DEPOSITIONAL ENVIRONMENT OF WOODBINE AND EAGLEFORD SANDSTONES AT OSR-HALLIDAY FIELD, LEON AND MADISON COUNTIES, TEXAS

A Thesis

by

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ABSTRACT

Depositional Environment of Woodbine and Eagleford
Sandstones at OSR-Halliday field, Leon and
Madison Counties, Texas. (August, 1984)
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Chairman of Advisory Committee: Dr. Robert R. Berg

OSR-Halliday field is a stratigraphic oil trap in Leon and Madison counties, Texas. The composition, texture, sedimentary structures including trace fossils and the morphology of three cored Woodbine sandstones have been used to determine depositional environments in and near the field. Knowledge gained from this study will enhance future petroleum exploration efforts in the area.

The "69-3" sandstone is the oil producing sandstone at OSR-Halliday field. The sandstone is dominated by ripple laminae with few trace fossils. The sandstone body is elongate north-south, and is irregular in outline with some east-west components. Delta front sediments of the "Harris" delta were transported to the north by longshore currents, and deposited as the "69-3" offshore bar. Offshore currents and paleotopography also affected sandstone distribution.

The "49-3" sandstones were cores approximately 250 feet below the "69-3" sandstones. These thin sandstone units have a sharp basal contact, are massive at the bottom and rippled or interlaminated with shales at the top. Bioturbation is restricted to the top of these sandstones. Storms deposited the "49-3" sandstones on the shelf about 40 miles from the shoreline.

The third core was taken from Woodbine sandstones in Trinity County, Texas about 50 miles east of OSR-Halliday field. Three facies have been distinguished - delta front, distributary channel, and interdistributary bay. Coarsening upward, bioturbated delta front sandstones are overlain by a fossiliferous channel lag, a thick cross-bedded sandstone and finally a rippled unit. This fining upward sequence represents the distributary channel. Fossiliferous shales of an indistributary bay were deposited on top of these sandstones following abandonment of the channel. A second delta front/distributary channel sequence overlies the interdistributary bay deposits.

Upper Eagleford sandstones at OSR-Halliday field were interpreted to be storm generated deposits by Theiss (1983). These sandstones have an elongate, irregular north-south trending morphology similar to the morphology of the "69-3" sandstone. Differential compaction of underlying sediments controlled the distribution of the Eagleford sandstones.

Three deltaic systems prograded from the east to the west during the middle Woodbinean to early Eaglefordian. The "MJ1" deltaic sandstones are from the second sequence, and may have been the source for the "49-3" storm deposits. The "69-3" offshore bar is equivalent to the base of the third or uppermost delta, the "Harris" delta. Upper Eagleford sandstones were deposited during a major transgression which brought deeper shelfal conditions back into Leon and Madison counties.

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Last and certainly not least I would like to thank Mom, Dad, Mary, Kenny, Ronnie and Donna, my family. Their unending support throughout my six years of college and total of 19 years of school is very much appreciated. Without them the following pages would be blank.

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INTRODUCTION

Depositional environments in the downdip part of the East Texas basin are poorly understood. Several studies have attempted to establish local and regional paleoenvironments, but conflicting interpretations were made. Early workers used electric logs and cuttings from widely spaced wells to determine regional facies. More recent studies have concentrated on local areas where full-diameter cores aid in the interpretation. Conflicting interpretations from these studies include depositional environments, stratigraphic nomenclature, extent of facies, and correlation of the stratigraphic units from updip areas. A better understanding of the local stratigraphy and depositional environments is needed to resolve conflicting interpretations. Because this region produces significant amounts of oil and gas, knowledge gained from this study will aid in the search for new traps.

Any subsurface study of environment of deposition requires the use of full-diameter cores to determine sedimentary structures, composition and texture. Analysis of these properties allows the interpretation of the provenance, type of sediment transport and depositional environment of the sediment. Electric logs are also necessary so that the morphology of the unit can be mapped, thus adding three-dimensional information.

The citations on the following pages follow the style and format of the American Association of Petroleum Geologists Bulletin.

The purpose of this investigation is to determine the environment of deposition and morphology of Woodbine and Eagleford sandstones at OSR-Halliday field, Leon and Madison Counties, Texas. Correlation of these sandstones with a core in Trinity County, Texas and comparison to other studies allows the construction of a regional facies model.

Regional Setting

OSR-Halliday field is located near the southern margin of the East Texas basin, a large downwarp in northeast Texas (Fig. 1). The basin is bounded to the north by the Ouachita Mountain system, the major source of sediments in the basin. To the west the stable Central Texas platform borders the basin, while the Sabine uplift forms the eastern margin. The ancestral Gulf of Mexico lies to the south of the basin. During the Late Cretaceous, structural activity within the basin included growth faulting along the Mexia-Talco fault zone, faulting in the Mt. Enterprise fault zone, and growth of numerous salt structures throughout the central basin (Barrow, 1953).

Stratigraphy

The Woodbine and Eagleford groups consist of sandstones and shales deposited during the Late Cretaceous lower Gulfian series. These groups have been divided into different formations and members by previous workers, but many of these subdivisions are not recognized regionally. The stratigraphic nomenclature used in this study is not

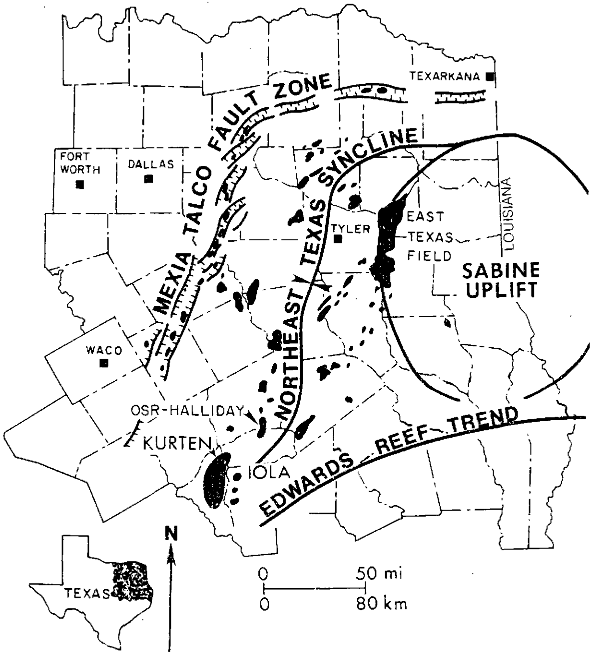


Figure 1. Index map of northeast Texas showing the location of OSR-Halliday field in relation to major structural features of the area.

intended to resolve the previous inconsistencies. Instead, important, easily recognized units are used, and these units are compared with the nomenclature of previous studies in Table 1.

Four formations are important in this study - the Austin Chalk, Eagleford, Woodbine and Buda Limestone. Between each of these divisions, unconformities have been recognized in parts of the basin, while conformable boundaries may be found in other areas. The nature of these contacts will be discussed later.

The Austin Chalk, which is composed of chalks, marls and shales, lies at the top of the section. It is underlain by the Eagleford Group, which is divided into two formations - the Upper and Lower Eagleford. The Upper Eagleford is composed primarily of sandstones, while marine shales dominate the Lower Eagleford. The total section is over 1100 feet thick (335 m) in the center of the basin (Eaton, 1956). In OSR-Halliday field, the Upper Eagleford sandstones were designated the "A" through "C" units by Theiss (1983). A fourth sandstone unit is recognized in southern part of the area, and will be called the "D" sand. The Sub-Clarksville, a sandstone member just below the Austin Chalk, is recognized in the area, but not cored. Therefore, discussion of Upper Eagleford sandstones are restricted to the "A" through "D" sands. In the Lower Eagleford Formation the Madisonville Tongue is found at the base of the unit. In the study area, this member changes from a shale unit at OSR-Halliday Field, to a thick sandstone body to the south and east.

Table 1. Comparison of stratigraphic nomenclature of the Woodbine and Eagleford groups in East Texas. Cross sections by Theiss (1983) and Anderson (1979) were used to correlate units.

	Nichols (1968)		Andersen (1979)		Turner and Conger (1980) Kurten Field		Theiss (1983) Pleasant Ridge Ridge		This Study OSR-Halliday Field	
Group	Fm.	Member	Fm.	Member	Units		Fm.	Member	Fm.	Member
Austin	Austin		Austin		Austin		Austin		Austin	
Eagleford		Sub-Clarksville				Woodbine Undifferentiated				Sub-Clarksville
	Eagleford	Coker	Upper Eagleford				Upper Eg'fd	"A" "B" "C"	Upper Eg'fd	"A" "B" "C" "D"
			Lower Eagleford		"A"		Lower Eagleford		Lower Eagleford	
		Harris		Madison-ville Tongue	"B"					Madison-ville Tongue
Woodbine	Lewisville		Massive Woodbine Sand		"C"		Woodbine		Woodbine	69-3 sand
	Dexter		Pepper Shale		"D" "E"					49-3 sand
Washita (part)	Maness Buda		Buda		Buda		Buda		Buda	

The Woodbine Group lies below the Eagleford Group. A single formation is recognized, the Woodbine, because its lithologic units are so variable or local in geographic distribution (Bailey et al., 1945; Eaton, 1956). In the study area the Woodbine Formation is comprised of thick shales, with only thin, local sandstones. Farther to the north however, sandstones dominate the section. In this study local sandstones in the Woodbine have been named after the well in which the sand was cored. (i.e. the "69-3" sandstone was cored in the Mosbacher OSR-Halliday Unit 69-3 well). Below the Woodbine Group, lies the carbonates of the Buda Limestone, the uppermost formation of the Lower Cretaceous Washita Group.

Depositional History

Near the end of Washitan time, a period of major uplift occurred in northeast Texas. The Sabine Uplift reversed its structural activity from an area of subsidence to one of active uplift (Barrow, 1953). This epeirogenic event marked the close of carbonate dominance in the basin, with the Buda Limestone being the uppermost deposit. A regional unconformity resulted from this uplift, with as much as 3000 feet of Lower Cretaceous strata eroded from the upper reaches of the Sabine Uplift, including the entire Washita Group (Eaton, 1956). Farther to the west, in Madison County, this unconformity may be due to non-deposition rather than truncation (Bornhauser, 1966). By the beginning of Woodbine deposition, the unconformable surface was peneplained (Halbouty and Halbouty, 1982).

Woodbine sediments were deposited during a major marine regression. Following a rapid transgression at the base of section, fluvial sediments prograded into the basin from the north and northeast. The sedimentary and weakly metamorphosed rocks of the Ouachita Mountains were the major source of these early Woodbine sediments. However, the Sabine uplift may have also supplied some sediment (Barrow, 1953; Nichols, 1964). Downdip the nonmarine clastics of the fluvial system are replaced by deltaic and nearshore deposits, with deposition of marine shales even farther south. As the shoreline prograded farther south, marine shales gave way to nearshore and nonmarine facies. The regional facies distribution was outlined by Oliver (1971). Four depositional systems were identified: the Dexter fluvial system; the Freestone high-destructive delta system; the Lewisville shelf-strandplain system; and the "Harris" delta system.

The Dexter fluvial system drained the highlands of the Ouachita Mountains in Oklahoma and Arkansas during the early Woodbinian (Fig. 2a, b). An updip tributary facies is composed of subparallel to dentritic, elongate, fining upward sandstones bodies separated by fine-grained interchannel areas. Downdip, tributaries converge into meandering streams, which laid down blanket sandstones that commonly coarsen upward.

Downslope, the high-destructive, strike trending sandstone bodies of the Freestone delta were deposited (Fig. 2a, b). Three facies have been distinguished: progradational channel-mouth bar sands; coastal barrier sands; and a prodelta-shelf facies. Prograding channel-mouth bars were deposited at the mouth of the meandering channels. These

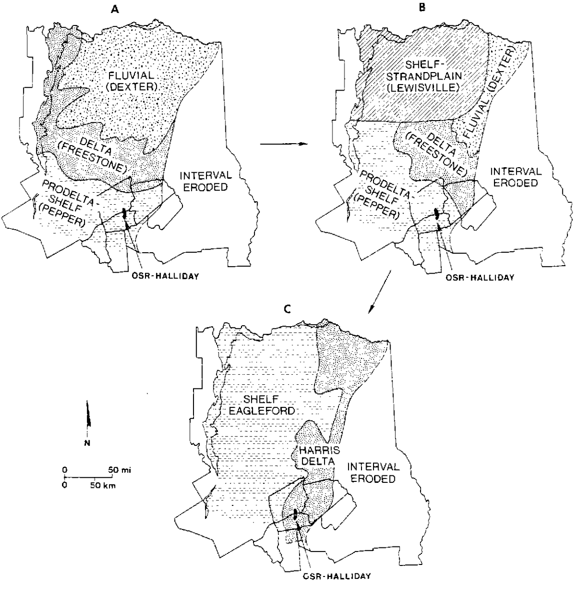


Figure 2. Map of northeast Texas showing Oliver's (1971) depositional systems. A, early Woodbinean; B, late Woodbinean; and C, Eaglefordian. Leon, Madison, Houston, Trinity, Brazos and Grimes counties are outlined. Modified from Oliver (1971).

sandstones coarsen upward, are well sorted, and may contain fossils and glauconite. Adjacent to the channel-mouth bars, coastal barrier sands were built up by longshore transport. These strike trending sandstones are highly quartzose, fine-grained, well-sorted, fossiliferous and glauconitic. Downslope, these deposits prograde over the dark, noncalcareous shales of the prodelta-shelf facies.

Streams feeding the Freestone delta migrated eastward, so that during the late Woodbinian an embayment replaced the land areas in the northwestern part of the basin. This shift in the fluvial system was probably the result of renewed uplift in southern Arkansas. Shales and isolated, narrow, parallel sand bodies of the Lewisville shelf-strandplain facies were deposited in this region (Fig. 2b). Shelf and prodelta muds of the Pepper Shale were deposited downdip from the Dexter, Freestone and Lewisville systems throughout the Woodbinian (Fig. 2a, b).

Near the end of Woodbinian time, a major period of uplift occurred to the east of the basin as the Sabine uplift began a new period of structural activity. This uplift, which continued into the Eaglefordian, caused erosion of the entire Woodbine sequence on top of the Sabine and resulted in the truncation of Woodbine sediments in the eastern part of the basin. The resulting unconformity continues into the Madison-Leon County area, but is probably due to erosion as the Eagleford sediments expanded at the expense of Woodbine strata (Bornhauser, 1966). During this second period of movement, the Sabine uplift became emergent and supplied much of the late Woodbine-Eagleford sediments to the basin (Bell, 1980). As a result of this uplift the major axis of deposition shifted even farther to the east and a new deltaic system became active.

This system, the "Harris" delta, redeposited lower Woodbine sediments along the eastern part of the basin as it prograded to the west over shelfal Eagleford Shale (Fig. 2c). Maximum thickness of these sandstones occurs in Madison, Houston and Walker Counties where over 400 feet of Upper Woodbine-Lower Eagleford sandstones are now found (Nichols, 1964; Turner and Conger, 1981).

The Sabine uplift continued to rise throughout the Eaglefordian. The transgressive shales and sandstones of the Upper Eagleford Formation were deposited during this time. A major resurgence of the Sabine at the end of the Eaglefordian brought this period of clastic deposition to an end in the basin. Much of the basin became emergent during this period, and an important regional unconformity resulted. Later, regional subsidence brought marine conditions back into the major part of the basin, and the Austin Chalk was deposited.

Oliver's (1971) depositional systems give a regional framework for the depositional history of the East Texas Basin. More recent studies have described local areas in the southern part of the basin. While Oliver (1971) used only outcrops. electric logs, and well cuttings, the recent studies were aided by full-diameter cores. Interpretation of these local depositional environments have better defined the boundaries of Oliver's (1971) systems, especially the "Harris" delta.

Woodbine sandstones in Leon, Madison and Houston Counties were interpreted to be prograding offshore bars deposited in relatively deep water on a marine shelf (Theiss, 1983). The Harris delta has been described in this same area (Oliver, 1971). Delta front sands were interpreted to the south of this area in Grimes County (Barton, 1982). In Brazos County, just to the west, offshore bars were formed by a combination of river mouth by-passing, storm-surge turbidity flows, and longshore currents (Turner and Conger, 1981). To the southeast, submarine fans and isolated turbidite channels were described (Foss, 1978). These deeper-water sediments were deposited on the prograding Woodbine Shelf edge.

Eagleford sandstones along the southern margin of the basin have generally been interpreted to be storm-generated bar sands (Theiss, 1983; Barton, 1982). Topographic highs may have controlled the distribution of these deposits.

These recent studies focused on oil and gas fields. Because this area is economically important, many wells have been drilled in the area. The information obtained from these wells has greatly aided in the interpretation of Woodbine and Eagleford paleoenvironments. However, because previous studies of this area have conflicting interpretations, a better understanding of the area is necessary. The study of sandstones at OSR-Halliday field will enhance the present knowledge of the area, and the interpretation of depositional environments will aid in the exploration and exploitation of hydrocarbon traps in the study area.

Production History

OSR-Halliday field is located in the East Texas basin, one of the most prolific hydrocarbon producing areas in the United States. The Woodbine Formation is the most productive zone within the basin, accounting for approximately 87% of all oil produced in the basin (Eaton, 1956).

The Woodbine first proved productive in 1920 at Mexia, Texas. Early exploration in the basin focused on structural traps associated with faults and salt structures. However, it was not until the discovery of the giant East Texas field in 1930 that the Woodbine became a major target of exploration (Alexander, 1951).

Recent exploration in the area has centered on stratigraphic traps in the downdip parts of the basin. Leona and OSR fields were early discoveries in the search for these traps. Kurten field, discovered in 1976, is the largest field in the area. Production may exceed 100 million barrels of crude oil and 100 billion cubic feet of natural gas (Bell, 1980).

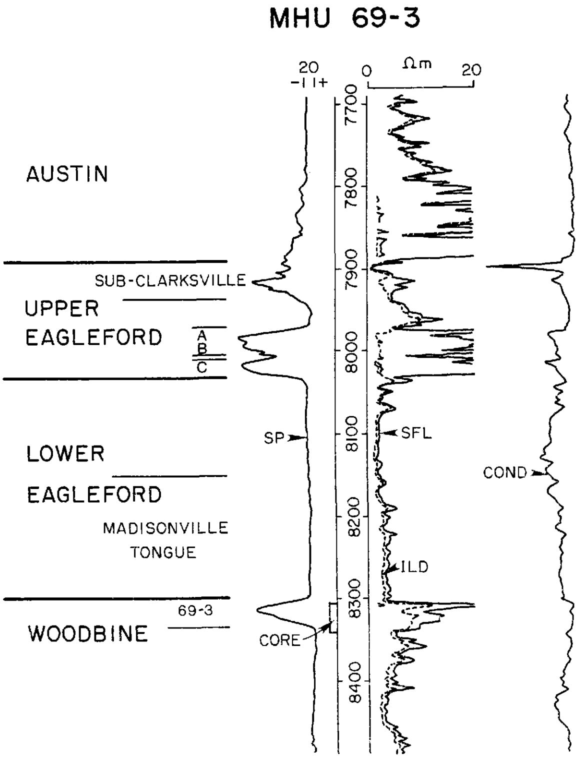
Although not as successful as Kurten, OSR-Halliday field has proven to be an economic oil producer. The discovery well for OSR field, the W.R. Hughey A.P. Andrews 1, was completed in Woodbine sandstones at a depth of 7870 feet in November, 1961 (Foudrait, 1978). Leona field, just to the west, was also discovered in 1961, with production from Upper Eagleford sandstones. In March, 1964, Halliday field was discovered in Woodbine sandstones at a depth of 8496 feet. OSR and Halliday fields were combined in 1972 as field wells proved the presence of a continuous reservoir. This reservoir sandstone is also productive at Pleasant Ridge field (Theiss, 1983) just north of OSR-Halliday. Woodbine sandstones at OSR-Halliday field had produced 6,269,000 barrels of oil through 1976 (Foudrait, 1978). The field is currently undergoing carbon dioxide injection to enhance oil recovery.

Methods

Conventional, full-diameter cores and electric logs were used to determine the primary properties of Woodbine sandstones. The cores were slabbed, photographed, and the vertical sequence of composition, texture and sedimentary structures described. The composition and texture of representative samples was determined by petrographic analysis using standard techniques. A point count of 100 grains was used to determine composition. Traverses across thin sections were made perpendicular to bedding in order to control any influences of bedding on composition. Quartz, feldspar, rock fragments, matrix (detrital and diagenetic), other detrital grains, and carbonate and silica cements were the categories used to classify composition. The percent of each detrital species was expressed as a fraction of the total detrital components, while cements were expressed as a percentage of total composition. The textural components of grain size and sorting were determined by measuring the long axis of 75 quartz grains in each thin section. The mean grain size of each sample was then calculated using standard statistical procedures. The single mineral quartz was measured so that the effects of composition on grain size could be minimized.

Morphology of the cored sandstones was determined where sufficient well control existed. The productive sandstone at OSR-Halliday field ("69-3" sandstone) was the only cored interval in which the morphology could be mapped. Sandstones within the Mosbacher OSR-Halliday 69-3 core were correlated to its well log and then correlated to logs in and adjacent to the field. A type log of the field area shows the characteristic electric log responses of the various units used in this study (Fig. 3). Cross sections, structure maps, net and gross sandstone maps, and interval isopachs were made in order to determine sandstone morphology, type of petroleum trap, and depositional topography. A cross section from OSR-Halliday field to the Mosbacher Joyce Foundation 1 cored well in Trinity County was made so that the regional facies distribution could be better understood. Interpretation of depositional environments was made from data obtained from 3 cores described in this study as well as several cores described by Theiss (1983). The location of these wells is shown in Figure 4. The names and cored formations are shown in Table 2.

Figure 3. Type log of OSR-Halliday field showing characteristic electric log response of the major stratigraphic subdivisions. Log is from the Mosbacher OSR-Halliday Unit 69-3 well. Location of well is shown in Figure 4.


MHU 69-3
20
-I I+
0
Ωm
20
7700
7800
7900
8000
8100
8200
8300
8400
AUSTIN
SUB-CLARKSVILLE
UPPER
EAGLEFORD
A
B
C
LOWER
EAGLEFORD
MADISONVILLE
TONGUE
69-3
WOODBINE
SP
SFL
ILD
COND
CORE

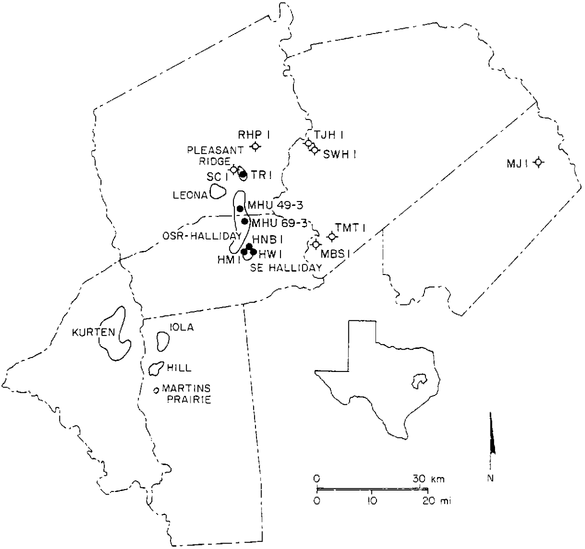


Figure 4. Map of Leon, Madison, Houston, Trinity, Brazos and Grimes counties showing location of cored wells and major oil fields referred to in this study. Cored wells are listed in Table 2.

Table 2. List of cored wells referred to in this study. Location of wells shown on Figure 3.

Abbreviation	Operator	Well Name	Cored Formation
MHU 69-3	Mosbacher	OSR-Halliday Unit 69-3	Woodbine (69-3 sandstone)
MHU 49-3	Mosbacher	OSR-Halliday Unit 49-3	Woodbine (49-3 sandstone)
MJ1	Mosbacher	Joyce Foundation Unit 1	Woodbine
TR1	Tenneco	Clyde Robeson 1	Upper Eagleford and Woodbine (69-3 sandstone)
SC1	Streif & Voight	Craig 1	Upper Eagleford and Woodbine (69-3 sandstone)
HM1	Houston Oil & Minerals	McFarland 2	Woodbine (69-3 sandstone)
HNB1	Houston Oil & Minerals	First National Bank 1	Woodbine (69-3 sandstone)
HW1	Houston Oil & Minerals	Lena Walker 2	Woodbine (69-3 sandstone)
RHP1	Rotary and Hall	Parker 1	Upper Eagleford
TJH1	Tenneco	J.W. Henry 1	Lower Eagleford (Madisonville Tongue)
SWH1	R.M. Sims	Walker and Harris 1	Lower Eagleford (Madisonville Tongue)
TMT1	Tenneco	T.M. Touler 1	Lower Eagleford (Madisonville Tongue)
MBS1	Magnolia	A.B. Spence	Woodbine

CHARACTERISTICS OF WOODBINE SANDSTONES

The primary properties of a sandstone can be used to interpret its depositional environment. These properties, sedimentary structures, composition, texture and morphology, reflect the physical processes that deposited the sandstones (Berg, 1970). These properties, along with reservoir properties and diagenesis, are discussed on the following pages.

Each of the three Woodbine sandstones have a different suite of sedimentary structures. The "69-3" sandstone is dominated by ripples. The "49-3" sandstones are massive at the base with ripples or horizontal laminations at the top. The "MJ1" sandstones has three facies: interlaminated, bioturbated sandstones and shales with some massive beds; a crossbedded sandstone; and a shale facies.

Sedimentary Structures

The "69-3" sandstone is dominated by wavy, nonparallel, continuous laminae (Fig. 5A, B, C). This type of sedimentary structure is characteristic of a ripple bed form. The ripple laminations are disrupted by rare trace fossils, are mostly horizontal, and many are crenulate (Fig. 5B, C, D). Spacing of the laminae is from less than 1 mm to 3 cm. This ripple dominated unit was deposited by low flow-regime currents (Simons et al., 1970).

The lower 7 feet (2.1 m) of the "69-3" consists of interlaminated sandstone and shale (Fig. 5E). Even, subparallel, continuous laminae within this unit are characteristic of lower flow regime planar beds.

Figure 5. Sequence of sedimentary structures and trace fossils in the Mosbacher OSR-Halliday Unit 69-3 (MHU 69-3), and the Mosbacher OSR-Halliday Unit 49-3 (MHU 49-3). Boldface letters refer to photographs.

A. Wavy, nonparallel, continuos and discontinuous laminae typical of the entire MHU 69-3 sandstone. Rare bioturbation interrupts laminae. 8307 ft.

B. Wavy bedding with shell fragments (arrow). MHU 69-3, 8313 ft.

C. Wavy bedded sandstone with escape burrow (arrow). MHU 69-3, 8322 ft.

D. Horizontal burrow (Thalassinoides?) indicated by "t". MHU 69-3, 8324 ft.

E. Interlaminated sandstones and shales at base of "69-3" sandstone. Chondrites indicated by "C". MHU 69-3, 8342 ft.

F. Massive and contorted bed with large, rounded chert pebbles. Interlaminated sandstones and shales above contain Chondrites (C). Sharp basal contact. MHU 49-3, 8151 ft.

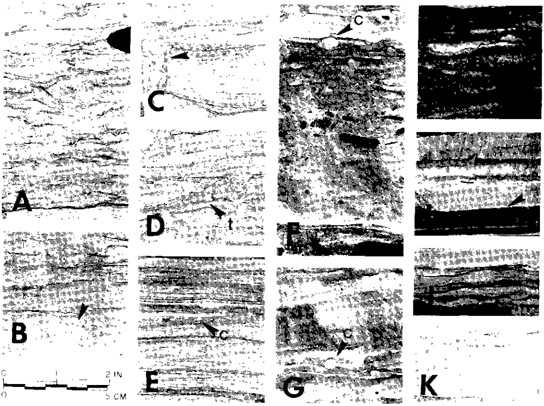
G. Interlaminated sandstones and shales with loading structures and Chondrites (C). MHU 49-3, 8161 ft.

H. Black shales with thin sandstone stringers. MHU 49-3, 8163.5 ft.

I. Thin massive sandstones with shale laminae at top. Note sharp basal contact (arrow). MHU 49-3, 8165.8 ft.

J. Large scale ripples that commonly occur above the massive sandstones in the thin beds. MHU 49-3, 8172 ft.

K. Massive sandstone found at base of thin sandstone beds. MHU 49-3, 8172.2 ft.


A
B
C
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t
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c
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C
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K
0
1
2 IN
0
5 CM

Rare starved ripples were introduced by intermittent pulses of sand during shale deposition. This unit is gradational from the quiet water shales below to the ripple dominated sandstones above.

The "49-3" sandstone is dominated by shales, with sandstone beds in units less than 2 feet (61 cm) thick. The thickness of shale units averages about 4 feet (122 cm). The sandstones are generally massive or contorted at the base, and grade upward into ripples or interlaminated sandstones and shales at the top (Fig. 5I, J). The ripples are generally of large scale, with foresets often preserved. The lower contact of these thin sandstone beds is sharp, with sole markings and flame structures commonly present. Large, rounded chert pebbles (up to 15 mm in length) are abundant in a 0.7 foot (21 cm) sandstone bed (Fig. 5F). Small horizontal burrows are usually found at the top of the sandstone units (Fig. 5F).

The thick shales which separate the thinner sandstones are usually massive and fissile. Where laminae are present they are even, parallel, continuous and subhorizontal (Fig. 5H). Small, horizontal burrows are rare, whereas contortions and loading features are common. Thin (less than 2 cm), isolated sandstone lenses are found throughout the shales. The shale units also contain whole and fragmented shells.

The sandstones and shales cored in the MJ1 have been divided into three facies. Facies 1, which is a total of 9.3 feet (2.8 m) thick, consists of interlaminated sandstones and shales at the base (Fig. 6K). Wavy, nonparallel, continuous and discontinuous laminae dominate this unit. Small horizontal burrows are found in the thin shales. Above the interlaminated beds, is a mottled unit with abundant, large

Figure 6. Sequence of sedimentary structures and trace fossils in the Mosbacher Joyce Foundation 1 (MJ1). Boldface letters in lower left refer to photographs.

A. Even continuous laminae in upper sandstone. Facies 2, 8049 ft.

B. _Arenicolites_ (arrow) at top of facies 1. 8050 ft.

C. Fossiliferous sandstone containing shell fragments. Facies 2, 8052 ft.

D. Black shales with abundant whole and fragmented shells. Facies 3, 8055 ft.

E. Wavy, nonparallel, continuous and discontinuous laminae at top of facies 2. 8063.8 ft.

F. Contortions present near top of facies 2. 8063.5 ft.

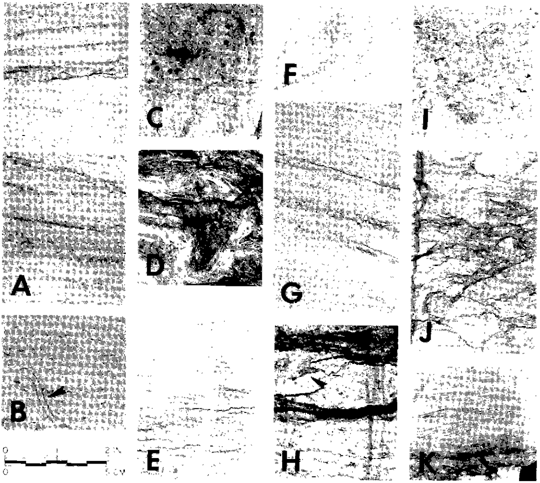
G. High angle, even, parallel, continuous laminae. Facies 2, 8072 ft.

H. Coal lenses and shale clasts (arrow) at the base of facies 2. 8082 ft.

I. Fossiliferous sandstone at base of facies 2. 8079 ft.

J. Mottled sandstone with abundant _Thalassinoides_. Facies 1, 8090 ft.

K. Interbedded sandstones and shales at base of facies 1. Ripples are seen in the sandstones. _Chondrites_ (arrow) are found in the shales, 8091.5 ft.


A
B
C
D
E
F
G
H
I
J
K

horizontal burrows (Fig. 6J). The intense bioturbation has erased any primary sedimentary structures. A massive unit overlies the mottled bed. One large horizontal burrow and few indistinct even, parallel, continuous laminae are the only sedimentary structures present. The lack of clay and silt-sized material in this unit may be responsible for the homogeneity of this sandstone bed. Thus, facies 1 exhibits increasing flow regimes upward as ripples are replaced by indistinct dunes higher in the section. Shale content decreases upward, which may also indicate an increasing flow regime upward, since the fines would be winnowed away by stronger currents.

Even to curved, parallel, continuous laminae dominate facies 2 (Fig. 6G). Laminae are inclined from 0° to 20°, and are characteristic of subaqueous, dune bed forms. At the top of the unit contorted laminations are overlain by wavy, nonparallel, mostly discontinuous laminae (Fig. 6E, F). This 3 foot (91 cm) thick bed of low flow-regime sedimentary structures was deposited during waning currents. The dune unit below, which is 17 feet (5.2 m) thick, contains cross-bedded sets generally less than 1 foot (30 cm) thick. At the base of the unit is a fossiliferous sandstone containing abundant whole and fragmented shells up to 60 mm in length (Fig. 6I). Shale clasts and coal lenses in thin nonfossiliferous sandstones are interbedded with these fossiliferous sandstones. Indistinct even, parallel, continuous laminae are also present in this unit. The abundance of large shell fragments indicates that this basal unit was deposited by the highest current velocities. Thus, a general decrease in flow regimes upward is found in facies 2.

The overlying facies 3 is separated from facies 2 by a sharp lower contact. Fossiliferous black shales are the dominant lithology of this facies (Fig. 6D). The shales may be massive, bioturbated, contorted, rippled or horizontally bedded. Thin sandstones and siltstones are interbedded with the shales. Wavy, nonparallel, continuous laminae and some massive beds with sharp contacts characterize the coarser-grained beds.

Another sandstone unit overlies facies 3 and shows a repetition of facies 1 and 2. This sandstone unit is only 13 feet (4 m) thick as compared to the lower sandstone unit, which is 32 feet (9.8 m) thick. The base of this sandstone is massive with some bioturbation, similar to the massive beds of facies 1. A fossiliferous sandstone lies above this bed and is similar to the base of facies 2 (Fig. 6C). Even to curved, continuous cross laminae inclined up to 20° are found above the bioturbated, massive sandstones (Fig. 6A). Cross laminae are interrupted in places by wavy, nonparallel, continuous laminae. These sedimentary structures are similar to facies 2.

Trace Fossils

Trace fossils are found in each of the three cores examined. Nutrient supply, substrate instability, dissolved oxygen, salinity, temperature, depth, sedimentation rates and currents are the variables that controlled the assemblage of organisms and, therefore, the types of trace fossils that are present in any strata (Rhoads, 1975). Identification of these trace fossils in rocks can aid in the reconstruction of paleoenvironments. Depth, sedimentation rates and current velocities are the most important information obtained from trace fossils. On a shallow shelf, the lower the energy conditions, the greater the availability of food, and the greater the biogenic activity (Howard, 1975). These factors aid in the reconstruction of depositional environments.

The "69-3" sandstone contains very few trace fossils. Small horizontal burrows of Chondrites are rare in the interlaminated shales and sandstones (Fig. 5E). The rippled sandstone unit above contains a few horizontal and vertical burrows. A large escape burrow, indicative of very rapid sedimentation, and a horizontal trace of Thalassinoides, are the only traces that can be identified in this thick sandstone (Fig. 5C and D). Higher in the section, a 2-foot (61 cm) section has indistinct vertical and horizontal burrows interrupting many ripple laminae (Fig. 5B). Rare bioturbation is also found in the uppermost unit, which contains more abundant shale laminae outlining ripples (Fig. 5A). In general, this mostly trace-free sandstone was deposited by rapid, continuous sedimentation. The presence of an escape burrow supports this conclusion. Variations in current velocities, and thus sedimentation rates, are reflected in the presence of some zones where traces are found. Slower currents, accompanied by slower deposition, allow more time for biogenic reworking of the sediment, whereas rapid sedimentation and currents reduces biogenic activity. Therefore, an increase in traces at the top and base of the sandstone indicate a decrease in sedimentation rates. The presence of the larger trace fossils in the sandstone indicates shallow water deposition. The Chondrites - Thalassinoides trace fossil assemblage is indicative of nearshore and shelf environments (Chamberlain, 1978).

Rare trace fossils are found in the "49-3" sandstones. The small, horizontal burrows of Chondrites are the only distinguishable traces (Fig. 5F and G). These burrows are present in the interlaminated sandstones and shales above the thin massive sandstone beds. Rapidly deposited beds are commonly bioturbated at the top of bedsets (Chamberlain, 1978). Chondrites is found in marine environments from nearshore to basinal (Chamberlain, 1978). Horizontal burrows, such as Chondrites, are typical of deep, quiet environments. The fine-scale of the traces also imply deeper, restricted environments. These sandstones were probably deposited in a middle to outer neritic environment by rapid, discontinuous currents.

Woodbine sandstones examined in the MJ1 core also contain relatively few traces. Chondrites is found at the base of Facies 1 (Fig. 6K). These burrows are restricted to the shales which are interbedded with the sandstones. This lithologic dependency is due to the slower deposition of the shales and the relatively rapid deposition of the sandstones. The mottled unit above the interlaminated sequence contains the large horizontal burrows of Thalassinoides (Fig. 6J). Tidal channels, shoreface, nearshore, and inner to middle shelf are the environments where Thalassinoides occur (Chamberlain, 1978). A few horizontal traces are present above this mottled bed, but bioturbation is absent in the cross-bedded sandstones of facies 2. This lack of bioturbation indicates either a change to non-marine conditions, or rapid, continuous sedimentation. The shales of facies 3 contain non-bioturbated to mottled beds. Large horizontal and vertical burrows are indistinct but are common where rippled and planar beds have been interrupted. The upper sandstone unit is non-bioturbated at the top where crossbedding is found, again placing this sandstone in facies 2. Below facies 2 in this sandstone are a few large horizontal and vertical burrows. Arenicolites, which occurs in a range of marine environments, is found near the base of the sandstone (Fig. 6B). The trace fossil assemblage of Chondrites - Arenicolites - Thalassinoides present in "MJ1" sandstones is common only in nearshore to middle shelf environments (Chamberlain, 1978). The lack of traces in much of the section may be indicative of a non-marine, or nearshore high energy environment.

Composition

The composition of a sandstone is a function of source, amount of weathering, transport history, grain size, diagenesis, and the amount of recycling. However, the mineralogy of a sandstone is also affected by its depositional environment (Davies and Ethridge, 1975). Woodbine sandstones examined in this study are highly quartzose, with rock fragments and matrix the only other significant detrital minerals. Physical processes were the main control on composition in these sandstones, but source, recycling of sandstones and diagenesis have also played important roles. The source of sediments remained relatively constant during Woodbine deposition. The recycling of Paleozoic and lower Woodbine sedimentary rocks may have caused the more resistant quartz grains to become abundant. These sandstones have undergone considerable replacement and alteration by calcite. Again, quartz, because of its resistive nature, is more abundant than the easily weathered rock fragments and altered feldspars. The average composition of sandstones discussed in this study are shown in Table 3.

The rippled sandstones cored in the Mosbacher OSR-Halliday Unit 69-3 well are quartz-wackes (Dott, 1964). Quartz content averages 73% in these sandstones (Table 3). Rock fragments, which make up 3% of the total detrital composition, include polycrystalline quartz, chert, and sedimentary rock clasts (mostly shell fragments). Only a trace of feldspar and other minerals was found. Other minerals include muscovite, hematite, pyrite, organic matter, limonite, tourmaline and zircon. Matrix constitutes 22% of the total composition, but all clays, both detrital and authigenic, were grouped as matrix in this sandstone as well as the other two cored sandstones. This grouping of clays was necessary because of the difficulty in distinguishing between the detrital and diagenetic fractions. Kaolinite along with some chlorite, smectites, and iron-rich clays were found in the "69-3" sandstone.

The cementing minerals in the sandstone were quartz overgrowths, poikilotopic and sparry calcite, and siderite. The amount of quartz overgrowths is variable and had no relationship to the amount of detrital quartz. A sample with over 50% calcite cement was taken in the fossiliferous zone in the core. Therefore, the calcite cement may have been derived from the dissolution of carbonate skeletal fragments.

Table 3. Average composition and texture for Woodbine sandstones in this study.

Well	Depth Core	Interval	Quartz Size			Detrital Composition					Cement	
			Mean mm	Max mm	σ mm	Qz %	F %	Rx %	Oth %	Mx %	Sil	Cal
											% of total	
MHU 69-3	8307-43	rippled	0.15	0.25	0.05	73	<1	3	<1	22	7	12
MHU 49-3	8147-74	massive	0.11	0.22	0.04	70	0	8	6	16	6	34
MJ1	8046-91.8	crossbedded	0.21	0.43	0.06	85	<1	7	1	7	7	11
From Theiss (1983)												
TR1		bioturbated & rippled	0.10	0.20	0.03	69	0	2	3	26	1	14
HM1		bioturbated	0.13	0.25	0.04	71	<1	7	4	17	6	4

No significant vertical variations of composition are present in this sandstone (Fig. 7). Within individual samples, however, quartz content decreases as matrix increases.

The thin, massive and rippled sandstones of the "49-3" sandstone are very similar in composition to the "69-3" sandstones, averaging 70% quartz and 16% matrix (Table 3). Percentages of rock fragments and other minerals are considerably higher. Polycrystalline quartz, chert, shell fragments and other sedimentary rock clasts make up the rock fragment fraction. Other detrital minerals identified in thin section were hematite, muscovite, pyrite, tourmaline, organic matter, limonite and zircon. Quartz overgrowths, and both poikilotopic and sparry calcite cements are present, with calcite cement averaging 34% of the total composition. Only a trace of authigenic clays (kaolinite) was recognized, but differentiating between authigenic and detrital clays was again difficult. No vertical variations in composition are present in the "49-3" sandstones because the individual sandstone beds are very thin (Fig. 8). As quartz content decreases, matrix increases, the same trend inherent in the "69-3" sandstone.

The Woodbine sandstones in the Mosbacher Joyce Foundation 1 core are quartz arenites (Dott, 1964). Matrix averages only 7% of the total detrital composition, while the mean quartz content is 85% (Table 3). Rock fragments, which make up 7% of the composition, include polycrystalline quartz, chert, volcanic rock fragments, and sedimentary rock clasts. Carbonate shell fragments dominate the rock fragment fraction, comprising 40% of the total detrital composition in one sample. Brown shale clasts were abundant at the top of facies 2. Other detrital

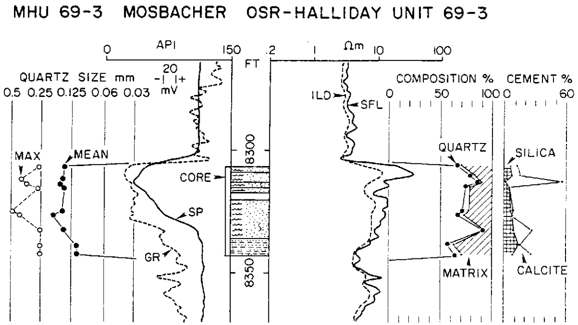


Figure 7. Composition, texture and sedimentary structures compared to the log response of the Mosbacher OSR-Halliday 69-3 well.

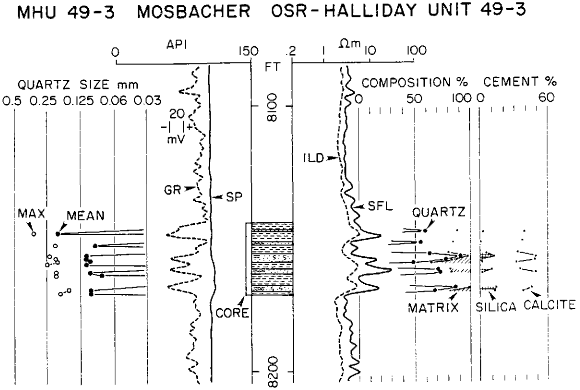


Figure 8. Composition and texture of the Mosbacher OSR-Halliday Unit 49-3 well plotted against the sedimentary structures and log response. Note that the SP log shows no response to thinly bedded, calcareous sandstones.

minerals include muscovite, tourmaline, organic matter, zircon, hematite, pyrite, spinel and augite. Glauconite was found only in facies 1. Authigenic clays, which account for approximately half of the total matrix, include kaolinite, chlorite, smectites and iron-rich clays. Cements make up 18% of the total composition, and consist of quartz overgrowths, siderite, and both sparry and poikilotopic calcite. The percentage of calcite cement greatly increases in samples with a high percentage of shell fragments. Quartz content is not reflected in the amount of silica cement. Samples with a high percentage of calcite cement have the lowest percentages of silica cement (Fig. 9).

In addition to the mineral content of a sandstone, which indicates source as well as the environment of deposition, vertical compositional trends are also important. These trends reflect changes in current velocity. In the "69-3" and "49-3" sandstones, no vertical variations in composition were present (Fig. 7 and 8). Because the "69-3" sandstone is a thick, uninterrupted unit, current velocities must have been relatively constant. In contrast, no vertical trends are seen in the "49-3" sandstones because the individual sandstone beds are very thin, and only one or two samples per individual sandstone could be taken.

Vertical compositional trends do exist in the "MJ1" sandstones (Fig. 9). The three facies which were distinguished by their lithology and sedimentary structures, show different trends. Facies 1 increases in quartz content upwards, reflecting higher energy conditions as deposition continued. A small decrease in quartz and an increase in matrix is found in facies 2. Decrease in flow velocities upward may account for this trend. At the base of facies 2, an anomalously low

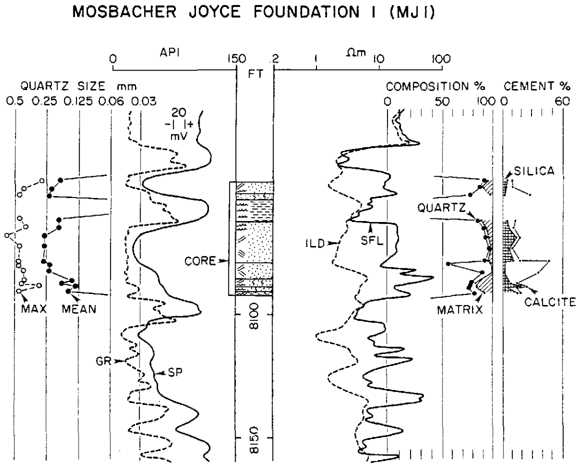


Figure 9. Composition, texture, sedimentary structures, and log response of the Mosbacher Joyce Foundation 1 well.

quartz percentage of 56% is found. Shell fragments make up 40% of this sample, which was taken from the fossiliferous sandstone. Very high energy conditions may have caused much of the sands to be transported away, leaving the larger shell fragments. Facies 3, because it is a shale, was deposited under very low energy conditions. Energy levels can be interpreted from the compositional trends because quartz is very resistant compared to the other minerals, especially feldspars and rock fragments.

Woodbine sandstones in this study are quartz arenites and quartz wackes. They are composed primarily of quartz and matrix, with carbonate shell fragments important in some samples. The lack of feldspar, and the low percentages of other detrital grains, indicate a highly quartzose source or a great deal of reworking of the sediment before deposition. Diagenesis altered the less resistant grains, with calcite commonly replacing them.

Texture

The textural components of grain size and sorting were determined for Woodbine sandstones in this study. Current velocities necessary to erode, transport and deposit sediments can be determined from grain size measurement (Hjulström, 1935). The sorting of grains in a sandstone can be used to compare individual beds. A comparison of the textures in Woodbine sandstones important in this study is shown in Table 3.

The "69-3" sandstone is fine-grained and well sorted, with a mean grain size of 0.15 mm and a standard deviation of 0.05 mm (Table 3). The maximum grain size observed in thin section was 0.47 mm. Currents with mean velocites greater than 15 cm/sec were necessary to erode the maximum grain size, while deposition occurred where current velocities slowed to at least 4 cm/sec (Hjulström, 1935). The sandstone coarsens upward from 0.11 mm at the base to an average of 0.15 mm throughout the middle and top of the section (Fig. 7). A coarsening upward sequence is typical of prograding environments where energy levels gradually increase. However, because most of the unit shows no significant change in grain size, current velocities must have also been relatively constant during most of sandstone deposition.

Very fine-grained, well-sorted sandstones were observed in the thin, massive "49-3" sandstones. The mean grain size is 0.11 mm with a standard deviation of 0.04 mm (Table 3). A coarser unit with fine-grained sandstones and maximum quartz grains 0.33 mm in size was observed at 8151 ft. Large clasts, up to 20 mm were described in this sandstone. Current velocities of over 150 cm/sec were necessary to erode these sediments, which would have been deposited as current velocities slowed to about 120 cm/sec (Hjulström, 1935). No gross change in texture is evident from the petrographic analysis (Fig. 8). However, a microscopic decrease in grain size upward in the thin sandstones was observed, indicating deposition by decreasing current velocities.

The "MJ1" sandstones are fine-grained (.20 mm) and well sorted (.07 mm) (Table 3). Vertical variations in grain size are observed in each of the facies. Facies 1 generally coarsens upward from 0.15 mm at the base to 0.24 mm at the top (Fig. 9). Increasing current velocities, typical of prograding environments, commonly coarsen upward. Facies 2 shows an overall decrease in grain size from 0.27 mm near the base to 0.19 mm at the top of the unit. Decreasing energy conditions upward are implied for this facies. The uppermost sandstone in the core, which may be a repetition of facies 1 and 2, also fines upward.

Woodbine sandstones are generally fine- to very fine-grained and are well to very well sorted. Macroscopically no textural variations are observed in the "69-3" or "49-3" sandstones. "MJ1" sandstones show both increasing and decreasing grain sizes in vertical section. These trends are similar to those found in the composition of the sandstones. Because only quartz grains were measured, the size of the quartz grains is related to the relative abundance of quartz. As quartz content increases, the size of quartz grains also increases. Matrix content increases as grain size decreases. Thus, texture and composition are related in these sandstones.

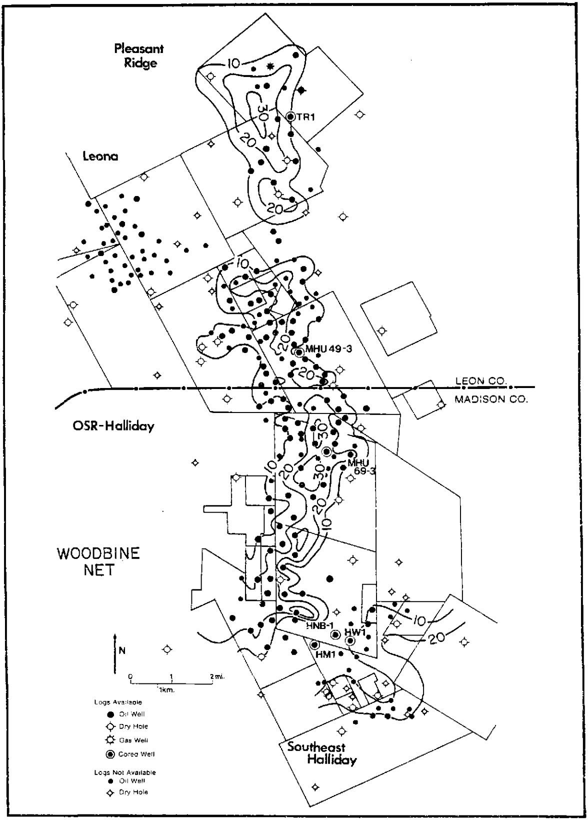
Morphology

The vertical sequence of composition, texture and sedimentary structures can be used to determine depositional environments, but a knowledge of sand body morphology is also essential (Berg, 1970). The morphology of the "49-3" and the "MJ1" sandstones could not be mapped because of insufficient well control. However, because the "69-3" sandstone is oil productive, many wells in and near OSR-Halliday field drilled through this sandstone. Electric logs from these wells were used to map the morphology.

A net sandstone map of the "69-3" sandstone outlines OSR-Halliday field, and suggests the presence of a stratigraphic trap (Fig. 10). This map was constructed by first measuring the thickness of the "69-3" sandstone from the SP log, and then contouring this value. Sand thickness was defined as the thickness (in feet) of the SP deflection one-third of the maximum response (the cleanest sandstone) and the shale base line, because the "69-3" sandstone is saturated with oil, and some dampening of the SP curve occurred. The isopach shows a north-south trending sand body with a very irregular outline. Minor east-west components are also apparent. The morphology is elongate, averaging 2 miles (3.2 km) wide and 10 miles (16.1 km) long.

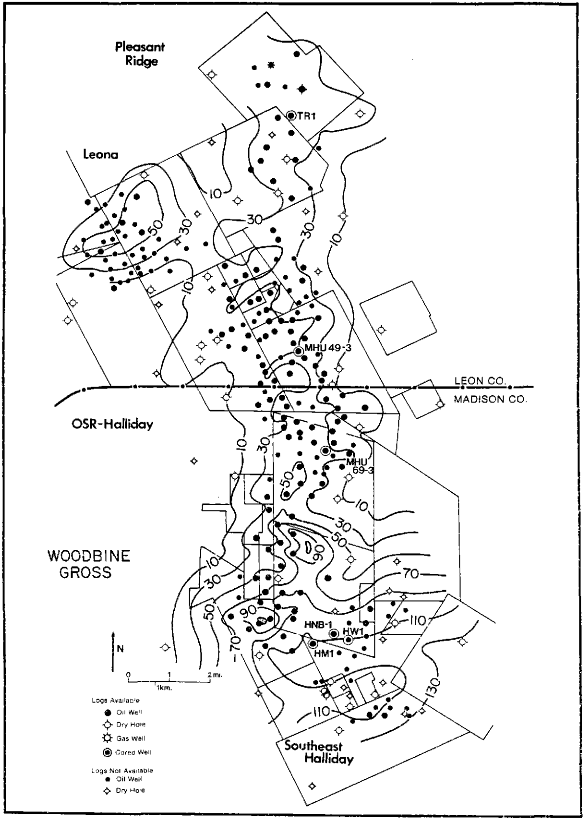
The Woodbine gross sandstone map is very similar to the net sandstone map (Fig. 11). This map was constructed by contouring the interval between the first and last deflection of the SP log off the shale base line for the "69-3" sandstone interval. This map shows the same north-south trending, narrow, elongate, irregular morphology present on the net sandstone map. The east-west components are generally found off the west flank of the main axis of this sandstone body. The most significant difference between the two Woodbine sandstone maps is the great increase in the thickness of gross sandstone in the southern part of the study area. The sandstones become very shaly in this area, which is obvious when one compares the net and gross sandstone maps. This thickening of the "69-3" sandstone interval is shown

Figure 10. Net sandstone map of the Woodbine "69-3" sandstone showing the elongate, north-south trending morphology of the body. The 10 foot sandstone thickness interval outlines the OSR-Halliday field limits very precisely. Pleasant Ridge field also shows the same north-south trending morphology. Contour interval is 10 feet.



Pleasant Ridge
Leona
TR1
MHU 49-3
LEON CO.
MADISON CO.
OSR-Halliday
MHU 69-3
WOODBINE NET
HNB-1
HW1
HM1
Southeast Halliday
N
0 1 2 mi.
1km.
Logs Available
Oil Well
Dry Hole
Gas Well
Cored Well
Logs Not Available
Oil Well
Dry Hole
10
20
30

Figure 11. Gross sandstone map of the Woodbine "69-3" sandstone showing the same general morphology as the net sandstone map. Note the east-west trending fingers extending toward the west, and the thickening of the interval to the south. Contour interval is 20 feet.

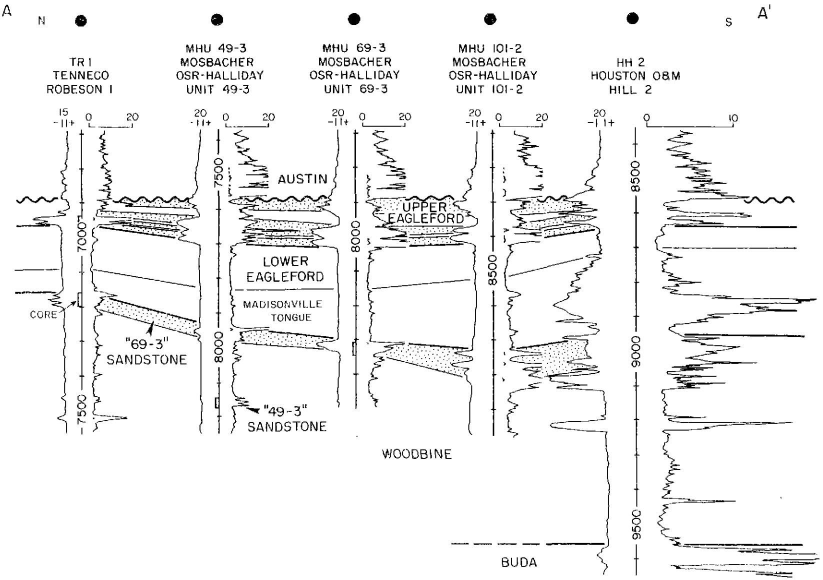

Pleasant Ridge
TR1
Leona
10
30
50
MHU 49-3
LEON CO.
MADISON CO.
OSR-Halliday
MHU 69-3
WOODBINE GROSS
70
90
110
130
HNB-1
HW1
HM1
N
0 1 2 mi.
1 km.
Logs Available
Oil Well
Dry Hole
Gas Well
Cored Well
Logs Not Available
Oil Well
Dry Hole
Southeast Halliday

on a north-south cross section through Pleasant Ridge, OSR-Halliday and Southeast Halliday fields (Fig. 12). The increasing shale content is apparent on the most southerly electric log.

The correlations on the cross section in Figure 12 also indicates that the "69-3" sandstone is present in Pleasant Ridge and is continuous with OSR-Halliday production from this sandstone. Completion data shows that the "69-3" sandstone is the producing interval in Pleasant Ridge field. Therefore, the "69-3" sandstone is a continuous reservoir body over 15 miles (24.2 km) long. However, thinning of the sandstone between the two fields is shown on the Woodbine net sandstone map (Fig. 10), making this area not economically attractive for oil production.

Evidence for the stratigraphic trapping of oil at OSR-Halliday and Pleasant Ridge fields is shown by the limits of net sandstone (Fig. 10). A structure map on the base of Austin Chalk shows only a regional dip of 1.5° in the study area (Fig. 13). The lack of any structural variations in the area suggests that stratigraphic traps may be present in the area. A cross section across OSR-Halliday field shows the "69-3" sandstone thinning or absent in non-productive wells along the margins of the field, while productive sandstones are well developed (Fig. 14). This cross section, the structure map, and Woodbine net sandstone map indicate the presence of a stratigraphic trap at OSR-Halliday and Pleasant Ridge fields.

Figure 12. North-south cross section through OSR-Halliday and Pleasant Ridge fields showing the continuity of the "69-3" sandstone in these fields and the thickening of the sandstone to the south. Note the facies change to the south where more sandstones are present. The Madisonville Tongue also thickens to the south. Location of cross section shown on Figure 13. No horizontal scale.



A
N
A'
S
TR 1
TENNECO
ROBESON 1
MHU 49-3
MOSBACHER
OSR-HALLIDAY
UNIT 49-3
MHU 69-3
MOSBACHER
OSR-HALLIDAY
UNIT 69-3
MHU 101-2
MOSBACHER
OSR-HALLIDAY
UNIT 101-2
HH 2
HOUSTON O&M
HILL 2
AUSTIN
UPPER EAGLEFORD
LOWER EAGLEFORD
MADISONVILLE TONGUE
CORE
"69-3" SANDSTONE
"49-3" SANDSTONE
WOODBINE
BUDA
7000
7500
8000
8500
9000
9500

Figure 13. Structure map contoured on the base of the Austin Chalk, indicating only regional dip in the OSR-Halliday field area. Contour interval is 200 feet.

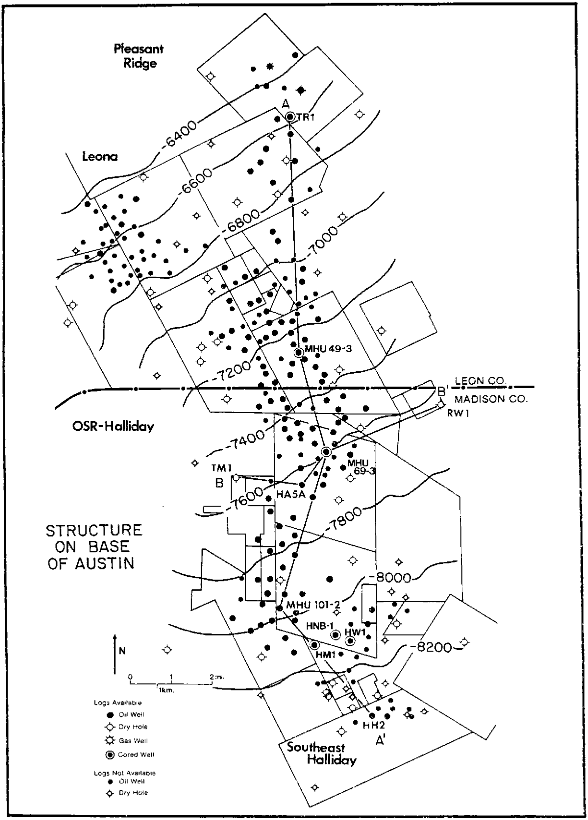
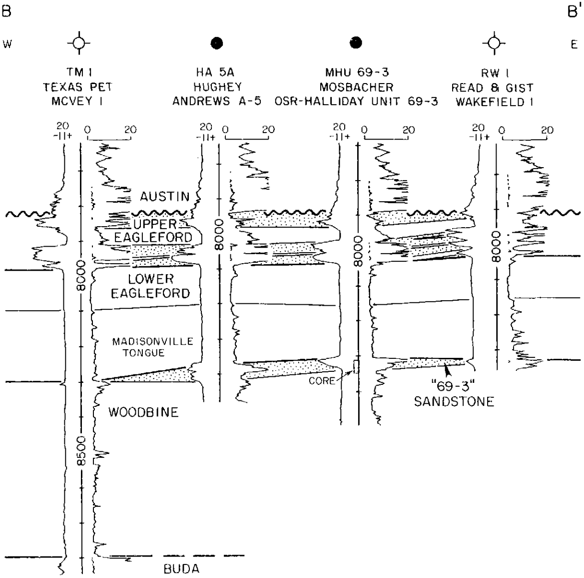

Pleasant Ridge
Leona
OSR-Halliday
Southeast Halliday
STRUCTURE ON BASE OF AUSTIN
-6400
-6600
-6800
-7000
-7200
-7400
-7600
-7800
-8000
-8200
A
A'
B
B'
TR1
MHU 49-3
MHU 69-3
HA5A
TM1
RW1
MHU 101-2
HNB-1
HW1
HM1
HH2
LEON CO.
MADISON CO.
N
0
1
2 mi.
1 km.
Logs Available
Oil Well
Dry Hole
Gas Well
Cored Well
Logs Not Available
Oil Well
Dry Hole

Figure 14. East-west cross section through OSR-Halliday field. The Woodbine reservoir sandstone is present only in the producing wells. Location of cross section is shown on Figure 13. No horizontal scale.


B
B'
W
E
TM I
TEXAS PET
MCVEY I
HA 5A
HUGHEY
ANDREWS A-5
MHU 69-3
MOSBACHER
OSR-HALLIDAY UNIT 69-3
RW I
READ & GIST
WAKEFIELD I
20
0
20
8000
8500
AUSTIN
UPPER
EAGLEFORD
LOWER
EAGLEFORD
MADISONVILLE
TONGUE
WOODBINE
BUDA
CORE
"69-3"
SANDSTONE

Diagenesis

Diagenesis affected all the Woodbine sandstones examined in this study. Subsurface diagenesis is dominated by two processes: 1) the mechanical compaction, dissolution and alteration of detrital framework grains; and 2) the growth, and possible later dissolution, of precipitated or replacement minerals. All of these processes were present, and occurred in a common sequence, in the cored sandstones.

Mechanical compaction due to overburden loading occurs immediately upon burial and continues to moderate depths. Microfracturing of detrital grains, macrofractures seen in cores, and deformed detrital grains (especially muscovite) illustrate this compaction. Early diagenesis also included growth of silica rim cements and overgrowths on detrital quartz grains. Overgrowth formation was inhibited in samples with large percentages of detrital clays.

Carbonate cementation, mostly in the form poikilotopic and sparry calcite, followed silica precipitation, and greatly reduced porosity and permeability. Calcite commonly replaced silicates during cementation, and in some samples completely surrounded grains, leaving them "floating" in calcite cement. Observed alteration of detrital grains by calcite include the recrystallization of skeletal fragments, neomorphism of twinned-plagioclase, and partially replaced quartz and rock fragments. Dissolution of calcite cement commonly occurred later, creating secondary porosity in many samples.

Detrital clays inhibited silica cementation and calcite precipitation. Samples with a high matrix content contained very little calcite cement. In these samples, small amounts of siderite formed instead of calcite, indicating the presence of iron-rich formation fluids.

Authigenic clays formed in the late stages of diagenesis. Kaolinite was the most common clay, with chlorite, smectites and iron-bearing clays also present. Moldic pores, formed by dissolution of shell fragments, were commonly infilled by kaolinite or chlorite. The iron-bearing clays were usually found in the proximity of altered rock fragments, pyrite, hematite or limonite, the probable sources of these clays. Macrofractures were commonly lined with the iron-bearing clays, indicating that adjacent strata (probably shales) may have brought in iron-rich formation fluids.

The above relationships are generalized for the three Woodbine sandstones studied. However, these sandstone do have slightly different diagenetic histories, mostly related to differences in the initial composition of the sandstones.

Sandstones in the MHU 69-3 unit contain 12% calcite cement on an average, with much variability from sample to sample. In samples with a high matrix content (over 20% of the total detrital composition), calcite averages only 4% of the total composition. Therefore, the occurrence of a high matrix content inhibited calcite precipitation, and promoted small amounts of siderite to form instead (generally less than 2%). Calcite cement is abundant (over 50%) in the sample with 40% shell fragments. This relationship suggests that the carbonate shell fragments supplied carbonates to subsurface waters, which was later precipitated out as calcite cement. Low vertical permeabilities within the sandstone caused the carbonate-rich waters to remain close to their source.

Authigenic clays are common in the "69-3" sandstone. The iron-bearing clays were precipitated along fractures and were often followed by chlorite and smectite formation. Pyrite, hematite and limonite were formed early and indicate the presence of iron-rich components in the initial composition. Kaolinite, chlorite and smectites are all present, and formed after calcite and the iron-rich clays. Moldic pores, formed after calcite cement, were infilled by kaolinite, chlorite or sparry calcite.

The massive sandstones of the MHU 49-3 were well cemented by calcite, which averages 34% of the total composition. Quartz grains in many samples, are "floating" in calcite cement. Carbonate shell fragments, commonly found throughout the cored interval, are the source of carbonate for the cement. The 16% mean clay content is mostly detrital matrix and is usually concentrated in the numerous shale laminae. Authigenic clays are uncommon, with only rare occurrences of iron-rich clays found in localized patches, and chlorite replaces shell fragments. In general, diagenesis progressed very little after calcite cementation.

The "MJ1" sandstones have all the diagenetic stages discussed previously. Clays inhibited calcite cementation, with samples containing over 25% calcite cement having less than 2% clay matrix. Two samples contained high percentages of calcite cement, but only one of these had a significant amount of skeletal debris (40%). However, the other sample was taken directly below a fossiliferous sandstone, suggesting downward migration of carbonate-rich fluids. Kaolinite, chlorite, smectites and iron-rich clays are all present in this sandstone.

Reservoir Rock Properties

Porosity and permeability are the two properties of a reservoir sandstone that control the amount of fluid in the reservoir (porosity), and the ability of the fluid to move through the rock in interconnected pores (permeability). These two properties are secondary properties of a sandstone, and are directly related to composition and texture (Berg, 1970). Diagenesis also plays an important role in determining the amount of pore space available for fluids in a sandstone.

The "69-3" sandstone is the reservoir sandstone at OSR-Halliday field. The commercial core analysis of the sandstone shows an average porosity of 10.5% and a range from 2.3% to 14.7% (Fig. 15). Permeability averages 0.61 md, and ranges from less than 0.01 to 5.23 md. Both porosity and permeability increase upward, reflecting the general increase in grain size and quartz content that was observed in the petrographic analysis. A zone near the top of the sandstone exhibits anomalously low values of porosity and permeability. This zone is well cemented by calcite, illustrating the affect of diagenesis on reservoir properties.

Core analysis were also available for other wells in OSR-Halliday field. From these wells the maximum average porosity and permeability was 18.2% and 3.8 md. The minimum porosity and permeability of a

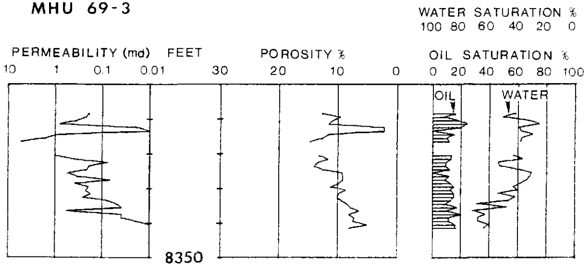


Figure 15. Core analysis of the "69-3" sandstone at OSR-Halliday field showing porosity, permeability and fluid saturations. Note the increase upward in porosity and permeability. Location of well is shown in Figure 4, and rock properties are illustrated in Figures 5 and 7.

producing well was 9.7% and 0.4 md. Oil production is probably not economical below these minimum values. The distribution of porosities is rather symmetrical in the field, with increasing values found where the sandstone thickens. The increase in porosity with an increase in gross sandstone is probably related to matrix content, amount of calcite cement, or grain size. Porosities would decrease where grain size decreases, matrix content increases, or calcite cement increases. Permeabilities are more variable within the field, with no clear trends observed. Because permeabilities are greatly affected by the infilling of pore throats, calcite cementation may be the major cause of this variability. Thin rims of calcite usually surround grains, and may thus decrease pore throat diameter greatly, while not significantly reducing the original porosity. Because skeletal fragments are the source of the calcite cement, local concentrations of shells may be related to some of the less permeable sandstones.

The "MJ1" and "49-3" sandstones are not reservoir sandstones, but their secondary properties are important in evaluating future possibilities of production from these sandstones. The thin "49-3" sandstones have low porosities and permeabilities, averaging only 4.3% and 0.38 md respectively (Fig. 16). The sandstones contain residual oil, which filled an average of 27.6% of the porosity in the core. The presence of oil in the core suggests that these sandstones may produce oil, but the low porosities and permeabilities, and the thin nature of individual sandstone beds, make the economical production of oil improbable. The high percentage of calcite in the sandstones (calcite cement averages 34% of the total composition) is responsible for the low

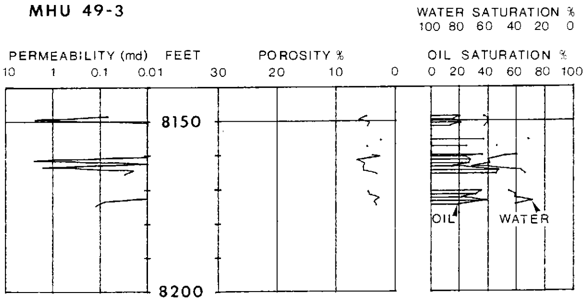


Figure 16. Core analysis of the "49-3" sandstones showing porosity, permeability and fluid saturations. Location of well is shown in Figure 4, and rock properties are illustrated in Figures 5 and 8.

porosities and permeabilities. These sandstones could be productive nearby where calcite cementation is not so extensive, or where dissolution of the calcite has created secondary porosities.

In contrast to the "49-3" sandstones, the MJ1 core recovered no oil, but some gas was recovered in the upper part of the core. These sandstones have good porosities and permeabilities in facies 2, but not in facies 1 (Fig. 17). Facies 2 averages 82.8 md of permeability and 14.2% pore space, while facies 1 sandstones have a mean permeability and porosity of 0.77 md and 6.4%, respectively. The differences between the two facies are mostly due to the larger mean grain size of facies 2 sandstones, and the greater amount of calcite cement in facies 1 sandstones. Because of the good porosities and permeabilities in facies 2 sandstones, they are considered to be potential reservoir sandstones. Future exploration efforts near the MJ1 well should concentrate on the stratigraphic trapping of oil in this sandstone.

The "MJ1" sandstones have the best reservoir qualities of the three cored intervals, while the "49-3" sandstones are the poorest exploration targets. The "69-3" has proved productive at OSR-Halliday and Pleasant Ridge fields which, although large in areal extent, produce only moderate amounts of oil because of the low porosities and permeabilities.

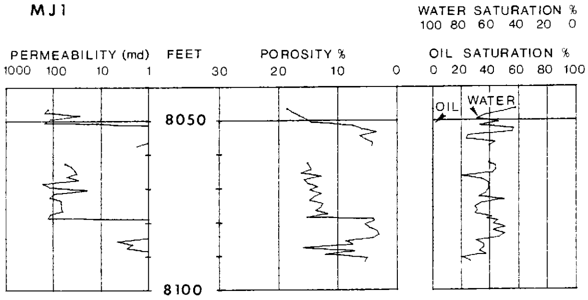


Figure 17. Core analysis of "MJ1" sandstones in the Mosbacher Joyce Foundation 1 showing porosity, permeability and fluid saturations. Location of well is shown in Figure 4, and rock properties are illustrated in Figures 6 and 9.

INTERPRETATION OF WOODBINE AND EAGLEFORD SANDSTONES

"69-3" Sandstone

The "69-3" sandstone is a shallow marine sand bar deposited adjacent to and contemporaneously with delta front sediments of the "Harris" delta. This interpretation is based on the composition, texture, sedimentary structures, trace fossils and morphology of the sandstones. The mechanisms that controlled sand distribution include longshore currents, offshore currents and paleotopography.

The composition and texture of the "69-3" sandstones indicate deposition by currents which increased in strength during early deposition, and remained relatively constant during deposition of the middle and upper sediments. The mean grain size of quartz increases upward at the base, and remains constant above (Fig. 6). Quartz content has a similar trend, while matrix shows an opposite trend.

Sedimentary structures and trace fossils show similar current activity. At the base of the "69-3" sandstone horizontally bedded sandstones and shales are present, and indicate very low current velocities. This interlaminated unit grades upward into clean sandstones with thin shale laminae outlining ripple bed forms. The slightly stronger currents which deposited these sandstones remained relatively constant during deposition of this 30 foot (9.1 m) unit. The rarity of trace fossils in the sandstone indicate rapid, continuous sedimentation (Rhoads, 1975). The presence of an escape burrow, which is typical of high sedimentation rates, and a few vertical traces suggest a shallow-water environment of deposition.

The local setting of the sandstone body also indicates a nearshore environment. Turner and Conger (1981) have mapped net sandstone within the Woodbine-Eagleford section (Fig. 18). The map shows a thick sandstone mass just south of OSR-Halliday field, and this thick has been interpreted as the "Harris" delta (Nichols, 1964; Oliver, 1970; Bell, 1980; Turner and Conger, 1981). The outline of the delta plain may follow the 200-foot isopach of Turner and Conger's (1981) Woodbine-Eagleford net sandstone map (Fig. 18). During deposition of the "69-3" sandstone, the delta plain and shoreline were probably a few miles farther east than that shown.

The orientation of the "69-3" sandstone body is generally north-south (Fig. 10 and 11), which is subparallel to the general trend of the coastline during the Late Cretaceous. The location of the sandstone body, and the inferred position of the "Harris" delta, are shown in a depositional model in Figure 19. This model takes into account the paleotopographic control of the sandstone body and inferred paleocurrents.

The "69-3" sandstone was deposited on the inner shelf, just seaward of two topographic ridges on the sea floor. An isopach map of the Eagleford Group shows a prominent thin which may represent a ridge that was present on the Late Woodbinean sea floor (Fig. 20). The thickening of the "69-3" sandstone (Fig. 11), and the thinning of the Eagleford Group to the south is due to the increased sediment accumulation in front of the "Harris" delta. The sediments of the delta apron may have formed a topographic high on the sea floor and also controlled sandstone distribution. The "69-3" sandstones were deposited on the

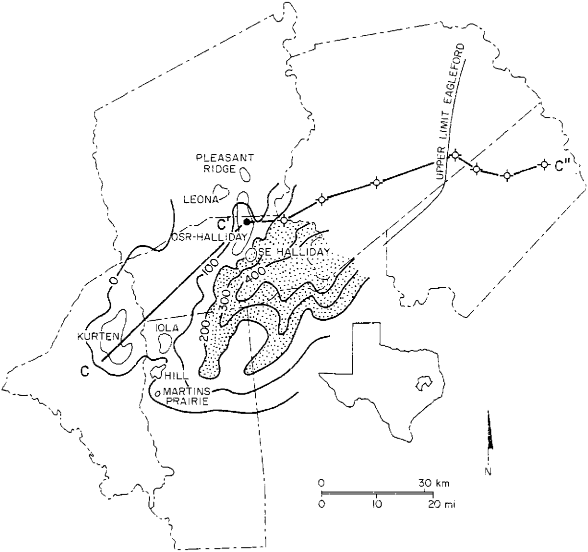


Figure 18. Map of study area showing the location of the "Harris" delta (stippled area). Total thickness of Eagleford and Woodbine sandstones modified from Turner and Conger (1981). The upper limit of the Eagleford Group is also shown (from Oliver, 1971). Cross sections C'-C" and C-C" are shown in Figures 25 and 26.

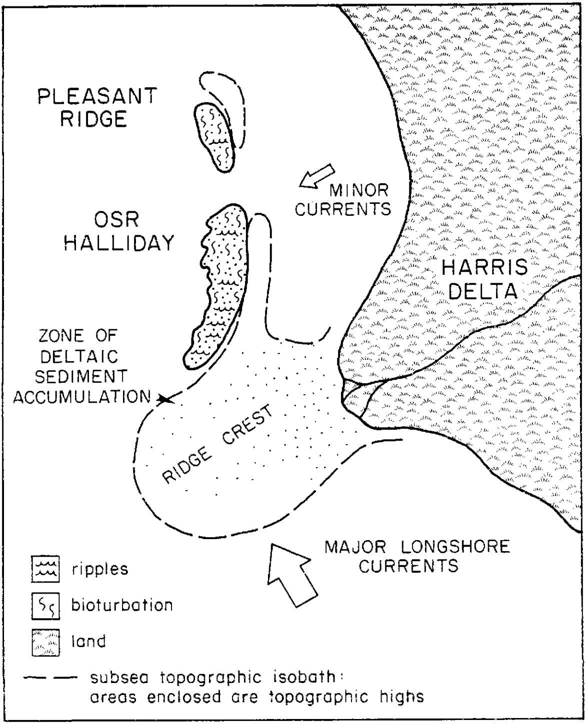
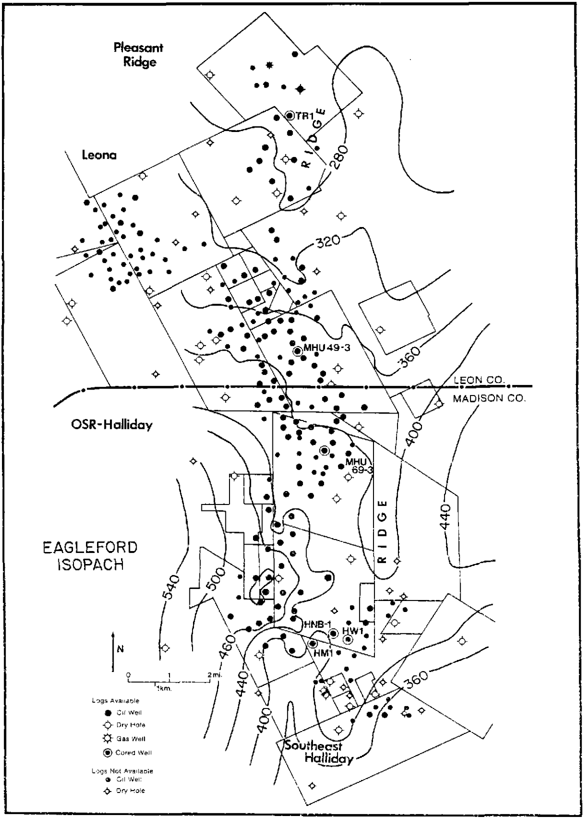


Figure 19. Model showing location of "Harris" delta, OSR-Halliday and Pleasant Ridge sand bars, topographic highs, and current directions during deposition of the "69-3" sandstone.

Figure 20. Isopach map of the Eagleford Group showing thinning to the north and south and paleoridges. Contour interval is 40 feet.

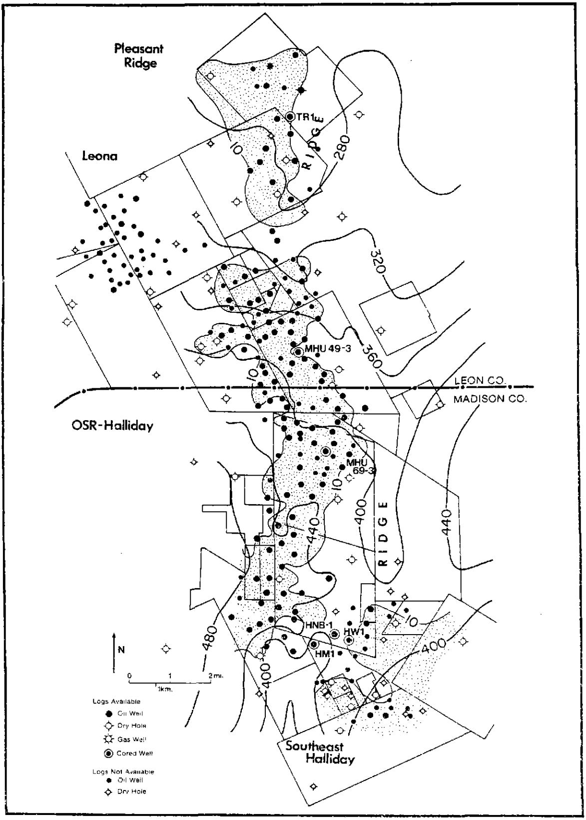

Pleasant Ridge
Leona
OSR-Halliday
EAGLEFORD ISOPACH
Southeast Halliday
RIDGE
RIDGE
TR1
MHU 49-3
MHU 69-3
HNB-1
HW1
HM1
LEON CO.
MADISON CO.
280
320
360
400
440
460
500
540
N
0
1
2 mi.
1km.
Logs Available
Oil Well
Dry Hole
Gas Well
Cored Well
Logs Not Available
Oil Well
Dry Hole

western flank of the north-south ridges and northern flank of the delta apron. Comparison of the paleotopographic map (Eagleford isopach) and the Woodbine net sandstone map illustrate this relationship (Fig. 21).

During deposition of the "69-3" sandstone, the predominate current direction was from the south, parallel to the shoreline (Fig. 19). The velocity of these currents accelerated on the southern flank of the delta apron because the flow must maintain its continuity (see Swift and Rice, 1982 for complete explanation). Erosion of sediments on the upcurrent flank of this high results from this acceleration. As the currents reach the crest, the currents decelerate and deposition follows. The steady influx of sediment from the delta mouth caused much of the reworked sediment to be mixed with deltaic sediment resulting in deposition of sands, silts and clays. However, farther north, deltaic sedimentation was not important and the clean reworked sandstones of OSR-Halliday field were deposited.

Further evidence of northward currents comes from the Tenneco Robeson 1 (TR1) which cored the "69-3" sandstone in Pleasant Ridge field. This well is 8 miles north of the MHU 69-3 (Fig. 4). This sandstone is generally bioturbated, with few of the original ripple laminae remaining (Theiss, 1983). The mean grain size is 0.10 mm, significantly finer-grained than the sandstones in the MHU 69-3 (mean grain size 0.15 mm, see Table 3). Decelerating currents dropped the coarser sandstones of the MHU 69-3 closer to the crest of the delta apron, while the finer-grained sandstones of the TR1 were deposited farther north. Because the MHU 69-3 contains very few trace fossils,

Figure 21. Comparison of the Woodbine net sandstone map (Fig. 10) and the Eagleford isopach (Fig. 20). Note that the Woodbine sandstones generally lie on the western flanks of the paleoridges.


Pleasant
Ridge
Leona
TR1
RIDGE
280
10
320
MHU 49-3
360
LEON CO.
MADISON CO.
OSR-Halliday
MHU
69-3
10
400
RIDGE
440
440
480
HNB-1
HW1
HM1
10
400
400
N
0
1
2 mi.
1 km.
Logs Available
Oil Well
Dry Hole
Gas Well
Cored Well
Logs Not Available
Oil Well
Dry Hole
Southeast
Halliday

stronger currents restricted fauna from this area. The abundance of trace fossils in the TR1 suggests slower current velocities in this area.

Other cores in Madison county support the nearshore-bar and delta-front interpretation of the "69-3" sandstone. Sandstones cored in southeast Halliday field are delta-front sandstones and are stratigraphically equivalent to the "69-3" sandstone. The Houston Oil and Minerals McFarland 2 (HM1) and the Houston Oil and Minerals Walker 2 (HW1) are dominantly interlaminated sandstones and shales (Theiss, 1983). The sandstones in the HM1 are fine-grained, averaging 0.13 mm. Common sedimentary structures include both planar, continuous, parallel laminations and wavy, continuous and discontinuous nonparallel laminae. Bioturbation is common, especially in the shales. Theiss (1983) interpreted these sandstones to be elongate offshore bars deposited in a deep shelf environment. However, these sandstones are actually part of the delta apron.

The north-south trending ridges to the east of the sand bars caused offshore currents (currents moving away from land) to deposit their coarsest sediments on the western flank of the ridges. The mechanism of deposition is the same as that proposed for the longshore currents. The north-south ridges were probably important in the early stages of sand deposition, but as bar formation progressed, the sand bar may have been topographically higher than the ridges. Sediment accumulation occurred on the seaward side of the sand bar during this later stage. Evidence of these currents is seen in the Woodbine net and gross sandstone maps (Fig. 10 and 11). East-west trending components are common on the western flank of the sand bar, where sedimentation by the offshore currents is proposed. Between OSR-Halliday and Pleasant Ridge fields, the thickness of net Woodbine sandstones decreases to less than 5 feet (1.5 m). Thickness of the Eagleford section is less variable in this area. Therefore the north-south ridges may have been less prominent, and had less of an effect on sand deposition. Sands brought to the area by longshore currents may have been transported farther west by the offshore currents and deposited at Leona field (Fig. 10).

The currents responsible for deposition of the sand bar have been described as longshore and offshore currents. It is difficult to determine the cause of these currents, primarily because the sedimentary structures present in the cores are not diagnostic of any specific process. Storms, waves or tides, or any combination of these, may have been responsible for the deposits. Tides are probably the dominant process.

D. Swift (1984, pers. com.) believes that storms were responsible for deposition of the "69-3" sandstone. In his theory, large bed sets, up to a few tens of centimeters in thickness, were laid down by storm currents. During the interstorm period only the upper few centimeters of the deposit were reworked by organisms. The next storm eroded much of previous deposits, including the bioturbated cap, leaving only the more massive sandstones at the base. The "69-3" sandstone is a series of these basal storm deposits. Swift's explanation is valid for the MHU 69-3 but does not explain the TR1 core. The sandstones in the TR1 are bioturbated throughout, suggesting that only a few centimeters of sediment were laid down during any one depositional event. One might argue that bed thicknesses were less than in the MHU 69-3 sandstones because the slower currents deposited less sediment. However, the total thickness of the "69-3" sandstones in both of these wells is about the same, indicating an equal amount of sediment accumulation during individual events. Storms were responsible for other Woodbine sandstone deposits (see "49-3" sandstone), but not the "69-3". This sandstone body was probably too close to the shoreline, in the area where storm currents are too strong to deposit rippled beds.

The dominance of ripple laminae suggests that fair-weather waves may have deposited the "69-3" sandstone. Because shales surround the sand bar, the bar must have been a topographic high reaching into fair-weather base. No evidence of the early formation of a topographic high is present. The "Harris" delta would cause waters to shallow as it prograded seaward, causing the wave base to also move seaward. High energy beach sandstones should have been deposited on top of the "69-3" sandstone. The absence of such deposits indicates that waves were not a primary process.

Tidal currents are preferred to storms or waves because they are frequent, but not continuous, and may be strong enough to carry delta front sediments a short distance. The flood current picked up delta front sands, silts and clays, and deposited them on the leeward side of the delta apron. As the currents decelerated the fine-grained sands were deposited first, on the southern part of the bar. With further deceleration, the very fine-grained sandstones found at Pleasant Ridge field were deposited. Farther north, as the currents decelerated even more, silts and clays were deposited. The delta apron is a major cause of the acceleration of the tidal currents and the transportation of delta front sediments. Because the "69-3" sandstone was deposited at the mouth of a narrow seaway, tidal currents velocities increased as they entered the seaway. This increase is due to the continuity of flow. The tidal forces are generally alongshore because they occur at the "mouth" of the seaway, where the waters of the ancient Gulf of Mexico entered during flood tide. During ebb flow, currents were weaker, and the main flow was probably to the west of OSR-Halliday field in deeper, less restricted waters. Tidal deposition is preferred because the currents occur often (twice a day) and may be of low velocities (the Cretaceous seaway has been proposed to be microtidal or mesotidal (Slater, 1981)). The abundance of ripple bed forms suggests low current velocities. The lack of trace fossils in the MHU 69-3 sandstones support the rather continuous deposition by tides.

The "69-3" sandstone bar is unlike any offshore bar previously described. The normal offshore bars are dominated by cross-bedded sandstones. The absence of cross-bedded strata at OSR-Halliday field is easily explained. The currents were never strong enough to deposit these higher flow regime bedforms.

Other workers have recently described topographic control of offshore bars. Theiss (1983) suggested that the "69-3" sandstone at Pleasant Ridge field was related to a "prograding break in slope" on an otherwise flat seafloor. Leethem (1984) believes that sandstone distribution in Kurten field was influenced by a topographic ridge south of the field. This ridge is probably related to a salt diapirism that includes Hill dome. Decreasing flow regime bedforms are found from south to north in the Kurten "C" sandstone. Cross-bedded sandstones are found to the south near the ridge, followed by ripples in the center, and bioturbated sandstones in the northern part of the field. A northward decrease in grain size was also observed. The similarity of Kurten sandstones and the "69-3" sandstones suggests that similar processes were responsible for their deposition.

"49-3" Sandstone

The "49-3" sandstones are typical storm deposits. They were deposited in rather deep water, probably middle neretic, about 40 miles (65 km) seaward of a delta system. Sedimentary structures and trace fossils in the sandstones are the main evidence for deposition by storm-generated currents. Sharp basal contacts are overlain by massive sandstones, followed by a rippled or interlaminated unit. Bioturbation is restricted to the upper part of the sandstones. The sandstones are generally less than 1 foot (30 cm) thick, and are separated by black shales up to 5 feet (1.5 m) thick. The only trace fossils recognized were Chondrites. The fine scale of these horizontal burrows indicate relatively deep-water sedimentation.

Similar deposits have been described by other workers (Hayes, 1967; Morton 1981; Reinick and Singh, 1972; Goldring and Bridges, 1973). A review of their storm-sands show two general types of deposits. The first is similar to many of the "49-3" sandstones, having a massive base overlain by interlaminated, and possibly graded sandstones and shales. The second type is horizontally bedded at the base instead of massive (Nittrouer and Sternberg, 1981). This second type is characteristic of the sand-poor Cretaceous Western Interior Seaway (Swift and Rice, in press). However, because the "49-3" sandstone are much like the first type, a sandy shelf may have been present in this area.

Various mechanisms have been proposed for these thinly bedded deposits. Hayes (1967) introduced the concept of storm surges creating strong gravity-induced currents that flow seaward as the storm diminishes. These storm-surge ebb currents become density currents as they cross the inner shelf. Swift (Swift, Heron and Dill, 1969; Swift, Freeland and Young, 1979; Swift and Rice, in press) and Morton (1981) have proposed that strong bottom currents that form in response to wind forcing (Csanady, 1976) are another explanation for the thin, upward-fining storm-sands. Wind-forced currents on the shelf form in response to strong storm winds. Deposition of sand may occur during waning flow periods associated with storm dissipation. Sand may also be deposited on the lee side of topographic highs continuously during storm activity.

The Streif and Voight Craig 1 (SC1), located north of Pleasant Ridge field, cored sandstones that are probably equivalent to the "49-3" sandstone. These sandstones are thin, and have a sharp basal contacts (Theiss, 1983). Massive sandstones are overlain by bioturbated shales. The sandstones are similar to the sandstones in the MHU 49-3 and were probably also deposited by storm currents.

Eagleford Sandstones

Four wells in western Houston county cored sandstones in the Madisonville Tongue of the Lower Eagleford Formation. Two of the wells, the Sims Walker and Harris 1 (SWH1) and the Tenneco J. Henry 1 (TJH1), are approximately 20 miles (32.3 km) to the northeast of OSR-Halliday field. These two wells cored shaly sandstones that are generally bioturbated (Theiss, 1983). These sandstones were deposited marginal to a main deltaic complex to the south. Sediments supplied from the "Harris" delta, were transported by longshore currents to the site of deposition where they were reworked by benthic organisms.

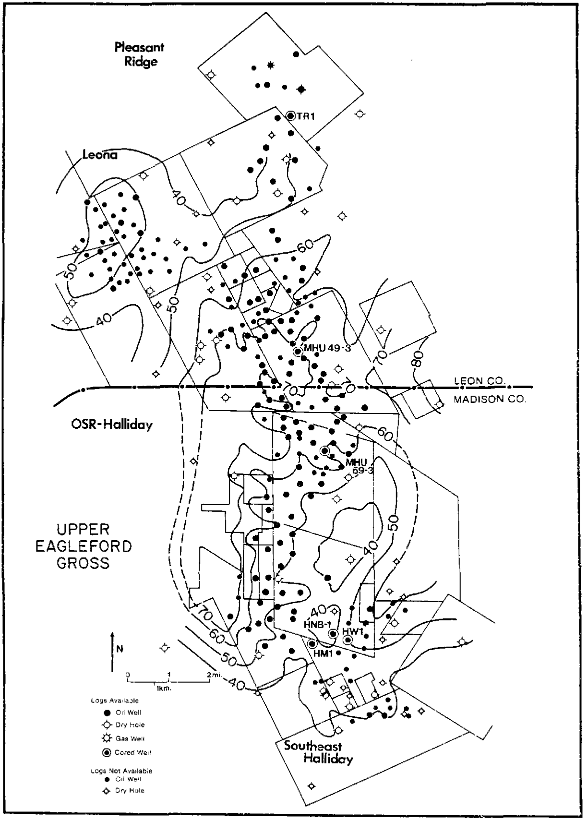
The Tenneco M. Towler 1 (TMT1) and the Magnolia A.B. Spence 1 (MBS1) cored Madisonville sandstones about 10 miles east of OSR-Halliday field. Over 150 feet (45.7 m) of bioturbated sandstones are found in these wells (Theiss, 1983). The mean grain size in the MBS1 is 0.20 mm, and the quartz content averages 79%. These values, which are the highest encountered in any Upper Woodbine or Lower Eagleford sandstone studied, indicate their proximity to the source where higher energy conditions are present. These sandstones were deposited in a delta-front environment.

Many of the Upper Woodbine and Lower Eagleford sandstones discussed in this study have been interpreted as delta front and delta margin deposits. Berg (1979) made a similar interpretation in Dakota sandstones at Lone Pine Field, New Mexico. A large amount of bioturbation in the sandstones suggested that sediment influx was relatively small, allowing benthic organisms to rework much of the sediment. Sandstones marginal to the "Harris" delta were deposited under similar conditions.

The primary properties of Upper Eagleford sandstones were described by Theiss (1983) in three cores north of OSR-Halliday field. The sandstones were divided into three units, the "A", "B", and "C". The "A" sandstone, which was cored in the Rotary and Hall Parker 1 (RHP1) and the Streif and Voight Craig (SC1), is heavily bioturbated. To the south, this unit changes facies to a cleaner sandstone. The "B" sandstone, cored in the SC1 and RHP1 as well as the Tenneco Robeson 1 (TR1), and the "C" sandstone, cored only in the TR1, are generally massive, with some crossbedding, ripple laminae and little bioturbation. The "C" sandstone becomes a heavily bioturbated sandy mudstone to the west. The similarity of these two units, and the similar changes in facies observed in both the "A" and "C" units, suggest that similar processes deposited these Upper Eagleford sandstones. Theiss (1983) interpreted these sandstones as storm deposits.

Because of insufficient well control, the morphology of these sandstones in Pleasant Ridge field was mapped as a sheet sandstone that thinned northward (Theiss, 1983). In OSR-Halliday field, over 130 well logs were used to define the morphology. An Eagleford gross sandstone map of the area shows a north-south, elongate sandstone body located just to the east of OSR-Halliday field (Fig. 22). This map was constructed by contouring the total sandstones between the top of the "A" sandstone and the base of the lowest Upper Eagleford sandstone. Minor east-west sandstone components are also present. The maximum sandstone

Figure 22. Gross sandstone map of the Upper Eagleford formation showing the elongate, irregular morphology of the sandstones. Note the thickening of the sandstone to the east. Contour interval is 10 feet.



Pleasant Ridge
TR1
Leona
40
50
60
70
80
MHU 49-3
LEON CO.
MADISON CO.
OSR-Halliday
MHU 69-3
UPPER EAGLEFORD GROSS
HNB-1
HW1
HM1
N
0
1
2 mi.
1km.
Logs Available
Oil Well
Dry Hole
Gas Well
Cored Well
Logs Not Available
Oil Well
Dry Hole
Southeast Halliday

thickness is located along the axis of the sandstone and to the east of OSR-Halliday field along the Leon-Madison county line. The thickening of sediments to the east along this dip trending component suggests a source of sands to the east.

An Upper Eagleford net sandstone map was constructed by measuring one-half of the maximum SP response and contouring the resulting thickness. This map shows the same north-south morphology as the gross sandstone map, but the axis of the body is shifted to the east over OSR-Halliday field (Fig. 23). A major, dip-trending component is present just north of the Leon-Madison county line, again indicating the direction and location of sediment input.

Theiss (1983) suggested topographic control of the Upper Eagleford sandstones at Pleasant Ridge field which resulted from the differential compaction of underlying sediments. He observed thinning of Eagleford sandstones where the thickest Woodbine sandstones occur, and thickening where the Woodbine is mostly shale. These relationships are confirmed at OSR-Halliday field. Figure 24 is a comparison of the gross sandstone maps of the Woodbine and Eagleford. The main axis of Woodbine sediments lies just to the east of the thickest Eagleford sandstones. East-west trending sandstone components are also offset, with Eagleford thicks forming in Woodbine thins.

These topographic highs (ridges) controlled Upper Eagleford deposition much like that proposed for deposition of the "69-3" sandstone. The main current direction was probably from the southeast, oblique to the crest of the ridge. This mechanism explains the offset in the axis of maximum deposition between the net and gross Upper

Figure 23. Upper Eagleford net sandstone map showing the north-south trending, elongate morphology. The east-west trending lobe in the center of the map suggests a sediment supply from the east. Contour interval is 10 feet.

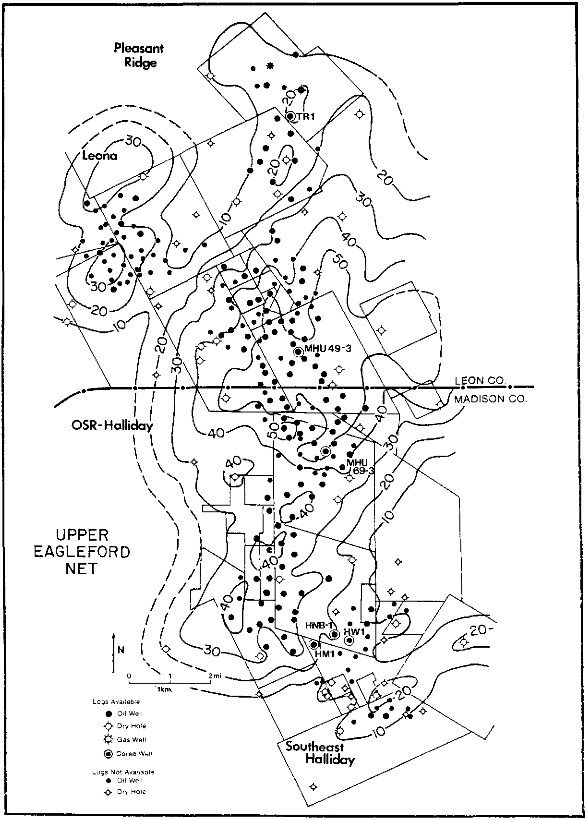
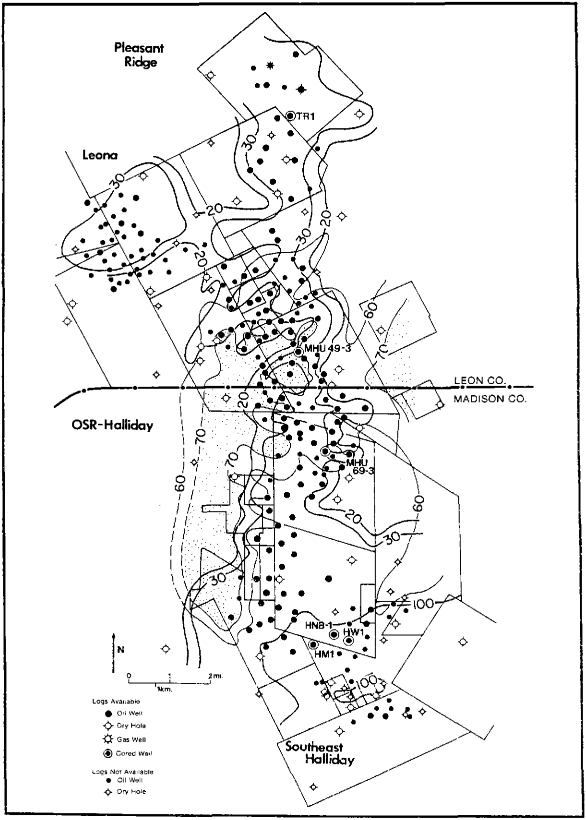

Pleasant Ridge
Leona
OSR-Halliday
Southeast Halliday
UPPER EAGLEFORD NET
LEON CO.
MADISON CO.
TR1
MHU 49-3
MHU 69-3
HNB-1
HW1
HM1
N
0 1 2 mi.
1 km.
Logs Available
Oil Well
Dry Hole
Gas Well
Cored Well
Logs Not Available
Oil Well
Dry Hole

Figure 24. Comparison of the Upper Eagleford and Woodbine gross sandstone maps (Figs. 11 and 22). The 60 and 70 foot contours (stippled area) are Upper Eagleford. The 20, 30 and 100 foot contours are Woodbine. Note the juxtaposion of the two bodies.


Pleasant Ridge
TR1
Leona
OSR-Halliday
MHU 49-3
LEON CO.
MADISON CO.
MHU 69-3
HNB-1
HW1
HM1
Southeast Halliday
N
0 1 2 mi.
1km.
Logs Available
Oil Well
Dry Hole
Gas Well
Cored Well
Logs Not Available
Oil Well
Dry Hole

Eagleford sandstones. The currents dropped the cleaner sandstones near the ridge crest. The net sandstone map, which includes only clean sand, supports this conclusion. The gross sandstone map shows a thicker sequence to the west on the flank of the ridge. These sediments which include sands, silts and clays were deposited as the currents decelerated on the basinward side of the ridge.

"MJ1" Sandstone

The "MJ1" sandstones were deposited in a deltaic environment. Three different subenvironments can be distinguished: the delta front; distributary channel; and interdistributary bay. The vertical sequence of the three facies indicates progradation of the delta. This delta is probably equivalent to Oliver's (1971) Freestone delta.

Facies 1, the lowest sandstone cored, is a delta front sequence. From bottom to top the unit coarsens, increases in quartz content, and changes from interlaminated sandstones and shales, to a mottled bed, and then to a massive sandstone with indistinct crossbedding. These changes reflect increasing energy conditions upward. The small burrows of Chondrites are replaced by large burrows of Thalassinoides upward, suggesting a change from a shelf environment to a nearshore setting.

Facies 2 is a distributary channel sequence which prograded over, and cut into, the delta-front deposits. The basal lag consists of a fossiliferous sandstone with some coal lenses. The shell fragments were reworked from delta front deposits and concentrated at the base of the channel where current energies were highest. Above the lag, is a thick sequence of crossbedded sandstones, capped by a ripple bed. The decrease in energy conditions upward in this facies is demonstrated by the sequence of sedimentary structures and the upward decrease in both grain size and quartz content.

Facies 3 is a shale zone that contains whole and broken shell fragments. This facies is interpreted to be an interdistributary bay. Restricted conditions of a bay environment are supported by the low taxonomic diversity present. Only oyster shells and a small number of pectens were identified. Thin sandstone beds within the shale unit are generally rippled. The high degree of bioturbation in the shales suggests slow continuous deposition, with some rapidly deposited sandstone beds that resulted from storms.

Above the shales of facies 3, sandstone beds having the same characteristics of facies 1 and 2 were deposited. This sandstone is a much thinner sequence of the facies 1, delta-front sandstones overlain by the distributary channel deposits of facies 2. This section is unconformably overlain by the Austin Chalk.

The "MJ1" sandstones are typical deltaic deposits with a very simple depositional history. Delta-front sands were deposited over prodelta muds as the delta prograded seaward. With further progradation, the distributary channel of the delta plain cut deeply into delta front sands, reworking them and leaving a basal channel lag of marine shells. This distributary channel migrated laterally or was temporarily abandoned, and the sandstones subsided into the delta-front muds below due to differential compaction. A shallow bay formed above the subsiding sandstones. Later, a distributary channel migrated back over the bay and the upper sandstone was deposited.

Regional Geology

Many workers have discussed the existence of the "Harris" delta (Nichols, 1964; Oliver, 1971; Bell, 1980; Turner and Conger, 1981). However, subsurface studies have discovered only offshore marine sand bodies, which have been described as either delta margin or offshore bars. The "Harris" delta does exist somewhere to the east of these study areas, but has eluded the core barrel. The "MJ1" Woodbine sandstone is a delta, but it is about 40 miles (64.5 km) to the east of the study area, suggesting that sediment derived from this delta was not the source for the OSR-Halliday longshore bar, nor any other sandstones discussed previously.

However, a cross section extending from the MJ1 to the MHU 69-3 in OSR-Halliday offers a ready explanation of the depositional history of this region (Fig. 25). The interpretation of this cross section is shown in Figure 26. Following shale deposition in the Lower Woodbine, two small deltas prograded westward from Trinity County into Houston County. Electric log responses on the cross section show coarsening upward sandstones typical of prograding deltas. The "MJ1" sandstone is equivalent to these sandstones, thus supporting the deltaic interpretation. The presence of deltaic deposits in this area suggests that the Sabine uplift, just to the northeast, was emergent during the middle and late Woodbinian.

During upper Woodbine deposition and following deposition of the second deltaic sequence, a major rise of the Sabine uplift occurred. Subsequent erosion on top of the Sabine removed all of the lower Woodbine sediments, which were then transported to the west and

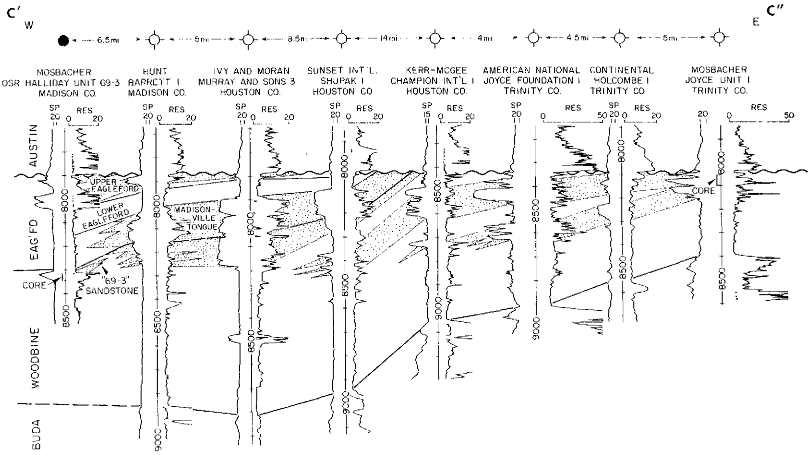


Figure 25. Regional cross section from OSR-Halliday field in Madison County to Trinity County. Note the truncation of the Woodbine and Eagleford to the east. Location of section shown in Figure 18. Interpretation of sandstone bodies shown in Figure 26. No horizontal scale.

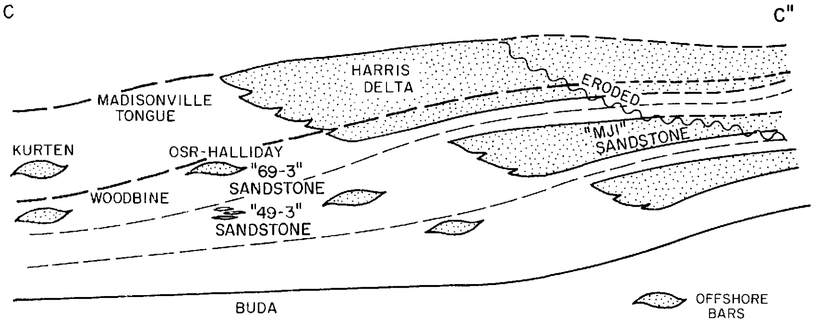


Figure 26. Interpretation of cross section C'–C" (Fig. 25) showing three deltaic bodies prograding westward. Location of offshore bars, the "69-3" sandstone, "49-3" sandstone, and "MJ1" sandstone are also shown. The eastern part of the deltaic systems was eroded following the late Woodbinean uplift of the Sabine. Location of cross section is shown in Figure 18.

deposited as upper Woodbine and Eagleford sediments. Sediment supply into the East Texas basin increased due to renewed uplift, and a third deltaic sequence prograded rapidly, with a much greater thickness of sandstones deposited. Over three hundred feet of sand was deposited as this delta, the "Harris" delta, prograded more than thirty miles east-southeast into the basin. This deltaic sequence, comprising the Upper Woodbine and Madisonville Tongue of the Lower Eagleford, also coarsens upward. The interpretation of this delta, however, comes only from electric log characteristics and the identification of delta margin facies found in this and other studies. Distributary channels or other delta-plain deposits have not been observed in this area because no cores have been available.

Cross section C'-C" supports work done by previous workers. The truncation of the Eagleford Group occurs in eastern Houston County, coincident Oliver's (1971) upper limit of the Eagleford line. The section also shows a rather constant thickness of lower Woodbine strata indicating deposition on a Buda peneplain, as suggested by Halbouty and Halbouty (1982). The general regressive nature of the Woodbine and the Lower Eagleford, the Late Eaglefordian transgression, and the erosional truncation of the Eagleford and much of the Woodbine are illustrated.

The location of the offshore bar at OSR-Halliday field and the position of the "49-3" sandstone in relation to the shoreline may be inferred from this section. The nearshore bar at OSR-Halliday field is equivalent to the base of "Harris" sandstones. Therefore, deposition of the bar occurred before maximum progradation of the delta, when the delta plain was a few miles to the southwest. The "49-3" sandstone, although not shown on the cross section, is located just below the total depth drilled in the MHU 69-3 well (the most westerly well on the section). This sandstone correlates with the second deltaic sequence equivalent to the "MJ1" sandstones in Trinity County. This delta may have been the source for the "49-3" storm deposits. Oliver (1971) has shown that the Freestone delta trends north-south in this area. Therefore, the source of the "49-3" sandstones was probably a delta to the north of OSR-Halliday field. Because the "MJ1" delta is oriented oblique to depositional dip on the section, the distance between the MHU 49-3 and the MJ1 wells is considered to be the maximum distance between the shoreline and the "49-3" sandstone deposits. Therefore, these storm sandstones were deposited less than 40 miles (64.5 km) offshore.

The Kurten offshore bars are also shown on Figure 26. The Harris delta reached its maximum regression just east of Kurten (Bell, 1980; Turner and Conger, 1981) and remained at still stand, because fluvial and marine processes were at equilibrium. The similarity of the Kurten and OSR-Halliday bars suggests that they were deposited in a similar setting. Other offshore bars illustrated in Figure 26 may be found in similar settings.

CONCLUSIONS

Woodbine sandstones in Leon, Madison and Trinity counties were deposited in shelf and delta environments. The "69-3" sandstone was deposited by longshore and offshore currents in shallow waters near the Harris delta. The sand body is elongate north-south and has minor east-west components. Topographic highs, present on the sea floor during deposition, controlled the distribution of sandstones. The source of the sandstones was reworked delta front sediments transported northward by longshore currents, probably caused by tides.

The "49-3" sandstone, cored below the "69-3" sandstone, has been interpreted to be deposited by storm-generated currents. These sandstones are probably middle neretic, and again may have been influenced by subsea topography.

The "MJ1" sandstones, cored in Trinity County, are deltaic deposits. A basal unit of delta front sandstones is overlain by deposits of a distributary channel. Following migration and subsidence an interdistributary bay deposited fossiliferous shale on top of the delta sandstones. The delta-front and interdistributary channel environments later returned to the area as channel migration continued.

The interpretation of these depositional environments was based on the composition, texture, sedimentary structures and trace fossils of cored sandstones. Well logs allowed the morphology of the "69-3" sandstone to be mapped, and the resulting morphology of the sandstone body supported the environmental interpretation.

Upper Eagleford sandstones were also mapped, and the resulting morphology is much like those of the "69-3" sandstone. Differential compaction of Woodbine and Lower Eagleford sediments caused a topographic highs during Upper Eagleford deposition. These sandstones were deposited on top, and seaward of, the ridges.

A regional cross section through Trinity, Houston and Madison counties supports most of the depositional history of Woodbine and Eagleford in East Texas sediments presented by Oliver (1971), and Halbouty and Halbouty (1982). However, the "MJ1" sandstones are deltaic, not coastal barriers, as Oliver (1971) indicated. The Sabine uplift was also emergent during the middle and upper Woodbinian, but this may be due to progradation of the shoreline rather than structural activity.

The study of sandstones at OSR-Halliday field has resulted in a local depositional model which will enhance exploration efforts in East Texas, as well as areas with similar depositional systems. Because paleo-ridges have been shown to influence sandstone distribution, paleotopographic maps will aid in predicting the location of other sandstone bodies. Identification of paleocurrent directions and source areas will also be useful. Knowledge gained from this study will aid in the quest for oil and gas traps, but two major problem areas show a need for further research. The first is the location and extent of the facies associated with the "Harris" delta. The morphology of the "MJ1" deltaic sandstones in Trinity County must also be defined.

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APPENDIX

The following pages include:

Core descriptions* and petrographic analyses of:

Mosbacher OSR-Halliday Unit 69-3

Mosbacher OSR-Halliday Unit 49-3

Mosbacher Joyce Foundation 1

*Abbreviations used in core descriptions and petrographic analyses include:

ft - feet

mm - millimeters

CORE DESCRIPTION
Mosbacher
OSR-Halliday Unit 69-3
OSR-Halliday Field
Madison County, Texas
Woodbine Sandstone
Core: 8307-8343 feet

Depth ft	Thickness ft	Description
8307	2	Sandstone, light gray to gray, fine-grained, wavy, discontinuous, nonparallel laminae spaced less than 5 mm. Laminae are horizontal and slightly crenulate. High matrix content. Abundant organic particles less than 1 mm in size found throughout. Rare bioturbation. Lower contact not preserved.
8309	4	Sandstone, gray, fine-grained, wavy, dicontinuous and continuous, nonparallel laminae. Laminae are crenulate, subhorizontal, and less frequent than previous unit. Organic matter with orange weathering rims common. Coarse zone (5 mm thick) with rounded pebbles (3 mm long) oriented horizontally found near top of unit. Sharp lower contact.
8313	2	Sandstone, calcareous, light gray, fine-grained, wavy, generally discontinuous, nonparallel laminae oriented subhorizontally. Bioturbation interrupts many laminae. Shell fragments (<u>Gryphea</u>) up to 5 mm long found at base of unit in a more massive zone. Sharp lower contact.
8315	2	Sandstone, shaley, gray, fine-grained, same as unit as 8307 ft. Large (12 mm) organic fragment near base. Lower contact not preserved.
8317	3	Missing core.
8320	16	Sandstone, gray, fine-grained, wavy, continuous and discontinuous, generally nonparallel laminae are closely spaced and usually crenulate. Rare large scale bioturbation include: Vertical escape burrow (5 mm x 35 mm) at 8322 ft; <u>Thalassincides</u>(?) (7 mm x 40 mm) at

MHU 69-3 (continued)

Depth ft	Thickness ft	Description
		8324 ft. Black organic fragments up to 5 mm in length are rare. Organic particles less than 1 mm in size are scattered throughout. A concentration of these organic particles are found in a fine- to medium-grained, 20 mm thick calcareous sand lense at 8327 ft. Matrix content increases upward. Gradational lower content.
8336	7	Interlaminated sandstone and shale, light gray to gray sandstones and black shales. Sandstone is very fine-grained and have a high matrix content. Laminae are planar, subparallel, continuous and less than 5 mm thick. Thinner laminae are crenulate. Minor contortions are present at 8340 ft. Starved ripples are rare and isolated. Shales are more common toward base. Shales are micaceous. Very rare small scale burrows (<u>Chondrites</u> ?). Lower contact not preserved.
8343		End of core.

Core description by Charles T. Bukowski Jr., 1983. Core was in representative two foot intervals, but in good condition.

PETROGRAPHIC ANALYSIS
Mossbacher Halliday Unit 69-3 (MHU 69-3)
OSR-Halliday
Madison County, Texas
Core: 8307-8343 ft

Depth ft	Quartz Size[a]			Detrital Composition[b]					Cement[c]	
	Mean mm	Max mm	σ mm	Qz %	F %	Rx/PQ %	Oth/Ch %	Mx %	Sil % of total	Cal
8307-08	0.14	0.26	0.04	67	1	1	1	30	6	6
8311-12	0.15	0.39	0.06	79	1	3	0	17	7	8
8313-14	0.16	0.34	0.06	86	0	3	1	10	1	55
8315-16	0.14	0.27	0.05	74	0	5	0	21	4	0
8324-25	0.16	0.47	0.07	71	0	5	2	22	7	1
8326-27	0.19	0.40	0.08	67	0	3	3	27	7	0
8332-33	0.15	0.25	0.03	91	0	0	0	9	9	19
8338-39	0.11	0.25	0.04	58	0	6	0	36	13	1
8342-43	0.11	0.25	0.05	65	0	5	1	29	8	18
MEAN	0.15	0.25	0.05	73	<1	3	<1	22	7	12

[a]Long-axis measurements; σ = standard deviation.
[b]Qz = monocrystalline quartz, F = feldspars, Rx = rock fragments including polycrystalline quartz, Mx = matrix, Oth = other minerals.
[c]Sil = silica as grain overgrowths, Cal = calcite.

Mosbacher
OSR-Halliday Unit 49-3
OSR-Halliday Field
Leon County, Texas
Woodbine Sandstone
Core: 8147-8174 feet

Depth ft	Thickness ft	Description
8147	3.3	Shale, calcareous, black, massive and fissile. Isolated sandstone laminae throughout. Sandstone is gray, very fine-grained, and is poorly sorted. Chert pebbles up to 6 mm in length and black iron oxide are common in the sandstone lenses. Minor bioturbation is present. Horizontal burrows (Chondrites) up to 10 mm are rare. Rare shell fragments up to 15 mm found in the shales. Soft sediment flowage of sands and loading is common. Gradational lower contact.
8150.3	.7	Sandstone, calcareous, white to gray, fine-grained, massive. Base of unit contains abundant pebbles up to 20 mm in length, well rounded and oriented subhorizontally. Pebbles are chert and iron oxide. Shale clasts are also present. Shale laminae at 8150.6 ft are interrupted by minor bioturbation and loading. Base of unit is contorted, showing evidence of flowage. Large, sand filled horizontal burrows found at 8150.6 ft. Lower contact is sharp with flame structures present.
8151	4.3	Shale, black, similar to unit at 8147 ft. Few thin, calcareous, very fine-grained sandstone laminae interrupt thicker shale beds. Sand laminae are discontinuous due to loading and possibly minor bioturbation. Few horizontal burrows (Chondrites) 5 mm in diameter lower in unit. Pyrite rich laminae at 8155 ft. Coiled gastropod shell 15 mm in diameter at 8155 ft. Gradational lower contact.
8155.3	.7	Sandstone, calcareous, light to dark gray, very fine-grained. Few shale laminae, even to wavy, subparallel and continuous. Interlaminated sand and shale bed 20 mm thick at 8155.6 ft, with the upper contact an erosional

MHU 49-3 (continued)

Depth ft	Thickness ft	Description
		surface (sole marks at top). Minor loading throughout unit. Iron oxide grains and organic matter concentrated near base in a contorted and generally massive sand .2 ft thick. Sharp lower contact.
8156	4.7	Shale, black, fissile, similar to previously described shale units (at 8147 and 8151 ft). Parting along horizontal bedding. Horizontal, planar, continuous laminations near top. Dark gray, calcareous, very fine-grained sandstone at 8159 ft is 40 mm thick, massive at the base, and fines upward. Shell fragments and iron oxide grains near base of sand. A light gray, contorted sandstone .2 ft thick occurs at 8160 ft. This bed is much like the unit at 8160.5 ft and may be out of place. Sharp lower contorted.
8160.7	1.8	Sandstone, calcareous with interlaminated shales, sands are light to dark gray and very fine-grained. Shales are black. Individual sand layers are up to .2 ft thick, have sharp basal contacts with sole marks and loading features (flame structures and scour marks). Base of sandstone beds is coarser sand with black iron oxide grains up to 7 mm long. Beds fine upward, are contorted or massive at the base, and may have horizontal laminae at the top. Slightly bioturbated. Horizontal burrows (Chondrites) up to 4 mm in diameter are common near the top of the sand beds and within the shale laminae separating the sands. Sharp lower contact.
8162.5	1.5	Shale, black, with interlaminated very fine-grained, gray sandstones. Similar to previous shale units except horizontal burrows (Chondrites, up to 4 mm) and isolated, starved sand ripples are common. Large carbonaceous plant fragment at 8163.9 ft. Gradational lower contact.

MHU 49-3 (continued)

Depth ft	Thickness ft	Description
8164	2	Sandstone, calcareous, light to dark gray, very fine-grained. Shale laminae interrupt thicker sand beds. Individual sand beds are similar to sandstone at 8160.7 ft. Loading, sole marks, iron oxide and contortions are common near base of each bed. The sandstone beds fine upward. The unit as a whole also fines upward, with more shale laminae near top. Small horizontal burrows (Chondrites) in shale laminae near top. Gradational lower contact.
8166	5	Shale, black. Same as other previously described shale units (8147 ft). Small horizontal burrows (Chondrites), discontinuous sandstone laminae, loading features and shale partings are present. Lower contact is gradational.
8171	2	Sandstone, calcareous, light to dark gray, very fine-grained. Black shale laminae interrupt sand unit. Individual sand beds similar to beds at 8160.7 ft. Ripples are common near the top of individual sand beds, and between shale laminae. Few horizontal burrows (Chondrites) are found near the top of individual sand beds or in the interlaminated shales and sands that separate the thicker (up to .2 ft) sandstones. Carbonaceous material at 8172 ft. Sharp lower contact.
8173	1	Shale, black, same as previously described. Large calcite nodule (120 mm) at top of unit. Fractures in nodule are filled with calcite. Lower contact not preserved.
8174		End of Core

Core description by Charles T. Burkowski Jr., 1984. Core was in good description.

PETROGRAPHIC ANALYSIS
Mossbacher Halliday Unit 49-3 (MHU 49-3)
OSR-Halliday
Leon County, Texas
Core: 8147-8174 ft

Depth ft	Quartz Size[a]			Detrital Composition[b]					Cement[c]	
	Mean mm	Max mm	σ mm	Qz %	F %	Rx/PQ %	Oth/Ch %	Mx %	Sil % of total	Cal % of total
8151	0.20	0.33	0.06	60	0	11	17	12	3	36
8154	0.09	0.21	0.04	56	0	15	6	16	0	36
8159	0.11	0.24	0.04	64	0	11	5	20	5	28
8160	0.11	0.21	0.04	92	0	3	3	2	12	37
8161	0.10	0.20	0.04	78	0	2	3	17	2	46
8162	0.11	0.25	0.04	48	0	9	8	35	1	31
8165	0.10	0.21	0.04	72	0	7	3	18	9	26
8165.8	0.08	0.21	0.03	74	0	5	4	17	3	46
8172	0.10	0.16	0.03	86	0	8	5	1	13	32
8173	0.10	0.19	0.03	69	0	10	2	19	12	26
MEAN	0.11	0.22	0.04	70	0	8	6	16	6	34

[a] Long-axis measurements; σ = standard deviation.
[b] Qz = monocrystalline quartz, F = feldspars, Rx = rock fragments including polycrystalline quartz, Mx = matrix, Oth = other minerals.
[c] Sil = silica as grain overgrowths, Cal = calcite.

Mosbacher
Joyce Unit 1 (MJ1)
Wildcat
Trinity County, Texas
Woodbine Sandstone
Core: 8046-8091.8 feet

Depth ft	Thickness ft	Description
8046	5	Sandstone, light gray, fine-grained. Planar to curved, parallel, continuous cross laminations are inclined up to 20°. Wavy, nonparallel, subhorizontal, continuous and discontinuous laminae interrupt planar cross laminae and are most common near base. Horizontal and vertical burrows 5 mm in diameter near base are rare. Vertical burrow (Arenicolites) at 8050 ft is 35 mm in height and 3 mm in diameter. Small (<3 mm) shell fragments occur in coarser laminae throughout the unit. Basal contact is sharp.
8051	2	Sandstone, calcareous, light to medium gray, fine-grained, massive. Abundant shell fragments throughout include oysters (Gryphea), gastropods, encrusting worm tubes, Pectens, and echinoderms (?). Oysters are most common, making up about 90% of the fragments. Shell fragments are up to 25 mm long. Black organic matter occurs in fragments up to 12 mm in length. Shale clasts up to 10 mm occur near base. Vertical fractures are sometimes filled with calcite and are up to 1 ft in length. Sharp basal contact.
8053	1	Shale, black. Abundant large (up to 50 mm) shells are mostly fragmented. Oysters are most common with a few Pectens also identified. Shells are generally oriented horizontal. Sharp lower contact.
8054	.4	Sandstone, white, very fine-grained, massive. Shell fragments are small (<9 mm) and common, especially near base. Calcite filled vertical fracture extends length of unit. Unit much like sandstone at 8051 ft, and thus may be out of place. Sharp basal contact.

MJ1 (continued)

Depth ft	Thickness ft	Description
8054.4	7.6	Shale, black, generally massive. Interlaminated gray silts and black shales at 8056, 8056.5, and 8058 ft are about .3 ft thick. Laminae are wavy, nonparallel and mostly continuous. Large shells of Gryphea, Pectens, fish vertebrae and unidentifiable fragments throughout. Bioturbation is evident at 8056.5 and 8058 ft with large horizontal and vertical burrows (5 mm in diameter). Bioturbated beds are generally churned (mottled). Soft sediment deformation near base. Wavy laminae are most common in interlaminated silts and shales at 8056 and 8058 ft. Sharp basal contact.
8062	17	Sandstone, light gray, fine- to medium-grained, fines upward, high quartz content. Even, parallel, continuous laminae inclined 0 to 20°. Same as sandstone unit at 8046 ft except: shale clasts (up to 4 mm) at 8062.5 ft; coal lenses at 8064 ft (3 mm thick) and at 8079 ft (base of unit); wavy, nonparallel, continuous, and usually crenulate laminae are common at top of unit and uncommon in remainder of unit; insipient faults at 8076.3 ft; large contortions (overturned beds) at 8063.5 ft; bed (1 ft thick) at 8067 ft is massive; fracturing at 8069 ft is filled with calcite. Sharp basal content.
8079	3.5	Sandstone, gray, fine-grained, abundant shell fragments. Same as unit at 8051 ft except: Indistinct subhorizontal, even, continuous, parallel laminations throughout; coal lenses up to 12 mm thick and yellow sulfur at 8079.1 and 8082 feet. Large (60 mm) Gryphaea shell at 8082.5 ft. Unit has vertical calcite filled fractures. Gradational lower contact.
8082.5	3.5	Sandstone, white to gray, fine- to medium-grained, well cemented by calcite, section appears massive, but indistinct, parallel, continuous, planar laminations are common. Laminations are horizontal to inclined 5° and contain abundant organic matter. Few small

MJ1 (continued)

Depth ft	Thickness ft	Description
		fragments of shell material. Organic lense at 8084.5 ft. Calcite cement decreases downward. Sharp basalt content.
8086	2.7	Sandstone, light gray, fine-grained. Massive with few indistinct even, parallel, continuous laminae at and near top. Large (17 mm) horizontal burrow at 8086.5. Shell fragments rare and concentrated in thin subhorizontal laminae. Shale clasts, shell fragments and bioturbation common at base. Sharp lower contact.
8088.7	1.8	Sandstone, shaley, brownish gray, fine-grained. Unit is mottled due to abundant large scale bioturbation. Trace fossils include Thalassinoides. Sharp lower contact.
8090.5	1.3	Sandstone with interlaminated silts and shales. Sand is gray and fine-grained; silts are brownish gray; shales are black. Wavy, nonparallel, continuous and discontinuous laminae throughout. Sandstones may also be massive. Small (<2 mm) horizontal burrows (Chondrites) are common especially in the shales. Lower contact not preserved.
8091.8		End of Core

Core description by Charles T. Bukowski Jr., 1984. Core was in very good condition.

PETROGRAPHIC ANALYSIS
Mossbacher Joyce Unit 1 (MJ1)
Wildcat
Trinity County, Texas
Woodbine
Core: 8046-8091.8 ft

Depth ft	Quartz Size[a]			Detrital Composition[b]					Cement[c]	
	Mean mm	Max mm	σ mm	Qz %	F %	Rx %	Oth %	Mx %	Sil % of total	Cal % of total
8046	0.19	0.28	0.05	92	0	3	0	5	5	5
8049	0.23	0.43	0.07	89	0	1	0	10	3	8
8052	0.24	0.46	0.08	79	0	17	2	2	2	26
8062	0.19	0.45	0.06	86	0	2	2	10	5	8
8065	0.19	0.40	0.05	92	0	2	0	6	7	4
8069	0.26	0.58	0.07	93	1	0	2	4	15	3
8073	0.26	0.46	0.08	97	1	1	0	1	7	3
8078	0.27	0.46	0.07	92	0	3	1	4	11	7
8079	0.23	0.46	0.09	56	0	42	1	1	1	46
8083	0.24	0.42	0.08	90	1	5	2	0	1	35
8087	0.14	0.41	0.07	80	0	1	3	16	9	5
8088	0.18	0.43	0.07	79	0	5	1	15	19	7
8088.5	0.13	0.30	0.06	77	0	5	3	15	6	8
8091	0.15	0.46	0.06	83	0	6	3	8	16	2
MEAN	0.21	0.43	0.07	85	<1	7	1	7	7	11

[a] Long-axis measurements; σ = standard deviation.
[b] Qz = monocrystalline quartz, F = feldspars, Rx = rock fragments including polycrystalline quartz, Mx = matrix, Oth = other minerals.
[c] Sil = silica as grain overgrowths, Cal = calcite.

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