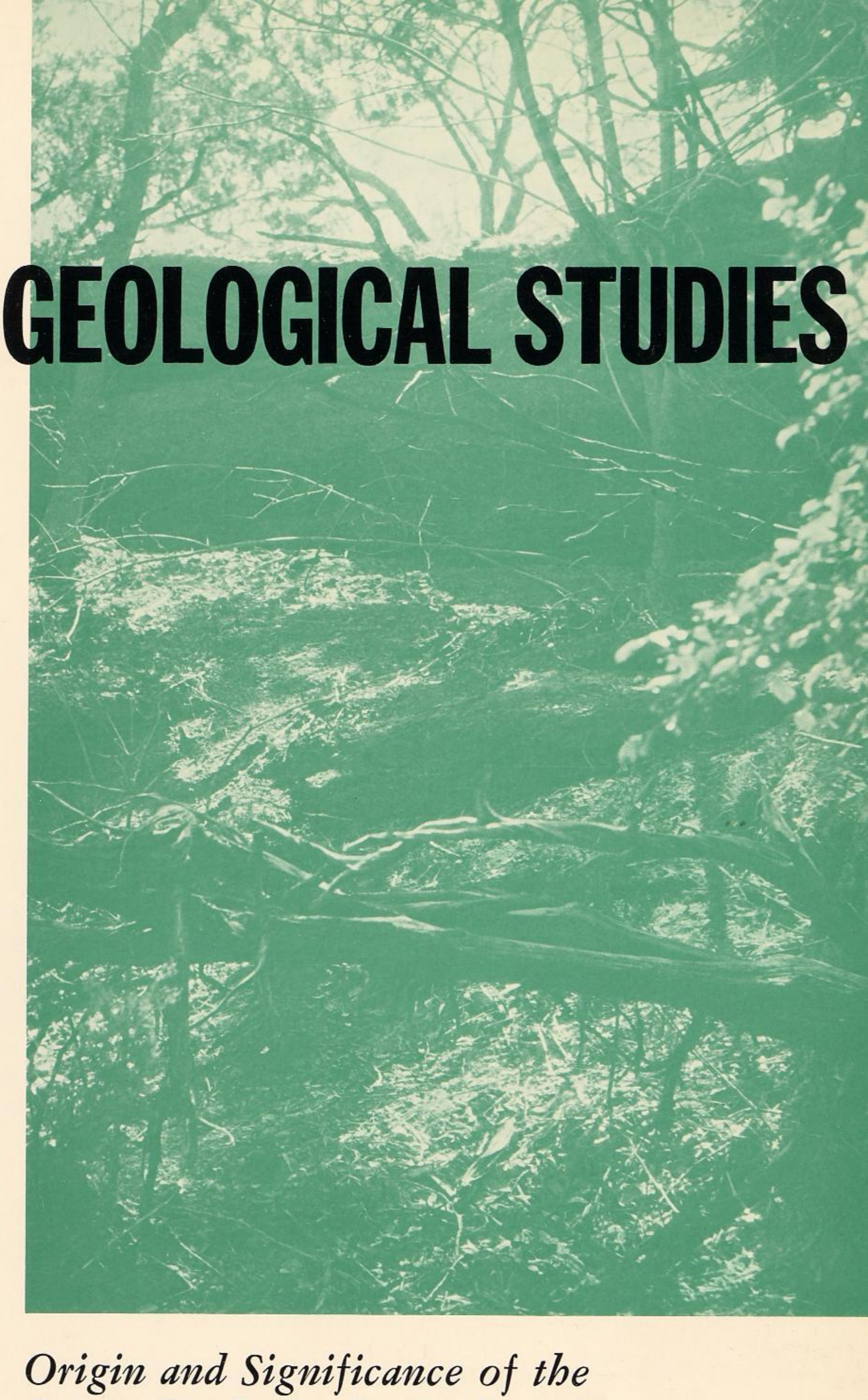

BAYLOR GEOLOGICAL STUDIES

SPRING 1976

Bulletin No. 30

BAYLOR UNIVERSITY - WACO, TEXAS
1845

Origin and Significance of the Oyster Banks in the Walnut Clay Formation, Central Texas

CARL DEAN FLATT

"Creative thinking is more important than elaborate equipment--"

Frank Carney, Ph.D.
Professor of Geology
Baylor University
1929-1934

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The training of a geologist in a university covers but a few years; his education continues throughout his active life. The purposes of training geologists at Baylor University are to provide a sound basis of understanding and to foster a truly geological point of view, both of which are essential for continued professional growth. The staff considers geology to be unique among sciences since it is primarily a field science. All geologic research including that done in laboratories must be firmly supported by field observations. The student is encouraged to develop an inquiring objective attitude and to examine critically all geological concepts and principles. The development of a mature and professional attitude toward geology and geological research is a principal concern of the department.

The cover photograph is of Santa Elena Canyon in the Big Bend Region of Texas.

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CONTENTS

ILLUSTRATIONS

Origin and Significance of the Oyster Banks in the Walnut Clay Formation, Central Texas

Carl Dean Flatt

ABSTRACT

The Walnut Clay in central Texas, a formation of the Lower Cretaceous Fredericksburg Group, has been divided into five informal members based on lithologic similarities and differences (Jones, 1966), from base to top: (1) Member One, (2) Member Two, (3) Member Three, (4) Member Four, and (5) Member Five. The Walnut Formation in central Texas formed as a back-reef series behind the topographically high Stuart City Reef of southeast Texas, which existed from late Trinity to early Washita time. Further restriction to open connection with the epicontinental Walnut Sea in the Stuart City Lagoon were the localized carbonate mounds: Whitestone Lentil and the Moffat Lentil. The five members of the Walnut Formation represent distinct changes in environmental conditions which existed throughout early Fredericksburg time. The Walnut Formation of central Texas was deposited in an environment of warm shallow seas which continually alternated between normal marine and brackish conditions.

The massive oyster banks, so characteristic of the Walnut Formation in central Texas, have long provided local stratigraphers with questions on origin, growth, and subsequent extinction. Initially they were believed to be storm lag deposits; however, field evidence, laboratory work, and library investigations reveal they represent ancient pelecypod banks growing in the same manner as modern oyster banks and subject to the same stringent environmental controls of temperature, siltation, predatorial and parasitic relationships, turbidity, and salinity.

Member One transgressed partially over the study area onlapping the subaerially exposed Paluxy Sand. The Member represents a nearshore deposit in the western part of the study area. Oyster bank growth was limited to the western area and occurred as scattered lenticular deposits of *Texigryphaea mucronata* and *Exogyra texana* (shallow water species of pelecypods).

Member Two rapidly transgressed over the entire study area to cover the remaining subaerially exposed Paluxy Sand. Environmental conditions during deposition of Member Two alternated among slightly brackish to brackish to marine. Oyster bank growth was limited due to rapid transgression.

Member Three represents a carbonate blanket that was deposited in a stable, low-energy, shallow, marine environment with possible regression taking place prior to deposition of Member Four. Oyster bank growth consisted of scattered low mounds of *Texigryphaea mucronata* and *Exogyra texana* interspersed with normal marine assemblages.

Member Four represents an unstable turbulent transgressive sub-facies of the Walnut Formation. During this transgressive period a large shallow bay formed in the northeastern part of the study area. Oyster bank growth reached a climax during deposition of this member, and represents brackish water conditions conducive to the growth of massive (30 feet) banks of *Texigryphaea mucronata.* Two stages of transgression may be observed, as distinguished by bank growth in the southern and northern parts of the study area. Periodic influxes of oligohaline to limnetic (fresh) water accompanied by large influxes of silt caused temporary cessation of the bank growth.

Member Five reflects a return to stable conditions of uniform carbonate deposition. The oyster banks diminished in size and distribution, with ultimate termination.

Growth of massive banks was ultimately terminated by the transgression of the euhaline (marine) waters of the Comanche Peak Sea. Member Five and the Comanche Peak Limestone transgressed over the shallow bay of Member Four in Bosque County bringing significant changes in the faunal associations and causing the *Texigryphaea mucronata* banks to be reduced in size and distribution.

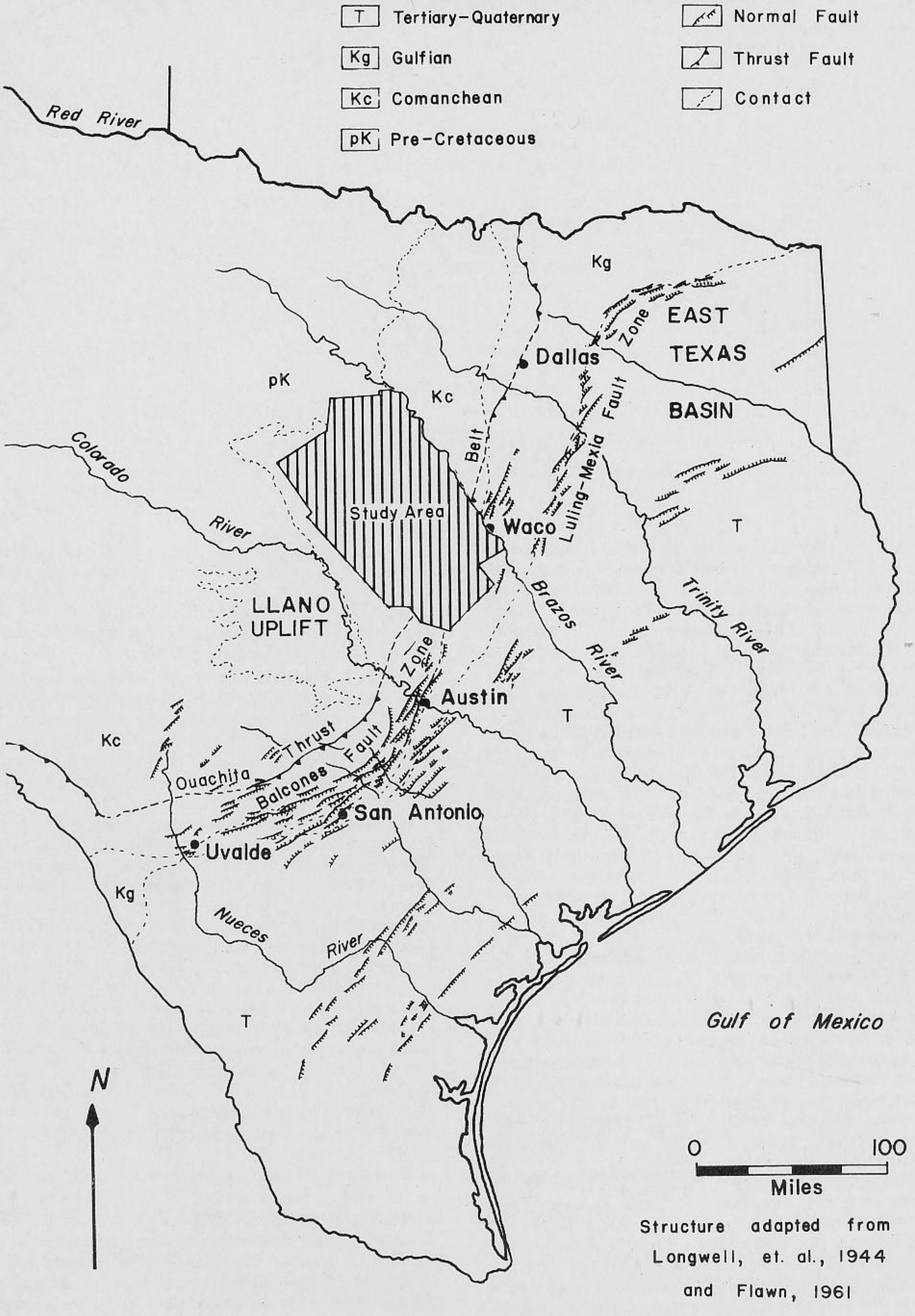

Fig. 1. Index map showing location of study area and principal geologic features of the region.

INTRODUCTION*

PURPOSE

One of the most striking features of Fredericksburg rocks of central Texas is the widespread occurrence of massive oyster banks composed almost entirely of *Texigryphaea mucronata* (Stenzel) in the Lower Cretaceous Walnut Formation. Observers of the geology of central Texas have made numerous references to the occurrence of these oyster mounds, generally describing them as *Gryphaea* banks (Hill, 1891, 1898; Adkins, 1932; Ikins, 1941; Lozo, 1949). Although there have been numerous localized studies and speculations as to the origins, there have been no detailed works dealing specifically with the oyster banks to determine how they formed or what they represent in terms of geological history.

Thus, the purpose of this study was to examine in detail the sedimentary environment of the oyster banks, the paleoecology of the oysters, the relationship of the banks to the Walnut Formation, and their significance in the evolution and subsequent diagenesis of Fredericksburg rocks of central Texas.

LOCATION

The area of study in north-central Texas includes all or parts of Bosque, Somervell, Hood, Erath, Comanche, Mills, Hamilton, Coryell, Lampasas, Bell, and McLennan Counties (Fig. 1). It lies entirely within the Lampasas Cut Plain, the northern extension of the Edwards Plateau, and is characterized "by the general level of its many remnantal summits" (Hill, 1901, p. 78) termed "mountains" by local citizens. The mountains are actually flat-topped circular-to-elongated buttes capped with Edwards Limestone forming the interstream divides. Beneath the resistant cap, slopes are composed of Comanche Peak Limestone, and valley floors are formed in Walnut Clay and Paluxy Sand.

Geographically the study area lies south of Dallas, north of Austin, and generally west of Waco. The northern border is the Brazos River, and the southern border is marked by the Lampasas River. The western border is a line drawn between the communities of Granbury, Stephenville, Dublin, and Comanche. The eastern border is the downdip margin of the Lampasas Cut Plain west of Interstate Highway 35, connecting the communities of Belton, Temple, and Waco.

Geologically the study area is on the eastern margin of the Texas Craton, north of the Llano Uplift, and northwest of the Balcones fault zone (Fig. 1). The study is confined entirely to the Walnut Clay, Fredericksburg Group, Comanche Series, Cretaceous System.

METHODS

One of the primary criticisms of paleoecological studies is the limited nature of methods utilized in the interpretation of paleoenvironmental problems. It was with this criticism under consideration that several methods were utilized to gather evidence for paleoenvironmental interpretations. The study involved field, laboratory, and library investigations.

Field work consisted of sampling sections previously described by Jones (1966). Sampling procedures consisted of description and collection of sections, including sediments below the oyster banks, the oyster banks proper, and sediments immediately above the banks. This was considered necessary for interpretation of the sequence of events that resulted in generation and extinction of the oyster banks.

The relationship of *Texigryphaea mucronata* (Stenzel) to other fauna was studied on both megascopic and microscopic levels with the intention of investigating the entire faunal assemblage of the oyster banks.

Aerial photographs, topographic maps and field control aided in geologic mapping, with subsurface control provided from selected electric logs in McLennan County.

Polished sections from 42 samples were examined with binocular microscope to determine composition and sedimentary structures.

Isopachous and interpretive paleogeographic maps were prepared based on information from this study.

An extensive review of the literature of modern bank-forming oysters was necessary to study the ecology of fossil-oyster banks. In conjunction with this, field examination of a modern oyster bank over a period of two years provided comparative field information of the ecology of modern bank-forming oysters.

TERMINOLOGY

To insure clarity, it was necessary to accept and/or modify terms that may have several connotations. The terms used in this study are here defined:

> CARBONATE BUILDUP: "A carbonate mass or a local portion of a carbonate unit which (1) differs in nature to some degree from equivalent deposits and surrounding and overlying rocks; (2) is typically thicker than equivalent carbonates; and (3) probably stood topographically higher than the surrounding sediment during some time in its depositional history" (Heckel, 1974, p. 91).
>
> REEF: "A product of actively building and sediment binding biotic organisms, which have the ability to erect rigid wave-resistant topographic structures" (A. G. I., 1962, p. 417).
>
> BANK: "The term bank was used by Lowenstam (1950) for structures formed by organisms which are incapable of raising their substrate; thus banks may be topographically well defined but are unconsolidated and have low-angle slopes" (Heckel, 1974, p. 93).
>
> ESTUARY: "A semi-enclosed coastal body of water having a free connection with the open sea and within which the sea water is measurably diluted with fresh water runoff" (Pritchard, 1967, p. 3).
>
> LAGOON: A body of shallow marine water periodically cut off from an open connection with the ocean.
>
> SALINITY: A measurement of the quantity of NaCl in water expressed as parts per thousand (‰). There is considerable disagreement as to the classification of estuaries based on salinity. As a consequence of this the salinity ranges and ecological classifications used in this paper are those of the Venice System outlined in Table 1.

PREVIOUS WORKS

Previous works that aided this study may be divided into five categories: (1) papers dealing with the Lower

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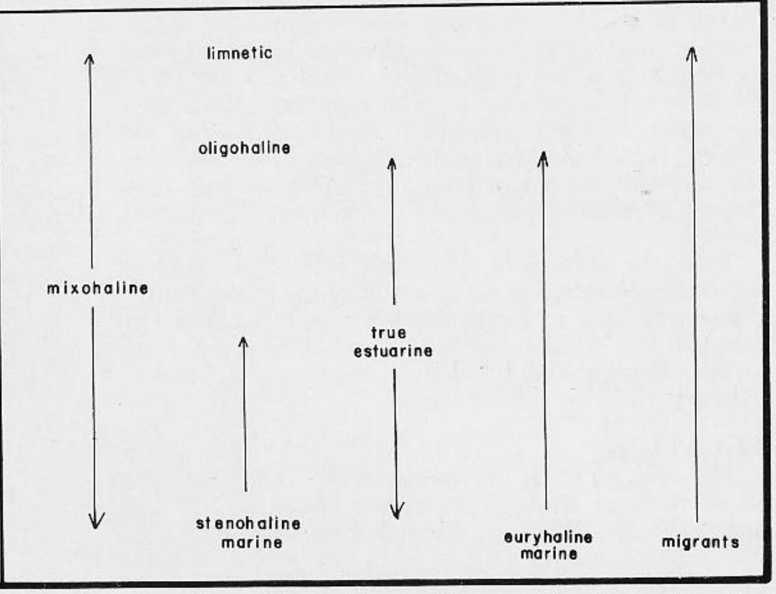
*A thesis submitted in partial fulfillment of the requirements for the M.A. degree in Geology, Baylor University, 1975.

TABLE 1. CLASSIFICATION OF GEOGRAPHIC DIVISIONS, SALINITY RANGES, TYPES AND DISTRIBUTION OF ORGANISMS IN ESTUARIES.

Divisions of estuary	Venice System Salinity Ranges ‰	Venice System Zones	Ecological Classification Types of organisms and range of distribution in estuary, relative to divisions and salinities
River	0.5	limnetic	
Head	0.5 – 5	oligohaline	
Upper Reaches	5 — 18	mesohaline	
Middle Reaches	18 – 25	polyhaline	
Lower Reaches	25 – 30	polyhaline	
Mouth	30 – 40	euhaline	

Adapted from Day, 1951, 1964 and Venice system, Symposium on the classification of brackish waters, 1959.

Cretaceous stratigraphy in the study area; (2) studies dealing specifically with fossil oysters in the Walnut Clay Formation, central Texas; (3) works on the microfauna of the Cretaceous System; (4) papers on the ecology of modern and ancient bank-forming oysters; (5) and paleontological studies dealing with the family Gryphaeidae.

The evolution of stratigraphic nomenclature of the Walnut Clay may be found in Table 2. It is readily apparent that many workers have investigated the Walnut Clay after the year 1891. Studies prior to 1891 were largely of reconnaissance, were highly speculative and limited in scope.

The history of earliest Comanchean nomenclature has been summarized elsewhere (Boone, 1968, p. 7) but, while early studies formed the essential foundation for later work, they have little direct bearing on the problem here investigated.

It was not until 1891 that Hill first differentiated the Walnut Clay and divided it into *Gryphaea* rock and Walnut Clays (Table 2). Prior to this, the formation had been unnamed.

Shortly thereafter Taft (1892, p. 272 and with Leverett, 1893, p. 245) proposed the names "Texana Limestone" (Walnut Clay), "Comanche Peak Limestone," "*Caprina* Limestone" (Edwards Limestone), and "Kiamitia Clay" (Kiamiche Clay) as subdivisions for the Fredericksburg Group.

In 1898 Hill and Vaughn used the term Walnut Formation in a formal publication for the first time. Hill (1898, p. 23) described the Walnut Formation as a sequence which

> consists of laminated clays alternating with limestone flags, and both clays and flags are accompanied by great quantities of the two peculiar species of oyster, *Exogyra texana* and *Gryphaea marcoui.*

R. T. Hill had previously described the Formation in 1891, but he never named a type locality, referring instead to the formations exposed in and around the hills of the town of Walnut Springs, northern Bosque County, Texas.

The first attempt to divide the Walnut Formation into members was made in 1930 by S. W. Horne, who studied the Formation from Lampasas to Comal County. Based on paleontological data he was able to divide the Formation into four members (Table 2).

Adkins (1932, p. 322) studied the paleontology of the Walnut Formation, and named the Cedar Park Member for localities two miles northwest of Cedar Park, near Austin, Texas. The Cedar Park Member may be correlative with the Upper Lime Member of Horne (1930).

Thompson (1935, p. 1534), working in the area of this study, proposed the name "Gatesville Formation" which downgraded the Walnut Formation, Comanche Peak Limestone, and Edwards Limestone to Members of the "Gatesville Formation." Thompson's designation has never found acceptance.

The Walnut Formation was divided into four members (Table 2) from a stratigraphic and paleontologic study completed by Ikins in 1941.

Lozo (1949) studied the Walnut Formation on a regional scale and divided it into four unnamed members. Later (1959) he named these members (Table

TABLE 2. EVOLUTION OF STRATIGRAPHIC NOMENCLATURE. WALNUT FORMATION, CENTRAL TEXAS.

Edwards Limestone Comanche Peak Limestone	Prior to 1891	Hill 1891	Taft 1892	Hill 1898	Horne 1930	Adkins 1932	Thompson 1935	Ikins 1941	Lozo 1949 1959	Moore 1961	Moore 1964	Jones 1966
Walnut Formation	Unamed and Undifferentiated	*Gryphaea* Rock and Walnut Clays	Texana Limestone	Walnut Formation			Walnut Member of the Gatesville Formation				Unnamed Marl Member	Member 5
					Upper Clay			Upper Clay	Upper Marls	Upper Clay	Keys Valley	Member 4
											Whitestone Limestone Member	
					Upper Lime	Cedar Park		Cedar Park	Cedar Park	Cedar Park	Cedar Park	Member 3
					Lower Clay			Lower Clay	Lower Marls	Bee Cave	Bee Cave	Member 2
					Lower Lime			Lower Lime	Lower Lime	Bull Creek	Bull Creek	Member 1
Paluxy Sandstone												

2) in a stratigraphic study based on exposures from Fort Worth to Austin.

Jameson (1959), in a study of the Fredericksburg "Division" of central Texas, identified the contact between the Walnut Clay and Comanche Peak Limestone on the basis of a zone of *Oxytropidoceras* sp. and *Exogyra texana.*

In a more detailed study of the Walnut Formation south of the present study area, Moore (1961) recognized four members in the Walnut Formation (Table 2), largely correlative with those of Ikins and Lozo.

Proctor (1961) believed the sedimentary history of the Formation was one of a transgressive-regressive facies.

Moore (1964) again studied the Fredericksburg Group in south-central Texas, and divided the Walnut Formation into six members (Table 2) based on detailed petrographic and stratigraphic data. He recognized a possible difference in the sedimentary history of the formation between south-central and north-central Texas, and speculated that the north-central area represents a brackish water environment with final transgression taking place from south to north.

Jones (1966), in an intensive study of the stratigraphy of the Walnut Formation within the present study area, concluded from field evidence that the formation could be divided into five recognizable members (Table 2) in north-central Texas. Jones agreed with Moore that parts of the formation represent brackish water facies; however, he postulated the direction of transgression was to the northwest.

Jackson (1974), in a study of the Fredericksburg Group in Bosque County, related the stratigraphy of the group to the physiography of the county.

Barnes (1974) studied the transitions of Fredericksburg rocks from surface to subsurface along the eastern margin of the present study area.

Flatt (1974) reviewed the stratigraphy of the Walnut Formation with emphasis on the relationship between stratigraphy of the formation and occurrence of *Texigryphaea mucronata* banks. He concluded that the Walnut Formation represents part of a transgressive-regressive subfacies, culminating with the transgression of the Comanche Peak Seas. In agreement with Jones (1966) and Moore (1964), he interpreted a brackish water environment for part of the Walnut sequence.

In addition to stratigraphic works, studies of fossil oysters in the Walnut Formation are prominent in the literature. Among early Cretaceous fossils, these were the most conspicuous and early workers endeavored to classify or identify each species. The quantity, diversity, and perfect preservation of the fossil oysters has sparked the interest of those other than geologists. It was George Catlin (Donaldson, 1886, p. 490) in the middle 1800's who became enchanted by their occurrence in what is now Oklahoma and described a typical exposure:

> One of the most curious places we met in all our route was a mountain ridge of fossil shells, from which a great number of the above-mentioned specimens [*Gryphaea pitcheri*] was taken. During our second day's march from the mouth of the False Washita we were astonished to find ourselves traveling over a bed of clam and oyster shells, which were all in a complete state of petrification. This ridge, which seemed to run from the northeast to southwest, was several hundred[?] feet high, and, varying from a quarter to half a mile in breadth, seemed to be composed of nothing but a concretion of shells, which on the surface exposed to the weather for the depth of 8

> or 10 inches, were entirely separated from the cementing material which had held them together, and were lying on the surface, sometimes for acres together, without a particle of soil or grass upon them, with the color, shapes and appearance exactly of the natural shells lying loosely together, into which our horses' feet were sinking at every step above their fetlocks. These I consider the most extraordinary petrifactions I ever beheld. In any way they could be seen, individually or in a mass together, they seemed to be nothing but the pure shells themselves, both in color and in shape. . . . This remarkable ridge is in some parts covered with grass, but generally with mere scattering bunches for miles together, partially covering this compact mass of shells, forming in my opinion one of the greatest geological curiosities now to be seen in this country, as it lies evidently some thousands of feet above the level of the ocean and 700 or 800 miles from the nearest point on the seacoast.

Although Catlin was notably impressed with the occurrence of Gryph-shaped oysters he was not the first to collect or describe them. The first collections were made by Thomas Nuttall in the years 1819-1820 and later described and classified *Gryphaea corrugata* by Say in 1823 (Hill and Vaughan, 1898, p. 34).

Fossil oysters received brief mention in numerous works. In Texas G. G. Schumard (1854) collected some fossil oysters, later identified by Jules Marcou (1856). R. T. Hill, in 1891, mentioned fossil oysters in naming the sequence of "*Gryphaea* Rock" (Table 2). Cragin (1893) made a brief reference to the fossil oysters of the Walnut Formation. He illustrated and described one species as *Gryphaea gibberosa* Cragin. However, he failed to describe the stratigraphic sections in detail, which later resulted in problems of zonation.

Hill and Vaughan in 1898 made one of the earliest studies on early Cretaceous oysters of the Texas region. They described and illustrated fossil oysters in the Glen Rose Limestone, Paluxy Sand, Walnut Formation, Comanche Peak Limestone, Edwards Limestone, Georgetown Formation, Eagle Ford Shale, Austin Chalk, and Taylor Formation. The monograph also contained an evolutionary sequence for early Cretaceous oysters. Hill and Vaughan attempted to show the zonation of the oysters by describing the stratigraphy of the collecting localities.

Adkins and Winton (1920) utilized fossil oysters in an attempt to correlate the Fredericksburg and Washita formations of north Texas. Adkins later (1928) compiled an updated handbook of Texas Cretaceous fossils and gave a brief summary of fossil oysters found within the Walnut Formation.

Gryphaea have been widely used in stratigraphic studies. Ikins (1941) used the fossil oysters as a zonational guide in his division of the Walnut Formation (Table 2). Stanton (1947) utilized previously known localities in his effort to identify and catalogue Comanchean pelecypods that had been collected over a 50 year period. He not only described and illustrated the fossils but also included a taxonomic review of each fossil. Stenzel (1959) described the most common Cretaceous oysters found over a vast area in North America. Jameson (1959) devoted much space to the oysters in the Walnut Formation and utilized them in his interpretation of the diagenesis of the Fredericksburg Group. Proctor (1961) described the sequence of events that surrounded the extinction of the oyster mounds in the Walnut Formation in one area of the present study. Jones (1966) described the various pelecypods contained within the Walnut Formation in central Texas with some emphasis on oysters.

In a study by Flatt (1974) the origin and ultimate extinction of the *Texigryphaea* banks were considered on a local level with attention being given to environmental controls.

The microfauna of the Walnut Formation has not been as well known as is the stratigraphy. Early workers overlooked this field, for they were concerned with regional aspects of the formation, and this still remains a neglected area. Previous studies are confined to a few localities, with limited attempts to extrapolate to the larger areas and thicker sequences.

The earliest work encountered in this investigation, was that by Dorothy Ogden Carsey (1926), who described samples from two localities west of Austin, Texas. She mentioned only four species of Foraminifera as follows:

Textularia conica d'Orbigny	scarce
Textularia rioensis n. sp.	scarce
Orbitolina walnutensis n. sp.	abundant
Rotalia sp.	scarce

She concluded that "this clay carries a very well marked macroscopic fossil fauna. The microscopic fauna, with the exception of one genus, is not well developed" (Carsey, 1926, p. 19).

However, Carsey did provide the foundation for micropaleontological studies in the Walnut Formation. This was later expanded by Alexander (1929) who produced the most comprehensive work on the Cretaceous ostracodes of north Texas. From 62 localities he described 90 species of which 56 were previously undescribed. However, only five species were from the Walnut Formation:

Schuleridea oliverensis Alexander
Cythere concentrica Reuss
Cythereis carpenterae Alexander
Cythereis fredericksburgensis Alexander
Cythereis mahonae Alexander

Later, in 1932, he added to the list of Walnut ostracodes two additional species.

Smiser (1933) completed a study emphasizing the identification of echinoid fragments in the Cretaceous rocks of Texas. In the same year Vanderpool, working in southern Oklahoma, studied the microfauna of the Trinity Group, some forms of which extend into Fredericksburg rocks.

A series of articles from 1933 to 1936 established Alexander as the authority on Cretaceous ostracodes of Texas. However, while Alexander did identify the ostracodes of the Cretaceous sediments, he did not extend his study to include paleoenvironmental interpretations.

In 1943 Lozo utilized ostracodes in defining the contact between the Fredericksburg and Washita Groups of north Texas. He described 14 foraminifers and 11 ostracodes belonging to the Walnut Formation. In 1944 he expanded on the stratigraphic relationships of Fredericksburg Foraminifera.

Cushman (1946) published a massive study of Cretaceous Foraminifera of Texas in which he described and illustrated over 600 species from various localities.

Loeblich and Tappan (1949) described and illustrated 47 species of ostracodes from localities in southern Oklahoma and northern Texas. Based on limited field evidence they concluded that the assemblage was dominated by arenaceous foraminifers of the Family Lituolidae.

In a major revision of this work by Frizzell (1954), 13 families and 51 species were recorded from the Walnut Formation. Of those families, Frizzell concurred with Loeblich and Tappan in the domination of arenaceous foraminifers (seven families, 29 species).

Howe and Laurencich (1958) compiled perhaps the most useful works on Cretaceous ostracodes, and included the entire range of known Cretaceous forms with descriptions and illustrations that are concise and clear.

Microfauna of the Walnut Clay in the area of the present study have received some attention. Morales (1960) studied the microfauna of the Walnut Formation in a portion of the present study area and described 11 genera (14 species) of foraminifers, and nine genera and 18 species of ostracodes. Jones (1966) examined the clay units in the upper part of the Walnut Formation, and recognized 28 genera of foraminifers; however, only nine were arenaceous forms. Flatt (1974) investigated the foraminifers of the oyster banks, and discovered limited diversity of genera and species.

Also significant to this study is the literature of modern bank-forming oysters, for interpretation of paleoecology of fossil oysters must rest in part on ecology of modern forms of similar habit and occurrence. The ecology of modern bank-forming oysters has been studied on a world wide scale by many authors over the course of almost 200 years. Most of these studies have been concerned with the commercial oyster *Crassostrea virginica.*

White (1884) gave a brief account on the relationship of fossil oysters to those living today. In addition he studied the ecology of living forms.

Grave in 1901, in one of the early studies on the geology and economy of oyster reefs, studied the position of the reefs with respect to water currents and faunal assemblages. He provided the ground work for later works by discovering that the reefs grew in directions at right angles to the prevailing currents and that within healthy reefs there is low species diversity.

Oyster ecology has been the subject of a number of papers. Orton (1937) in a major account of the biology and culture of the commercial oyster, described the effects of various parasites and predators on the destruction of banks. Gunter (1947) focused attention on a possible relationship of salinity to marine organisms, with emphasis on the oyster *Crassostrea virginica.* Baughman (1947) in an extensive annotated bibliography of oysters, both fossil and recent, provided a major aid in the search for earlier works.

Norris (1953) discussed the geology, formation, and economic importance of buried oyster reefs in some Texas bays. He discovered that the reef growth was temporarily halted by siltation; however, the reefs soon reestablished themselves in approximately the same position. In his study he found the reefs could be traced laterally for miles and were approximately 30 to 40 feet thick.

Puffer and Emerson (1953) studied the entire faunal group found in association with the oyster reef on the Texas Coast. Of importance was the discovery that a low species diversity was associated with banks found in mesohaline areas.

Butler (1954) summarized what was known at the time about oyster ecology in the Gulf of Mexico, and established "type areas" of oyster habitation, defined by the controlling factor of salinity-predatorial relationships (Table 5). Butler's "type areas" were described by physio-chemical controls.

The growth and eventual decline of oyster banks was studied by Nicol (1954), who described the characteristics of early bank growth, stable growth, and decline and ultimate extinction.

Hedgpeth (1954) described the common oyster community in relation to total faunal assemblages, and noticed the limited species diversity commonly encountered in banks associated with mesohaline areas.

A study conducted by Parker (1955) evaluated changes in the oyster population induced by changes in salinity levels.

Ladd and others (1957) reported on various environments (with associated fauna) in bays on the Texas Coast, and again noticed the limited diversity of fauna in banks associated with mesohaline conditions, and the diversity of fauna associated with euhaline zones.

Wells (1961) extended the work of Gunter, Butler, and Parker in a study of oyster ecology and its relation to salinity. He established convincingly the importance of salinity levels to oyster growth. Kinne (1964) also studied the effects of variations in salinity and temperature on the abundance of oysters and associated organisms. Carriker (1967) summarized the ecology of estuarine benthic organisms with special reference to the oyster and oyster habitat. Hofstetter in a series of studies (1969, 1970, 1971) drew attention to the decline of the oyster banks on the Texas Coast resulting from increases in predation brought about by increases in salinity.

The study of the oyster Family Gryphaeidae has always been problematical. This is partly due to the fact that there are only two living genera today and the early studies were largely inconclusive, plagued by poor descriptions of illustrations. The papers here listed are in part repeated from earlier sections on stratigraphy, but since the emphasis is also on paleontology, they require mention in this section as well. Hill and Vaughan (1898) studied the *Gryphaea* of Texas from a taxonomic and stratigraphic view. They did not study the ecology of the *Gryphaea;* however, they proposed evolutionary trends in the Cretaceous Gryph-shaped oysters (1898, p. 65).

The majority of the early works on Gryph-shaped oysters are purely taxonomic. It was not until 1922 that Trueman used *Gryphaea* for correlation purposes in the Lower Liassic of Great Britain.

Arkell (1934) and with Moy-Thomas (1940) introduced a "rationalised" classification of Jurassic and Cretaceous oysters (Table 3). Arkell's classification consisted of a trinomial name (genus, subgenus, species). The basis for the classification was the assumption of iterative evolution within the family. He placed all species of Gryph-shaped oysters into one genus (*Ostrea*). The classification was never accepted widely and has not been used in recent years.

Maclennan and Trueman (1942) demonstrated variations in the size and curvature of *Gryphaea incurva,* and postulated evolutionary trends.

Two articles by Hallam (1959a, b) dealt with the evolution of the *Gryphaea* sp. in the Lower Liassic of Great Britain. The articles by Hallam prompted another study (1960) by Hallam and others of rebuttal by Joysey (1960). Philip (1962) and Hallam (1962) summarized the debate of divergent versus convergent evolution utilizing biometrics.

Swinnerton (1964) completed a study on the early evolution and development of the *Gryphaea*. Burnaby (1965) studied a trend of reversed coiling in *Gryphaea arcuata* as a form of evolution.

The *Gryphaea* of the Walnut Formation in central Texas were studied by Jones (1966) who related the sedimentary environment at the time of deposition to oyster ecology and postulated a brackish water environment for *Gryphaea marcoui*.

Stenzel (1971) attempted to solve the problem of the separation of a monophyletic genus from similar genera (Table 4). He illustrated this clearly by showing the relationship of Texigryphaea to homeomorphs using subfamilies, variations in stratigraphic time ranges, and variations in geographic distribution. Stenzel was the first to recognize that oysters are not a monophyletic family but rather are diphyletic. He subdivided the Ostreacea into two families: Ostreidae and Gryphaeidae. The family Ostreidae includes the subfamilies Ostreinae and Lophinae; whereas the family Gryphaeidae includes the subfamilies Gryphaeinae, Pycnodonteinae, and Exogyrinae (Stenzel, 1971, p. N 1096).

Flatt (1974) studied the *Texigryphaea mucronata* of the Walnut Formation in central Texas in relation to interpretation of sedimentary history.

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STRATIGRAPHY OF THE WALNUT CLAY

INTRODUCTION

The Walnut Formation of central Texas represents a marginal marine sequence time-transgressive over the stable central Texas Craton, deposited as the East Texas basin was slowly subsiding. The formation is in the Fredericksburg Group (Division) of the Comanchean Series as classified by Hill (1887, p. 298). The Walnut Formation is generally conformable over the Paluxy Sand, and the Paluxy and Walnut are in parallel beds (Fig. 2). However, there are areas of slight unconformity where the underlying Paluxy consists of dipping, truncated sandstone beds probably representing initial dip on bar sands, overlapped by strata of the Walnut Clay (Fig. 3). The contact between the Walnut Clay and the overlying Comanche Peak Limestone is gradational and conformable (Fig. 4).

While the Walnut Formation represents an overall marine transgression there are several intervals that show a transgressive-regressive sequence of events. These intervals may be seen clearly in the upper part of the formation and appear to be confined to the area

Fig. 2. Locality 132. Contact of the Paluxy Sand with the Walnut Formation, central Coryell County. Notice the horizontal beds of Paluxy Sand overlain by the Walnut Formation.

Fig. 3. Locality 139. Contact of the underlying Paluxy Sand with the overlying Walnut Formation in northern Bosque County. Notice the steeply dipping truncated Paluxy Sand overlain by the horizontal Walnut Formation. The dip appears to be primary, however, and does not give evidence of significant unconformity.

TABLE 3. "RATIONALISED" CLASSIFICATION OF JURASSIC AND CRETACEOUS OYSTERS AS PROPOSED BY ARKELL, 1934, 1940.

Old Names	"Rationalised Names"
Pycnodonta marcoui (Hill and Vaughan)	Ostrea (Marcoui) gryphaea
Pycnodonta wardi (Hill and Vaughan)	Ostrea (Marcoui) catinula
Gryphaea dilatata Sowerby	Ostrea (Dilatata) gryphaea
Ostrea (Catinula) alimena Cossmann	Ostrea (Dilatata) catinula
Gryphaea bilobata Sowerby	Ostrea (Bilobata) gryphaea
Ostrea (Catinula) matisconensis Lissajous	Ostrea (Knorrii) catinula mut. matisconensis
Ostrea (Catinula) knorrii Voltz	Ostrea (Knorrii) catinula
Ostrea (Liostrea) subrugulosa Morris and Lycett	Ostrea (Acuminata) catinula
Ostrea (Liostrea) hebridica var. elongata Dutertre	Ostrea (Acuminata) virgula mut. elongata
Ostrea (Liostrea) hebridica Forbes	Ostrea (Acuminata) virgula mut. hebridica
Ostrea (Liostrea) acuminata Sowerby	Ostrea (Acuminata) virgula
Gryphaea incurva Sowerby	Ostrea (Incurva) gryphaea
Ostrea (Liostrea) irregularis von Schlotheim	Ostrea (Incurva) catinula
Ostrea (Liostrea) liassica Strickland	Ostrea (Incurva) virgula
Pycnodonta corrugata (Say)	Ostrea (Corrugata) gryphaea

TABLE 4. GRYPH-SHAPED OYSTERS ILLUSTRATING TIME RANGES, DISTRIBUTION, AND THE RELATIONSHIP TO GRYPHAEA.

Name	Subfamily & relationship to Gryphaea	Stratigraphic time range	Geographic distribution
Aetostreon imbricatum (Krauss, 1843)	Exogyrinae, homeomorph	Neocomian	East and South Africa
Gryphaea Lamarck, 1801	Gryphaeinae, homeomorph	Late Carnian—Kimmeridgian	Nearly worldwide
Odontogryphaea von Ihering, 1903	Ostreinae, homeomorph	Late Maestrichtian—early Lutetian	Nearly worldwide
Pycnodonte Fischer de Waldheim, 1835	Pycnodonteinae, descendant	Early Albian—Miocene	Nearly worldwide
Sokolowia Böhm, 1933	Ostreinae, homeomorph	Late Lutetian—Ledian	Transylvania and central Asia
Texigryphaea Stenzel, 1959	Pycnodonteinae, descendant	Mid-Albian—Cenomanian	Southwestern North America

After Stenzel, 1971, p. N1067.

Fig. 4. Locality 137. Contact of the underlying Walnut Formation with the overlying Comanche Peak Limestone in southern Bosque County. Notice the transitional and conformable nature of the contact.

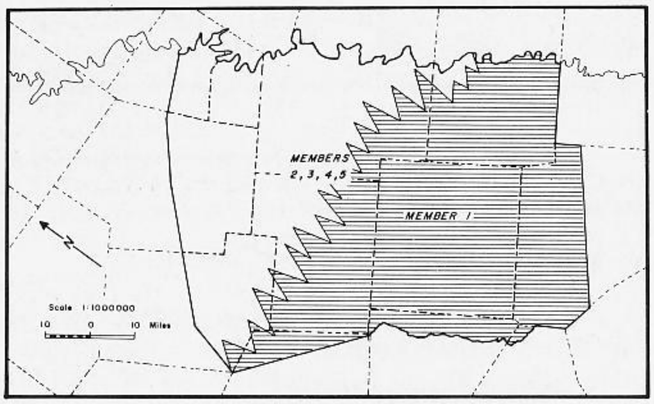


Fig. 5. Geographic distribution of the members of the Walnut Formation. Members are numbered in sequence from bottom to top, one through five.

of Bosque and Coryell Counties, where the section consists of interlaminated dark calcareous clays, argillaceous nodular limestones, and thin ripple-marked limestones. Terrigeneous detritus, largely plant remains, may be found in the dark clays.

Probably the most conspicuous feature of the Walnut Formation in central Texas is the accumulation of massive oyster banks dispersed over large areas, the subject of this study.

NATURE AND DISTRIBUTION OF THE WALNUT FACIES, CENTRAL TEXAS

The Walnut Formation in central Texas has been divided into five members (Table 2) by Jones (1966) based on lithologic character. These members represent the northern equivalent of Moore's 1964 classification (Table 2). The distribution of the five members is shown in Figure 5.

Member One, composed of argillaceous limestone, dark clay, and alternating clay and thin flaggy limestone beds is limited in area of exposure (Fig. 6). Generally it is almost barren of fossils. In Bosque County (localities 179, 183, 193, Fig. 7) the clays contained a limited number of ostracodes (Appendix 1, Table 7). Two small restricted oyster "banks" occur at localities 134 and 141 (Fig. 7). These, however, are not considered typical of Walnut oyster banks for the diverse fauna indicate normal marine conditions.

Jones (1966, p. 169-171) believed the limestone was deposited in shallow nearshore waters while the dark clay of Bosque County (locality 183) represented a highly restricted lagoonal deposit. The alternating beds of limestone and clay (localities 134, 141) were believed to represent unstable conditions; limestone being deposited in a zone of high wave energy while the clay was deposited in quiet waters of a bay, lagoon, or estuary.

Member Two, consisting of alternating beds of clay and thin ripple-marked limestone, is more widespread than Member One (Fig. 8). Four small oyster banks occur at localities 106, 126, 141, 182, where they consist of abundant *Exogyra walnutenfordensis, Trigonia* sp. and *Texigryphaea mucronata.* Member Two has been interpreted as the product of the first major transgression over the Paluxy Sand (Jones, 1966, p. 171-173). Deposition was apparently rapid and conditions turbulent, as indicated by ripple-marked limestone and slight erosional unconformity at the contact (Fig. 3).

Member Three is less widespread than Member Two (Fig. 9). Member Three consists of light tan to buff colored argillaceous nodular limestone with a limited number of thin beds of clay and flaggy ripple-marked limestone. Faunal diversity is greater in Member Three, with the appearance for the first time of echinoids. Oyster banks of Member Three are more common and larger than in Members One and Two. This member has been interpreted as a deposit of "a less restricted environment, quiet, shallow water, but deeper than Members One and Two" (Jones, 1966, p. 91).

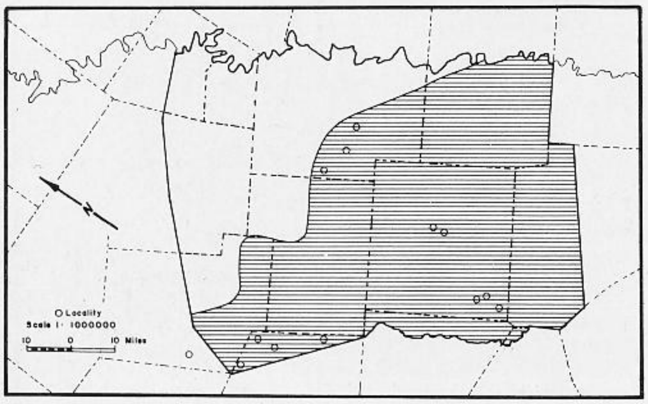


Fig. 6. Distribution of section localities of Member One. Shaded area indicates maximum extent of Member One.

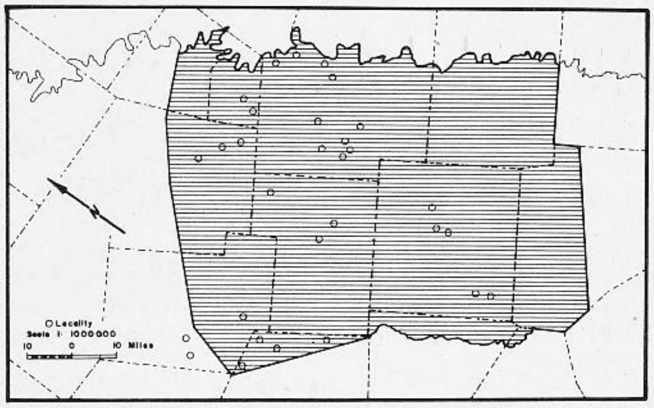


Fig. 8. Distribution of section localities in Member Two. Circles show localities where Member Two has been identified.

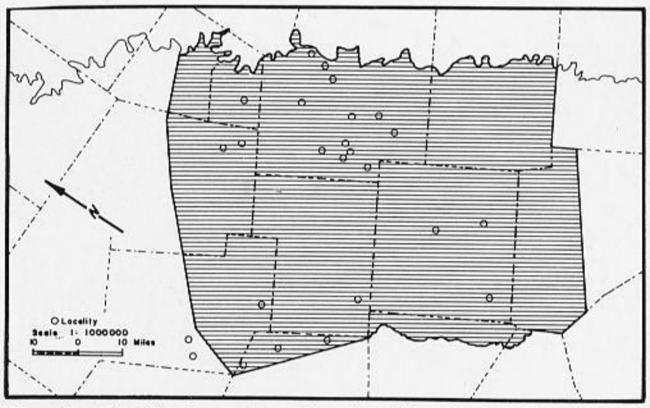


Fig. 9. Distribution of section localities in Member Three. Circles show localities where Member Three has been identified.

Member Four is more widely distributed than Members One, Two, or Three (Fig. 10). It commonly consists of beds of argillaceous limestone and calcareous clay and may be recognized by abundant thick, massive to bedded oyster banks. Oyster banks reach a maximum in size and number in Member Four. Limited faunal diversity (both micro and megafauna, Appendix 1, Table 7) in association with the oyster banks is typical of Member Four.

Member Five is areally less widespread than Member Four (Fig. 11). It consists of beds of burrowed calcareous clay and light tan to buff colored argillaceous limestone.

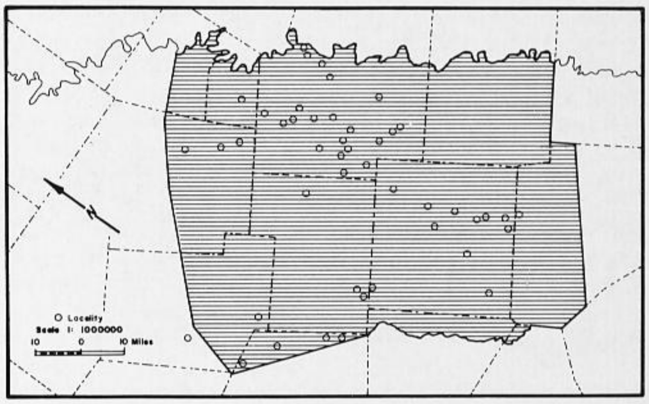


Fig. 10. Distribution of section localities in Member Four. Circles show localities where Member Four has been identified.

The base of Member Five has been placed at the top of the last massive oyster bank, and the upper contact is drawn at the base of the nodular Comanche Peak Limestone (Fig. 4) (Jones, 1966, p. 132). Member Five is characterized by a diverse faunal assemblage (both micro and megafauna, Appendix 1, Table 7), yet with numerous but thinner banks.

While all members contain accumulations of oysters, the massive banks are best developed in Members Four and Five (Figs. 14, 16), and in these members the term "bank" may be properly used. For this reason, the remainder of this paper is concerned primarily with sections of Members Four and Five.

NATURE AND DISTRIBUTION OF OYSTER BANKS

GENERAL DISTRIBUTION

While pelecypods are common throughout the Walnut Clay, they are most abundant in massive oyster banks which occur throughout the study area and which form resistant benches in the Lampasas Cut Plain. The occurrence has been described, and although oyster accumulations are present in all members of the formation, true banks are confined to the upper two members.

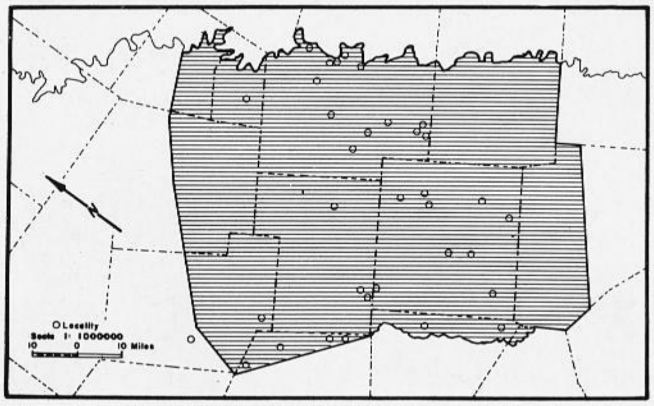


Fig. 11. Distribution of section localities in Member Five. Circles show localities where Member Five has been identified.

SPECIFIC DISTRIBUTION

Texigryphaea and *Exogyra* banks in Member One appear to be concentrated in the western part of the study area (Fig. 12), where they appear as small lenticular or pod-like deposits barely discernable from the surrounding sediments.

Pelecypod banks in Member Two are concentrated in the eastern part of the study area (Fig. 13). Four banks occur in this member and, like those of Member

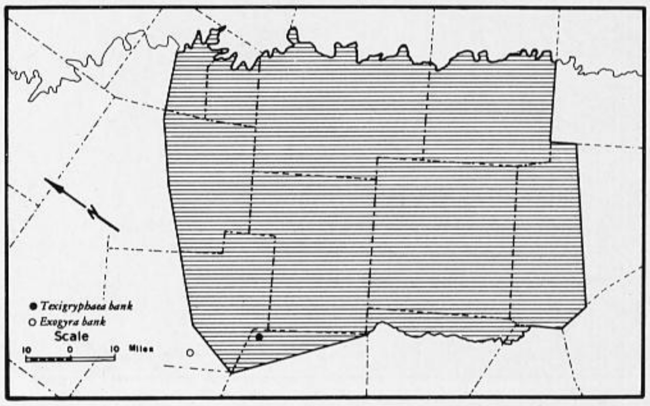


Fig. 12. Sampled localities, known oyster banks in Member One.

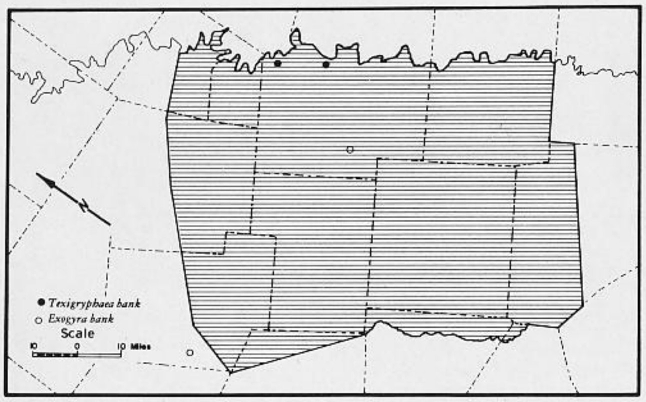


Fig. 13. Sampled localities, known oyster banks in Member Two.

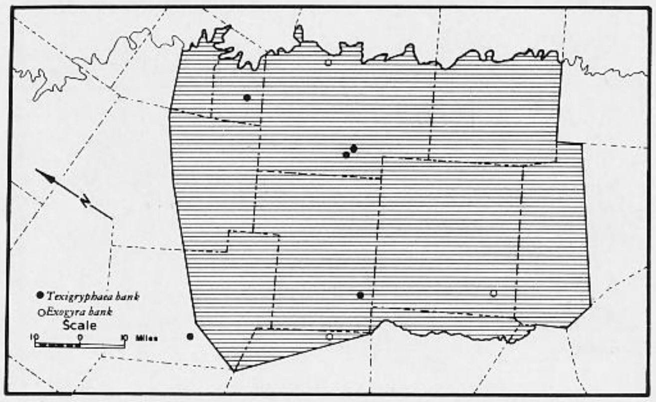


Fig. 14. Sampled localities, known oyster banks in Member Three.

One, they are difficult to distinguish from surrounding sediments.

Oyster banks in Member Three appear to be widespread (Fig. 14). The banks form prominent ledges easily distinguished from surrounding sediments. *Exogyra* banks reach their maximum development in this member.

Texigryphaea banks are most widespread in Member Four (Fig. 15). The largest number of these may be found in Bosque County, correlative with the thickening of the formation as shown on the isopach map (Fig. 7). Significant to the study is the curious lack of *Exogyra* banks within this member.

Oyster banks of Member Five remain concentrated in Bosque County (Fig. 16). The number of banks have been reduced to 17 and *Exogyra* banks are once again conspicuous in the study area.

GENERAL DESCRIPTION OF THE OYSTER BANKS

Oyster banks of the Walnut Formation are widely distributed. They extend from McLennan County westward to a point near Abilene, Texas (Jones, 1966, p. 3). The thickest banks are confined, however, to Bosque and Coryell Counties. *Texigryphaea* banks are not confined to any one member of the Walnut Formation; however, they are more abundant in Members Three, Four, and Five. *Exogyra* banks may be found in all members with the exception of Member Four.

One of the most striking features of a typical *Texigryphaea* bank is the almost complete singularity of the fauna contained within it [*i.e. Texigryphaea mucronata* (Stenzel)]. A conservative count of the individuals in one bank reveals 3600 per cubic foot. A bank 100 feet long, six feet thick covering one acre will contain over 900 million per acre. The figure is even more astonishing in banks that extend for miles (six hundred billion per square mile). The individual banks range in thickness from 0.5 foot to approximately 30 feet (Figs. 17, 18, 19) and may be traced laterally for miles, for they form prominent benches (Fig. 20) and perched water tables in the Lampasas Cut Plain.

Although banks vary from member to member, certain similarities may exist in overall appearance. They are all underlain and overlain by thin beds of clays and calcareous shale (maximum six inches). This clay and shale sequence is usually devoid of *Texigryphaea,* large or small, as well as any other fossils. Banks are usually biostromal and often of great lateral extent (Fig. 21).

The *Texigryphaea* are loosely cemented in a fine-grained carbonate matrix (micrite) in what appears to be growth position. Most of the valves are unabraded and show few signs of borings (Fig. 22). The normal community consists of juveniles and adults as distinguished by size (Fig. 19). Adults occupy the central portion of the bank (Fig. 21) and juveniles are concentrated on the gentle slopes at the margins of the banks.

Exogyra banks present a different picture of bank growth. They are limited in areal distribution, and are

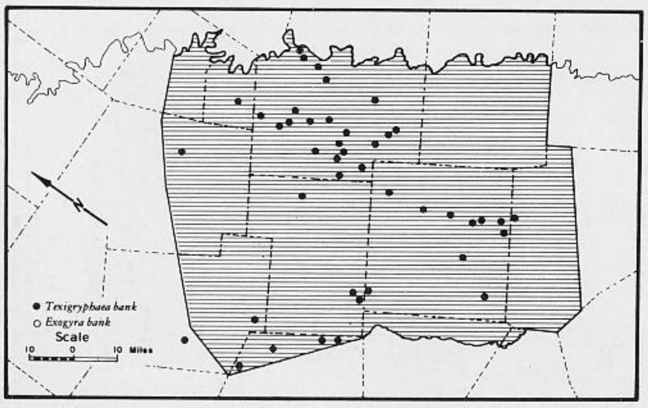


Fig. 15. Sampled localities, known oyster banks in Member Four.

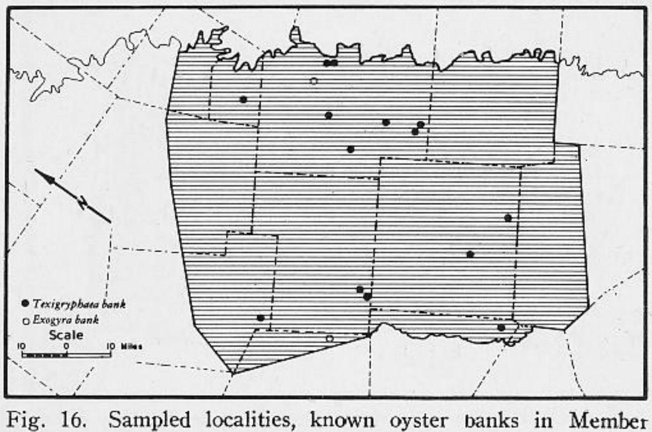


Fig. 16. Sampled localities, known oyster banks in Member Five.

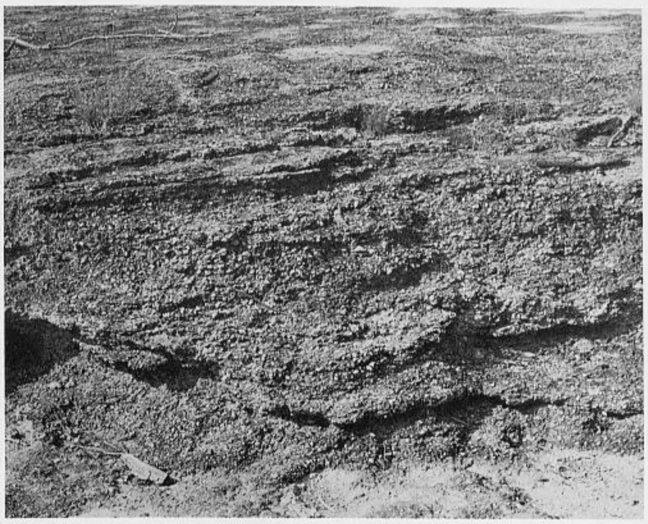


Fig. 17. Locality 123. Bank flank deposit, massive oyster banks in Member Four, northern Bosque County. Notice the massive appearance of the bank and the weathering rubble of *Texigryphaea mucronata* below thin clay seams.

best developed in the western part of the study area (Fig. 7). They range from two to six inches in thickness and are limited in lateral extent (Fig. 23). Individual banks contain hard, dense, sparry limestone matrix and adjacent banks are separated by argillaceous, tan, nodular, micritic limestone beds. Whereas *Texigryphaea* banks are of limited faunal diversity *Exogyra* banks have a varied marine fauna. *Exogyra* valves are most commonly bored and contain abundant serpulid worm tubes attached to the interior and exterior of the valves (Fig. 24).

SPECIFIC DESCRIPTION OF THE OYSTER BANKS

Two oyster banks are known to occur in Member One in the study area, and these are restricted to the western part (localities 134, 141, Fig. 7). They differ radically from the "typical" oyster bank previously described.

The *Texigryphaea* bank (Fig. 7, locality 134) is of limited exposure, but *Texigryphaea* is found in association with *Exogyra, Pecten, Turritella,* and *Protocardia.* This association readily distinguishes it from a "typical" *Texigryphaea* bank. The *Texigryphaea* banks are distributed as lenses in a clay section. Clay beds between banks increase in thickness upward. Within the banks, some *Texigryphaea* are replaced by sparry calcite.

Individual *Texigryphaea* specimens are unabraded, although they have abundant borings. Valves are primarily small in size and no distinction could be made between juveniles and adults. In the clay overlying the bank are abundant horizontal burrows filled with micrite.

Banks contain abundant microfossils (Appendix 1, Table 7) although diversity is low, while clays surrounding the bank contain few microfossils. A large part of the washed residue of the clay is fine to very fine-grained frosted angular to sub-angular white quartz sand apparently reworked from the Paluxy Sand.

Exogyra banks (Fig. 7, locality 141) represent typical marine assemblages with few variations among banks. The faunal assemblage consists of *Actaeonella, Ostrea, Trigonia, Turritella, Pecten, Protocardia, Cyprimeria, Tylostoma,* and a limited number of extremely small *Texigryphaea.*

The *Texigryphaea* banks found in Member Two (Fig. 7, localities 126, 181) consist of alternating beds of barren calcareous clay, and dense limestone. *Texigryphaea* are confined to the limestone beds and are highly fragmented (Fig. 25). Banks in Member Two are commonly capped by pararipples, trending N. 45° E., and developed in fragmented shells (Fig. 26).

Texigryphaea are found in association with *Exogyra, Trigonia, Tylostoma, Turritella, Pecten,* and *Protocardia.* Individual *Texigryphaea* valves are bored and the surrounding sediments contain abundant burrows filled with micrite.

The clays are almost devoid of microfauna; however, the samples contain an abundance of sand, similar to that of Paluxy Sand (Figs. 27, 28).

Exogyra banks reach maximum thickness (six inches) in Member Two. While individual *Exogyra* occur throughout the member, only two banks were encoun-

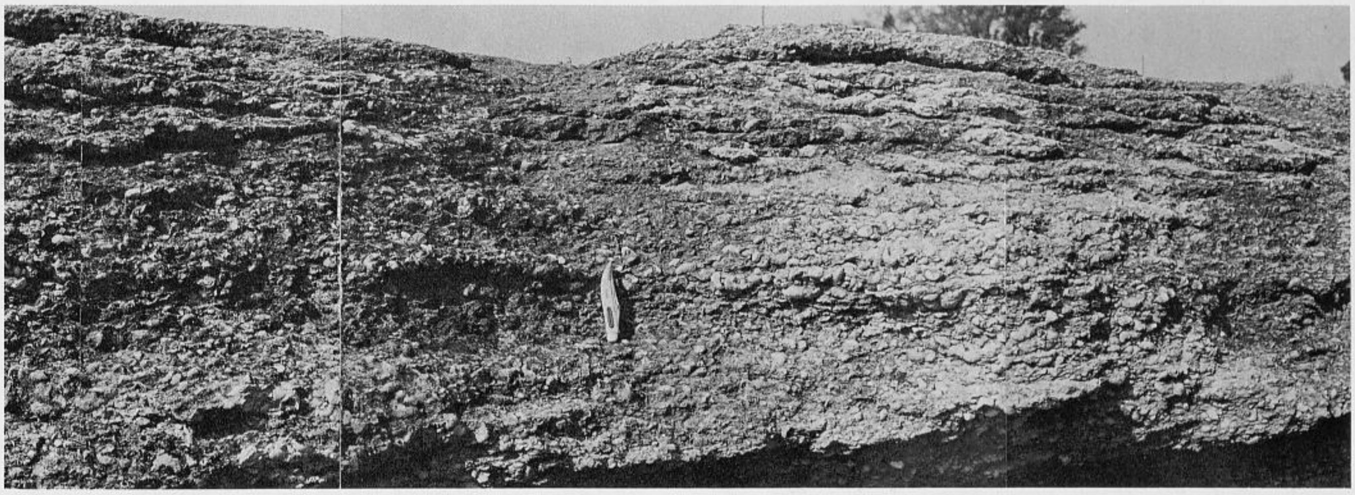


Fig. 18. Locality 123. Close up view of the *Texigryphaea* bank seen in Figure 17. Notice the oyster beds separated by thin clay and shale seams. The knife is four inches long. *Texigryphaea* valves are largely those of adults.

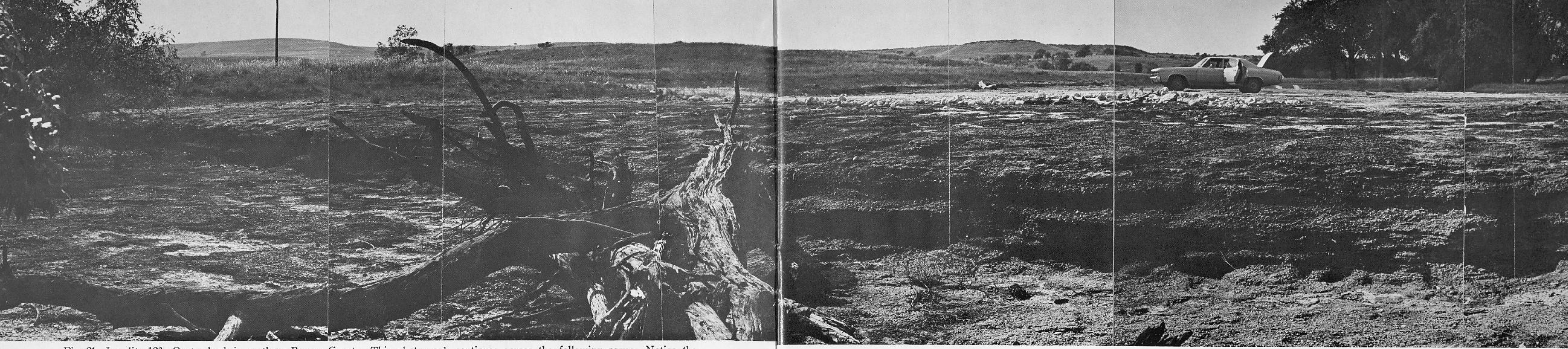


Fig. 21. Locality 123. Oyster bank in northern Bosque County. This photograph continues across the following pages. Notice the lateral extent of the massive biostromal bank. The present upper surface appears to have the initial configuration developed during growth. Notice also the close partings in the bank, apparently caused by sudden siltation, resulting in equally sudden extinction of bank growth. For this bank, simple calculation suggests that within the visible bank, approximately 30 yards wide, 100 yards long, and 5 yards thick, there are more than one billion individuals.

tered (Fig. 7, localities 141, 179). Most shells occur with one valve concave down, the cavity filled with fine-grained micrite. At both localities pelecypod valves are large and show borings, encrustations, and serpulid worm tubes (Fig. 29). *Exogyra* occur together with *Cyprimeria, Texigryphaea, Metengonoceras, Trigonia, Tylostoma, Turritella, Pecten, Protocardia,* as well as bryozoans, and serpulid worm tubes.

The *Texigryphaea* banks in Member Three (Fig. 7, localities 121, 140, 147, 173, 179) rest upon a hard limestone, similar to that of the Comanche Peak. Banks are relatively free of quartz sand and contain smaller amounts of clay than do banks of Members One or Two. The banks occur as scattered lenticular deposits with diverse but not abundant fauna, consisting of *Texigryphaea, Turritella, Pecten, Exogyra, Protocardia, Pinna, Tylostoma,* and *Enallaster.* Echinoid spines (*Enallaster*) dominate the micro-samples.

Fig. 19. Locality 123. Close up view of the flanks of an oyster bank of Member Four in northern Bosque County. Notice the assortment of adults and juveniles, with most of the valves whole and unabraded. Both right and left valves may be seen near the knife which is four inches long. This illustrates a life assemblage with little post-depositional disturbance.

Above the oyster banks, are beds of clay containing horizontal burrows filled with carbonate mud and abundant fossil fragments. The banks lack the cap of ripple-marked limestone of Member Two, except at locality 179 (Fig. 7).

Exogyra banks (Fig. 7, localities 145, 153, 181) are quite local and interfinger with clay beds. The banks are commonly burrowed and reworked (locality 145, Fig. 7). Large symmetrical ripple marks may be seen on the upper surface of the banks at locality 153 (Fig. 7).

Individual *Exogyra* are limited in numbers within the banks; however, other fauna are abundant. The typical assemblage consists of *Tylostoma, Turritella, Enallaster, Texigryphaea, Hemiaster, Metengonoceras, Oxytropidoceras, Pecten, Pinna, Protocardia,* and *Trigonia.*

Texigryphaea banks of Member Four are the most widespread and lithologically consistent of the Walnut Formation, similar to the "typical" oyster bank earlier described. They are thickest and best developed in Bosque County where the Walnut Clay is also thickest (Fig. 7). Banks are thinnest on the western border of the study area. In Bosque County individual banks range in thickness from 0.5 foot to 30 feet (Figs. 21, 30, 31), and 0.5 foot to two feet in Coryell County (Figs. 32, 33).

The lower part of Member Four is exposed at locality 101 (Fig. 7) and consists of dense ripple-marked limestone (Fig. 34). The ripples are similar to those of tidal flats and may be seen forming on the modern Texas Coast (Namy, oral communication). Above the ripple-marked limestone is a thin bed of *Texigryphaea,* overlain by nodular argillaceous limestone four feet thick (Fig. 35) containing abundant *Enallaster, Exogyra, Pecten, Protocardia, Turritella,* and an abundant normal shallow marine microfaunal assemblage (Table 7, Appendix 1). Of particular importance is the occurrence of brittle sea stars (previously unreported), indicative of normal marine conditions.

Overlying the nodular limestone is a dense, ripple-marked limestone four inches thick (Fig. 36) containing macerated shells, indicative of high wave energy.

Above the ripple-marked limestone is the first "typical" *Texigryphaea* bank (Fig. 37).

Within Member Four all typical *Texigryphaea* banks have certain features in common. *Texigryphaea* are usually found in an argillaceous matrix, with pelecypods constituting perhaps 90 percent of the rock. Quartz sand grains are more abundant than in the interlaminated clays. Commonly one bed is thicker than the others in the section. The banks in Bosque County are composed of both large and small individuals (Fig. 38) whereas those in Coryell County consist only of small individuals (Fig. 39). The interlaminated black shales are usually devoid of microfauna and *Texigryphaea.*

No *Exogyra* banks were encountered in Member Four; however, individual shells occur scattered through the nodular limestone underlying the *Texigryphaea* banks.

The interlaminated clays have been examined by X-ray diffraction (Proctor, 1961) and found to contain a high proportion of kaolinite.

Texigryphaea banks of Member Five range in thickness from 0.2 to 1.0 foot (Figs. 40, 41, 42). Banks are less common in this member and the individual oysters are not as abundant as in banks typical of Member Four. The banks of Member Five occur in thin dense limestone flags between thicker calcareous clay beds (Figs 40, 41, 42). The calcareous clay beds are most notable for the abundance of horizontal burrows containing mollusk and echinoid fragments.

Texigryphaea are commonly found in association with *Enallaster* (a euhaline species). The surrounding sediments contain a greater abundance of echinoids and echinoid fragments than any other member.

Individual *Texigryphaea* valves are bored inside and outside. The clays contain, for the first time, planktonic

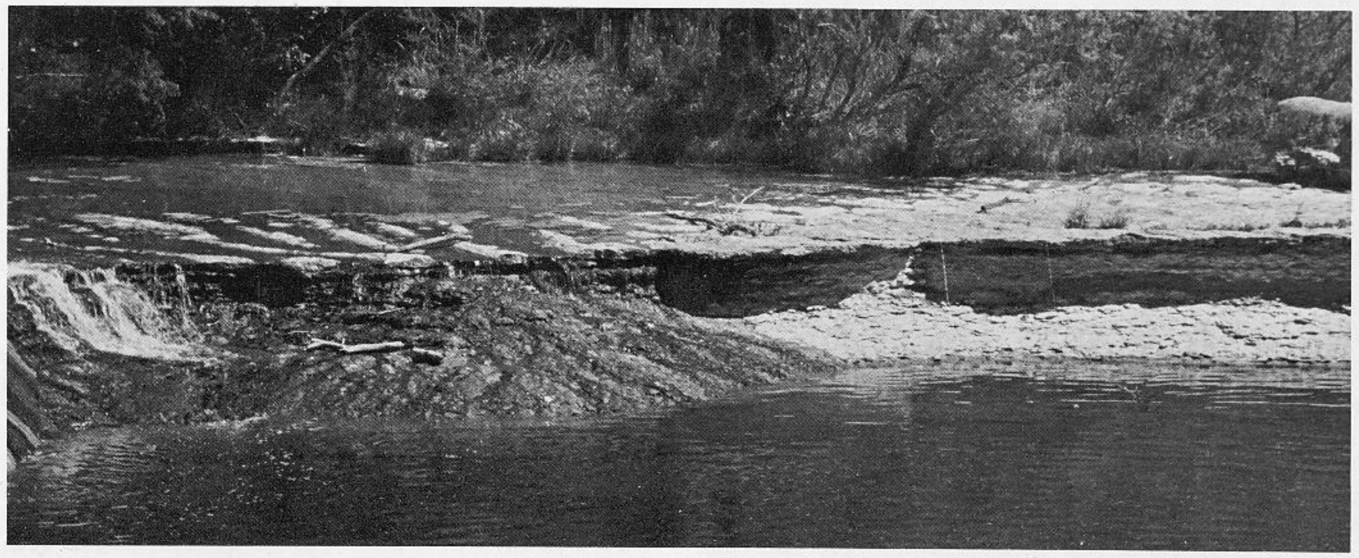


Fig. 20. Locality 136. Ripple-marked oyster bank in central Bosque County. Ripples are made of abraded and fragmented oyster shells forming the surface of a bank.

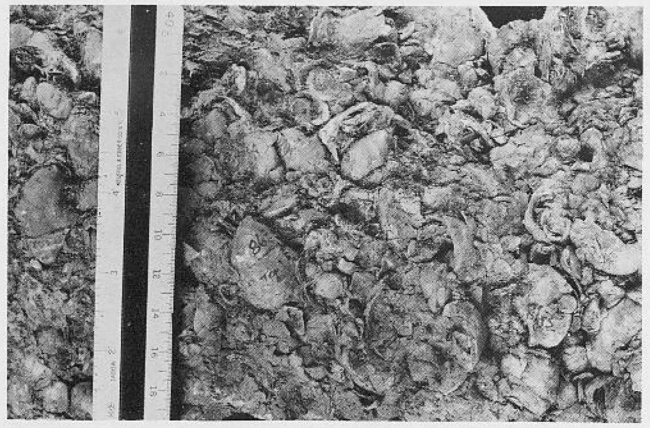


Fig. 22. Locality 102. Specimens from a *Texigryphaea* bank. Notice the few signs of borings, unabraded nature of the valves, and the common occurrence of both valves. This indicates a growth assemblage inhabiting calm water along the flanks of a bank.

Fig. 23. Locality 134. Individual beds in *Exogyra* banks range in thickness from two inches to six inches. Oysters commonly occur in a sparite matrix, and beds of oysters are separated by tan agrillaceous limestone. This indicates a higher energy environment than that suggested by the exposure shown in Figure 22, and apparently records a short period of growth terminated by clay influx.

Fig. 24. Locality 134. *Exogyra* specimen showing serpulid worm tubes on the interior of the valve. Serpulids commonly prefer brackish water so this colony may indicate brief brackish conditions. Magnification 2X.

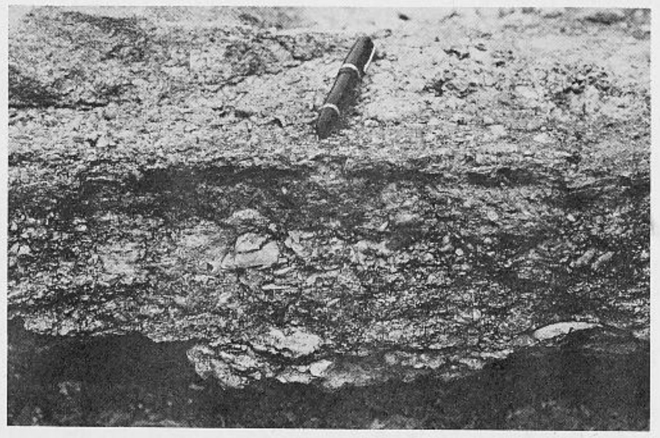


Fig. 25. Locality 121. Dense ripple-marked limestone of Member Two. Notice the highly fragmented shells of *Texigryphaea*, suggestive of an environment of vigorous wave energy.

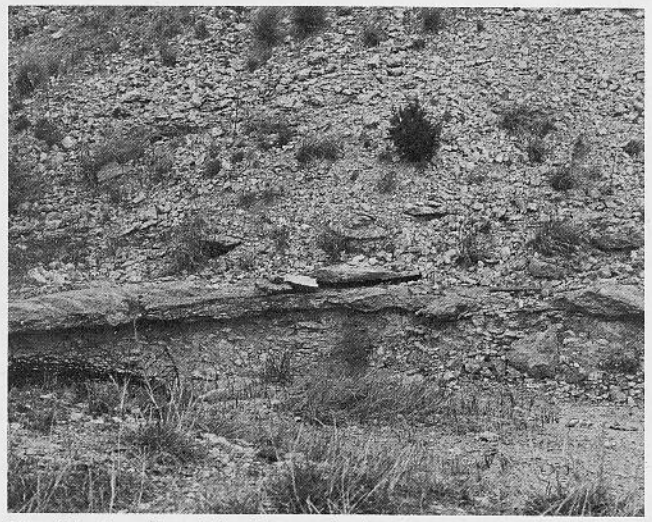


Fig. 26. Locality 121. Dense ripple-marked limestone as seen in Figure 25. Notice the megaripples trending N 45° E. Wave length is approximately six feet. Similar ripples may be seen forming today on oyster banks as a product of storm waves on the Gulf Coast of Texas.

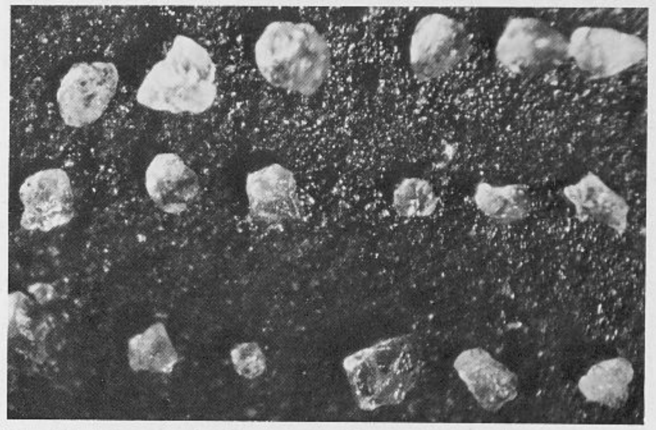


Fig. 27. Microscopic view of sand from clay samples of Member Two. Notice the rounded to sub-angular quartz grains. Magnification approximately 50X.

foraminifers (Appendix 1, Table 7). The maximum diversity in microfauna occurs in this member.

Exogyra banks (Fig 7, localities 145, 196) are limited in abundance and size and show wide faunal diversity. Banks commonly occur in a dense limestone matrix and reach a maximum thickness of three inches. Individual *Exogyra* valves commonly have serpulid worm growth both on the interior and exterior surfaces. The common *Exogyra* valves are distorted, often show signs of borings, and large points of attachment. Other fossils found in the *Exogyra* banks are *Ciprimeria, Enallaster, Oxytropidoceras, Pecten, Protocardia, Trigonia, Turritella,* and *Tylostoma.*

Clays above and below *Texigryphaea* banks of Member Five contain abundant illite (Proctor, 1961, p. 20).

STRATIGRAPHIC SIGNIFICANCE OF *TEXIGRYPHAEA* BEDS, WALNUT CLAY

INTRODUCTION

The particular genus, *Texigryphaea,* ranged from Early Cretaceous to Late Cretaceous time, while the subfamily, Pycnodonteinae, range from Early Cretaceous to Holocene (Stenzel, 1971, p. N 1096). The particular bank forming species, *Texigryphaea mucronata* (Stenzel) appears to be restricted to Lower Cretaceous rocks. As a result of this narrow geologic range, the ecology of *Texigryphaea mucronata* (Stenzel) must be based on faunal and stratigraphic associations. It is not possible to speak of their ecology from direct knowledge. However, in their mode of occur-

Fig. 30. Locality 102. *Texigryphaea* bank overlain by nodular limestone. Notice the alternation of nodular limestone, shale, and *Texigryphaea* bank which contributes to the weathering profile. Notice also the great extent of the thin *Texigryphaea* banks.

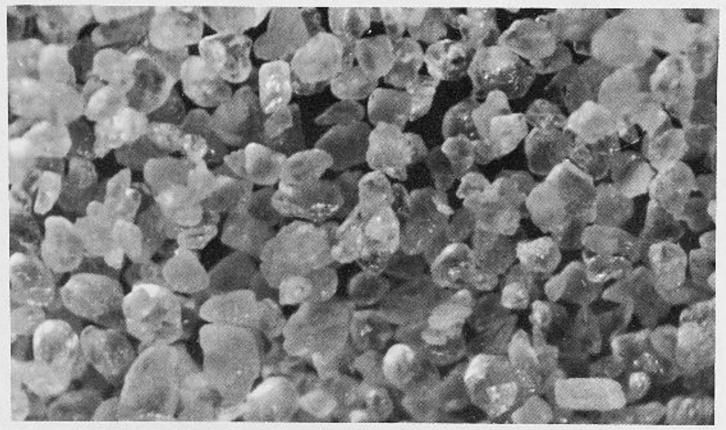


Fig. 28. Microscopic view of Paluxy Sand. Notice the similarity between this and the grains in Figure 27. Magnification is approximately 25X.

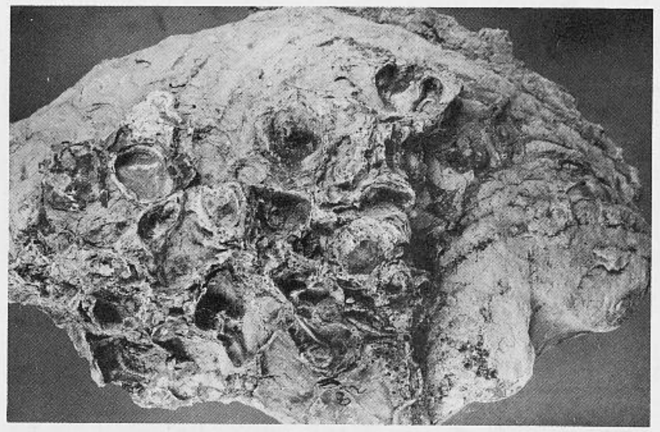


Fig. 29. Locality 125. *Exogyra* sp. attached to *Metengonoceras.* Notice the bored valves of *Exogyra* with serpulid worm tubes attached. Approximately ⅓ scale.

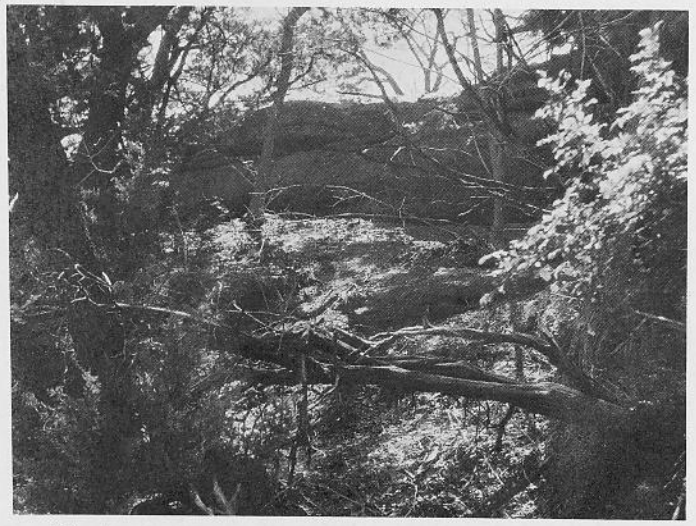


Fig. 31. Locality 102. Typical *Texigryhaea* bank in Member Four. Notice the massive appearance of the bank and the thin shale interbeds. The shale laminae are devoid of *Texigryphaea* valves indicative of environmental conditions not conductive to bank formation.

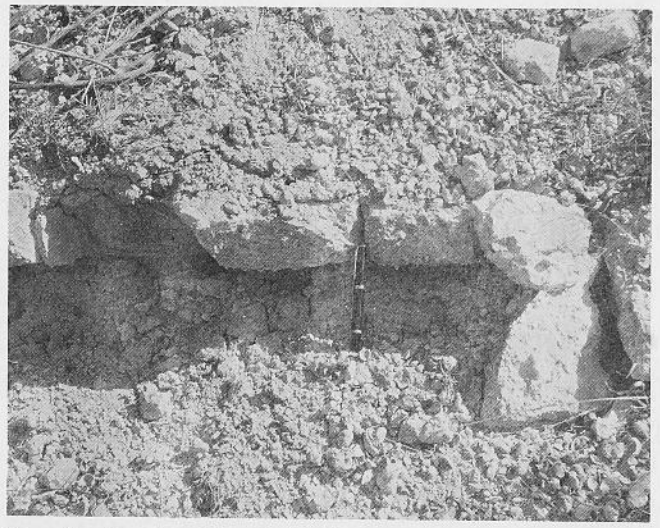


Fig. 32. Locality 133. Thin *Texigryphaea* bed in Lampasas County. Notice the thin (eight inches) bank and the abundant *Texigryphaea* on the rubble slope.

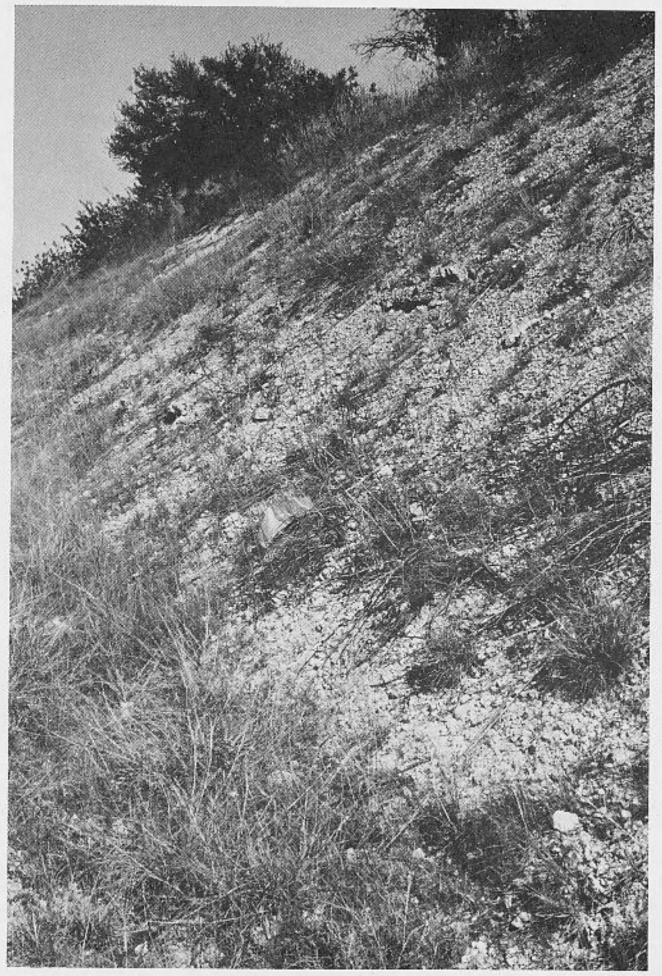


Fig. 33. Locality 133. Thin *Texigryphaea* beds in Lampasas County separated by beds of nodular limestone which contain abundant marine fauna. Slope rubble consists largely of *Texigryphaea.*

rence, the structure of the banks, the nature of the community of which they are a part, they are not unlike modern bank-forming oysters. Hence in order to understand the oyster banks in the Walnut Formation it is beneficial to study modern bank-forming oysters. Consequently, since *Texigryphaea* occur as commensal organisms, in association with other fossils, and in recognizable sediment sequences we may infer life habits. They were sedentary organisms, that lived much as modern oysters do today. Therefore *Texigryphaea* may best be understood in comparison with modern oysters, utilizing the vast body of information now available, and significant knowledge may thus be transferable to the fossil record.

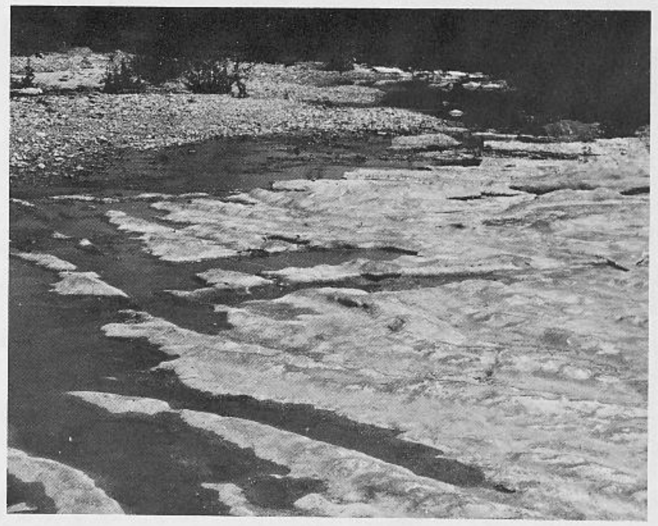


Fig. 34. Locality 101. Dense ripple-marked limestone. The trend of the ripple drainage is to the southeast. Similar ripples and drainage are developing today on tidal flats on the Texas Gulf Coast. The ripples lie immediately beneath the *Texigryphaea* banks.

ECOLOGY OF MODERN BANK-FORMING OYSTERS

Modern bank-forming oysters have been studied extensively for commercial applications. The best understood oyster is the *Crassostrea virginica.* The major ecological controls for this species are: nature of the bottom, type of clutch, amount of food, silting rate, existence of crevasses, temperature, disease, predation, commensual community, and salinity (Butler, 1954).

Oysters are dependent on the nature of the bottom as a means of attachment. They generally require a hard substrate in which to establish colonies. A hard clean bottom is preferable; however, the free swimming post-larval spat will attach themselves to anything

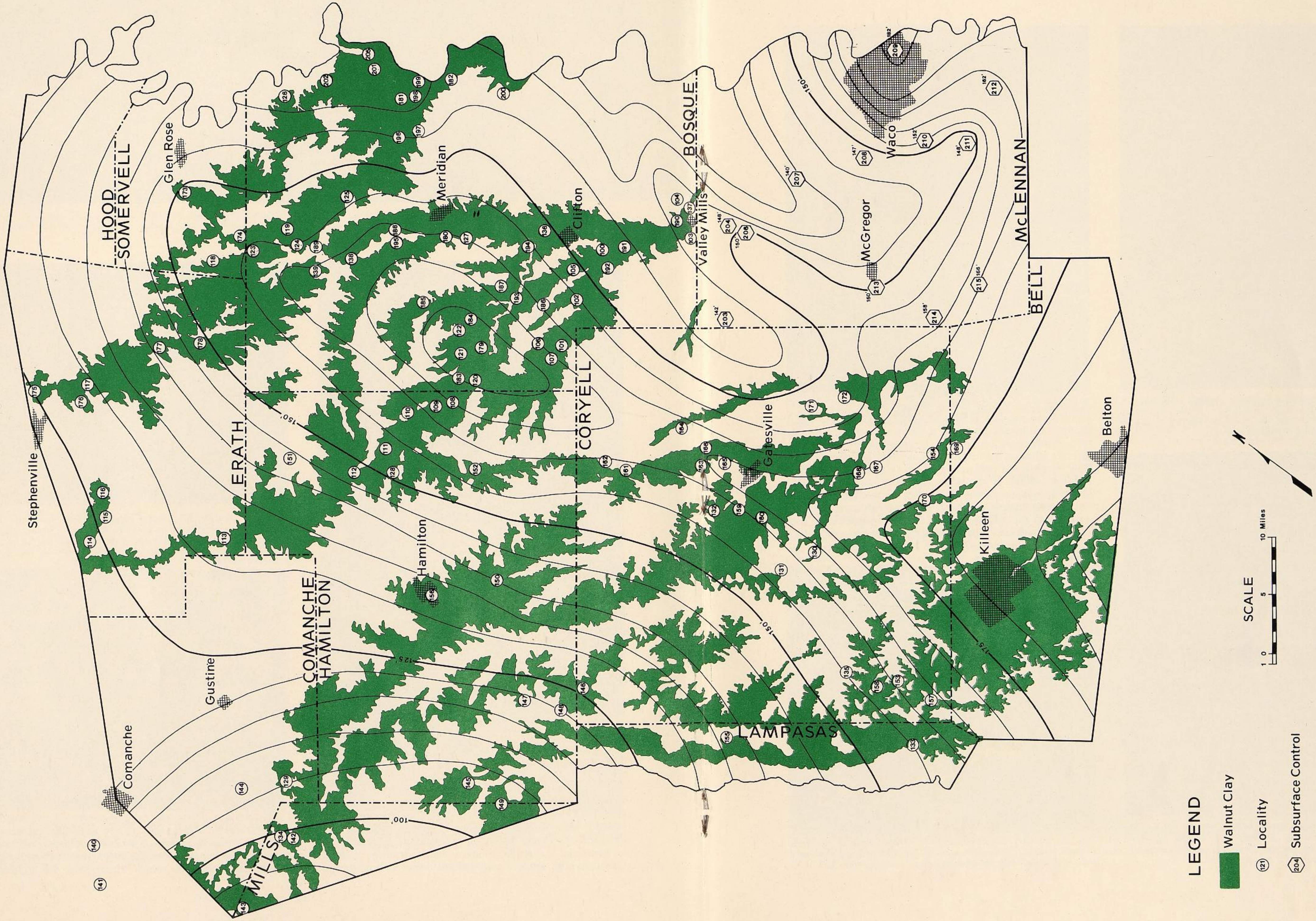


Fig. 7. Geologic map showing sampled localities, area of outcrop, and thickness of Walnut Formation. (Isopach data largely from Jones, 1966).

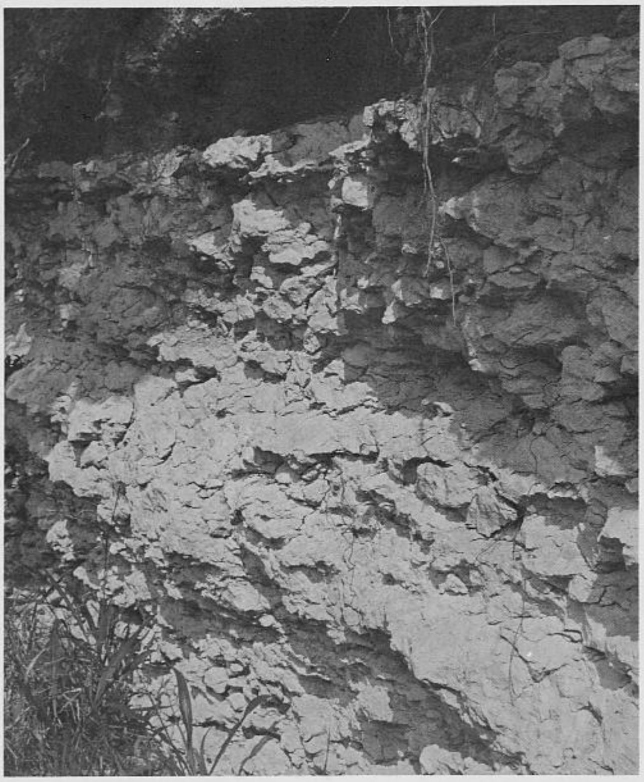


Fig. 35. Locality 101. Nodular limestone overlain by a massive *Texigryphaea* bank. The nodular limestone is similar to that of the Comanche Peak Formation and contains fragmented brittle sea stars and other normal marine fauna.

Fig. 37. Locality 101. Typical *Texigryphaea* bank. Notice that the pelecypods are relatively the same size, loosely cemented together, and weather out readily. Both valves are commonly found together surrounded by a micrite matrix.

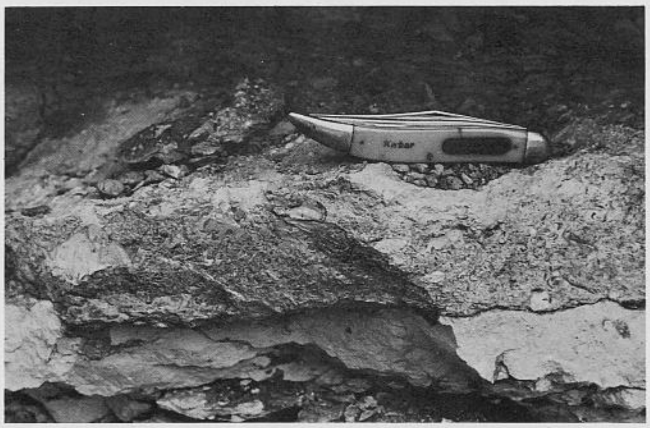


Fig. 36. Locality 101. Dense ripple-marked limestone. Notice that macerated shells constitute about ¾ of the volume of the ledge. The matrix is dense packed bioforammicrite.

(sand-grains, micro shell fragments, glass bottles). The necessity for attachment of the spat is not well understood; however, death will follow should the spat fail to attach.

The amount of food entering an oyster bank is dependent on a number of variables, but major among them is the mixture of river discharge with oceanic water. Rivers carry nutrients, providing an adequate food supply for the nannoplankton which in turn is the principal food supply of the oysters.

Siltation, or the influx of large amounts of fine-grained sediments produces a disastrous effect on oysters, resulting in suffocation by covering the gills. Indirectly siltation may reduce the penetration of sunlight, thus limiting the production of nannoplankton (Butler, 1954, p. 483). If the silt is fine and remains only a short time it may coat the oyster valves and prevent them from serving as clutch for spat. Silt may be ingested into the gills, and collected and ejected from the valve in the form of pseudofecal matter. Consequently, oyster banks in estuaries may include sediments composed of pseudofeces.

Fig. 38. Locality 123. Typical *Texigryphaea* bank in northern Bosque County. Notice the variation in size of the individuals indicating the flanks of a bank.

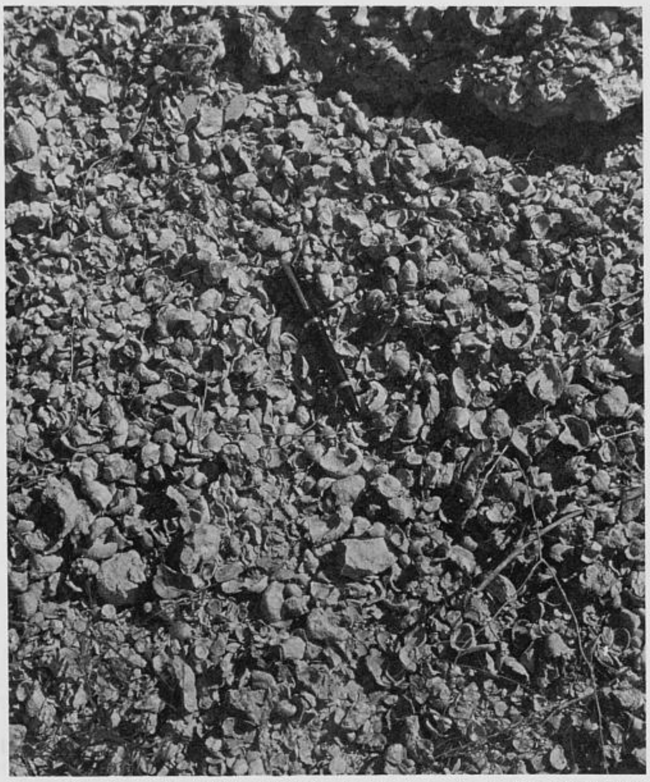


Fig. 39. Locality 133. Rubble derived from a *Texigryphaea* bank in southern Coryell County. Notice the uniformity and small size of the individuals indicative of the lower reaches of an estuary.

Disastrous but temporary changes in banks may result from floods in river basins feeding estuaries. Floods cause siltation, temperature change, and decreased salinity. While floods are often major factors in bank evolution, they are temporary, and the oysters will establish the bank in approximately the same position following a return to more normal conditions.

The oyster is versatile in adaptation to various temperatures from –2°C to +30°C (28°F to 86°F). The commercial oyster *Crassostrea virginica* thrives and spawns at 24°C (75°F); however, sudden changes in temperature may be detrimental. Cold spells with freezing temperatures will not affect oysters unless they are exposed in shallow water at low tide. High summer temperatures may be harmful to oysters in shallow water at low tide. Temperatures over 32°C (90°F) result in death to the community.

Modern oyster banks are periodically decimated by one of two diseases. One of these appears to be the result of the fungus parasite, *Dermocystidium,* and attacks only the older oysters in the summer months (Hofstetter, 1959, p. 22). With the exception of the larva of the trematode worm, *Bucephalus,* the effect of other parasites are not well known. *Bucephalus* develops in the gonads of the oyster, destroying them in the process, thus preventing the oyster from spawning (Hofstetter, 1959, p. 22).

Turbidity has both positive and negative effects. Currents bring food to the sessile filter-feeding oysters, thereby supplying nourishment. Currents also serve to provide more abundant oxygen to the water. On the other hand currents may tend to stir the substrate, and load the water with sediment resulting in hindrance to gill action.

The most serious predator to modern oysters is the gastropod *Thais haemostoma.* This small gastropod constitutes a serious problem leading to the deterioration of a bank, and a single individual has been observed to eat 100 small oysters per day (Hofstetter, 1959, p. 13). *Thais,* commonly called the drill, appears to be limited to waters of near marine salinity. Hence, in areas of above normal salinity for *Crassostrea, Thais* presents a problem and correspondingly those *Thais* infested banks deteriorate rapidly (Hofstetter, 1971, p. 112). For example, an oyster bank on Stedtman

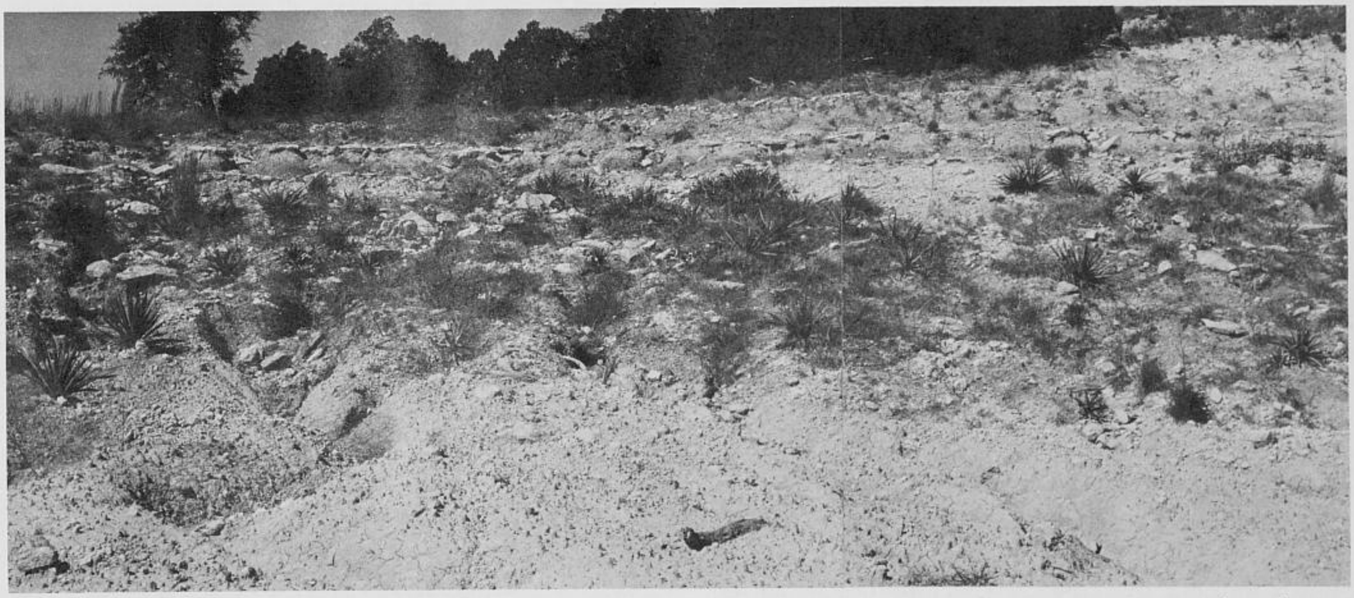


Fig. 40. Locality 103. *Texigryphaea* banks in Member Five. Notice the thin banks of great lateral extent separated by calcareous clay. The clay weathers rapidly contributing to the profile.

Fig. 41. Locality 104. Thin (two inches) *Texigryphaea* bank in Member Five. Notice the bank forms a conspicuous break in the slope because of its greater resistance to weathering.

Fig. 42. Locality 131. Four thin *Texigryphaea* banks in Member Five. Bank at the top of the outcrop is about one-foot thick; the others are substantially thinner.

Reef at Port Aransas, Texas, was *Thais* infested, where the water contained 30 parts per thousand salinity. *Thais* were observed to attack young oysters; however, where these were unavailable they would attack and consume older stock. Over a period of two years the bank was reduced from extensive production to largely barren patches.

Though not a predator, the boring sponge (*Cliona*) also poses problems for the oyster, for it penetrates the shell as a means of protection. The sponge forms an extensive network of channels in the shell with a variety of openings to the outside until the oyster is fragile and crumbles (Hofstetter, 1959, p. 19). The boring sponge thrives in normal marine waters and appears to be restricted to that environment.

The major factor in oyster ecology is the degree of fresh water and saline water in an oyster bay. Maximum growth of the community is dependent on near-stable salinity levels, and limited seasonal fluctuations in salt content. Both size and abundance of oysters, appearance of shell, reproductive potential, commensual community, predation, and parasites are all related to salinity levels of the environment. Adequate data have been collected to show type areas of oyster habitation (Table 5). These data are substantiated by Puffer and Emerson (1953), Norris (1953), Parker (1955), Kinne (1964), Stanley (1970), and Hofstetter (1959, 1970, 1971). It is apparent from Table 5 that oyster bank growth reaches a maximum in type two conditions and is at a minimum in type four. Other workers conclude that the oyster "is adapted to an estuarine environment with a salinity of 12 to 19 % , and does not form extensive reefs in areas of high salinities" (Parker, 1955, p. 200).

In addition salinity may affect oysters indirectly, through modification of eco-systems and species variation or by changes in biotic relationships within the community (Kinne, 1964, p. 281). With change in salinity the diversity of life and number of species also change. Diversity is a maximum in euhaline waters and decreases in limnetic, polyhaline, hypersaline, and brine waters (Kinne, 1964, p. 283).

OYSTER REEFS ON THE TEXAS GULF COAST

The typical oyster reef on the Texas Gulf Coast in cross-section (Fig. 43) is a series of "low mounds occupied by loose dead shells with the live oysters on the sloping shoulders" (Hedgpeth, 1954, p. 207). The margins of the banks have been found to contain abundant juveniles and newly settled spat (Butler, 1954, p. 479). The banks are founded on muddy bottoms and are re-

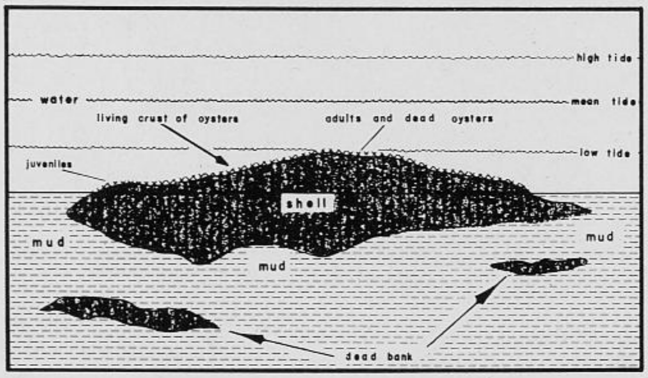


Fig. 43. Generalized cross section of a modern oyster reef typical of the Texas Gulf Coast. This shows marked similarities to *Texigryphaea* banks of central Texas.

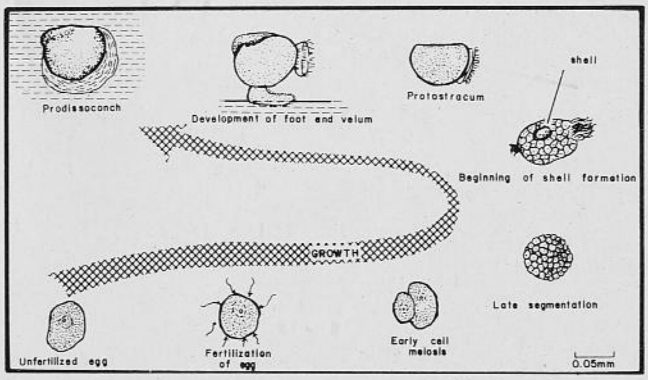
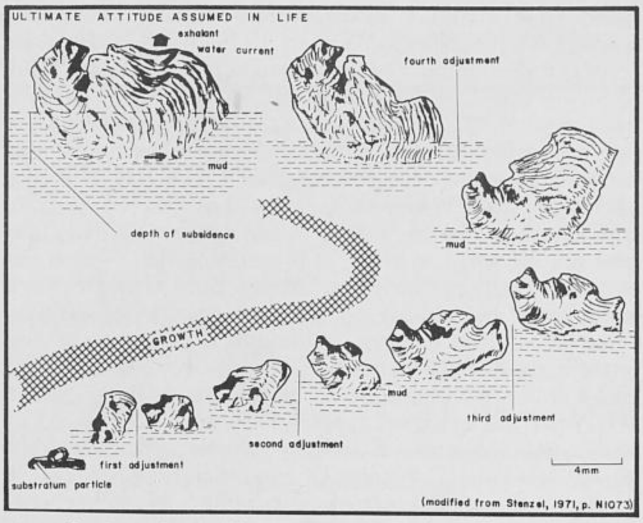


Fig. 44. Postulated early development of *Texigryphaea mucronata* showing development from unfertilized egg through the prodissoconch stage. Stages in this figure precede life patterns shown in Figure 45. Note scale, lower right.



(modified from Stenzel, 1971, p. N1073)

Fig. 45. Postulated life pattern of *Texigryphaea mucronata* showing growth from prodissoconch stage through adult stage. Note scale, lower right.

stricted to the shoreward reaches of low salinity bays and estuaries, with the long axis of the bank perpendicular to prevailing currents of the bays (Hedgpeth, 1954, p. 207). In plan the banks are oval or spindle-shaped, may be many acres in area and extend for 25 miles or more in length (Butler, 1954, p. 479). Living oysters may occur from a foot above low tide to a depth of 30 feet (Fig. 43). Where the substrate is firm the oysters establish massive banks; however, where the bottom is fine mud they occur as small isolated patches of loosely cemented shells.

Banks apparently grow from these "patches." Single oysters grow until their own weight carries them below the sediment-water interface. New spat settle on the old shell and they too grow until their own weight carries them below the surface. Under favorable conditions over a period of years a massive reef may form when eventually a firm substrate is established. Banks exist in this manner for years, under "the period of equilibrium" (Nicol, 1954, p. 24). It is during the stage of equilibrium that the areal distribution is at a maximum, with maximum number of individuals, and minimum diversity of fauna. Following the period of equilibrium there is a state of decline in which living individuals become restricted in area of occurrence and numbers (Nicol, 1954, p. 25).

ECOLOGY OF *TEXIGRYPHAEA*

Texigryphaea was also a bank-forming oyster, found in sedimentary associations similar to those of modern bank-forming oysters. Thus the early development of *Texigryphaea mucronata* (Stenzel) may parallel that of other sedentary pelecypods (Fig. 44). Occurrence leads us to believe that *Texigryphaea* was nonincubatory, (i.e. fertilization and incubation of eggs occurred outside the shell). Once the eggs were ejected fertilization probably took place in a matter of minutes, as it does in modern oysters (Fig. 44). Following early cell meiosis and late segmentation the shell probably began forming (Fig. 44). As development proceeded, (protostracum, or initial shell formation) the larva probably consisted of two equilateral hyaline valves.

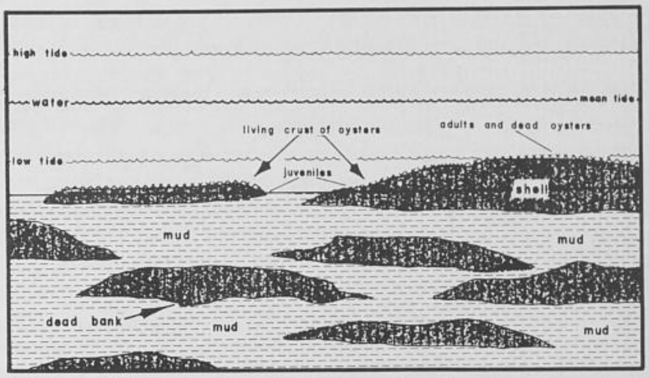


Fig. 46. Generalized cross section of a *Texigryphaea* bank sequence, central Texas. Horizontal scale much compressed.

The mode of locomotion during this stage, if similar to modern oysters, was by the disc-shaped ciliated organ (velum). As the protostracum continued to grow, a foot developed for initial contact with the substratum. During this stage the early protostracum may have continued to grow in size and thickness until it became the prodissoconch. Eventually the spat settled on a hard substratum and metamorphosed into a permanently attached pelecypod. The elapsed time from fertilization to attachment of the prodissoconch might have been in the range of 18 days (Stenzel, 1971, p. N. 1072).

Following the larval stage the *Texigryphaea* possibly existed on a soft ooze bottom (Stenzel, 1971, p. N 1072). If this were the case then a series of adjustments in the final life history of the *Texigryphaea* would have been necessary. The attachment area in *Texigryphaea* is relatively small and the juvenile would rapidly outgrow the space. As initial growth took place, the umbonal area would sink into the mud (Fig. 45). A period of growth should follow whereupon the valve should become unbalanced through subsidence and topple over once again (Fig. 45). This could continue in a series of adjustments (four in modern forms) until the ultimate attitude assumed in life was reached (Fig. 45), when the weight of the pelecypod was equal to that of the mud it displaced.

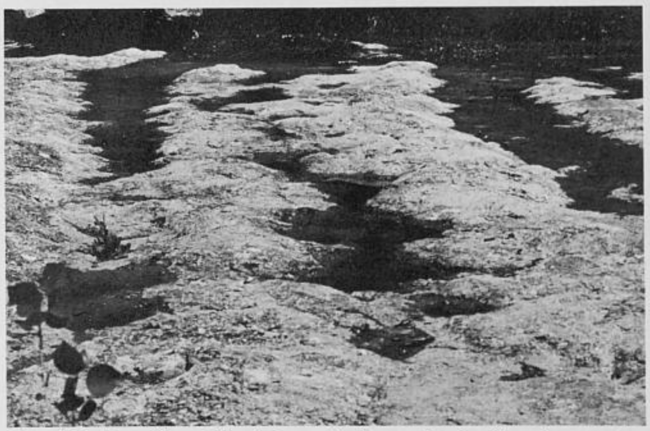


Fig. 47. Locality 136. Large ripple-marks in limestone, wave length approximately two feet. Broken and abraded fossils constitute the principal sediment of the ripples. The poor sorting of the fragments is suggestive of storm deposition.

During growth the typical *Texigryphaea* bank of the Walnut Formation may have appeared much the same as a recent oyster bank, a series of low mounds, possibly exposed at low tide, with a high center giving the appearance of a gentle bioherm (Fig. 46). The individual oysters would have been loosely assembled in fine-grained mud, and as the bank grew in height, width, and length they would ultimately sink into the substrate (Fig. 46). Juveniles would have been concentrated on the slopes, and living and dead adults occupied the central area. *Texigryphaea* banks were probably subject to the same environmental controls as are modern bank-forming oysters (i.e., nature of the bottom, type of clutch, amount of food, siltation, existence of crevasses, temperature, disease, predation, commensual community, and salinity).

The nature of the bottom during the initial formation of the bank must have been a soft silty mud as is evidenced by the geologic section. Growth occurred from this stage and continued with successive generations growing on top of earlier generations.

Siltation probably affected *Texigryphaea* as it does modern oysters. Sudden cessation of bank growth resulted from periods of extensive siltation and/or long periods of exposure to oligohaline waters. Sudden influx of flood waters may have affected *Texigryphaea* growth by changes in the composition of the water.

It is difficult to determine what effect temperature had in *Texigryphaea* growth; however, it may be implied it was similar to that of modern bank-forming oysters.

Many individual *Texigryphaea* contain borings, some showing interconnected passages. These may represent parasites of the *Texigryphaea.* Bored *Texigryphaea* are found in a diverse faunal association with the gastropod *Tylostoma* and the echinoid *Enallaster.* In those occurrences *Texigryphaea* banks are limited in size, and number of individuals. Valves show drilled holes and are all small in size. It is possible that *Tylostoma* was the *Thais* of Early Cretaceous time, though this is speculation based only on common occurrence—*Tylostoma* and bored oysters. Although *Texigryphaea* was a reclining variety of pelecypod this would in no way make it more vulnerable to attack by drilling gastropods than are attached species (Stanley, 1970, p. 35).

The establishment of salinity tolerances for *Texigryphaea mucronata* (Stenzel) is difficult, for it is an extinct species of an extinct genera. However, one may infer salinity tolerances and optimal conditions from the fossil oyster biocoenose. *Texigryphaea mucronata* was apparently stenohaline (Table 1). The pelecypods were probably limited in adaptive ability to variations in salinity in a range of 18-40 parts per thousand.

While Stenzel (1971, p. N 1040) stated that all members of the family Gryphaeidae are strictly euhaline, the occurrence of *Texigryphaea mucronata* in association with brackish water ostracodes and foramini-

TABLE 5. OCCURRENCES AND CHARACTERISTICS OF RECENT OYSTER BANKS AND THEIR RELATIONSHIPS TO ENVIRONMENTAL CONTROLS.

	LOCATION	SALINITY	POPULATION	SPATFALL	MORTALITY RATES	PREDATORS OR PARASITES	ADDITIONAL COMMENTS
TYPE 1	Near the head of a typical estuary	15‰ to 0‰ average 10‰	Sparse, mostly small and rounded (smooth whitish shells)	Low	High, Periodically decimated by excessive freshwater	Few fouling organisms, few predators or parasites present	
TYPE 2	Any location of brackish conditions in an estuary	10‰ to 20‰ average 15‰	Maximum, high reproductive ability due to the availability of clutch	Medium	Low	Low concentration of predators and parasites	Growth is uniform, population forms definite year classes, valves are smooth and dense and form large or small interlocking clusters
TYPE 3	Near the mouth of a typical estuary	10‰ to 30‰ average 25‰	Variety of animals reaches a maximum	High	High in young oysters	Large numbers of predators and parasites present	Shells have a massive appearance
TYPE 4	At the estuary and the Gulf	35‰	Sparse	High	Excessive	Highest concentration of predators and parasites	Marginal environment, slow growth rates

Data from Butler, 1954, p. 480, 481.

TABLE 6. ENERGY INDEX CLASSIFICATIONS SHOWING MINERALOGY, TEXTURE, AND CHARACTERISTIC FOSSILS ASSOCIATED WITH FIVE DIFFERENT WAVE ENVIRONMENTS.

Type	Mineralogy	Texture	Characteristic Fossils
Quiet I	Calcite Clay (<15% to 50%) Detrital quartz (< 50%)	Microcrystalline carbonate matrix, angular or whole fossils.	Crinoids, echinoids, pelecypods predominate. Bivalve assemblages usually articulate.
Intermittently Agitated II	Calcite (predominant) Clay (<25%) Detrital quartz (< 50%)	Microcrystalline to medium-grained carbonate matrix with terrigenous material.	Fossil assemblages similar to I, there are more broken and abraded fossils, and rougher water fossils are present.
Slightly Agitated III	Calcite (predominant) Detrital quartz (up to 50%)	Micrograined clastic carbonate matrix.	Echinoderm and bivalve shell debris. Fossil materials from larger fossil structures well abraded.
Moderately Agitated IV	Calcite (predominant) Detrital quartz (up to 50%)	Medium-grained clastic carbonate matrix.	Crinoids, echinoids, and bivalve shell fragments. Mixtures of I, II, and III assemblages present.
Strongly Agitated V	Calcite (predominant) Detrital quartz (< 25%) Clay (< 5%)	Gravel-sized clastic carbonate (fossil material > 2.0 mm).	Fossil associations similar to type IV, however materials are generally broken and abraded.

After Plumley and others, 1962, p. 88.

fers (Appendix 1, Table 7) suggests polyhaline zones. The banks are composed almost entirely of one species, with few predators and parasites, a minimum diversity of fauna, which also is a feature of polyhaline zones (Table 5, type 2). *Texigryphaea* banks diminish in size where echinoderms, gastropods, and other pelecypods occur and suggest euhaline conditions (Table 5, type 4).

Individual shells of *Texigryphaea* found in association with gastropods, echinoderms and other pelecypods are small and bored, also a feature of euhaline zones. Individual shells of *Texigryphaea* found in banks in association with brackish water ostracodes and foraminifers (Appendix 1, Table 7) are larger and not bored, a feature of polyhaline zones.

While the generalization to all members of the family Gryphaeidae is invalid, *Texigryphaea mucronata* represents a distinct species in the Walnut Formation that formed massive banks, apparently in polyhaline zones with salinity tolerances of 18 to 35 parts per thousand.

The turbidity index of the Walnut Formation alternated between type one and type five (Table 6). The large symmetrical ripple marks (Fig. 47) are indicative of type five (Table 6) with broken and abraded shell hash constituting the matrix. The oyster banks represent energy conditions of type one or two, or an environment of low physical energy.

SIGNIFICANCE OF *TEXIGRYPHAEA* BEDS IN THE DEPOSITION OF THE WALNUT FORMATION, CENTRAL TEXAS

The Walnut Formation was apparently deposited as a transgressive marine sequence behind the Stuart City Reef (Fig. 48). The reef was apparently the major barrier between free circulation in the Stuart City Lagoon and the open marine waters of the continental shelf (Fig. 48). Two paleo-features which further re-

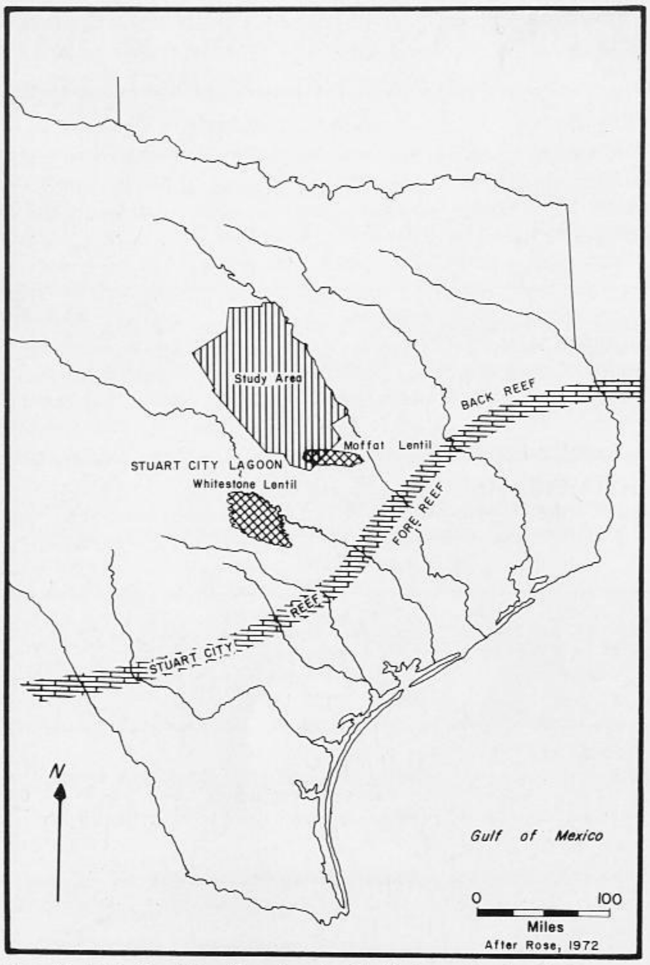


Fig. 48. Relationship of regional paleofeatures to the study area.

stricted free circulation were mapped by Moore (1964, p. 21), the Moffat Lentil and the Whitestone Lentil (Fig. 48).

In this setting the Walnut Formation initially transgressed northwestward across the stable central Texas Craton over the Paluxy Sand (Fig. 49). Conditions of the environment at any one point alternated between shallow marine and brackish water, as it does on the present Texas Gulf Coast. In the southern part of the study area the environment remained shallow marine as suggested by the presence of shallow-water normal euhaline fauna. The northern part of the study area may have consisted of a series of tidal flats, marshes, or extremely shallow bays as suggested by the presence of plant remains and a limited number of vertical burrows.

MEMBER ONE

The paleogeography of Member One may be inferred from its limited geographic distribution and the fauna it contains (Appendix 1, Table 7). The transgression of Member One over the Paluxy Sand was apparently slow and uniform, as suggested by the conformable nature of the contact and the interfingering of sand and clay.

The maximum extent of Member One marks the shoreline during this time (Fig. 50). Two sources of river discharge apparently existed during the deposition of Member One (Fig. 50), delivering sediments consisting of clay with abundant quartz sand, probably reworked from the subaerially exposed Paluxy Sand to the north (Fig. 50).

Texigryphaea banks originated in a shallow bay (Fig. 50) with a probable initial salinity of 25 parts per thousand, as indicated by the relatively diverse faunal association at locality 134. The banks grew at right angles to the prevailing currents as modern banks do today. The thin limited banks appear to be of type three (Table 5), as typified by the abundant parasites and predators, bored shells, and *Tylostoma.* Individual valves are massive in appearance and there are abundant microscopic *Texigryphaea* and possibly *Exogyra* prodissoconchs.

Deposition during the middle and final stages of Member One appears to have been rapid as is shown by the absence of burrowing organisms in the banks. The turbidity index during bank growth was of type one (Table 6), low energy, as indicated by the accumulation of micrite.

Vertically the *Texigryphaea* banks are replaced by sediments containing valves of individual *Exogyra* and of other euhaline species, suggesting a major change from polyhaline zones to euhaline zones while Member Two was being deposited to the southeast.

MEMBER TWO

Member Two represents a major transgression of the Walnut Seas over the entire study area (Fig. 51). Member Two probably represents a nearshore facies, time eqivalent to Member Three farther out (Jones, 1966, p. 172).

Transgression was apparently rapid, for it overlapped the dipping truncated Paluxy Sand in northern Bosque County (Fig. 3). The beds immediately above the Paluxy Sand in Member Two contain abundant reworked Paluxy Sand derived from farther north.

Early transgression resulted in growth of *Texigryphaea* banks and two *Exogyra* banks (Fig. 51). *Texigryphaea* banks were of type three (Table 5), salinity

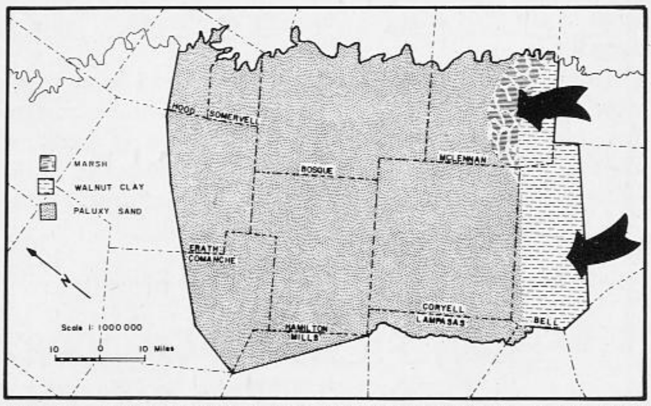


Fig. 49. Paleogeographic map showing conditions at the start of Walnut deposition. The end of Paluxy time is represented by a broad expanse, probably of subaerially exposed, poorly cemented sand. The initial Walnut transgression progressed northwestward over the study area as across present Bell and McLennan Counties. During the initial transgression the area of Bell County was an epicontinental sea, while the area of McLennan County was an area of low relief, possibly a tidal marsh or shallow bay. Arrows show the direction of marine transgression.

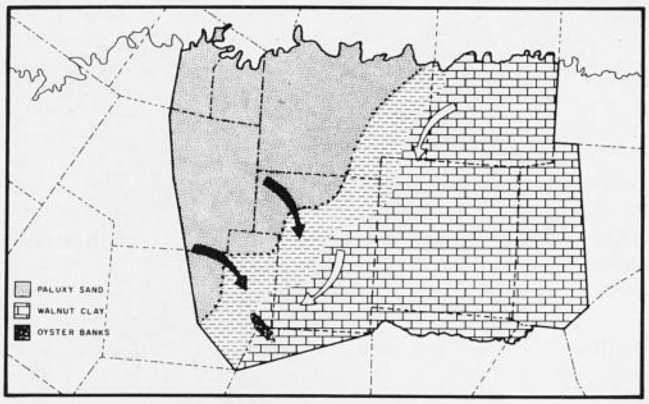


Fig. 50. Paleogeographic map showing conditions during deposition of Member One. The margin of the Walnut sea is the Walnut-Paluxy shoreline (heavily dotted line). Two possible sources of river discharge exist in the area of Hamilton and Comanche Counties (dark arrows). The Paluxy Sand was apparently exposed subaerially in the northeastern part of the study area and supplied terrigeneous materials to shallow bays. Offshore, longshore currents (light arrows) carried sediments to the south and west. *Texigryphaea* banks (stippled pattern) grew in banks with long axes perpendicular to prevailing currents.

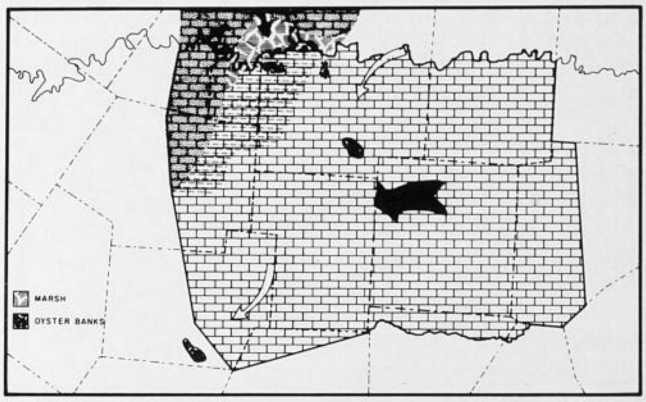


Fig. 51. Paleogeographic map showing conditions during deposition of Member Two. Transgression took place in a general northwestern direction (large dark arrow). The northeastern part of the study area remained low topographically, an area of tidal marshes during the early transgression. During the later stages this area was a shallow bay receiving terrigeneous sediments from the north (small dark arrow). Two *Texigryphaea* banks formed in this bay at right angles to the prevailing currents (see both dark- and light-colored arrows in northwestern area). Two *Exogyra* banks formed south of the *Texigryphaea* banks at right angles to the longshore currents (both northern and southwestern light-colored arrows).

30 parts per thousand, as is indicated by the faunal association. Individual valves are highly bored and fragmented, indicative of high predation. Ripple marks in conjunction with the fragmented nature of the fossils indicate the turbidity index was type five (Table 6). Abundant quartz sand in the banks indicates possible river influx or more likely longshore currents (Fig. 51).

Exogyra banks may indicate an environment more favorable to it than to *Texigryphaea* growth. The position of *Exogyra* banks, south of the *Texigryphaea* banks, may represent euhaline conditions, 32 to 34 parts per thousand. Conditions within the *Exogyra* banks never approached true marine salinity as shown by the growth of colonial serpulids, a brackish water indicator (Trippet, 1972) found commonly on *Exogyra* valves.

MEMBER THREE

Member Three was apparently an offshore deposit far from the effects of river discharge (Fig. 52), as suggested by paucity of quartz sand grains. *Texigryphaea* banks were apparently of type four (Table 5) as suggested by varied but sparse fauna and absence of ripple marks. The turbidity index was type one (Table 6) as suggested by fine-grained micrite matrix in the samples. Environmental conditions were stable over large areas as is indicated by the consistent nature of the member.

At the termination of deposition of Member Three there was a minor regression in which sea level dropped over large areas. This is suggested by *Texigryphaea* banks high in the member in the southern part of the study area. In other areas during regression Member Three was exposed to subaerial erosion prior to the deposition of Member Four (Moore, 1961).

MEMBER FOUR

Member Four represents a series of regressive-transgressive sub-facies reflected in the sediments by the interlaminations of black pyritic shales, nodular limestones, *Texigryphaea* banks, terrigeneous sand, and ripple-marked limestone beds.

In Member Four *Texigryphaea* banks reach their maximum distribution and thickness.

Member Four transgressed over the stable carbonate blanket of Member Three (Fig. 53). Possibly Member Three was subaerially exposed in the northern part of the study area (Moore, 1961); however, specific evidence was not encountered in the progress of this study.

The *Texigryphaea* banks originated in shallow bays (Fig. 53) or salt marshes with probable initial salinities of 25 parts per thousand, as evidenced by fauna at localities 146, 147, 148, and 154, 167, 168, 169, 170. Modern oysters in the same salinity zone are characterized by an exceptional growth rate (Butler, 1954, p.

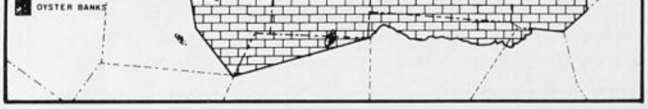


Fig. 52. Paleogeographic map showing conditions during the deposition of Member Three. Initial transgression was rapid (large dark arrows) over the entire study area. The study area was far from a source of terrigeneous sand derived from land in the north (small dark arrow). *Texigryphaea* and *Exogyra* banks (stippled areas) formed small isolated mounds. Final regression progressed to the south (large white arrow).

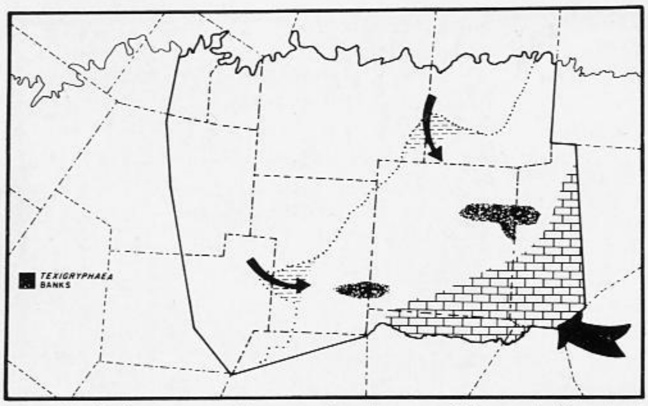


Fig. 53. Paleogeographic map showing conditions at the start of deposition of Member Four. The deposition of Member Four transgressed in a direction almost south to north (large dark arrow). Initial *Texigryphaea* banks (stippled pattern) grew in either shallow bays of carbonate mud or salt marshes. Possible river discharge areas (small dark arrows) contributed fresh water and clay to the bank areas and diluted the normal euhaline water to polyhaline. Transgression proceeded at a uniform rate pushing the paleostrand line northwestward (heavy dotted line) to a position shown in Figure 54.

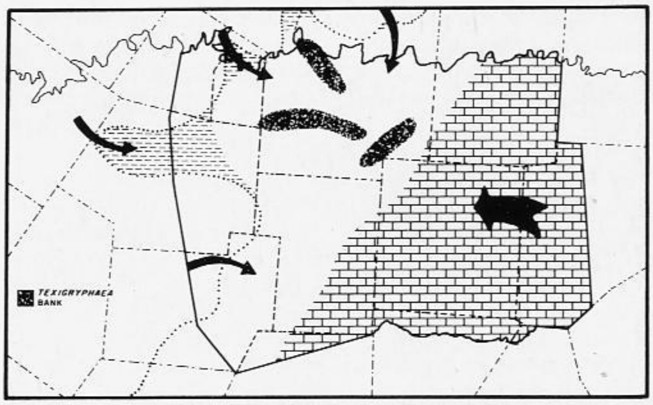


Fig. 54. Paleogeographic map showing conditions during the height of deposition of Member Four. The paleostrand line (heavy dotted line) has retreated following the further transgression of Member Four, creating a large open bay. Three massive banks form (stippled pattern) and are rigidly controlled in development and periodically exterminated by large influxes of fresh water from four rivers (small dark arrows) entering the bay. Stable conditions existed for a long period while Member Five was being deposited toward the south.

480). The *Texigryphaea* valves in the bank have a rather uniform growth rate and the individuals are smooth, dense, and form interlocking groups. A similar situation may be observed in modern banks where the oyster population is sparse due to predators and parasites (Ladd, 1957, p. 622). Deposition during the initial stages of bank growth (Fig. 53) was rapid, as shown by the absence of burrowing organisms. The area around the banks was apparently of low energy as seen by the accumulation of micrite.

As Member Four continued to transgress across the study area the paleo-strand line retreated (Fig. 54). During this late stage of transgression *Texigryphaea* banks established themselves as prominent massive features (Table 5, type 2). This may be inferred by the minimal faunal diversity, absence of evidence of predators and parasites, and the apparent uniform growth rate of the oysters. This situation may be observed in modern banks where the population reaches a maximum, due to high reproductive rate, availability of food, and limitation of predators (Ladd, 1957, p. 622).

The periodic extermination of the banks was apparently caused by large influxes of fresh limnetic water with abundant clay. River discharge may be inferred by clay mineralogy and terrigeneous sand. The major rivers in the northern area (Fig. 54) contributed kaolinitic clay and quartz sand to the banks, whereas in the southern part of the study area illite was being deposited in a nearshore water (Fig. 54).

As Member Four transgressed out of the study area to the northwest, Member Five was being deposited in the south.

With the subsequent transgression of Member Five, salinity conditions in the banks returned to normal euhaline as suggested by the normal marine fauna found

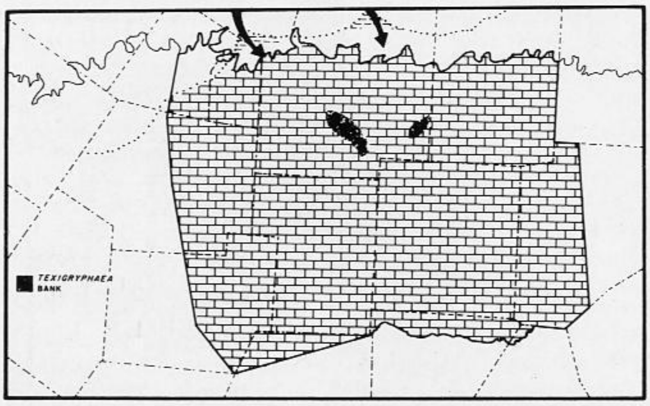


Fig. 55. Paleogeograpic map showing conditions during deposition of Member Five. Transgression took place while the paleostrand line (heavy dotted line) retreated out of the study area. Two small thin banks (stippled pattern) may be seen in Bosque County. Deposition was at a uniformly slow rate. To the east Comanche Peak Limestone was being deposited contemporaneously with Member Five (Fig. 56).

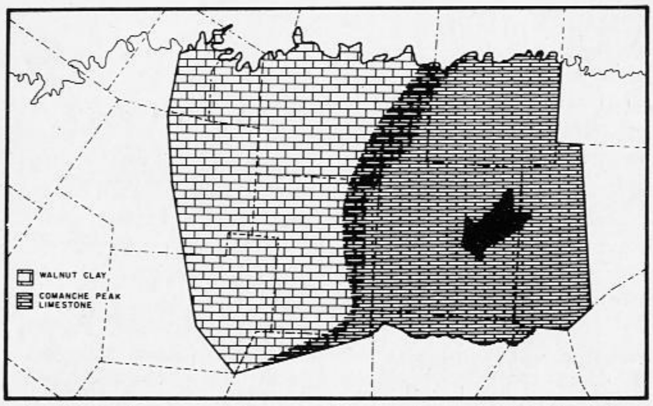


Fig. 56. Paleogeographic map showing the end of Walnut deposition. The end of Walnut deposition resulted from a slow transgression of the Comanche Peak seas. While the Walnut Formation was being deposited in the northern part of the study area (large pattern), the Comanche Peak Limestone (small pattern) was being deposited slowly in the southern area, eventually to cover the Walnut deposits by slow northwestward transgression.

at the top of the highest bank in Member Four. These banks are overlain by ripple-marked limestone and argillaceous limestone of Member Five.

MEMBER FIVE

Member Five represents a transgressive sub-facies of the Walnut Sea (Fig. 55). It was during deposition of Member Five that the banks diminished in size (both thickness and area). This Member has been considered representative of normal marine deposition, in which the water depth increased while becoming less turbulent than that of Member Four (Jones, 1966, p. 179).

During transgression the paleo-strand line retreated and salinity levels approached 30 parts per thousand in the area of the banks (Fig. 54), as shown by the small size of *Texigryphaea* and substantial evidence of predators and/or parasites. The morphology of the individual valves together with the variation of species is indicative of the seaward margins of a modern estuary (Butler, 1954, p. 482). River discharge apparently did not enter the study area, as indicated by clay mineralogy.

Increases in water depth are indicated by the first appearance of planktonic Foraminifera (Appendix 1, Table 7). The small number of planktonic species is critical to the interpretation of *Texigryphaea* banks. It has been shown that planktonic Foraminifera are abundant on the continental slope and abyssal deeps; and may be rare or absent in nearshore environments where benthonic arenaceous Foraminifera dominate the population (Phleger, 1965).

It is in this environment that the *Texigryphaea* banks may have been replaced by *Exogyra* as the dominant bank formers. A similar situation, replacement by new species, has been observed and described in modern oyster banks where during periods of higher than normal salinities *Crassostrea virginica* is replaced by *Ostrea equestris* (Parker, 1955, p. 210; Hofstetter, 1971, p. 115).

END OF WALNUT DEPOSITION

As Member Five was being deposited in the northern part of the study area, Comanche Peak Seas were transgressing northwestward in the southern part (Fig. 56). The transgression apparently was uniform, as indicated by the uniform thickness of Comanche Peak Limestone over the study area. The conformable nature and interfingering of the Walnut Formation and Comanche Peak Limestone confirm a slow uniform rate of transgression.

Of importance is the absence of massive *Texigryphaea* banks in the Comanche Peak Limestone. Comanche Peak Seas were probably normal in salinity (euhaline, 35 parts per thousand) as shown by the abundant and diverse fauna. The absence of ripple marks and other indicators of shallow agitated waters suggests the water depth was greater than the Walnut Seas.

SUMMARY AND CONCLUSIONS

1. In the study area the Walnut Formation crops out in valley floors and low prairies. The maximum thickness exists in Bosque County, and the minimum thickness in the western part of the study area.
2. The Walnut Formation of central Texas may be separated into five numbered members (Table 2) based on lithological similarities and differences.
3. Member One is composed of argillaceous limestone, dark clay, and alternating clay and thin flaggy limestone beds, almost barren of fossils. Member Two consists of alternating clay and thin ripple-marked limestone. Member Three is composed of argillaceous nodular limestone beds. Member Four consists of argillaceous nodular limestone with thin calcareous clay units characterized by massive *Texigryphaea mucronata* banks. Member Five is composed of calcareous clay beds with horizontal burrows and argillaceous limestone.
4. The lower contact of the Walnut Formation with the Paluxy Sand ranges from conformable to unconformable. Where the Paluxy Sand is composed of dipping truncated beds overlain by horizontal Walnut beds of Member Two the contact is unconformable, though erosional hiatus is very slight. Where beds of the Walnut Formation overlie the horizontal beds of the Paluxy Sand, the contact appears conformable.
5. The upper contact with the Comanche Peak Limestone is conformable and gradational, with Walnut and Comanche Peak facies interfingering in Member Five.
6. The Walnut Formation represents a time transgressive unit over the study area. The overall direction of transgression across the study area was northwestward.
7. Deposition of the Walnut Formation was continuous; however, it did not take place at a uniform rate. Member Two represents rapid transgression, whereas Member Five represents slow transgression.
8. Member One represents a nearshore deposit in the western part of the study area and a restricted lagoonal deposit in the eastern part of the study area. Member Two represents a major rapid transgressive sequence. Member Three was deposited in a stable, low energy, shallow marine environment with possible regression occurring at the end of Member Three. Member Four represents a turbulent transgressive sub-facies of the Walnut Formation in which a large shallow bay formed in the northeastern part of the study area. Member Five represents a return to the stable conditions of uniform marine deposition.
9. The oyster banks of Member One crop out in the western part of the study area (Fig. 12). In Member Two the oyster banks are best exposed in eastern Bosque County (Fig. 13). The oyster banks of Member Three are exposed in Bosque, Somervell, Hamilton, Mills, and Coryell Counties

(Fig. 14). It is with Member Four that the oyster banks reach their maximum distribution (Fig. 15). In Member Five the oyster banks once again become restricted (Fig. 16).

10. *Texigryphaea mucronata* banks in the Walnut Formation underwent evolution in geographic distribution and ecological development during the deposition of Members One, Two, Three, Four, Five.
11. The limited variety of the fauna in the *Texigryphaea* banks are representative of estuarine conditions.
12. The periodic influx of oligohaline or euhaline waters into the oyster banks caused temporary destruction of pelecypod growth.
13. The depositional history of the Lower Fredericksburg Group may be summarized in central Texas. The Paluxy Sand was in part subaerially exposed, and over this Member One of the Walnut Formation was deposited. Member Two rapidly transgressed over Member One and the remainder of the Paluxy Sand while Member Three was being deposited outside the study area. Member Three transgressed throughout the area then followed a period of regression ending with the transgressive fluctuating conditions of Member Four. Member Five represents uniform largely marine deposition while the Comanche Peak Limestone was being contemporaneously deposited. Walnut deposition ended with deposition of the marine Comanche Peak Limestone over the entire area.

APPENDIX 1

One of the difficulties in utilizing microfauna is the problem of justifying similar ecological niches for similar genera and species, widely separated in time. Recent genera, however, have probably descended from Cretaceous relatives with similar habits. Consequently, if certain genera of recent foraminifers or ostracodes live in brackish waters, and similar genera are found in Cretaceous rocks, the Cretaceous genera probably inhabited brackish waters also. If an assemblage consisting of several forms of brackish water ostracodes and foraminifers is found in Cretaceous rocks, there is considerably more reason to infer a brackish water environment. This philosophy guided the present investigation.

A study of the microfauna of the Walnut Formation had as its original purpose the interpretation of microenvironments below the oyster banks, in the oyster banks, and the sediments above the banks. Samples were collected for each of these intervals at a number of localities in each member. Differences in rock type necessitated various methods of preparation (Appendix 2). Distribution and abundance of microfossils for all members are shown in Table 7.

MEMBER ONE

The limited number of microfossils identified from the limestone and clay of Member One may be the result of ineffective breakdown techniques (Appendix 2). However, abundance and variety were adequate to establish a general zonation of microfossils as seen in Table 7.

The assemblage concentrated in the *Texigryphaea* banks (specifically *Cytherella scotti* and *Cytherella comanchensis*) represents genera of distinct brackish mesohaline zones (Van Morkhoven, 1963, p. 18). The species of *Textularia rioensis* may be indicative of a genus found in lagoons (Phleger, 1965, p. 152). The remaining species may be found in mesohaline to euhaline zones.

The microfossils collected in the surrounding sediments are indicative of marginal marine environments. Four of the species (*Barkerina barkerensis, Dictyoconus walnutensis, Textularia rioensis, Cytheropteron howelli*) include modern genera representative of marginal environments (Treatise Invert. Paleo, 1964; Phleger, 1965). Modern forms of the other fauna may be representative of euhaline zones.

MEMBER TWO

Although diversity increased in Member Two, it took place chiefly through increase in abundance of ostracodes. A general zonation of microfossils may be seen in Table 7.

The assemblage found in the *Texigryphaea* banks is indicative of lagoon, estuary, salt-marsh, or marine marsh environments. The presence of *Haphlophragmoides globosus,* and *Trochammina* sp. suggests estuarine and salt marsh (Phleger, 1965, p. 153; Murray, 1973, p. 27). The ostracodes *Cythere concentrica, Cytherella comanchensis, Cytherella scotti,* and *Cytheropteron howelli* have modern genera adapted to brackish water environments (Van Morkhoven, 1963, p. 18, 101; Treatise Invert. Paleo. 1964, p. Q 292).

The microfossils collected in the surrounding sediments are indicative of warm shallow (less than five meters) epicontinental seas. In these sediments benthonic foraminifers replace ostracodes in abundance and diversity.

MEMBER THREE

In this member microfossils were poorly preserved and in some cases it was necessary to use mechanical disintegration. Foraminifera were well rounded and difficult to identify, due to the mechanical abrasion. No distinct zonation appeared to distinguish microfossils found in *Texigryphaea* banks and those found in surrounding sediments; however, *Barkerina barkerensis* and *Cytheropteron howelli* were more abundant in the banks than any other microfossil. Taken as an entity, the entire faunal assemblage represents an inner-neritic shallow (five-ten meters) marine sequence.

MEMBER FOUR

Preservation of microfossils in *Texigryphaea* banks was excellent; however, they were poorly preserved in the indurated crystalline limestone. Although foraminifers increased in diversity in Member Four, ostracodes were more abundant in the banks. A distinct micro zonation was apparent (Table 7).

The assemblage found in the banks have related modern genera indicative of lagoon or estuarine conditions. The presence of *Ammobaculites subcretaceus, Haplophragmoides globosus,* and *Trochammina* sp. have modern relatives inhabiting estuaries and lagoons (Phleger, 1965; Murray, 1973). The foraminifers *Ammobaculites* is indicative of the upper reaches of an estuary (Murray, 1973, p. 40) and *Haplophragmoides* sp. is indicative of hyposaline marsh conditions (Murray, 1973, p. 27). The ostracode *Cytheridea truncata* has modern related genera inhabiting brackish waters (Van Morkhoven, 1963, p. 276) with *Cythere* sp. being able to tolerate salinities as low as 10 parts per thousand (Van Morkhoven, 1963, p. 101).

The assemblage found in the surrounding sediments appears to be indicative of shallow inner-neritic marine waters. The foraminifers are more abundant than the ostracodes, although both are poorly preserved. The presence of *Lenticulina* and *Lingulina* sp. is indicative of normal euhaline zones, and the ostracodes *Cytheropteron howelli* and *Paracypris dentonensis* are shallow euhaline indicators.

MEMBER FIVE

Maximum diversity appeared in Member Five and the microfossils were well preserved. A distinct zonation of the Foraminifera and ostracodes could be observed between the *Texigryphaea* banks and the surrounding sediments (Table 7).

The assemblage found in the banks has related modern genera living in lagoons or estuaries. *Ammobaculites, Haplophragmoides,* and *Trochamminoides* may be found in modern lagoons and estuaries (Phleger, 1965; Murray, 1973). The ostracodes are indicative of salinity conditions of 10 parts per thousand to 25 parts per thousand.

TABLE 7. DISTRIBUTION AND ABUNDANCE OF MICROFAUNA, WALNUT CLAY, CENTRAL TEXAS.

MICROFOSSIL	MEMBER ONE		MEMBER TWO		MEMBER THREE		MEMBER FOUR		MEMBER FIVE	
	Texigryphaea banks	Surrounding sediments	*Texigryphaea* banks	Surrounding sediments	*Texigryphaea* banks	Surrounding sediments	*Texigryphaea* banks	Surrounding sediments	*Texigryphaea* banks	Surrounding sediments
FORAMINIFERA										
Ammobaculites subcretaceus Cushman and Alexander							A		A	
Barkerina barkerensis Frizzell and Schwartz	C	A	R	A	C	R	R	A	R	A
Bolivia textularioides Reuss								R		R
Buccicrenata subgoodlandensis Vanderpool								R		R
Citharina intumescens Reuss		A		A		C		A		A
C. kochii Roemer										R
C. recta Reuss										C
Dentalina cucumis Loeblich and Tappan										R
D. striatifera Tappan										C
Dictyoconus walnutensis Carsey		A	R	A				A		R
Discorbis floscula Loeblich and Tappan							C		C	
D. minima Viezux							C		R	
Flabellammina alexanderi Cushman				C		R				R
Globigerina washitaensis Carsey										C
Guttulina symploca Loeblich and Tappan		A		A		C				C
Haplophragmoides globosus Lozo			A				A		A	
Lagena apiculata Reuss										A
Lenticulina gaultina Berthelin								A		A
L. sp.								A		
Lingulina furcillata Berthelin										A
L. sp.								A		
Marginulina texasensis Cushman										C
Neobulimina minima Tappan										C
Nodophthalmidium pyriforme Tappan										A
Nodosaria ithystoecha Loeblich and Tappan								C		C
N. paupercula Reuss										C
Patellina subcretacea Cushman and Alexander			R	C				C		R
Pseudopolymorphia plectilis Loeblich and Tappan										R
Quinqueloculina minima Tappan										C
Textularia rioensis Carsey	C	C	C	R				C	C	C
Trochammina sp.			R				A			
Trochamminoides coronus Loeblich and Tappan			R				R		A	
Turrispirillina subconica Tappan										C
Verneuilinoides schizeus Cushman and Alexander			C	R				R		R
OSTRACODA										
Bythocypris goodlandensis Alexander						R				C
Cythere concentrica Reuss			A				C		C	
Cythereis fredericksburgensis Alexander	R	C		C		R				C
C. mahonae Alexander					R					A
C. worthensis Alexander					R					C
Cytherella austinensis Alexander						R				R
C. comanchensis Alexander	A		A				C		C	
C. scotti Alexander	A		A				C		C	
Cytherelloidea sp.								C		R
Cytheridea truncata Berry							A		C	
Cytheropteron howelli Alexander	R	C	R	C	R	C		A		R
Eocytheropteron tumidum Alexander										R
Paracypris alta Alexander										C
P. dentonensis Alexander						R		A		C
P. pulchella Alexander										C
Schuleridea oliverensis Alexander						R				C
S. washitaensis Alexander										C

A — More than 25/ 50 cm²
C — More than 5/ 50 cm²
R — Less than 5/ 50 cm²

The assemblage found in the surrounding sediments has modern counterparts inhabiting shallow inner-neritic waters. Foraminifera are both more diverse and more abundant than ostracodes. The presence of the planktonic foraminifers *Globigerina washitensis* only in the upper units of Member Five indicates a change to deeper waters where planktonic foraminifers are more abundant (Phleger, 1965).

APPENDIX 2

PETROGRAPHY

The standard methods for making thin sections were utilized in this study. This involved cutting the sample into "chips," polishing the "chips," mounting on a petrographic slide, and making a thin section for examination under direct and polarized light.

MICROFAUNA

Because of lithologic differences among samples, various methods were utilized in the breakdown of samples for study. Samples included dark to black shale, calcareous clay, nodular marly limestone, and indurated crystalline limestone. Methods used for each of these rock types are summarized below.

DARK SHALES

The method of breakdown for these samples produced excellent results in a minimum of time. The sample first was mechanically broken into pieces about 2 mm square, then placed in an oven at 150° C (300° F) for 4 to 5 hours. Following this the sample was placed in a beaker with kerosene and allowed to soak overnight (10 hours). The kerosene was decanted, water added, and allowed to soak four to six hours. Complete disintegration took place and the samples were washed through standard Tyler screens. The residue was dried in an oven at 100° C (212° F) for one hour, then stored in glass vials to await study.

CALCAREOUS CLAY AND NODULAR LIMESTONE

The samples were crushed into fragments ranging in size from 0.5 to 2 mm. Following this they were oven dried at 150° C (300° F). The dried samples were then placed in beakers filled with kerosene and allowed to soak overnight (10 hours). The kerosene was decanted and the samples were placed in a boiling solution of 50% Na_2CO_3 in water and boiled until substantial disintegration occurred. They were then washed through standard Tyler screens and the residue oven dried at 100° C (212° F) and placed in glass vials to await further study. The degree of disintegration with this method ranged from 50% to 80% and, unfortunately, many microfossils were ultimately destroyed in the process.

INDURATED CRYSTALLINE LIMESTONE

The samples were first crushed into fragments to pass through No. 10 Tyler screen, then oven dried at 150° C (300° F) for 48 hours. The samples were then placed in a beaker of solution A composed of the following:

5cc sodium carbonate
2cc Nacconol (an alkyl sulphonate)
400cc water (tap)

and allowed to soak overnight (10 hours). Following this the sample and solution A were "rolled" on a hobby rock tumbler. If insufficient disintegration occured, a second method was utilized.

The samples were oven dried at 150° C (300° F) for 48 hours. Following this the sample was placed in a beaker of boiling Varsol for 15 minutes. The Varsol was decanted, water added and the sample soaked for four hours. If disintegration was still unsatisfactory a third method was utilized.

The samples were oven dried at 150° C (300° F) for 48 hours. The samples were then immersed in solution A and placed in a Waring blender with special steel plates and agitated for five minutes. Following this the disintegrated sample was washed through standard Tyler screens, oven dried at 100° C (212° F) and stored in glass vials to await further study.

Due to the nature of the indurated crystalline limestone microfossil recovery was poor. The microfossils that were recovered were fragmented and lacked ornamentation which made identification difficult. The mechanical breakdown method was utilized as a last resort after other methods had failed.

IDENTIFICATION

Reference sources included the Treatise on Invertebrate Paleontology and miscellaneous publications on local studies referred to in the text of this study. Of particular advantage was the utilization of selective staining, thin sectioning, and photography, for comparison to figured specimens in the literature.

STAINING

Common food colors were used as stains in bringing out details of forminiferal tests and ostracod carapaces. The best results were obtained using a green dye. A few drops of the color were placed in a watch glass and the water allowed to evaporate. Following this a moist 0000 pure red sable brush was dipped into the concentrated residue and applied directly to the fossil. This stained the recessed areas and aided in the identification of apertures, and muscle scars.

THIN SECTIONING

Because of the minute dimensions of microfossils, useful thin sections are difficult and time consuming to make, yet they are sometimes necessary in identification procedures. To prepare comparison sections, five samples of the same species were selected and placed on a pre-heated microscope slide coated with liquid Lakeside cement. The samples were randomly oriented to provide five different views. After the Lakeside solidified the slide was placed under a binocular microscope and using a frosted glass slide the specimens were ground down manually to one-fourth the original thickness, then the slide was placed on a hot plate, the specimens were turned over and recemented. They were again ground down so only one-fourth to one-half the original thickness remained. For identification it was necessary to utilize indirect lighting from the substage of the microscope.

Photography

Photographic methods aided the microfaunal study by providing clear illustrations for comparison with figured forms from the literature. Three cameras were used: a 35mm single lens reflex camera fitted with a commercially available microscope adapter for general photography, an Olympus PM7 for photography under the microscope, and a Graflex 2¼ x 3¼ sheet film camera fitted with a homemade microscope adaptor for extreme magnification. The film was processed to assure uniform results and 8- x 10-inch prints were made of species whose identification was in doubt. Photographic prints were used in direct identification and for cross reference in library research. The best results were obtained with the Graflex; however, because of cost its use was limited to extremely small foraminifers that required high resolution and great (8- x 10-inch) enlargement. In the case of the thin sections, indirect lighting was used from the substage of the microscope. Specimen photography utilized direct lighting with the more powerful light positioned at N 45° W and the fill-in light of lower illumination at S 45° E.

APPENDIX 3

Locality 100. Bosque County (31°43'N; 97°35'W). Walnut Clay, Member Four. Four-foot *Texigryphaea* ledge exposed in bar ditch 0.1 mile north on dirt road from intersection with Farm Road 2602, 1.5 miles west from its intersection with State Highway 6.

Locality 101. Bosque County (31°43'N; 97°42'W). Walnut Clay, Member Four. Excellent exposure consisting of ripple-marked dense limestone overlain by *Texigryphaea* banks, and nodular limestone. Exposed in Neil's Creek, 2.5 miles west of Crossroads Store on Farm Road 219, and 0.5 mile south on dirt road.

Locality 102. Bosque County (31°44'N; 97°39'W). Walnut Clay, Member Four. Excellent exposure of 20 feet of *Texigryphaea* banks. The banks alternate in thickness with interlaminations of thin clay units. Exposed in banks of Gary Creek on Farm Road 219, 0.9 mile northeast of Crossroads Store.

Locality 103. Bosque County (31°41'N; 97°32'W). Walnut Clay, Member Five. Exposure contains normal marine faunal assemblage of *Exogyra, Tylostoma, Turritella, Enallaster, Pecten,* and small bored *Texigryphaea.* Exposed in hills on southwest side of State Highway 6, 3.8 miles from the intersection with State Highway 56 at Valley Mills.

Locality 104. Bosque County (31°41'N; 97°28'W). Walnut Clay, Member Five. Consists of nodular Comanche Peak type limestone, clay and thin *Texigryphaea* banks. Exposed in bar ditch at the intersection of Farm Road 56, and Farm Road 2704, 1.5 miles north of Valley Mills.

Locality 105. Bosque County (31°46'N; 97°37'W). Walnut Clay, Member Five. Consists of two one-half foot oyster banks exposed in road cut on Farm Road 219, 2.6 miles northwest of Clifton, 0.7 mile east of Turkey Creek.

Locality 106. Bosque County (31°44'N; 97°44'W). Walnut Clay, Member Five. Exposure contains one-half foot *Texigryphaea* bank in bar ditch 10.2 miles northwest of Clifton on Farm Road 219, 1.6 miles east of the Boggy Cemetery.

Locality 107. Bosque County (31°44'N; 97°43'W). Walnut Clay, Member Five. Exposure contains oyster banks interlaminated with clay units. Exposed in road cut 0.6 mile east of the Boggy Cemetery on Farm Road 219.

Locality 108. Hamilton County (31°48'N; 97°52'W). Walnut Clay, Member Five. Exposure consists of a one-half foot oyster bank. Exposed in bar ditch on west side of Farm Road 219, 4.4 miles northwest from its intersection with State Highway 22.

Locality 109. Hamilton County (31°49'N; 97°53'W). Walnut Clay, Member Five. Exposure consists of one scattered oyster bank. Exposed in bar ditch on west side of Farm Road 219, 6.1 miles northwest from its intersection with State Highway 22.

Locality 110. Hamilton County (31°50'N; 97°55'W). Walnut Clay, Member Five. Exposure contains thin *Texigryphaea* bank. Exposed in bar ditch on east side of Farm Road 219, 8.4 miles northwest from its intersection with State Highway 22.

Locality 111. Hamilton County (31°51'N; 97°58'W). Walnut Clay, Member Five. Exposure consists of one oyster bank with normal marine fossils. Exposed in bar ditch on north side of Farm Road 219, 11.6 miles northwest from its intersection with State Highway 22, 0.4 mile east of Fairy.

Locality 112. Hamilton County (31°51'N; 98°02'W). Walnut Clay, Member Five. Exposure consists of two-inch oyster banks interlaminated with thick clay units. Exposed in road cut on the east side of Farm Road 219, 3.7 miles northwest of Fairy.

Locality 113. Erath County (31°57'N; 98°12'W). Walnut Clay, Member Five. Exposure consists of thin oyster banks with abundant normal marine fossils. Exposed in bar ditch on both sides of Farm Road 219, 5.8 miles southeast of Purves.

Locality 114. Erath County (32°06'N; 98°18'W). Walnut Clay, Member Five. Exposure contains hard indurated limestone ledge with abundant normal marine fossils. Exposed in road cut on south side of Farm Road 847, 1 mile northeast of Dublin.

Locality 115. Erath County (32°05'N; 98°16'W). Walnut Clay, Member Four. Exposure contains three small lenticular banks with clay interlaminations. Exposed in banks of Cottonwood Creek, 9.4 miles east of Dublin on State Highway 6.

Locality 116. Erath County (32°06'N; 98°15'W). Walnut Clay, Member Five. Exposure consists of hard indurated limestone. Exposed in bar ditch 3 miles west on dirt road from White Chapel.

Locality 117. Erath County (32°12'N; 98°07'W). Walnut Clay and Paluxy Sand, Member Two. Exposure consists of four feet of extremely small *Texigryphaea* overlying dipping beds of Paluxy Sand. Exposed in road cut on U. S. Highway 67, 6.9 miles southeast of Stephenville.

Locality 118. Somervell County (32°18'N; 97°52'W). Walnut Clay, Member Four. Exposure consists of oyster ledges interlaminated with thin clay units. Exposed in bar ditch 0.7 mile on dirt road east of Oden Chapel, 0.7 mile west on dirt road from intersection with Farm Road 204, 3.1 miles southeast from intersection with U. S. Highway 67.

Locality 119. Bosque County (32°04'N; 97°47'W). Walnut Clay, Member Four. Exposure consists of massive *Texigryphaea* banks with thin interlaminations of clay. Exposed 100 feet on west side of dirt road, 1.7 miles northeast of Walnut Springs.

Locality 120. Bosque County (31°48′N; 97°49′W). Walnut Clay. Member Four. Exposure consists of nodular limestone and *Texigryphaea* banks. Exposed in bar ditch on southwest side of State Highway 22, 1.95 miles northeast of Cranfills Gap.

Locality 121. Bosque County (31°49′N; 97°48′W). Walnut Clay, Members Two and Three. Consists of hard ripple-marked limestone and tan nodular limestone with thin *Texigryphaea* beds. Exposed in banks of Mustang Creek, southwest side of State Highway 22, 3.4 miles northwest of intersection with Farm Road 219 at Cranfills Gap.

Locality 122. Bosque County (31°48′N; 97°47′W). Walnut Clay, Members Two, Three, and Four. Consists of clay, nodular limestone, and *Texigryphaea* banks. Exposed in banks of Camfield Branch, 4.2 miles northeast on State Highway 22 from intersection with Farm Road 219.

Locality 123. Bosque County (32°06′N; 97°48′W). Walnut Clay, Member Four. Massive *Texigryphaea* bank exposed in bottom of Mustang Creek, 4.0 miles northwest of Farm Road 203 from intersection with State Highway 144 at Walnut Springs, 1.6 miles southeast and southwest on gravel road.

Locality 124. Bosque County (32°04′N; 97°45′W). Walnut Clay, Member Four. Massive oyster bank exposed in Steele Creek, 0.5 mile southwest on gravel road to Flat Top Ranch from State Highway 144 at Walnut Springs.

Locality 125. Bosque County (32°02′N; 97°41′W). Walnut Clay, Members Three and Four. Massive oyster bank exposed in bottom of Steele Creek, 4.4 miles southeast on Farm Road 927 from intersection with State Highway 144 at Walnut Springs, 0.3 mile southwest over railroad tracks on gravel road, 0.5 mile northwest on gravel road, 0.2 mile southwest on gravel road in pasture to creek.

Locality 126. Bosque County (32°11′N; 97°37′W). Walnut Clay, Member Two, and Paluxy Sand. Exposed in road cut 1.1 miles southeast from Brazos Point on Farm Road 56. Measured section 18 of Jones (1966).

Locality 127. Bosque County (31°53′N; 97°39′W). Walnut Clay, Members Three and Four. Consists of nodular limestone, dark clay, and *Texigryphaea* ledges. Exposed in banks of Dyes Branch where it crosses U. S. Highway 6, 2.8 miles from intersection with State Highway 22.

Locality 128. Hamilton County (31°49′N; 97°56′W). Walnut Clay, Member Four. *Texigryphaea* ledge exposed in valley 3.2 miles southwest on Farm Road 219 from its intersection with Farm Road 1602, southwest on gravel road 1.3 miles, southeast 0.7 mile on gravel road.

Locality 129. Comanche County (31°44′N; 98°27′W). Walnut Clay, Members Four and Five. Consists of clay, nodular limestone, and *Texigryphaea* ledges. Exposed in road cut of Cowhouse Mountain, 0.25 mile north on gravel road from intersection with Farm Road 2561.

Locality 130. Coryell County (31°18′N; 97°49′W). Walnut Clay, Members Four and Five. Composed of nodular limestone and *Texigryphaea* banks. Exposed in road cut and tank trail on side of Stampede Mountain, asphalt road on Fort Hood Reservation, 10.2 miles from its intersection with State Highway 36.

Locality 131. Coryell County (31°30′N; 97°51′W). Walnut Clay, Member Five. Thin *Texigryphaea* bank exposed in road cut on Farm Road 116, 7.4 miles from its intersection with U. S. Highway 84.

Locality 132. Coryell County (31°28′N; 97°49′W). Walnut Clay Paluxy Sand contact. Contains normal marine fossils in the Walnut Clay. Exposed in road cut on Farm Road 2412, 4.9 miles northwest from its intersection with U. S. Highway 84.

Locality 133. Lampasas County (31°06′N; 97°57′W). Walnut Clay, Member Five. *Texigryphaea* bank consisting of small individuals. Exposed in road cut 1.4 miles west on U. S. Highway 190 from county line.

Locality 134. Mills County (31°43′N; 98°31′W). Walnut Clay, Members One and Two, and Paluxy Sand. Contains horizontal burrows and *Exogyra* banks. Exposed in road cut, 3.4 miles north of Priddy on State Highway 16.

Locality 135. Coryell County (31°11′N; 97°46′W). Walnut Clay, Member Two, and Paluxy Sand. Exposed in ditch on west side of asphalt road 4.5 miles northeast of gravel road to Copperas Cove on Fort Hood Reservation.

Locality 136. Bosque County (31°48′N; 97°35′W). Walnut Clay, Members Three and Four. Exposed in Bosque River at low water dam, 0.9 mile northwest on U. S. Highway 6, from Clifton and 0.5 mile northeast on gravel road.

Locality 137. Bosque County (31°40′N; 97°28′W). Walnut Clay, Member Four. Exposed in Bosque River, 1 mile downstream from where it crosses Farm Road 56.

Locality 138. Bosque County (31°59′N; 97°46′W). Walnut Clay, Member Two, and Paluxy Sand. Exposed in bar ditch on dirt road 2.4 miles north from State Highway 6.

Locality 139. Bosque County (32°01′N; 97°49′W). Walnut Clay, Member Two, and Paluxy Sand. Exposure consists of dipping Paluxy Sand overlain by horizontal beds of Walnut Clay. Exposed in road cut 9.8 miles on Farm Road 927 from Walnut Springs.

Locality 140. Comanche County (31°55′N; 98°42′W). Edwards Limestone, Comanche Peak Limestone, and Walnut Clay, Members Two, Three, Four, and Five. Exposed in quarry, 450 yards southwest of Farm Road 1689, 4.7 miles northeast on Farm Road 1689 from intersection with State Highway 36 at Comanche. Measured section 6 of Jones (1966).

Locality 141. Comanche County (31°53′N; 98°41′W). Walnut Clay, Members One, Two, Three, and Paluxy Sand. Exposed in road cut on U. S. Highway 67, 3.5 miles southwest of Comanche. Measured section 7 of Jones (1966).

Locality 142. Mills County (31°42′N; 98°31′W). Walnut Clay, Members One, Two, Three, Four, Five, and Paluxy Sand. Road cut on State Highway 16, 1.9 miles north of Priddy. Measured section 8 of Jones (1966).

Locality 143. Comanche County (31°44′N; 98°39′W). Walnut Clay. Exposed in hills 3.6 miles north of Democrat on Farm Road 573.

Locality 144. Comanche County (31°44′N; 98°26′W). Walnut Clay Paluxy Sand contact. Exposed in road cut on Farm Road 2561, 2.6 miles from Newburg.

Locality 145. Hamilton County (31°33′N; 98°20′W). Walnut Clay, entire section. Exposed in north bank of Lampasas River where bridge on Farm Road 1047 crosses the river. Measured section 9 of Jones (1966).

Locality 146. Coryell County (31°28′N; 98°06′W). Walnut Clay, Members Four and Five. Exposed in road cut 2.8 miles east on U. S. Highway 84 from intersection with U. S. Highway 281. Measured section 10 of Jones (1966).

Locality 147. Hamilton County (31°32′N; 98°12′W). Walnut Clay, Members Three, Four, and Five. Exposed in road cut 11.3 miles southwest of Hamilton on U. S. Highway 281 from intersection with State Highway 36, 4.2 miles northwest on gravel road.

Locality 148. Hamilton County (31°30′N; 98°13′W). Walnut Clay, Members Four and Five. Consists of massive *Texigryphaea* banks consisting of small individuals. Exposed in ditch on dirt road 4.3 miles west on U. S. Highway 281 at Evant, and 1.4 miles northwest on dirt road.

Locality 149. Hamilton County (31°30′N; 98°19′W). Walnut Clay, Members Four and Five. Thin *Texigryphaea* bank exposed on west side of road, 1.8 miles north of intersection with U. S. Highway 84 at Star.

Locality 150. Hamilton County (31°38′N; 98°03′W). Walnut Clay, Member Two. Ripple-marks exposed in Mustang Creek, 0.5 mile northwest of Aleman on Farm Road 932 and 0.6 mile southwest on gravel road.

Locality 151. Hamilton County (31°55′N; 98°0.5′W). Walnut Clay and Paluxy Sand contact. Exposed in road cut southwest of U. S. Highway 281, 5.5 miles from its intersection with State Highway 6 at Hico.

Locality 152. Hamilton County (31°45′N; 97°57′W). Walnut Clay, Member Five. Clay and nodular limestone exposed in ditch 0.9 mile southeast on Farm Road 1602 from intersection with State Highway 22.

Locality 153. Coryell County (31°09′N; 97°54′W). Walnut Clay, entire section. Exposed in valley of House Creek, 1.4 miles north on Farm Road 116 from intersection with Farm Road 113 at Copperas Cove. Measured section 11 of Jones (1966).

Locality 154. Coryell County (31°15′N; 97°35′W). Walnut Clay, Members Four and Five, and Comanche Peak Limestone. Exposed in banks of Owl Creek, 1.9 miles east from Cold Springs, Fort Hood Reservation. Measured section 12 of Jones (1966).

Locality 155. Lampasas County (31°18′N; 98°04′W). Walnut Clay, Member Five. Tan nodular limestone exposed in quarry 0.3 mile southwest from intersection at Izoro with Farm Road 1690.

Locality 156. Hamilton County (31°43′N; 98°08′W). Walnut Clay and Paluxy Sand contact. Exposed in road cut in Hamilton where State Highway 36 and Farm Road 218 intersect.

Locality 157. Coryell County (31°05′N; 97°55′W). Walnut Clay, Member One, and Paluxy Sand contact. Exposed in bar ditch 2.0 miles south on dirt road from U. S. Highway 190 and dirt road is 0.5 mile southwest from intersection of Farm Road 116 and U. S. Highway 190.

Locality 158. Coryell County (31°10′N; 97°55′W). Walnut Clay, Member One, and Paluxy Sand contact. Exposed in quarry on west side of Farm Road 116, 4.0 miles north of intersection with U. S. Highway 190 at Copperas Cove.

Locality 159. Coryell County (31°23′N; 97°47′W). Walnut Clay, Member Five. Consists of dense ripple-marked limestone with abundant marine fossils. Exposed in road cut 3.0 miles southwest on Farm Road 116 from its intersection with U. S. Highway 84.

Locality 160. Coryell County (31°26′N; 97°47′W). Walnut Clay, Member Two, and Paluxy Sand contact. Exposed in banks of Dodd Branch, 0.4 mile west on U. S. Highway 84 from intersection with Farm Road 116.

Locality 161. Coryell County (31°34′N; 97°50′W). Walnut Clay, Member Five, composed of dense limestone with abundant marine fossils. Exposed in ditch 3.7 miles southeast on State Highway 36 from intersection with Farm Road 1602.

Locality 162. Coryell County (31°36′N; 97°50′W). Walnut Clay, Member Four. Small *Texigryphaea* bank exposed in bar ditch along gravel road, 2.2 miles southeast on State Highway 36, 0.9 mile on gravel road.

Locality 163. Coryell County (31°30′N; 97°49′W). Walnut Clay, Member Five, and Comanche Peak contact. Exposed in road cut 3.5 miles northeast on State Highway 36 from intersection with U. S. Highway 84.

Locality 164. Coryell County (31°33′N; 97°45′W). Walnut Clay, Member Five, exposed in ditch on Farm Road 182, 5 miles south from Turnersville.

Locality 165. Coryell County (31°29′N; 97°44′W). Walnut Clay, Member Two, pararipples exposed in bar ditch 3.4 miles northwest on State Highway 36 from its intersection with U. S. Highway 84.

Locality 166. Coryell County (31°29′N; 97°49′W). Walnut Clay, Member Four. Massive oyster bank composed of small *Texigryphaea*. Exposed in road cut, 0.4 mile northeast from its intersection with State Highway 36, 3.5 miles northwest from U. .S Highway 84.

Locality 167. Coryell County (31°19′N; 97°39′W). Walnut Clay, Member Four, *Texigryphaea* bank exposed in bar ditch at intersection of State Highway 36 and Farm Road 1829.

Locality 168. Coryell County (31°19′N; 97°50′W). Walnut Clay Members Three and Four. Exposed in bank of Henson Creek where East Range Road crosses at low water crossing, Fort Hood Reservation.

Locality 169. Coryell County (31°15′N; 97°37′W). Walnut Clay, Member Four. *Texigryphaea* bank consisting of small individuals cemented in a micrite matrix. Exposed in banks of Owl Creek, 0.3 mile northwest on gravel road from Cold Springs.

Locality 170. Coryell County (31°15′N; 97°40′W). Walnut Clay, Member Four *Texigryphaea* bank exposed in bar ditch on gravel road on Fort Hood Reservation.

Locality 171. Coryell County (31°25′N; 97°36′W). Walnut Clay, Member Four. Three *Texigryphaea* banks exposed in banks of Coryell Creek at the intersection with U. S. Highway 84.

Locality 172. Coryell County (31°24′N; 97°35′W). Walnut Clay, Member Five, and Comanche Peak contact. Exposed in road cut 2.8 miles east on Farm Road 107 from intersection with Farm Road 1829.

Locality 173. Somervell County (32°11′N; 97°52′W). Walnut Clay Members Two, Three, Four, and Five. Exposed in road cuts along U. S. Highway 67, 2.6 miles from intersection with Farm Road 203.

Locality 174. Bosque County (32°05′N; 97°51′W). Walnut Clay, Member Two, and Paluxy Sand contact. Exposed in Aerena Lake spillway on Flat Top Ranch, 6.5 airline miles northwest of Walnut Springs.

Locality 175. Erath County (32°15′N; 98°09′W). Walnut Clay, Member Four. *Texigryphaea* bank exposed in road cut 2.5 miles northeast on U. S. Highway 377 from its intersection with U. S. Highway 281.

Locality 176. Erath County (32°12′N; 98°07′W). Walnut Clay, Member Two, and Paluxy Sand contact. Exposed in road cut in Indian Creek, 3.5 miles southeast on U. S. Highway 67.

Locality 177. Erath County (32°08′N; 98°01′W). Walnut Clay, Member Two. Exposed in road cut 1.4 miles south of Johnsville on gravel road.

Locality 178. Erath County (32°06′N; 97°58′W). Walnut Clay, Members Two and Three. Exposed in road cut on State Highway 220, 4.3 miles from its intersection with U. S. Highway 67.

Locality 179. Bosque County (31°48′N; 97°48′W). Walnut Clay, complete section exposed along south banks of Meridian Creek where dirt road crosses creek at low water crossing, 3.2 miles northwest on State Highway 22 from intersection with Farm Road 219, southwest on dirt road 1.1 miles. Measured section 14 of Jones (1966).

Locality 180. Bosque County (31°52′N; 97°39′W). Walnut Clay, Member Five, and Comanche Peak Limestone contact. Exposed in road cut on State Highway 6, 1.5 miles southeast of Meridian.

Locality 181. Bosque County (32°03′N; 97°31′W). Walnut Clay, Members Two, Three, and Four, exposed in banks of Mesquite Creek 2.3 miles northwest of intersection of Farm Road 56 and Farm Road 927.

Locality 182. Bosque County (32°00′N; 97°29′W). Walnut Clay, Member Five. Exposed in banks of Steele Creek where bridge on Farm Road 56 crosses the creek.

Locality 183. Bosque County (31°48′N; 97°46′W). Walnut Clay, Member One, and Paluxy Sand contact. Exposed in banks of Meridian Creek, 3.6 miles northeast on gravel road from its intersection with State Highway 22.

Locality 184. Bosque County (31°50′N; 97°46′W). Walnut Clay, Member Five, exposed in road cut 5.2 miles northeast on State Highway 22 from intersection with Farm Road 219.

Locality 185. Bosque County (31°50′N; 97°44′W). Walnut Clay, Members Two, Three, and Four. Exposed in banks of Spring Creek, 7.5 miles northeast of Cranfills Gap on State Highway 22.

Locality 186. Bosque County (31°46′N; 97°40′W). Walnut Clay, Member Five, consisting of nodular limestone with abundant marine fossils. Exposed in quarry on Farm Road 162, 2.3 miles from intersection with Farm Road 219.

Locality 187. Bosque County (31°49′N; 97°41′W). Walnut Clay, Member Four. Consists of nodular limestone overlain by *Texigryphaea* banks. Exposed in road cut 3.6 miles on Farm Road 2136 from intersection with State Highway 6.

Locality 188. Bosque County (31°59′N; 97°43′W). Walnut Clay, Member Two, and Paluxy Sand. Exposed in road cut of dirt road, 3.5 miles northwest on State Highway 22, 2.7 miles on dirt road.

Locality 189. Bosque County (32°02′N; 97°46′W). Walnut Clay, Member Four. *Texigryphaea* bank exposed in road cut 1.9 miles on Farm Road 927 southwest from intersection with State Highway 144.

Locality 190. Bosque County (31°39′N; 97°30′W). Walnut Clay, Member Five, consisting of clay, nodular limestone, and thin oyster banks with abundant marine fossils. Exposed in ditch along Farm Road 217, 0.5 mile southwest from its intersection with State Highway 6.

Locality 191. Bosque County (31°43′N; 97°33′W). Walnut Clay, Member Four. Exposure consists of thick oyster banks exposed in ditch 6.9 miles northwest of Valley Mills on State Highway 6 from intersection with Farm Road 56.

Locality 192. Bosque County (31°42′N; 97°33′W). Walnut Clay, Members Three and Four. Exposed in Neil's Creek, 0.5 mile from its intersection with State Highway 6.

Locality 193. Bosque County (31°48′N; 97°38′W). Walnut Clay, Members One and Two, and Paluxy Sand. Exposed in banks of Meridian Creek on gravel road 0.85 mile from intersection with Farm Road 2136.

Locality 194. Bosque County (31°49′N; 97°36′W). Walnut Clay, Member Five. Consists of thin *Texigryphaea* banks. Exposed in hills on gravel road 0.7 mile from its intersection with State Highway 6, 0.1 mile from where State Highway 6 crosses Meridian Creek.

Locality 195. Bosque County (31°53′N; 97°38′W). Walnut Clay, Member Four, consists of *Texigryphaea* banks. Exposed in hills on northeast side of State Highway 6, 3.2 miles from intersection with State Highway 22.

Locality 196. Bosque County (32°02′N; 97°37′W). Walnut Clay, Member Five, consists of clay and dense ripple-marked limestone. Exposed in bluff northeast of gravel road that intersects Farm Road 927, 1.4 miles southeast near Morgan.

Locality 197. Bosque County (32°01′N; 97°33′W). Walnut Clay, Members Two, Three, and Four. Consists of dense limestone and *Texigryphaea* banks exposed in banks of Steele Creek, 3.8 miles southeast on Farm Road 927 from intersection with State Highway 174.

Locality 198. Bosque County (32°02′N; 97°30′W). Walnut Clay, Member Five, consists of dense limestone exposed in road cut 1 mile northwest on Farm Road 56 from Lakeside Village.

Locality 199. Bosque County (32°02′N; 97°30′W). Walnut Clay, Member Five, and Comanche Peak Limestone; consists of nodular limestone and thin oyster banks; exposed in road cut at Lakeside Village, 900 yards northeast on Farm Road 56.

Locality 200. Bosque County (31°57′N; 97°27′W). Walnut Clay, Member Five, exposed in bluffs along the shoreline of Lake Whitney, 6.6 miles northwest on Farm Road 56 from intersection with State Highway 22.

Locality 201. Bosque County (32°05′N; 97°29′W). Walnut Clay, Member Four, consists of *Texigryphaea* banks exposed in Plowman Creek, 0.7 mile northwest of Kopperl on Farm Road 56.

Locality 202. Bosque County (32°10′N; 97°41′W). Walnut Clay, Member Two, draped over truncated Paluxy Sand. Exposed in road cut 4.7 miles southwest of Brazos Point on Farm Road 56.

Locality 203. Coryell County (31°33′N; 97°36′W). Shell Oil Co., No. 1 Rabbe.

Locality 204. McLennan County (31°36′N; 97°28′W). E. J. Muth, No. 1 Freeman.

Locality 205. Bosque County (32°06′N; 97°29′W). Walnut Clay, Members Three, Four, and Five; consists of clay overlain by *Texigryphaea* banks. Exposed in road cut 0.7 mile northwest of Kopperl on Farm Road 56, 1.6 miles northeast on gravel road.

Locality 206. McLennan County (31°36′N; 97°27′W). M. S. Kemmerer, No. 1 Eula Holt.

Locality 207. McLennan County (31°34′N; 97°21′W). Harvie Meadows, No. 1 McKethan Water Well.

Locality 208. McLennan County (31°30′N; 97°16′W). Robert C. Smith and Falcon Oil Corporation, No. 1 H. G. McKethan.

Locality 209. McLennan County (31°33′N; 97°08′W). H. C. Buchanan, No. 1 H. C. Buchanan.

Locality 210. McLennan County (31°27′N; 97°14′W). Beacon Oil and Refining Company, No. 1 Myrtle Trice.

Locality 211. McLennan County (31°25′N; 97°11′W). Gray Oil Company, No. 1 C. B. and H. C. Warren.

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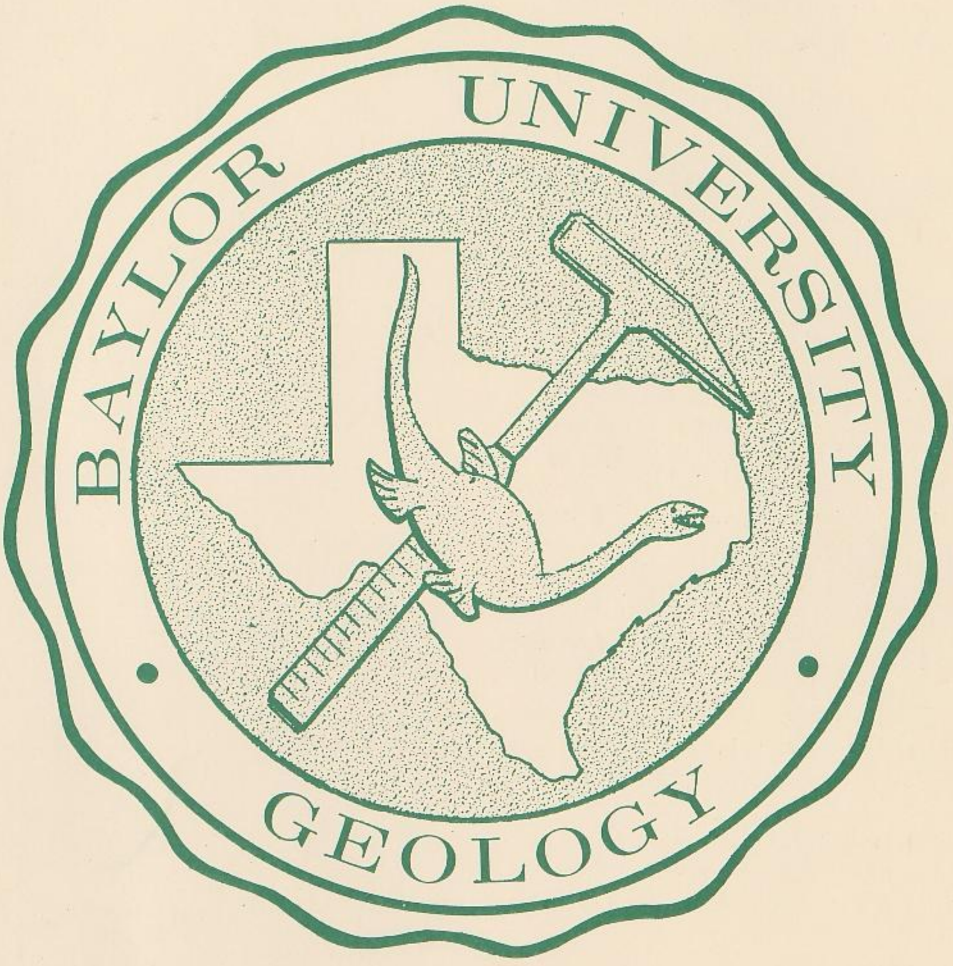
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