Hickory may be of Middle Cambrian age. Bell and Barnes (1961, 1962) refer to the Hickory as Middle Cambrian based upon Palmer's work.

Previous Studies

The following summary traces important developments in the stratigraphic understanding of the Hickory and emphasizes past conclusions and evidence concerning its depositional environments. Studies emphasizing economic aspects of the Hickory are discussed in greater detail within the next section, "Economic Uses". The Hickory has been referred to in several regional studies of the Lower Paleozoic of the Llano uplift region, but determination of depositional environments within the

Hickory has not been the primary objective of any previous study.

Barnes and Parkinson (1940) first theorized about Hickory depositional environments. They noted the presence of faceted ventifacts near the Precambrian surface and concluded that the Hickory must be in part eolian or that the material was reworked from eolian deposits.

Bridge *et al.* (1947) first divided the Hickory into a lower sandstone and an upper red sandstone. Later, three distinct facies were recognized and defined by Goolsby (1957). These were:

1) Lower Hickory - conglomeratic crossbedded nonfossiliferous coarse-fine sandstone
2) Middle Hickory - interbedded shale and sandstone
3) Upper Hickory - divided into
    a) Medium-coarse ferruginous sandstone
    b) Alternating calcareous and ferruginous sandstone of the eastern part of the outcrop

Goolsby used field relationships, sedimentary structures, and paleocurrent data to conclude that each facies of the Hickory represented different depositional environments. The Lower Hickory Sandstone was deposited as fast flowing ephemeral streams (braided); the middle unit as epeiric sea deposits, and the upper sandstones as nearshore and offshore deposits.

Barnes _et al_. (1959), in a major subsurface study of the Lower Paleozoic of Texas and New Mexico were the first to delineate the extent of the Hickory Sandstone on regional cross sections. Correlations in this study were based upon sample logs. Electric log characteristics were not considered. They demonstrated the pinchout of the Cap Mountain Limestone to the northwest as well as showing that much of the Cambrian section in this region was sandstone.

Barnes and Schofield (1964) attempted to outline areas of potential Cambrian iron ores in the northern Llano uplift region by mapping three Hickory facies. They believed the iron precipitated from the sea and accumulated in a bay with restricted or modified circulation favorable to the precipitation of hydrous iron oxide.

Various studies (Barnes _et al_., 1959; Wilson, 1962; Barnes and Schofield, 1964) have dealt with Hickory petrography. Wilson's outcrop work represents the most comprehensive regional petrographic study. He emphasized thin-section analysis to determine trends in composition, sorting, and roundness. Two sources of the sand were determined, the Texas Craton and Llanoria. His paleocurrent map shows dominant sediment transport to the southeast, but he failed to distinguish from which facies his readings came. He concluded that the Hickory was reworked eolian sands deposited within the neritic environment by southeast flowing bottom currents.

The trace fossils Cruziana and Climactichnites were first recognized by Bell and Barnes (1961). They used paleontological data to conclude that the Hickory was deposited during the transgressive part of a transgressive-regressive shelf cycle of the Riley Formation (Bell and Barnes, 1961, 1962).

This brief summary of previous works shows that a variety of interpretations of the depositional environments of the Hickory have been given. These conclusions have been based primarily upon one or a few criteria. None of these studies attempted to use modern concepts of depositional environments or used all the criteria now deemed necessary for genetic interpretion.

Economic Uses

The Hickory has been used for a variety of purposes, most of which are only of local importance. These have ranged from the common rock usage as a building stone to a more unique usage as a hydraulic fracturing sand. Its greatest importance is as an aquifer that yields high quality fresh water.

Numerous small quarries have been opened within the transitional contact with the Cap Mountain Limestone for both building stone and for road metal (Barnes *et al.*, 1947). Its even bedding characteristics made it useful for this purpose and as a flagstone.

The hematitic upper Hickory has been considered a potential source of iron ore (Barnes and Schofield, 1964). These units contain as average 12.4% iron in the upper 10 m with reserves estimated at about 2750 metric tons/km^2.

The lower crossbedded sandstone lithofacies of the Hickory is being quarried near Voca, McCulloch County, for hydraulic fracturing sand by two companies. The refined product is used by the petroleum industry in secondary recovery operations. Properties that make it desirable are its well rounded and well sorted nature (Barnes and Schofield, 1964).

Although not a major producer of hydrocarbons, Cambrian rocks were an exploration objective during the early fifties (Troutman, 1954; Morrisey, 1954; Gardner, 1955). This early but short lived interest in Cambrian sandstone is responsible for the amount of near basement well control in this area. Discovery fields in Nolan and Coke counties were at first reporting production from Hickory Sandstone, but later "Cambrian Sandstone" was reported because subsurface stratigraphy had not been worked out satisfactorily.

Most important has been its use as a secondary aquifer in and around the Llano uplift (Krieger _et al._, 1957; Mason, 1961; Mount _et al._, 1967; Follett, 1973). These publications summarize the aquifer characteristics of the Hickory. The basal lithofacies serves as the important water bearing unit (Mason, 1961). Mount _et al._ (1967) estimated that the Hickory is capable of supplying a water volume of up to 61,700,000 m^3/yr periennially, a supply that should be sufficient for the low density population of central Texas for a number of years.

Nature of the Basement

The Precambrian basement surface has served as a control on location and on thickness for the Hickory. An understanding of basement lithology, structure, and late history is necessary in order to better appreciate the relationship between the Precambrian and the Hickory Sandstone.

The Precambrian basement of Texas is composed of seven lithologic-structural provinces as defined by Flawn (1956). The Hickory was deposited upon the province designated as the Texas Craton, a mass of plutonic granites and granodiorites with some patches of metamorphosed sedimentary and igneous rocks. The largest exposure of this unit is within the Llano uplift region. Here northwest-southeast trending folds of schist and gneiss were intruded by granitic batholiths of different ages (Stenzel, 1935; Clabaugh and McGehee, 1962).

Following a complex history of tectonic activity, the Precambrian evolved into a stable cratonic mass and was exposed to erosion for approximately 400 million years (Clabaugh and McGehee, 1962). The regional structure of the craton during the Cambrian is shown on

Figure 3. The Sierra Grande arch formed a positive element to the west and northwest of the study area (Lochman-Balk, 1971). Slight depressions had developed in the areas of the Southern Oklahoma Geosyncline (Ham *et al*., 1964) and along the Ouachita trough (Flawn *et al*., 1961; p. 167). The immediate area of Hickory deposition was affected by the West Central Texas upwarp and Comanche Arch which formed positive areas flanking portions of the study area. The Cambrian Trough formed axes of deposition through the central area (Holmquest, 1955). These features are reflected in the isopach map of the Hickory (fig. 9).

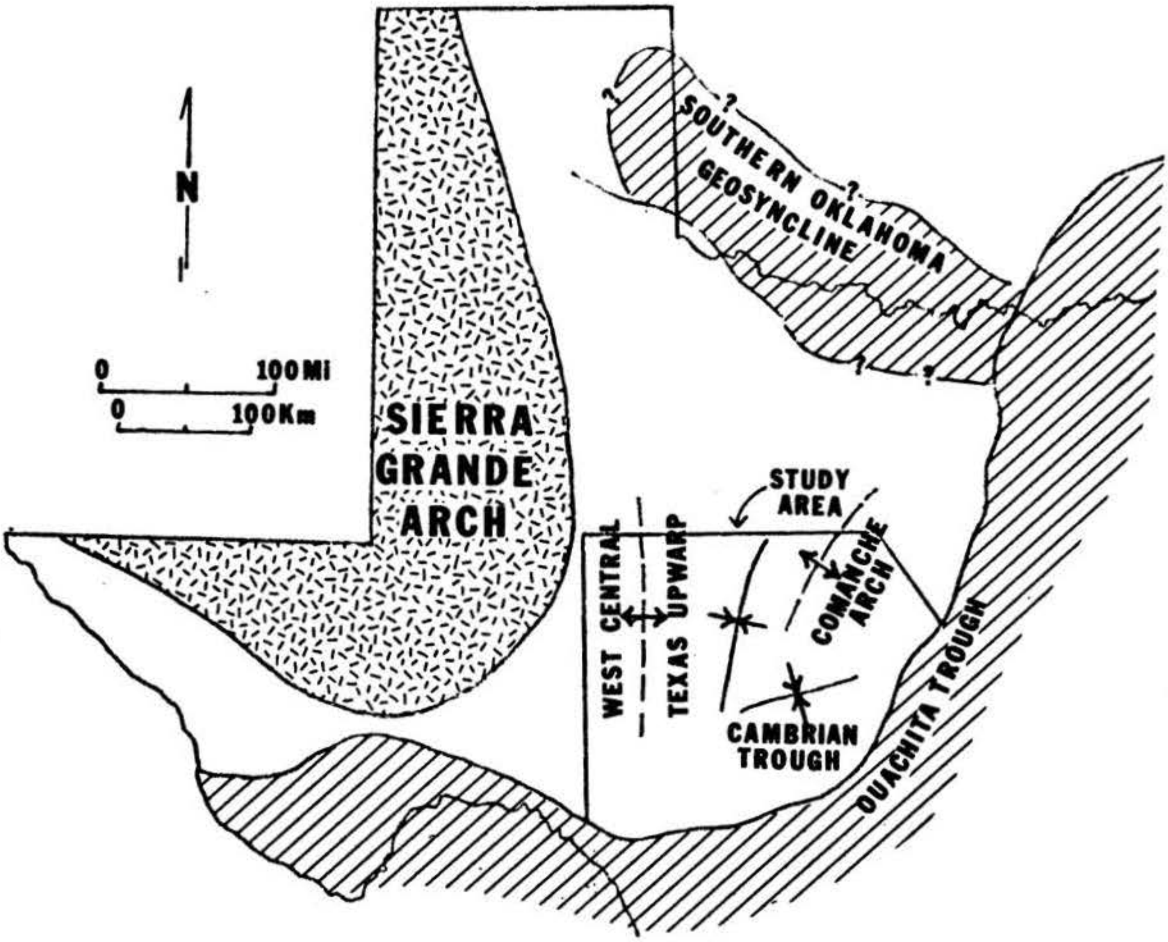


Figure 3. Regional structure of the Texas craton and adjacent areas during the Cambrian, modified from Holmquest (1955), Flawn et al. (1961), Ham et al. (1964), and Lochman-Balk (1971)

REGIONAL RELATIONSHIPS

In a study of the subsurface stratigraphy of the Cambrian of Texas, Barnes _et al._, (1959) utilized only sample logs for correlations. Electric log characteristics were shown on cross sections by Abilene Geological Society (1950) and Stiles _et al._ (1955). These studies point out several correlation problems that should be considered:

1. Much drilling occurred before availability of mechanical logs.
2. The Cambrian section is largely sandstone to the northwest of the Llano uplift.
3. In addition to the Hickory Sandstone, other sandstones such as the Welge, Lion Mountain, and Wilberns, also rest directly on the Precambrian.
4. Several geologists, unaware of the regional stratigraphy, considered any basal Paleozoic sandstone as the Hickory Sandstone.
5. Disappearance of the Cap Mountain Limestone to the northwest (fig. 4-6) makes distinction of Hickory from Lion Mountain difficult or impossible on electric logs and sample logs.

With these problems in mind, several regional sections utilizing electric logs and existing sample logs were constructed to determine characteristic electric log responses for the Riley Formation. The tops of the Wilberns Sandstone and the Welge Sandstone are utilized as a regional marker. From these sections (fig. 4-6), the Hickory can be traced away from the outcrop region. Absence of abundant shale throughout the Hickory does not permit facies to be distinguished except near the outcrop (fig. 7) and minimizes the usefulness of a net sandstone map.

Cambrian sandstones on the section northwest of the outcrop area are stratigraphically higher than the Hickory and are probably Lion Mountain equivalents rather than the Hickory as previously considered by Barnes et al. (1959). Basal sandstones in this area, with a composition similar to the Hickory Sandstone, are present most probably as lateral facies of the overlying Cambrian stratigraphic units. Lack of control through Concho and Tom Green counties plus the depositional pinchout of the Cap Mountain Limestone (fig. 4-6) precludes exact correlations of units across the area. The dotted line represents

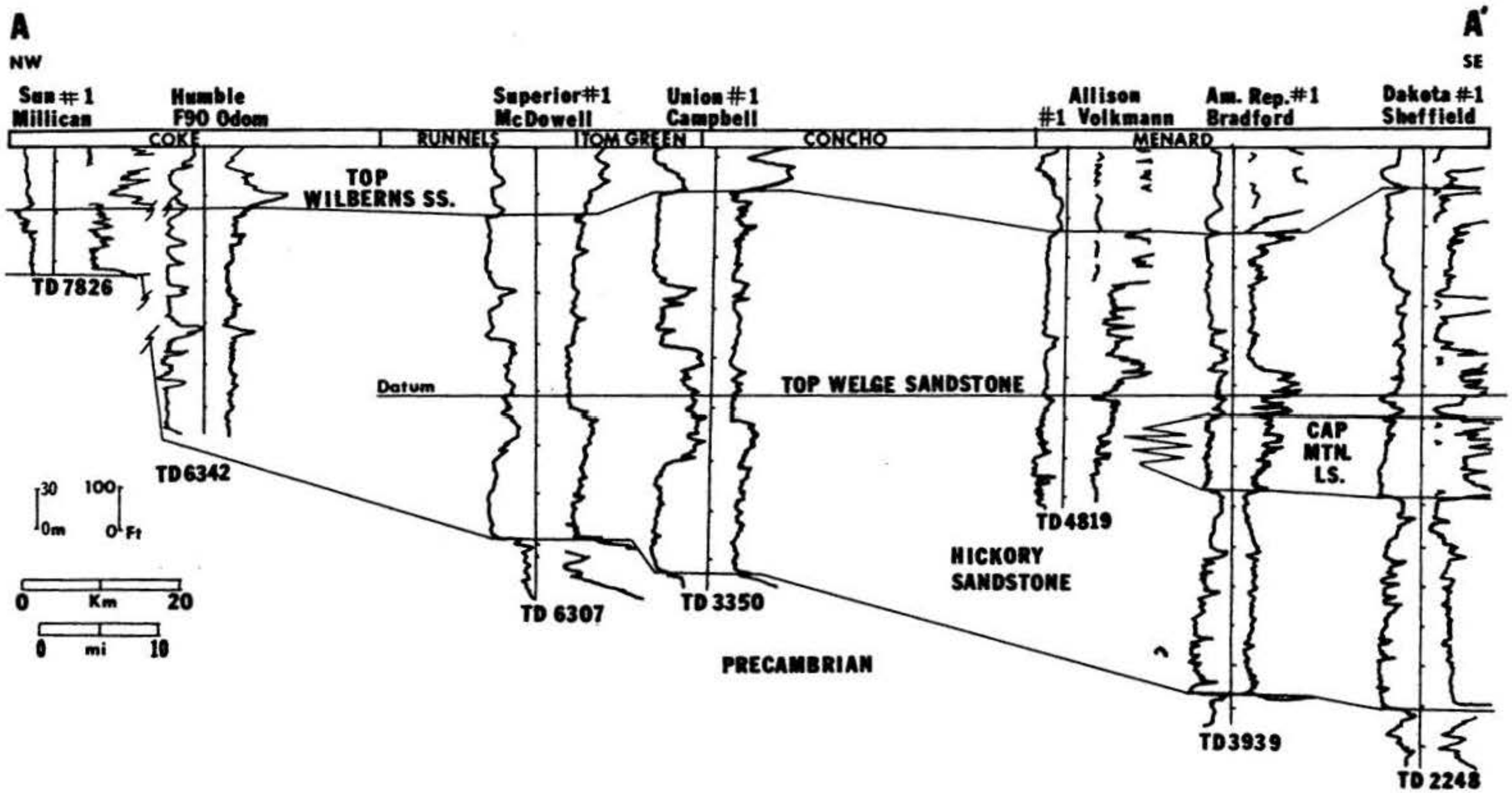


Figure 4. Regional subsurface stratigraphic correlation section, A - A', location shown on Figure 1.

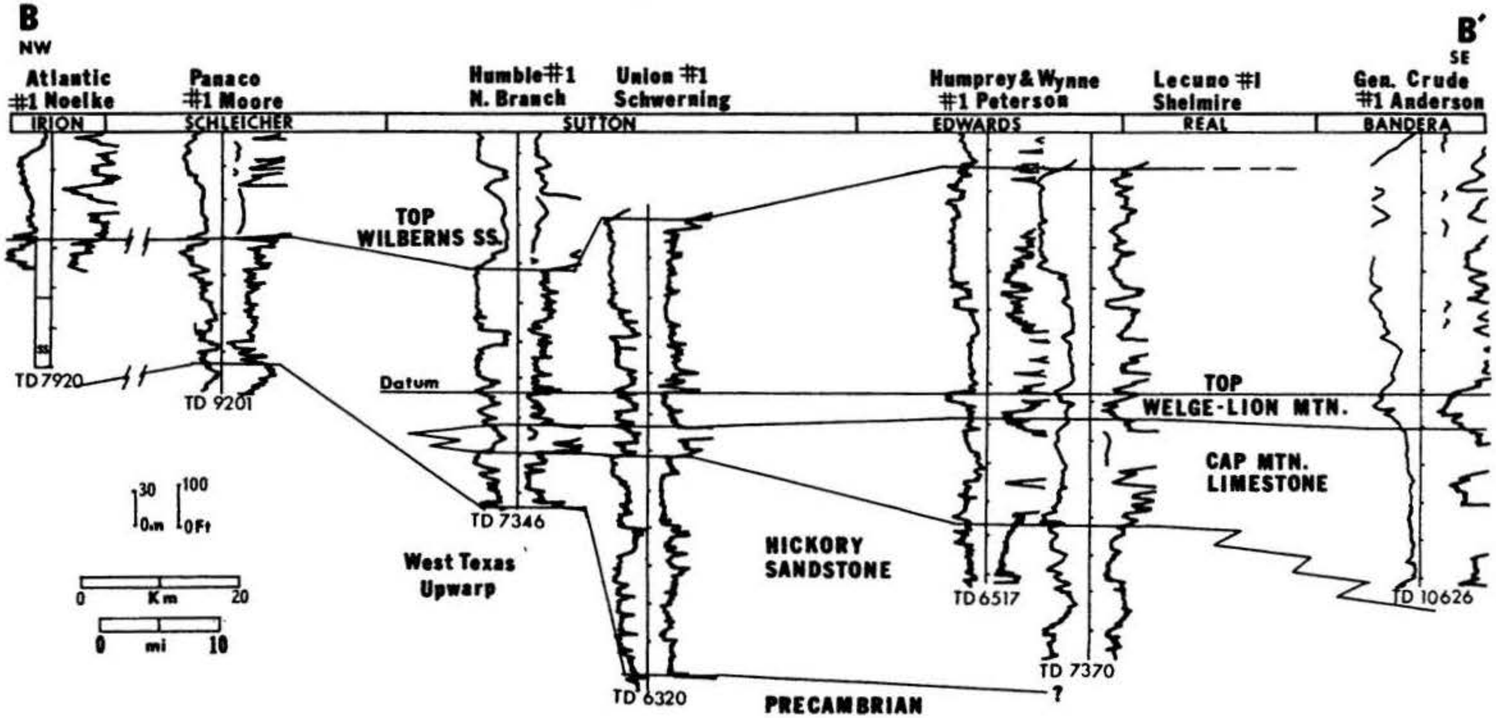


Figure 5. Regional subsurface stratigraphic correlation, B - B', location shown on Figure 1.

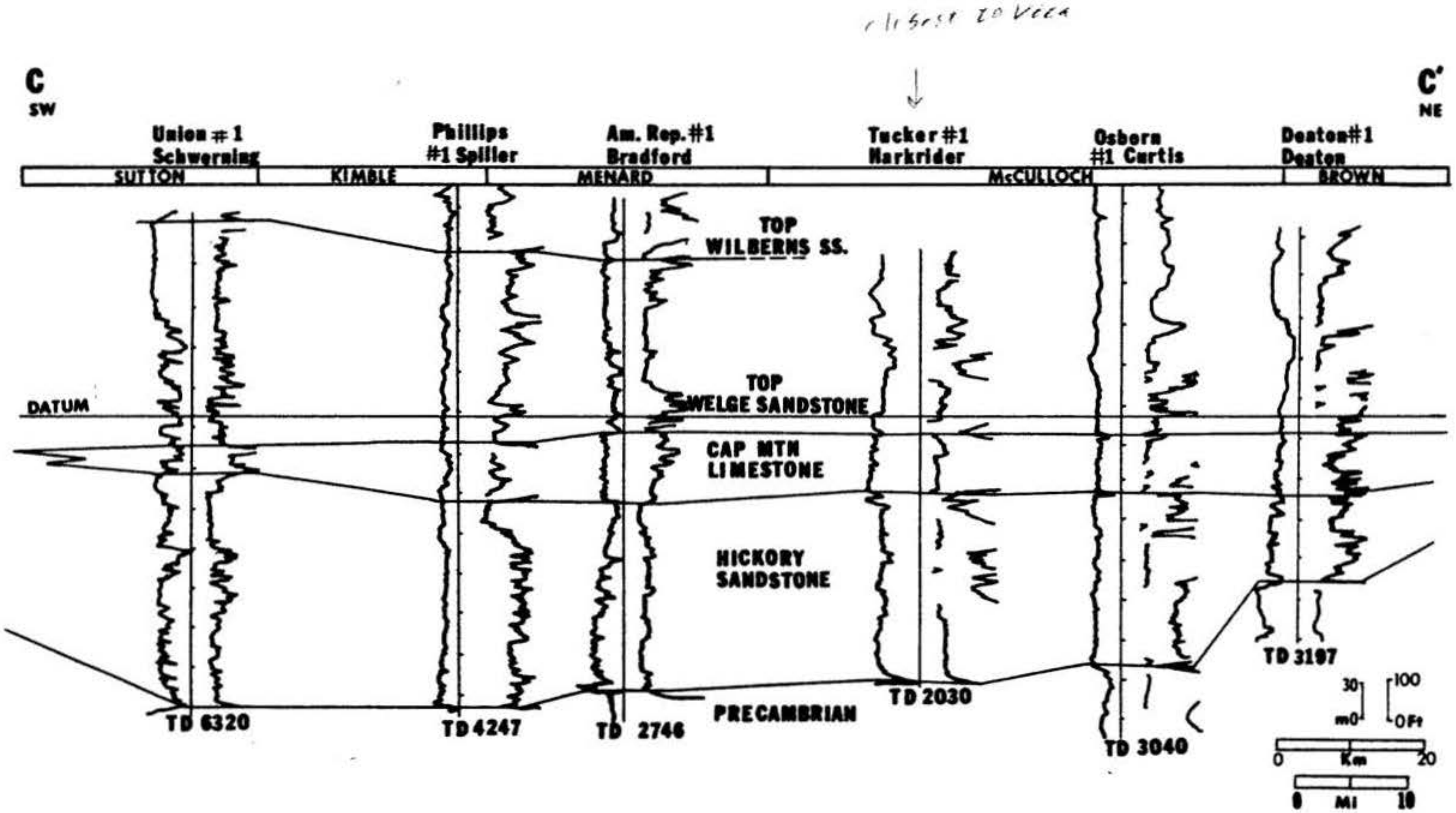


Figure 6. Regional subsurface stratigraphic correlation section, C - C', location shown on Figure 1.

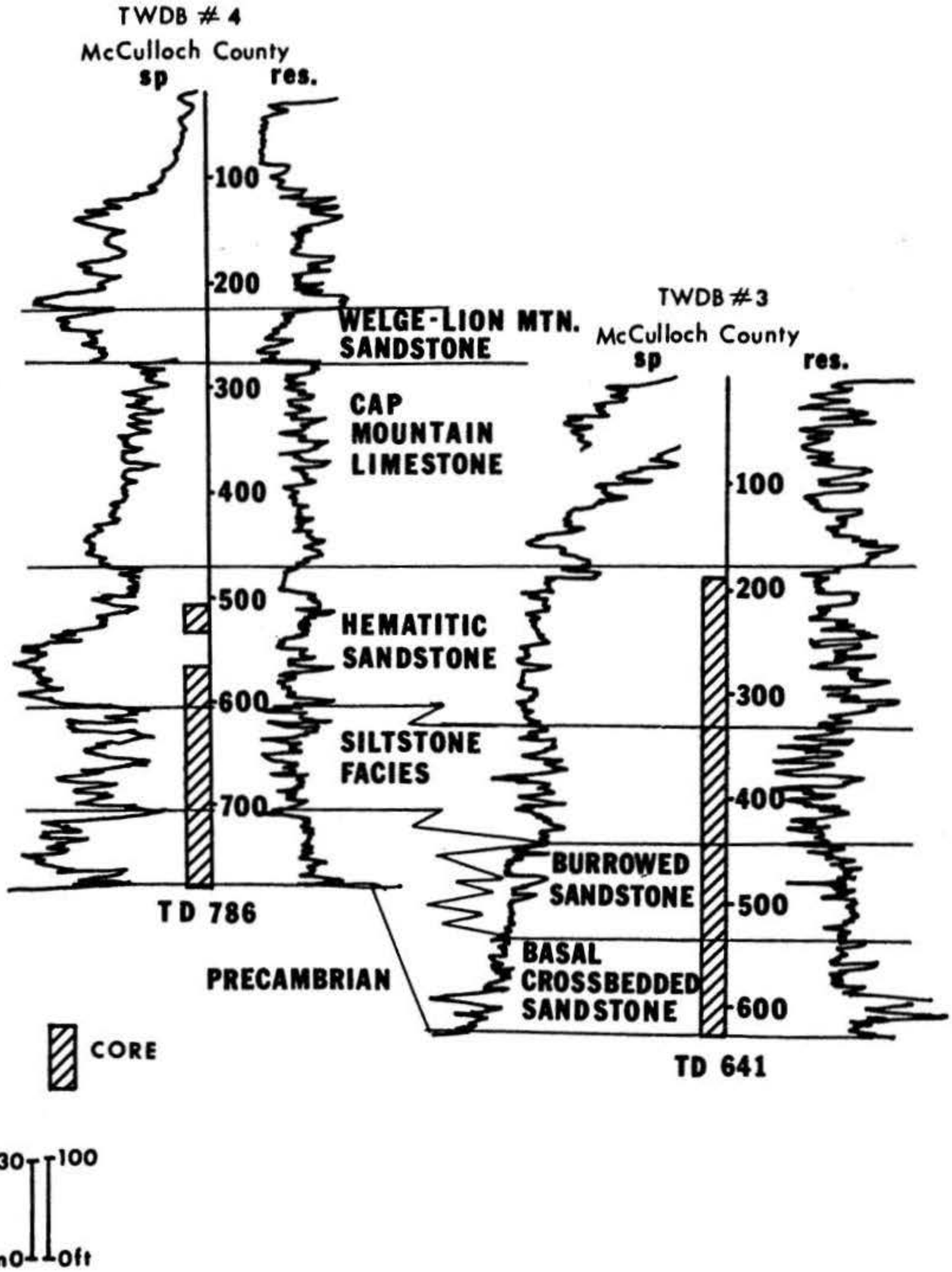


Figure 7. Electric log characteristics of some Hickory lithofacies showing core control

the farthest northern and western extent of Cap Mountain Limestone as a recognizable unit (fig. 9).

Lack of sufficient control limits the delineation of sandstone geometry. However, the structural highs and lows identified by Holmquest (1955) shown in Figure 3 are reflected in the isopach map of the Hickory Sandstone (fig. 9). It should be noted that the Hickory crops out along only one of the axes of deposition. Abrupt thinning of Hickory next to major axes of sediment accumulation are associated with the cratonic highs (e.g., West Central Texas Upwarp and the Comanche Arch). The paleocurrent data shown on Figures 12, 14, 15, 16, and 17, does not correspond to any isopach trends developed. However, the hematitic sandstone is confined to the northern half of the outcrop area paralleling one major axis of deposition (fig. 9).

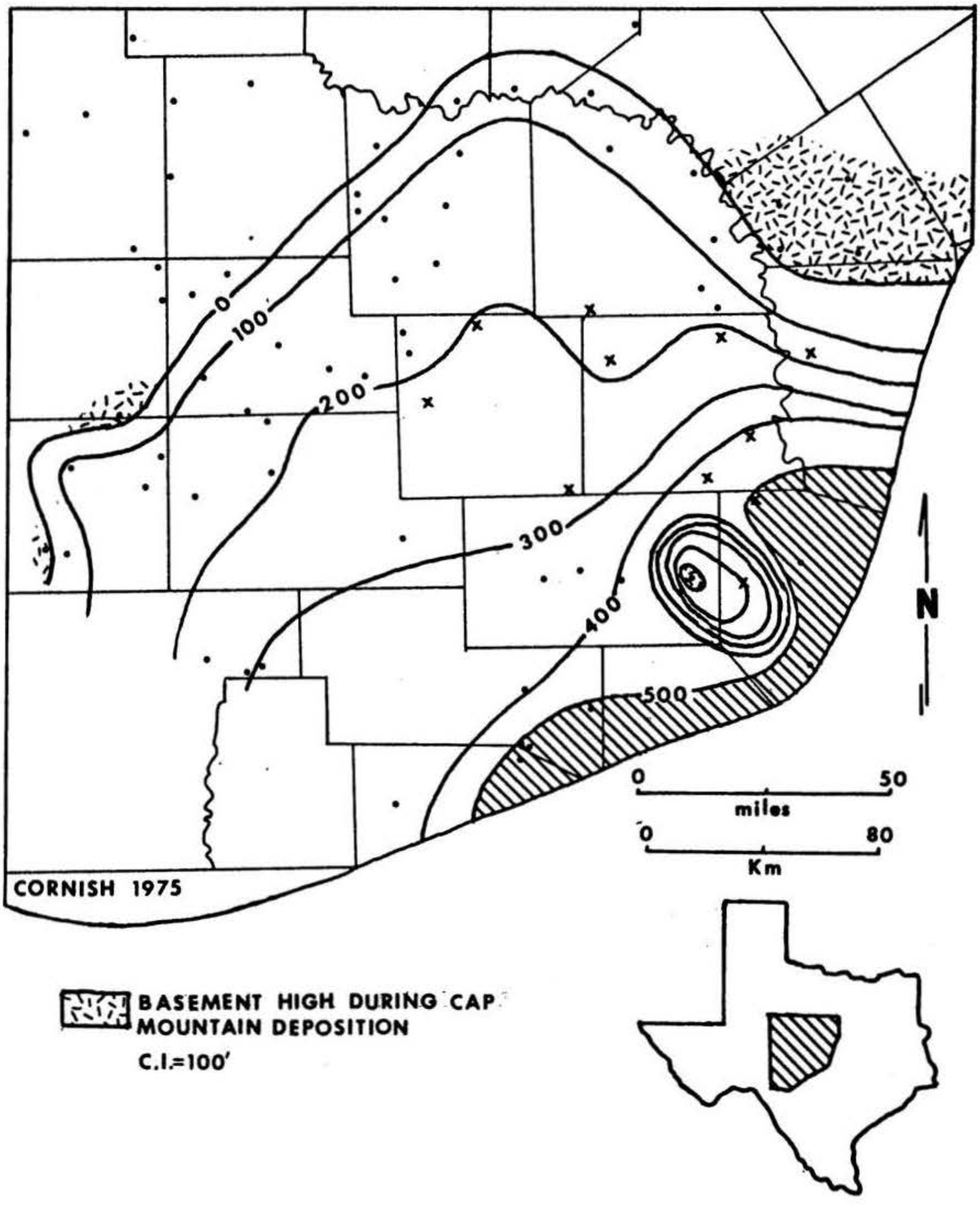


Figure 8. Isopach map of Cap Mountain Limestone

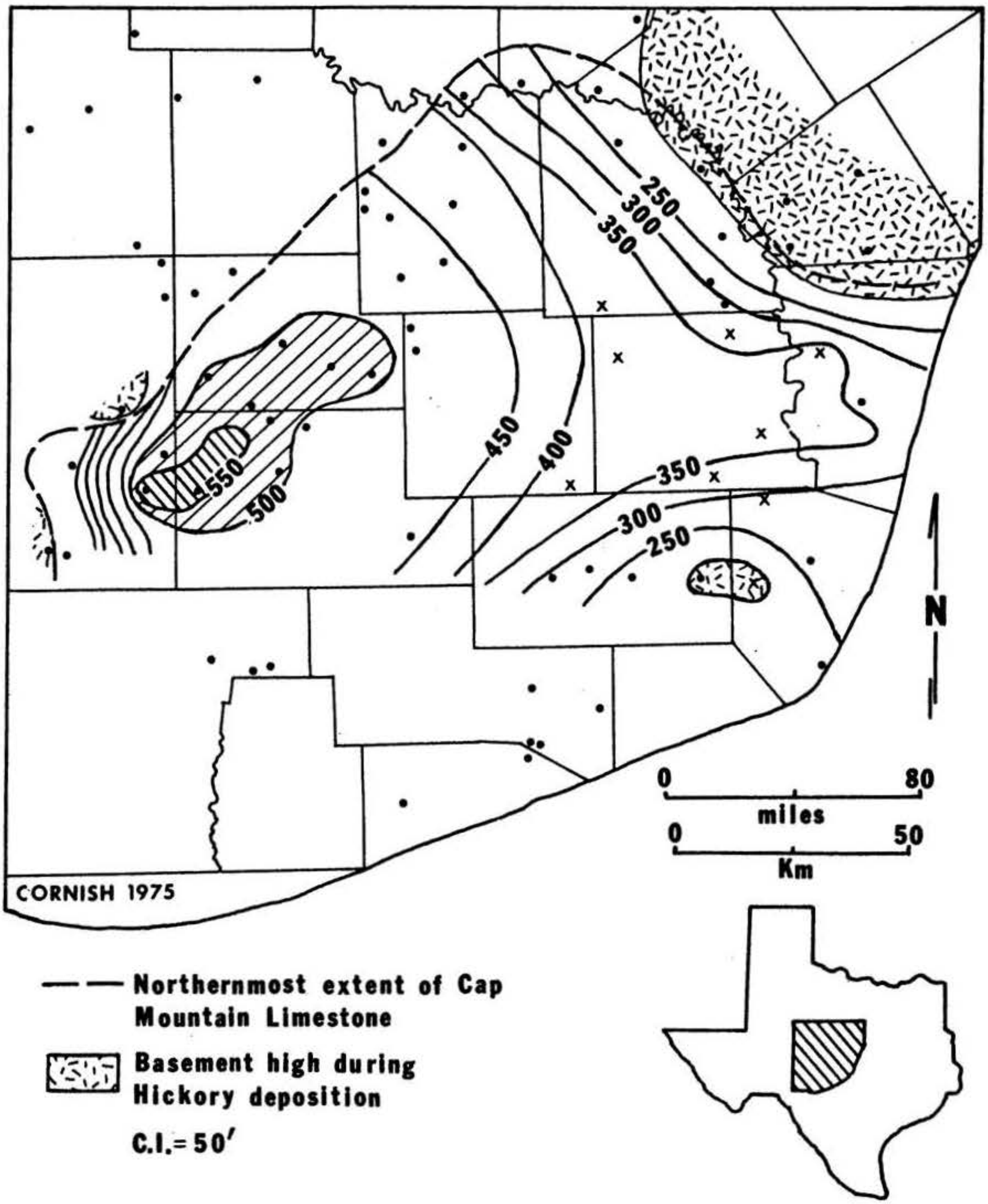


Figure 9. Isopach map of the Hickory Sandstone

LITHOFACIES

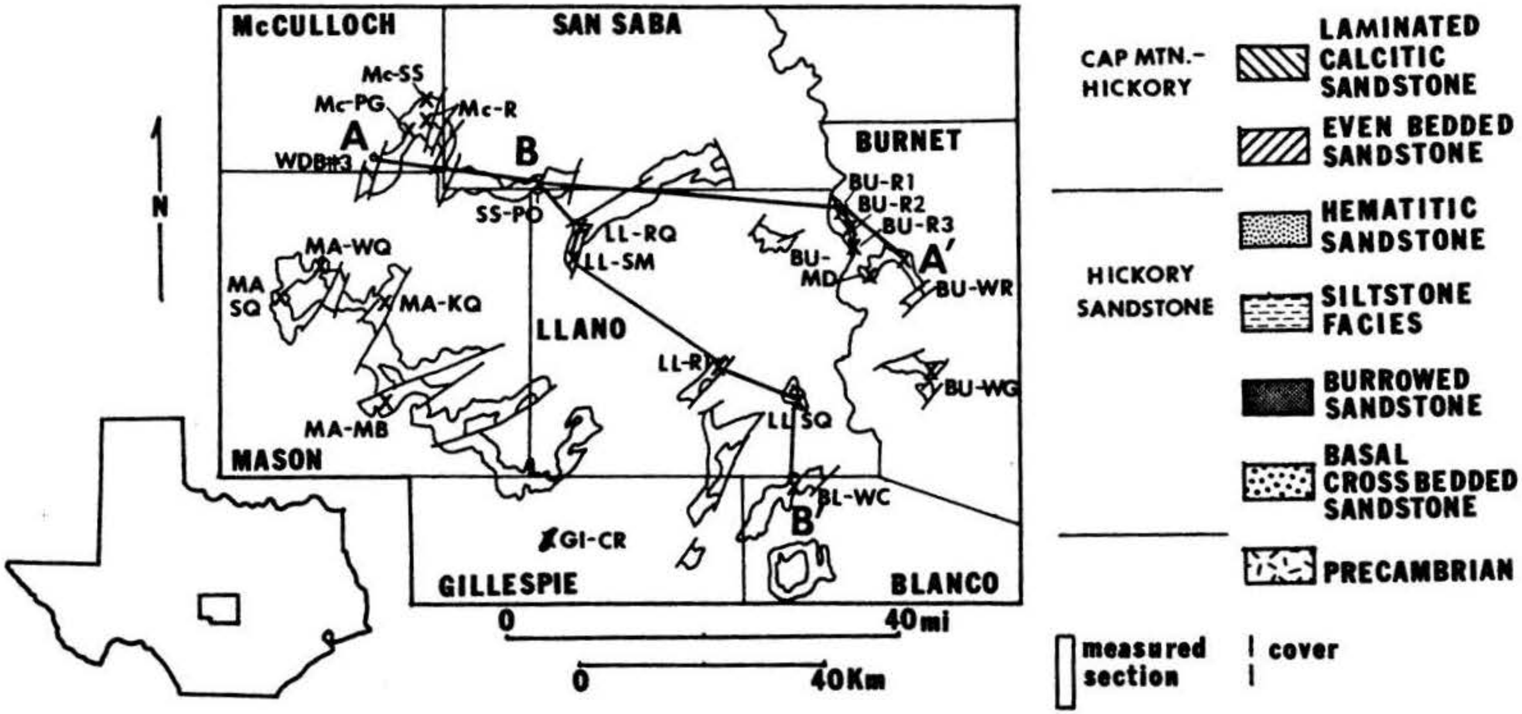
Six lithofacies representing different genetic units have been identified from exposures of the Hickory. These lithofacies are defined on the basis of: bedding characteristics; grain size; mineral composition; prominent primary sedimentary structures, their vertical and lateral sequences; and lebenspurren and fossil assemblages. These facies, named for their dominant characteristics, are: the basal crossbedded sandstone; burrowed sandstone; siltstone facies; hematitic sandstone; the even bedded sandstone; and the laminated calcitic sandstone. The last two facies are characteristic of both the lower Cap Mountain Limestone and the upper Hickory. Bridge et al. (1947) chose criteria to define the boundary between these members as an aid to geologic mapping on aerial photographs. Subsequent work has shown that this boundary crosses lithofacies boundaries and represents a diagenetic feature related to cementation rather than to lithofacies distribution. This accounts for the extreme difficulty in consistantly determining the boundary in outcrop. These two facies were the only observed portions of the Cap Mountain and will be discussed individually.

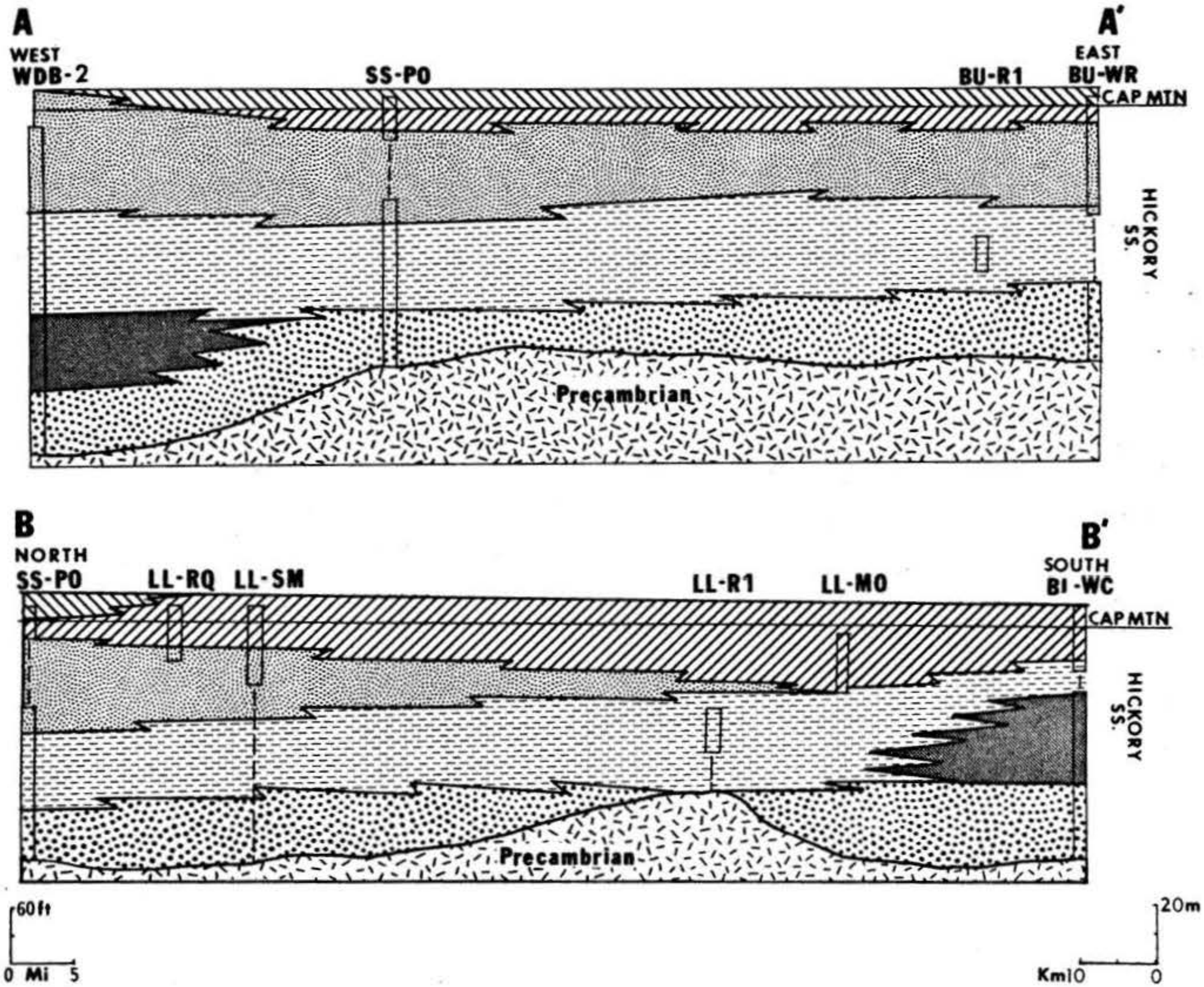
The six lithofacies considered here are a finer division of the units identified by Goolsby (1957) and mapped by Barnes and Schofield (1964). The basal crossbedded sandstone and the burrowed sandstone is equivalent to their lower Hickory. Their middle Hickory is the siltstone facies of this work. The upper Hickory has been divided into the hematitic sandstone, the even bedded sandstone, and the laminated calcitic sandstone. Red color imparted by hematite occurs in all facies and cannot be used to designate a specific facies, as previously thought.

Lithofacies Distribution

The distribution of lithofacies as defined from surface exposure is shown on regional cross sections (fig. 10). The basal crossbedded sandstone lies upon the Precambrian and ranges in thickness from 0-50 m. This facies is present throughout the outcrop area and it appears to have a sheetlike distribution interrupted only by Precambrian highs. In areas of basement highs the lower facies or the entire Hickory is absent locally. The basal crossbedded facies is overlain by either the

Figure 10. Location map of measured sections and regional cross sections of outcrop area showing lithofacies distribution.




A
WEST
WDB-2
SS-PO
BU-R1
A'
EAST
BU-WR
CAP MTN
HICKORY SS.
Precambrian
B
NORTH
SS-PO
LL-RQ
LL-SM
LL-R1
LL-MO
B'
SOUTH
BI-WC
CAP MTN
HICKORY SS.
Precambrian
60 ft
0 Mi 5
20m
Km 10 0

burrowed sandstone or more commonly, the siltstone facies. The contact between the basal crossbedded sandstone and the burrowed sandstone is transitional. The burrowed sandstone ranges in thickness from 25-35 m and grades vertically and laterally into the siltstone facies. The siltstone facies is the most poorly exposed Hickory facies because, being chiefly fine grained material, it weathers easily. In the southern outcrop area the even bedded sandstone lies gradationally above it, and to the north the hematitic sandstone overlies it with a sharp, erosional base. The hematitic sandstone is easily recognized in the field by its dark reddish brown (10R3/4) hematitic stain and thick sequences of hematitic sandstone. One of its noteworthy featured is the presence of hematite-goethite oolites. Laterally and vertically it interfingers with the even bedded sandstone. The hematitic sandstone is well developed in the northern part of the outcrop area where it reaches its maximum thickness of 35 m. It grades southward into the even bedded sandstone in which there are more abundant shales and siltstones. The even bedded sandstone is also present as a thin gradational zone overlying the hematitic sandstone where it is more calcitic (fig. 18). The laminated calcitic sandstone lies gradationally above the even bedded facies. In Mason County where it is mapped as Hickory Sandstone it is well exposed. In Llano and Burnet Counties it is mapped within the Cap Mountain Limestone.

A description of each of the six lithofacies will be presented following the format outlined below:

I. Lithofacies Name

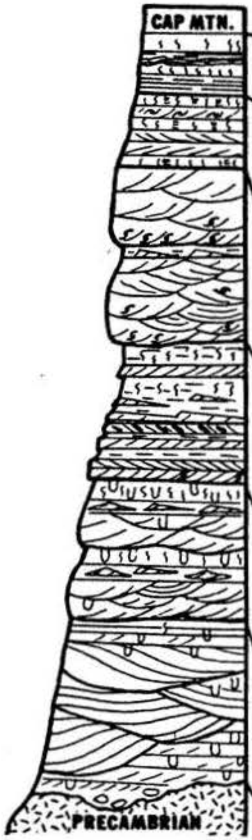
A. Lithologic features

1. Grain size and trends
2. Mineralogic composition
3. Fossils and lebenspurren

B. Sequences present

1. Vertical and lateral sequences and paleo-current data
2. Detail of units making up the sequence

Terms used in this study are discussed in Appendix I. Figure 11 and Appendix IV summarize the dominant characteristics for each of the six lithofacies. Appendix III shows the distribution of the trace fossils and describes them in detail.



FACIES NAME	COMPOSITION AND TEXTURE	CONTACTS, ASSOCIATED FACIES, THICKNESS	COMMON SEDIMENTARY STRUCTURES: SEQUENCES	FOSSILS AND LEBENSPURREN
LAMINATED CALCITIC SANDSTONE	Sandstone, calcitic, fine; carbonate lenses	Gradational with underlying even bedded sandstone	Alternations between burrow mottling and laminations	Lingulid brachiopod and trilobite fragments; Cruziana
EVEN BEDDED SANDSTONE	Sandstone, calcitic, fine-coarse, siltstone and shale common, siltstone clasts	Lateral transition into hematitic sandstone; overlies hematitic facies as thin layer; 35 m thick	Alternations between burrow mottling, laminations and crossbedding	Lingulid brachiopod and trilobite fragments; escape structures, Planolites, Diplichnites, Phycodes, others
HEMATITIC SANDSTONE	Sandstone, hematitic, poorly sorted; hematite oolites, siltstone clasts	Sharp, erosional contact with underlying siltstone facies; lateral transition into even bedded sandstone 35 m thick	Upward fining sequences; festoons, wavy-lenticular beds	Lingulid brachiopod fragments; lined branched tubes
SILTSTONE FACIES	Sandstone with abundant siltstone and shale; disc shaped siltstone clasts	Sharp, erosional contact with hematitic facies; transitional with crossbedded and burrowed sandstone; 35 m thick	Upward fining sequences; wavy-lenticular bedding, burrow mottling	Lingulid brachiopod fragments; Planolites
BURROWED SANDSTONE	Sandstone, fine-coarse, poorly sorted, minor siltstone and shale	Transitional contact with basal crossbedded sandstone; lateral and vertical transition with siltstone facies; up to 35 m thick	Slight upward fining, festoons, ripples, burrow mottling	No body fossils found; Corophioides; Climactichnites
BASAL CROSSBEDDED SANDSTONE	Sandstone, fine-coarse; minor siltstone and shale; ventifacts in basal conglomerates	Lies unconformably on Precambrian; transition contact with siltstone facies and burrowed sandstone; 0-50 m thick	Large scale foresets, planar-festoon crossbeds filling large channel scours	No body fossils found; Cruziana, Rusophycus, Corophioides, Diplocraterion

Figure 11. Schematic section and dominant characteristics of the Hickory lithofacies

Basal Crossbedded Sandstone Facies

Lithologic features

Dominant characteristics of this unit are listed in Figure 11 and Appendix LV. Pale red (5R6/2) to grayish orange pink (5YR7/2), coarse to fine, poorly sorted sandstone makes up most of the facies. Composition of the sandstone ranges from arkose to quartz arenite. Siltstone composition is quartz arenite, arkose, or subphyllarenite. Siltstone and shale are only of minor importance. Rock fragments of the conglomeratic sandstones are concentrated in the lowest 5 m of the facies and form thin beds. However, because of the proximity to nearby Precambrian highs, conglomeratic sandstones are present at all levels and within all facies. These conglomerates contain pebbles and rock fragments that are the same composition as the local Precambrian rocks - granite, gneiss, or schist. Gravel may be concentrated in thin lenses or isolated along laminae of bedding planes. Among the more interesting of these are the faceted ventifacts of vein quartz (plate I-G). These occur locally in the basal 3 m and are up to 15 cm in diameter. Typically they have three or more sides and a distinct base.

Plate I

A. Ichnogenus Cruziana; bilobate trilobite crawling trace; hypichnial ridge; basal crossbedded sandstone, Pennsylvania Glass Sand quarry, Voca, McCulloch County

B. Ichnogenus Cruziana and Rusophycus and scratchmarks; bilobate trilobite crawling and resting trace; hypichnial ridge; basal crossbedded sandstone, section BU-WR, Burnet County

C. Ichnogenus Crossochorda; bilobate crawling trace; hypichnial ridge; basal crossbedded sandstone, Pennsylvania Glass Sand quarry, Voca, McCulloch County

D. Ichnogenus Diplocraterion; dwelling structure; endichnial tube, showing retrusive spreite between arms of U-tubes, in parallel bedded unit of basal crossbedded sandstone, section BU-R3, Burnet County, scale= 5 cm/bar

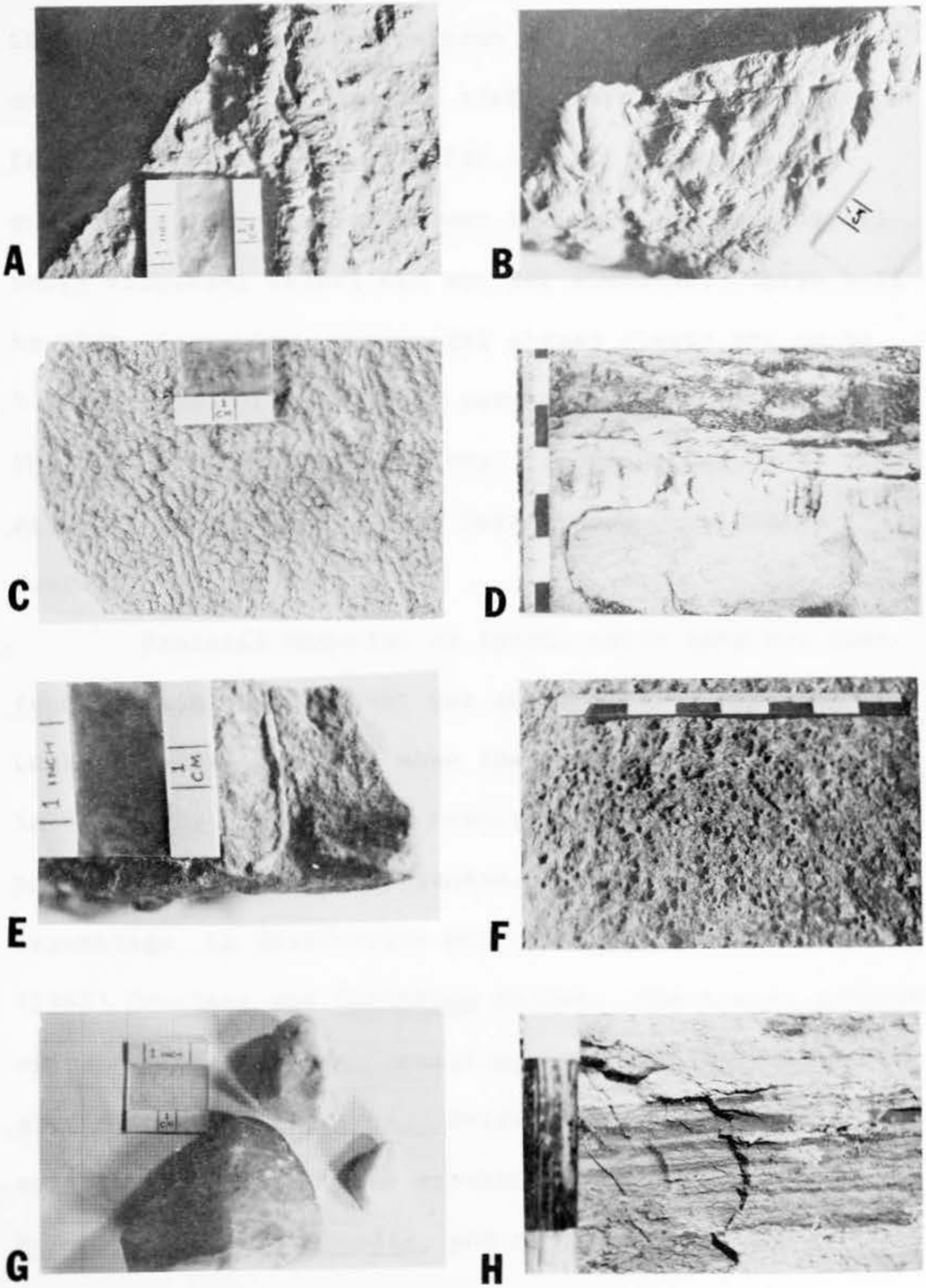
E. Ichnogenus Corophioides; dwelling structure; endichnial tube; basal crossbedded sandstone, section BU-R3, Burnet County

F. Ichnogenus Corophioides; paired epichnial depressions; from basal crossbedded sandstone, section BL-WC, Blanco County, scale= 5 cm/bar

G. Ventifacts of vein quartz with 3-4 sides and distinct base, basal crossbedded sandstone, Dorbandt Ranch, Burnet County

H. Hematite stained, thin sandy siltstone unit displaying parallel laminations and small scale current ripple cross lamination, basal crossbedded sandstone, section Mc-PG, scale= 10 cm/black bar

PLATE I



Ventifacts have been used as evidence to indicate that the Hickory sands may have been subjected to an eolian environment in some part of their history (Barnes and Parkinson, 1940; Wilson, 1962). Small siltstone and mudstone clasts are found near the bases of the channel units discussed below, but are not abundant. These buff to pink, irregular, spheroidal shaped clasts are up to 4 cm in size. Porosity and permeability of this unit is the best of the entire Hickory. Porosity may be as great as 36.8% (unpublished data, Texas Water Development Board).

Skeletal material or fossil molds have not been found within this facies, but trace fossils are common. Lack of faunal remains, when their presence cannot be in doubt, is probably the result of leaching of shell material from the porous sandstone. The trace fossil assemblage is distinctive and corresponds to Seilacher's (1967) Cruziana and Skolithos facies. The traces preserved represent the resting, crawling, and dwelling activities of the unpreserved fauna. Evidence of abundant trilobite activity is found in the epichnial casts of Cruziana, Rusophycus, Crossochordia, and numerous trilobite scratchmarks (plate I-A-C, Appendix III for descriptions). Two types of U-shaped burrows are present - Diplocraterion (plate I-D) and Corophioides (plate I-E) and they become progressively more common upwards. The protrusive and retrusive spreite of Diplocraterion (plate I-D) illustrate its vertical movement in response to erosion or sedimentation by active currents (Goldring, 1964). Bedding plane surfaces reveal this ichnofossil as short, randomly oriented depressions. Corophioides burrows are revealed along horizontal bedding planes as paired holes (plate I-F). Their U-tubes are 0.4 cm in diameter and 70 cm in depth. Isolated elongate (15 cm) vertical burrows (possibly Skolithos) and their cross sections (3 cm in diameter) are present. Other trace fossils are small (0.3-0.8 cm in diameter) sand-filled horizontal burrows (exichnia) locally abundant in the siltstone and shale units.

Sequences present

The basal crossbedded sandstone consists of channel and nonchannel units. All paleocurrent data of this facies shows a prominent southeast oriented mode with a vectoral mean of 128° and a vector magnitude of 56.2% for 111 readings (fig. 12). The channels are large asymmetric scours with maximum dimensions of 2.5 m deep

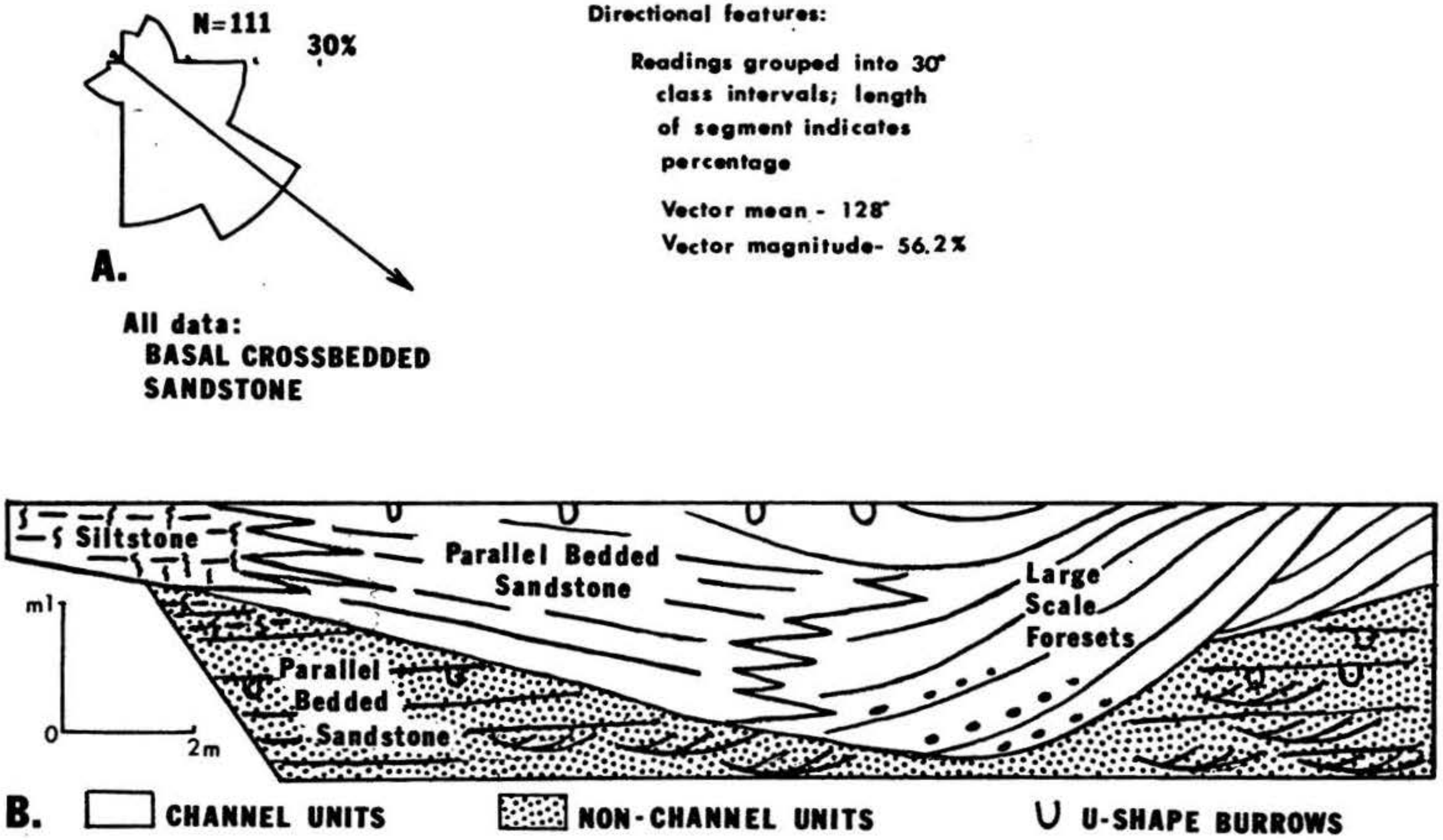


Figure 12. A. Paleocurrent rose diagram showing depositional trend of the basal crossbedded sandstone. B. Idealized channel-nonchannel relationships in the basal crossbedded sandstone.

and 50 m wide. They have a concave-upwards sharp erosional base crosscutting other channel or nonchannel units (fig. 12 and 13). Distinctive vertical sequences within the channels were not noted; instead a lateral gradation in character was found. Lateral migration of some channel sequences is shown by the several stages of infilling and scouring (fig. 13). Large-scale avalanche foresets (up to 2 m thick) occupy the steepest sides of the scours and their maximum thickness usually equals the channel depth (plate II-A). These are the coarsest units of the sequence and they grade laterally into either of the two other units that complete the whole lateral sequence (fig. 12). The tops of some foreset beds are bioturbated and contain U-shaped burrows.

The parallel to nonparallel bedded sandstone units (up to 2.5 m thick) are horizontal to slightly inclined, thick to very thick bedded (50 cm) units. These units infill the shallower more distal portions of the channel. Some beds thin laterally and are interbedded with thin laminated siltstone. Sedimentary structures are dominantly small-medium scale (up to 20 cm) festoon or planar crossbedding with parallel laminations present

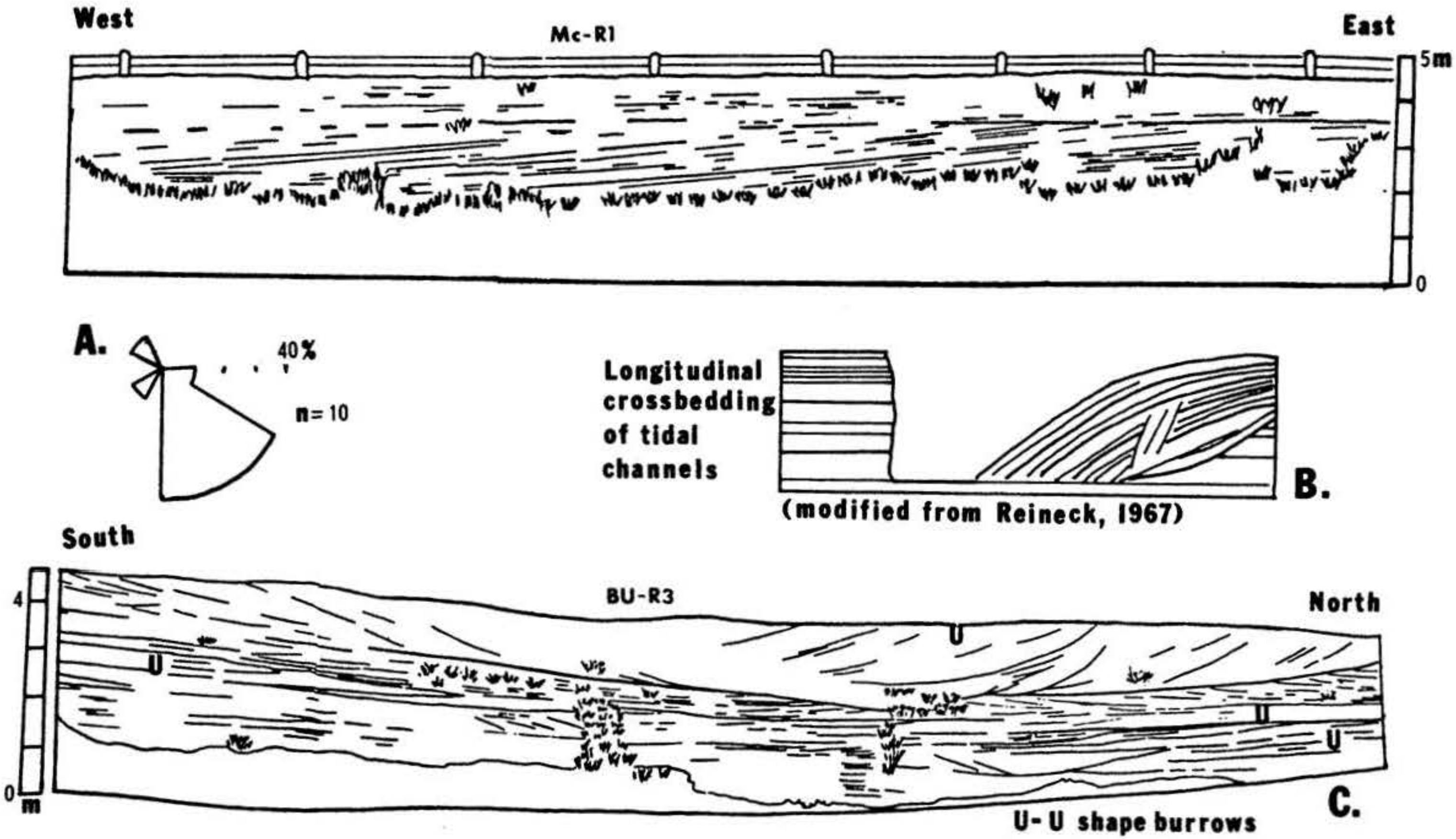


Figure 13. Vertical change in channel character A. Near transition with siltstone facies, note inclined nature of interbedded siltstone-sandstone; paleocurrent rose, note bimodality B. Tidal channel crossbeds (Reineck, 1967), note similarity to A C. channel scour near base of Hickory.

but infrequent. Primary structures may be disrupted by numerous U-shaped burrows (plate I-D). Some parallel bedded sandstone units grade laterally into siltstone units.

The siltstone units are thin to thick (up to 80 cm) inclined or horizontal beds of tan to red-brown fine sandstone, sandy siltstone, and sandy mudstone (plate I-H). Abundant biotite flakes and hematite stain are characteristic. These units may show parallel laminations and current or oscillation ripple cross stratification. Small sand filled burrows may disrupt primary structures. The sand filled trilobite epichnia mentioned previously are found on bases of sandstone beds overlying this unit.

In addition to these individual channel features, there is an apparent upward increase in the frequency of the siltstone units. The channels change in character, containing progressively more siltstone upward (fig. 13). The inclined distal channel-fill siltstone - sandstone alternations which are found in the transition with the siltstone facies is very similar in appearance to the longitudinal crossbedding developed by lateral channel shifting on intertidal flats of the Wadden Sea, Netherlands (Straaten, 1954) and the Jade Bay, Germany (Reineck, 1967; fig. 2A). This upward increase in finer material is accompanied by paleocurrent data showing a tendency towards bimodality (fig. 13A) but with a prominent southeast mode.

Nonchannel units are truncated vertically and laterally by numerous channels. Nonchannel units consist of parallel bedded sandstone and siltstone similar to those described in the channel units (fig. 13B). Siltstone units are subordinate in importance. Dominant sedimentary structures include small to medium-scale festoons and foresets. Some parallel laminations are found. No distinct vertical sequences of structure, or textures were noted. The major differences between these units and channel units is the absence of large-scale foresets and distinct scoured bases. Non-channel units resemble portions of the distal channel and may simply be truncated channel units.

Burrowed Sandstone Facies

Lithologic features

The dominant characteristics of this unit are listed in Figure 11 and Appendix IV. Lithically, it is similar to the basal crossbedded sandstone. Grain size ranges from pebbly sandstone to poorly sorted fine to coarse sandstone. Siltstone and shale are present but not prominent. Sandstone composition ranges from quartz arenite to subarkose. Locally, it may be cemented with calcite or hematite.

Preserved skeletal material or recognizable molds were not found in this facies, but evidence of bioturbation and distinctive trace fossils occur. Most prominent are the types of the U-shaped burrow (domichnia) *Corophioides* (plate II B and E). These may be either isolated or so abundant in one unit that they cause a burrow mottled appearance. Sawed samples from these burrow mottled sandstones reveal vertical structures and cross sections of portions of U-shaped burrows attributed to *Corophioides*. A variety of this trace shows a flaring of the upper portions of the U-tube (plate II-E). Wide (5-8 cm) discontinuous trails, probably portions of *Climachtichnites*, are also present (plate II-D). The trace fossil assemblage of the burrowed sandstone is comparable to the *Corophioides-Diplocraterion* association of Ager and Wallace (1970). They found their association to be equivalent to Seilacher's (1967) *Skolithos* bathymetric facies.

Plate II

A. Large scale foresets (scale: 1 bar=10 cm) of basal crossbedded sandstone, base of section BU-WR, Burnet County

B. Upper burrowed, muddy unit sandstone of burrowed sandstone facies revealing U-tubes of Corophioides, section BL-WC, Blanco County, scale: bar=5 cm

C. Mudcracks from middle rippled unit of burrowed sandstone facies, section GI-CR, Gillespie County, scale: bar=10 cm

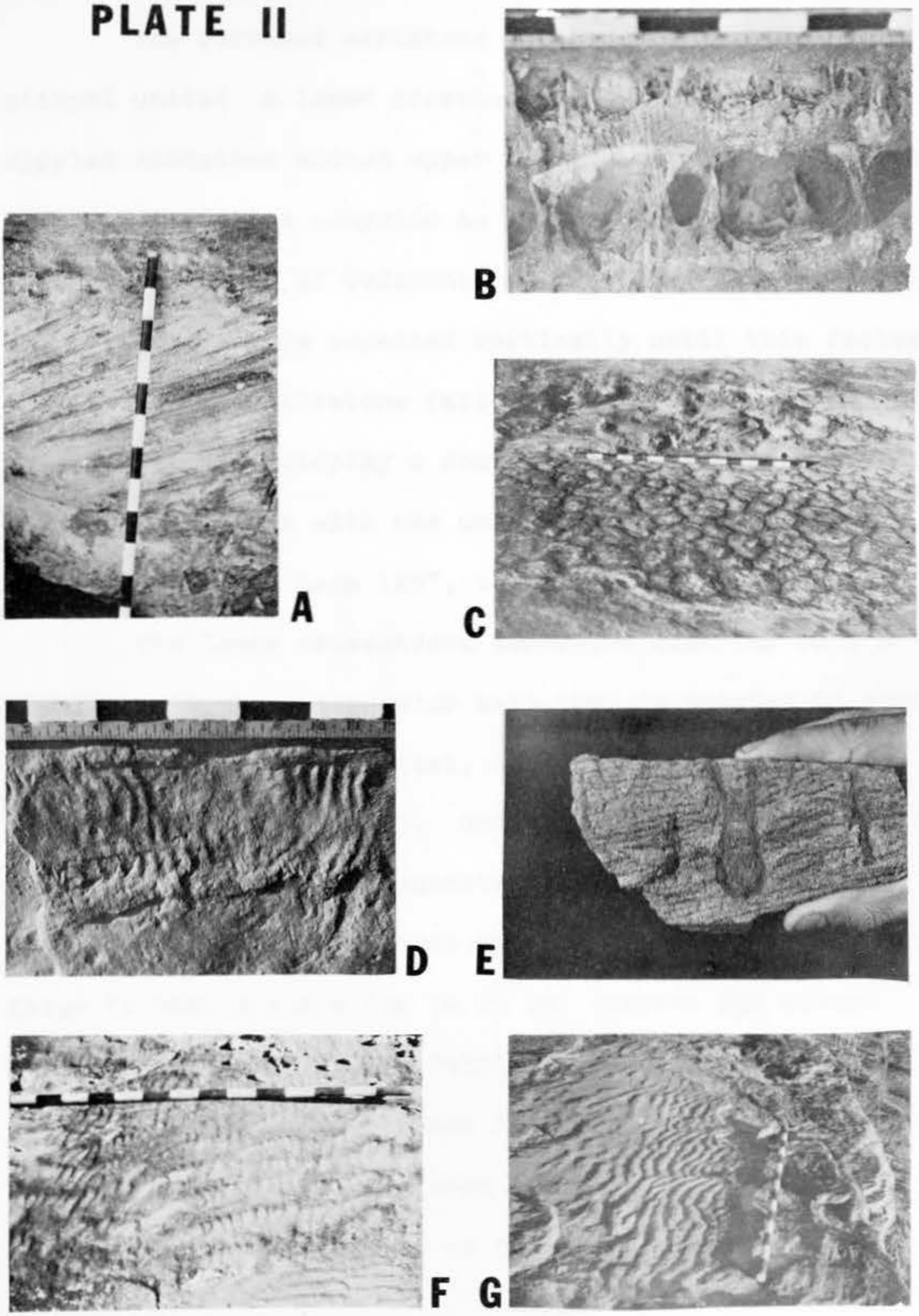
D. Portion of epichnial trail, Climactichnites, from middle rippled unit of burrowed sandstone facies, section GI-CR, Gillespie County, scale: bar=5 cm

E. Ichnogenus Corophioides; displaying flaring of one branch of U-tube, lower crossbedded unit of burrowed sandstone facies, section GI-CR, Gillespie County, scale: thumbnail approximately 1.5 cm

F. "Ladder back" or interference ripples from middle rippled unit of burrowed sandstone facies, section GI-CR, Gillespie County, scale: bar=lo cm

G. Straight - slightly sinuous bifurcating current ripples from middle rippled unit of burrowed sandstone facies, section GI-CR, Gillespie County, scale: bar=10 cm

PLATE II



Sequences present

The burrowed sandstone consists of three gradational units: a lower crossbedded sandstone, a middle rippled sandstone and an upper muddy sandstone or burrowed unit. These units comprise an upward-fining sequence in texture and scale of sedimentary structures (fig. 14). These sequences are repeated vertically until this facies grades into the siltstone facies. Paleocurrents from this facies (fig. 14) display a dominant mode to the southeast and are consistent with the underlying lower crossbedded sandstone (vector mean 125°, vector, 98%).

The lower crossbedded sandstone unit (up to 3 m thick) has a sharp irregular base that is scoured in some places. Bedding is parallel, laterally continuous, and very thick (0.5 to 2.0 m). Grain size is dominantly fine to coarse poorly sorted sandstone. Minor thin beds (up to 10 cm) of sandy siltstone are present, but not common. Large to medium scale (up to 25 cm) festoon and planar crossbeds are prominent. Parallel laminations or ripple cross laminations are present in the associated siltstones. Bedforms are preserved on some bedding planes and allow further characteristics to be noted. For example, scour

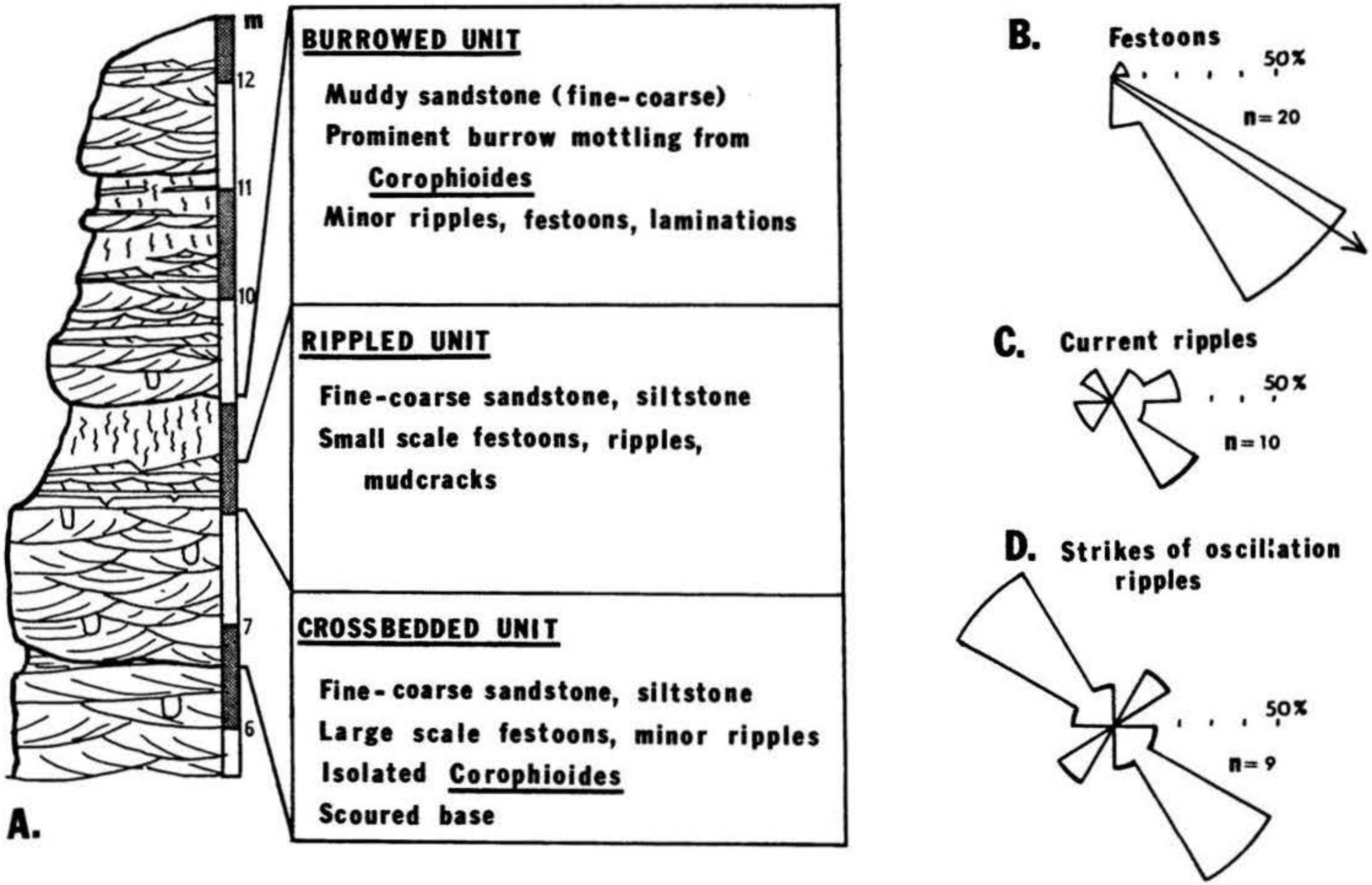


Figure 14. Portion of measured section, GI-CR, burrowed sandstone A. Vertical section showing three gradational units B. Paleocurrents of festoons showing prominent southeast orientation C. Paleocurrents of current ripples showing polymodal distribution D. Strikes of oscillation ripple crests showing orientation at 90° to festoons

holes (10 cm deep) are preserved down current from sinuous sandwaves and in association with festoon crossbedding. Current-ripple bedforms within these scours are oriented at 90° to the festoon orientation and are found along the sloping edges, as well as the horizontal middle of the scour. Large symmetrical round top ripples are also found.

The middle rippled unit (up to 90 cm) lies gradationally above the lower crossbedded sandstone unit. The parallel to wavy bedding is very thickly bedded (40-80 cm). Grain size is dominantly fine-coarse poorly sorted sandstone. Sandy siltstone and siltstone drapes (flasers) are present. Sedimentary structures are small-scale festoons, planar crossbeds and ripple cross lamination. Several types of ripple bedforms were observed. Current-ripple forms vary from straight crested (plate II-G) to sinuous to linguiid forms. Orientations of current ripples are trimodal (fig. 14C). Some oscillation ripples were superimposed on the crests and troughs of current ripples and form interference or "ladder back ripples" (plate II-F). Strikes of oscillation ripples were oriented both with the prominent festoon crossbedding directions and at 90° to it (fig. 14D). Desiccation features are preserved as polygonal sandstone ridges representing infilling between mudcracks (plate II-C). The trace fossil Climactichnites (plate II-D) occurs in this unit.

The upper muddy unit lies gradationally above the previous unit. The lower crossbedded sandstone of the next sequence sharply overlies it. Bedding varies from massive thick beds to thinner laminated beds. Sandy siltstone, muddy poorly sorted sandstone or fine sandstone make up the unit. Primary structures are rare, but parallel laminations and small-scale festoons are present. The unit contains recognizable trace fossils, especially Corophioides but is usually intensely bioturbated (plate II-B) and has a massive or mottled appearance.

Siltstone Facies

Lithologic features

Dominant characteristics of the siltstone facies are summarized in Figure 11 and Appendix IV. Color ranges considerably. Finer sediments may be yellowish gray

(5Y7/2) or grayish red (5R4/2). Sandstone ranges from grayish orange (10YR7/2) to grayish red (5R4/2). Grain size ranges from pebbly coarse sandstone to sandy siltstone and shale. Disc-shaped hematite or phosphate-cemented fine sandstone or siltstone clasts are locally abundant in trough or planar crossbedded sandstone beds (plate III-B). These may be up to 5 cm in diameter. Most are flat discs, but some are curved and bent showing some flexibility during transport and/or deposition. Sandstone composition ranges from quartz arenite to subphyllarenite. Siltstone and shale contain abundant biotite. Glauconite is present in some places, but nowhere exceeds 2-3%. Some units may contain hematite or calcite cement.

The fossils of this unit consists of grayish yellow (5Y8/4) to bluish white (5B9/1) phosphatic lingulid brachiopod fragments. These are found broken and disarticulated within crossbedded sandstone beds. Few distinct trace fossils occur. Sand-filled horizontal burrows (exichnia) of Planolites within siltstone or shale beds are the most abundant. Small (0.3-0.8 cm) unornamented epichnial trails may be found upon rippled

Plate III

A. Scratchmarks of trilobites?; hypichnial ridges from thin sandstone of wavy-lenticular bedded unit of the siltstone facies, sedtion LL-Rl, Llano County

B. Irregular - elongate siltstone - fine sandstone clasts within crossbedded unit of siltstone facies, section LL-SM, Llano County

C. Unornamented trails; epichnial grooves and ridges upon current rippled sandstone from wavy-lenticular unit of siltstone facies, sedtion BU-Rl, Burnet County

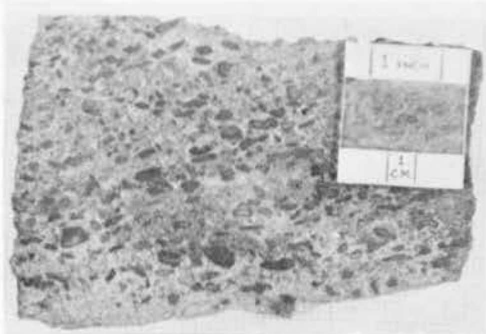
D. Wavy-lenticular bedded unit of siltstone facies, section LL-Rl, Llano County, scale: bar=5 cm

E. Ichnogenus Pelecypodichnus?; football shaped depressions; epichnial grooves; from thin sandstone of wavy-lenticular bedded unit of the siltstone facies, section LL-Rl, Llano County

F. "Herringbone crossbedding" in sandstone of cross-bedded unit; section LL-Rl, Llano County, scale: bar=10 cm

PLATE III

A



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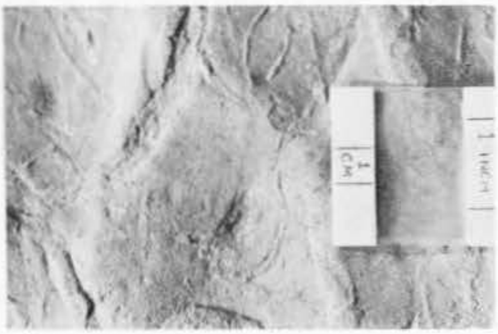

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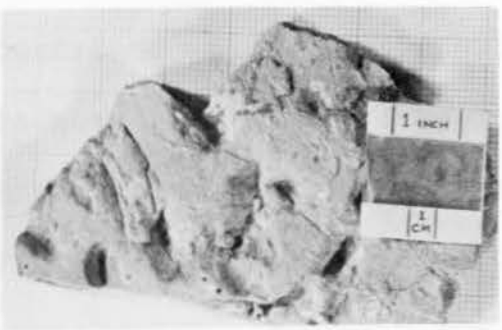
D



E

F

surfaces (plate III-C). Isolated football shaped depressions (0.5-1.0 cm in diameter, 1.4-2.0 cm in length) may be the resting trace, Pelecypodichnus (plate III-E). Other epichnial traces resemble trilobite scratchmarks (plate III-A).

Sequences present

The siltstone facies consists of sequences of three units that are rhythmically interstratified. These are a crossbedded sandstone, lenticular-wavy bedded unit, and a siltstone unit (fig. 15). The relative thickness and abundance of each of these units causes a wide variation in the type of sequence found. Figure 15 shows two such sequences displaying a variation in the relative amounts of each unit from predominantly sandstone to predominantly sandy siltstone and shale. The predominantly siltstone sequences are thinner (3.2-4.5 m) while the sandstone sequences are much thicker (10-30 m) and may be sharply terminated by the hematitic sandstone facies. These units may display small cycles (1-2 m) of upward fining or coarsening depending upon their vertical arrangement. However, the overall vertical arrangement of any one sequence is an upward fining one, by loss of

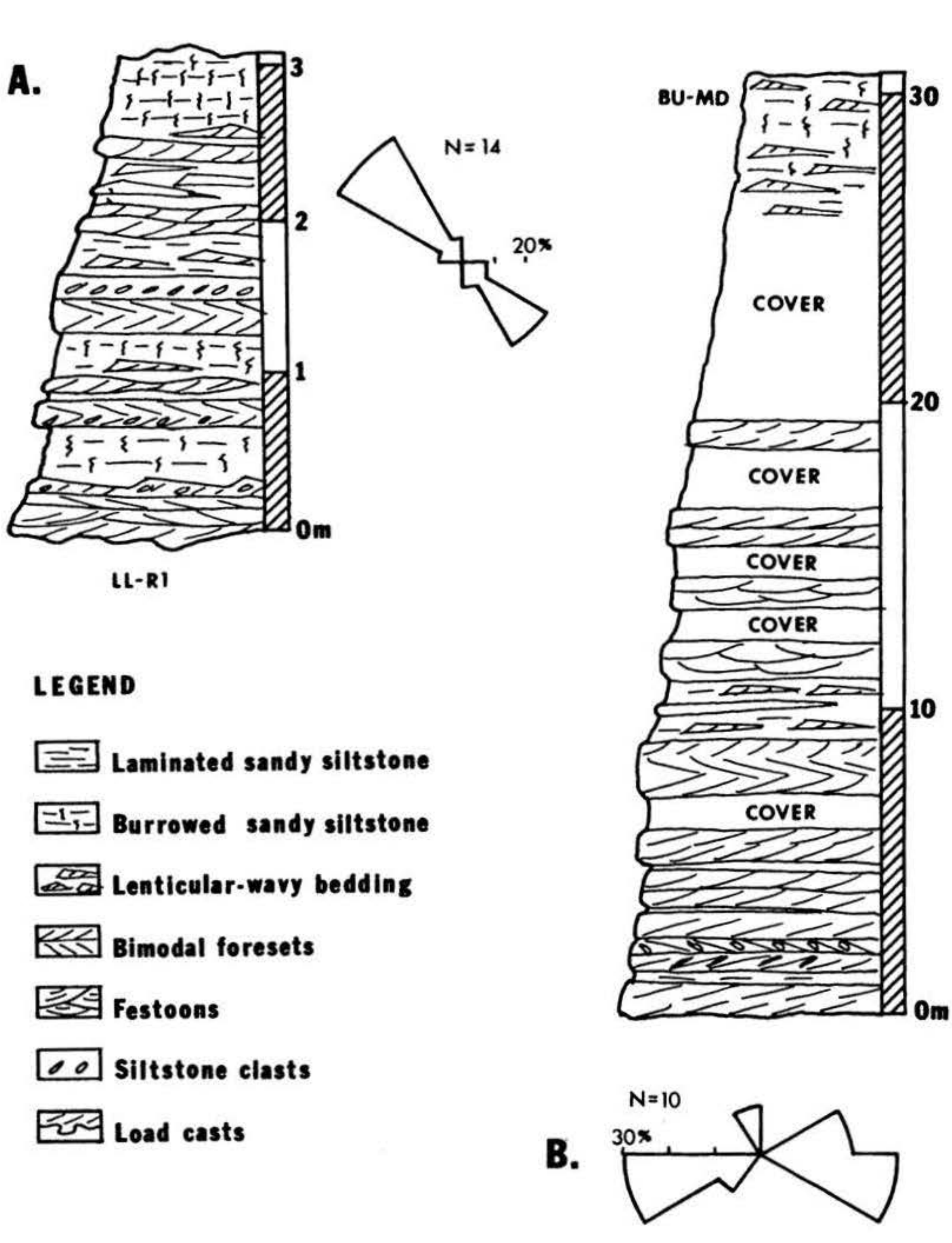


Figure 15. Sequences of the siltstone facies, both with paleocurrent roses showing vectorial bimodality of crossbeds
A. Thinner, predominately siltstone upward-fining sequence
B. Thicker, predominately sandstone sequence

the crossbedded sandstone and an increase in the abundance and thickness of the siltstone unit. Bioturbation is most prominent in the siltstone unit, so that within a single sequence the degree of bioturbation increases upwards. Several of these upward-fining sequences may be repeated vertically in an exposure. Paleocurrents display a bimodally opposed pattern (fig. 15).

The sequences begin with a basally scoured crossbedded sandstone unit, with abundant siltstone clasts, and broken shell fragments of brachiopods. Load casts may be present along the base if it overlies fine grained sediments. Structures include small-to large-scale festoon, tabular, and "herringbone" crossbedding (plate III-F). Burrowed sandstones are present but rare. Thickness varies from 10 cm to 2 m, with thicker units occurring in the predominantly sandstone sequences. This unit may be gradational with the wavy-lenticular bedded unit or be in sharp contact with the siltstone unit.

Sandstones of the lenticular-wavy bedded unit (up to 1 m in thickness) are laterally discontinuous over several meters (plate III-F). Isolated current or oscillation ripples within shale-siltstone cause lenticular bedding. Flaser bedding is prominent. Ladder-back ripples may be present. Siltstone clasts are present along troughs of ripples in places. Thickness of the sandstones decreases upwards and relative amounts of siltstone and shale increase vertically in an upward-fining cycle causing it to grade into the siltstone unit.

The siltstone unit lies gradationally above the previous unit and is usually in abrupt contact with the crossbedded sandstone of the next overlying cycle. It consists of fine sandstone, sandy siltstone or sandy shale. Thin parallel laminae are prominent, when not destroyed by bioturbation. Bioturbation manifests itself in isolated sand filled horizontal burrows, Planolites. Small (up to 2 cm) sand lenses are present locally.

Hematitic Sandstone

Lithologic characteristics

The coarse to fine sandstones of this facies are well rounded, poorly sorted, and fossiliferous. Iron oxide oolites, previously described by Barnes and Schofield (1964) locally make up 5% of the sandstone.

Concentric banding of goethite, altered to hematite, form around nuclei of goethite, sand grains, or fossil fragments (Barnes and Schofield, 1964). The oolites are not found spatially separated from the quartz sandstone in distinct beds of mudstone like typical oolitic ironstone (Brookfield, 1971), but rather are intermixed with the sandstone. Iron oxide and poikilotopic calcite form cements. Small (up to 3 cm) irregularly shaped hematitic siltstone clasts are commonly found in crossbedded sandstone units, but do not exceed 5% in abundance.

Fossils consists of fragments of unidentified brachiopods and trilobites within the crossbedded sandstone unit. Phosphatic valves of lingulid brachiopods are the most abundant identifiable fossil. Biogenic structures are not abundant. Within the upper portions of the crossbedded sandstone units, branched limonitic lined tubes (plate IV-A and B) are found. The tubes may be up to 1 cm in diameter. They are usually found along horizontal surfaces but some branches may tend to be oriented obliquely to the bedding. A dendritic trace (plate IV-C) was found near the top of this facies.

Plate IV

A. Limonitic branching lined tubes upon shale drape in crossbedded unit of hematitic sandstone facies; section LL-SM, scale: field book=19 cm on long side

B. Close up of IV-A

C. Dendritic trace on mudstone drape, upper portion of hematitic sandstone; section LL-R2, Llano County

D. Mudcracks on thin mudstone drape from upper portion of hematitic sandstone; unornamented epichnial trails cross mudcracks, section LL-SM, Llano County, horizontal scale: bar=5 cm

E. Lenticular-wavy bedded unit overlying thick burrowed coarse hematitic sandstone, section LL-SM, Llano County, horizontal scale: bar=5 cm

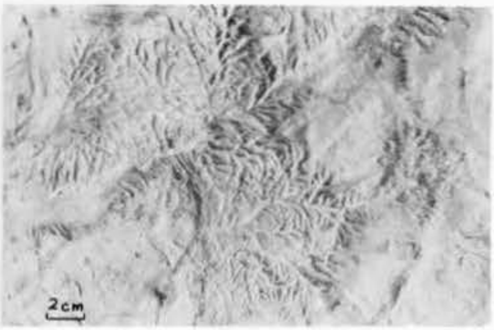
F. Core; Tucker#1 Perkins 3340 feet, burrowed fine sandstone-sandy mudstone of laminated calcitic sandstone facies, Kerr County

PLATE IV

B

A

D



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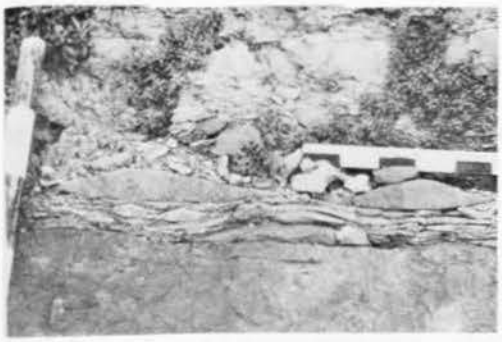
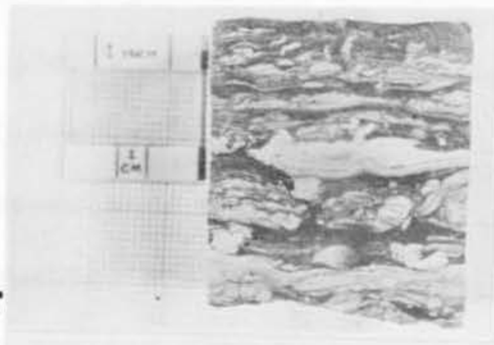


E



F

Traces similar to this (Dendrophycus) have been usually interpreted as rill marks of inorganic origin (Häntzchel, 1962). However, the reconnection of the thinner branches to each other indicates that it is probably an intricate feeding pattern rather than a drainage feature. Numerous horizontal sand filled burrows of Planolites are present within fine grained units.

Sequences present

The hematitic sandstone consists of complete or partial sequences (up to 25 m) of three units: a thick festoon crossbedded sandstone, a wavy-lenticular sandstone unit, and a hematitic siltstone unit. Vertical transitions from one unit to the next may be gradational or abrupt. The units are arranged in two sequences: 1) a vertical intermixing of units showing no particular grain-size trend and 2) thick sandstone terminating in siltstone (fig. 16). Both of these begin with a sharply scoured base overlain by coarse poorly sorted sandstone with siltstone pebbles and shell fragments. Sequences are repeated vertically. The presence of many scour contacts indicates that many sequences may be truncated. Regional paleocurrents show wide scatter with prominent

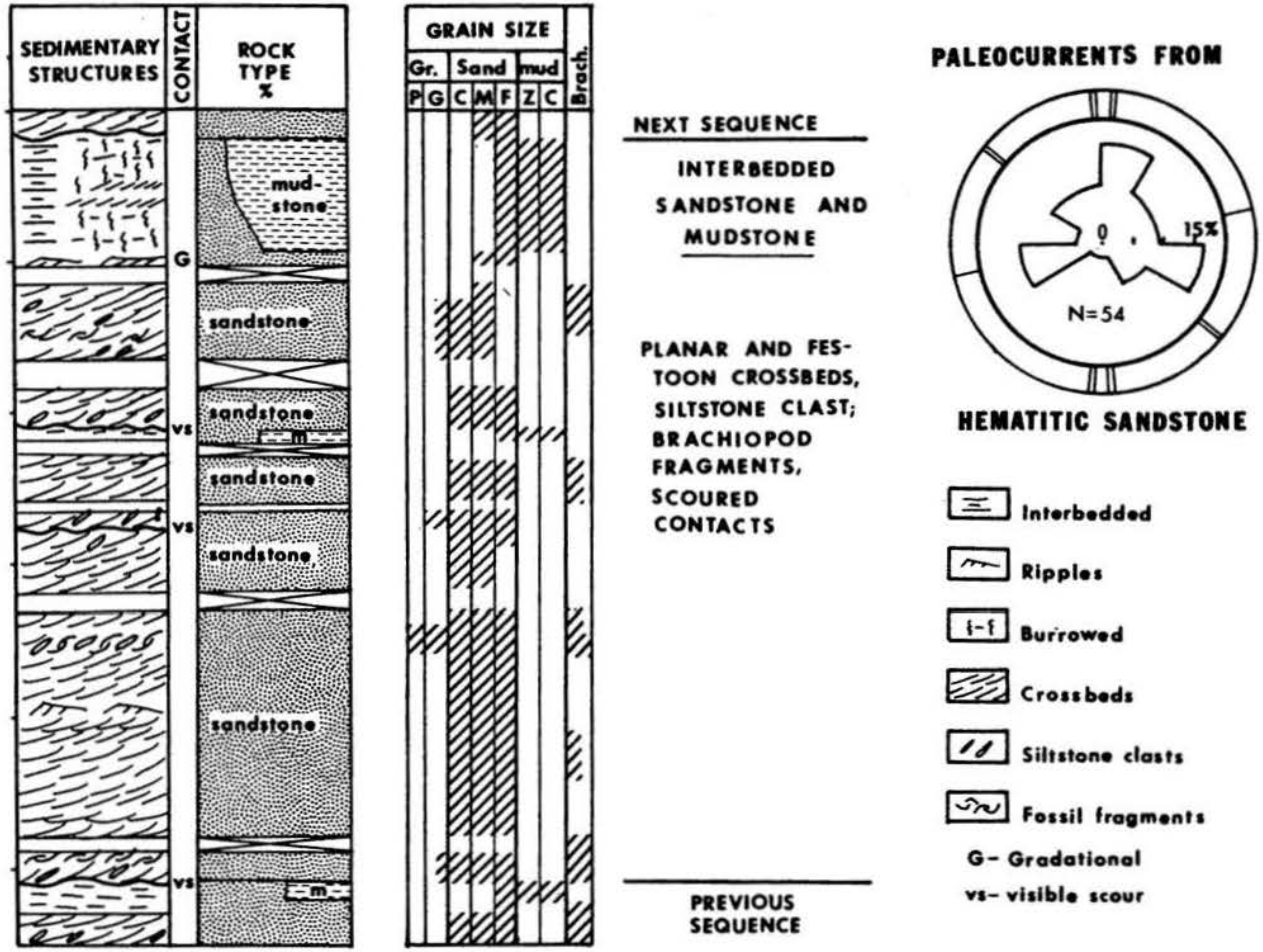


Figure 16. Hematitic sandstone, portion of core, TWDB #3, McCulloch County, showing vertical sequence with repeated scour contacts and paleocurrent diagram of all data surface exposures of this facies

modes to the north and east (fig. 16). Individual outcrops may show vectoral bimodality. This trend is distinctly different from those of the previously discussed facies.

The festoon crossbedded sandstone is the thickest and most abundant unit of these sequences. Bedding of the unit is thick to very thick (.70-1.5 m), laterally persistent, and often indistinct. Small clasts and oolites previously described are found in this unit. Shell fragments are found along the bases of the characteristic (10-30 cm) festoon crossbedding. Thin (1-2 cm) flaser bedding and shale drapes are common features. Some of these are truncated laterally by festoons in some places. Mudcracks are found on these thin drapes in those sequences near the top of the facies (plate IV-D). Reworking of the drapes is most probably responsible for generation of the siltstone clasts. Upper portions of this unit may be completely bioturbated (plate IV-E) or be occupied by isolated branched tubes (plate IV-A and B).

Thin units (up to 40 cm) of lenticular-wavy bedding (plate IV-E) may overlie the crossbedded unit. This unit consists of thin sandstone beds with current or oscillation ripple bedforms separated by thin siltstone with wavy to parallel laminations. Isolated ripple or oscillation crosslaminated sandstone within a siltstone matrix is also present. The small horizontal sand filled burrows, Planolites, are common.

Even Bedded Sandstone

Lithologic features

The most prominent characteristic of the even bedded sandstone is its laterally continuous, parallel bounded medium-very thick (10-60 cm) beds. Medium to fine sandstone predominates, but siltstone and shale are fairly abundant. Calcite- or hematite-cemented sandstone of quartzarenite or subarkose are abundant. Minor amounts of hematite oolites are found in the crossbedded units. Sandy carbonate grainstones commonly occur as lenses within crossbedded units. Clasts of laminated shales or calcite cemented fine to medium sandstone are present within crossbedded units. The sandy grainstones and clasts are most abundant in the thin zone overlying the hematitic sandstone. Glauconite, a common constituent, reaches 2-3% of the framework grains.

Fossils occur as shell hash of unidentified trilobite and brachiopod debris. Biogenic structures are quite prominent and the most diverse forms of the entire Hickory are present (plate V). Short (up to 4 cm) vertical, back-filled burrows resembling escape structures are quite common. Planolites (plate V-C) is well developed where fine-grained material is present. Diplichnites (plate V-A) and other trilobite markings (plate V-B) are common. Along with these smaller forms two types of larger epichnial casts are present. These are the isolated horizontal burrow (up to 15 cm) Phycodes? (plate V-C) and a large (up to 10 cm) burrow arranged in a radial pattern (plate V-G). Two types of vertical burrows were recognized (plate V-D and E). One type (whose burrow diameter reaches 1.3 cm) has concentric furrows of sandstone surrounding the burrow entrance (plate V-D). Small spreite are found adjacent to the burrow entrance of the second type (plate V-E). This probably represents a feeding pattern (Seilacher, 1964). Numerous types of trails with smooth to ornamented interiors are also present.

Plate V

A. Ichnogenus Diplichnites; trilobite walking trace; hypichnial ridge; from even bedded sandstone, section BU-MQ, Burnet County

B. Scratchmarks and Planolites?; hypichnial ridges; from even bedded facies, section LL-MP, Llano County

C. Ichnogenus Phycodes? (large burrow) and Planolites (smaller forms); even bedded sandstone facies, section LL-MP, Llano County

D. Vertical burrow with concentric sand furrows; even bedded sandstone, section BU-MQ, Burnet County

E. Vertical burrow with horizontal spreite (feeding trace); even bedded sandstone facies, section BU-MQ, Burnet County

F. Core Tucker #1 Perkins, 3326 feet with vertical burrow and burrow mottling in fine sandstone-sandy mudstone of laminated calcitic sandstone facies, Kerr County

G. Large radial burrow (right) and smaller Planolites; hypichnial ridge; even bedded sandstone facies, section BU-MQ, Burnet County

PLATE V

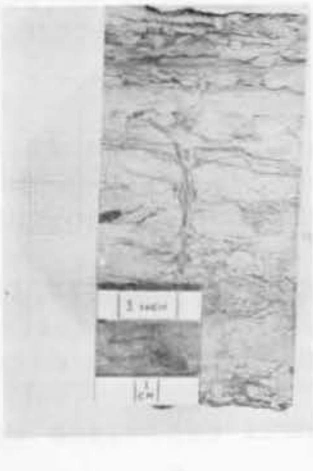
B

A

D

C

E



F

G

Sequences present

Sequences are characterized by alternations between crossbedded units and burrowed to laminated units with a general increase upward in burrowed and laminated units and in calcite cement (fig. 17).

Crossbedded units range considerably in thickness (10-80 cm). They have irregular sharp erosional scoured bases. Festoons and single or multiple sets of planar crossbedding are abundant. Oscillation or current ripples may form along the top surfaces of these sets and siltstone drapes cap some of these units. Laterally, they may become bioturbated. Paleocurrent data from this facies is quite variable and shows no consistent orientation (fig. 17). These units are generally coarser than the burrowed units with grain size ranging from fine to coarse sandstone.

Burrowed units vary in character from well laminated sandstone and sandy siltstone with a few isolated burrows to completely burrow mottled sandstones, sandy siltstones or sandy shales. These units are finer grained with more abundant shale and siltstone than in the previously described crossbedded unit.

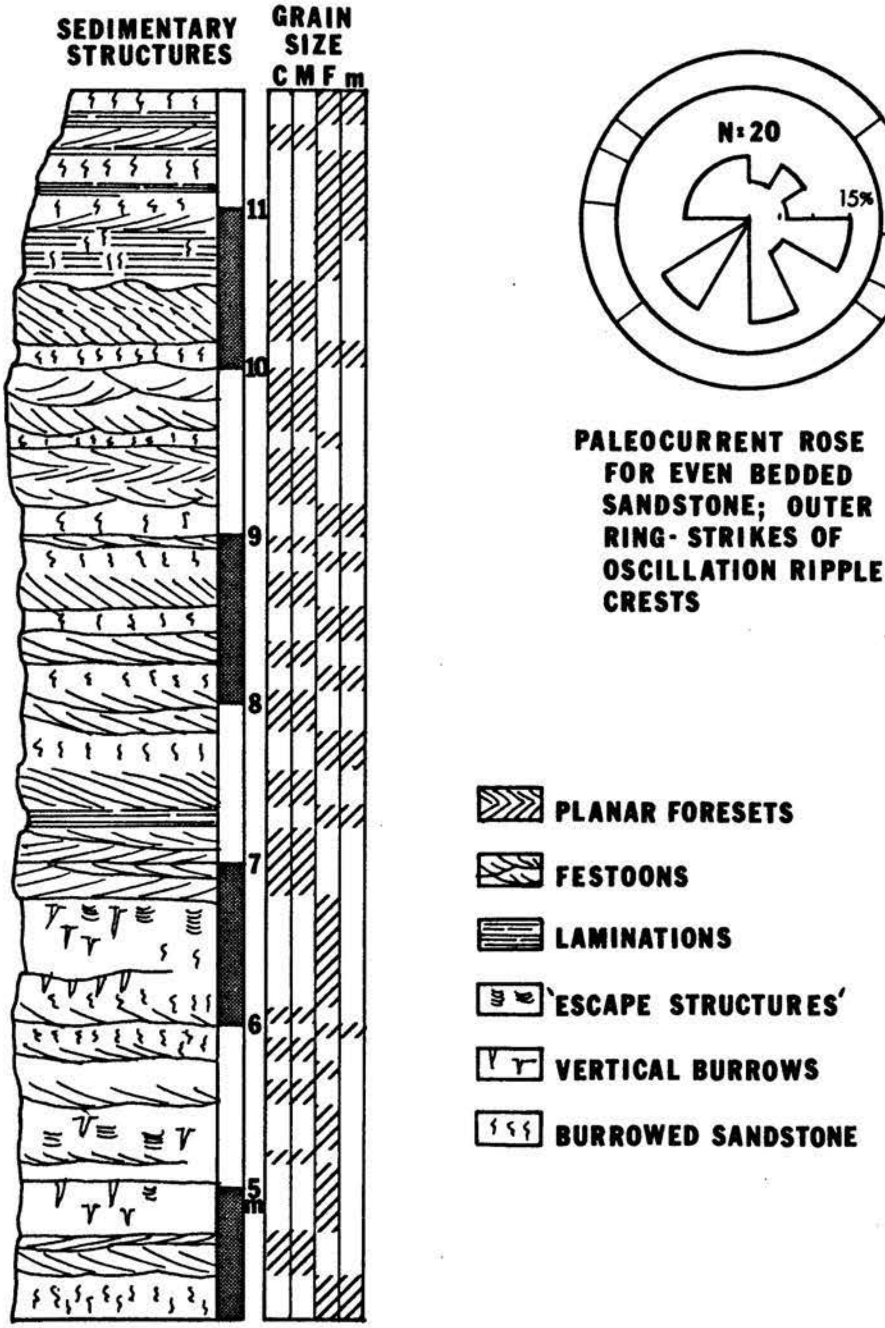


Figure 17. Portion of measured section. LL-SQ, Llano County (see Appendix II), illustrating even bedded sandstone sequence; Paleocurrent rose shows no distinct regional trend

Laminated Calcitic Sandstone

Lithologic features

The laminated calcitic sandstone is predominately pinkish gray (5YR8/1), well sorted, calcite-cemented fine sandstone with very little shale or siltstone. Finer sediment is usually found as burrow linings. Calcitic, laminated fine sandstone clasts (up to 4 cm diameter) are locally present. Thin lenses of carbonate occur as sandy grainstones. Glauconite is quite often present and it is locally abundant (up to 4%).

Fossils are common. They are preserved as a shell hash mixed with sandstone or as carbonate lenses. Identification is difficult. Biogenic structures such as burrow mottling are abundant but poorly preserved (plate IV-F and V-F). The only distinct trace fossils are *Cruziana* and *Rusophycus*. Short (up to 4 cm) vertical backfilled burrows resembling escape structures are present in some beds (plate V-F).

Sequences present

No particular vertical sequences were noted, but rather a random alternation between burrow mottling and primary structures. The most common primary structures are wavy to horizontal laminations of fine to medium sandstone (fig. 18). Crossbedded units are thin and not abundant, consisting of local sandy grainstones of rounded trilobite and brachiopod debris. The most common structures are massive, well sorted sandstone or burrow mottled sandstone. Precambrian highs have a local effect upon this facies. Crossbedded units with siltstone clasts become more prominent than burrow mottled sandstones.

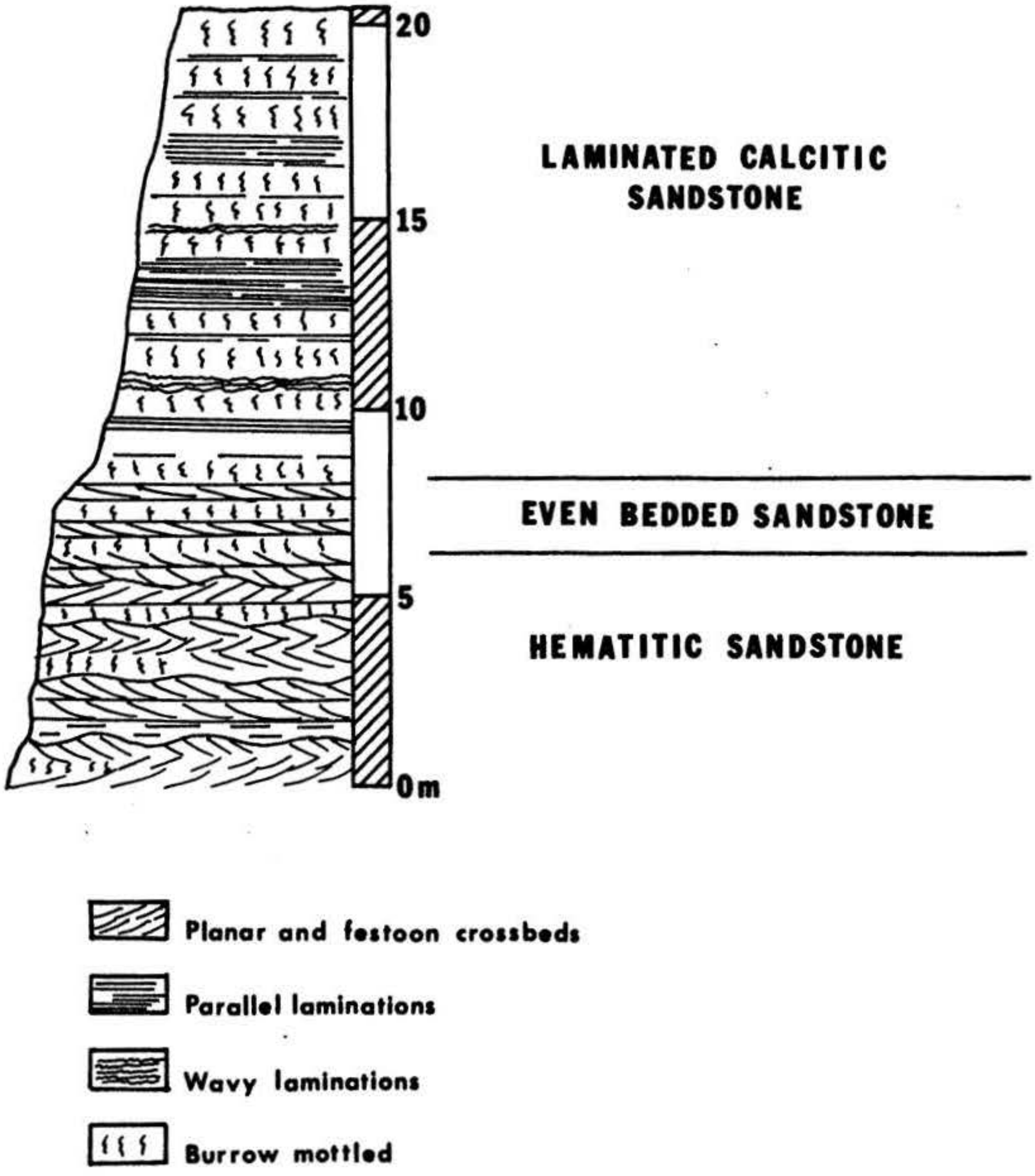


Figure 18. Measured section, Mc-SS1, McCulloch County (see Appendix II), illustrating transition from hematitic sandstone to even bedded sandstone to laminated calcitic sandstone and showing typical sedimentary structures and sequence

DEPOSITIONAL SYSTEMS

As defined by Fisher *et al*. (1969) and Fisher and Brown (1972), depositional systems are process-related sedimentary facies that are stratigraphic equivalents of geomorphic or physiographic units. Examples of depositional systems are delta systems or barrier island systems which can be characterized by distinct geometric, lithologic, and biologic features. Application of this concept to the ancient record meets with varying degrees of success depending upon the extent to which a modern environment is known and the kinds of data available from the ancient.

Each depositional system is represented by a spectrum of examples which vary in the relative intensity and the kinds of formative processes, sedimentary supply, basin tectonics, etc. For example, the spectrum concept has been applied to fluvial and deltaic systems by Fisher *et al*. (1969), Fisher and Brown (1972), Coleman and Wright (1975), and Galloway (1975). Individual studies of Holocene systems may represent only portions of that spectrum. The limits of our present knowledge must be recognized and the concept of a spectrum of models kept in mind.

Holocene Equivalents

The Hickory has features of several estuarine-related or tidally influenced Holocene environments. The term 'estuary' implies the tidally-influenced lower reaches of a river and 'tidal' implies completely marine environment. There is no general term that defines both tidally-influenced and estuarine-related systems as a whole. For simplicity, the term 'estuarine system' is adopted to encompass both tidal and estuarine systems. Dutch and German workers have used the terms 'inner' and 'outer' when refering to portions of the estuarine system (e. g., Terwindt, 1971; Reineck and Singh, 1973). These terms are adopted for use in this study.

The basic model utilizes the German-Dutch coast as its Holocene analog (since it is the best studied) and is augmented by studies of estuarine- and tidally-influenced environments developed elsewhere. Emphasis is placed upon a spectrum of existent models, based upon process intensity (tidal range) and geomorphic relationships (barred or non-barred). The terms microtidal, mesotidal, and macrotidal proposed by Davies (1964) will be used. Most studies of tidal environments have been limited to temperate climate, mesotidal, high mud environments bordering the Atlantic (There are notable exceptions, e.g. Tables I and II). A list of important works dealing with major divisions of the system - outer estuary, inner estuary, and tidal flats - are given in Tables I and II.

Estuarine and tidally influenced environments are typical of many coastlines. They occur as drowned river valleys (Delaware and Chesapeak Bay), reworked distal portions of tide-dominated deltas (Rhine and Colorado deltas), embayed coasts (Thames and German coasts) and along barred coastlines (Georgia, Netherlands, and Germany).

Hydrodynamics and sediment accumulation

The hydrodynamics of tides and its specific application to estuaries is discussed in Ippen (1966). Johnson and Belderson (1969) give a simpler account of tidal effects and the following discussion is summarized from these works. The relative motions of the earth-moon-sun system cause the periodicy of tide producing forces. Amplitude, phase, and velocities of tides and tidal currents result from interaction of oceanic tides with water depth, submarine topography, and basin configuration.

Tides within a specific drainage area of an estuary are determined by the characteristics of the tide entering the mouth, boundary friction of the basin, water density differences, and the Coriolis effect.

Sediments are transported as bed load and as suspended material. Bedload moves only when the necessary entrainment velocities are reached during each tidal cycle. Suspended load may settle during slack water periods. Net transport is determined by time averages of the velocities in a tidal cycle. Sediments tend to decrease in size up-estuary (Daboll, 1969; Howard and Frey, 1973) with major sand accumulation occurring at estuary mouths. A combination of tidal current asymmetry, scour lag, and settling lag is responsible for transporting fine material further landward during each tidal cycle (Postma, 1967; Straaten and Kuenen, 1958). Convergence of tidal currents at the estuary mouth accounts for sand accumulation there (Coleman and Wright, 1975). The importance of tides through geologic time deserves a brief discussion. Merifield and Lamar (1968) proposed that the abundant Late Precambrian and Cambrian quartz arenites were tidal sand bodies related to stronger tidal currents due to a presumed lesser distance between the earth and moon. Instead of the expected decreasing numbers of reported tidal deposits through time, Ginsburg and Klein (1973) found a trimodal time distribution of occurrences. Sedimentological studies do not at this time fully support the hypothesis of Merifield and Lamar.

Major facies components

The major facies components of the estuarine system consist of the shelf, outer estuary channels and shoals, and inner estuary complex of channels, tidal flats, and marshes (fig. 19).

Shelf: The shelf models developed by Fisher and Brown (1972) and Swift (1974) were derived from study of the modern shelf environment. The sediments of the shelf environment are predominately relic sediments from earlier Pleistocene environments existing during low stand. These sediments in places are reworked in the present environment. Active modern shelf sedimentation requires a process to bypass coastal or paralic storage of sediment. Depending upon the relative intensity of the processes, the shelf environment may be described as storm- or tide-dominated.

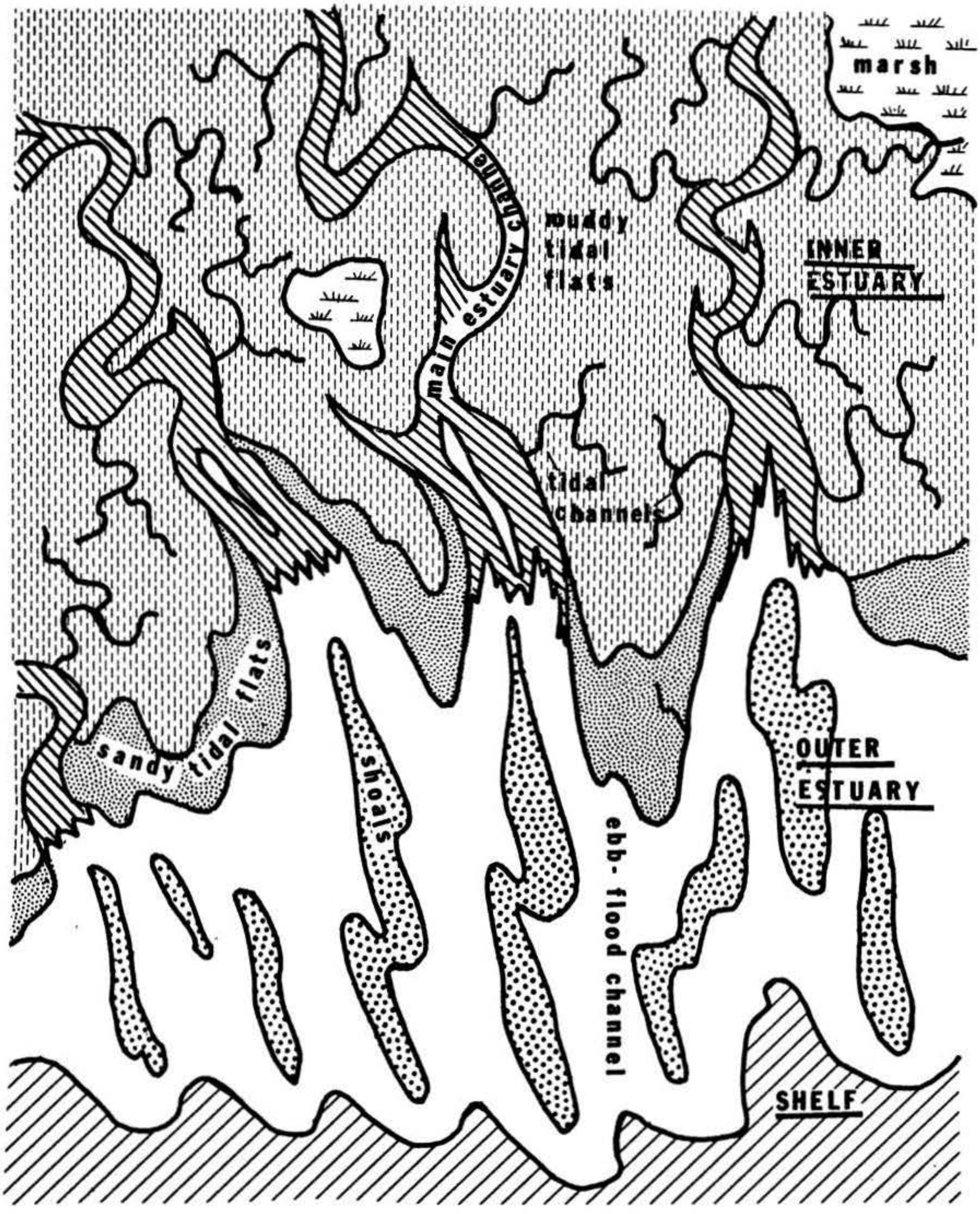


Figure 19. Tidal and estuarine facies components

The storm dominated shelf (e.g., Atlantic) as described by Swift (1974) endures long periods of quiescence interrupted by periodic storm activity. Sedimentation on the shelf results from coastal erosion, input from river mouths, and storm surge deposits funneled through tidal passes. These sediments are then modified by the storm dominated hydraulic regime and biologic activity.

Active transport of sediments from coastal storage in estuaries occurs on tide-dominated shelves (The North Sea is a good example of a well studied tidal shelf, but even here winter storms are significant agents of transport; e.g., Reineck and Singh 1972). Sediments may be reworked into a series of sand bodies related to tidal current transport paths as described by Kenyon (1970) or take on the form of tidal-current ridges (Off, 1963; Houbolt, 1968).

The reader is referred to Curray (1960), Emery (1968), and Swift et al. (1972), for discussion of shelf evolution and shelf sediments. Studies of sediments and sedimentary structures from both types of shelf environments include those of Reineck (1963), Howard and Reineck (1972), and Reineck and Singh (1973).

Outer estuary: The outer estuary is a dominantly subtidal area adjacent to the shelf. Table I lists important works dealing with this facies. The outer estuarine geomorphic units consist of alternating ebb and flood channel system separated by sand shoals (fig. 20A). Channels along these type coasts are broad and shallow (up to 45 m deep and 2 km wide). Flood channels shallow seawards.

Net direction of bedload transport of sediments will be affected by the dominant residual tide. Sediment distribution is affected by the sorting of waves and tidal currents; tidal currents being more active along channel bottoms and wave activity being concentrated on that portion of the shoals above wave base (Oertel and Howard, 1972; Terwindt, 1973). Biological activity is concentrated along the flanks of the shoals and is largely absent from channel bottoms and above wave base (Reineck, 1963).

Sand shoals (the Dutch term, 'plaaten', is widely used) separating subtidal channels (fig. 20B) have been referred to by various names in the literature, including tidal current ridges (Off, 1963), inlet margin shoals (Swift *et al.*, 1972) wave swash platform (Oertel and Howard, 1972), and zig-zag shoals (Ludwick, 1974). Shoals

Table I. Literature summary of outer estuarine - tidal shelf environments

AUTHOR	YEAR	EMPHASIS	AREA	FACIES
Coleman and Wright	1975	Morphology, processes, sed. struc., sequence	Deltas of the world	Deltas and assoc. facies
Houbolt	1968	Sediments, sed. struc. cores, processes	North Sea	Shelf tidal current ridges
Howard and Reineck	1972	Sediments, sed. struc.	Georgia Coast	Estuarine shoal; shoreface, shelf
Ludwick	1972 1974	Morphology, processes, hydraulics, sed. transport	Chesepeak Bay	Ebb-flood channel system, shoals
Meckel	1975	Sediments, sed. struc. sequence fm. cores	Colorado delta Gulf of Calif.	Marine tidal bars estuary, tidal, fluvial channels tidal flate, cheniers
Oertel	1973	Sed. struc. of mud	Georgia Coast	Tidal inlet
Oertel and Howard	1972	Processes, sed. transport	Georgia Coast	Estuary shoals
Off	1963	Morphology	Tidal shelves	Tidal current ridges
Oomkens	1974	Sed., struc., sequence, cores	Niger Delta	Estuarine and fluvial channels
Raaf and Boersma	1971	Sed. struc. and sequence	Several European examples, Holocene and ancient	Subtidal-intertidal channel; tide dominated shelf
Reineck	1963	Sed., struc., sed. distribution	German Coast	Channels, shoals, sand tongues
Reineck and Singh	1973	Sed. struc., sequence	German Coast	Channels, shoals, sand tongues
Robinson	1960	Morphology, process	Thames estuary	Ebb-flood channel shoals
Swift et al.	1972	Topography, process	Atlantic Shelf	Shelf, shoals, channels
Swift	1975	Morphology, process		Tidal ridges
Terwindt	1967	Processes, mud transport	Netherlands	Outer and inner estuary
Terwindt	1973	Processes, sand transport	Netherlands	Outer and inner estuary

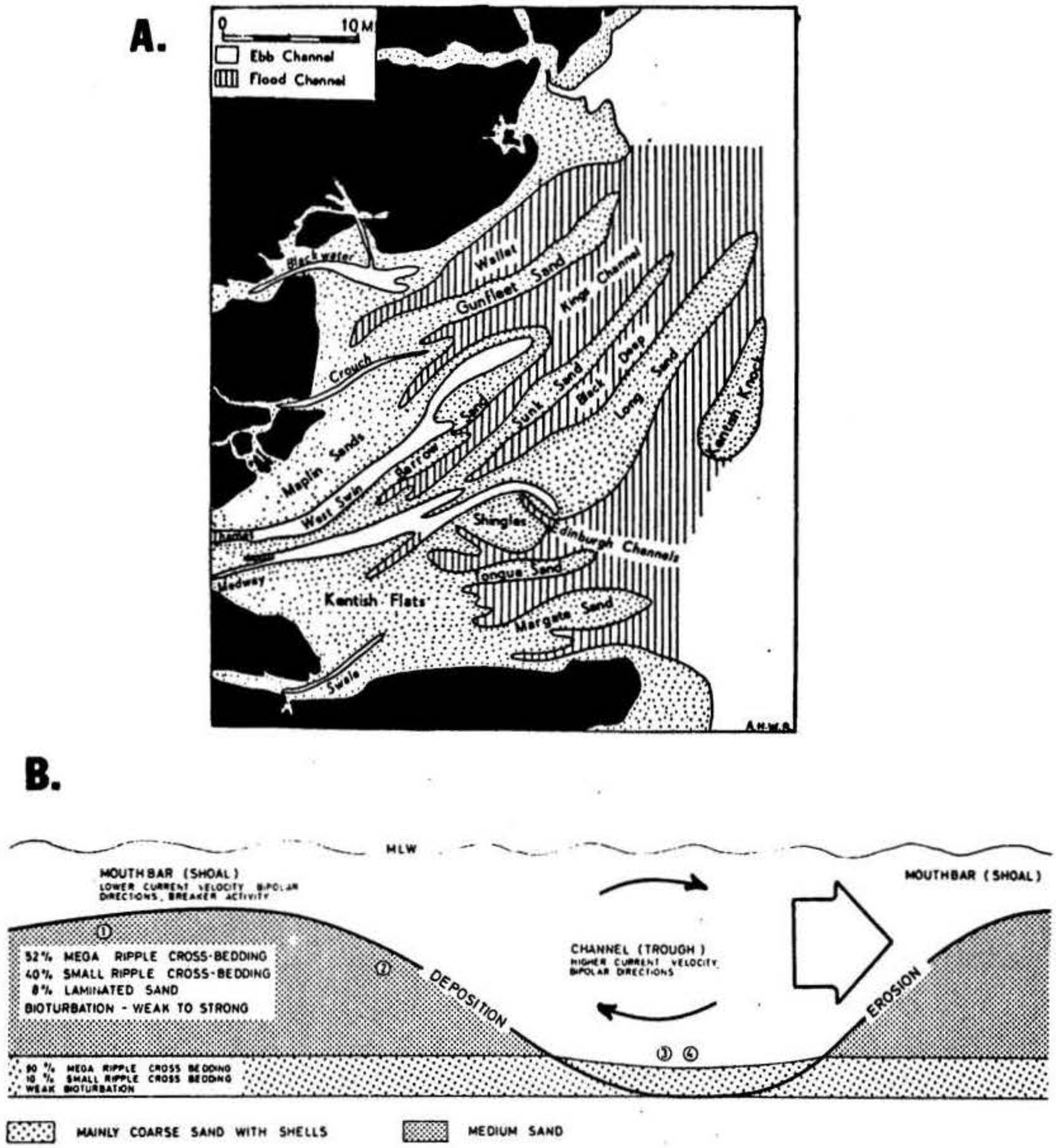


Figure 20. Outer estuarine facies components A. Ebb and flood channel systems alternating with sand shoals or 'plaaten', from Robinson (1960) B. Section of channel-shoal system showing stratification types, current pattern (small arrows), and resultant migration direction of sand shoals (large arrow), modified from Reineck (1963) and Reineck and Singh (1973).

may be attached to shore (sand tongues of Reineck, 1963) or separated by channels into 'plaaten'. They are dominantly subtidal but significant portions may be intertidal and grade landward into sandy tidal flats (fig. 24A). Evolution of estuarine shoals into shelf tidal current ridges has been proposed by Swift (1975).

Internal structures and vertical sequences have not been extensively investigated because of difficulty in sampling subtidal areas. Sediments are dominately clean sands with bedforms from small-scale ripples to large megaripples (fig. 20B). Reineck and Singh (1973) proposed a hypothetical vertical sequence of this environment (fig. 21).

Inner estuary: This facies is both subtidal and intertidal. Table II summarizes important works in this area. Principle facies consist of the meandering main estuary channel and the numerous smaller tidal channel branches. Mid-channel bars (shoals or plaaten) and point bars are characteristic of these. Lateral to the channels, sandy and muddy tidal flats and marshes develop. These are subjected to constant reworking by the meandering tidal channels.

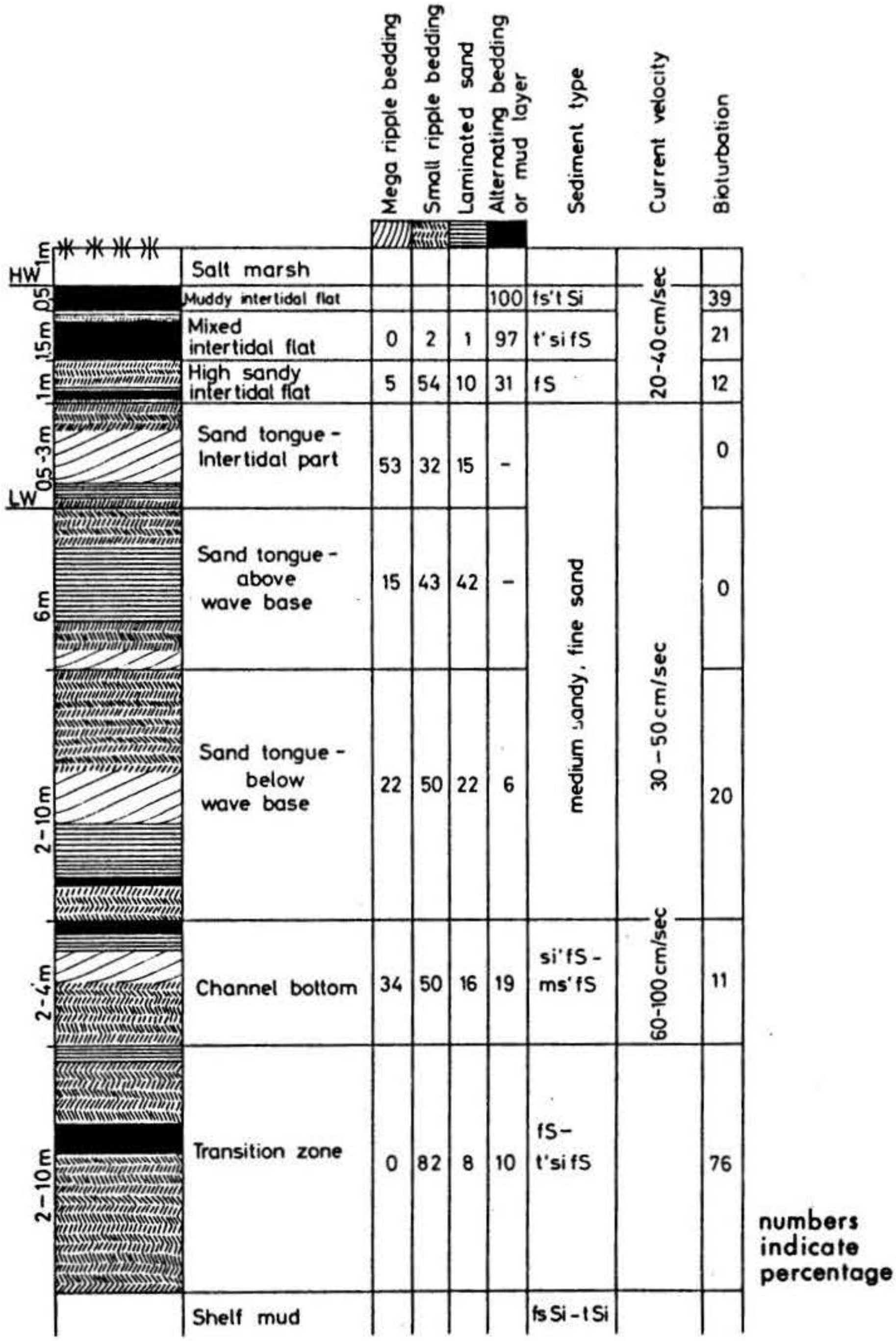


Figure 21. Hypothetical vertical sequence of the outer estuarine facies, modified from Reineck and Singh (1973), fig. 473.

Table II. Literature summary of inner estuarine environments

AUTHOR	YEAR	EMPHASIS	AREA	FACIES
Beek and Koster	1962	Sequence of sed. struc.	Netherlands	Fluvial-estuarine transition
Boersma	1969	Sedimentary struc.	Netherlands	Intertidal shoal
Boothroyd	1969	Process, bedforms, sed. structures	Massachusetts	Inner estuary
DaBoll	1969	Processes, bedforms, sed. struc., biota	Massachusetts	Inner estuary, point bars, tidal flats
Evans	1965	Processes, sed. struc. cores	The Wash, Eng.	Tidal flats
Gellatly	1970	Bedforms, sed. struc.	King Sound, Australia	Outer estuary, intertidal
Frey and Howard	1969	Biogenic structures	Georgia Coast	Tidal, estuary channels
Hayes	1969	Bedforms, sed. struc.	Massachusetts	Inner estuary
Hayes _et al._	1969	Sequence of sed. struc.	Massachusetts	Inner estuary sand bodies
Howard	1969	Biogenic and sed. struc. by X-ray	Georgia Coast	Tidal channels, shoals, shoreface, shelf
Howard and Frey	1973	Biogenic and sed. struc.	Georgia Coast	Inner estuary, point bars, tidal flats
Hulsemann	1955	Processes, sed. struc.	German Coast	Inner estuary
Klein	1970	Processes, bedforms, sed., sed. struc.	Minas Basin, Nova Scotia	Intertidal sand bars
Kruijff and Lagaaij	1960	Biota, sequence of sed. struc.	Netherlands	Channel shoal of inner estuary
Land and Hoyt	1966	Processes, sed., sed. struc., biota	Georgia Coast	Estuary point bar
Mayou and Howard	1969	Biogenic structures	Georgia Coast	Tidal-estuary channel
Meckel	1975	Sequence of sed. struc. cores	Colorado Delta	Marine tidal bars, estuary, tidal, fluvial channel, tidal flat
Oomkens	1974	Sequences of sed. struc. cores	Niger Delta	Estuarine and fluvial channels
Oomkens and Terwindt	1960	Processes, sequence of sed. struc.	Netherlands	Channel-shoal of inner estuary

Table II. (continued)

AUTHOR	YEAR	EMPHASIS	AREA	FACIES
Raaf and Boersma	1971	Sequences and sed. struc.	Several Euro. examples	Subtidal-inter-tidal channel; tidal shelf
Reineck	1967	Processes, sed., sed. struc., biota	Germany	Tidal flat
Reineck and Singh	1966	Sed. struc	Germany	Estuary channel
Straaten	1954	Sed. struc.	Netherlands	Tidal flats
Straaten	1960	Sediments, sed. trans-port	Netherlands	Main estuary channel
Straaten	1961	Sediments, sed. struc.	Netherlands	Tidal flats
Straaten and Kuenan	1958	Processes of mud accumulation	Netherlands	Inner estuary
Terwindt	1967	Mud transport	Netherlands	Inner and outer estuary
Terwindt	1970	Processes, bedforms	Netherlands	Main estuary channel
Terwindt	1971	Sequence of sed. struc. subsurface distribution	Netherlands	Channel-shoal of inner estuary
Terwindt	1973	Processes, sand trans.	Netherlands	Outer and inner estuary
Terwindt *et al.*	1963	Processes, sediments	Netherlands	Fluvial-estuarine channel
Thompson	1968	Processes, sediments, sed. struc., cores	Colorado Delta	Tidal flats
Wright *et al.*	1973	Processes, geomorph	Cambridge gulf, Aus.	Channels

Wright *et al*. (1973) considered end members of tidal channels representing opposite extremes of morphology and tidal processes. End members were slightly meandering channels and funnel-shaped channels. Channel systems are divided into ebb and flood portions (fig. 22A). Flood channels tend to be straight and wedge inland. Ebb channels tend to meander (Straaten, 1960).

Channel bottoms are occupied by migrating sand waves which move in response to tidal flow. Net sand movement is in the direction of residual tidal current. Orientation of bedforms varies with the tide. Predominance of one tide over the other from channel to channel or within the channel can cause bedform orientations and therefore cross stratification to be oriented toward the ebb, flood, or in both directions. Bedform characteristics vary from megaripples to small ripples. Bedforms and sedimentary structures of this environment have been studied by numerous workers (Table II; e.g., Boothroyd, Daboll, Land and Hoyt).

Interchannel shoals and bars of this region may be entirely subtidal or portions may be intertidal. Sediment transport follows a roughly circular pattern around

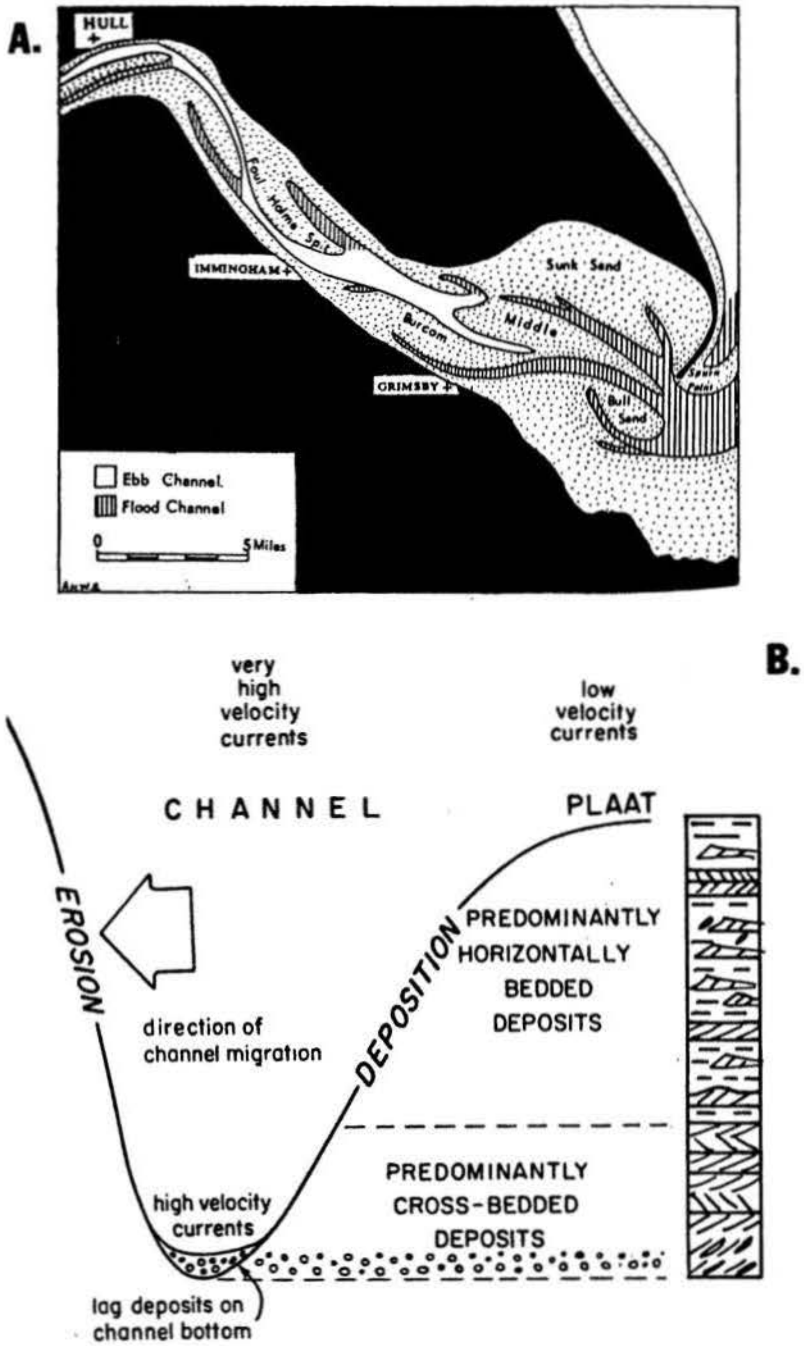


Figure 22. Inner estuarine facies A. Ebb and flood channel patterns of inner estuary, from Robinson (1960) B. Vertical sequence of inner estuarine main channel-shoal, modified from Oomkens and Terwindt (1960)

the shoal (Straaten, 1960; Terwindt, 1973).

Lateral migration of tidal channels results in point bars (Straaten, 1961; Land and Hoyt, 1966; Reineck, 1967). These reveal vertical sequences much the same as in fluvial point bars, in as much as there is a vertical decrease in velocity and a resultant decrease in grain size. Important differences exist as a result of the different operative processes. Vertical sequences resulting from estuarine channel migration have been studied by Oomkens and Terwindt (1960), (fig. 22), Kruijft and Lagaaij (1960), Hayes et al. (1969), Terwindt (1971), Oomkens (1974) and Meckel (1975). Figure 22B illustrates a typical sequence from the Haringvleit estuary, Netherlands, studied by Oomkens and Terwindt (1960). Crossbedded sand, clay chips, and marine fauna are found in channel bottom deposits. Interbeds of sand and mud, displaying flaser, lenticular, and wavy bedding characterize upper point bar deposits. Biogenic structures are important in the upper point bar away from high bottom current velocities (Mayou and Howard, 1969; Howard and Frey, 1973). Several workers (Terwindt, 1971; Oomkens, 1974; Meckel, 1975) have shown that estuarine channels are filled by several cycles.

Tidal flats: These have a facies tract consisting of lower sand flat, mixed flat, upper mud flat, marsh, and meandering tidal creeks (Straaten, 1961; Evans, 1965; Reineck, 1967). Tidal creek bottoms and lower sand flats are mostly subtidal, but the other facies are intertidal (fig. 23A). These facies develop in response to depositional processes that vary in intensity across the flat. Reineck (1967) has emphasized the importance of both physical processes (wave and tidal energy) and biological activity (fig. 23A). Wave energies are concentrated upon the lower flat region, except during storms when they may be sufficiently strong enough to cause erosion of the marsh unit and accumulation of shell berms. Tidal currents are concentrated in the lower flat region and in the channels. The combination of these processes causes a gradation in physical energy across the flat which results in a gradation of grain size from sand to mud. Relative intensity of biological activity increases from the sand flat to the marsh. Deeper burrowing forms exist upon the intertidal portions and more shallow burrowing fauna are found subtidally (Rhoads, 1967).

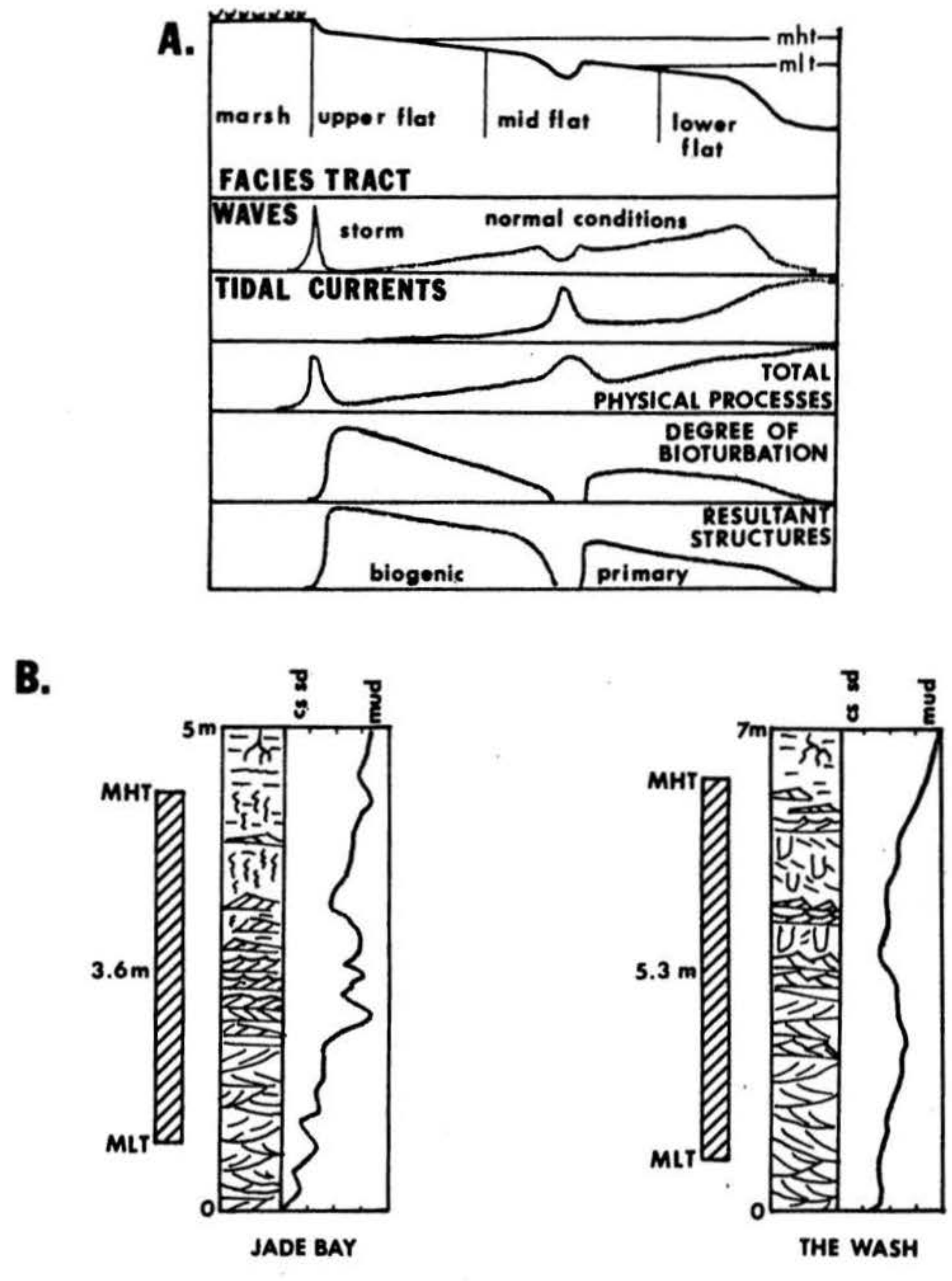


Figure 23. Tidal flat environment. A. Processes active on tidal flat, modified from Reineck (1967) B. Two sequences displaying upward fining character, after Reineck (1967) and Evans (1965), respectively.

The depositional process responsible for tidal flat deposition cause an upward-fining sequence (fig. 23B) consisting of lower sand flat with large-scale crossbedding, midflat with wavy-lenticular bedding, an upper mud flat with laminated or burrowed muds and a marsh unit consisting of root mottling or laminated silts or muds.

A spectrum of Holocene examples is available to explain variations from these ideal sequences (fig. 24). End members of this are based upon geomorphic relationships (open or barred coast) and upon the intensity of tidal energy. Barred coastlines occur where the ratio of wave energy to tidal energy is significant. This part of the spectrum includes the addition of the shoreface environment behind which develop estuaries and tidal flats. Barred environments include the mesotidal German-Dutch coast (Straaten, 1961), Eastern Atlantic (Coastal Research Group, 1969; Howard and Reineck, 1972) and the Niger Delta (Oomkens, 1974). Nonbarred sequences include mesotidal environments of the Wash, England (Evans, 1965), the German estuaries (Reineck, 1963; Reineck and Singh, 1973; Reineck, 1967), and macrotidal environments such as Colorado delta (Thompson, 1968; Meckel, 1975), Ord delta (Wright _et al_.,

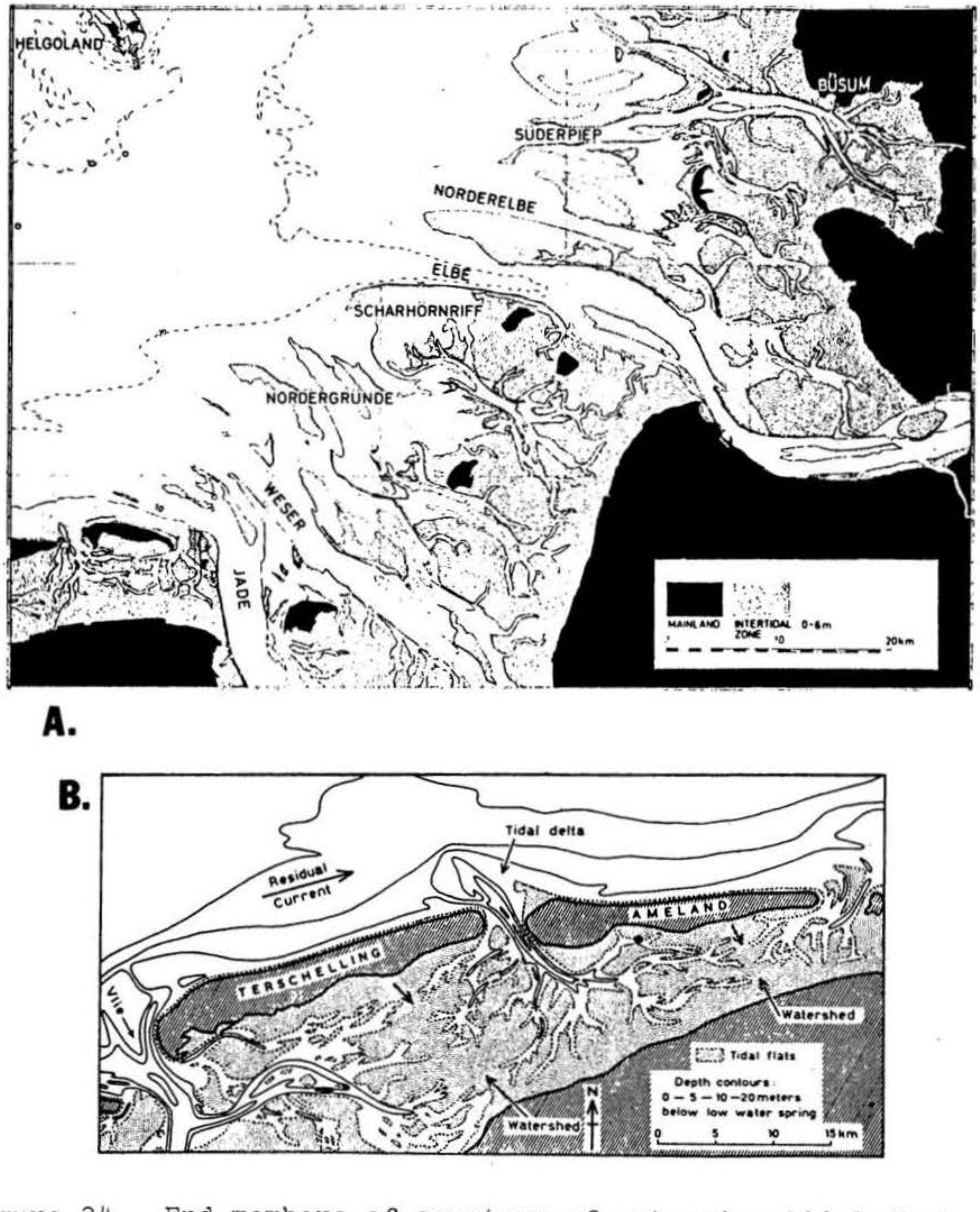


Figure 24. End members of spectrum of estuarine-tidal flat environments A. Mesotidal non-barred German Coast, from Reineck and Singh (1973) B. Mesotidal barred Dutch Coast, from Straaten (1961).

1973; Coleman and Wright, 1975) and the Bay of Fundy (Klein, 1970).

Interpretation of Environments

The nonbarred estuarine complex model best serves to explain the distribution and occurence of Hickory Sandstone facies. Modification of this model need only be made in sediment supply to account for the limited amount of fine material available to the Hickory environments. No evidence has been found in outcrop of a fluvial feeder system for the Hickory Sandstone. Such a system, if present would be expected in the subsurface to the northwest.

Basal Crossbedded Sandstone

Several characteristics of this facies have similarities to the outer estuarine environment. The basal crossbedded sandstone consists largely of basally scoured channel sequences exhibiting large-scale foreset crossbedding. It fines upwards into the siltstone facies or is overlain by the burrowed sandstone facies. A lag deposit of craton-derived rock fragments and faceted ventifacts occurs at the base. Siltstone clasts and parallel laminations are also present. Its trace fossil assemblage is a mixture of two of Seilacher's (1967) bathymetric facies. The *Cruziana* assemblage has been interpreted as characteristic of littoral shallow shelf environment (Seilacher, 1967; Frey, 1971). Ager and Wallace (1970) and Fürsich (1975) found that their *Corophioides-Diplocraterion* assemblage was equivalent to Seilacher's *Skolithos* facies. Their assemblage was indicative of very shallow subtidal to high energy sandy intertidal sediments. In a study of an ancient shoreface deposit Howard (1966) showed that distinctive trace fossils and minor burrow mottling were indicative of higher current energy and representative of nearshore deposition. This mixture of trace fossil assemblages can also be expected in the outer estuarine environment since it is transitional with the subtidal shelf and the more intertidal inner estuary.

Sedimentary aspects of the basal crossbedded sandstone are also similar to Holocene outer estuarine environments. Coleman *et al.* (1975) indicate that tidal ridges associated with tide-dominated deltas have numerous cut and fill scours and lie upon the shelf surface. Houbolt (1968) documents a basal lag deposit, no vertical grain size change, large- and small-scale crossbedding and some bioturbation in shelf tidal current ridges. Large-scale foresets similar to those of the basal crossbedded sandstone have been found in several estuaries as the result of tidal megaripple migration (Hulsemann, 1955; Reineck, 1963; Boersma, 1969; Gellatly, 1970). Parallel laminated sands may be produced by beach swash action, plane bed form of upper flow regime or sedimentation from suspension clouds formed by shoaling waves. Parallel laminations of the basal crossbedded sandstone were probably formed by the latter process, which has been observed in the outer estuary environment (Reineck, 1963; Reineck and Singh, 1973).

The hypothetical vertical sequence (fig. 20) resulting from migration of channel and sand shoals of the outer estuary is similar to the basal crossbedded sandstone. In the hypothetical sequence channel bottoms contain rippled and megarippled sands with a channel lag of shells and mud pebbles. Bioturbation is common along the flanks, and parallel laminated sands are produced by sedimentation from suspension clouds formed by shoaling waves. Paleocurrent directions are bimodal with ebb directions more prominent. Deposits of intertidal origin overly this hypothetical sequence and combine to form a fining upward pattern from channel bottom to intertidal mudflat. The upward increase in finer sediments observed in the basal crossbedded sandstone plus the resemblance of upper channel units to tidal channels of Straaten (1954) and Reineck (1967) shows this transition well. Interpretation of overlying deposits as intertidal flats and inner estuarine sediments is also consistent.

The main differences between Holocene ridges and the basal crossbedded sandstone is geometry. Holocene tidal sand bodies have an elongate geometry. Net sand deposits reported by Coleman and Wright (1975) from tide-dominated deltas display adjacent linear trends. The geometry of the basal crossbedded sandstone of the Hickory appears to be sheetlike and is largely controlled by basement topography. Control is not sufficient enough to resolve geometry into more detailed trends. Aggradation and progradation caused by rapid sediment supply coupled with lateral migration of channels and shoals may be responsible for the sheetlike geometry. In addition to these factors, the length of time available for sedimentation adds another dimension to be considered. The Holocene example has had only the short time since the last sea level rise to come to equilibrium and begin progradation. Presently we observe only the beginning of the development of this system, whereas in the Hickory we probably see the final product.

The basal crossbedded sandstone was deposited as a outer estuarine channel-shoal complex along an open tide-dominated shelf. Sediments were deposited during ebb tidal flow and eroded during flood tide in the same manner as tidal deposits in the Minas Basin, Canada (Klein, 1970). A process similar to this probably produced the regional southeast directed paleocurrents (fig. 11A).

Burrowed Sandstone

Features of this facies have similarities to sandy tidal flats and intertidal bars. The reader is referred to the discussion of the lithofacies for details. Some of the major features include an upward-fining sandstone-muddy sandstone transition; predominance of U-shaped burrow *Corophioides* increasing in abundance upwards; numerous ripple bedform types; and the predominance of southeast (ebb) oriented current directions.

Holocene tidal flat sediments exhibit upward-fining sequence from sand to mud (Straaten, 1961; Evans, 1965; Reineck, 1967). Sandier intertidal sediments may occur in areas with higher wave energy (Reineck, 1967; Coleman *et al*., 1970; Coleman *et al*., 1975) such as open coasts. On intertidal bars of the Minas Basin, Klein (1970) documents the occurrence of round topped sand waves, and trimodal current ripple distribution, similar to those of this facies. "Ladder back" ripples are common on tidal sand flats of Massachusetts (Coastal Research Group, 1969) and in Germany (Reineck, 1967). Crossbedding orientations may be unimodal or bimodal. Varieties of current and oscillation ripple bedforms are observed on tidal flats (Reineck and Singh, 1973) similar to those found in this facies. Mud cracks can be expected where intermittent exposures occur (Straaten, 1954). Increase in amount of bioturbation upward in the tidal flat sequence has been recorded by Reineck (1967) and Straaten (1961). Bioturbated muddy sand similar to the burrowed unit of this sequence has been observed in *Arenicola* sand flats of the Wash, England (Evans, 1965) and on sandy *Mya* flats in Massachusetts (Coastal Research Group, 1969). Deeper burrowing forms are also indicative of intertidal origin (Rhoads, 1967). Ager and Wallace (1970) and Fürsich (1975) found that Corophioides is indicative of sandy intertidal deposits. Intertidal deposits overlie the estuarine mouth channel shoal environments in the model shown in Figure 21.

Vertically repeated Holocene tidal flat deposits have been noted in the Netherlands by Jong (1970) and along the Thames by Greensmith and Tucker (1973). According to Greensmith and Tucker vertical stacking may be due to eustatic sea level changes, subsidence, changes in the rate of sedimentation, and climatic changes.

The burrowed sandstone facies was deposited as open coast sandy tidal channel-intertidal flat deposits developed upon shore-attached shoals adjacent to main estuarine channel influence. The three units of the sequence - crossbedded sandstone, rippled sandstone, and burrowed unit - represent lower, mid, and upper flat deposits respectively. Primary structures preserved in the burrowed unit were deposited as storm layers.

Siltstone facies

The siltstone facies has sedimentary features resembling both inner estuarine point bar deposits and muddy intertidal flat deposits. Important characteristics to be noted are a repeated upward transition from cross-bedded sandstone with siltstone clasts to wavy-lenticular bedding to burrowed or laminated sandy siltstones. Marine fossils are locally abundant, and paleocurrents display vectorial bimodality. Two vertical upward-fining sequences are present. One is a thick, predominantly sandstone sequence and the other is thinner and contains more siltstone and shale.

The thick sandstone deposits are similar to inner estuarine main channel sequences. Oomkens and Terwindt (1960) divided the Haringvleit migrating estuarine-shoal sequence into channel lag, crossbedded sand deposits, and horizontally bedded deposits of sand and mud. Rounded clay clasts are present in estuarine and tidal channels as lag deposits (Straaten, 1961). Vertical repetition of estuarine channel fill deposits have been recorded in the Colorado River estuary (Meckel, 1975), and in the Niger River estuaries (Oomkens, 1974), and in the Haringvleit estuary of the Netherlands (Oomkens and Terwindt, 1960; Terwindt, 1971). Rapid vertical variations in sedimentary structures were found in the Haringvleit and in estuarine point bars in Georgia (Land and Hoyt, 1966). Terwindt (1971) believed these resulted from fluctuating bottom currents due to changing tides. Land and Hoyt (1966) and Howard and Frey (1973) found that bioturbation increased away from channel bottoms in estuarine point bars. Vectorial bimodality of cross stratification has been documented in the estuarine channels they studied.

The thinner, muddier sequences are similar to muddy tidal channel-tidal flat couplet of the inner estuary. The upward-fining character, glauconite, and basal siltstone pebble lag are all similar to migrating tidal channel-tidal flats of Netherlands (Straaten, 1961), Germany (Reineck, 1967), and the Colorado delta (Meckel, 1975). Wavy and lenticular bedding has been attributed by Reineck and Wunderlich (1968) to action of tidal currents, in which sand accumulates as bed load deposits and mud accumulates during the slack water periods at high tide. Reineck (1967) describes lenticular and wavy bedding occurring on muddy intertidal deposits in Germany. Bioturbation structures similar to those of Hickory siltstone sequences have been observed on tidal flats by Reineck (1967), Straaten (1961), and on muddy _Mya_ flats by Coastal Research Group (1969).

The predominently sandstone sequences of this facies (fig. 14) represent main estuarine channel-point bar and channel fill deposits of the inner estuary. The thinner, finer sequences (fig. 14) were deposited lateral to the main channel as muddy tidal flats. The relative position of this facies above the outer estuarine sediments and the similarity of channel units near the facies transition with the basal crossbedded sandstone (fig. 13) to tidal channels supports this interpretation.

Hematitic sandstone

Abundant hematite and the presence of hematite oolites make this facies rather enigmatic. Iron minerals are known to accumulate in a variety of environments today (Taylor, 1969). Oolites of iron minerals have only been documented in swamps and bogs (Taylor, 1969) and lakes of restricted circulation (Lemoalle and Dupont, 1973). In ironstone deposits, oolites are found spatially separated from iron-bearing sandstones. Depositional environments interpreted from ancient ironstones and iron bearing sedimentary rocks vary considerably; e.g., deltaic, Taylor (1963), Hallam (1966); barrier complex, Adeleye (1973); tidal sands and tidal flat, Hunter (1970). The presence of hematite and hematitic oolites alone can not be used to indicate a particular physical depositional environment. The sedimentary sequence again becomes the primary tool of interpretation. Features of the hematitic sandstone include basal scour and vertical repetition of thick festoon crossbedded sandstone with minor units of wavy-lenticular bedded sandstone and laminated siltstone. These cause minor upward-fining successions. Abundant marine fossils are reworked into shell hash. Siltstone pebbles are locally abundant.

These sequences are most similar to migrating tidal channel fill-shoal deposits. Sequences in tidal channels from the Niger delta (Oomkens, 1974) and the Colorado delta (Meckel, 1975) show channel sediments of predominately crossbedded sandstone fining upward into thin muds. Rounded clasts are present as lag deposits, as are shells of marine fauna. Repeated vertical occupation of the same channel truncated previously deposited sequences. Migration of channel gives a wide lateral distribution to the facies. Howard and Reineck (1972) found festoon crossbedding and infrequent bioturbation in tidal channel-shoal environment of the Georgia coast.

Lack of regional paleocurrent trends is probably due to influence of longshore currents.

The hematitic sandstone represents estuarine channel-shoal complex along a high wave energy coastline. The hematitic sandstone - even bedded sandstone relationship is similar to the shoal - offshore transition of the Georgia coast.

Even bedded sandstone

The even bedded sandstone consists of alternations between crossbedded coarse sandstone and glauconitic burrow mottled fine sandstone. It lies gradationally to the south of the hematitic sandstone and overlies it as a thin calcitic zone. Similar Holocene deposits have been found on the nearshore shelf.

Sands stored in paralic systems are carried onto the shelf by ebb surge currents generated by storms (Hayes, 1964, 1967; Reineck and Singh, 1972). In the North Sea these sands contained pellets derived from estuarine shoals. Storm deposits formed thin laterally persistent current bedded sands. The coarse crossbedded hematite bearing sandstone units were probably derived by storm ebb-surge deposits through tidal channels and shoals of the hematitic sandstone in much the same manner. Escape structures similar to those of this facies have been noted by Reineck and Singh (1973) from sediments deposited by storms in the North Sea. Evenly laminated silty layers were reported by Reineck and Singh (1973) in the Gulf of Gaeta from offshore shelf deposits. Howard and Reineck (1972) found either laminated sand alternating with bioturbated beds or complete bioturbation in offshore shelf zones of the Georgia coast.

The even bedded sandstone represents storm-dominated shelf deposits near the influence of tidal shoals. Ebb surge deposition generated by storms through estuarine tidal channels and shoals of the hematitic sandstone, interrupted normal shelf sedimentation causing the alternation of bioturbated and crossbedded sandstone.

Laminated calcitic sandstone

The characteristic features of this facies are alternating calcitic parallel laminated and burrow mottled sandstone. Cruziana and Rusophycus are the only identifiable trace fossils. These sediments are similar to storm dominated shelf deposits developed away from the nearshore influence of tidal channels and shoals.

In shelf sediments of the Gulf of Gaeta, Italy, Reineck and Singh (1973) report strong bioturbation with primary structures preserved only as traces. When they are preserved they found evenly laminated silt layers and fecal pellets. Howard and Reineck (1972) found similar bioturbated and laminated sediments in the offshore shelf of the Georgia coast. Howard (1966) showed that intensely burrowed siltstone with few distinctive trace fossils is related to low current energy and representative of offshore deposition. The *Cruziana* assemblage is indicative of shelf environment (Seilacher, 1967).

The laminated calcitic sandstone represents storm dominated shelf deposits. Its calcitic nature, marine fauna, and trace fossils indicate a transition into the carbonate shelf environment. Primary structures were produced by sedimentation from storm suspension clouds.

SUMMARY AND DEPOSITIONAL HISTORY

The Hickory Sandstone was deposited upon the tectonically stable Texas craton during the Late Cambrian transgression. The transgression advanced from the area of the Ouachita trough (south) to the north and northwest (Bell and Barnes, 1962). Initial transgressive deposits are represented by the basal conglomeratic lag. Reworking of previously deposited materials is evidenced by the pebbles that are faceted ventifacts which formed in a previously existent eolian environment.

Continued rise in sea level caused inundation of the Hickory basin except for persistant highs of Precambrian rocks. These continued to furnish coarse detritus and influenced local environments of deposition.

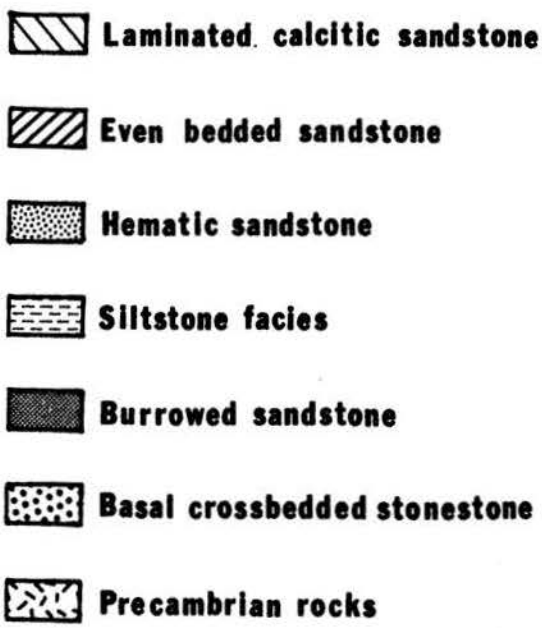
The basal crossbedded sandstone was deposited in outer estuarine channel-sand shoals (fig. 25A) that migrated laterally. Channel scours were infilled by large-scale foresets, parallel bedded sandstone with small- to medium-scale festoons, and minor siltstone. The trilobite trackway, Cruziana, and resting trace, Rusophycus, occur in these deposits associated with the U-shape burrows,

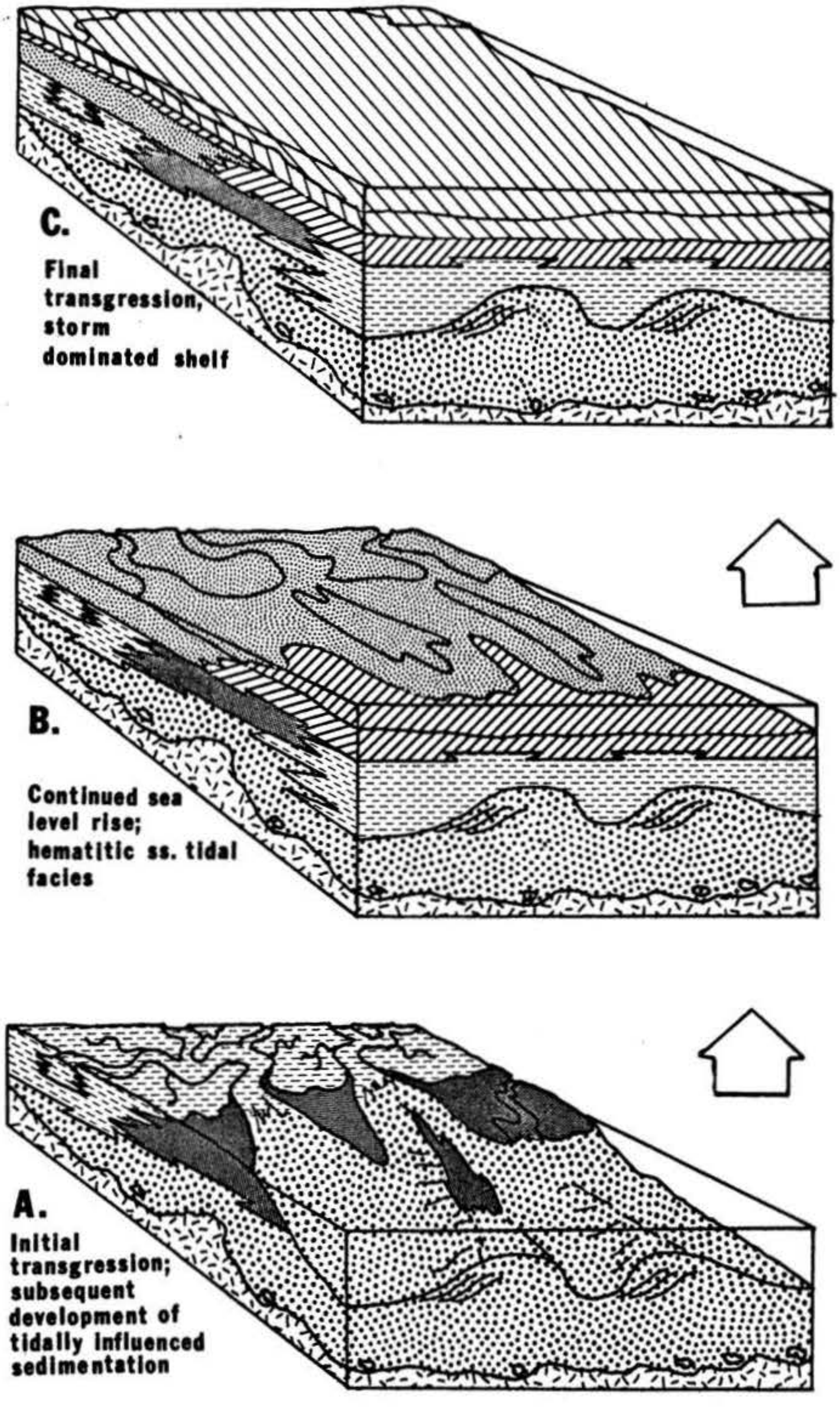
Figure 25. Block diagrams illustrating depositional history of the Hickory Sandstone.

A. Progradation of tidal channel, shoals, and tidal flats of the basal crossbedded sandstone and the siltstone facies.

B. After sea level rise cut off progradation of A, hematitic sandstone and even bedded facies were deposited as tidal channel-shoal complex and inlet influenced shelf.

C. Sea level rise again, causing deposition of calcitic even bedded sandstone above hematitic sandstone and deposition of calcitic laminated sandstone as storm dominated shelf sand.




C.
Final transgression, storm dominated shelf
B.
Continued sea level rise; hematitic ss. tidal facies
A.
Initial transgression; subsequent development of tidally influenced sedimentation

Corophioides and Diplocraterion. Rapid sedimentation rates and ebb-dominanted bottom currents left thick sand accumulations. It is assumed that southeast is the ebb direction because of the relative position of the cratonic land mass to the north and northwest and the sea which advanced from the south. Upon shore-attached sand shoals, intertidal bars and tidal sand flats developed as the burrowed sandstone facies. These deposits are characterized by an upward-fining from festoon crossbedded sandstone, to ripple laminated sandstone, and finally to laminated or burrow mottled muddy sandstone. The abundant ripple bedforms include sinuous, straight, and cuspate current ripples, 'ladder back' ripples, and oscillation ripples. Burrow mottling resulted from the U-shape burrow, Corophioides. The arthropod trackway, Climactichnites, disrupts primary sedimentary structures in some places. Wave energy, tidal currents, and low mud supply were responsible for relatively high sand. Ebb current influence was still predominent since these were developed lateral to the main channels

Further inshore from the sand shoals, the siltstone facies accumulated as inner estuarine sediments protected from the intense wave energy of the open coast (fig. 25A). Meandering main estuary-tidal channels deposited sandstone in channel bottoms, while wavy-lenticular bedding and burrowed sandy siltstone were deposited on channel flanks. This resulted in texturally upward-fining deposits with bimodal paleocurrent patterns. Lateral to these deposits finer grained sediments of muddy tidal flats accumulated. These deposits are also characterized by upward-fining and bimodal paleocurrent patterns, but the sequences are thinner and contain fewer significant sandstone units.

After progradation of these environments, sedimentation rates were not sufficient to keep pace with sea level rise. Inundation of these deposits occurred. This sea level rise caused a shift in depositional environments to the north so that progradation of tidal channel-shoal deposits of the hematitic sandstone reached only the northern outcrop area (fig. 25B). These deposits are characterized by festoon crossbedded sandstone, wavy-lenticular bedding, and abundant fossil debris. To the south of this facies, storm ebb-surge currents in tidal channels transported coarse sandstone and intraclasts to the shelf.

Parallel laminated fine sandstone may have accumulated from suspension during high wave activity. Sediments were reworked by benthic organisms to produce the bioturbated sandstone and siltstone. These storm dominated shelf deposits of the even bedded facies were also influenced by tidal currents.

Rising sea level finally inundated the hematitic sandstone area. The main axis of paralic sedimentation shifted to the northwest out of the outcrop area. The calcitic laminated sandstone was deposited by storm processes in an offshore shelf environment (fig. 25C). Trilobite and brachiopod shell hashes were deposited as carbonate sands and the Hickory served as a platform for the development of the Cap Mountain Limestone.

APPENDICES

APPENDIX I. Terms and methods used.

Facies were distinguished by noting differences in rock composition, texture, vertical and lateral relationships, bedding types, sedimentary structures and sequences, body fossil content, and Lebenspurren. Color terms used in the text are those of Goddard et al. (1963). Composition was determined by binocular microscope examination of samples. Folk's (1968) textural classification of terrigenous sediment and classification of sandstone composition was utilized. Terms used in describing bedding thickness are those of Ingram (1954). The classification of crossbedding utilized was that of Pettijohn et al. (1973) and was augmented by Reineck and Wunderlich's (1968) classification of interbedded sand and mud.

Measurements of paleocurrent trends were made on outcrops exposed in three dimensions. Tectonic corrections and analysis followed the method of High and Picard (1971). Ripple mark trends were analysed separately, since equivalence to other sedimentary structures was not established. The trace fossil terminology is threefold: toponomic, ethological, and taxonomic. This standardized description was suggested by Frey (1973) and has been followed by most workers in this field. Toponomic descriptions utilized Martinsson's (1970) terminology. Ethologic assemblages are those suggested by Seilacher (1964). Taxonomic names were given whenever possible and are those compiled by Häntzschel (1962, 1965, 1966).

Regional correlations utilized all available subsurface data. Lithologic logs were matched to E-logs to determine characteristic responses to lithology. Cores were described whenever available on a standardized form.

APPENDIX II. description of measured sections and cores. Locations of measured sections are shown on figure 10. Core locations are shown on figure 1. Descriptions of measured sections are listed alphabetically by county and section name. Core descriptions follow the measured sections.

BL-WC, White Creek section, Blanco County, upper branch of White Creek on West Ranch; Tectonic orientation- N46E, 7N

Facies: Basal crossbedded sandstone, burrowed sandstone, siltstone facies, even bedded sandstone, laminated calcitic sandstone

Thickness in meters	Description of measured sections
	Laminated Calcitic sandstone
3.0	Gray, glauconitic, calcitic, poorly sorted, medium sandstone; festoons (0-15 cm), fragments of lingulid brachiopod and trilobites
	Even bedded sandstone
0.8	Brown, muddy fine sandstone; burrow mottled
2.2	Cover
6.8	Brown, poorly exposed, calcitic, glauconitic, fine-medium sandstone; mostly burrow mottled some small (0-14 cm) festoons
	Siltstone facies
2.6	Brown, muddy fine sandstone, sandy mudstone, siltstone; thinly laminated, burrow mottled, some thin lenticular bedded sandstone
0.5	Brown, medium sandstone, festoons (0-10 cm)

Thickness in meters	
2.3	Brown, glauconitic, muddy fine sandstone, sandy mudstone, lenticular-wavy sandstone units, sand filled burrows in fine grained units
6.0	Cover
	Burrowed sandstone
6.0	Poorly exposed, fine-medium sandstone, low angle crossbeds, but mostly *Corophioides* burrow mottling
1.8	Poorly exposed, fine sandstone, festoons (0-29 cm)
1.8	Tan-buff, fine-medium sandstone; *Corophioides* burrow mottling
1.5	Poorly exposed, sandy mudstone; horizontal laminations lenticular sandstones, ripple cross laminations
2.0	Tan-buff, fine sandstone; ripple cross lamination
1.0	Tan-buff, fine sandstone; burrow mottled
1.1	Tan-buff, fine-medium sandstone; tabular and festoon crossbeds (0-40 cm), basal scour
1.9	Tan-white, muddy fine sandstone, sandy mudstones; inclined contact with above unit, lenticular sandstones, laminated mudstones, upward fining
1.0	Cover
1.2	White-buff, fine sandstone, sandy mudstone; ripple cross lamination, horizontal burrows, flaser drapes

Thickness in meters	
1.2	White-buff, medium sandstone (subarkose); festoons (10-30 cm), basal scour
1.9	White-buff, poorly exposed, fine-medium sandstone; even bedded (20-40 cm), low angle crossbeds interrupted by U-shape burrows
1.5	White-buff, poorly sorted, fine-medium sandstone (subarkose); massive to burrow mottled, some relic bedding
0.4	Brown, fine sandstone, sandy mudstone; parallel laminations, ripple cross laminations
2.2	White-buff, medium to fine subarkose; massive to crossbedded, crossbeds decrease in size upward (0-15 cm), isolated U-shape burrows
1.1	White-buff, medium sandstone; indistinct bedding, burrow mottled; N46W, 12N; N8W, 11S
0.7	Brown, muddy fine sandstone, sandy siltstone, shales; thin (2-7 cm) beds, parallel laminations, U-burrows
0.8	Cover
1.6	Tan, medium-coarse subarkose; mostly burrow mottled, with few thin (0-10 cm) beds of festoon and tabular crossbeds
1.0	Cover
3.0	Orange, fine subarkose; 2-15 cm beds, U-shape burrows
0.9	Tan, medium-coarse subarkose; tabular crossbeds
1.5	Coarse tan, fine-coarse sandstone; mostly burrow mottled, with laminations disrupted by U-burrows, *Corophioides*

Thickness in meters	
	Basal Crossbedded sandstone
3.0	Cover, *Rusophycus*, in float blocks
1.5	Tan-white, poorly sorted, medium-coarse arkose; 20-40 cm beds, scour contact, parallel laminations, distinct burrows, *Skolithos*?, *Rusophycus*, *Corophioides*
1.5	Tan, medium-coarse sandstone; festoon and tabular crossbeds, U-shape burrows
1.4	Cover
7.5	Tan, poorly sorted, pebbly, coarse arkose; large foresets filling trough shape scours, thick units of smaller festoons and tabular foresets, S10E, S59E, S49E, S54E, S56E, capped by fine sandstone, sandy mudstone with scoured top
5.1	Tan, medium-coarse sandstone, thick units of festoon and tabular crossbeds with angular truncation surfaces grading laterally into large scale foresets filling assymmetric shaped scour
3.0	Tan, poorly sorted, pebbly coarse sandstone (4 cm angular pebbles of quartz); large scale (0.8-1.1 m) avalanche foresets (N65W, 25N; N65W, 14S; N11W, 20S; N85W, 21N) grading into tabular and festoon crossbeds (4-16 cm) (N58W, 31N; N56W, 34N; N49W, 20S) with thin (0-25 cm) sandy siltstone units of ripple, festoon crossbedding (0-15 cm); all in laterally related units, numerous scoured contacts
1.5	Poorly exposed, pebbly coarse sandstone
	Town Mountain Granite, medium grained, biotite quartz microline granite
85.8	Total thickness

Thickness
in meters

Paleocurrent data: Large scale foresets - N55W, 13E; N80E, 11NW; N52E, 8NE; N60W, 16SE; N56W, 21SW; N17E, 22SE; festoons and tabulars - N40E, 13SE; N14W, 21SE; N84E, 20SE; N56W, 12S; N82E, 9NW; N80E, 11NW; N66E, 12SE; N65W, 24NE; N43E, 12SE; N49W, 21NE; N45W, 28S; N6W, 11NE; N35W, 16S; N55W, 47NE; N13E, 23SE; N70W, 21NE; N89E, 14S; N25W, 5NE; N67E, 35SE; N25E, 13NW; N25W, 35NE

BU-MD, Mather Dorbandt section, Burnet County, on Highpoint, Mather Dorbandt ranch; Tectonic orientation - N85W, 7N

Facies: hematitic sandstone, siltstone facies, basal crossbedded sandstone

Hematitic sandstone

1.6 Tan, poorly sorted-well sorted, calcitic, medium sandstone; tabular crossbeds (4-10 cm), bimodal orientation, N2E, 15SE; N7W, 16SW; N27E, 9W

1.4 Tan, poorly sorted, hematitic and calcitic pebbly medium sandstone; bedding (0.1-0.6 m) tabular crossbeds (0-5 cm), lingulid brachiopod fragments, hematitic siltstone clasts

3.4 Brown, very poorly sorted, hematitic, calcitic, pebbly coarse sandstone; tabular and festoon crossbedded, (0-6 cm); lingulid brachiopod fragments along base, broken siltstone clasts

2.8 Mostly brown, poorly sorted, muddy medium sandstone; tabular crossbed (0-30 cm), laminated sandy siltstone, wavy-lenticular bedding, siltstone clasts, some burrow mottling

0.8 Gray-brown, muddy fine sandstone, sandy mudstone; wavy-lenticular bedding (2-5 cm),

Thickness in meters	
2.4	Dark brown, poorly sorted, fine and coarse sandstone; bimodal, tabular crossbeds (0-5 cm), N10W, 23SE; N74E, 12NW; N33W, 19SW; N15W, 23NE; N16E, 16SE; N3E, 23SE; abundant lingulid brachiopod fragments
0.9	Dark brown, poorly sorted, coarse sandstone; tabular crossbeds, abundant lingulid fragments
	Siltstone facies
2.2	Brown, moderately sorted, hematitic, coarse sandstone; parallel laminations, massive and crossbedded (0-40 cm)
0.4	Brown, muddy, medium sandstone; laminated, lenticular sandstone (0-2 cm), glauconite
1.7	Cover
3.6	Tan-brown, sandy mudstone with minor thin sandstone; wavy-lenticular bedding, (0-2 cm) siltstone clasts; tabular crossbeds in sandstone, N7E, 13SE
8.3	Cover
0.6	Brown, moderately sorted, glauconitic, coarse quartz arenite; small scale crossbeds (0-40 cm)
0.9	Cover
1.8	Tan, medium sandstone; tabular foresets, (0.3-0.6 m), lingulid brachiopod fragments
2.4	Cover
3.9	Brown, calcitic, medium and coarse sandstone; crossbeds (0-15 cm), glauconite
1.4	Cover

Thickness in meters	
1.1	Brown, calcitic, very coarse quartz arenite; festoon and tabular crossbeds, N12W, 12N; (0-20 cm)
0.7	Brown, muddy fine sandstone, thin bedded (5 cm), laminated
1.4	Mostly covered
1.3	Brown, poorly sorted, coarse subarkose; tabular and festoon crossbeds; (0-20 cm)
1.2	Cover
6.0	Alternating 1) thick bedded (0.4-1.4 m), tan, brown, poorly sorted, coarse quartz arenite; festoon, tabular crossbedded, scour contacts abundant siltstone clasts and 2) thin bedded (0-30 cm), brown, tan, gray, sandy siltstone, and shale; wavy-lenticular beds, laminations with burrows, *Planolites*
1.1	Brown, sandy mudstone, fine sandstone; wavy-lenticular bedding, (0-3 cm), oscillation ripple crests
2.8	Cover
0.7	Tan, moderately sorted, glauconitic, medium sandstone; tabular crossbeds (0-10 cm), abundant lingulid brachiopod fragments
16.2	Cover
0.4	Tan, moderately sorted, medium quartz arenite; tabular crossbeds (0-5 cm), oscillation ripples on top surface, glauconite, siltstone pebbles, lingulid brachiopod fragments
12.8	Cover

Thickness
in meters

Basal crossbedded sandstone

3.0 Brown, poorly sorted, pebbly coarse subarkose; tabular crossbeds (0-30 cm), abundant angular quartx pebbles along laminae, large (0-10 cm) rock fragments along basal irregular contact

Valley Springs Gneiss, gray-black, foliated (N3W) biotite, quartz, gneiss, with thin quartz veins

89.2 Total thickness

BU-MQ, Murray quarry, Burnet County, on Murray ranch, north of Fairland; Tectonic orientation - N56W, 5N

Facies: even bedded facies of Hickory and Cap Mountain

3.1 (poorly exposed) Tan, sandy micrite, poorly sorted, calcitic fine-medium sandstone; laminations, festoon or tabular crossbedding (2-8 cm), interbedded with thin (0-30 cm) sandy siltstones and muddy fine sandstones

2.8 Tan, calcitic fine sandstone, sandy grainstone; tabular crossbedding (0-25 cm) (estimated thickness)

0.7 Tan-purple, fine sandstone with laminations disrupted by burrows (escape structures)

0.3 Red-brown, poorly sorted, well rounded, hematitic, coarse sandstone; fossiliferous, shale drapes, crossbedded

3.7 Alternating units of 1) thin (10-70 cm), red-brown, graded coarse sandstone; tabular crossbedding 2) thicker (60-90 cm), tan to red-brown, fine sandstone; laminated, ripple cross laminations with some burrow mottling and 3) tan, muddy, fine sandstone, burrow mottled, units 2 and 3 most common

Thickness in meters	
3.0	Alternating units of 1) thin (10-30 cm), red-brown, coarse sandstone; with tabular, festoon crossbedding, scoured bases, 2) Tan-red-brown, fine sandstone, sandy siltstone, shale with drapes, thin bedded (2-5 cm), laminated and ripple cross-laminated and 3) Gray-tan, muddy fine sandstone (2-10 cm), sandy siltstone with horizontal burrows. Unit 1 most common

Paleocurrent readings: N7E, 19SE; N1W, 22SE; N35W, 19S; N35W, 14SE; N7W, 12SE

BU-R2A, Roadcut 2A, Burnet County, along east side of RM. 2341, immediately west of Adams Creek; Tectonic orientation - N25E, 7S

Facies: hematitic sandstone

0.2	Brown, sandy siltstone, shale in parallel laminated beds
0.4	Red-brown, medium sandstone, tabular crossbeds
0.5	Brown, poorly sorted, medium sandstone alternating with sandy siltstone
0.7	Red-brown, poorly sorted, medium-coarse sandstone, in tabular foresets (15-25 cm)
0.4-0.5	Red brown, alternating units of medium sandstone and fine sandstone; parallel-wavy laminations with shale drapes
1.0	Red brown, medium sandstone; parallel laminated
0.8	Red-brown, alternating units of medium-coarse sandstone in tabular foresets and thin (2-6 cm) beds of sandy shales, and lenticular sandstones; burrowed or laminated

Thickness in meters	
0.4	Red-brown, fine sandstone; parallel laminated
0.7	Red-brown, medium-coarse sandstone, (25-45 cm beds); planar and festoon crossbedded with thin shale drapes
0.6	Red-brown, wavy-lenticular, sandy siltstone and shalem horizontal burrows present in units
0.7	Red-brown, coarse to medium sandstone in tabular crossbeds with thin, hematitic sandy siltstone drapes
0.8-0.9	Red-brown, thin, even bedded (0-6 cm), very poorly sorted, medium-coarse sandstone and thin laminated shale drapes in wavy-lenticular bedding
1.2	Red-brown, poorly sorted, coarse-medium hematitic sandstone, multiple crossbed sets (6-12 cm) with thin (1-3 cm) laminated shale drapes, elongate siltstone clasts (up to 2 cm), abundant broken fragments of brachiopods; N8W, 22E; N2E, 19E; ripple stride N49W
1.0	Tan-brown, poorly sorted, medium and fine hematitic quartz arenite, thin (2-5 cm) irregular, lenticular beds with thin (4 cm) micaceous shale drapes; horizontal sand filled burrows on top surfaces of sandstone, ripple strike, N5E
1.0	Cover
8.8	Total thickness

Thickness
in meters

BU-R2B, Roadcut 2, Burnet County, west side of RM 2341, immediately west of Adams creek

Facies: Laminated calcitic sandstone (Cap Mountain Limestone)

1.9	Tan-gray, sandy lime mudstone, burrowed indistinct beds (2-6 cm), alternating with thin (0-2 cm) laminated muddy sandstone and lime grainstone
0.6	Tan, sandy grainstone, calcitic medium sandstone; festoons (4-6 m)
0.2	Gray, glauconitic, brachiopod grainstone
0.3	White-tan, fine quartz arenite; crossbedded to burrowed
1.4	Gray-buff, very fine-medium quartz arenite; crossbedded to burrowed
0.2	Red-brown, poorly sorted coarse hematitic sandstone, current ripple lamination
1.65	White-buff, calcitic, fine quartz arenite with some thin beds of coarse quartz arenite; parallel beds (35-50 cm); parallel-wavy laminations disrupted by shale lined, horizontal burrows, 'escape structures' (1 cm high), some thin crossbedding
6.3	Total thickness

Thickness
in meters

BU-R3, Roadcut 3, Burnet County, west side of RM 2341, 0.4 mi. South of Council Creek

Facies: Basal crossbedded sandstone, three laterally related units

0-2.0	Tan-gray, very poorly sorted, well rounded, pebbly coarse-fine quartz arenite; large scale avalanche foresets, thinning laterally and grading into parallel bedded unit; scoured contact with underlying parallel bedded unit, isolated Diplocraterion along upper surface
1.5-3.5	Tan-gray, very poorly sorted, well rounded coarse-fine quartz arenite with thin sandy mudstone partings; parallel and wavy bedded laminations, festoons (0-20 cm), some beds massive, burrow mottled or with numerous U-shape burrows, Corophioides
0.02-0.35	Tan-buff, fine sandstone, micaceous sandy siltstone; thin bedded, numerous horizontal sand filled burrows, laminations, lies laterally to and is interbedded with above unit
3.5	Total thickness (vertical
60.0	(lateral)

BU-WR, Wall Ranch, Burnet County, south side of Morrishead on Wall ranch; Tectonic orientation - N77E, 7W

Facies: Basal crossbedded sandstone, hematitic sandstone, even bedded sandstone, laminated calcitic sandstone

Laminated calcitic sandstone

4.0	Gray-tan, calcitic fine sandstone, or sandy lime grainstone; crossbedded, N9E, 20SE; N34W, 11SW: 2-5 cm irregular beds, wavy laminated

Thickness in meters	
	Even bedded sandstone
1.3	Mostly covered, brown, calcitic, coarse sandstone, some sandy grainstone; law angle crossbeds, laminated, lingulid brachiopod fragments, N1E, 25E
1.4	Tan, poorly sorted, pebbly medium quartz arenite; crossbeds decreasing in size upwards (0- 30 cm), siltstone clasts, scoured base
0.4	Tan, muddy, fine sandstone; laminated
	Hematitic sandstone
1.7	Brown, poorly sorted hematitic, calcitic, pebbly coarse sandstone; tabular crossbeds (5-20 cm), siltstone clasts, abundant lingulid brachiopod fragments
1.8	Brown, poorly sorted, hematitic, medium sandstone; tabular crossbeds, N2E, 13E; N7E, 14W; overlain by parallel laminations, abundant lingulid fragments
0.4	Cover
10.3	Thick (0-1.5 m), red brown, poorly sorted, fine coarse hematitic sandstone; tabular and festoon crossbeds (0-15 cm), N1W, 11W; N5W, 25E; N42E, 12SE; N48W, 24SE; N28W, 22NE; N53W, 17NE; N40E, 15NW; siltstone clasts. hematite oolites, abundant and thinner (0-30 cm), red brown, muddy fine sandstone; burrow mottled
1.4	Poorly exposed, red brown, muddy fine sandstone; burrow mottled
1.0	Cover

Thickness in meters	
5.0	Red brown, moderately sorted, hematitic, medium sandstone; bimodal tabular crossbeds (0-20 cm) N53W, 12NE; N1W, 11SW; N15E, 20NW; N65W, 12SW; N22W, 11NE; lingulid brachiopod fragments
3.3	Interbedded 1) red brown, medium-coarse, sandstone; festoon and tabular crossbeds (15-20 cm) and 2) muddy fine sandstone; thin (0-5 cm), burrow mottled
0.9	Red brown, poorly sorted, medium sandstone; wavy-lenticular bedding, oscillation ripples along top surfaces
1.3	Red brown, poorly sorted, medium sandstone; tabular and festoon crossbedding (0-15 cm)
5.9	Red-brown, tan, gray, poorly sorted, medium sandstone, muddy fine sandstone, and sandy mudstone; wavy-lenticular bedding
33.7	Cover
	Basal crossbedded sandstone
1.7	Tan, moderately sorted, coarse subarkose; tabular crossbeds (10-25 cm), *Skolithos*?, burrow mottling
2.5	Tan, poorly sorted, medium quartz arenite; large scale foresets (40 cm)
4.5	Buff, tan, very poorly sorted, fine-coarse subarkose or quartz arenite; mostly large scale foresets (0.4-1.9 m), scoured into each other, isolated *Skolithos*, thin (0-30 cm) siltstone units

Thickness in meters	
1.8	Buff, poorly sorted fine-coarse subarkose; tabular crossbeds (3-40 cm), microcline fragments up to 1.5 cm, randomly oriented depressions on top surface, Diplocraterion
0.4	Tan, poorly sorted, medium quartz arenite; tabular crossbeds (0-12 cm) scoured into each other
1.5	Cover
1.8	Tan, poorly sorted, fine-coarse quartz arenite; large scale foreset, N80W, 15 SW, thinning laterally, scoured base, Diplocraterion along top 30 cm
7.9	Tan, pink, poorly sorted, fine-coarse subarkose alternating foresets (10-20 cm) and large scale foresets (1.1-1.3 m) scour contact, N8W, 25NE; N25E, 22NE; N32E, 15SE; N4W, 15NE; N12E, 20SE; N15E, 22SE; N25W, 8NE; N11E, 18SE; N17E, 24SE; N7E, 15SE; N74E, 21SE; Rusophycus at base
0.5	Brown, muddy fine sandstone; sandy mudstone; burrow mottled
2.3	Pink, poorly sorted, fine-coarse subarkose; tabular crossbeds (0-50 cm) alternating with burrow mottling of Diplocraterion or Corophioides
1.0	Tan, pebbly coarse subarkose; large scale foresets, N65W, 24SE, quartz pebbles at base
0.5	Pink, very poorly sorted, fine-coarse pebbly arkose; festoon and tabular crossbeds, N84W
	Valley Springs Gneiss; pink, medium grained foliated, biotite-albite gneiss
100.2	Total thickness

Thickness <u>in meters</u>	
GI-CR, Crabapple Creek, Gillespie County, RM 596, 10 mi. north of Fredericksburg on Mueller Property	
Facies: Burrowed Sandstone	
1.1	Red-brown, coarse sandstone; 4-18 cm festoons, basally scoured
1.1	Red-brown, muddy fine-medium sandstone; mostly burrow mottled from <u>Corophioides</u>, with relic laminations and thin (3-8 cm) crossbedded medium sandstone unit
1.1	Red-brown, medium-coarse sandstone; 10-20 cm festoons and ripple bedforms
0.6	Red-brown, very poorly sorted, muddy medium sandstone; burrow mottled
1.7	Red-brown, and white, medium-coarse sandstone; scoured base, festoons, current and oscillation ripple bedforms, dessication marks, mudstone drapes
0.3	Red-brown hematitic fine sandstone; thin laminated (1-2 cm); ripple cross laminations
5.8	Red-brown and white, poorly sorted, hematitic calcitic, medium-coarse quartz arenite or subarkose; bedding 8-40 cm, low angle foresets, ripple bedforms, festoons most abundant, some burrow mottling, mostly isolated <u>Corophioides</u>
11.6	Total thickness

LL-R1, Roadcut 1, Llano County, along Texas 71, 12 mi. south of Llano: Tectonic orientation- N76E, 4S

Facies: Siltstone facies

1.5	Red-brown, poorly sorted, coarse sandstone with thin sandy siltstone (30-70 cm); foresets, current and oscillation ripple crests, ladder back ripples, siltstone pebbles along scoured base, current ripple crest strike, N79E, N42E, N49E, dip to south
3.3	Tan-brown, sandy siltstone, shale with thin (25 cm) lenticular-wavy bedded sandstone; thin bedded (0-5 cm), mostly sand filled horizontal-oblique burrows (*Planolites*), wavy to parallel laminations, thin beds with siltstone clasts
0.3	Tan, fine sandstone; siltstone clasts, scoured base
1.2	Brown-yellow, sandy shale and muddy fine sandstone; wavy-lenticular bedded, some flasers, some burrows (*Planolites*) thin units (0-15 cm)
0.6	Brown-yellow, muddy sandstone with thin sandy mudstone, siltstone; wavy-lenticular beds, bimodal foresets, siltstone clasts, scoured bases
1.2	Brown-yellow, poorly sorted, muddy sandstone, sandy siltstone and shale; mostly burrowed, some lamination and ripples, thin bimodal foresets, sandstone with siltstone clasts
0.3	Tan, medium sandstone; current ripples tops, bimodal foresets (0-10 cm) base with load casts

Thickness in meters	
1.0	Tan, interbedded, burrowed to laminated sandy shale, fine sandstone and bimodally crossbedded, muddy sandstone; massive sandstone
0.7	Tan, mostly wavy-lenticular bedded muddy sandstone between burrowed sandy mudstone, siltstone, and fine sandstone
0.6	Tan, wavy-lenticular bedded muddy sandstone between burrowed sandy mudstone, siltstone, and fine sandstone
0.7	Tan, muddy sandstone with siltstone clasts, grading into wavy-lenticular bedded sandstone with burrows grading into burrowed sandy shale
0.4	Tan, burrow mottled, sandy mudstone, muddy coarse sandstone with load casts, some crossbeds
0.5	Tan, poorly sorted, coarse sandstone; bimodal (1-5 cm) foresets and festoons, load casts
1.6	Tan-brown, wavy-lenticular sandstone interbedded with laminated and burrowed sandy siltstone, mudstone, with some siltstone clasts, thinly bedded, thickly laminated (1-5 cm)
14.2	Total thickness

Paleocurrent readings from crossbedded sandstone units:
N78E, 15S; N33E, 12N; N37E, 24S; N20E, 12N;
N55E, 28S; N22E, 15N; N37E, 31SE; N24W, 33SW;
N44E, 16N; N43E, 28N; N74E, 10N; N54E, 12N;
N34E, 27S; N48E, 26S

Thickness
<u>in meters</u>

LL-SM, Slick Mountain, Llano County, south side, quarry in Miller Ranch: Tectonic orientation- N55E, 16N

Facies: Hematitic sandstone, even bedded sandstone; Hickory-Cap Mountain

<u>Even bedded sandstone</u>

0.6	Brown, alternating evenly bedded (10-20 cm), calcitic coarse sandstone, and sandy lime grainstones with intraclasts, crossbedded, rippled
2.0	Cover
0.2	Brown, sandy brachiopod grainstone, crossbedded
2.2	Red-brown, poorly sorted, fine-medium, well rounded quartz arenite, hematitic with hematite oolites, crossbedded (10-30 cm) with carbonate lenses of brachiopod grainstone, and burrow mottled sandstone

<u>Hematitic sandstone</u>

3.3	Red-brown, poorly sorted, fine to coarse pebbly sandstone with lenses of white carbonate along crossbeds, topped by thin shale, siltstone with mudcracks, brachiopod fragments; bimodal festoon and planar foresets, N23W, 22W; N66E, 10N; N85W, 16N
3.0	Cover
7.0	Red-brown, poorly sorted, fine to coarse sandstone with siltstone clasts, brachiopod fragments, thin units of shale or mudstone cut out laterally; festoon-planar crossbedding most abundant, burrow mottled units common, branched lined tubes present along shale drapes and lieing obliquely to

Thickness in meters	
	them; much cover
18.3	Total thickness

LL-SQ, Stotts Quarry, Llano County, south flank Packsaddle Mountain on Stotts ranch; Tectonic orientation- N73W, 7N

Facies: Even bedded sandstone

2.8	Alternating units of 1) Tan, fine-medium sandstone; festoon and tabular crossbeds (3-5 cm) and 2) tan, muddy sandstone; in burrow mottled (10-40 cm beds), mostly crossbedded units
0.9	Tan, poorly exposed fine sandstone; laminated, burrow mottled ornamented trails
0.6	Cover
1.2	Red-brown, poorly sorted, hematitic, coarse sandstone; crossbedded and burrow mottled, siltstone clasts, lingulid brachiopod fragments
0.3	Cover, second quarry level
3.6	Alternating units of 1) Tan, fine sandstone; burrowed, overlying 2) red-brown, coarse sandstone; crossbedded (0-10 cm) or laminated and 3) Tan, sandy shales and fine sandstone; burrowed
3.4	Alternating units of 1) Red-brown, poorly sorted, hematitic, coarse sandstone; tabular-festoon crossbeds (3-7 cm) N44E, 17N; and 2) tan, fine sandstone, sandy mudstone; burrow mottled, 'escape structures', unornamented trails
3.9	Alternating units of 1) Tan, calcitic, glauconitic sandy mudstone; burrowed, trails, Phycodes?, 'escape structures', 10-45 cm beds

Thickness in meters	
	and 2) Red-brown, fine-medium, hematitic sandstone; crossbedded (0-15 cm), siltstone clasts, N44W, 12W; N22W, 24N; burrowed units most abundant, begin quarry wall
0.8	Gray, red-brown, and tan, moderately sorted, fine sandstone; shale lined burrows
0.7	Cover
1.5	Mostly tan, red-brown, moderately sorted, fine sandstone; burrowed with thin (20 cm) red brown, hematitic, medium sandstone; tabular crossbed, (10 cm)
21.0	Total thickness

Trace fossils: ornamented and unornamented trails, large radially arranged burrows, Phycodes?, vertical burrows with furrows and horizontal spreite Planolites

MA-KQ, Kothman quarry, Mason County, northwall, along 0.1 miles south of Mason; Tectonic orientation - N51E, 6E

Facies: hematitic sandstone

4.7	Sequences of 1) tan-brown, very thickly bedded (60-70 cm), muddy fine sandstone, and sandy shales, siltstones; small burrows disrupting parallel laminations 2) Red-brown, thickly laminated, medium-coarse, hematitic sandstone 3) Laminated shales with siltstone lenses
1.9	Tan, muddy fine quartzarenites (0.3-0.5 m); burrowed or laminated or with foresets, N86W, 21N; N81W, 21S; alternating with thin (0.1-0.5 m) medium sandstone in low angle crossbeds with siltstone clasts

Thickness in meters	
1.1	Red brown, poorly sorted, hematitic fine-medium sandstone, thin laminated shales; siltstone clasts, lingulid brachiopods, and thin (2-4 cm) tabular crossbeds, N79W, 29N; N47E, 7N; N42W, 9N; N35E, 19E; N51W, 14N
7.7	Total thickness

MA-MB, Martin bluffs, Mason County, along south bluffs of Llano River on Martin Ranch; Tectonic orientation - N35E, 4E

Facies: Siltstone facies, even bedded sandstone, laminated calcitic sandstone

Laminated calcitic sandstone

0.4	Tan, calcitic, poorly sorted, medium-coarse hematitic quartz arenite with sandy lime grainstone lenses; tabular foresets
2.6	Tan, calcitic, fine-coarse sandstone; mostly burrow mottled, some thin lenses carbonate
0.5	Tan, calcitic medium-coarse sandstone; festoons (2-8 cm), hematitic oolites
1.3	Tan-white, calcitic, fine sandstone, mostly burrow mottled, some parallel laminations with burrows
2.2	Tan-white, alternating coarse crossbedded (N49E, 26S) and fine burrowed calcitic sandstone
0.7	Tan-gray, calcitic, fine sandstone, burrows disrupting laminations

Thickness in meters	
2.3	Alternating units of 1) well sorted, calcitic, fine sandstone; laminated or burrowed (20-70 cm) and 2) red-brown, calcitic, medium-coarse sandstone with crossbedding
	Even bedded sandstone
1.3	Tan, fine and coarse, calcitic sandstone; bimodal foresets (5-15 cm)
1.4	Cover
2.0	Alternating coarse and fine sandstone units, crossbedded (30-60 cm)
0.9	Cover
3.2	Poorly exposed, alternating units of 1) red brown, calcitic, medium-coarse sandstone, foresets (5-15 cm), hematite oolites, lingulid brachiopod fragments and 2) tan-white, well sorted, calcitic, fine-medium sandstone; low angle crossbeds, parallel laminatione or burrow mottling
	Siltstone facies
0.8	Tan, moderately sorted, fine sandstone; low angle crossbeds, tabular foresets (8-11 cm)
5.3	Alternating units of 1) thin bedded (5-20 cm), poorly sorted, medium-coarse sandstone; tabular foresets, basally scoured, rippled tops, with clasts of fine sandstone (0-2 cm) and 2) thicker (40-70 cm) sandy siltstone, sandy shales, muddy fine sandstone with relic laminations, sand filled burrows, and thin lenticular sandstone (2-4 cm)

Thickness in meters	
3.0	Tan-red brown, muddy sandstone, sandy shales and siltstones; wavy-lenticular bedding (0-6 cm), crossbedded sandstones, sand filled burrows in finer grained units
0.7	Tan, red-brown, poorly sorted, medium sandstone; festoons (2-7 cm), lingulid brachiopod fragments
1.8	Tan, alternating sandstones, sandy siltstones and shales; wavy-lenticular beds, sandstones decrease in thickness upward, fine-grained units increase; sandstones crossbedded, fine-grained units burrowed
1.35	Mostly crossbedded fine sandstone with lingulid brachiopod fragments; increasing amounts of wavy-lenticular sandstone upward and sandy siltstone upward; basally scoured unit with load casts
0.7	Purple-brown, muddy fine sandstone; horizontal burrows, shale drapes
32.5	Total thickness

MA-RQ, road quarry, Mason County, along highway 71 west of Valley Springs

Facies: transition of hematitic sandstone and even bedded sandstone

Even bedded sandstone

4.5	Tan, calcitic fine sandstone, mostly burrow mottled, (inaccessible, lithology noted from float)
1.4	Gray, tan, red-brown, calcitic fine sandstone, lenses of lime sandy grainstone; interbeds of sandy siltstone, shale, all burrow mottled

Thickness in meters	
2.3	Tan, red-brown, calcitic, fine sandstone, thin sandy siltstone units; festoons (5-20 cm), scoured bases
3.9	Alternating units of 1) Red-brown, poorly sorted, coarse hematitic sandstone with oolites, siltstone clasts, lingulid fragments and 2) Tan, calcitic fine sandstone; thin bedded (0-10 cm), laminated to burrow mottled
	Hematitic sandstone
5.6	Red-brown, poorly sorted, hematitic, medium-coarse sandstone; hematite oolites, lingulid brachiopod fragments, branched lined burrows, dendritic trace; alternating units of festooned (0-30 cm) and burrow mottled (20-50 cm) sandstone
17.7	Total thickness

MA-SQ, Streeter Quarry, Mason Co., along highway 377, 0.6 mi. west of Streeter; Tectonic orientation - N79E, 3N

Facies: hematitic sandstone, even bedded sandstone

	Even bedded sandstone
3.7	Tan, very thickly bedded, calcareous medium-coarse sandstone or sandy trilobite-brachiopod grainstone; mostly festoon, tabular crossbeds (8-25 cm)
	Hematitic sandstone
3.8	Red-brown, hematitic coarse-medium sandstone; thin to medium bedded (0.2-0.5 cm) with festoon or planar crossbedding, horizontal burrows, lingulid brachiopod fragments, hematite oolites and thin bedded

Thickness in meters	
	(20-70 cm) fine sandstone and sandy mudstones with burrow mottling
1.5	Red-brown, poorly sorted, well-rounded hematitic sandstone; hematite oolites, shale drapes, lingulid brachiopod fragments, mostly burrowed, discrete branched tubes
9.1	Total thickness

Paleocurrent data: N39W, 23N; N25E, 19W; N64W, 33N; N54W, 15N; N4E, 20E

MA-WQ, Wagner Quarry, Mason County, next to highway 29, 8 mi. NW of Mason

Facies: Hematitic sandstone

1.4	Poorly exposed; red-brown, poorly sorted, medium-coarse sandstone, wavy bedding planes, medium-thick bedded; small scale planar foresets
0.7	Tan, moderately sorted, medium to coarse sandstone; 10-25 cm sets tabular foresets, N77E, 23NW; N7W, 17SW
0.1-0.2	Red-brown, hematitic, interbeds of laminated siltstone-shale and sandstone
1.7	Tan, red-brown moderately sorted, hematitic, medium-coarse sandstone; hematite oolites with festoons (35 cm), N3W, 14E; Planar foresets, N22E, 17SE; N64E, 17N; N50W, 13N
1.5	Alternations between red brown, poorly sorted, medium sandstone; hematite oolites in festoon and tabular foresets (50-80 cm) with internal shale drapes, and thin burrowed to laminated red brown hematitic sandy shale and siltstones; N43W, 23N; N17W, 19N; N66W, 14N; N45W, 18N

Thickness in meters	
0.1	Tan, red-brown, moderately sorted, hematitic fine sandstone; parallel laminations (thin beds 1-3 cm) disrupted by burrows
0.5	Red-brown, poorly sorted, hematite coated medium sandstone; hematite oolite; 8-12 cm tabular foresets
6.0	Total thickness

McPG, Pennsylvania Glass Sand Quarry, McCulloch County, north of Voca

Facies: basal crossbedded sandstone

1.1	Poorly exposed, medium-coarse sandstone; festoons (0-20 cm) grading into parallel laminated siltstone units (0-20 cm)
1.5	Red-tan, coarse sandstone; large scale foresets filling scours, grade laterally into parallel bedded units of festoon or tabular foresets, thin siltstones interbedded
3.5	Tan, pebbly fine-coarse sandstone; 15-40 cm bedding, scour filling of parallel laminations mostly festoon (0-15 cm) and tabular foresets (0-20 cm)
0-0.1	Red, fine sandstone and siltstone; parallel laminations, ripple cross laminations, cut out laterally
2.3	Tan, siltstone to coarse sandstone; in laterally related units of large scale foresets with basal scour contact cutting into underlying siltstone unit; festoon-planar crossbedding (2-10 cm)
1.6	Tan-orange, poorly sorted, pebbly fine sandstone; foresets, (5-10 cm)

Thickness in meters	
1.7	Tan-red, pebbly fine-medium sandstone; discontinuous nonparallel bedding; parallel laminae or low angle cross beds
2.1	Red, pebbly medium subarkose; tabular foresets (8-15 cm), (10-30 cm) siltstone in middle and top
0.5	Orange-red, pebbly medium subarkose; reverse graded laminae in steep foresets, flattening laterally; interbedded with thin (0-5 cm) red sandy siltstone, parallel laminae
14.3	Total thickness

Paleocurrent data: festoon S66E, tabular crossbeds N45E, 25SE; N55E, 21SE; N61E, 12SE; N72E, 16SE; N62E, 22SE; N30E, 35SE; N17E, 24SE; N20E, 25SE; S89W, 22E; N16E, 24SE; N32E, 25SE; N42E, 25SE; N26E, 24SE; N68E, 21NW; N69E, 24SE; N75E, 22SE; N71E, 15SE; Large scale foresets N3W, 19NE; N12E, 30SE; N25W, 12NE; N80E, 27SE; N40E, 29SE;

McRI, McCulloch County; both sides of US highway 71: 3 mi. east of Voca

Facies: Basal crossbedded sandstone-siltstone facies transition shows lateral relationship of units

1.5	Red-brown to yellow-brown sandy mudstone, siltstone, and fine sandstone; thin bedded (20-30 cm) with flasers, ripple cross lamination (up to 3 cm); burrow mottling, parallel laminations; grades laterally into massive medium sandstone
0.8-1.0	White or yellow-brown basally scoured pebbly sandstone with festoons grading upward into burrowed sandstone and into thin laminated, burrow mottled or cross laminated medium sandstone

Thickness in meters	
2.3	Yellow-brown, thin bedded (3-8 cm), discontinuous, mostly medium to fine sandstone interbedded with sandy siltstones; prominently burrowed, few thin crossbedded units, flaser drapes, wavy-lenticular bedding; grades laterally into faintly laminated medium to coarse sandstone
4.8	Total thickness

Paleocurrent data: N62E, 12S; N44E, 19N; N76E, 28S; N16E, 28S; N54W, 28S; N34E, 12S; N46E, 24S; N41W, 15S; N60E, 26S; N86E, 12S

Mc SS1, San Saba River, McCulloch County, on north bank near shallow ford on Bodenhammer Ranch; Tectonic orientation - N79, 7N

Facies: Hematitic sandstone, even bedded sandstone laminated calcitic sandstone

Laminated calcitic sandstone

4.5	Gray, alternating sandy lime mudstones and calcareous fine sandstone, burrow mottled with some relic laminations
1.0	Alternating gray, burrowed and laminated fine sandstones with thin (4-7 cm) red-brown coarse hematitic sandstone with hematite oolites
5.6	Gray, alternating burrowed and laminated fine sandstones; parallel laminations every 20-40 cm
1.4	Gray, alternating thick, burrow mottled, fine sandstone with thin bedded (2-4 cm) laterally discontinuous units of parallel to wavy laminated calcitic fine sandstone, some thin laminae of lime mudstone

Thickness in meters	
1.5	Tan-gray, calcitic fine sandstone; mostly burrow mottled with relic laminae and crossbedding
	Even bedded sandstone
1.5	Alternating tan-gray, fine sandstone; burrowed, and red-brown, poorly sorted, coarse, hematitic, calcitic, sandstone with siltstone clasts; crossbedded
	Hematitic sandstone
3.0	Red-brown (20-70 cm thick), hematitic, fine to coarse sandstone with intraclasts, hematite oolites; fossil fragments; crossbedded units and burrow mottled units, with more crossbedding upward
3.0	Red-brown, poorly sorted, hematitic, calcitic, coarse-medium sandstone with thin (8-20 cm) sandy siltstone units; mostly festoon or low angle foresets, siltstone clasts, abundant fossil fragments, burrow mottled zones, wavy-lenticular bedded units
21.5	Total thickness

Mc-SS2, San Saba River, section 2, McCulloch County, South bluffs of river on Bodenhammer ranch

Facies: Hematitic sandstone

0.4	Red-brown, poorly sorted, medium-coarse hematitic sandstone; with hematite oolites, siltstone clasts, shale drapes, festoon crossbedding, N65E, 17N
0.2	Red-brown, thinly laminated, sandy siltstone, sandy shale

Thickness in meters	
3.0	Red brown, thick bedded, poorly sorted, medium-coarse, hematitic, sandstone with hematite oolites, siltstone clasts, shale as flasers, and tabular crossbeds; N87W, 17N
0.4	Red-brown to gray-green, fine sandstone, sandy siltstone in wavy-lenticular beds (1-3 cm), numerous horizontal burrows in sandy siltstone
0.3	Red-brown, poorly sorted, fine-medium sandstone, crossbedded (0.5-15 cm)
0.4	Red-brown to tan, fine sandstone, sandy siltstone in wavy-lenticular beds (1-4 cm), disrupted by burrows
0.7	Red-brown, poorly sorted, hematitic sandstone, massive
5.4	Total thickness

SS-PC, Panther Creek, San Saba County

Facies: Hematitic sandstone, siltstone facies, basal crossbedded sandstone

Hematitic sandstone

2.5	Red-brown, poorly sorted, medium-coarse sandstone; festoons, N12E, N22E, N65E, small amount of burrowing, siltstone intraclasts abundant, scoured base
0.5	Cover
0.3	Tan, very fine quartz arenite; burrow mottling interrupting laminations

Thickness in meters	
3.2	Red-brown, hematitic, poorly sorted to well sorted, medium-coarse sandstone; festoons, burrowing, abundant lingulid brachiopod fragments, siltstone clasts, thin wavy-lenticular bedded sandstone, flasers
1.7	Tan, red brown, fine sandstone, sandy siltstone; mostly burrow mottling (vertical) interrupting parallel laminations, some crossbeds
0.9	Cover
	Siltstone facies
1.5	Tan, mostly burrow mottled, muddy fine sandstone and sandy siltstone; wavy-lenticular beds
0.7	Tan, well sorted, medium sandstone, foresets grading into festoons
0.7	Tan, calcitic fine sandstone; wavy-lenticular bedded, burrowed
3.9	Cover
2.4	Tan, brown, calcitic, medium sandstone, muddy fine sandstone, sandy mudstone; thin beds (0-70 cm), mostly wavy-lenticular, some burrow mottling, Planolites, parallel laminations, siltstone clasts
8.3	Cover
4.1	Tan, poorly exposed, muddy fine sandstone, sandy siltstone; thin beds (0-70 cm), lenticular-wavy bedding, parallel laminations, sand filled horizontal and oblique burrows

Thickness in meters	
1.2	Tan, very poorly sorted, very coarse pebbly sandstone; bimodal foresets, N85E, 27N; N74W, 13S; siltstone clasts, scoured base
1.0	Tan, sandy siltstone, muddy fine sandstone; wavy-lenticular bedded, burrow mottled siltstone, sand filled burrows
0.8	Cover
	<u>Basal crossbedded sandstone</u>
1.2	Interbedded 1) poorly sorted, medium sandstone; foresets (0-5 cm) and 2) sandy siltstone; thin (0-5 cm), laminated or burrowed
1.2	Tan, poorly sorted, very coarse-fine quartz arenite-subarkose; large scale foresets N90E, 14S
1.0	Tan, very poorly sorted, fine sandstone; burrow mottled, isolated lined vertical burrows, <u>Skolithos?</u>
1.0	White, poorly sorted, coarse subarkose; two sets of large scale foresets (50 cm)
0.5	White, very fine sandstone; parallel laminations
3.5	Pink, tan, very poorly sorted, coarse sandstone; numerous sets of large scale foresets (30-70 cm), laminations reverse graded, N27E, 32E
1.2	Cover
2.0	Tan, poorly sorted, fine-coarse sandstone; festoons (0-30 cm) S32E, S65E, S30E, S35E, S39E, S19E

Thickness in meters	
0.1	Pink, fine sandstone; parallel laminations
3.0	White, poorly sorted, pebbly fine sandstone; festoon (N4W) and tabular crossbeds, (0-30 cm) and large scale foresets (0-1.0 m) N80E, 17SE; N22E, 14E; N59E, 16E
1.3	Cover
3.5	Poorly exposed, mostly pink, poorly sorted, coarse subarkose; tabular foresets, festoons scoured bases, some thin (0-30 cm) sandy siltstone beds, burrow mottling infrequent
	Valley Springs Gneiss: Gray, red-brown, foliated, N40W, 16N; fine grained biotite, microcline gneiss, fine grained granite veins
53.2	Total thickness

SS-PO, Pontotoc section, San Saba County, both sides of road, 2 mi. north of Pontotoc

Facies: Hematitic sandstone, even bedded sandstone, laminated calcitic sandstone

Laminated calcitic sandstone

4.1	Gray, calcitic, muddy fine sandstone; bedding (5-20 cm), mostly burrow mottled units (0-70 cm), some parallel laminations, few festoons with basal scour
0.9	Gray-tan, calcitic, muddy fine sandstone; parallel laminations with burrows disrupting laminations
1.0	Tan-gray, fine-medium, well sorted, calcitic sandstone; parallel laminations, festoons (10-20 cm), and burrow mottling

Thickness in meters	
1.9	Tan, gray, calcitic, fine sandstone; mostly burrow mottled but with few festoons (0-20 cm)
	Even bedded sandstone
1.4	Red-brown, poorly sorted, hematitic, pebbly coarse sandstone; festoons (0-30 cm) and shale drapes, oscillation ripples along top surface trending N79W
0.4	Tan, calcitic, muddy fine sandstone; burrow mottled
	Hematitic sandstone
1.0	Red-brown, poorly sorted, hematitic, pebbly coarse sandstone; hematite coated siltstone intraclasts, lingulid fragments, shale drapes near top, festoons (0-20 cm)
0.4	Red-brown, poorly sorted, hematitic, coarse sandstone; festoons (0-5 cm), burrowed near top
11.1	Total thickness

G.L. Rowsey, #2 Fee, Bandera County, cored interval 6731-6860 feet

Facies: laminated calcitic sandstone

interval in feet	description
6730-6740	Tan, brown, well sorted, calcitic, medium quartzarenite and poorly sorted, pebbly coarse subarkose; crossbedded, stylolites, fossil fragments, glauconite

interval in feet	
6740-6744	Gray, calcitic fine subarkose, sandy siltstone; laminations disrupted by 'escape structures' and minor burrow mottling, glauconite
6745-6750	Gray, medium subarkose; mostly crossbedded, basal scour contact, glauconite, mudstone clasts, trilobite and other fossil fragments
6750-6767	Gray, fine sandstone and sandy mudstone; mostly burrow mottled, glauconite, fossil fragments including trilobite debris
6767-6770	Gray, medium-coarse quartz arenite; crossbedded, glauconite, siltstone fine sandstone clasts, trilobite fragments
6770-6776	Gray, silty mudstone; laminated and ripple cross laminated; glauconitem trilobite debris
6776-6801	Gray, pebbly fine-coarse arkose, thin interbeds of sandy mudstone; mostly festoons, and tabular crossbeds, abundant glauconite and fine sandstone intraclasts (0-3 cm)
6805-6813	Gray, green, interbedded, sandy mudstone, and medium sandstone; laminated, lenticular, and crossbedded glauconite
6813-6822	Gray green, sandy mudstone; laminated with horizontal burrows
6822-6828	Gray, coarse arkose; crossbedded, laminated
6828-6837	Light gray, fine-coarse sandstone, sandy mudstone; laminated, 'escape structures'

interval in feet	
6837-6860	Tan, light gray, poorly sorted, pebbly coarse arkose and fine-coarse arkose; mostly crossbed, ripple cross laminations, some clay clasts, abundant fractures

Tucker #1 Perkins, Kerr County; cored interval 3307-3334 feet

Facies: laminated calcitic sandstone

3307-3312	Black and gray, shaley sandstone, medium sandstone, and shale; small scale ripple cross laminations, burrow mottling disrupting laminations, glauconite
3312-3315	Gray, fine-medium quartz arenite; 2-3% porosity, small scale festoons, basal scour contact
3315-3317	Gray, fine-medium quartz arenite and sandy, silty shale; burrow mottling
3317-3319	Gray, fine-medium sandstone; tabular cross-beds, gradational upper contact
3319-3323	Gray, silty shale, muddy fine sandstone; calcitic, ripple laminations, burrow mottling, 'escape structures'
3323-3327	Gray, fine-medium sandstone, with thin shale parting; crossbedded with burrow mottling, glauconite
3327-3331	Gray, sandy and silty shale; burrow mottling abundant, some ripple cross lamination, brachiopod? fragments
3331-3334	Gray, fine-medium quartz arenite; cross-bedding abundant, minor burrow mottling, brachiopod? fragments

interval
in feet

Texas Water Development Board #2 White, Mason County; cored interval 41-299 feet

Facies: basal crossbedded sandstone and siltstone facies

Siltstone facies

41-42	Red, medium quartz arenite; laminated, siltstone clasts (0-5 cm)
42-50	Red, sandy siltstone and muddy fine sandstone; ripple lamination, and burrowing
50-61	Orange, fine-medium quartz arenite; cross-bedded, some flasers, siltstone and clay clasts
61-82	Orange, red, fine sandstone interbedded with sandy siltstone; wavy-lenticular bedding, ripples, flasers, load casts, siltstone clasts
82-84	Red, fine-medium quartz arenite; cross-bedded, siltstone clasts
84-89	Orange, interbedded sandy siltstone and fine sandstone; wavy-lenticular bedding flasers, minor burrowing
89-92	Orange, poorly sorted, fine-coarse sand-stone; festoons, scoured base
92-96	Orange, interbedded fine-medium sandstone and sandy shale; laminated, rippled, burrowed

interval in feet	
	Basal Crossbedded sandstone
100-123	Red brown, poorly sorted medium sandstone; tabular and festoon crossbeds, minor ripples
123-129	Red brown, fine sandstone, ripples
129-233	Pink, poorly sorted medium sandstone; fine-coarse, crossbedded, rippled, U-shape burrows (136, 143, 151, 167, 198)
250-294	Pink, red, poorly sorted, fine-coarse arkose; crossbedded, graded laminae, isolated vertical burrow traces, thin siltstone beds
294-297	Red, sandy mudstone; ripples
297-299	Red, poorly sorted, pebbly coarse arkose; crossbedded

Texas Water Development Board #1 Behrens, McCulloch County, core interval 60-366 feet

Facies: basal crossbedded sandstone, and siltstone facies

	Siltstone facies
60-62 75-78	Orange, tan, fine-medium pebbly quartz arenite; crossbedded, siltstone clasts, lingulid brachiopod fragments, leisagang banding
78-93	Tan, interbedded, sandy siltstone and muddy sandstone; horizontal sand filled burrows, laminations, lingulid brachiopod fragments

interval in feet	
93-96	Tan, pebbly coarse sandstone; crossbedded, flasers
96-115	Gray-tan, thin interbeds, sandy siltstone and muddy sandstone; horizontal burrows, small scale lenticular bedding, sandier towards bottom
115-121	Red, muddy sandstone; ripple cross laminations, burrows, flasers
121-147	Red, tan, mostly pebbly coarse sandstone; crossbedded, ripple laminations, flasers
147-167	Tan, interbedded medium sandstone and sandy siltstone; crossbedded, rippled, and burrows
	Basal crossbedded sandstone
167-191	Red, fine sandstone to pebbly coarse sandstone; bimodal, crossbedded, rippled, U-shape burrows, burrow mottling, coarsens towards base
191-198	Red, interbedded coarse quartz arenite and sandy siltstone; crossbedded, burrowed
198-238	Red, poorly sorted coarse and pebbly coarse quartz arenite; crossbedded, some flasers, some burrow mottling isolated U burrows (223 and 227)
238-245	Tan, red, interbedded medium sandstone, and sandy siltstone; crossbedded, and laminated U burrows
245-271	Tan, pebbly coarse subarkose; large scale foresets and smaller crossbeds
271-277	Tan, muddy fine sandstone with thin sandy siltstone; ripple cross laminations

interval in feet	
277-295	White, red brown, poorly sorted medium-coarse sandstone; crossbedded, vertical burrow traces
295-310	White, red-brown, fine sandstone; ripple cross laminations, laminated sandstone, burrows
310-317	White, pebbly coarse subarkose; cross-bedded
317-321	Red brown, sandy siltstone; laminations, burrows
321-334	Red brown, pebbly coarse subarkose to fine subarkose; crossbedded, some flasers, coarsest at base

Precambrian

334-366	Pack Saddle Schist?, green foliated serpentine

Texas Water Development Board #3, McCulloch County; cored interval 198-628 feet (uncut)

Facies: basal crossbedded sandstone, siltstone facies, hematitic sandstone

Hematitic sandstone

198-224	Red brown, pebbly coarse hematitic sandstone to fine-medium hematitic sandstone; cross-bedding abundant, minor burrow mottling, siltstone clasts, abundant lingulid brachiopod fragments, branched tubes (214'), upward fining
224-226	Yellow brown, sandy mudstone; rippled burrow mottled

interval in feet	
226-241	Red brown, poorly sorted, fine-coarse sandstone; hematitic abundant lingulid brachiopod fragments, crossbedded, scour contacts burrowed zone (233)
241-249	Light brown, hematitic sandy mudstone; burrows, minor ripples
249-290	Red brown, hematitic, pebbly coarse sandstone; crossbedded, siltstone clasts, numerous scour contacts, abundant lingulid fragments

Siltstone facies

290-332	Red, mostly hematitic, poorly sorted sandstone; crossbedded, rippled, thin flasers, and mudstone units
332-421	Gray, tan, mostly crossbedded medium sandstone interbedded siltstone clasts (4-12 feet) with wavy-lenticular bedded muddy sandstone and sandy siltstone
421-449	Tan, medium sandstone; crossbedded with numerous fractures
449-465	Tan, medium sandstone; crossbedded
465-468	Tan, sandy siltstone; ripples, burrows

Burrowed sandstone

468-538	Tan, brown, coarse sandstone; mostly crossbedded, some thin sandy siltstone interbeds, U-shape burrows isolated

interval in feet	
	Basal crossbedded sandstone
543-628	Tan, poorly sorted, pebbly coarse arkose; mostly crossbedded, siltstone clasts (610') with minor thin sandy siltstone beds
628	Precambrian

Texas Water Development Board Development Board #4, McCulloch County; cored interval 509-780 feet (uncut)

Facies: hematitic sandstone, siltstone facies, basal crossbedded sandstone

	Hematitic sandstone
509-529	Red-brown, poorly sorted hematitic sandstone; mostly crossbedded, some burrow mottling, siltstone clasts, flasers
	Siltstone facies
570-609	Brown, poorly sorted, hematitic, fine-medium sandstone; mostly crossbedded, siltstone fragments, thin sandy siltstone beds, lingulid brachiopod fragments
609-622	Red brown, sandy siltstone; ripples, burrows
622-630	Red brown, poorly sorted, fine-medium sandstone; crossbedded, flasers, siltstone clasts
630-637	Tan, sandy mudstone; laminated, rippled
637-653	Tan, poorly sorted, fine-medium sandstone; crossbedded, ripples, flasers, lingulid brachiopod fragments
653-672	Orange and gray, sandy mudstone; rippled and burrowed

interval in feet	
672-682	Orange, fine sandstone; rippled, flasers, fractures
682-706	Tan, fine-coarse sandstone and pebbly coarse sandstone; crossbedded, some burrow mottling, minor flasers, basal scour contact coarsening downwards
	Basal crossbedded sandstone
706-717	Buff, sandy mudstone; ripple laminations, burrows
717-767	Buff, poorly sorted pebbly coarse sandstone, mostly crossbedded, some minor flaser and ripple bedding, abundant scour contacts
767-778	Buff, poorly sorted, medium-coarse sandstone; burrow mottled
778-780	Precambrian, Town Mountain granite, pink biotite-quartz-microcline granite

FACIES NAME \ LEBENSPURREN	VERTICAL BURROWS WITH FURROWS	VERTICAL BURROWS WITH SPREITE	SMOOTH TRAILS	SCRATCHMARKS	RADIAL BURROWS	ORNAMENTED TRAILS	'ESCAPE STRUCTURE'	DENDRITIC RIDGES	BRANCHING TUBES	SKOLITHOS?	RUSOPHYCUS	PLANOLITES	PHYCODES?	PELECYPODICHNUS?	DIPLOCRATERION	DIPLICHNITES	CRUZIANA	CROSSOCHORDA	COROPHIOIDES	CLIMACTICHNITES
BASAL CROSSBEDDED SANDSTONE										Cs	Cs	Fn			Cs		Cs	Cs	Cs	
BURROWED SANDSTONE																			Cs	Cs
SILTSTONE FACIES			Cs	Cs								Fn		Cs						
HEMATITIC SANDSTONE								Fn	Cs			Fn								
EVEN BEDDED SANDSTONE	Cs Fn	Cs Fn	Cs Fn	Cs Fn	Fn	Cs Fn	Cs					Fn	Fn			Fn				
CALCITIC LAMINATED SANDSTONE							Cs				Cs						Cs			

Occurrence by sediment grain size

Cs coarse-fine sandstone

Fn muddy sandstone, sandy siltstone, sandy shale

For terms used, see Appendix I.

APPENDIX III. Occurrence and description of Lebenspurren

Ichnogenus CLIMACTICHNITES

Plate II-D

Description- unbranched linear, straight to meandering, shallow trackway with internal ridges and grooves oriented perpendicular to long axis: width (5-8 cm); length (only traced to 15 cm); height (less than 1 cm).

Toponomy- epichnial groove

Ethology- crawling trace (repichnia)

Occurrence- fine to coarse sandstone of burrowed sandstone facies

Ichnogenus COROPHIOIDES

Plate I-E, I-F, II-B, II-E

Description- U-shaped vertical burrow, with or without protrusive and retrusive spreite, tubes of U are not parallel: distance between U tubes (1.5-2.5 cm); diameter of tube itself (0.3 cm); length (up to 10cm).

Toponomy- U-shaped endichnial tubes, horizontal surfaces reveal paired holes or epichnial groove

Ethology- dwelling structure (domichnia)

Occurrence- confined to fine-coarse sandstone of basal crossbedded sandstone and burrowed sandstone

Ichnogenus CROSSOCHORDA

Plate I-C

Description- unbranched linear, straight to meandering, bilobate trail with internal scratchmarks: diameter (0.3-1.0 cm); height (less than 0.5 cm); length (5 cm maximum).

Toponomy- hypichnial ridge

Ethology- crawling trace (repichnia)

Occurrence- confined to sandstone of the basal crossbedded facies

Ichnogenus CRUZIANA

Plate I-A, I-B

Description- unbranched linear, shallow bilobate trackway with internal scratchmarks: width (2-4 cm); height (1-3 cm) length (9 cm on longest preserved specimen).

Toponomy- hypichnial ridge

Ethology- crawling trace (repichnia)

Occurrence- confined to sandstone of basal crossbedded facies and laminated calcitic sandstone

Ichnogenus DIPLICHNITES

Plate V-A

Description- unbranched straight track of paired scratchmarks: length (6 cm - incomplete); diameter (3 cm).

Toponomy- epichnial grooves

Ethology- crawling trace (pascichnia)

Occurrence- muddy fine sandstone of evenbedded facies

Ichnogenus DIPLOCRATERION

Plate I-D

Description- U-shaped vertical burrows with or without protrusive and retrusive spreite, both tubes of U parallel: distance between U tubes (2.0-3.0 cm); diameter of tube itself (0.3-0.5 cm); length (up to 10 cm).

Toponomy- U-shaped endichnial tube, horizontal surfaces, several epichnial grooves or paired holes

Ethology- dwelling structure (domichnia)

Occurrence- confined to fine-coarse sandstone of basal crossbedded sandstone

Ichnogenus PELECYPODICHNUS?

Plate III-E

Description- small, football shaped grooves: diameter (0.5-1.0 cm); length (1.4-2.0 cm).

Toponomy- epichnial groove

Ethology- resting trace (cubichnia)

Occurrence- in thin sandstones of siltstone facies

Ichnogenus PHYCODES?

Plate V-C

Description- unbranched linear burrow cast, poor preservation: diameter (1.5 cm); length (15 cm).

Toponomy- hypichnial ridge

Ethology- feeding structure (fodinichnia)

Occurrence- confined to muddy sandstone, sandy siltstone, and shale of the even bedded sandstone

Ichnogenus PLANOLITES

Plate V-B, V-C, V-G

Description- short straight-curved, branched or unbranched linear ridges on bottoms of beds or internal sand filled burrows, horizontal or randomly inclined: diameter (less than 0.4 cm); length (less than 3 cm).

Toponomy- hypichnial ridge or exichnial cast

Ethology- feeding structure (fodinichnia)

Occurrence- found as sand filled burrows within fine grained units of basal crossbedded sandstone, siltstone facies, hematitic sandstone, and even bedded sandstone

Ichnogenus RUSOPHYCUS

Plate I-B

Description- bilobate mound with scratchmarks: width (0.9-7.6 cm); length (1.1-10.6 cm); depth (0.1-2.2 cm).

Toponomy- hypichnial ridge

Ethology- resting trace (cubichnia)

Occurrence- fine to coarse sandstone of the basal crossbedded sandstone, and laminated calcitic sandstone

Ichnogenus SKOLITHOS?

Description- straight vertical burrow, cross sections are circular depressions: diameter (up to 2 cm); length (15 cm)

Toponomy- endichnial tube

Ethology- dwelling structure (domichnia)

Occurrence- isolated tubes confined to basal crossbedded facies

Branching tubes

Plate IV-A, IV-B

Description- linear, curved, branching lined tubes, horizontal or randomly inclined, external ornamentation - random knobs, branching occurring at 4-6 cm intervals: external tube diameter (0.9-1.2 cm); internal tube diameter (0.4 cm).

Toponomy- endichnial tube

Ethology- dwelling structure (domichnia)

Occurrence- confined to crossbedded sandstone of hematitic sandstone unit

Dendritic hypichnial ridges

Plate IV-C

Description- intricately branched (dendritic) pattern, branches decrease in size with branching, branches reconnect: diameter of main stem (1 cm); diameter of smallest branch (0.1 cm); whole structure (32 cm - incomplete).

Toponomy- hypichnial ridge

Ethology- feeding structure (fodinichnia)

Occurrence- near top of hematitic sandstone on base of muddy fine sandstone

"Escape structures"

Description- mechanically backfilled burrows showing parallel-subparallel upward curving laminae: diameter (1-4 cm); depth (2-4 cm).

Toponomy- endichnial burrow

Ethology- dwelling structure? (domichnia?)

Occurrence- fine sandstone of evenbedded sandstone and laminated calcitic facies

Ornamented trails

Description- horizontal, straight to slightly curved, nonbranching trails with internal ornamentation of either several parallel grooves or sinuous grooves running parallel to trail trend: length (up to 35 cm); width (2-3 cm).

Toponomy- epichnial groove or hypichnial ridge

Ethology- crawling trace (repichnia)

Occurrence- preserved upon sandstone surfaces of even bedded sandstone

Radial burrows

Plate V-G

Description- large straight unbranched burrow ridges arranged in a radial pattern: individual burrow diameter (2-4 cm); length (up to 15 cm); entire structure (1o-15 cm in diameter).

Toponomy- hypichnial ridge

Ethology- feeding structure (fodinichia)

Occurrence- on bottom of muddy sandstone of even bedded sandstone facies

Scratchmarks

Plate I-B, III-A, V-B

Description- numerous parallel-subparallel straight to slightly curved grooves or ridges, grouped or isolated: length (up to 5 cm).

Toponomy- epichnial grooves, hypichnial ridges

Ethology- crawling traces (pascichnia)

Occurrence- fine sandstones of basal crossbedded sandstone siltstone facies, even bedded facies

Unornamented trails

Plate III-C, IV-D

Description- smooth, unbranched, straight to sinuous, linear trail: length (less than 10 cm); diameter (0.2-0.3 cm).

Toponomy- epichnial groove

Ethology- crawling trace (repichnia)

Occurrence- on top of rippled fine-medium sandstone of siltstone facies, on muddy fine sandstone, sandy siltstone and of even bedded facies

Vertical burrow with horizontal spreite

Plate V-E

Description- vertical burrow capped by horizontal spreite at upper end, spreite pattern: width (2 cm).

Toponomy- spreite as epichnial ridges, burrow as endichnial casts

Ethology- feeding trace (fodichnia)

Occurrence- muddy fine sandstone, sandy siltstone, sandy shales of even bedded facies

Vertical burrow with concentric furrows

Plate V-D

Description- vertical burrow capped by concentric furrows at upper end: diameter of entire trace (7.5 cm); diameter of tube (1.3 cm); length (indeterminable).

Toponomy- burrow - endichnial cast, concentric furrows, epichnial ridges

Ethology- dwelling or feeding structure (domichnia or fodinichnia)

Occurrence- in fine-coarse sandstone of even bedded sandstone facies

FACIES NAME	BEDDING THICKNESS				BEDFORMS				
	VERY THICK	THICK	MEDIUM	THIN BEDDED LAMINATED	ROUNDTOP SYMMETRICAL RIPPLES	SHARP CRESTED SYMMETRICAL RIPPLES	STRAIGHT ASYMMETRICAL RIPPLES	LINGULID RIPPLES	LADDER BACK RIPPLES
BASAL CROSSBEDDED SANDSTONE	A	A	C	C	R				
BURROWED SANDSTONE	C	A	C	C	C	R	C	C	C
SILTSTONE FACIES	C	C	A	A		C	C		C
HEMATITIC SANDSTONE	C	A	A	R	C	C	C		
EVEN BEDDED SANDSTONE		C	A	C	R				
LAMINATED CALCITIC SANDSTONE	C	C	A	A					

APPENDIX IV. Table of characteristic sedimentary features of the lithofacies; A - abundant, C - common, R - rare.

FACIES NAME	SEDIMENTARY STRUCTURES										OTHER		
	Large scale foresets	Planar crossbeds	Festoon crossbeds	Parallel laminations	Oscillation cross laminations	Ripple cross laminations	Wavy-lenticular bedding	Flaser bedding	Mudcracks	Burrow mottling	Siltstone clasts	Hematite oolites	Glauconite
BASAL CROSSBEDDED SANDSTONE	A	A	C	C	R	R				C	R		
BURROWED SANDSTONE		C	A	R	C	C	R	R	R	A	R		
SILTSTONE FACIES		C	R	R	C	C	A	C		C	A	R	R
HEMATITIC SANDSTONE		C	A		R	C	C	C	R	C	C	C	C
EVEN BEDDED SANDSTONE		A	C	C		R				C	C	R	C
LAMINATED CALCITIC SANDSTONE		R	R	A		R				A	R	R	C

APPENDIX IV. (continued)

APPENDIX V. List of wells used for regional correlations and isopach maps. Locations shown on Figure 1.

E - electric log, L - lithologic log, C - core (total thickness in meters), X - used in cross section

Bandera County

X	1.	Gen. Crude #1 Anderson	E	L	
	2.	G.L. Rowsey #2 Fee	E	L	C(47.5)

Blanco County

	1.	Stratoray #1 A Stribling	E	L	
	2.	Shell #3 Stribling	E		
	3.	Blumberg #1 Wagner		L	

Brown County

	1.	Ambassador #1 A Newton	E		
	2.	Danewood #] Smith		L	
X	3.	Deaton #1 Deaton	E		

Burnet County

	1.	Murchison Ranch Well	E	L	
	2.	Pitcher Mining		L	

Coke County

X	1.	Sun #1 Millican	E		
	2.	Sun #1 Central National Bank	E		
	3.	Humble F90 Odom	E	L	
X	4.	Sun #1 Millican	E		

<u>Coleman County</u>

	1.	Killam #1 Gill	E		

<u>Comanche County</u>

	1.	Davis #1 Hanson	E		
	2.	Humble #1 Autry	E		

<u>Concho County</u>

X	1.	Union #1 Campbell	E	L	
X	2.	Humble #1 Sims	E	L	

<u>Edwards County</u>

X	1.	Humphrey and Winn #1 Peterson	E	L	
X	2.	Naylor #1 Mitchell	E	L	
X	3.	Lecuno #1 Shelmire	E		

<u>Gillespie County</u>

	1.	Rowntree #1 Kott		L	
	2.	Thousand Island #1 Hayden		L	
	3.	Lewis #1 Kott		L	
	4.	Gillespie #1 Dickey		L	

<u>Irion County</u>

X	1.	Atlantic #1 Noelke	E	L	

<u>Kerr County</u>

	1.	Rowsey #2 Nowlin	E	L	
	2.	Tucker #1 Perkins		L	C(8.2)

Kimble County

X	1.	Phillips #1 Spiller	E	L	
	2.	Irwin #1 Kothman	E	L	
	3.	Humble #1 Bolt	E	L	
	4.	Manahan #1 Grosenbach	E		
	5.	Forest #1 Stapp		L	

Lampasas County

	1.	West Lampasas #1 Whittenburg		L	
	2.	Roeser and Pendleton #1 Bunch		L	
	3.	Texoleum #1 White		L	
	4.	American #1 Abney		L	

Mason County

	1.	Water Dev. Board Test Hole #2	E	L	C(103.9)
	2.	Carpenter #1 Bradshaw		L	
	3.	Cochran and Steward #1 Brandenburger		L	

McCulloch County

	1.	Prairie #1 Zelle		L	
X	2.	Osborn #1 Curtis	E		
	3.	Burford and Brimm #1 Cawyer		L	
	4.	Thomas #1 Craig		L	
	5.	McDaniel #1 Hedge	E		
	6.	Thomas #1 White		L	

X	7.	Kent and Preston #1 Brady	E		
	8.	Tucker #1 Harkrider	E		
	9.	Water Dev. Board test hole #4	E		C(70.1)
	10.	Water Dev. Board test hole #1	E		C(89.3)
	11.	Water Dev. Board test hole #3	E		C(132.6)
Menard County					
	1.	Humble #1 Rogers	E		
X	2.	Allison #1 Volkmann	E		
X	3.	Deep Rock #1 Bevans	E	L	
	4.	Phillips #1 Meta	E	L	
X	5.	American Republic #1 Bradford	E	L	
X	6.	Dakota #1 Rudder	E		
	7.	Naylor #1 Nasworthy	E		
Mills County					
X	1.	Slavin #1 Reeves	E		
	2.	Venture #1 Harrison and Slavin		L	
Runnels County					
X	1.	Superior #1 McDowell	E	L	
San Saba County					
X	1.	Bobbie Griffithe #1 Sofge	E	L	
	2.	Cayce #1 Moore		L	
X	3.	Humble #1 Millican			

	4.	Montgomery #1 Yates		L
X	5.	Murray #1 Yates	E	

<u>Schleicher County</u>

	1.	Tucker #1 Boyd	E	L
	2.	Phillips #1 Callan	E	L
	3.	Scherkz and Chizum #1 Wilson	E	L
X	4.	Panaco #1 Moore	E	
X	5.	Humble #1 Stanford	E	L
	6.	Humble #1 Spencer	E	

<u>Sutton County</u>

X	1.	Humble #1 North Branch	E	
X	2.	Hunt #1 Gibbs	E	
X	3.	Union #1 Schwerning	E	L
X	4.	Phillips #1A Libbwallis	E	
	5.	Shell #3 Miers	E	

<u>Tom Green County</u>

X	1.	Honolulu #1 Nasworthy	E	
X	2.	Richardson #1 Schwartz	E	L

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