INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps.

ProQuest Information and Learning
300 North Zeeb Road, Ann Arbor, MI 48106-1346 USA
800-521-0600

UMI®

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

UNIVERSITY OF CINCINNATI

May 19, 1941

I hereby recommend that the thesis prepared under my supervision by Willis George Meyer

entitled Stratigraphy and Historical Geology of Gulf Coastal Plain in Vicinity of Harris County, Texas

be accepted as fulfilling this part of the requirements for the degree of Doctor of Philosophy

Approved by:

John L Rich

Head, Department of Geology and Geography

Form 668—G. S. and Ed.—1M—7-37

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

STRATIGRAPHY AND HISTORICAL GEOLOGY
OF GULF COASTAL PLAIN IN VICINITY
OF HARRIS COUNTY, TEXAS

A dissertation submitted to the

Graduate School
of the University of Cincinnati

in partial fulfillment of the
requirements for the degree of

DOCTOR OF PHILOSOPHY

1941

by

Willis G. Meyer

A.B. University of Nebraska 1930
A.M. University of Cincinnati 1933

CINCINNATI
UNIVERSITY
LIBRARY

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

UMI Number: DP15928

INFORMATION TO USERS

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleed-through, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

UMI®

UMI Microform DP15928
Copyright 2009 by ProQuest LLC
All rights reserved. This microform edition is protected against unauthorized copying under Title 17, United States Code.

ProQuest LLC
789 East Eisenhower Parkway
P.O. Box 1346
Ann Arbor, MI 48106-1346

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Contents

29 Ap '41

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Introduction.

Since the publication of E. T. Dumble's comprehensive studies of the Tertiary of eastern Texas, a vast amount of stratigraphic data has been made available by the drilling of thousands of deep oil wells in this region. Although numerous admirable papers have been written on the Tertiary of the Texas Gulf Coast since the advent of deep drilling in this area, full advantage has rarely been taken of available subsurface data with the result that the emphasis, in most cases, has been placed upon surface geology.

The purpose of this investigation is to make a detailed study of the subsurface formations of an area to be defined later and to carry the investigation up the regional dip to the outcrop of these formations. By thus emphasizing the subsurface development of the formations, it is hoped to bring about a better understanding of the stratigraphy and historical geology of the area than was previously possible.

The writer has relied largely upon the work of others for descriptions of the formations at the outcrop though some of them are based upon his own field work. To a large extent, the report which follows complements the surface work of other geologists.

The area here described centers in Harris County, Texas. Surface and subsurface studies were extended northward from Harris County to the outcrop of the Cook Mountain formations which are the oldest beds penetrated, at the time of this writing, by wells drilled in Harris County[1]. The investigation was also carried

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

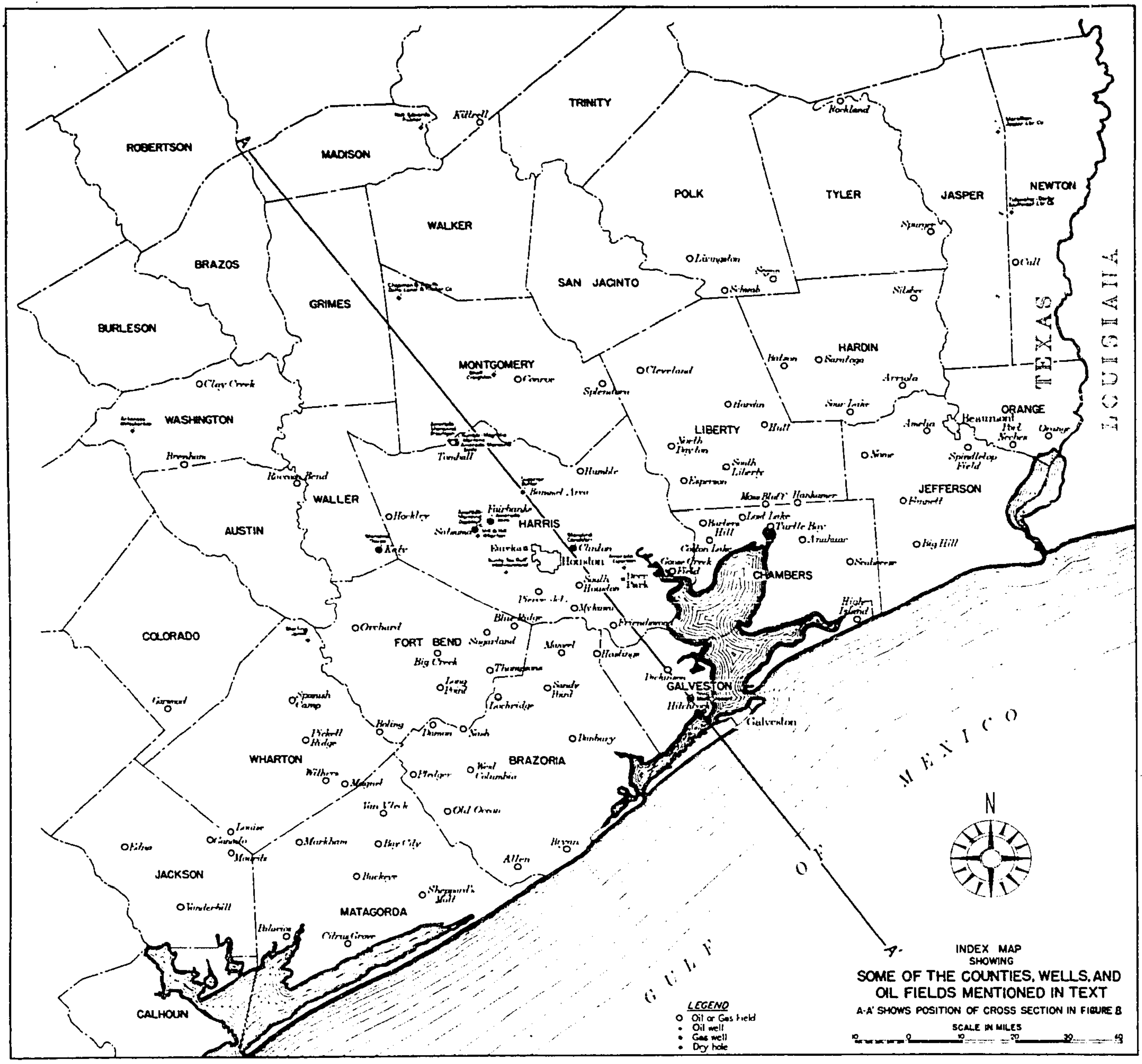
1. Note: One well was recently drilled in northern Harris County approximately 2500 feet below the top of the Cook Mountain. This may be as much as 1000 feet below the Cook Mountain, but definite information is not yet available on this well section.

southward to the Gulf of Mexico and into neighboring counties on the east and west. It is hoped that a sufficiently large area has been included that the post-Weches stratigraphy and historical geology of most of southeastern Texas will be apparent. Insofar as time would permit, the results of this investigation have been presented in the framework of a generalized comparison of the formations in this area with those of southwestern Texas and southern Louisiana.

The writer has received the cooperation of many people in this undertaking. Officials of the Amerada Petroleum Corporation made available all laboratory facilities of the company, cores and samples of rock-cuttings from numerous wells and other geologic data on all wells drilled in this area. Without this cooperation, the completion of this investigation would have been impossible. The writer is particularly grateful to Mr. A. R. Denison, Chief Geologist of the Amerada Petroleum Corporation, for making possible continued residence in Houston, Texas, when the normal workings of the company would have required residence elsewhere before the completion of this work.

The writer is also indebted to Drs. W. H. Bucher, N. M. Fenneman, and J. L. Rich of the University of Cincinnati for reading the manuscript and offering valuable recommendations. Mr. Lewis W.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.



INDEX MAP
SHOWING
SOME OF THE COUNTIES, WELLS, AND
OIL FIELDS MENTIONED IN TEXT
A-A' SHOWS POSITION OF CROSS SECTION IN FIGURE 8

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Mac Naughton contributed freely from his unpublished surface studies and read and criticized the first draft of the manuscript. Dr. G. I. Atwater, Mr. Lon D. Cartwright Jr., Dr. H. N. Fisk, and Mr. J. W. Kisling, Jr., also read the manuscript and offered many suggestions. Conversations on various phases of the work were also had with Mr. J. C. Cruse, Jr. and Dr. Bruce Harlton. Finally, the writer is grateful to Mrs. W. G. Meyer who typed the manuscript and rendered valuable assistance in its preparation in many other ways.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Stratigraphy.
General Features.

The Tertiary and Quaternary systems of the Texas Gulf Coast at the outcrop are a succession of marine and continental deposits. As the seas periodically advanced and retreated over the area now occupied by the outcrop of these systems, series of strata were deposited which are alternately marine and continental. The two oldest Tertiary formations and all but the upper part of the next oldest are marine at the outcrop. Succeeding formations as far up in the section as the Frio (Oligocene) are alternately marine and continental while the Frio and all younger formations are entirely continental at the surface.

In the area adjacent to the present shore line, no continental deposits are encountered below the Middle Miocene while drilling for oil. If a well, located in this area, were to be drilled to the base of the Crockett (Upper Claiborne) all beds encountered from ~~the Lower Miocene down would be marine. The beds above the Lower~~ Miocene, except for the upper 200-300 feet, contain shell fragments and may be largely marine though some are probably continental. All formations from the base of the Crockett to the Lower Miocene that are continental at their outcrop grade into a marine facies in the area between the outcrop and the modern shore line of the Gulf of Mexico.

Harris County, Texas, is located in this intermediate area (Fig. 1.). Due to this fact we are concerned, among other things in the stratigraphic part of this investigation, with the determination of valid criteria for distinguishing marine from non-marine

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

deposits in well sections, with the structural, petrographic and faunal changes that occur in a formation incident to its transition from the continental to the marine facies, with the correlation of formations that undergo such lateral changes, and with the relationship of paleogeography to oil accumulation.

Argillaceous and arenaceous sediments predominate in the Cenozoic deposits of the Texas and Louisiana Gulf Coast. Almost all formations contain these two types of sediments in varying proportions, and this general lithologic similarity among the formations contributes to the difficulty of defining formational limits. The continental facies of some of the formations contains volcanic ash and other pyroclastic material. Pure limestone strata are rare and most of the lime in the section is in the form of cementing material in sandstone, as reefs around salt domes, in the form of lime nodules, or contained in marls.

A number of unconformities are present in the Tertiary section at the outcrop and some probably extend as far gulfward as Harris County. The section must also contain many diastems as will be shown later.

The general classification of the Tertiary and Quaternary deposits in eastern Texas, according to Plummer[1], is given below.

---

1. Sellards, E. H., Adkins, W. S., and Plummer, F. B., Geology of Texas: The Univ. of Texas Bull., no. 3232, p. 530, 1932.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Classification of stratigraphic divisions in Texas

Age	Group		Formation	Members Northeast Texas
Pleistocene	Houston		Beaumont	Undivided
			Lissie	Undivided
Pliocene	Citronelle		Goliad	Undivided
Pliocene and Miocene	Fleming		Lagarto	Undivided
			Oakville	Undivided
Oligocene?	Gueydan		Catahoula	Onalaska Chita
Oligocene			Subsurface strata	Discorbis zone Heterostegina zone Marginulina zone
			Frio	Absent east of Brazos
			Subsurface strata	Undivided
Eocene	Jackson		Fayette	Whitsett McElroy Caddell
	Claiborne		Yegua	Undivided
		Cook Mt.*	Crockett	Undivided
			Sparta	Undivided
		Mt. Selman*	Weches	Undivided
			Queen City	Undivided
			Reklaw	Undivided
			Carrizo	Undivided
	Wilcox		Sabinetown	Undivided
			Rockdale	Calvert Bluff Simsboro Butler
			Seguin	Caldwell Knob Solomon Creek
	Midway		Wills Point	Kerens Wortham Mexia
			Kincaid	Pisgah Littig

*According to United States Geological Survey usage in 1932.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Formations older than the Crockett have not yet been reached by the drill in Harris County[1], and the classification of the deposits in

1. Note: See footnote on p. 2.

Harris County to be used here is not identical with that of Plummer. A table of classification for the deposits in Harris County and vicinity with a resume of formational properties will be given when a detailed description of the formations is made.

A most striking feature of the Cenozoic section here is its great thickness and a characteristic gulfward thickening of most of the constituent formations. An estimate of the thickness of these beds may be obtained by combining the sections from a series of deep wells which are located along a line generally parallel to the regional dip. The well nearest the coast will give the thickness of the younger formations, and those located farther inland will give successively the thickness of the older formations. The following wells have been selected for this purpose and the sectional thicknesses recorded:

	Feet
Shell Petroleum Corporation No. 1 Maco Stewart, located in southern Galveston County; Recent to Top of Frio -	10,257
Skelly Oil Company No. B-14 F. C. Cobb, located in Van Vleck Oil Field in northern Matagorda County; Frio -	4,275
Bunte Oil and Gas Company - Texas Gulf Producing Company No. 1 Westmoreland Development Company, located in Harris County west of Houston; top of <u>Textularia warreni</u> zone to top of Yegua - - - - - - - -	2,050
The Superior Oil Company of California No. 1 D. F. Butler, located in northern Harris County; top of Yegua to top of Wilcox[2] - - - - - - - - - - - - - - - - -	3,513

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Hall-Edwards et al No. 1 Francis Fulcher, located in east-central Madison County; top of Wilcox to lower part of Midway - 3,964

Total thickness of Cenozoic more than - - - - - 24,059

2\. Note: The contact which is called the top of the Wilcox in this well may be as young as the top of the Sparta. It is the top of the first sand below the Crockett. No Weches fossils have been found. The interpretation that this sand is Wilcox in age rests on the assumption that the Sparta, Queen City, and Carrizo sands have completely shaled up and that the Weches marine fauna has graded down-dip into a fauna indistinguishable from the Crockett fauna. This interpretation is the most conservative one possible and is the one here accepted for the purposes of this table though the writer considers a younger age for this sand quite possible. If the sand is younger than the Wilcox, then the observed thickness of the Cenozoic is considerably greater than the thickness here attributed to it.

As indicated above, this figure for the total thickness of the Cenozoic formations represents only a first approximation obtained by projecting shoreward the thicknesses of the lower formations measured at points farther inland. It is not probable that the formations retain their thicknesses over the distances involved. Two other possibilities exist. One is that during any particular cycle of sedimentation, the supply of sediment may not have been sufficient to build the wedge-shaped formation out as far as the present shore line, or that the cycle may have been interrupted before this could be accomplished. The other possibility is a continued gulfward thickening of the formations. As deeper drilling for oil continues in the Gulf Coast, it is becoming more and more certain that thickening continues at least as far as the present shore line. If one assumes a continuation of formational thickening instead of a maintenance of the actual thicknesses recorded at points inland, a much greater figure for the estimated thickness of the

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Cenozoic is obtained. The following table shows the thickness of the Cenozoic formations estimated by projecting shoreward rates of thickening observed in areas farther inland:

	Feet
Recent to Transition Beds (inclusive)	11,000
Frio	5,200
Textularia warreni Beds	1,490
Jackson	2,500
Yegua [1]	1,850
Crockett-Carrizo (inclusive)	2,760
Wilcox-Midway	11,600
	36,400

1. Note: This estimate is based on the same assumption given in the footnote on page 8. If the age of this sand should be proven to be younger than Wilcox, several thousand feet must be added to the estimated thickness of these beds.

It is altogether possible that even this estimate is less than the real thickness of these deposits. All evidence available at the present time shows not only that formational thickening continues but also that the rate of thickening itself increases with proximity to the present shore line. For example, if we were to estimate the thickness of the deposits from the Recent to the top of the Frio in southern Galveston County by projecting the amount of thickening involved between Tomball wells and the Westmoreland well in southern Harris County, an estimate of 7400 feet would be obtained. When the Shell Petroleum Corporation's No. 1 Maco Stewart well was drilled in southern Galveston County, however, these deposits were found to be 10,257 feet thick. Thus the estimated thickness is only 72 per cent of the true thickness of these formations. The area occupied by the tier of counties adjacent to the coast has been depressed much more than the area farther inland. In view of this

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

fact, it would not be unexpected to find that the Cenozoic deposits along the coast south of Houston, Texas, reach a thickness greatly in excess of 35,000 feet.

While it is probable that these deposits do reach a thickness of 35,000 feet, the fact remains that formational thickening as far south as the present shore line has not yet been proved for formations older than the Frio. However, formational thickening to a point 15 miles north of Houston for deposits of Cook Mt. age has been proved.

It is interesting to note that Howe[1] has arrived at a similar

1. Howe, Henry V., Russell, Richard J., McGuirt, James H., Geology of Cameron and Vermilion Parishes: La. Geol. Surv. Bull. no. 6, p. 41, 1935.

estimate for the thickness of the Cenozoic in southern Louisiana. He and his colleagues estimate that the base of the Tertiary in the southeastern portion of Vermilion Parish is at a depth of 31,250 feet. While the post-Oligocene deposits there are thicker than they are in southern Galveston and Matagorda Counties, Texas, the total thickness of the Cenozoic in the former area is probably not greater than in the latter.

<u>Criteria for Distinguishing Marine Deposits from Non-Marine</u>.-

Before going forward to a detailed description of the Cenozoic formations and to an interpretation of the facts of stratigraphy as represented by the core records, Schlumberger Logs and other data to be presented, we shall summarize the criteria here relied upon to distinguish a marine facies from a non-marine facies.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Some of the criteria that are useful when studying surface exposures are not available to the sub-surface geologist. Such features as raindrop impressions and mud cracks are obliterated by the drill and megascopic fossils are usually broken beyond recognition.

The presence of marine fossils generally implies marine deposition. Echinoid fragments are valid evidence for marine conditions of accumulation, but they do not occur with sufficient abundance throughout the Texas Gulf Coast Tertiary and Quaternary to be of more than occasional assistance. All but an insignificant number of ostracods are restricted to marine or brackish waters. Since fresh-water ostracods do not appear to be present in the beds in this area, the presence of ostracods may be taken as indicating marine deposition. They are not found in great abundance, however, and their value is correspondingly limited. Fragments of pelecypods and gastropods occur abundantly in parts of this section, but while they are usually marine, some may be fresh-water forms, and they should not be used unless their identity can be established. Frequently this is not possible. The only fossils which are small enough to escape destruction during drilling operations and yet occur in sufficient abundance to be generally useful are the foraminifera. While this group is not exclusively marine, it is nearly so, and the fresh-water forms seem either not to have existed here during Cenozoic time or were not preserved. Even errors due to the possible existence of non-marine forms can be eliminated because the foraminifera usually are sufficiently well-preserved to permit identification.

Care must be exercised, however, that only fossils indigenous

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

to the formations are used. It is a fact that marine fossils can be, and have been, eroded out of Cretaceous and older beds and redeposited in non-marine Cenozoic strata. Furthermore, small marine fossils may occur far inland in terrestrial dunes, having been transported when the winds were from the sea. No exact rule can be formulated to guard against such a contingency. Only the general aspect of the fossil will give evidence of possible redeposition by wind or water. Fossils bearing evidence of redeposition cannot be used as a criterion for determining the conditions of deposition of the beds in which they are found.

The presence of indigenous glauconite in a bed also indicates marine deposition. Galliher[1] in his recent work on glauconite states

1. Galliher, E. Wayne, Geology of Glauconite, A. A. P. G. Bull. vol. 19, no. 11., pp. 1569-1601, 1937.

that its diagenisis from biotite occurs exclusively in a marine environment. While glauconite is thus a useful index mineral for marine beds, the difficulty of distinguishing indigenous glauconite from reworked glauconite detracts from its usefulness. There is, seemingly, no good way of distinguishing these two types. For the purposes of this investigation then, the presence of glauconite in a bed will not be taken as conclusive evidence of a marine origin of that bed but will be considered as strong supporting evidence when other characteristics suggest a marine origin.

While glauconite and marine fossils are the only indices of a petrographic and paleontologic nature for marine beds, one other type of criterion is available. This type is structural, and only

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

one such criterion seems to be applicable to subsurface work. A large areal distribution and relatively uniform thickness of thin sands is found only in marine beds in the Gulf Coast Cenozoic deposits. The transition from highly lenticular sands in the non-marine facies of a formation to "blanket sands", as the more continuous beds are called, in the marine facies is an almost universal characteristic of the Cenozoic deposits of this area. The areal extent of the non-marine lenses is measured in hundreds or thousands of feet, while the extent of the marine blanket sands is measured in miles or tens of miles. There is generally no mistaking these types of sand bodies.

To prove that sediments are non-marine is ordinarily more difficult than the converse because they rarely contain fossils of any kind and because the absence of a marine fauna cannot be taken to imply a non-marine facies. It is true that leaf imprints and pieces of silicified wood are sometimes found in cores, but these can be and sometimes are washed out to sea some distance from the shore and become deposited in marine sediments.

There is likewise little evidence to be derived from the petrography of the sediments because the source generally is the same for all facies of any particular formation. There is one lithologic character, however, which seems to furnish a valid criterion for this particular area. At the outcrop of the Yegua where tree stumps _in situ_ establish its terrestrial character, there are many beds of unaltered ash, ashy sandstone and ashy shale. This is not true of the formation a considerable distance down the regional dip where there is an abundance of marine fossils though it does contain, as an equivalent, thin beds of bentonite and bentonitic

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

shale. Thus a section barren of marine fossils but containing numerous ash beds may be considered non-marine.

Just as blanket sands suggest marine deposition so highly lenticular sand bodies point toward non-marine deposition. Where a considerable number of wells have been drilled, and Schlumberger Logs are available, any lenticularity of the sands may be readily detected and non-marine deposition is implied.

Of the several criteria given, none can be said to supply absolute proof of the mode of origin of the beds which they characterize. We have noted that marine fossils and glauconite can find their way into non-marine beds. Likewise ash beds and sand lenses can be found in marine deposits. Yet a strong case is established for the mode of origin of nearly every formation, because in nearly every instance where one of the criteria is present one or more other criteria, indicating the same mode of origin, are present also. Each case rests upon two or more convergent lines of evidence. But what is most important is that in formations where evidence of both marine and non-marine deposition is present, the features which indicate non-marine deposition are found landward from the area where marine characteristics are prevalent in the formation. This presents a rational picture of the formation and is consistent with the Cenozoic history of the area since all marine invasions came from the south.

Eocene Series.
Claiborne Group.
Crockett Formation.

The oldest formation penetrated by wells drilled for oil in Harris County, Texas, is the Crockett[1]. The lower limit of this

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

1. Note: See footnote on p. 2.

formation at the outcrop is the contact between the underlying non-fossiliferous, continental sands of the Sparta formation and the overlying fossiliferous, marine shales, sandy shales and sands. The upper limit is the highest occurrence of Ceratobulimina eximia (Rzehak).

Little is known of the Crockett formation in Harris County since only a few wells ever reached beds of this age, and only data of a general nature are available on the Crockett of those well sections. However, many wells have been drilled through the Crockett up the regional dip from Harris County, and generalizations can be made about the strata of this age in the eastern part of the Texas Gulf Coast, and some inferences can be made about them in Harris County.

Contact with the Sub-Formation.

Plummer[2] reports the presence of a disconformity at the Sparta-

2. Plummer, F. B., loc. cit., p. 652.

Crockett contact in the outcrop. There are no subsurface data to indicate the nature of the basal contact in the vicinity of Harris County.

Distribution and Thickness.

Strata containing a Crockett fauna have been reported in well sections from Webb County in southwestern Texas northeastward across

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

the state to the Sabine River. The formation is exposed at the surface in the eastern and central part of the Texas Coastal Plain. In the Lower Rio Grande Region, Trowbridge[1] describes the upper part

1. Trowbridge, A. C., Tertiary and Quaternary Geology of the Lower Rio Grande Region, Texas: U. S. Geol. Surv. Bull. no. 837, pp. 121-124, 1932.

of the Cook Mountain as being more shaly than the rest and having a distinctive fauna. Since this immediately underlies the Yegua, it is probably the equivalent of the Crockett formation in eastern Texas. Crockett strata were also encountered in the Amerada Petroleum Corporation's No. 1 Weil well in the Cheneyville Oil Field in Rapides Parish, Louisiana, and equivalent beds have been reported at the surface in Louisiana.

The Crockett is 125 feet thick at the outcrop in the Brazos River valley of Robertson County according to Renick and Stenzel. It is from 400 to 450 feet thick in well sections in Houston County, nearly 500 feet thick in Walker County and 550 feet thick in Grimes County. The Magnolia Petroleum Company's No. 1 Wm. Martens well, located in northern Harris County, was drilled approximately 750 feet into the Crockett without any indication of having reached Sparta beds, and The Superior Oil Company of California No. 1 Butler well in northcentral Harris County encountered at least 1500 feet of Crockett strata. In the Cheneyville Oil Field in Louisiana, it is 539 feet thick.

Lithology.

The following generalized descriptions of the cores from the Crockett formation in the Magnolia Petroleum Corporation's No. 1

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Wm. Marten well, located in the Tomball Oil Field, have been reported:

(Figures at the left represent distances in feet below the estimated top of the Crockett).

0-2	Brown sand and shale.
3-5	Hard, broken sand and shale.
20-22	Hard sand and shale.
53-55	Sand and brittle shale.
62-64	Sandy shale.
109-111	Brown sandy shale.
126-128	Sand and brittle shale.
137-139	Hard sandy shale.
157-169	Brittle shale.
184-186	Brittle shale.
210-212	Black, brittle shale.
231-233	Black, brittle shale.
251-253	Sandy shale.
284-286	Sandy shale.
304-306	Brittle shale.
321-323	Black, hard, sandy shale.
351-353	Sandy shale.
408-410	Sandy shale.
425-427	Hard, brown shale.
452-464	Hard, sandy shale.
494-496	Sandy shale.
524-526	Hard shale.
553-555	Sandy shale.
597-599	Brittle shale.
607-609	Brittle shale.
631-633	Brittle shale.
664-666	Brittle shale.
704-706	Brittle shale.
723-724	Brittle shale.
757-759	Brittle shale.

Samples of these cores are not available so that more detailed descriptions cannot be given. However, data from well sections outside of Harris County indicate that the Crockett is largely shale with a minor amount of sandy shale and sandstone. The shale varies in color from gray to chocolate brown, is fossiliferous and, frequently, glauconitic. All beds have parallel lamination.

Plummer[1] describes the formation at the surface as consisting

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

1. Plummer, F. B., loc. cit., p. 660.

"of about 90 per cent fine sediments, clay, shale and sandy shale, 9 per cent medium-grained sediments, sand and glauconite, and 1 per cent rock, limestone and ferruginous concretions".

Conditions of Accumulation.

The Crockett in well sections contains marine fossils and glauconite. While the Crockett in the vicinity of Harris County is nearly devoid of sands and the criterion of the continuity of thin sands cannot be applied, the faunal evidence leaves little doubt as to the marine origin of this formation. Most of it at the surface is likewise marine. The lower and middle portions at the surface are entirely marine while the upper part contains both marine and non-marine sediments deposited, apparently, near the shore line.

Paleogeography.

The shore line during lower and middle Crockett time was an unknown distance inland from the site of the present day outcrop, and during upper Crockett time, the seas retreated to a position a short distance south of the outcrop, leaving the area now occupied by Harris County a considerable distance seaward from the shore line all during that period.

Yegua Formation.

Overlying the Crockett beds is the Yegua formation. Two wells in the Tomball Oil Field have been drilled through the Yegua, and another, the Amerada-Stanolind's No. 1 John Bode, located in the

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

same area, penetrated 1138 feet below the top of the Yegua but did not reach the Crockett. The Amerada-Stanolind's No. 1 Louis Dopslauf well at Fairbanks was drilled 970 feet into the Yegua. The two wells last mentioned were extensively cored in the Yegua and furnish a great deal of information in this formation. Another well, located three miles west of the Harris County-Waller County line, was drilled into the top of the Crockett, and its records are quite extensive and available. In addition to these wells which were drilled through or nearly through the Yegua, there are many which have been drilled 300 to 500 feet into this formation giving abundant data on this part of the section.

Contact with the Sub-Formation.

At the outcrop the Yegua lies unconformably upon the Crockett formation. It is not definitely known whether or not this unconformity extends as far south as Harris County.

Distribution and Thickness.

The Yegua underlies all parts of Harris County except the places where it is pierced by salt plugs. This is likewise true of all the rest of the Texas and Louisiana Gulf Coast south of the outcrop.

The Superior Oil Company of California No. 1 Butler well in northern Harris County went through 1434 feet of Yegua sediments. A greater thickness must be given to the formation in southern Harris County. In northern Montgomery County it is 1242 feet thick and at the outcrop it is about 1000 feet thick.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Lithologic Character and Structures.

Descriptions of the cores taken in the Yegua from two wells in Harris County and from two wells located in Montgomery County are given below. While the latter two were not extensively cored, certain facts are shown which have important bearing on the paleogeography of the area.

The figures at the left indicate the distances in feet below the top of the Yegua.

Cored portion of the Amerada-Stanolind's
No. 1 Louis Dopslauf at Fairbanks

0-20	Not cored. Schlumberger indicates shale.
20-21	Fine-textured sandstone.
21-23	Brownish black, pyritic, micaceous shale with very few streaks of fine sandstone; foraminifera present.
23-24	Fine-textured sandstone, slightly micaceous and lignitic.
24-33	Brownish black, micaceous, lignitic shale with very thin streaks of fine sandstone.
33-35	Brownish black, biotitic, lignitic shale; a considerable amount of pyrite and abundance of fossils.
35-40	No recovery from core. Schlumberger shows shale.
40-45	Brownish black, biotitic shale with woody lignitic fragments and a considerable amount of pyrite; foraminifera and shell fragments abundant.
55-180	Not cored. Schlumberger shows shale with a few thin sandy beds.
180-182	Brownish gray, biotitic shale; shell fragments abundant and foraminifera common.
182-187	Brownish gray, biotitic, lignitic shale; shell fragments abundant and foraminifera common.
187-187½	Gray, slightly sandy, very glauconitic shale containing yellow chert grains; shell fragments and foraminifera abundant.
187½-194	Brownish gray, glauconitic shale; shell fragments and foraminifera abundant.
194-195	Fine-textured, light gray, friable sandstone.
195-196	Intercalated, brownish gray shale and fine sandstone.
196-198	Fine-textured, light gray, friable sandstone.
198-200	Intercalated, fine-textured, cross-bedded sandstone and brownish gray, biotitic, silty shale containing lignite fragments.
200-202½	Fine-textured, friable sandstone.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

202½-203	Light gray siltstone with very thin laminae of lignite and shale.
203-208½	Brownish gray, biotitic, pyritic shale with very thin laminae of siltstone.
208½-209½	Fine-textured, very micaceous, lignitic sandstone.
209½-210½	Brownish gray, very micaceous shale with thin laminae of siltstone.
210½-212	Fine-textured, light gray sandstone.
212-213	Brownish gray, lignitic, biotitic, pyritic shale with thin laminae of siltstone.
213-214½	Fine-textured, light gray sandstone.
214½-215	Laminated, brownish gray shale and siltstone.
215-218	Fine-textured, light gray sandstone.
218-220	Fine-textured, light gray sandstone with laminae of dark micaceous shale.
220-221	Fine-textured, biotitic sandstone.
221-227	Brownish gray, silty shale with thin laminae of fine gray sandstone; foraminifera present.
227-236	Brownish gray, micaceous, lignitic, slightly silty shale; foraminifera present.
236-240	Brownish gray, micaceous shale; foraminifera present.
240-251	Brownish gray, micaceous shale, small lignite fragments; shell fragments and foraminifera very abundant.
251-251½	Gray, very glauconitic, slightly sandy shale; shell fragments and foraminifera present.
251½-253½	Fine-textured, slightly glauconitic, shaly sandstone; pelecypods and foraminifera present.
253½-255	Cross-bedded, micaceous siltstone with thin laminae of lignitic, micaceous shale.
255-260	No recovery. Schlumberger shows shale.
260-271	Brownish gray, lignitic, micaceous shale; foraminifera present.
271-274	Brownish gray, lignitic, micaceous, slightly glauconitic shale; foraminifera present.
274-275	Gray shale with very thin streaks of fine sandstone.
275-293	Fine-textured, light gray sandstone with thin laminae of dark carbonaceous shale.
293-296	Fine, gray, silty sandstone with laminae of dark gray shale.
296-301	Not cored. Schlumberger shows sandy shale.
301-311	No recovery from core. 301-305 Schlumberger shows sandstone. 305-308 Schlumberger shows shale. 308-311 Schlumberger shows sandstone.
311-311½	Dark gray, silty shale.
311½-313½	Fine gray sandstone.
313½-317	Intercalated fine gray sandstone and dark gray micaceous shale.
317-318	Very fine-textured sandstone with very thin laminae of dark shale.
318-320	Intercalated, fine gray sandstone and dark gray micaceous shale.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

320-321	Fine-textured, light gray, shaly sandstone with a considerable amount of lignitic, woody fragments; foraminifera present.
321-326	Dark gray, very lignitic, slightly silty shale; foraminifera rare.
326-349	Dark gray shale; foraminifera very abundant.
349-352	Light gray siltstone with thin laminae of dark shale.
352-356	Fine-textured, light gray, slightly shaly sandstone with an abundance of lignitic, woody fragments.
356-358	Light gray siltstone with thin laminae of dark shale.
358-359	No recovery from core. Schlumberger shows shale.
359-362	Fine-textured, gray, quartzitic sandstone with an abundance of plant remains, some of which are pyritized.
362-363$\frac{1}{2}$	Intercalated, fine gray sandstone with brownish gray shale containing plant remains.
363$\frac{1}{2}$-364$\frac{1}{2}$	Very fine-textured, gray, shaly sandstone containing plant remains.
364$\frac{1}{2}$-366$\frac{1}{2}$	Intercalated, very fine-textured sandstone and brownish gray shale; plant remains present.
366$\frac{1}{2}$-368	Fine-textured, gray, lignitic sandstone.
368-379	Intercalated, fine, gray, lignitic sandstone and brownish gray shale.
379-381	Fine-textured, gray sandstone.
381-383	Fine-textured, cross-bedded sandstone with laminae of black carbonaceous shale.
383-386$\frac{1}{2}$	Fine-textured, gray sandstone.
386$\frac{1}{2}$-388$\frac{1}{2}$	Black, carbonaceous, biotitic, shaly siltstone.
388$\frac{1}{2}$-392	Brownish gray shale with thin laminae of sandstone and siltstone.
392-395	Brownish gray, slightly silty shale; foraminifera abundant.
395-396	Very fine laminated sandstone with lignitic fragments.
396-399	Not cored. Schlumberger shows silty shale.
399-405	Brownish gray shale; shell fragments and foraminifera abundant.
405-413	Brownish gray shale with streaks of siltstone; foraminifera rare.
413-414	Gray, very glauconitic, slightly sandy shale; shell fragments and foraminifera present.
414-417	Dark gray, slightly bentonitic shale with thin laminae of siltstone.
417-428$\frac{1}{2}$	No recovery from core. Schlumberger shows slightly silty shale.
428$\frac{1}{2}$-434	Brownish gray shale with laminae of sandstone and siltstone.
434-437	Brownish gray shale with laminae of sandstone and siltstone and containing an abundance of lignitic, woody fragments.
437-446	Brownish black, biotitic, pyritic shale containing lignitic plant remains and an abundance of foraminifera.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

446-449	Fine-textured, cross-bedded sandstone with thin beds of brownish black, biotitic, lignitic shale.
449-452	Hard, medium-textured, cross-bedded sandstone with laminae of lignitic shale.
452-454	Hard, medium-textured sandstone with a considerable amount of lignite.
454-460	Fine-textured, very lignitic, micaceous sandstone.
460-464	Fine-textured, biotitic sandstone with laminae of carbonaceous shale.
464-465	Hard, fine-textured sandstone.
465-477	Fine-textured, lignitic, biotitic sandstone with laminae of carbonaceous shale.
477-483	Finely interbedded brownish black, biotitic shale and fine-textured sandstone.
483-488	Brownish black, very silty, lignitic, micaceous shale.
488-497	Medium-textured sandstone.
497-500	Intercalated, brownish black shale and fine-textured sandstone.
500-502	No recovery from core. Schlumberger shows shale.
502-503	Brownish black, lignitic shale with thin laminae of fine sandstone.
503-505	Fine-textured, black, shaly sandstone.
505-516	Brownish black, biotitic, lignitic shale with thin streaks of fine, gray, cross-bedded sandstone.
516-521	Brownish black, lignitic, micaceous, silty shale.
521-522	No recovery from core. Schlumberger shows shale.

Cored portion of the Yegua in the
Amerada-Stanolind's No. 1 John Bode well in the
Tomball Oil Field.
(Figures indicate distances in feet below the top of the Yegua)

0-88	Not cored. Cuttings show brownish black shale, slightly sandy in places; foraminifera and shell fragments present.
88-94	Brownish black, biotitic, glauconitic shale, containing pyrite and lignite fragments, and a very small amount of very fine sand; foraminifera and shell fragments present.
94-95	Brownish black, lignitic, micaceous, glauconitic shale and fine to medium-textured sand; foraminifera present.
95-97	Fine, silty, cross-bedded sandstone containing glauconite, mica and a considerable amount of fragmental lignite; shell fragments and foraminifera rare.
97-98	Brownish black, biotitic, lignitic shale and a very small amount of sand; shell fragments and foraminifera rare.
98-99	Lignitic, slightly pyritic siltstone; few shell fragments.
99-100	Brownish black, lignitic shale with streaks of siltstone; shell fragments and foraminifera present.
100-108	Intercalated brownish black shale and siltstone containing lignite, mica, foraminifera and an abundance of shell fragments.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

108-111	Brownish black, very lignitic, micaceous shale; shell fragments and foraminifera rare.
111-112	Intercalated fine, gray sandstone and brownish black, biotitic shale.
112-114	Brownish black, lignitic, biotitic shale; shell fragments and foraminifera present.
114-114½	Fine to medium-textured sandstone, containing lignite, biotite and shell fragments.
114½-122	Brownish black, lignitic, micaceous, slightly silty shale; shell fragments and foraminifera present.
122-130	Brownish black, lignitic, micaceous shale; shell fragments and foraminifera present.
130-134	Brownish black, slightly silty shale; foraminifera exceedingly abundant.
134-136	Brownish black, slightly silty shale; foraminifera rare.
136-140	Brownish gray, lignitic, micaceous shale with thin streaks of very fine sandstone.
140-144	Fine, silty, lignitic sandstone; shell fragments rare.
144-145	Fine, cross-bedded, lignitic, micaceous sandstone with thin laminae of shale.
145-153	Brownish black, lignitic, micaceous shale; shell fragments and foraminifera present.
153-157	Brownish black, lignitic, micaceous, glauconitic shale; foraminifera abundant and shell fragments common.
157-166	Brownish black, lignitic shale with a few laminae of fine sandstone; foraminifera and shell fragments common.
166-172	No recovery from core.
172-196	Brownish black, very glauconitic, slightly silty, lignitic, micaceous shale; foraminifera and shell fragments abundant.
196-200	Laminae of brown shale and fine sandstone; shell fragments and foraminifera present.
200-208	Brownish black, micaceous, lignitic, pyritic shale with very little sand and silt; shell fragments and foraminifera present.
208-217½	Brownish black, lignitic, micaceous, slightly silty shale; shell fragments and foraminifera common.
217½-222	Brownish black, lignitic, micaceous shale; foraminifera abundant and shell fragments common.
222-235	Brownish black, lignitic, micaceous shale with streaks of very fine sandstone; shell fragments and foraminifera rare.
235-240	Brownish black, lignitic, micaceous shale with fine sandy streaks; pelecypods and foraminifera very abundant.
240-254	Medium-textured gray, lignitic quartzitic sandstone.
254-255	Lignite with a little medium-textured sand.
255-260	Medium-textured, gray, lignitic, quartz sand; grains rounded to angular.
260-261	Brownish black, micaceous shale with a small amount of fine sand.
261-282	No recovery from core. Cuttings indicate shale.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

282-294	Brownish black, lignitic, slightly silty shale; foraminifera rare.
294-294½	Light green bentonite with a very little coarse-grained sand, glauconite and a few foraminifera.
294½-296	Coarse sandstone with a little hard, reddish brown, glauconitic shale; sand grains rounded.
296-297	Medium to coarse-textured, friable, glauconitic, fossiliferous quartzitic sandstone.
297-301	Brownish black, lignitic, pyritic, slightly sandy shale; no fossils.
301-310	Not cored. Schlumberger indicates shale.
310-317	Medium-textured, gray quartzitic sandstone.
317-338	No recovery from core. Schlumberger shows sandstone.
338-339	Laminated brownish black, biotitic shale and medium-textured sandstone.
339-344	Medium-textured, quartzitic sandstone.
344-348	Brownish black, lignitic, biotitic, slightly silty shale; foraminifera rare.
348-352	Intercalated greenish brown, lignitic, micaceous, bentonitic shale and fine to medium-textured sandstone.
352-354	Greenish brown, lignitic, bentonitic shale with laminae of fine sandstone.
354-456	Greenish brown, lignitic, micaceous, bentonitic shale.
356-358	Fine, gray, quartzitic sandstone.
358-363	Greenish brown, lignitic, bentonitic shale; foraminifera present.
363-368	Greenish brown, lignitic, biotitic, bentonitic shale.
368-372	Not cored. Schlumberger shows shale.
372-375	Greenish brown, lignitic, bentonitic shale.
375-379	Greenish brown, lignitic, bentonitic, glauconitic shale; shell fragments and foraminifera present.
379-382	Greenish brown, bentonitic shale.
382-388	Gray, very sandy, very micaceous, lignitic shale.
388-398	Medium to fine-textured, very micaceous, lignitic sand with partings of lignite and mica.
398-538	Not cored. 398-450 Schlumberger shows shale. 450-460 Schlumberger shows sand. 460-485 Schlumberger shows shale. 485-538 Schlumberger shows shale with thin sandy beds.
538-541	Greenish brown, lignitic, pyritic, slightly silty shale with a waxey luster; shell fragments rare.
541-550	Greenish brown, lignitic, pyritic, slightly silty shale with a waxey luster.
550-555	Medium-textured, gray, micaceous sand.
555-556½	Brownish black, lignitic shale.
556½-561½	Sandy, silty, lignitic, micaceous shale; foraminifera present.
561½-566	Greenish brown, sandy, lignitic shale; foraminifera present.
566-572	Medium-textured, gray, lignitic, micaceous sandstone.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

572-574	Brownish black, lignitic, micaceous shale; shell fragments rare.
574-581	Medium-textured, lignitic, micaceous sandstone.
581-584	Interbedded fine sandstone and brownish black, lignitic shale.
584-588	Coarse-textured, friable, light gray sandstone.
588-594	Grayish green, slightly sandy, lignitic, micaceous shale.
594-644½	Medium to coarse-textured, friable, light gray, quartzitic sandstone with occasional laminae of lignite and shale.
644½-645½	Grayish green, lignitic, slightly sandy shale; foraminifera present.
645½-646	Medium-textured, light gray, micaceous, quartzitic sandstone.
646-647½	Grayish green, biotitic, slightly lignitic, sandy shale.
647½-654	Medium-textured, friable sandstone.
654-659	Light gray siltstone; foraminifera present.
659-667	Grayish green, lignitic, micaceous, slightly sandy shale; foraminifera abundant.
667-672	Medium-textured, light gray, quartzitic sandstone.
672-677	Dark brownish gray, lignitic, biotitic slightly sandy shale.
677-681	Fine-textured, light gray, friable sandstone.
681-682	Brownish gray, silty, lignitic, biotitic shale.
682-686	Very fine, light gray sandstone.
686-688	Brownish gray, lignitic, micaceous shale; shell fragments and foraminifera present.
688-695	Very fine, light gray, silty sandstone.
695-697	Gray, lignitic, micaceous, slightly sandy shale.
697-775	Not cored. 697-735 Schlumberger shows shale. 735-745 Schlumberger shows sand. 745-755 Schlumberger shows shale. 755-770 Schlumberger shows sand. 770-775 Schlumberger shows shale.
775-777	Very fine, light gray, laminated, cross-bedded sandstone; foraminifera present.
777-779½	Fine-textured, gray sandstone.
779½-783½	Fine-textured, interbedded, gray sandstone and lignitic shale.
783½-785½	Fine-textured, lignitic, biotitic, indurated sandstone.
785½-790	Grayish green, lignitic, micaceous, slightly sandy shale.
790-791	Fine-textured, cross-bedded sandstone with thin partings of dark brown shale.
791-793	Brownish black, lignitic, micaceous shale with laminae of very fine sandstone.
793-796	Brownish black, lignitic, silty shale.
796-796½	Medium to coarse-textured, quartzitic sandstone.
796½-798	Brownish gray, silty, lignitic shale.
798-803	Medium to coarse-textured, glauconitic sandstone.
803-815½	Medium-textured, light gray, micaceous, friable sandstone.
815½-825	Fine-textured, light gray, micaceous, friable sandstone.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

825-829	Fine-textured, light gray, micaceous, friable sandstone with thin laminae of dark shale.
829-831	Gray, very micaceous, very silty, lignitic shale.
831-839	Brownish gray, silty, sandy, micaceous shale.
839-843	Brownish gray, slightly sandy, micaceous, lignitic shale; foraminifera present.
843-847	Brownish gray, silty, sandy, micaceous shale.
847-852	Medium-textured, micaceous sandstone with laminae of dark shale.
852-857	Medium-textured sandstone with thin partings of lignite.
857-880	Fine-textured, lignitic, micaceous sandstone with thin laminae of dark lignitic shale.
880-898	No recovery of core. Schlumberger shows sandy shale.
898-905	Medium to fine-textured sand with thin beds of gray shale.
905-906	Grayish brown, lignitic, biotitic, slightly sandy shale.
906-907½	White, micaceous siltstone.
907½-910	Brownish gray, lignitic, micaceous, slightly sandy shale; foraminifera present.
910-913	Medium-textured, lignitic, light gray sandstone.
913-921	Fine-textured, very lignitic, micaceous sandstone with laminae of dark shale.
921-926	Laminated siltstone and dark shale.
926-933	Brownish black, silty, biotitic shale; foraminifera present.
933-935	Fine-textured, light gray, biotitic sandstone.
935-939	Brownish black, biotitic shale; foraminifera abundant.
939-943	Brownish black, biotitic shale; foraminifera and shell fragments very rare.
943-950	Brownish black, slightly lignitic, biotitic shale; foraminifera and small pyritized gastropods common.
950-957	Brownish black, biotitic, lignitic, slightly sandy shale; foraminifera rare.
957-965	Fine to medium-textured, light gray sandstone with laminae of dark shale.
965-966	Brownish black, very micaceous, lignitic, slightly silty and sandy shale.
966-968	Fine to medium-textured, light gray sandstone.
968-969	Fine-textured, laminated, micaceous sandstone.
969-971	Fine to medium-textured sandstone; contains excellent mollusk casts.
971-973	Very fine-textured, silty, laminated, cross-bedded sandstone.
973-974	Gray, lignitic, very micaceous, silty shale.
974-975	Fine-textured, micaceous, laminated sandstone with plant and lignite fragments; some leaves well preserved.
975-989	No recovery of core. Schlumberger shows shale.
989-992	Fine-textured, light gray, lignitic sandstone.
992-995	Brownish black, lignitic, micaceous shale.
995-997	Fine-textured, lignitic, micaceous sandstone.
997-999	Brownish black, lignitic shale.
999-1008	Fine-textured, very light gray sandstone.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

1008-1013	Brown, very micaceous shale with laminae and small lenses of fine sandstone.
1013-1018	Brownish black, lignitic, micaceous shale.
1018-1024	Brownish black, micaceous shale with laminae of fine sandstone.
1024-1031	Medium-textured sandstone.
1031-1055	Not cored. Schlumberger shows sandstone.
1055-1058	Very fine-textured sandstone with laminae of lignitic, micaceous shale.
1058-1061	Gray, shaly, lignitic, micaceous siltstone.
1061-1063	Dark gray, lignitic, micaceous shale with laminae of siltstone; foraminifera and shell fragments rare.
1063-1066	Brownish black, micaceous shale.
1066-1067	Brownish black, micaceous, glauconitic shale.
1067-1070	Brownish black, micaceous shale, foraminifera present.
1070-1073	Brownish black, micaceous shale.
1073-1075	Very fine-textured, cross-bedded sandstone.
1075-1080	Brownish black, micaceous shale; foraminifera and ostracods present.
1080-1083	Brownish black, micaceous shale; foraminifera and shell fragments present.
1083-1093	Brownish black, micaceous shale; foraminifera present.
1093-1102	Brownish black, micaceous, slightly silty shale.
1102-1105	Fine-textured sandstone with laminae of black shale.
1105-1107	Medium to coarse-textured, micaceous, friable sandstone.
1107-1108	Fine-textured sandstone with laminae of black shale.
1108-1111	Medium to coarse-textured, micaceous, friable sandstone.
1111-1114	Medium-textured, micaceous, friable sandstone.
1114-1117	Gray, shaly sandstone.
1117-1119	Brownish gray, micaceous shale.
1119-1122	Laminated siltstone and gray shale containing lignite and biotite.
1122-1127	Fine-textured, very light gray, friable sandstone.
1127-1128	Fine-textured, light gray, shaly sandstone.
1128-1130	Fine-textured, light gray, micaceous sandstone.
1130-1131	Interbedded, fine, micaceous sandstone and gray shale.
1131-1135	Very fine-textured, very light-colored, friable, micaceous sandstone.
1135-1139	Fine-textured, light gray sandstone with laminae of dark shale.

Cored portion of the Yegua from the Shell Petroleum Corporation's No. 1 H. M. Creighton well near Conroe in Montgomery County.

6-8	Greenish brown, micaceous shale; foraminifera and shell fragments very abundant; echinoid plates and bryozoans also present.
8-9	Very fine, very micaceous sandstone; foraminifera common.
9-18	Brown, micaceous, pyritic shale; foraminifera, gastropods, and other shells very abundant.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

18-32	Greenish brown, micaceous, glauconitic shale; pelecypods, gastropods and foraminifera very abundant.
32-33	Hard, brown, glauconitic, ferruginous, fossiliferous claystone.
33-36	Greenish brown, glauconitic, slightly sandy shale; shell fragments and foraminifera very abundant.
45-47	Brownish gray, very micaceous shale; shell fragments and foraminifera rare.
52-53	Brownish black, micaceous shale; foraminifera rare.
53-54	Gray, lignitic, sandy shale.
63-64	Gray, lignitic shale and fine sandstone; foraminifera rare and shell fragments abundant.
64-65	Fine, friable, micaceous sandstone.
75-76	Brown, sandy, micaceous shale.
80-81	Brown, lignitic shale and fine, micaceous sandstone; foraminifera and shell fragments rare.
81-84	Interbedded, brown shale and fine, micaceous sandstone; shell fragments present.
84-85	Brownish black, micaceous, very lignitic shale; shell fragments rare.
91-92	Gray, micaceous, very lignitic shale; shell fragments rare.
96-97	Gray, micaceous shale.
103-105	Brown, micaceous, lignitic, glauconitic shale; shell fragments and foraminifera present.
113-114	Gray, micaceous, lignitic, glauconitic shale; foraminifera rare.
123-125	Very fine, silty, light gray sandstone.
131-132	Brownish black, lignitic shale; foraminifera and shell fragments present.
143-144	Very fine, silty, light gray sandstone.
164-165	Brownish black, micaceous shale; foraminifera present.
175-176	Medium-textured, micaceous sandstone.
183-185	Brown, lignitic shale; foraminifera and shell fragments present.
194-195	Brownish black, micaceous shale; foraminifera and shell fragments rare.
203-204	Yellow, ferruginous claystone; gastropods and pelecypods common.
214-215	Fine-textured, light gray sandstone.
216-217	Brown, lignitic shale; foraminifera present.
227-230	Fine to medium-textured, light gray, micaceous sandstone.
240-243	Fine to medium-textured, micaceous, lignitic sandstone.
253-254	Medium-textured, micaceous sandstone.
255-256	Grayish green, micaceous, sandy shale.
266-267	Gray, lignitic, micaceous, sandy shale.
268-269	Gray, lignitic, micaceous shale; foraminifera and shell fragments very rare.
292-295	Light brown shale; foraminifera and shell fragments very rare.
313-314	Medium-textured sandstone.
332-335	Medium-textured, lignitic sandstone.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

344-345	Fine-textured, grayish brown sandstone.
345-348	Fine-textured, lignitic, micaceous sandstone.
358-361	Gray, lignitic, micaceous sandy shale.
371-374	Fine, laminated sandstone.
384-387	Fine, micaceous sandstone.
397-400	Dark gray, micaceous, sandy shale.
410-413	Fine to medium-textured, light gray sandstone.
423-426	Gray, lignitic, glauconitic, sandy shale.
439-442	Fine to medium-textured, micaceous sandstone.
452-455	Fine to medium-textured, lignitic, laminated sandstone.
463-466	Fine-textured, light gray, micaceous sandstone.
476-479	Fine, laminated, micaceous sandstone.
489-492	Fine, laminated, lignitic, micaceous sandstone.
502-505	Grayish green, lignitic, micaceous shale; foraminifera very rare.
515-518	Grayish green, lignitic, micaceous shale.

Cored portion of the Yegua of Chapman & Smith's
No. 1 Delta Land and Timber Company

0-4	Dark, greenish gray, micaceous, lignitic, glauconitic shale; typical upper Yegua marine fauna present.
112-116	Fine-textured, indurated micaceous sandstone.
116-119	Soft, lignitic, micaceous, sandy shale.
119-121	Grayish green, lignitic, micaceous shale.
121-129	Fine to medium-textured, friable, micaceous sandstone.
129-130	Fine, lignitic, sandy shale; one Textularia sp., one shell fragment found.
130-140	Gray, micaceous, pyritic shale; Ammobaculites sp., and one pyritized Globerigina sp.
227-232	Fine-textured, light gray, micaceous sandstone.
232-234	Slightly sandy, ashy, lignitic shale containing angular, glassy fragments.
308-312	Fine-textured, lignitic, micaceous sandstone.
312-316	Light gray siltstone; Ammobaculites sp. present.
563-566	Fine-textured, lignitic, micaceous, ashy sandstone; many grains very angular.
566-570	Dark gray, lignitic, ashy, slightly sandy shale.
575-580	Fine-textured, gray sandstone.
580-586	Fine-textured, micaceous, shaly sandstone.
588-589	Lignitic shale and very fine-textured sandstone.
592-602	Calcareous sandstone; many red quartz grains and angular, glassy fragments.
643-652	Grayish green, lignitic shale.
652-653½	Fine, ashy, lignitic sandstone.
653½-655	Fine-textured, silty sandstone.
658-666	Fine to medium-textured, lignitic sandstone.
666-670	Grayish green shale.

These core records together with the cores, rock-cuttings and Schlumberger logs from other wells show that sandstone, sandy and

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

silty shale, and shale make up the entire Yegua with the exception of several very thin beds of bentonite and one thin bed of lignite which occur only in the north part of the county. At Tomball, sandstone beds varying in thickness from one foot to fifty feet make up forty per cent of the Yegua, while at Fairbanks they comprise twenty per cent of the formation.

The sandstones are almost entirely quartzose. Plummer[1]

1. Plummer, F. B., Geology of Texas: Univ. of Texas Bull., no. 3232, p. 672, 1933.

estimates that the continental sandstones at the outcrop are more than ninty-nine per cent quartz. This is probably true of the marine sandstones in Harris County also. The grains are subround, usually clear, but some are milky and a very few are grayish blue. Very rarely chert grains are present, and many of the sandstone beds contain muscovite and fragmental lignite.

The shale is characterized by a chocolate brown or greenish brown color, is brittle and has a conchoidal fracture. The chocolate brown color is particularly characteristic of the upper part of the formation and contrasts rather sharply with the gray shales of the overlying Caddell formation. Nearly all the Yegua shales contain small fragments of lignite and are micaceous, biotite being particularly conspicuous. Many of the beds are also glauconitic and pyritic and occasionally the fossils and lignitic fragments have become pyritized.

In the vicinity of Tomball a six-inch bed of light green

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

bentonite is present at the top of the formation and another bed of very light-colored bentonite occurs just above the second sandstone about 275 feet or 300 feet below the Yegua-Jackson contact. In the same area a six-inch lignite bed is found in the middle of the first sandstone.

The distribution of the sandstone and shale beds is not uniform throughout this part of the section. The upper 220-240 feet are shale with occasional thin streaks of sandy or silty shale. Below this, sandstone beds from a few inches to fifty feet thick are interstratified with the shale, making a very distinct lithologic break. That this sandstone and shale series continues down as far as the top of the Crockett is shown by the Schlumberger log and the cores from the Stanolind et al No. 1 J. W. Thorpe well in Waller County which was drilled completely through the Yegua formation.

Generally speaking, the sandstone beds are of the blanket type and do not lens out and interfinger as they do at the outcrop. The upper five sandstone strata have been drilled or cored frequently in the quest for oil. All of these can be traced as much as twenty miles down the regional dip from Tomball and for considerable distances along the strike.

A considerable number of the thinner sandstone strata are cross-bedded. Since cores give a very small sample of the formation, a detailed study of the cross-bedding is not possible. It is important to note, however, that this structure may be encountered anywhere in the sandy part of the formation and is not restricted to a particular zone.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Conditions of Accumulation.

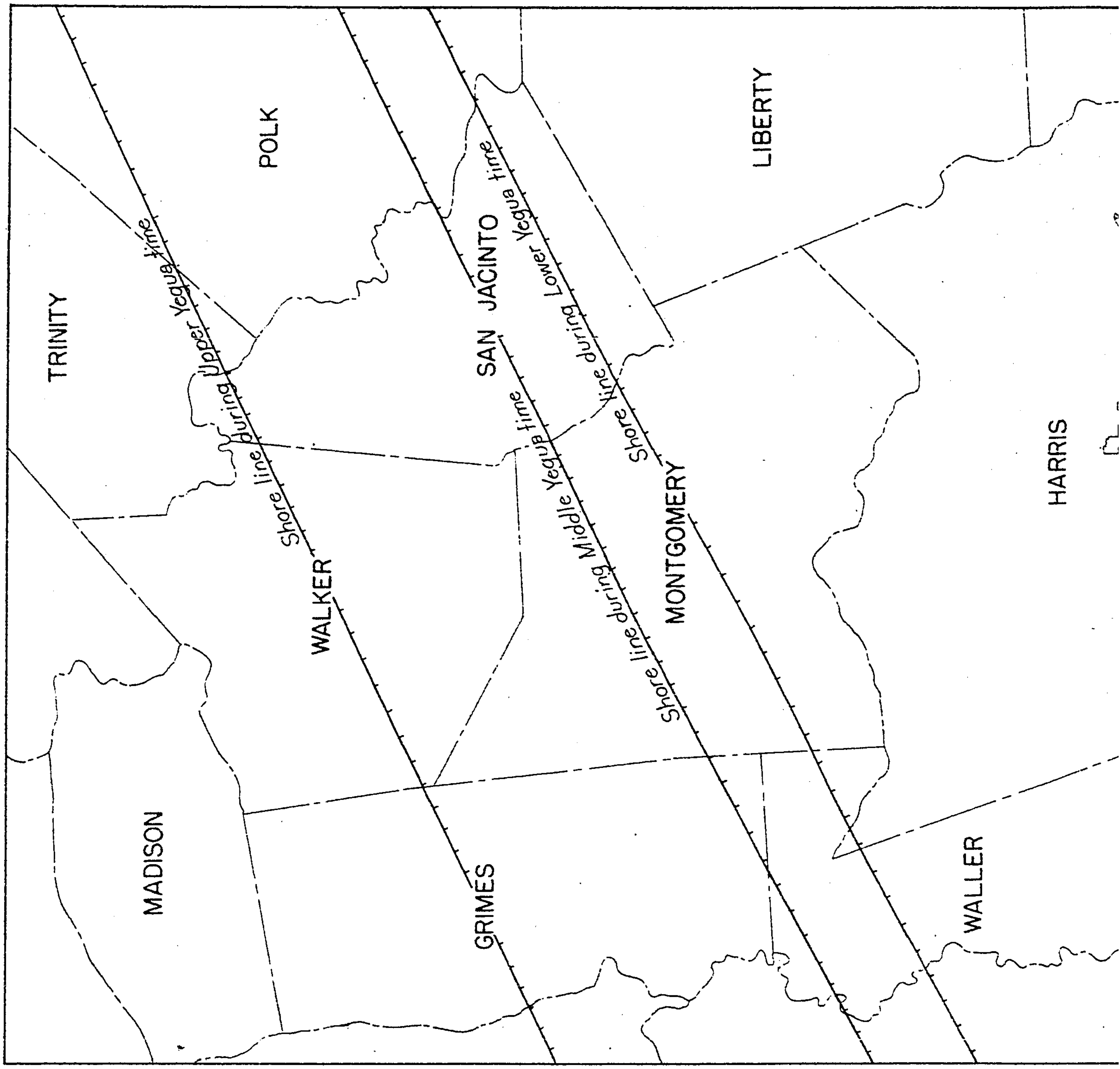
The presence of marine foraminifera, marine ostracods, and pelecypod and gastropod fragments together with abundant glauconite establishes the marine character of the Yegua in Harris County. This is corroborated by the continuity of the blanket sands which are in striking contrast to the lenticular, interfingering sands of the continental facies at the outcrop.

Paleogeography.

While the approximate position of the shore line of the Yegua sea can be determined from a study of the sections from wells drilled north of Harris County, the exact position cannot be established because of the relatively small number of the wells that have been drilled into the Yegua formation in this area. The core descriptions of two of the more significant wells have been given above. It is on the basis of these core records supplemented by a study of the rock cuttings from their uncored portions and by a study of the sections from other wells that the conclusions given below were reached.

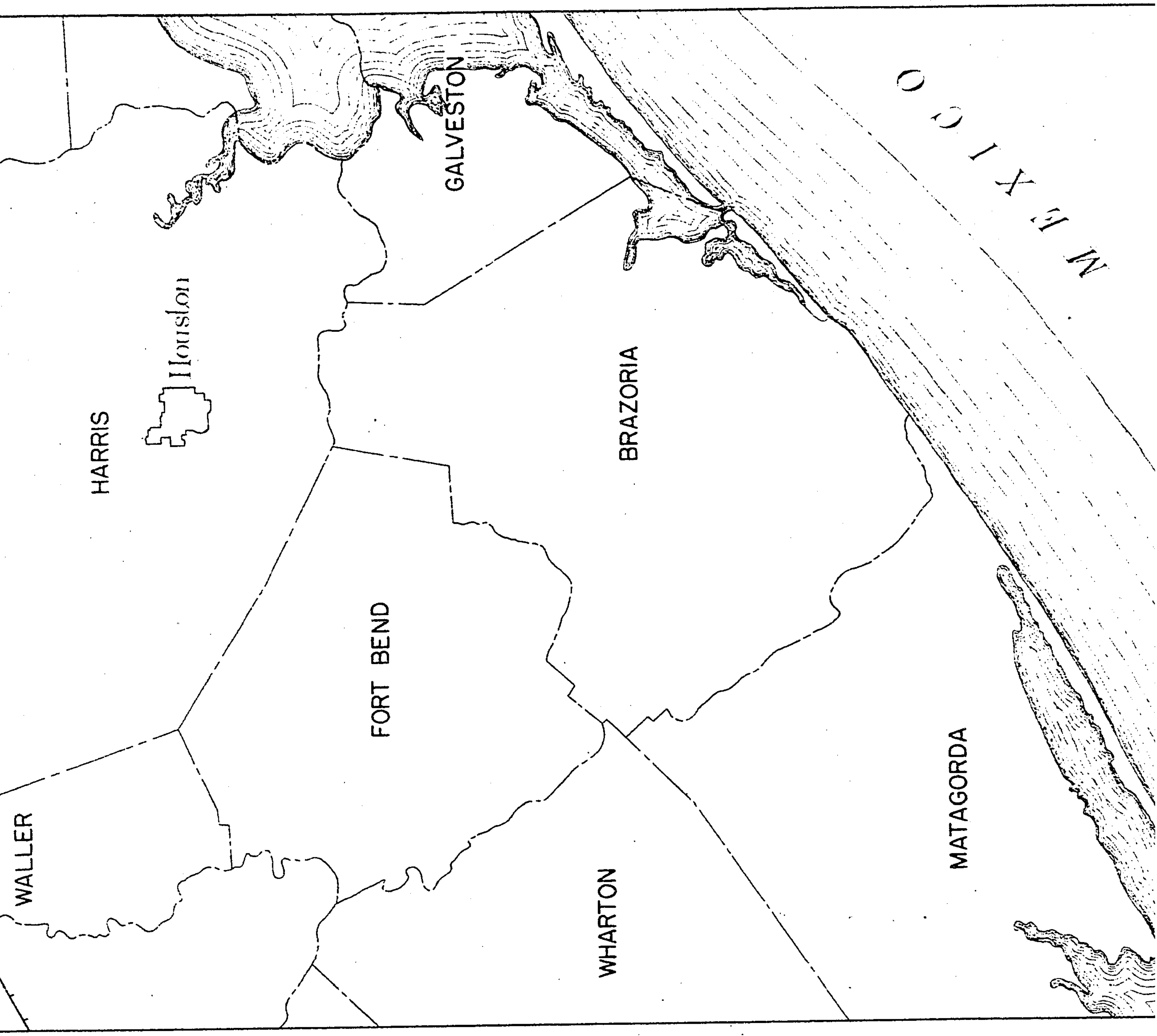
The Shell Petroleum Corporation's No. 1 H. M. Creighton well in central Montgomery County was drilled 518 feet into the Yegua. This is completely marine. While fossils are very common in the upper 220 feet they are very rare below this point. It is this point too that marks the break between the upper shale zone and the lower zone of sandstone and shale. This suggests that the shore line was a relatively short distance north of this well while all but the upper 220 feet of the sediments were being deposited. It is probable that during early Yegua time the shore was a very short

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.



Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.



Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

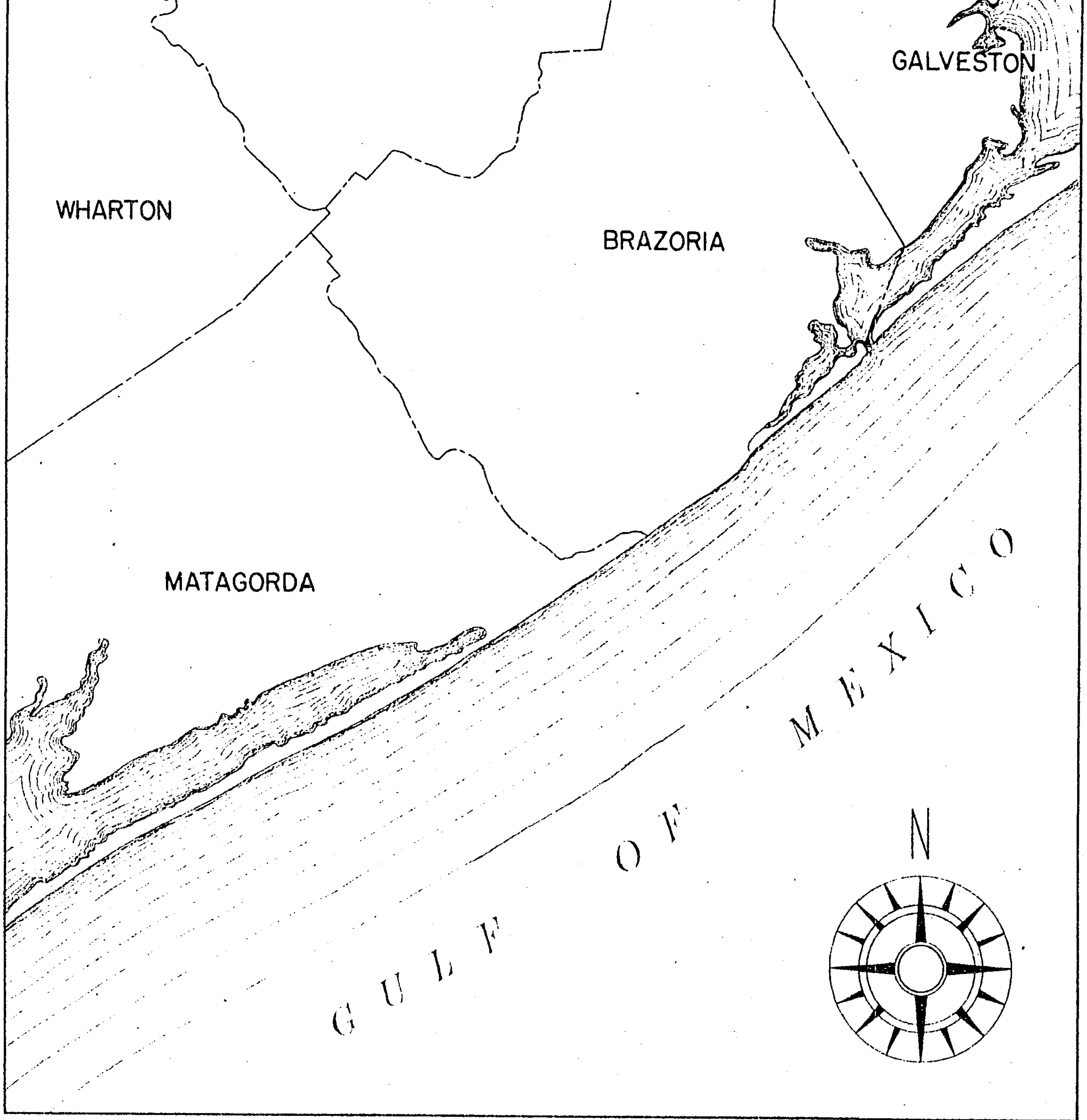


Fig.2

PALEOGEOGRAPHIC MAP FOR YEGUA TIME

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

distance south of the site of the Middle Yegua shore line since foraminifera are a little more rare in the Lower Yegua than in the Middle Yegua at Tomball. Near the close of the epoch, the shore line moved northward into Walker County and remained there while the 230 feet of shale in the upper part of the formation were being deposited in the area now covered by Harris County.

These positions for the Lower, Middle and Upper Yegua shore lines are substantiated by evidence from the Chapman and Smith No. 1 Delta Land and Timber Company well in northern Montgomery County. While cores were taken in this well only in the upper 670 feet of the Yegua, it was drilled into the Crockett and the rock-cuttings from the whole formation have been examined. In a core 232 feet below the top of the formation an ashy, slightly sandy shale bed was found. Below this bed are a number of similar ashy strata. One bed of ash more than 10 feet thick was encountered a little less than 1000 feet below the top.

In the upper part of this ashy series are several sandy shale beds that contain Ammobaculites sp. Special significance is attached to this genus. Of it Cushman[1] says: "There is a wide range of habitat in the present ocean, some species only found in cold, deep water, others in very shallow warm waters of the tropics." While it is often found here in the Tertiary associated with other

---

1. Cushman, J. A., Foraminifera Their Classification and Economic Use: Cushman Laboratory for Foraminiferal Research Special Publication, No. 1, p. 108, 1928.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

marine foraminifera, it frequently occurs alone in sandy beds situated in localities farther north (shoreward) than the areas where other genera are found. It seems to have been able to survive in shallower water and nearer shore than other forms. Its presence in these sandy beds when other marine fossils are absent is considered indicative of the proximity of the shore line. Above the first ashy bed in this well is an abundance of marine fossils.

Aside from minor fluctuations, these facts indicate that during Lower Yegua time the shore line was in the vicinity of the Shell Petroleum Corporation's No. 1 H. M. Creighton well, that during Middle Yegua time it migrated a short distance northward somewhere between the latter well and the Chapman and Smith No. 1 Delta Land and Timber Company well and that during Upper Yegua time when the upper 230 feet of shale were being laid down in Harris County the shore line stood somewhere in Walker County (Fig. 2). It should be noted that the greatest movement of the shore line came after the lower 1100 feet of sand and shale had been deposited and before the upper 230 feet of shale were laid down. The difference in the position of the Lower and Middle Yegua shore lines was not great. The only reason for assuming any difference at all is the greater scarcity of fossils, aside from Ammobaculites sp., in the Lower Yegua than in the Middle Yegua at Tomball.

Jackson Group.
Fayette Formation.

Immediately overlying the Yegua beds in the Texas Gulf Coast is the Fayette, the only formation in the Jackson Group of Texas. While many wells have been drilled through this formation in Harris

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

County and elsewhere in the Gulf Coast, it is rarely cored in the eastern half of the Texas Gulf Coast because it generally contains no beds that would make suitable reservoir rock for oil accumulation.[1]

---

1. Note: The Raccoon Bend Oil Field furnishes the only instance in eastern Texas of oil derived from the Jackson.

One must, as a consequence, rely largely on Schlumberger logs and the rock-cuttings washed up while drilling to furnish the data for a subsurface study of the Fayette. Because of the delay in the return of these cuttings to the surface and because caving of the overlying formations contaminates the samples, it is difficult to determine accurately the properties of a section from rock-cuttings.

Contact with the Sub-Formation.

The Jackson group rests conformably upon the Yegua both at the outcrop and in well sections throughout Texas.

Subdivisions.

A division of the Fayette of Texas into three members has come into general recognition. From the oldest to the youngest, these members are called the Caddell, the McElroy and the Whitsett. Various writers have subdivided each of these at the outcrop on a lithologic basis into a number of thinner zones.

While these names for the three members of the Fayette are in general use, there is no unanimity in defining their limits. Three of the most recent writers on the Jackson, Ellisor[2], Plummer[3], and Renick[4], have defined the members on a basis of lithologic proper-

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

2. Ellisor, Alva Christine, Jackson Group of Formations in Texas with Notes on Frio and Vicksburg: A. A. P. G. Bull., vol. 17, no. 11, pp. 1293-1350, 1933.

3. Sellards, E. H., Adkins, W. S., and Plummer, F. B., The Geology of Texas: The Univ. of Texas Bull. no. 3232, pp. 667-699, 1932.

4. Renick, B. Coleman, The Jackson Group and the Catahoula and Oakville Formations in a part of the Texas Gulf Coastal Plain: The Univ. of Texas Bull. no. 3619, pp. 13-55, 1936.

ties shown at the outcrop.

The contacts thus described at the outcrop cannot be found in well sections because the Fayette, with the exception of the Massilina pratti zone, grades rapidly into a shale facies in the gulfward direction in the eastern half of the Texas Gulf Coast. The Fayette from Goliad County southward contains some sand bodies, but even there the contacts between the members as described by these writers probably cannot be recognized.

The purpose here is to redefine the several members as much as possible on the basis of properties that are common to the beds both at the outcrop and in well sections south of the outcrop. Obviously a lithologic basis does not meet this requirement. The faunas of these Fayette beds provide the only basis for breaking the formation into members that can be recognized over wide areas. Two fossil zones which limit the two lower members can be recognized in well sections from the Rio Grande to the Sabine Rivers and everywhere at the outcrop except in the southwestern part of the state. There the Fayette is more or less unfossiliferous, and largely non-marine. These zones are the Textularia dibollensis and

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

the Textularia hockleyensis zones. The definitions of the members thus developed divides the Fayette much as it has been divided at the outcrop by recent writers, but they are applicable over larger areas. Finally, they define the members as they are recognized by a majority of oil company stratigraphers working in the Gulf Coast.

Caddell.

The lower limit of the Caddell is the top of the Yegua, and the upper limit is the top of the *Textularia dibollensis* zone. Because of the abundance of *Textularia dibollensis* Cushman and Applin, which is the key fossil for this member, it is often known as the "*Textularia dibollensis* zone".

The Caddell is very fossiliferous both at the outcrop and in well sections. Gastropods, pelecypods and foraminifera are especially abundant, and echinoid plates, ostracods, pyritized diatoms, and less frequently, fish teeth may be found at certain places. A detailed study of the Caddell faunas would doubtless reveal a number of distinct fossil zones which would be useful stratigraphic markers. One such zone at the base of the Caddell, the Moody's Branch, is widely recognized. It contains *Camerina moodybranchensis*, Gravell and Hanna and *Operculina vaughani* Cushman. This zone can be traced from Texas eastward across Louisiana and Mississippi into Alabama.

McElroy.

The McElroy extends from the top of the Caddell to the top of the *Textularia hockleyensis* zone. *Textularia hockleyensis* Cushman

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

and Applin is the index fossil for this member.

This definition of the McElroy is not entirely in accord with that of Ellisor[1] whose work is based primarily on lithologic features

1. Ellisor, Alva Christine, Jackson Group of Formations in Texas with Notes on Frio and Vicksburg: A. A. P. G. Bull., vol. 17, no. 11, pp. 1310-14, 1933.

shown at the outcrop. She includes the Dilworth sand and the Falls City shales in the Whitsett. Since the Falls City shales contain *Textularia hockleyensis* Cushman and Applin, it is here included in the McElroy.

Plummer[2] places the top of the McElroy "at the base of the

2. Plummer, F. B., loc. cit., p. 687.

persistent sandstone locally known as Grovetown or 'quarry' sandstone which caps the top of the Lipan Hills". The Grovetown is the same as Ellisor's Stones Switch sandstone which overlies the Falls City shales. Thus the upper limit of the McElroy according to Plummer is the top of the Falls City shales which is also the top of the *Textularia hockleyensis* zone. Plummer actually divides the Fayette as it is done here, but his definitions cannot be applied to the formation as it is encountered in well sections.

Like the Caddell, the McElroy is very fossiliferous in well sections. Pelecypods, gastropods and foraminifera are especially abundant. At the outcrop, the middle part is largely non-fossiliferous and the rest of the McElroy is not as fossiliferous there as it is a short distance gulfward.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Whitsett.

The Whitsett includes all beds between the top of the McElroy and the top of the _Trochammina teasi_ zone. At the outcrop it is in contact with the ashy Catahoula formation in the eastern end of the state and with the Frio formation in the southwestern part of the state. In well sections a wedge of marine Vicksburg sediments overlies the Whitsett.

The Whitsett is very fossiliferous where it is encountered in wells drilled south of the outcrop. Foraminifera, pelecypods and gastropods are most abundant. It is less fossiliferous at the outcrop, but such faunas as it contains distinguish it clearly from the overlying unfossiliferous, ashy Catahoula and Frio formations.

About seventy feet below the top of the Whitsett in well sections _Marginulina cocoaensis_ Cushman is found. Being easily recognized and coming in at a rather constant interval below the top of the Jackson, it is a good marker for correlating well sections. The lowest part of the Whitsett is known as the _Massilina pratti_ zone. The key fossil for this zone is _Massilina pratti_ Cushman and Ellisor. The zone is generally 80 feet to 100 feet thick, is easily recognized both in well sections and at the outcrop in the eastern part of the state but is poorly developed in southwest Texas.

Distribution and Thickness.

The Jackson is present in all parts of the Texas-Louisiana Gulf Coast south of the outcrop except in those places where it is pierced by salt domes. Wherever the Jackson is present in Texas,

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

it is represented by all three members except at the outcrop in the vicinity of Gonzales County where the Whitsett is overlapped.

In the wells drilled a few miles south of the outcrop in Polk, San Jacinto, Walker, Montgomery and Grimes Counties, Texas, the Jackson varies in thickness from 900 feet to 1000 feet. In the northern part of Harris County it is approximately 1075 feet thick. The formational thickening of the Jackson between these two localities is scarcely more than 10 per cent. In northern Harris County the average thickness of the Caddell is 245 feet, the McElroy 580 feet to 600 feet and the Whitsett 230 feet. Few wells located in or along the strike of the southern part of Harris County have gone through the Jackson. One well, however, the Bunte-Texas Gulf Producing Company's No. 1 Westmoreland Development Company well, located six miles southwest of Houston, was drilled into the Yegua. In this well, the total thickness of the Jackson is 1380 feet. It is interesting to note that the most thickening occurred in the Caddell which is 505 feet thick here. The Caddell has twice the thickness in this area that it has at Fairbanks just twelve miles northward. The McElroy in this same well is 640 feet thick while the Whitsett is the normal 230 feet in thickness. In the Stanolind Oil and Gas Company's No. 1 Angelo Candelari well which is located four miles east of Houston and is 500 feet higher structurally than the Westmoreland Development Company well, the total thickness of the Jackson is 1243 feet. The Caddell again shows the largest amount of thickening, its thickness being approximately 400 feet. In the Sterling Oil and Refining Company's No. 1 Frank Janek well which is located in northern Wharton County and is over 1400 feet

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

higher structurally than the Westmoreland Development Company well, the total thickness of the Jackson is 1179 feet. The Caddell is 302 feet in thickness. While there may not yet be sufficient evidence to make definite generalizations, the data here given strongly indicates a considerable amount of formational thickening of the Lower Jackson. It is very significant that the rate of thickening is much greater south of Fairbanks and vicinity than it is north of there. If one assumes a continuation of the same degree of thickening as is shown between Fairbanks and the Westmoreland Development Company well, the Jackson must be 2500 feet thick at the present shore line. It is altogether possible that the degree or rate of thickening increases south of the Westmoreland well as it does north of it in which case the Jackson would be much more than 2500 feet thick at the shore line.

Lithology.

The subsurface Jackson in the eastern half of the Texas Coastal Plain is made up entirely of shale except for the realtively thin Massilina pratti[1] zone which in its typical development is sand and sandy shale. South of Goliad County, the Jackson

1. Note: An exception to this is a sandy zone in the Whitsett in the Racoon Bend Oil Field. This is a very local condition, however, and is confined to the area of the structure.

contains well-developed sand bodies and is petroliferous. At the outcrop, the Jackson is lithologically unlike the Jackson below the surface. Plummer[2] estimates that it consists of about 40 per

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

2. Plummer, F. B., loc. cit., p. 690.

cent sand, 40 per cent sandy or ashy clay, 10 per cent clay, 5 per cent bentonite or fuller's earth, 4 per cent quartzite, and 1 per cent lignite.

The shale is bluish gray to greenish gray in color and contains a very small amount of very minute flakes of mica. Occasionally, shale beds of a chocolate brown color are encountered in the Caddell. This lowest member is also quite glauconitic and locally contains bentonitic beds. The Moody's Branch zone is especially glauconitic and is slightly marly.

Conditions of Accumulation.

The presence in well sections of foraminifera, echinoid plates, and other marine fossils together with glauconite show that the Caddell was deposited under marine conditions over the area beginning a short distance south of the outcrop. It is also marine at the outcrop in the eastern part of the state, and *Textularia dibollensis* Cushman and Applin has been found at the surface as far west as Cheepside, Gonzales County. The surface studies of Renick[3], however, show that westward from Trinity County fluviatile and palustrine deposits are interstratified with marine beds.

3. Renick, B. Coleman, loc. cit., p. 23.

The entire McElroy is also marine in well sections which are located a short distance south of the outcrop. Marine fossils are

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

abundant. It is partly marine and partly non-marine at the outcrop. Ellisor[1] describes the Wooley's Bluff clays, the lower part

1. Ellisor, Alva Christine, loc. cit., p. 1303.

of the McElroy in the eastern part of the state, as being marine. The overlying Manning beds, however, contain many beds of volcanic ash and ashy sandstone which are non-fossiliferous and non-marine. Renick[2] believes that these strata were deposited "under palustrine,

2. Renick, B. Coleman, loc. cit., p. 42.

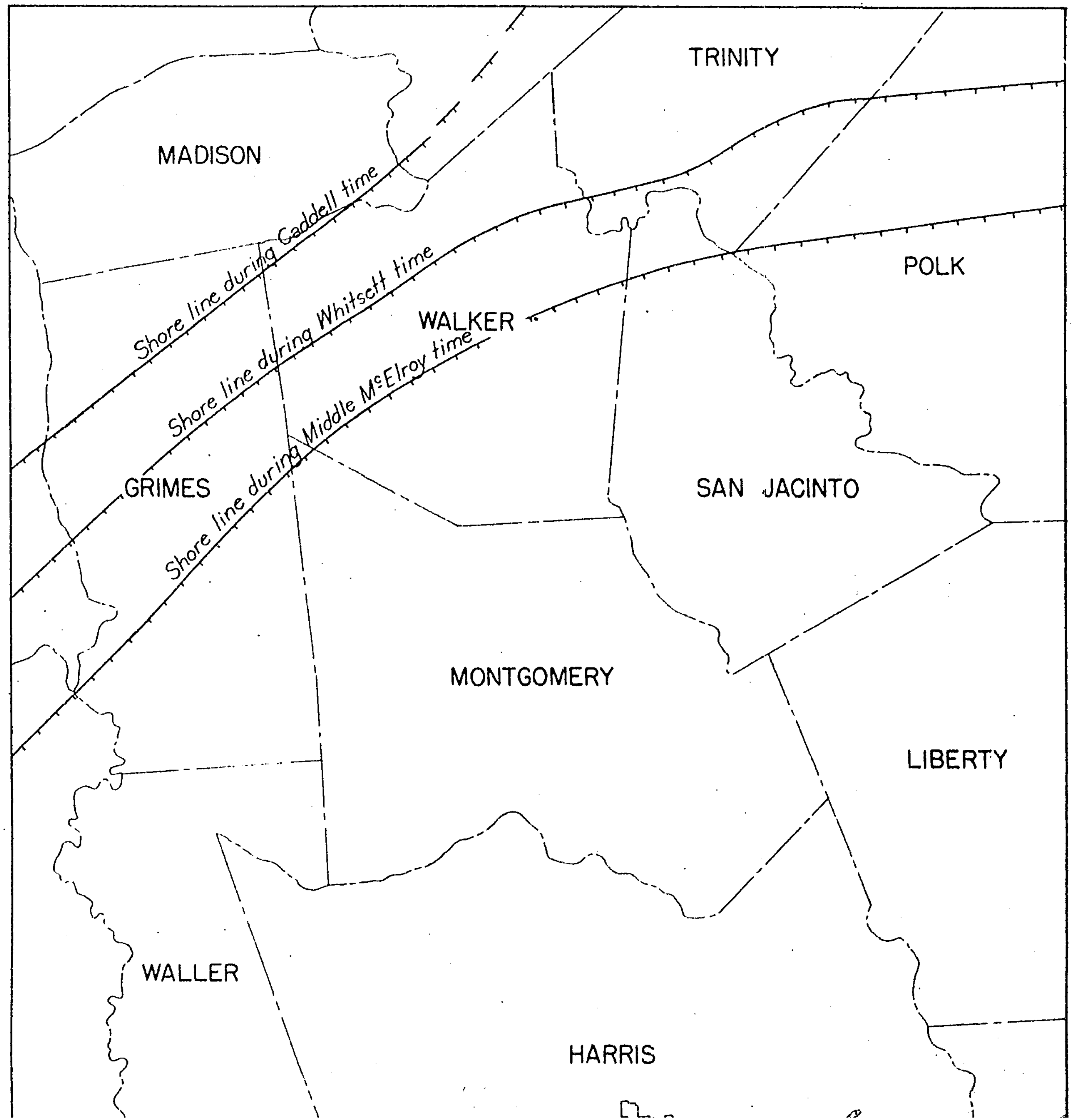
fluviatile, lagoonal and littoral conditions". The Dilworth sand and Falls City shales, the upper part of the McElroy, are marine, probably near-shore deposits.

The Whitsett below the surface is marine in all parts of the Texas Coastal Plain, but at the surface in eastern Texas both marine and non-marine deposits are present. Fluviatile and strand-line deposits are interstratified with shallow water beds.

Paleogeography.

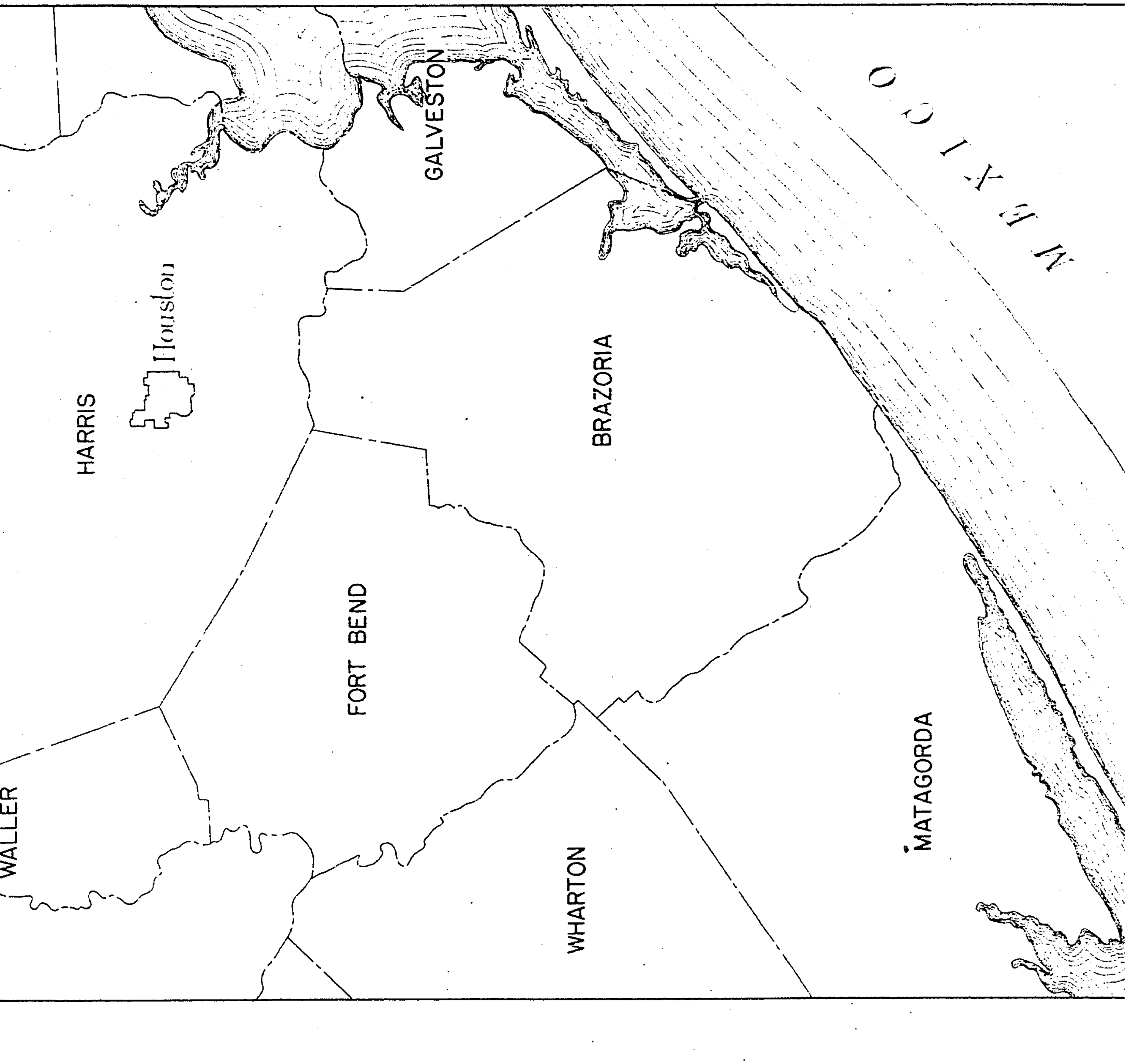
The general advance of the seas which occurred during Yegua time continued during the Jackson. A maximum for this invasion in eastern Texas occurred during Caddell time where the shore line was an unknown but probably not great distance north of the present outcrop. West of Trinity County, however, the strand-line was approximately at the position of the present outcrop. A slight retreat of the sea took place during middle McElroy time. Then the

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.



Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.



Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

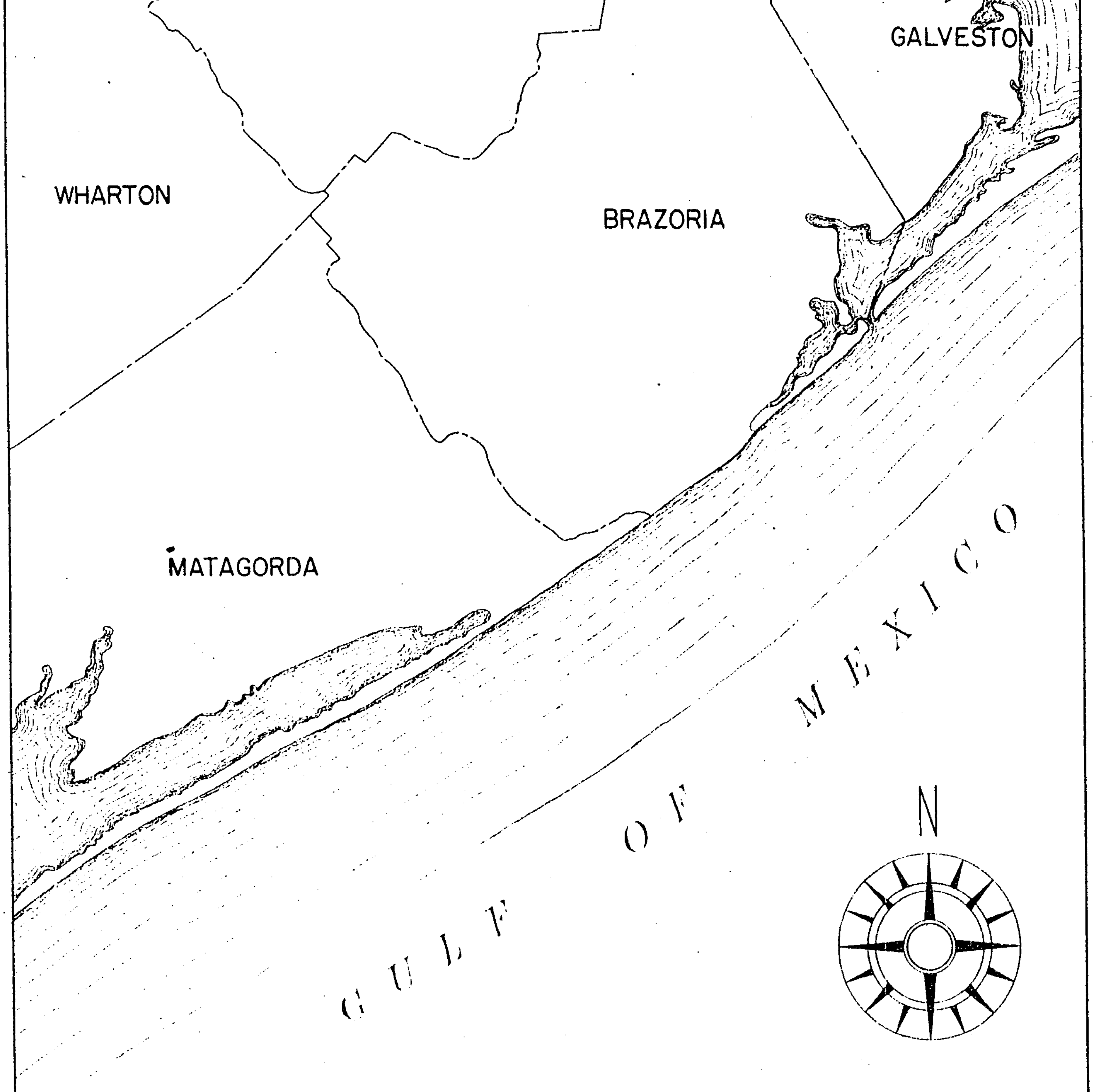


Fig. 3

PALEOGEOGRAPHIC MAP FOR JACKSON TIME

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

strand-line was approximately five miles south of its former position. The sea readvanced in late McElroy time to a position a very short distance north of the present outcrop where, with the exception of minor retreats, it remained until the close of the Jackson epoch (Fig. 3).

Oligocene Series.
Textularia warreni Beds (Vicksburg in part).

A wedge of marine shales and sands overlies the Jackson Group in well sections in Texas. The upper part of this marine wedge contains few, if any, diagnostic fossils. Textularia warreni Cushman and Ellisor and shell fragments comprise the greater part of the fauna. The first diagnostic fossils are generally found approximately 200 feet below the top of the Textularia warreni zone. Ellisor[1] has identified this fauna as Vicksburg in age. Out of

1. Ellisor, Alva Christine, loc. cit., pp. 1293-1350.

sixty species identified, fifty-seven were found in the Vicksburg strata of Mississippi. Although the Vicksburg age of the lower part of these beds is unquestioned, the equivalent, in the Mississippi section, of the upper part has not been determined. The true Vicksburg portion of this marine wedge and the upper part which contains no diagnostic faunas are treated together here as a unit because the deposition of the entire wedge marked a single event in the geologic history of the Texas Gulf Coast -- namely, the retreat of the seas at the close of Jackson time from a position far inland to a position near the present shore line. The whole

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

marine wedge thus forms a natural stratigraphic unit. Whether unfavorable environmental conditions account for the absence of typical Vicksburg fossils in the Upper Textularia warreni Beds or whether these upper beds are really younger than the youngest Vicksburg strata in Mississippi is yet to be determined.

Contact with the Sub-Formation.

Schlumberger logs and rock-cuttings show no pronounced textural change in the sediments at the Jackson-Vicksburg contact. Textularia warreni Beds have never been found at the outcrop in Texas so that the nature of the basal contact has not been observed directly. In view of the fact that these beds were deposited, as will be shown later, as the seas moved gulfward from the inland position which they occupied at the close of Jackson time, continuous deposition and conformable basal contact are to be inferred.

Distribution and Thickness.

As stated previously, Textularia warreni Beds have never been found at the outcrop in Texas, but they have been reported at the surface in La Salle Parish, Louisiana[1]. The Jackson has always been

1. Fisk, H. N., Personal communication.

found to be overlain by the Catahoula or Frio formations in Texas.

Fossils of the Textularia warreni zone have been found in the California Company No. 1 Garcia well in Brooks County, Texas, and in the Tidewater-Darby Oil Company No. 1 Southwestern Lumber Company well in Jasper County, Texas, and in numerous wells between these

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

two counties. That a continuous wedge of Textularia warreni Beds extends from the Rio Grande River to the Sabine River is a certainty. The distance inland that this wedge extends is not exactly known although it must be very near the outcrop of the Catahoula-Jackson contact in the eastern part of the state[1].

---

1. Note: Mr. L. W. Mac Naughton has pointed out to the writer that the outcropping beds mapped as Jackson in Trinity, Polk, and Angelina Counties occupy a wider belt than is normal for the Jackson of Texas. The upper part of these beds are non-marine, contain no diagnostic fossils, and may be equivalent to the Textularia warreni Beds.

These beds are 290 feet thick in the Tidewater-Darby Oil Company No. 1 Southwestern Lumber Company well which is 29 miles south of the outcrop of the Catahoula-Jackson contact, and they are 165 feet thick in the Marathon Oil Company No. 1 Jasper Lumber Company well located 13 miles north of the former well. This gives an average rate of thinning between these two wells of approximately 9.5 feet per mile. If this same rate of thinning continues northward, then there should be from 10 to 20 feet of these beds at the outcrop. The rate of thinning, however, probably increases as the outcrop is approached, and the beds may be entirely absent there. The probability is that the inner limit of this body of sediments is within five miles of the outcrop. Westward from here in Live Oak County, 120 feet of Vicksburg strata were reported in a well 15 miles from the outcrop of the Frio-Jackson contact. Exact data of a similar nature for the area southwest of Live Oak County are not available to the writer. Reason to believe that these beds do

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

not extend as near the outcrop there as in eastern Texas, however, is to be found in the fact that the Jackson in southwestern Texas is probably non-marine, and since the Vicksburg records a yet greater retreat of the sea than the Jackson, the assumption is that the Vicksburg must be farther from the Jackson outcrop there where the Upper Jackson at the outcrop is non-marine than in eastern Texas where the Upper Jackson is a littorial facies.

In the Westmoreland well, southwest of Houston, the Textularia warreni Beds are 670 feet thick. At Fairbanks they are from 400 to 425 feet thick, and at Tomball they are generally between 300 and 400 feet thick. As in the Jackson, a larger amount of formational thickening occurs in the area between the Westmoreland well and Fairbanks than in the area north of Fairbanks. The Textularia warreni Beds thicken at the rate of 20 feet per mile in the former area, and if this rate of thickening continues southward, these beds are 1490 feet thick at the present day shore line.

Lithology.

The Textularia warreni Beds are composed of shale, sandy and silty shale, and sandstone. In the northern part of Harris County, Texas, approximately 25 per cent of the beds are sandstone or sandy shale whereas in the southern part of the county they are 10 per cent sandstone or sandy shale.

The shale varies in color from dark gray to greenish gray, and much of it is lignitic. The washed residue of nearly all the shale beds contains a small amount of siltstone flakes. The sandstones are quartzose, and most of the grains are colorless although

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

some are gray, bluish gray or black.

Conditions of Accumulation.

The presence of marine foraminifera and echinoid plates in the Textularia warreni Beds shows clearly that these are marine deposits. In the lower beds where the typical Vicksburg fossils are present, Ellisor[1] found two distinct faunas. The older of these

1. Ellisor, Alva Christine, loc. cit., p. 1324.

faunas is present farther inland than the younger, establishing the fact that these beds were deposited in a retreating sea. In nearly all well sections, the upper beds are quite sandy while the rest contains very little sand. This suggests, possibly, that this upper portion is a facies nearer the shore line than the lower part. This may also account for the scarcity of foraminifera in the upper beds. A near shore environment may not represent the optimum of conditions for Vicksburg life.

Paleogeography.

The shore line at the beginning of this epoch was probably within five miles of the present outcrop of the Catahoula-Jackson contact in eastern Texas. This conclusion, based on evidence already given, rests on the assumption that there was no beveling of these beds before the deposition of younger strata[2]. The seas

2. Note: See p. 88.

gradually withdrew during the entire epoch. The lower Frio in

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

well sections near the modern shore line is marine, and it is probable that the seas which deposited the Textularia warreni Beds did not withdraw as far south as the present shore line. The shore line at the close of the epoch was probably in the central part of Matagorda, Brazoria, Galveston and Chambers Counties.

Frio Formation.

A thick sequence of clays and sandstones, which are ashy and continental at least as far south as Houston, overlies the Textularia warreni Beds in Texas. These beds are known as the Frio formation. The strata mapped as Frio at the outcrop in southwest Texas represent only the lowermost portion of the Frio as it is here defined. The rest is overlapped by the Catahoula. Some geologists place these beds in the Catahoula formation. A statement of this problem together with the reasons for retaining the Frio as a separate, older formation are given later.

Contact with the Sub-Formation.

The nature of the basal contact of the Frio in eastern Texas is not known since it is not known to outcrop in this area. According to Plummer[1], the Frio strata lie conformably upon the Fayette in southwestern Texas. Some workers in that area, however, have found local areas where the contact appears to be unconformable. The probability is that no extensive unconformity marks the basal contact of the Frio formation.

1. Plummer, F. B., loc. cit., p. 705.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Distribution and Thickness.

The Frio formation is found in well sections from the Rio Grande River to the Mississippi River. In the outcrop, however, it is not found east of Karnes County, Texas, since the Catahoula completely overlaps the truncated surface of the Frio in the central and eastern parts of Texas.

The Frio is 1300 feet thick in northern Harris County and is 1886 feet thick in the Westmoreland well southwest of Houston. A well located 7 miles west of Spindletop, Jefferson County, drilled 2075 feet of Frio beds. The Frio is over 2000 feet thick in a well section four miles south of Louise Oil Field in Jackson County. In Van Vleck Field, Matagorda County, one well section had 4265 feet of Frio strata. This indicates that the Frio must be over 5000 feet thick at the present shore line.

Lithology and Structure.

The Frio formation in Harris County consists of strata of ashy clays, sandy and silty clays, and ashy sandstones. The sandstone content varies from Louisiana and eastern Texas to southwestern Texas. In the Chenneyville Oil Field, Rapides Parish, Louisiana, at least 25 per cent of the formation is sand while in Harris County, Texas, sand accounts for about 18 per cent of all beds. Plummer[1] estimates that the Frio is 95 per cent clay at the

---

1. Plummer, F. B., loc. cit., p. 706.

---

outcrop in southwestern Texas. The thickness of individual sand

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

beds varies from a few inches to more than 100 feet. All sand bodies in the up-dip portion are lenses of limited areal extent. It is not uncommon to find a 75-foot or 100-foot sand bed present in one well and entirely absent in a well 1000 feet removed.

The Frio clay in the eastern and central part of the Texas Coastal Plain is characteristically ashy and light green in color. Small amounts of red and gray clay are also found. In the lower 200 or 300 feet there is a considerable amount of dark gray, lignitic shale. Well sections in Brooks County show that the clay is largely red in color in that area. The sand grains are angular to subangular and often have a glassy luster. In the lower part of the Frio are two or three zones of "rice sand". The grains in these zones are coarse and composed of milky quartz. These rice sands are lenticular and cannot be used for correlation purposes. In Brooks county well sections, the sands are found to be very feldspathic but this characteristic is limited to the southwestern part of the Texas Coastal Plain. In this same area, the Frio contains less pyroclastic material and more calcareous material than is found elsewhere.

Conditions of Accumulation.

The presence of large amounts of volcanic ash, the lack of parallel structures in the clays, the absence of marine fossils and glauconite, and the lenticularity of the sands indicate that the Frio was deposited under non-marine conditions.

Wells drilled near the modern shore, insofar as they have penetrated the Frio, show that it is marine. Here glauconite and

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

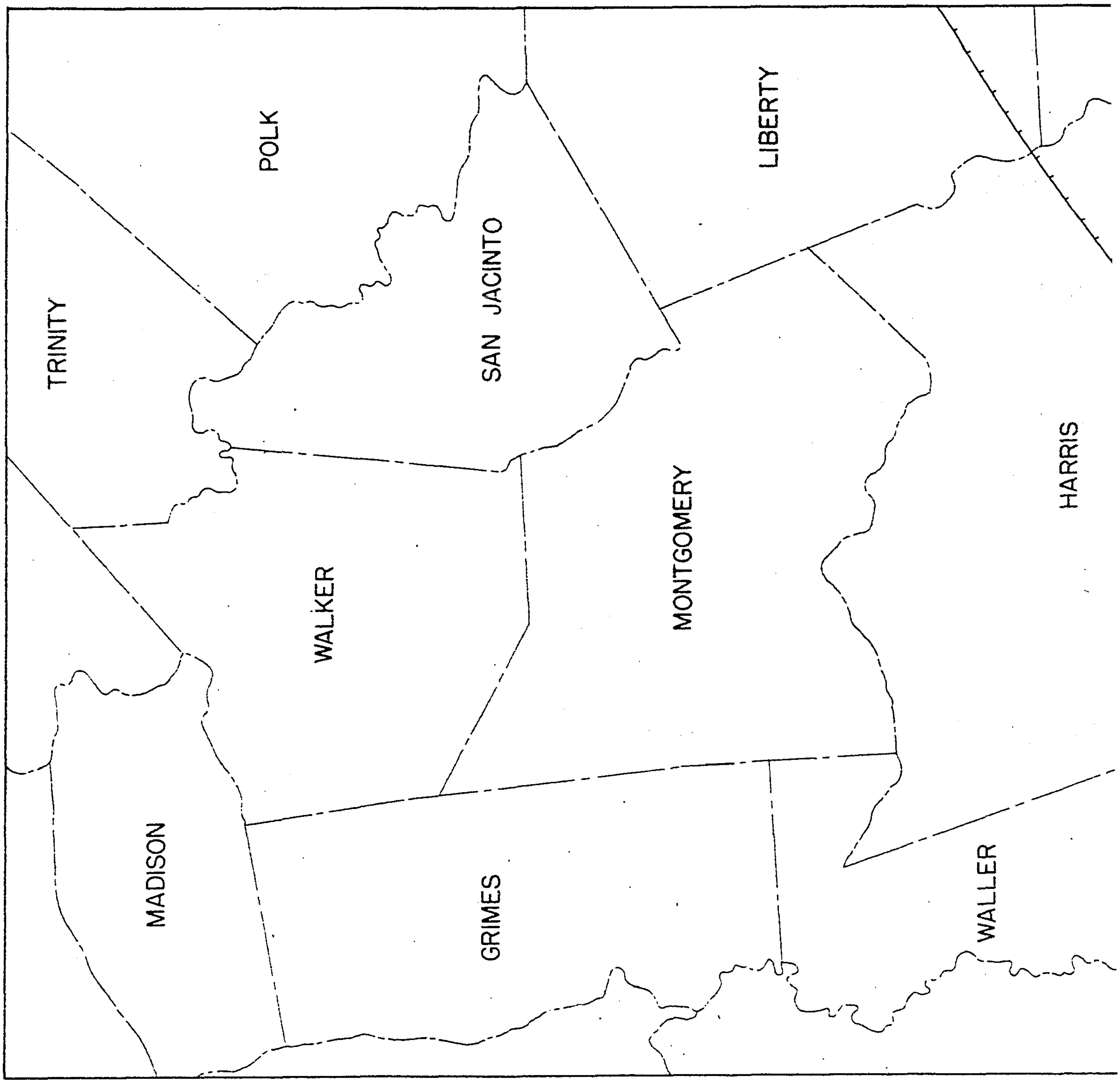
marine fossils are universally present in the Frio. One well located in the Old Ocean area of Matagorda County was drilled through 1600 feet of marine Frio strata. The non-marine Frio in the areas along the strike of central Harris County and in the areas up-dip from here changes into a marine facies southward.

The arkosic character of the sands and the dearth of pyroclastic material in the Frio of southwestern Texas indicates a different source of the sediment there than in southcentral and southeastern Texas where the Frio sands are non-arkosic and pyroclastic material is abundant. The Frio of southwestern Texas was deposited by east-flowing streams, and the source must have been the outcrop of igneous rocks, as well as limestone and shale, in Mexico. This region was south of the main area of volcanic activity and received only a small amount of ashy material. The Frio of the central and eastern parts of the Texas Coastal Plain was deposited by south-flowing streams. The source of the sediment was in a region toward the north which was receiving pyroclastic material since the volcanic centers were in the belt of westerly winds. The Frio of the central and eastern parts of the Texas Coastal Plain has, therefore, much reworked pyroclastic material, and it also has some that was deposited directly in the beds. Since the source area for this part of the Frio had only sedimentary rocks outcropping, the sands are quartzose.

Paleogeography.

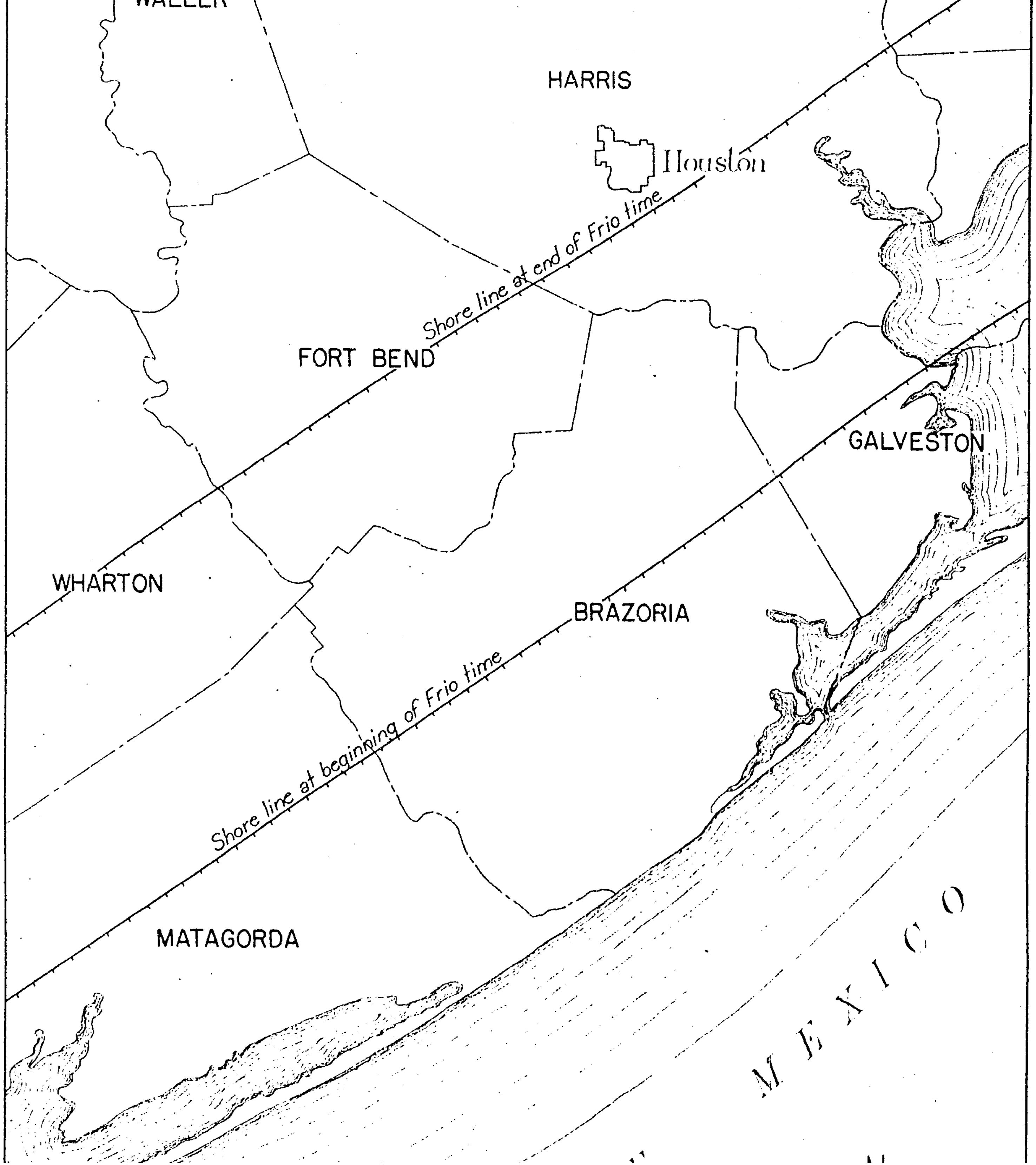
Marine deposition continued throughout all of Frio time in the region of the present shore line. The Frio seas gradually moved inland and by the close of the epoch the shore line was somewhere

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.



Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.



Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

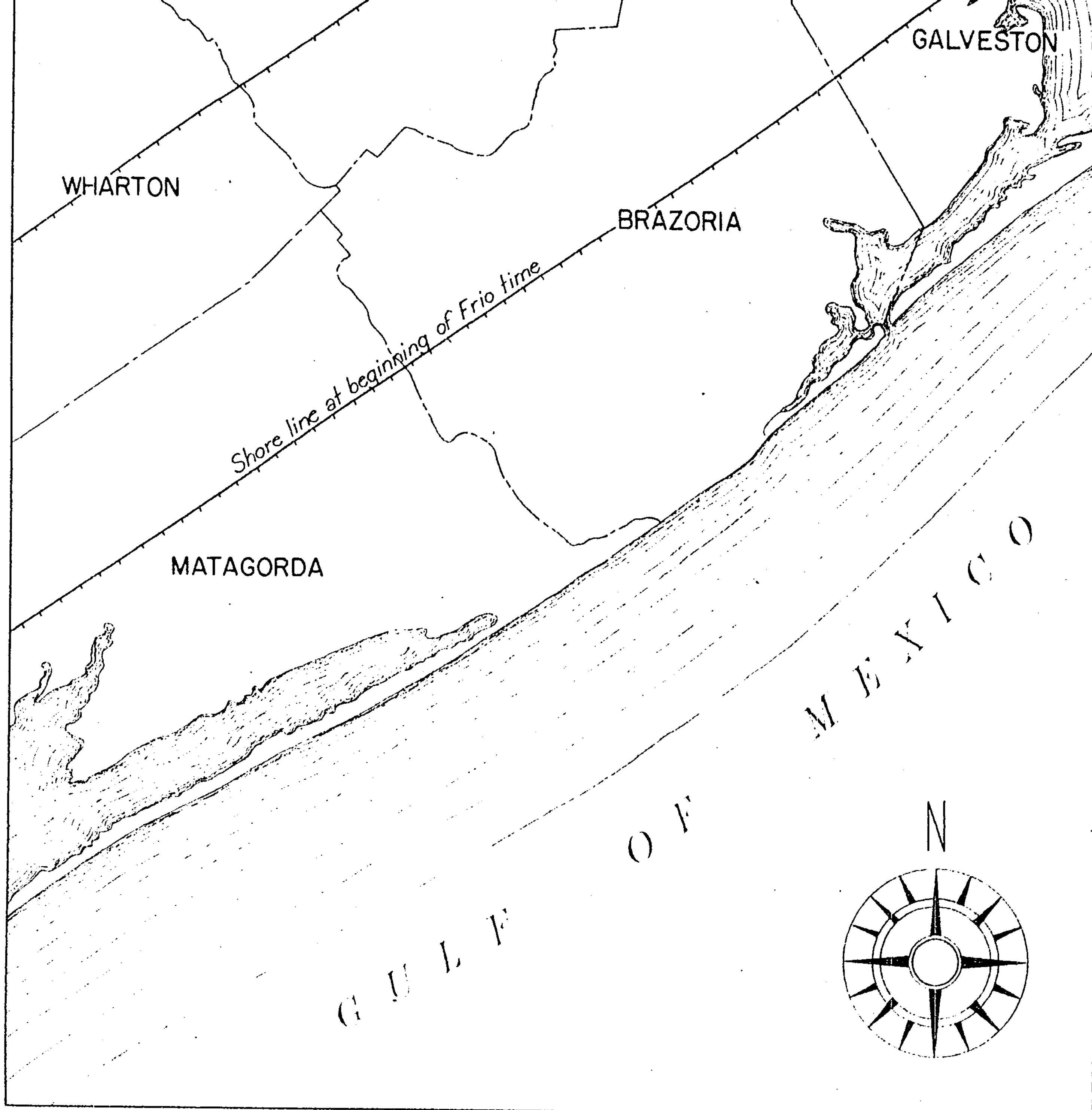


Fig. 4

PALEOGEOGRAPHIC MAP FOR FRIO TIME

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

between the Harris County-Galveston County line and the parallel of Houston (Fig. 4). Several fossil zones have been reported in the upper 300 feet of Frio at Hastings Field in northern Brazoria County. On the other hand, the Frio in the Amerada Petroleum Corporation's No. 1 Mellie Esperson well, located in the Deer Park area 9 miles east of Houston, contained ash beds and abundant plant remains but no marine fossils. The shore line at the close of Frio time must, therefore, have been between these two areas.

The Frio-Catahoula Problem.

The age of the Frio and the correlation of the subsurface Frio with outcropping beds are in question and a subject of controversy among Gulf Coast geologists.

The Frio is overlain by a marine wedge in an area extending inland from the present shore line approximately 80 miles in eastern Texas and considerably less than 80 miles in southwestern Texas. The marine wedge is divided into the *Marginulina*, *Heterostegina*, and *Discorbis* zones. Above the marine wedge is a sequence of pyroclastic and fluviatile beds generally called the subsurface Catahoula. The surface Catahoula also is composed of pyroclastic and fluviatile sediments. It rests unconformably upon the Jackson in the central and eastern parts of the Texas Coastal Plain and unconformably upon the Frio in southwestern Texas.

In attempting to correlate the subsurface beds from the base of the Frio to the top of the Catahoula with outcropping beds, three possibilities arise.

First, the surface Catahoula may be the equivalent of the

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

subsurface Frio making the subsurface Catahoula the equivalent of the lower part of the surface Fleming.

Second, the surface Catahoula may be correlated with all the beds between the base of the subsurface Frio and the top of the subsurface Catahoula.

Third, the surface Catahoula may be the equivalent of the subsurface Catahoula - the pyroclastic deposits above the marine wedge - in which case the truncated surface of the Frio would be completely overlapped by the Catahoula in the eastern and central parts of the Texas Coastal Plain and partly overlapped by the Catahoula in southwestern Texas.

Sufficient evidence is now available to eliminate the first possibility. Dip sections in San Patricio, Bee, and Live Oak Counties show that the clearly discernible Catahoula-Fleming contact in well sections can be traced up-dip and is found to come out at the surface exactly where the Catahoula-Fleming (Catahoula-Oakville) contact has been mapped at the surface. The well sections are sufficiently close together and the contact sufficiently clear to make the tracing of this contact from sub-surface sections to the surface indisputable. The subsurface Catahoula cannot, therefore, be correlated with the lower part of the surface Fleming, eliminating the correlation of the surface Catahoula _in toto_ with the subsurface Frio.

Another fact unfavorable to the first possibility is made clear by projecting toward the outcrop the observed rate of thinning of the subsurface Catahoula and Frio in the area where the marine

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

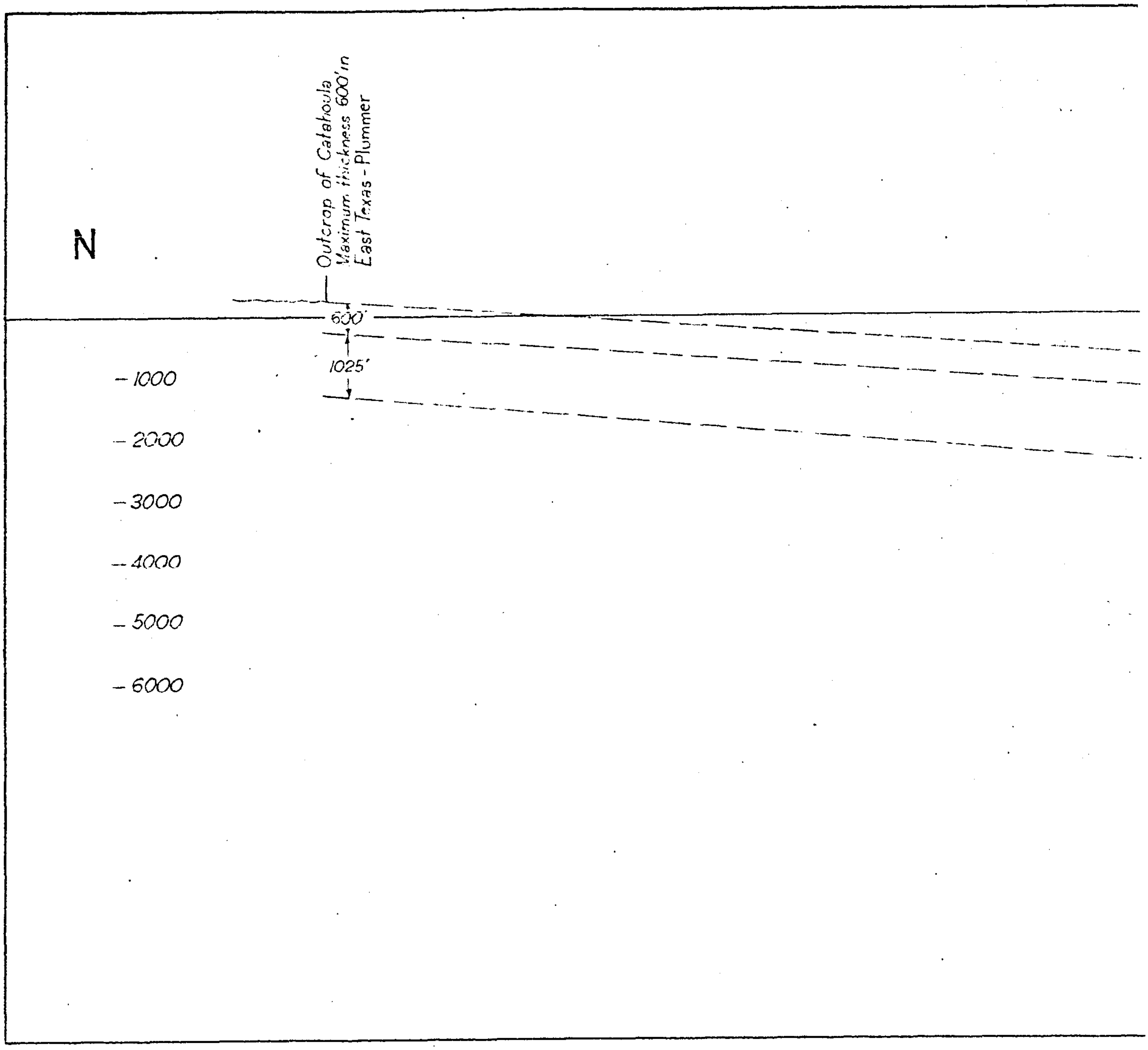
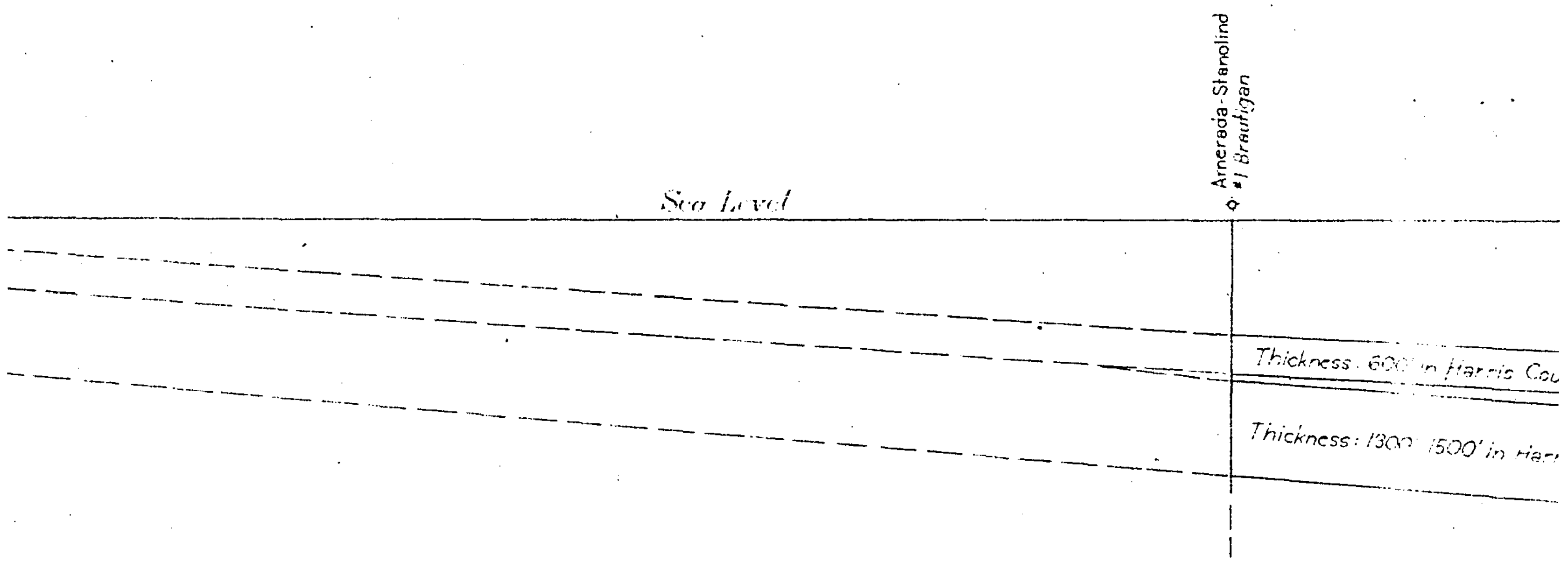


Fig. 5

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.



CROSS-SECTION SHOWING THAT THICKNESS OF FORMATIC
OF FORMATIONAL THINNING INDICATE A CORRELATION OF
CATAHOULA WITH PYROCLASTIC BEDS ABOVE MARINE WE
OF THOSE BELOW MARINE WEDGE IN WELL S

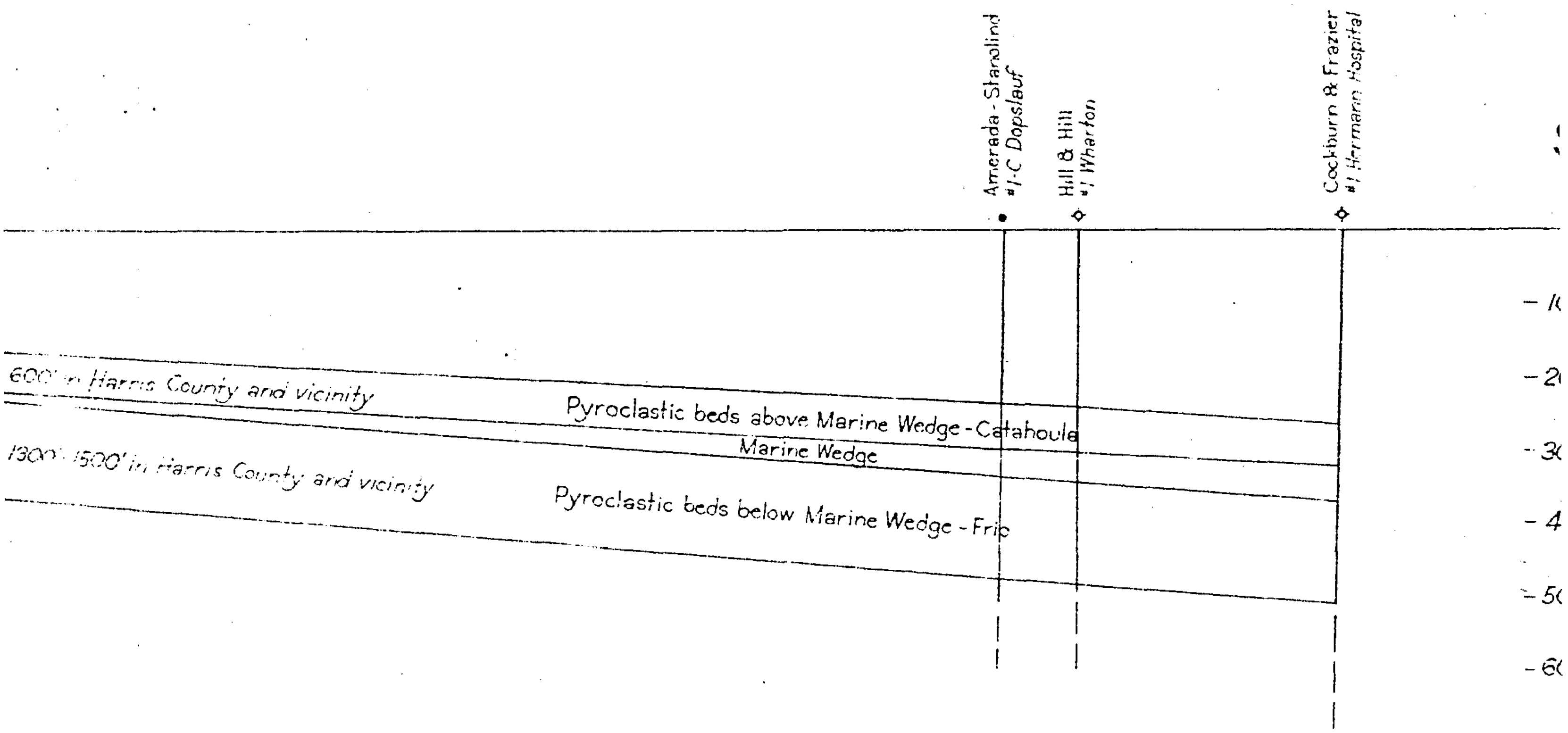
Horizontal scale: 3 Miles

Horizontal Scale

0 5 10 15

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.



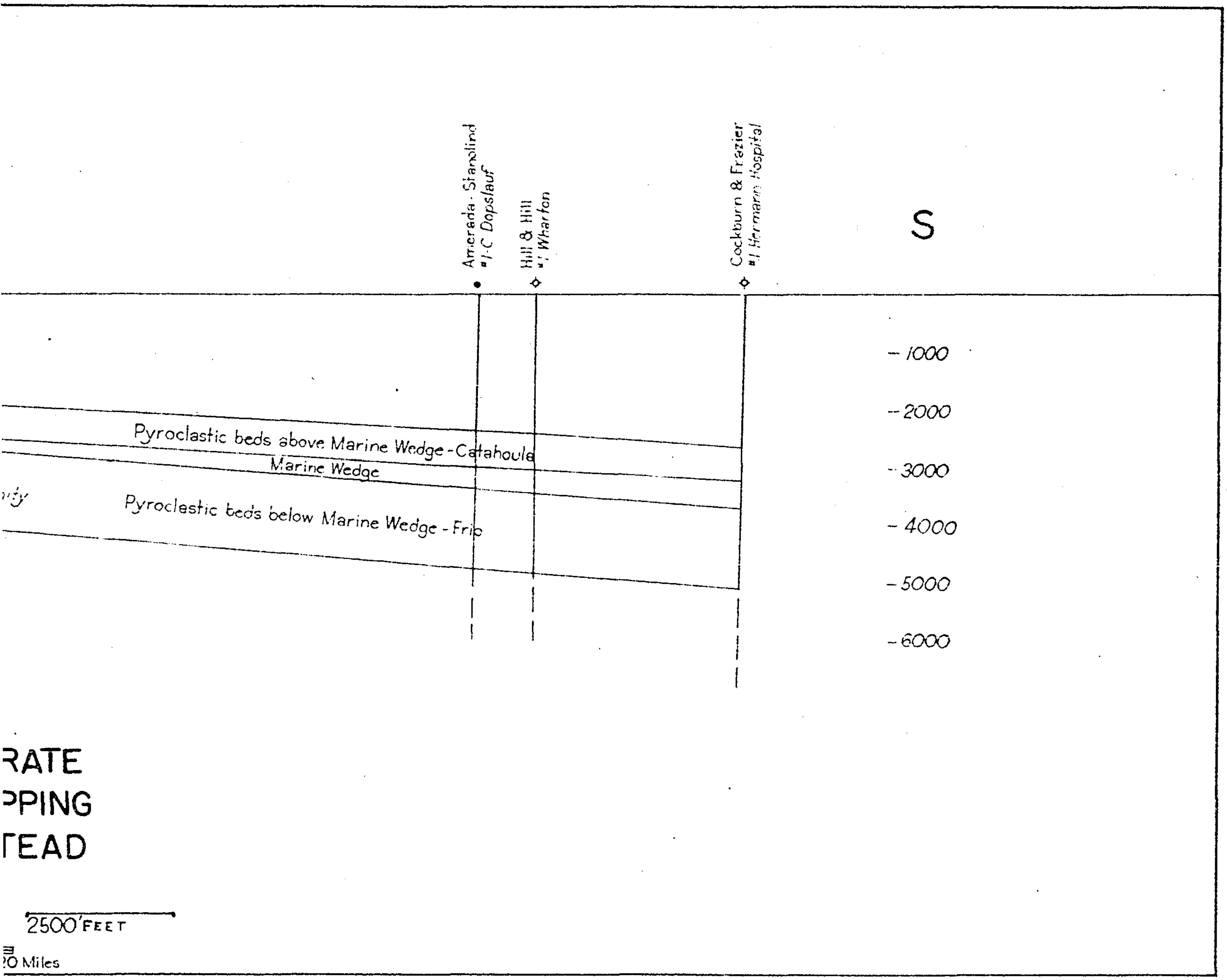
FORMATIONS AND RATE
.ATION OF OUTCROPPING
ARINE WEDGE INSTEAD
N WELL SECTIONS

Vertical scale: 2500' FEET

15 20 Miles

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.



Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

wedge is present to see which series of beds has a thickness more consistent with the observed thickness of the Catahoula at the outcrop (Fig. 5). The Catahoula is from 200 to 300 feet thick at the outcrop north and northwest of Harris County. It thickens to about 600 feet east of here and from 800 to 1000 feet southwest of this area. The probability is that 600 feet represents the true thickness of the Catahoula in the first area mentioned because there is an unconformity at the top of the Catahoula and the Fleming seems to overlap the Catahoula in this area. However, this does not appear to be critical since the projected thicknesses do not indicate that the subsurface Frio is the equivalent of the Catahoula whether a thickness of 200 or 600 feet is used for the latter formation.

In selecting the area to make the projections, well sections should be found which are as near to the inner limit of the marine wedge as possible since this will permit an unquestionable determination of the contacts of the formations and at the same time be near the outcrop thus reducing the margin of error by limiting as much as possible the area over which the projections are to be extended. The down-dip well should be located far enough south to show a marked change in thickness, if the formation does thicken gulfward, and at the same time a section should not be used along the strike of southern Harris County and northern Brazoria County because here the rate of thickening increases greatly. The most northerly well section with the marine zone present that could be found in eastern Texas is located in southern Montgomery County

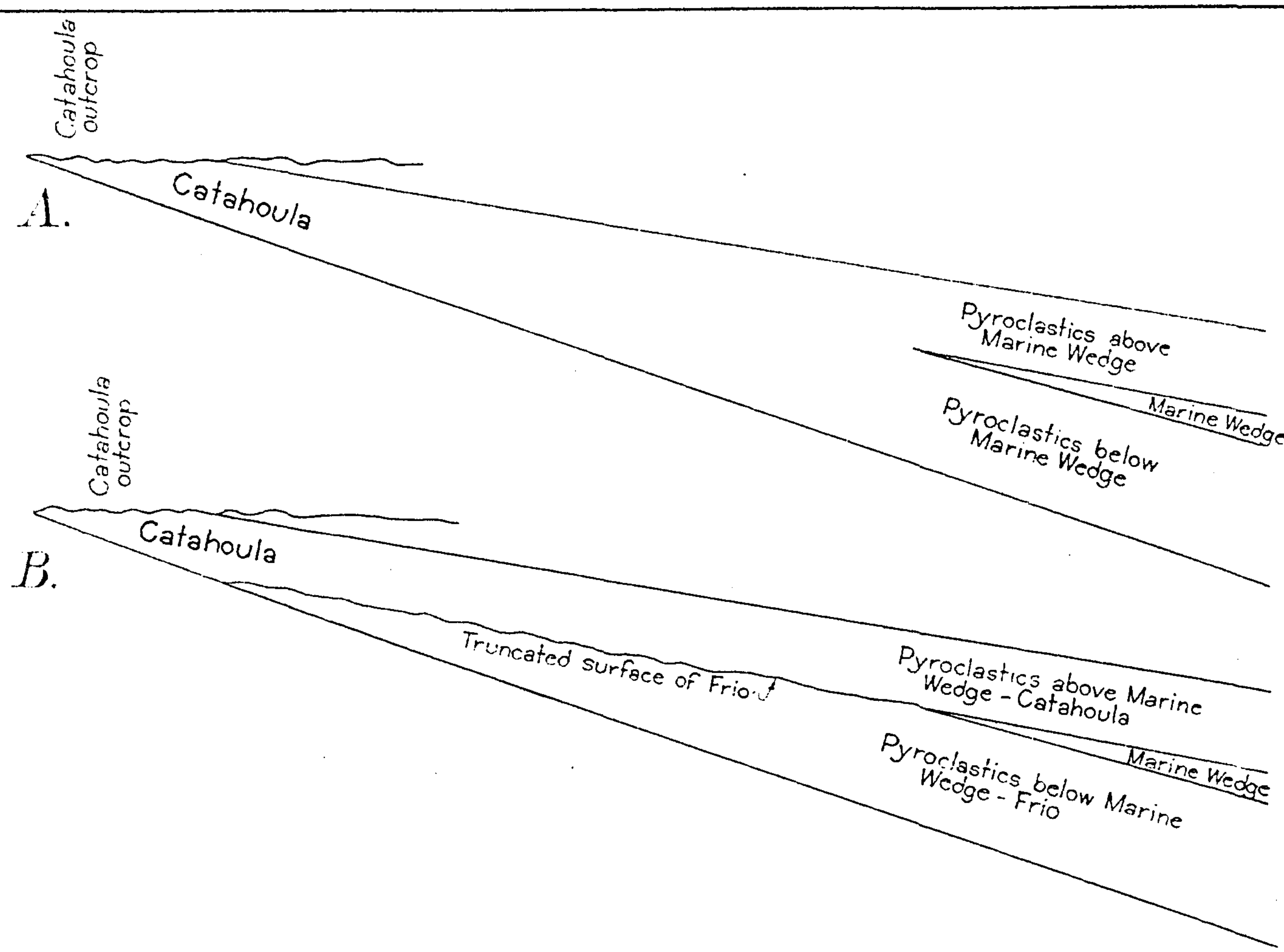
Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

just north of Tomball Oil Field. The marine zone is only 40 feet thick in this well section and the Frio is 1300 feet thick. In a well section 19 miles south of here the Frio is 1460 feet thick. This is a thinning of 8.4 feet per mile. If this rate of thinning is projected to the outcrop, the Frio should be 1025 feet thick. Nowhere in eastern and central Texas is there such a great thickness of Catahoula beds. On the other hand, the strata containing pyroclastic material above the marine zone is 620 feet thick in the first well mentioned and 600 feet thick in the well to the south. Samples were taken only at 20-foot intervals in these wells so that there is a limit of error from 20 to 40 feet in the recorded thicknesses of these formations. The Catahoula seems to be the only formation in eastern Texas which does not thicken gulfward. The thickness of the beds carrying ash and tuff above the marine zone in these wells is much more consistent with the thickness of the Catahoula in eastern Texas at the outcrop where it is from 300 to 600 feet according to Plummer[1].

1. Plummer, F. B., loc. cit., p. 714.

The Catahoula-Frio problem is thus reduced to the two alternatives shown in Fig. 6. Either the surface Catahoula is equivalent to all subsurface beds from the base of the Frio to the top of the pyroclastic deposits above the marine wedge or it is the equivalent only to the pyroclastic beds above the marine wedge i.e. the subsurface Catahoula. Fortunately, critical evidence is to be found in the lithology of the deposits in question.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.



SHOWING ALTERNATIVE CORRELATIONS OF SUBSURFACE SECTION WITH SURFACE CATAHOULA

A. Correlation of outcropping Catahoula with subsurface pyroclastics below Marine Wedge, Marine Wedge, and pyroclastics above Marine Wedge.

B. Correlation of outcropping Catahoula with subsurface pyroclastics above Marine Wedge

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

The amount of pyroclastic material increases greatly toward the southwest in the surface Catahoula but it decreases greatly toward the southwest in the subsurface Frio. Plummer[1] states that

1. Plummer, F. B., loc. cit., p. 720.

in the surface Catahoula "pyroclastic materials predominate in the south Texas area. Boulders, pebbles, and chunks of lava, porphry, and pumice are common in McMullen, Duval, and Starr Counties." He believes that some of the craters "were located in or near the southwestern part of the state because in south Texas the volcanic material is thickest and coarsest".

The subsurface Frio on the other hand, contains very little pyroclastic material in southwestern Texas, and the pyroclastic material that is present is fine. It seems impossible that such a change in the amount and texture of this material could take place in the few miles between the outcrop and well sections down-dip. Southwestern Texas thus appears to have been remote from volcanic craters during the time of the deposition of subsurface Frio beds and near the craters during the time of deposition of the surface Catahoula beds. The subsurface Frio cannot therefore be contemporaneous with any part of the surface Catahoula.

The absence of any conspicuous intraformational hiatus in the Catahoula that could be contemporaneous with the retreat of the sea during late Heterostegina and Discorbis time suggests that the Catahoula is post-Discorbis. An uplift sufficient to cause the sea to retreat nearly 65 miles would probably cause such an interrup-

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

tion in sedimentation at the site of the present outcrop that a conspicuous hiatus would now be visible in the exposed section. If the Frio and the marine wedge were Catahoula in age then the hiatus would be within the outcropping Catahoula. No such hiatus is found in the Catahoula, but a major unconformity is found at its base. The most probable assumption is that the same uplift that caused the formation of this basal unconformity caused the seas to retreat during late Heterostegina and Discorbis time. If this is true, then the surface Catahoula is the equivalent to the pyroclastic strata above the Discorbis zone in the subsurface section.

The known facts thus indicate that the Frio is older than the Catahoula. Observed conditions are best explained with the idea that the Catahoula completely overlaps the truncated surface of the Frio in central and southeastern Texas and partially overlaps it in southwestern Texas. Only in this way can the radical difference in the distribution of pyroclastic material in the surface Catahoula and the subsurface Frio be explained. Likewise, this is the only correlation that will give a major hiatus up-dip to correspond to the retreat of the Heterostegina-Discorbis sea. The writer, therefore, correlates the surface Catahoula with the pyroclastic deposits above the marine wedge and retains the Frio as a separate formation older than the Catahoula.

The present difficulty in understanding the stratigraphic relationship of the Frio arises in part from the fact that the classification of the beds in this part of the section was based on data from well sections located some distance inland where the Frio is continental. These wells went through the continental

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Catahoula then through the marine wedge and into the continental Frio. The Marginulina zone was defined as those beds above the non-marine strata as high in the section as Marginulina sp. is found. Now that deep wells have been drilled near the shore where the Frio is all marine, it is not surprising that fossils typical of the Marginulina zone are found in beds older than the lowest Marginulina beds inland. In other words, the lower limit of the fauna of the Marginulina zone in areas farther inland was determined by the geographic conditions of the times rather than by the distribution of this species in time. Although it is true that some Marginulina zone fossils are found in wells located near the modern shore line in beds that grade up-dip into the upper part of the continental Frio, it is not correct to call the entire Frio the continental equivalent of the Marginulina zone as that zone has previously been defined. The correct approach to this problem is to study the deep well sections along the coast, where all the beds are marine, and to correlate the several stratigraphic units there with the marine type sections elsewhere. Until a definition of the Marginulina zone is made that is applicable both up-dip and down-dip, it is useless to attempt to say how much of the Frio is the equivalent of the Lower Heterostegina and Marginulina zones. That the entire Frio will be found to be the equivalent of the Marginulina zone, as that latter term is now generally used, is highly improbable. The logical view to take of these non-marine beds between the Textularia warreni Beds and the Marginulina zone is that the uppermost part is the non-marine equivalent of the Lower Heterostegina zone and the Marginulina zone and that the lowermost part is the non-marine equivalent of

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

the *Textularia warreni* Beds which were deposited in a retreating sea. A possible exception to the latter is the possibility of an hiatus in the section up-dip which is contemporaneous with the *Textularia warreni* Beds. Just how much is left after the equivalents of the overlying and underlying marine beds have been taken away is not yet known, but it probably represents the greater part of the entire non-marine zone, and this portion must be considered a separate formation. It is convenient, though admittedly arbitrary, for practical working purposes in the inland areas to extend the limits of the Frio formation to include all the continental deposits between the marine wedge and the *Textularia warreni* Beds. While this may be acceptable as a working definition, one should not lose sight of the time relationships of the upper and lower parts of this zone.

Since the strata mapped as Frio at the surface in southwestern Texas represent only the lower part of the entire formation, the remainder being overlapped, it is probable that part or all of these beds at the outcrop are the continental equivalent of the *Textularia warreni* Beds down-dip. The key to this problem is in the presence or absence of an hiatus at the base of the surface Frio.

Miocene Series.
Marine Lower Miocene or Transition Beds.

Extensive drilling operations in the Gulf Coast have revealed the existence of a wedge of marine sandstones and shales between the Frio and Catahoula formations, which is entirely absent in the

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

outcrop. These beds have been placed in the Oligocene by most of the writers on Gulf Coast stratigraphy due to certain Oligocene affinities in the fauna. Recently, however, many Gulf Coast paleontologists have recognized unmistakable Miocene affinities in the fauna of these beds. Of these two main faunal characteristics, namely, the carrying over of typical Oligocene forms and the influx of typical Miocene forms, the latter is the more significant as far as age determination is concerned, and these beds should therefore be taken out of the Oligocene.

This does not necessarily mean that they can be correlated with any known surface formation of lower Miocene age. Attention should be directed to the fact that these are subsurface strata while the type sections described in the literature on the Tertiary are all outcropping deposits. It is altogether possible that these subsurface strata are not the equivalent of any described outcropping formation. Further credence is attached to this idea by the fact that a major unconformity marks the Miocene-Oligocene contact at the outcrop in Texas. This opens up the possibility that these strata are neither typically Oligocene nor Miocene as those terms have been used in surface studies, but are transitional in age, being deposited in part while the hiatus was being formed in the region now occupied by the outcrop. In this case, they would be Miocene in age but older than the Catahoula, the oldest outcropping Miocene formation in the Gulf Coast.

The key to the solution of this problem is the determination of the subsurface equivalent of the outcropping Catahoula. If the pyroclastic deposits above the marine wedge are the time equivalent

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

of the Catahoula, then that part of the marine wedge which was deposited in a retreating sea is contemporaneous with the hiatus at the base of the Catahoula and is transitional between the outcropping Oligocene and Miocene.

Under the discussion of the Frio, evidence was presented which seems to indicate the equivalency between the Catahoula and the pyroclastics above the marine wedge. It is therefore conservative to say that these facts justify a serious consideration of the idea that the upper part of the marine wedge is contemporaneous with the hiatus at the base of the Catahoula and that the marine wedge is truly a transition between the outcropping Oligocene and Miocene.

Fossil Zones.

The marine wedge has been divided into three widely-recognized fossil zones. From the oldest to the youngest these are the *Marginulina* zone, the *Heterostegina* zone, and the *Discorbis* zone. The index fossils for these are *Marginulina* cf. *M. philippinensis* Cushman, *Heterostegina* cf. *H. antillea* Cushman, and *Discorbis* cf. *D. vilardeboana* d'Orbigny respectively.

The top of the *Heterostegina* zone is perhaps the best datum above the McElroy for structural contouring. It extends a considerable distance inland, appears to come in at a very consistent stratigraphic level, and its fauna is easily recognized. The only difficulty in mapping on this zone is the absence of a lithologic change at its top making impossible its recognition in Schlumberger logs.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Thickness and Distribution.

The thickness of this formation varies from 0 feet in southern Montgomery County, where it wedges out, to 3395 feet in southern Galveston County. At Tomball these beds are 40 feet thick, at Fairbanks 320 feet thick, in the Hill and Hill No. 1 Wharton well 340 feet thick, and in southern Harris County and northern Brazoria County they are 850 feet thick. In the Shell Petroleum Corporation's No. 1 Maco Stewart well located in southern Galveston County, this wedge has a thickness of 3395 feet.

These beds have a wide areal distribution. They occupy a belt from Mississippi to southwestern Texas. The marine wedge does not appear at the surface, but is found only in well sections.

Lithology.

Shales, sands, and locally, limestone lentils make up the marine wedge. The relative amount of sand varies locally. At Fairbanks the formation is 31 per cent sand, southwest of Houston it is 10 per cent sand, and in northern Brazoria County the formation is barren of sand except in its extreme upper and lower parts. From Victoria County, Texas, southwestward and in Louisiana, the central and lower parts of this zone are sufficiently sandy to provide an oil reservoir.

Limestone bodies are found in the *Heterostegina* zone and appear to be reefs deposited on local submarine elevations while the sea had reached its maximum of invasion. They are now most commonly found around salt domes located relatively near the modern shore line. A well drilled on the flank of Stratton Ridge Dome in

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

southern Brazoria County encountered 1675 feet of Heterostegina limestone.

The shales are predominately gray in color though they may be brown or greenish. Generally they contrast markedly with the overlying buff-colored Catahoula tuffs and clays and with the underlying green Frio clays. The shales are fossiliferous, glauconitic, and generally micaceous and calcareous. The sandstones are quartzose and very similar to the sandstones of the previously described marine formations.

Conditions of Deposition.

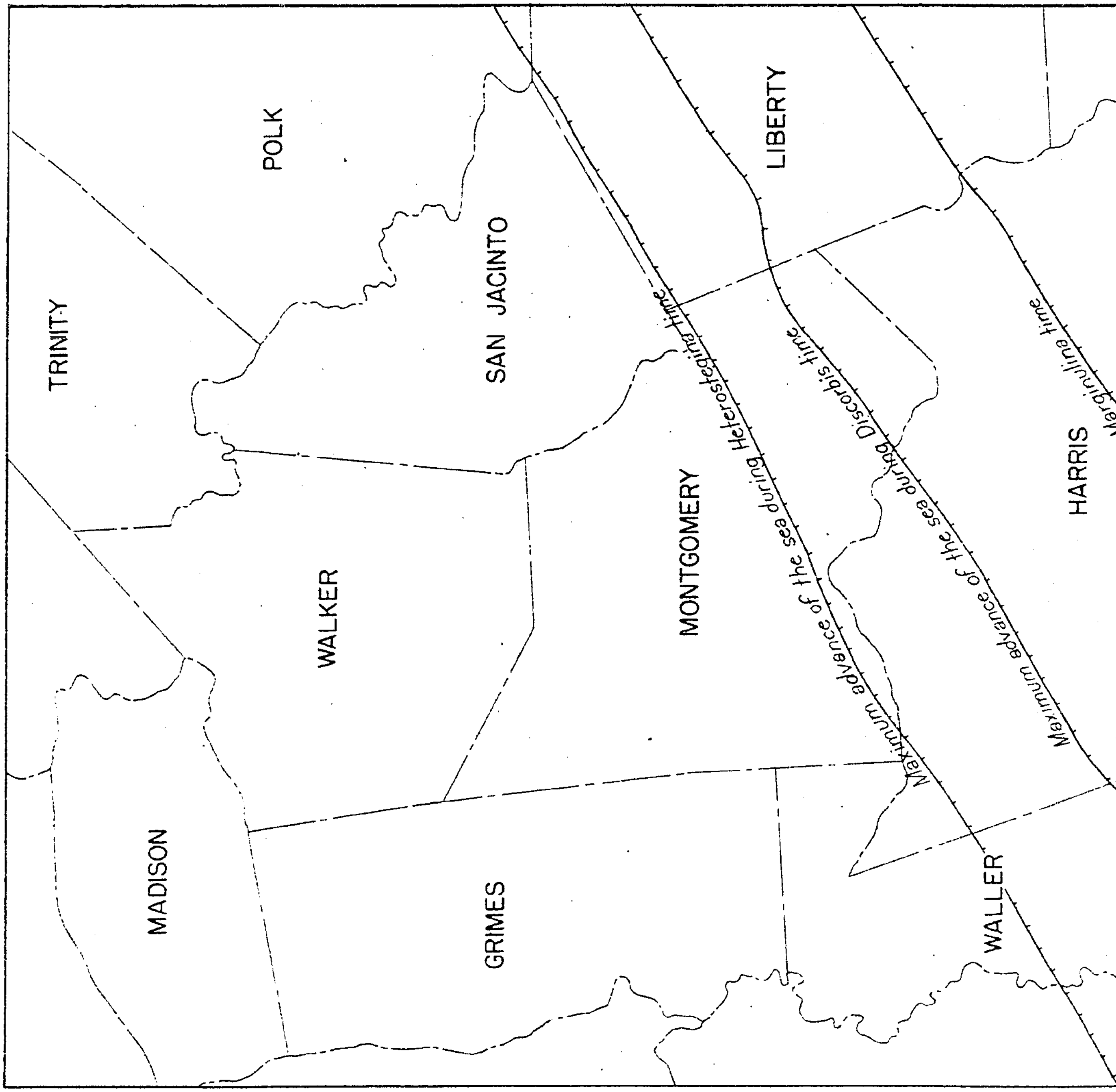
The presence of marine fossils and glauconite everywhere in this formation proves its marine origin. This conclusion is substantiated by the presence of continuous blanket sands in the region southwest of Jackson County, Texas, and also in Louisiana. Since the Heterostegina zone extends farther inland than either the lower or higher zones in eastern Texas, the Marginulina and lower Heterostegina beds must have been deposited in a transgressive sea and the upper Heterostegina and Discorbis beds must have been deposited in a regressive sea. This marine wedge is a typical on-lap-off-lap deposit. In Louisiana and southwestern Texas, the maximum advance of the sea may have been in Discorbis time[1].

1. See p. 88.

Paleogeography.

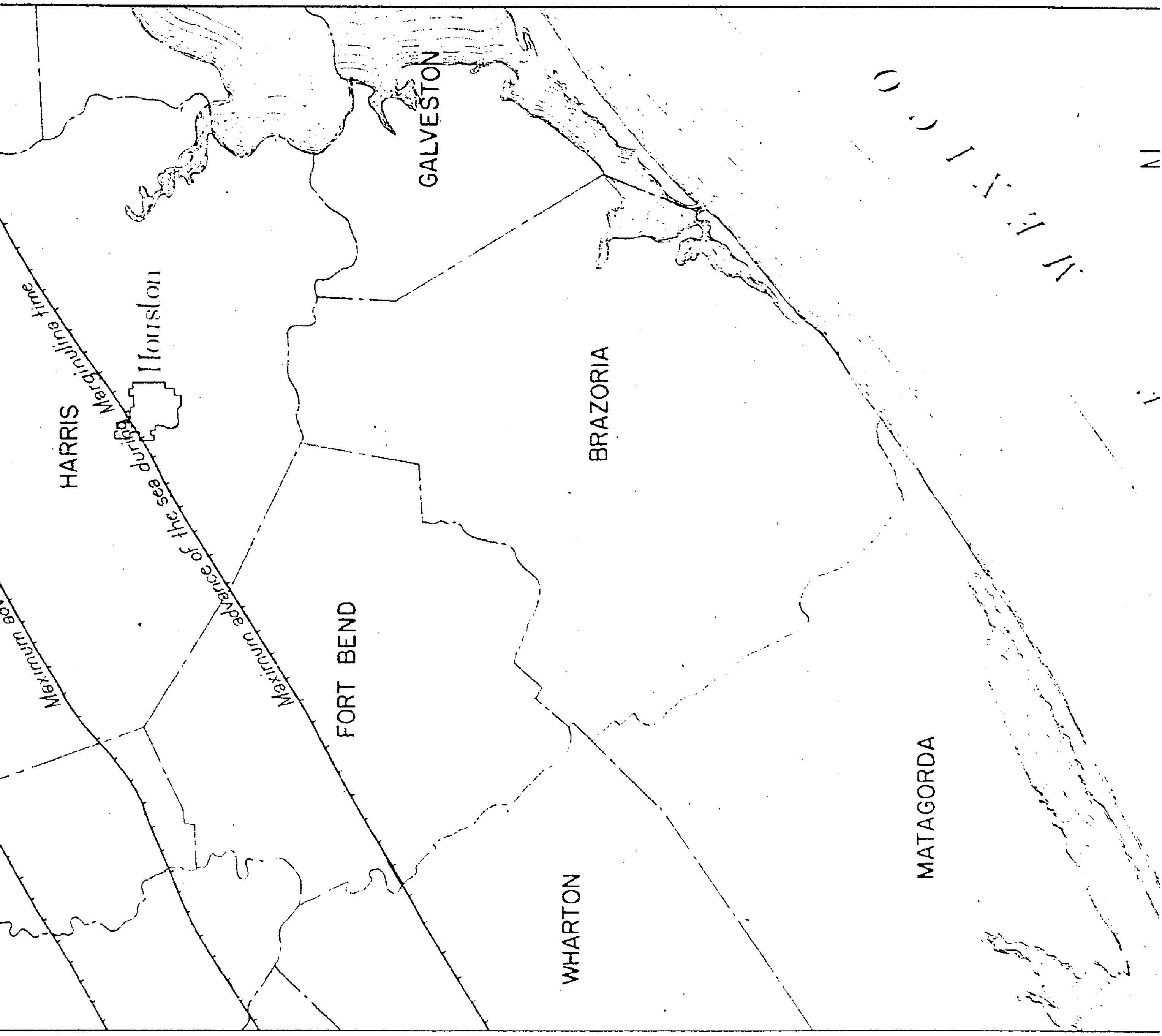
The Marginulina zone is found in well sections in Clinton and

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.



Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.



Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

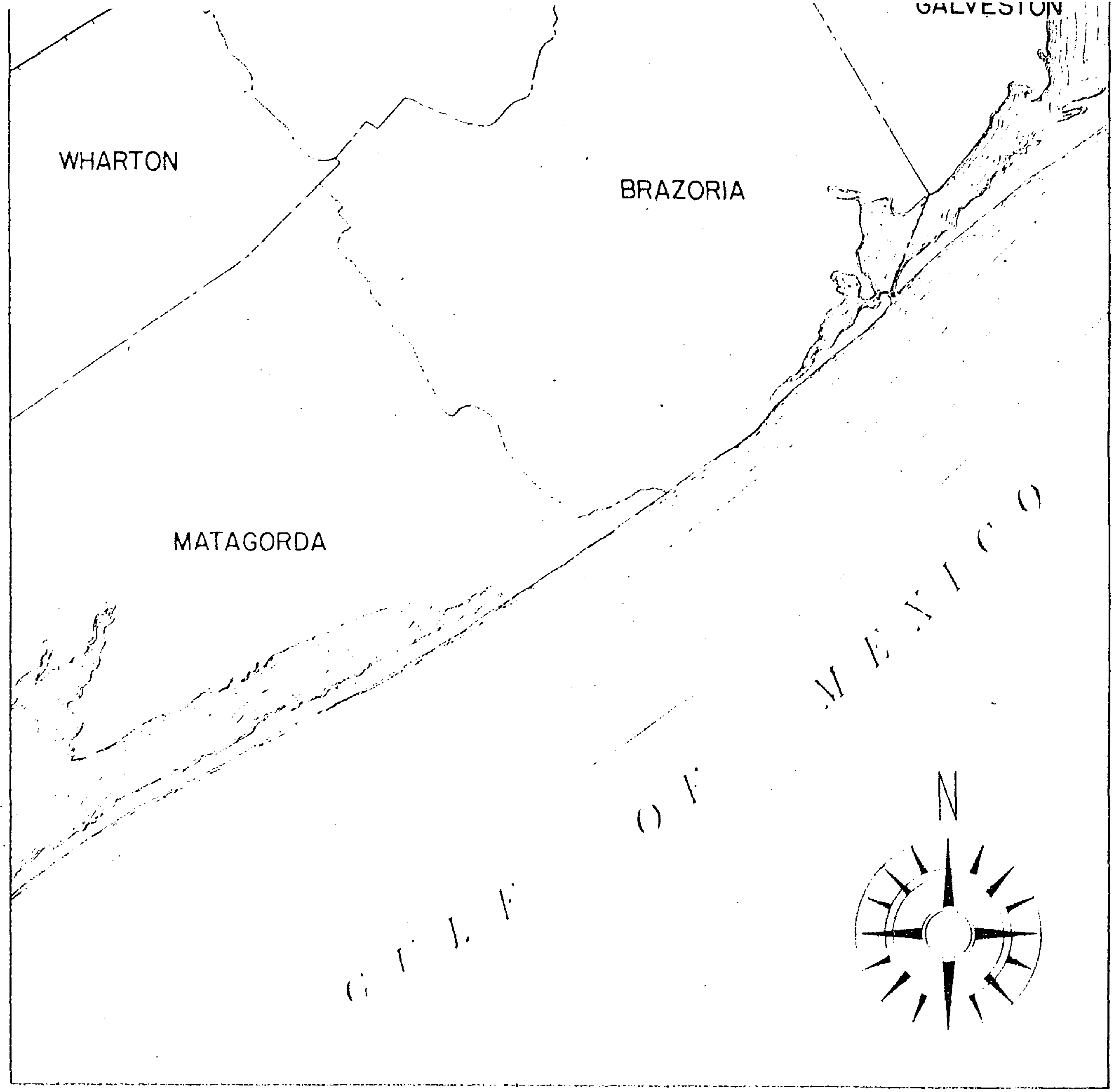


Fig 7

PALEOGEOGRAPHIC MAP SHOWING DISTRIBUTION OF LAND AND SEA DURING MARGINULINA, HETEROSTEGINA, AND DISCORBIS TIMES

Deer Park due east of Houston but is absent at Eureka and Fairbanks a short distance northwest of Houston. The shore line at the end of Marginulina time was in the area now occupied by the northwestern city limits of Houston and followed the present day strike of the beds (Fig. 7). By middle Heterostegina time the seas had advanced to the area now occupied by southern Montgomery County. A test drilled on the north flank of the Tomball structure encountered 40 feet of Heterostegina beds. The maximum of invasion was reached during middle Heterostegina time after which the seas retreated. At the beginning of Discorbis time the strand line was along the strike of Bammel 7 or 8 miles south of Tomball. Its exact position at the close of Discorbis has not been determined, but it was near central Brazoria and Matagorda Counties.

Catahoula Formation.

A series of strata composed largely of pyroclastic material interstratified with fluviatile deposits is found above the Discorbis zone in well sections, above the Frio in the outcrop in southwestern Texas and above the Fayette in outcrop in eastern Texas. This series is generally called the Catahoula, but contemporaneity with the Catahoula of Mississippi and Louisiana has not been definitely established. Howe[1] considers the Catahoula to

---

1. Howe, Henry V., Louisiana Petroleum Stratigraphy: La. Dept. of Conserv. General Minerals Bulletin no. 27, p. 30, 1936.

---

be Lower Miocene in age. This is confirmed by the Miocene affinities in the fauna of the underlying beds.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

The relationship of the outcropping Catahoula with the subsurface beds down-dip has been discussed previously. The preponderance of evidence favors the correlation of the outcropping beds with the 600 feet of pyroclastic strata found above the Discorbis zone everywhere in Harris County and areas along the strike. Near the present shore line the Catahoula grades into a marine series with a fauna which is difficult to distinguish from the fauna of the Discorbis zone.

Contact with the Sub-Formation.

The basal contact of the Catahoula in the outcrop is unconformable. Eastward from Karnes County the Catahoula completely overlaps the Frio, and in places in central Texas it overlaps a portion of the Fayette. The Frio is exposed in southwestern Texas but the Frio-Catahoula contact is unconformable.

Distribution and Thickness.

The Catahoula outcrop is continuous in Texas from the Rio Grande River to the Sabine River. Likewise a series of pyroclastic beds is encountered above the Discorbis zone in well sections everywhere south of the outcrop.

The thickness of the Catahoula is very difficult to determine in well sections where the marine wedge does not occur between it and the Frio because of the similar appearance of these two formations. The upper contact is placed at the top of the first pyroclastic bed. This may not always be an accurate definition of the upper limit of the subsurface Catahoula because the lower part of the Fleming contains some pyroclastic material. The probability

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

is, however, that in eastern Texas no great error is made by thus defining the upper contact of the subsurface Catahoula.

The Catahoula at the outcrop is thinnest in central Texas, being from 100 to 200 feet thick in Gonzales, Fayette, and Washington Counties. It thickens both eastward and southwestward from there, thicknesses from 300 to 600 feet having been reported in eastern Texas and from 800 to 1000 feet in southwestern Texas.

This formation appears to thicken little if any gulfward. The pyroclastic beds above the Discorbis zone are 600 feet thick in the extreme southern part of Montgomery County and over most of Harris County. At Van Vleck Oil Field, Matagorda County, a series of interstratified pyroclastic continental and marine deposits overlies the Discorbis zone. This is probably the equivalent of the Catahoula where it is grading into a marine facies. This zone is 700 feet thick at Van Vleck.

Lithology.

The Catahoula is an interstratification of pyroclastic material and fluviatile sediments. The rocks are tuff, tuffaceous, or ashy sand, ashy clay, sandy clay and clay. The pyroclastics predominate.

Schlumberger logs show that 25 per cent of the formation is a coarse-textured deposit at Tomball, 30 per cent at Fairbanks and 28 per cent in the Westmoreland well. Most of the sand is concentrated into the bottom part of the formation with only a few thin sand beds occurring above. This sand body is frequently called the Basal Miocene Sand and can be readily recognized along the strike of Harris County in the eastern part of the state. Near the

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

modern shore line, the upper part of the Discorbis zone is sandy so that the base of the formation is not readily determined by lithology. In some structures the basal sand becomes very thick. It is 350 feet thick at Hastings field, Brazoria County, and in some structures it is petroliferous.

The sandstone strata are often cross-bedded, generally very ashy, and locally very indurated. Opal, silica, and argillaceous material are common cementing materials. Individual beds may grade horizontally from a well-indurated sandstone into an unconsolidated deposit. Bailey[1] reported the following mineral com-

1. Bailey, Thomas L., The Gueydan, a New Middle Tertiary Formation from the Southwestern Coastal Plain of Texas: The Univ. of Texas Bull. no. 2645, p. 145, 1926.

position of an Upper Catahoula sandstone in Tyler County:

Quartz	30%.
Plagioclase (mainly andesine)	28%.
Chert	25%.
Orthoclase and sanidine	4%.
Microcline	1%.
Magnetite	1%.
Biotite	trace.
Volcanic glass	trace.
Muscovite	trace.
Zircon	trace.
Opal (from cement)	11%.

That the compositions of Catahoula sandstones vary greatly is shown by the following mineral composition of a sample from Gonzales County as reported by Bailey[2]:

2. Bailey, Thomas L., loc. cit., p. 144.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Quartz	70%.
Plagioclase (albite to labradorite)	3%.
Chert	5%.
Orthoclase and sanidine	1%.
Zircon	trace (common).
Magnetite	trace (common).
Horneblende	trace (rare).
Jarosite (occurs in cavities as tiny, orange-colored hexagonal plates with a habit typical of this mineral)	1%.
Volcanic glass	trace (rare).
Hematite (from weathering of jarosite)	trace.
Opal (from cement)	20%.

The majority of the quartz grains are subangular or subround and are colorless. Some of the beds contain "rice sands" which resemble the "rice sands" of the Frio.

The volcanic tuffs are white, buff, gray, or greenish gray in color, are massive, and some types break with a conchoidal fracture. The Catahoula tuffaceous beds may grade from a pure tuff into tuffaceous clays and tuffaceous sand. Some of the tuffs are highly silicified in which case they are relatively resistant and break with a conchoidal fracture. Some appear to be an altered form and may even be reworked. Lava boulders are frequently found in them in southwestern Texas. Bailey[1] gives the following composition for a sample of white tuff from Live Oak County:

1. Bailey, Thomas L., loc. cit., pp. 128-129.

Volcanic glass	70%.
Soda-lime feldspar	20%.
Sanidine	5%.
Quartz	trace.
Leverrierite aggregares	4%.
Opal	1%.
Magnetite	trace.
Marcasite	trace

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Zircon	trace.
Apatite	trace.
Chlorite	trace.
Serpentine (?)	trace.
Barite	trace.
Witherite	trace.

The Catahoula clays in central and eastern Texas are generally buff, gray, or green in color and they are commonly very ashy. These clays are commonly red in the extreme southwestern part of the state and resemble the red Frio clays.

Conditions of Accumulation.

Volcanic centers in the west were exceedingly active during Catahoula time. The ejected material was deposited widely over the western part of the Gulf Coastal Plain. Much of the material has been reworked by the coastal plain streams of the time. These streams deposited some non-pyroclastic material also. Rarely, however, are the fluviatile deposits found to be entirely free of tuff, indicating that the volcanic activity was quite continuous. The feldspar in the sands indicate that the source of the non-pyroclastic deposits was near the coastal plain. The streams in eastern Texas were more vigorous than those in the west in the latter part of Catahoula time and more sand was deposited in the former area than the latter.

Fossils are not common in the continental facies of the Catahoula. Unios and a number of fossil plants have been observed in some beds. Berry[1] reports a relative abundance of palms which

1. Berry, Edward Wilber, The Flora of the Catahoula Sandstone: U. S. G. S. Prof. paper no. 98, pp. 227-251, 1916.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

indicates a tropical climate.

Paleogeography.

The Catahoula is rarely cored in well sections so that good descriptions of this formation in down-dip well sections are lacking. It appears certain, however, that the Catahoula along the strike of Harris County is continental. This is indicated by the ash beds and the absence of marine fossils and glauconite. Previous mention has been made of the presence of 700 feet of section above the Discorbis zone at Van Vleck which contains both marine and non-marine beds. The ash and bentonite in these beds indicate that this is the equivalent of the pyroclastic deposits above the Discorbis zone in Harris County, which in turn, is correlated with the surface Catahoula. The Catahoula shore line thus appears to have been in central or northern Matagorda, Brazoria, and Galveston Counties.

Miocene and Pliocene Series

Fleming Group.

The Fleming group, which overlies the Catahoula, is a sequence of mottled calcareous clays and sands. Southwest of the Brazos River it has been divided into the Oakville sand below and the Lagarto clay above. In southeastern Texas however, the Oakville changes into a clayey facies which cannot be distinguished from the Lagarto clay either in the outcrop or in well sections. For this reason all the Fleming strata are grouped together in the discussion which follows.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Fleming strata are distinguished from the Catahoula by the presence of reworked Cretaceous fossils, and large amounts of lime in the clays and sands and by the dearth of pyroclastic material. In central and southwestern Texas, the basal Oakville contains some pyroclastic material but this was probably derived largely from the Catahoula. There is little ash in the Fleming of southeastern Texas. The Fleming is distinguished from overlying strata by the presence of reworked Cretaceous fossils.

Contact with the Sub-Formation.

The basal contact of the Fleming is unconformable at the outcrop. Locally a basal conglomerate is present. The upper part of the Catahoula in southcentral Texas is overlapped by the Fleming. As in the case of other Tertiary formations, the gulfward extent of this hiatus is unknown.

Distribution and Thickness.

This group of strata occupies a continuous belt along the margin of the Texas Gulf Coastal Plain. It is found in every well section south of the outcrop except in those located over salt plugs which have pierced it.

The following list shows the thickness of the Fleming in a series of well sections in Montgomery, Harris and Brazoria Counties:

Stanolind-Amerada No. 1 Fred Brautigan, located in southern Montgomery County. - - - - - - - - - - - 1300 feet

Amerada-Stanolind No. 1-C Louis Dopslauf, located at Fairbanks, Harris County. - - - - - - - - - - 1680 "

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Cockburn and Frazier No. 1 Herman Hospital, located three miles southeast of Addicks in Harris County. - 1685 feet

Capps, Benedum, and Trees No. 1 Westmoreland, located 5 miles west of Bellaire in Harris County. - 2224 "

Amerada No. 1 Houston Farms Dev. Co., located in southern Brazoria County. - - - - - - - - - - - - - 4000 "

As stated previously, there is some doubt as to the down-dip equivalent of the Catahoula. This will affect the thickness of the Fleming reported in the last well. If the down-dip equivalent of the Catahoula is the upper part of the Miocene Discorbis zone, then the Fleming in the last-mentioned well is 4700 feet thick.

Lithology.

The Fleming is composed of sandstone and calcareous, mottled clay. The relative amount of sand varies. Generally, there is less in southeastern Texas than in the southwestern part of the state. At Fairbanks it is approximately 25 per cent sand and at Rattlesnake Mound in southern Brazoria County it is approximately 35 per cent sand.

The sand grains are predominantly quartz, but lime nodules are very common. The cementing material is often calcite. The sandstone strata are lenticular and more often friable than well-indurated, but in southwestern Texas the Oakville sandstones are sufficiently strong and continuous to form the Bordas cuesta. No equivalent of this escarpment is present in eastern Texas because clays replace the sandstones east of the Brazos River. Most of the Fleming sands are intricately cross-bedded.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

The clays are calcareous and mottled. Tan, red, green, purple and gray are common colors in Fleming clays. They are poorly bedded and contain numerous lime concretions and reworked Cretaceous fossils.

The following is a generalized description of the Fleming as shown by the rock-cuttings from a well at Fairbanks:

(Figures at left are distances in feet from top of group.)

0-640	Predominantly fine-textured quartzose sand with lime nodules and small amounts of red, brown, and gray clay.
640-1000	85 per cent purple, red, brown, and gray mottled clay and 15 per cent fine-textured sand.
1000-1180	Predominantly fine-textured quartzose sand with lime nodules and small amounts of mottled clay.
1180-1320	50 per cent fine-textured sandstone and 50 per cent calcareous, mottled, gray, green, and brown clay.
1320-1640	Fine-textured sandstone with a small amount of mottled, calcareous clay.
1640-1680	60 per cent red, brown, gray, and green mottled, calcareous clay and 40 per cent fine-textured sandstone.

The above description shows too high a percentage of sand because overlying sand formations cave in the hole and contaminate the samples of the rock-cuttings. Bailey[1] described the following section from the outcrop of the Lagarto in Colorado County:

1. Bailey, T. L., The Geology and Natural Resources of Colorado County: The Univ. of Texas Bull. no. 2333, p. 78, 1923.

Unconformity

Lagarto

2. Whitish gray and yellowish-white, greatly cross-bedded and irregularly-bedded, conglomeratic sandstone interbedded with strata of bright to dull yellow sands. Most of the sandstone, conglomerate and sand contains abundant pebbles of yellow clay. All these beds are strongly

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

calcareous. The sands are thin in the upper part but near the base one bed locally reached a thickness of 5 feet. Thickness of No. 2 - - - - - - - - 10' to 30'

3. Ocher-yellow, concretionary, laminated marl containing calcareous concretions - - - - - - - - - - - - - - - 0' to 5'

4. Massive buff to bright yellow, gray-splotched, joint clay containing calcareous concretions up to 3 inches in diameter. Exposed - - - - - - - - - - - 20' to 40'
(The upper surface of this clay is irregular and undulatory and sandstone lenses occur in the upper 5 feet. The great variation in thickness is due to the irregular bedding of these rocks.)
Covered with later terrace gravel and fill from outer edge of Cummins Creek bottom to bank of creek - -20'

5. Cross-bedded sandstone, similar to No. 2 to water's edge. (No. 5 is exposed in the vertical bank of Cummins Creek) - 10' to 20'

Conditions of Deposition.

The Fleming is a fluviatile complex laid down upon the eroded south-sloping surface of the Catahoula. Some of the deposits show a deltaic structure, but much of it is channel deposit of numerous widely-meandering streams.

The sudden influx of great amounts of calcareous material at this time together with the presence of reworked Cretaceous fossils in Fleming beds shows that the region of the Cretaceous outcrop was abruptly uplifted and was the source of the Fleming deposits. The Cretaceous fossils present include both foraminifera and macrofossils. The Fleming in well sections near the present shore contain glauconite and late Tertiary foraminifera, indicating that a marine facies is present.

Paleogeography.

The younger beds encountered in most wells are so poorly

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

logged that sufficient accurate data is not available for the determination of exact position of the Fleming shore line. These beds are almost entirely continental along the strike of Harris County. In the Amerada Petroleum Corporation's No. 1 Houston Farms Development Company well in southern Brazoria County, however, Miocene foraminifera are present throughout the Fleming and other wells similarly located show the same condition. The Fleming is unquestionably marine at the site of the modern shore line. The probability is that except for minor fluctuations the Fleming shore line passed through the central or northern part of the most southerly tier of counties.

Pliocene Series.
Willis Formation.

The post-Fleming formations cannot be differentiated in most well sections, and the study of this part of the section is consequently based on surface data. If cored sections were available a subsurface study of these beds would undoubtedly be possible. However, they are generally neither cored nor sampled except in rare cases where special core tests are drilled for correlation purposes, and the data from such core tests is generally not available for publication.

The name "Willis" was first proposed by Doering[1] for the strata

1. Doering, John, Post-Fleming Surface Formation of Coastal Southeast Texas and South Louisiana: A. A. P. G. Bull. vol. 19, no. 5, pp. 651-688, 1935.

between the Fleming and the Pleistocene. Plummer[2] had previously

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

2. Plummer, F. B., loc. cit., pp. 761-762.

recognized these strata as distinct from either the Fleming or Lissie, but he did not name them. The Willis has been recognized under that name as a valid formation on the 1937 geologic map of Texas.

According to Doering, this formation is the equivalent of the Upper Citronelle. Although most of it is probably younger than the Goliad of southwestern Texas, the lower part of the Willis may be the equivalent of the upper part of the Goliad.

The basal contact is unconformable. The underlying formation in southeastern Texas is the Lagarto, but in places in central and southwestern Texas it is probably the Goliad.

Distribution and Thickness.

The Willis has been mapped in Texas from the Colorado River to the Sabine River, but strata belonging to this formation are also present southwest of the Colorado River. It also occupies a discontinuous belt across southern Louisiana. Wherever a stream of any size crosses the Willis belt, the beds are either eroded away or covered, giving an irregular pattern to the outcrop area.

Doering states that the Willis is from 80 to 85 feet thick in southeastern Texas and southwestern Louisiana and from 120 to 125 feet thick in southeastern Louisiana.

Lithology.

The Willis is composed of alluvial gravels, sands, and clays. The gravels and sands are quartzose and generally light-colored and

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

cross-bedded. In a section north of Tomball, many ferruginous nodules are disseminated through the sand. The sand is red and somewhat indurated. The sands in other parts of the formation are light gray. Willis clays are generally disseminated through the sands and gravels, but a few clay beds are present in the formation.

Doering has recognized three lithologically distinct members in the Willis formation. The reader is referred to his paper for detailed descriptions of these members.

Conditions of Accumulation.

All outcropping beds of the Willis are fluviatile in origin. They were deposited upon the eroded surface of the older beds after a down-warping of the Coastal border brought about a change from a cycle of denudation to one of deposition. The presence of Catahoula material in Willis beds and the presence of isolated remnants of Willis strata over the Fleming outcrop suggests that it was deposited seaward from the Catahoula scarp by streams that had cut through this cuesta. These streams deposited their load of coarse and fine sediment widely over the flat surface behind the scarp. Subsequent erosion has reduced the outcrop to its present limits.

Pleistocene Series.
Houston Group.

The name Houston was first proposed by Plummer[1] for the group

1. Plummer, F. B., loc. cit., p. 780.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

of formations which make up the Pleistocene in the Texas Gulf Coast. The outcrop of the Houston group in eastern Texas is generally limited on the north by the Hockley scarp and on the south by Recent beach deposit. It occupies a continuous belt from the Rio Grande River to the Sabine River. Equivalent beds are present in Louisiana.

The Houston group has been divided into the Lissie and Beaumont formations.

Lissie Formation.

The Lissie formation is a sequence of gravels, sands, sandy clays, and clays, and lies above the Willis. It is limited by unconformities at both its upper and lower contacts and is distinguished from the underlying Willis formation by a generally finer texture and from the overlying Beaumont formation by a generally coarser texture.

The Pleistocene age of the Lissie is suggested by the following list of Lissie fossils prepared by Plummer[1]:

---

1. Plummer, F. B., loc. cit., p. 787.

Trucifelis fatalis Leidy	Equus complicatus Leidy
Canis sp.	Equus francisci Hay
Cistudo marnockii Cope	Equus crenidens? Cope
Megatherium sp.	Equus tau? Owen
Bison latifrons (Harlan)	Equus semiplicatus Cope
Mastodon serridens Cope	Equus excelsus Leidy
Glyptodon petaliferus Cope	Equus occidentalis? Leidy
Elephas columbi Falconer	Camelid
Elephas primigenius (Blumenbach)	Ox
Elephas imperator Leidy	

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Distribution and Thickness.

The outcrop of the Lissie is continuous across the Texas Coastal Plain. In a general way, the inner limit of the outcrop is at the foot of the Hockley scarp, but in the larger stream valleys in the eastern part of the state it extends farther north in tongues which cover the Willis and part of the Fleming. This condition is shown clearly on the geologic map of Texas published in 1937.

Wells drilled near the southern limit of the Lissie outcrop show a combined thickness of more than 1000 feet for the Lissie and Willis formations in the vicinity of Harris County. The amount that belongs to the Willis and Lissie respectively cannot be determined since well-cuttings do not show a recognizable difference between these formations. Plummer[1] attributes a thickness of 600 feet to the Lissie in eastern Texas and 400 feet in southwestern Texas. The combined thickness of the post-Fleming strata in the Amerada Petroleum Corporation's No. 1 Houston Farms Development Company well located in southern Brazoria County near the modern shore line is 2060 feet. Again it is not possible to determine how much of this belongs to the Lissie and how much to the Willis and Beaumont.

1. Plummer, F. B., loc. cit., p. 783.

Lithology.

The lissie beds are gravel, sand, sandy clay and clay. Sand

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

predominates, making up more than 50 per cent of the formation. The amount of gravel is less than early descriptions of the formation indicate because Willis beds were then included. Probably not more than 15 per cent of the Lissie is gravel and some estimates are considerably less than this. Plummer[1] states that the Lissie

---

1. Plummer, F. B., loc. cit., p. 785.

" is made up of about 60 per cent sand, 20 per cent sandy clay, 10 per cent gravel, and 10 per cent clay". Bailey[2] has described

---

2. Bailey, T. L., loc. cit., p. 102.

---

the following Lissie section located on the west bank of the Colorado River one-fourth mile north of Garwood, Texas:

Lissie (possibly Beaumont):

Pale yellowish to pinkish, slightly calcareous, medium-grained, loose sand, which is greatly cross-bedded and contains near the middle of the bed a thin layer with pinkish calcareous concretions up to 3 centimeters in diameter - - - 8'

Lissie:

Brownish-red to orange, medium-grained, arenaceous and argillaceous, non-calcareous gravel containing a number of large rounded clay lumps - 2' to 3'

Coarse, cross-bedded, gravelly sand with a few streaks of slightly calcareous red clay - - - - 5'

Sandy gravels with pebbles up to 2 inches in diameter and a few lenses up to 8 inches thick of brownish-red, laminated clay, to water's edge at low stage - - - - - - - - - - - - - - - - - 6'

Total - 28'

The sands are quartzose, frequently cemented with clay, and are cross-bedded. Red, orange, buff and gray are the common colors

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

of the Lissie sands. The gravels occur in lenses, and the pebbles are composed of chert and quartz, and sometimes fragments of igneous and metamorphic rocks.

Lissie clays are mottled red, orange, green, blue and gray. They resemble the Beaumont clays but make up a much smaller preportion of the formation than they do in the Beaumont.

Conditions of Deposition.

The fauna of the Lissie at the outcrop shows that it is nonmarine in origin. Streams which cut through the Willis cuesta deposited alluvial fans which coalesced to form a continuous debris apron behind the cuesta. This was laid down upon the eroded surface of the Willis. Lissie sands were also deposited in the gaps and in terraces in front of the Willis cuesta. Southward these alluvial deposits merge into deltaic and marine deposits. Marine shell fragments are found throughout the Lissie in well sections near the modern shore line and marine microfossils are reported to be present in some of the shale beds.

Bailey[1] and Plummer[2] believe that the alluviation during Lissie

---

1. Bailey, T. L., loc. cit., pp. 111-113.

2. Plummer, F. B., loc. cit., pp. 784-785.

---

time was a direct result of glaciation. The coarse deposits of the Lissie indicate that the Coastal Plain streams of that time were very vigorous. This, in turn, may mean a very humid climate which could have been a result of a glacial epoch. However, it is not

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

sufficient to predicate such a thesis merely on the fact that coarse sediments were deposited, for the Pliocene contains sediments equally as coarse. Although the Pleistocene was generally humid because of the glacial epochs, the Lissie time interval probably includes both glacial and interglacial epochs.

Beaumont Formation.

The Beaumont is a sequence of clays and fine sands, and it occupies a belt along the outer border of the Texas Coastal Plain. It includes all strata above the Lissie and below the Recent deposits. Both upper and lower contacts are unconformable. The Beaumont is distinguished from the Lissie by its much greater clay content and by the absence of gravel. It is also unlike the Lissie in the structure of some of the sand bodies. Surface exposures of sand in the Beaumont of eastern Texas are largely confined to long narrow belts which are believed to be abandoned distributaries.

Distribution and Thickness.

The Beaumont occupies a continuous belt along the border of the Coastal Plain from the Rio Grande River to the Sabine River. This belt is from 40 to 50 miles wide in eastern Texas. Like the Lissie, it extends northward in irregular tongues in the major stream valleys. The equivalent of the Beaumont is also found in Louisiana.

Although the Beaumont-Lissie contact can rarely be established beyond question in well sections, Plummer[1] estimates that the thick-

---

1. Plummer, F. B., loc. cit., p. 788.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

ness of the Beaumont varies between 450 feet and 900 feet and that the average thickness is 700 feet. These estimates appear to be reasonable in view of the fact that the combined thickness of post-Fleming strata is approximately 2000 feet in southern Brazoria County and approximately 1200 feet in central Harris County.

Lithology.

The Beaumont is composed of calcareous, mottled clays and sand and silt. The clays predominate in eastern Texas, comprising as much as 80 per cent of the entire formation in some places. More sand has been reported to be present in the Beaumont of southwestern Texas.

The clays are red, pink, green, tan, blue, and gray. In most places they are plastic and calcareous. Bailey[1] made the following

1. Bailey, T. L., loc. cit., table 4.

analysis of a sample taken from the west bank of the Colorado River nine miles southeast of Garwood, Texas:

Clay	79 per cent	Chert	trace
Calcite	10 per cent	Epidote	"
Calcareous nodules	7 per cent	Hornblende	"
Quartz	2 per cent	Limonite	"
Hematite	1 per cent	Magnetite	"
Feldspar	1 per cent	Muscovite	"
Apatite	trace	Zircon	"
Barite	trace	Carbonaceous matter	"
Biotite	trace	Chara stems	"

The sands in eastern Texas are light-colored, quartzose and vary from fine to medium in texture. The sands in southwestern Texas are somewhat feldspathic.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Conditions of Deposition.

Barton[1] has shown that the Beaumont of eastern Texas was formed largely by the coalescence of deltas of the Brazos, Trinity, Neches, and Sabine Rivers. Low, sandy, dendritically-branching ridges have been interpreted as old, abandoned distributaries. These distributaries extend inland almost to the Beaumont-Lissie contact. The Beaumont is not entirely deltaic, however, for marine and lagoonal deposits are interstratified with the delta deposits. Foraminifera and shell fragments are found in these marine beds. Coastal Plain streams were less vigorous during Beaumont time than during the preceding epoch and much of the sediment was laid down as true delta deposits in the gulf.

1. Barton, Donald C., Deltaic Coastal Plain of Southeastern Texas: Bull. G. S. A., vol. 41, pp. 359-382, 1930.

Recent Series.

Recent deposits have many different facies in Texas and Louisiana. At the shore line between the Rio Grande and Sabine Rivers, barrier beach, lagoonal, and estuarine deposits are being formed. Dune sands and alluvial sands and clays have been deposited in large quantities in southwestern Texas during Recent time while southern Louisiana has been the site of delta, marsh, and alluvial plain deposition. Contemporaneously marine sands, sandy shales and shales are being deposited in the Gulf of Mexico.

Modern conditions of deposition are significant because they reflect conditions as they must have been many times during the Cenozoic era. Simple descriptions such as "delta deposits" or

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

"alluvial plains" as applied to the entire non-marine portion of a formation must be incorrect. Probably no Gulf Coast Tertiary formation is entirely deltaic; deposits of differing origins must combine to make up every formation.

The limited areal extent of the non-marine facies of Recent deposits over the large area between southern Louisiana and the dune area in southwestern Texas is noteworthy. Recent deposits are all but absent in this region a few miles fack from the shore line. This shows that a thick marine deposit encountered in well sections may have no equivalent in the outcrop. It is the writer's thesis that this was the condition during Upper Heterostegina and Discorbis time. The shore line during its maximum advance in late Heterostegina time was a very short distance north of Tomball. Continental deposition then, as now, was limited to a very narrow belt, and the Coastal Plain was being eroded in the area now occupied by the outcrop. Thus, a hiatus marks the equivalent position of Upper Heterostegina and Discorbis strata in the outcrop as it does Recent strata a few miles inland from the modern shore line.

Geologic History.
Pre-Tertiary.

The pre-Tertiary history of the Coastal Plain in the vicinity of Harris County, Texas, is entirely conjectural. Deposits older than the Tertiary are beyond reach with present drilling methods, and conclusions on the early history of this area must, therefore, be based on evidence found farther inland where these older rocks have been penetrated by the drill or are exposed at the surface.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

This region must have been a part of the Llanoria land mass during the Paleozoic era. The source of the deposits which filled the Ouachita geosyncline was a land mass toward the south, and since the buried Ouachita structure now occupies approximately the position of the inner boundary of the Coastal Plain in Texas, the conclusion that the central and eastern parts of the Texas Coastal Plain was a part of that great, positive land mass seems unescapable. This is corroborated by the fact that a well in Guadalupe County, Texas, went directly out of Travis Peak (Trinity) beds into the crystalline basement. The Paleozoic history of this area until the time of the orogeny, then, was predominately one of repeated uplift and almost continuous degradation.

The main streams flowed northward during Paleozoic time, bearing sediments which filled the geosyncline to a maximum depth of more than 25,000 feet.

The geologic history between the time of the Ouachita orogeny and the beginning of the Cretaceous period is obscure. Non-marine Triassic beds have been mapped in the Panhandle of Texas and in West Texas, and marine Jurassic beds outcrop in Hudspeth County, but these beds are all absent in the region of the Llano uplift, and in well sections in Guadalupe County. The Jurassic seas that deposited the beds in Hudspeth County invaded from the south, and although this sea may have transgressed over what is now the southern border of the Coastal Plain and yet did not reach the vicinity of Guadalupe County and the Llano area, evidence to indicate that such was the case is lacking.

<u>Age of Gulf Coast Salt Deposits</u>. -- Numerous salt plugs have

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

pierced the older Coastal Plain sediments and arched up the younger strata in parts of Texas, Louisiana, and Mississippi to form the well-known Gulf Coast salt domes.

The age of the source beds for these salt plugs is unknown. Early speculation on this problem favored the assignment of the salt to the Permian chiefly because the great salt deposits of West Texas were known to be of that age. A large portion of contemporary opinion still favors such a correlation. Spooner[1] in concluding that the salt must have been deposited during Permian time, is impressed by events which he believes must have transpired after the uplift in early Permain time. He reasons that the elevation of the Ouachita Mountains must have been "concomitant with depression of Llanoria" in early Permian time. The Permian peneplanation of the mountainous region must then have been coincident with deposition in the region of old Llanoria. Spooner then concludes that "if the assumption of a Permian sedimentary basin is admitted, the salt in northern Louisiana and eastern Texas is most logically correlated with the Permain series". While this line of reasoning is a definite contribution toward the solution of this problem, the assumption of a Permian sedimentary basin here and the assumption that Permian deposition means salt deposition is not inevitable.

1. Spooner, W. C., Oil and Gas Geology of the Gulf Coastal Plain in Arkansas: Ark. Geol. Surv. Bull. 2, pp. 20-21, 1935.

The presence of fossil algae in the salt at Markham dome, Matagorda County, Texas, which are believed to be identical with

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

algae found elsewhere in the Permian was Powers'[1] basis for assign-

1. Powers, Sidney, Interior Salt domes of Texas, Geology of Salt Dome Oil Fields: Amer. Assoc. Petrol. Geol., p. 218, 1926.

ing the salt to the Permian. Schuchert questioned the reliability of algae as stratigraphic markers on the ground that they are poorly-preserved and slowly-evolving.

The alternative to the above possibility is the assignment of the salt to a post-Permain-pre-Navarro age. Schuchert[2] is convinced

2. Schuchert, Charles, Historical Geology of the Antillean-Caribbean Region: John Wiley and Sons Inc., pp. 290-291, 1935.

"on the basis of facies and faunal changes plus paleogeography, that Permian formations at the surface in central and western Texas can not extend under cover of the Cretaceous as far east as the present Gulf border, and he has on different occasions said that the salt probably comes from the older part of the Comanchean series". Brown[3] in a detailed paper, which approaches the problem through a

3. Brown, Levi S., Age of the Gulf Border Salt Deposits: A. A. P. G. Bull., vol. 18, no. 10, pp. 1227-2186, 1934.

general study of the origin of salt deposits, paleogeography, and inclusions in cap rock, considers the Cretaceous age of these deposits proven though he assigns a different age to the salt in each of the several basins. Barton, in a review of Brown's paper, very logically questions the validity of Brown's criteria, pointing out in particular that inclusions of Navarro strata in the cap rock

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

do not establish the Navarro age of the cap rock, but that they rather prove a pre-Navarro age. Barton[1] considers the age of the

1. Barton, Donald C., Mechanics of Formation of Salt Domes with Special Reference to Gulf Coast Domes of Texas and Louisiana: A. A. P. G. Bull. vol. 17, no. 9, pp. 1045-50, 1933.

mother salt deposit unknown but believes that it must be at least as old as early Comanchean because "Glen Rose has been brought up by the Boggy Creek dome, Anderson and Cherokee Counties, Texas". He also points out that "basal Lower Cretaceous rests on the top of the salt at Smackover, Union County, Arkansas".

The Navarro inclusions mentioned above were found in the South Liberty dome which is a short distance east of Harris County. This proves that the salt in the gulf border area is pre-Navarro while the Glen Rose inclusions at Boggy Creek prove a pre-Glen Rose age for the salt of the interior basin. With only such inconclusive data on this problem, a solution is not possible at the present time.

<u>Cretaceous Seas</u>. -- Most of the epeiric seas had withdrawn from the continent by the end of the Jurassic, and the entire Texas Gulf Coast may have been above sea level.

The Cretaceous seas advanced far inland, covering much of Texas. The minimum extent of the seas which deposited the several Comanchean and Upper Cretaceous groups have been shown by Adkins[2]. The maximum

2. Sellards, E. H., Adkins, W. S., and Plummer, F. B., The Geology of Texas: The Univ. of Texas Bull. no. 3232, p. 277 and p. 403, 1932.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

advance of this period was during Austin time. The seas withdrew at the end of the Cretaceous period and have never since advanced over central North America as extensively as they did then.

These epeiric seas deposited large amounts of limestone and chalk together with arenaceous and argillaceous beds in the region now occupied by the western part of the Gulf Coastal Plain. That they withdrew at times and then readvanced is shown by the unconformities in the outcropping sections. Whether these regressions brought the shore line as far south as the outer border of the Coastal Plain or whether there was continuous deposition here throughout Cretaceous time is unknown.

Cenozoic.

In contrast to the Cretaceous seas, those of the Tertiary and Quaternary time did not advance far inland, and they oscillated frequently, resulting in a characteristic interfingering of marine and non-marine deposits.

The era opened with an advance of the sea over the Coastal Plain which lasted during all of Midway and earliest Wilcox time. The Kincaid formation at the outcrop rests unconformably on the Cretaceous, and its basal strata are near-shore, shallow-water deposits, recording the invasion of the sea over the previously eroded Cretaceous surface. The Wills Point strata at the outcrop were deposited in relatively deep water, but the Seguin formation is a shallow water deposit, recording the beginning of the retreat of the sea. Formations above the Seguin of the Wilcox and Claiborne groups are alternately continental and marine at the surface, and

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

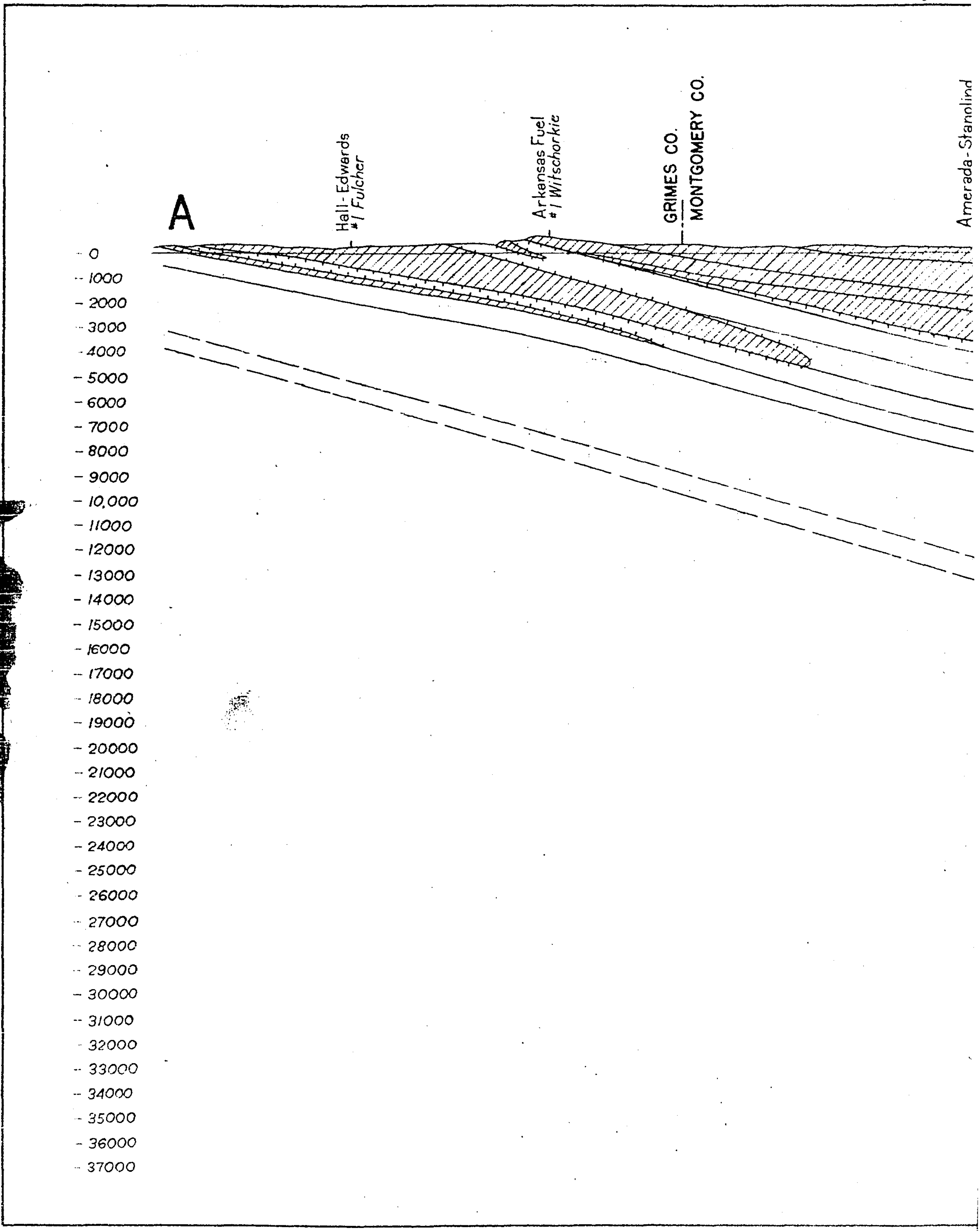
the Jackson is part marine and part non-marine. The remainder of the Cenozoic strata at the outcrop is continental, but deep wells drilled in the vicinity of Harris County and other areas similarly located with respect to the present shore line show that many of these beds are marine there. The history of the Cenozoic seas is thus one of frequent oscillations and a gradual withdrawal in the latter part of the era. The detailed succession of paleogeographies, beginning with the Crockett, has been given in the section on stratigraphy and illustrated in the series of paleogeographic maps.

Gulf Coast Geosyncline.

The aggregate thickness of these Tertiary and Quaternary strata shows that during Cenozoic time the area now occupied by Galveston and Brazoria Counties, Texas, was depressed at least 30,000 feet and probably as much as 35,000 feet (Fig. 8). The area now occupied by Harris County was depressed somewhat less. The general process of down-warping was interrupted frequently by reversals of movement. These epochs of uplift were probably brief in comparison with the periods of sinking which is the dominant factor in the Cenozoic history of the Gulf Coast.

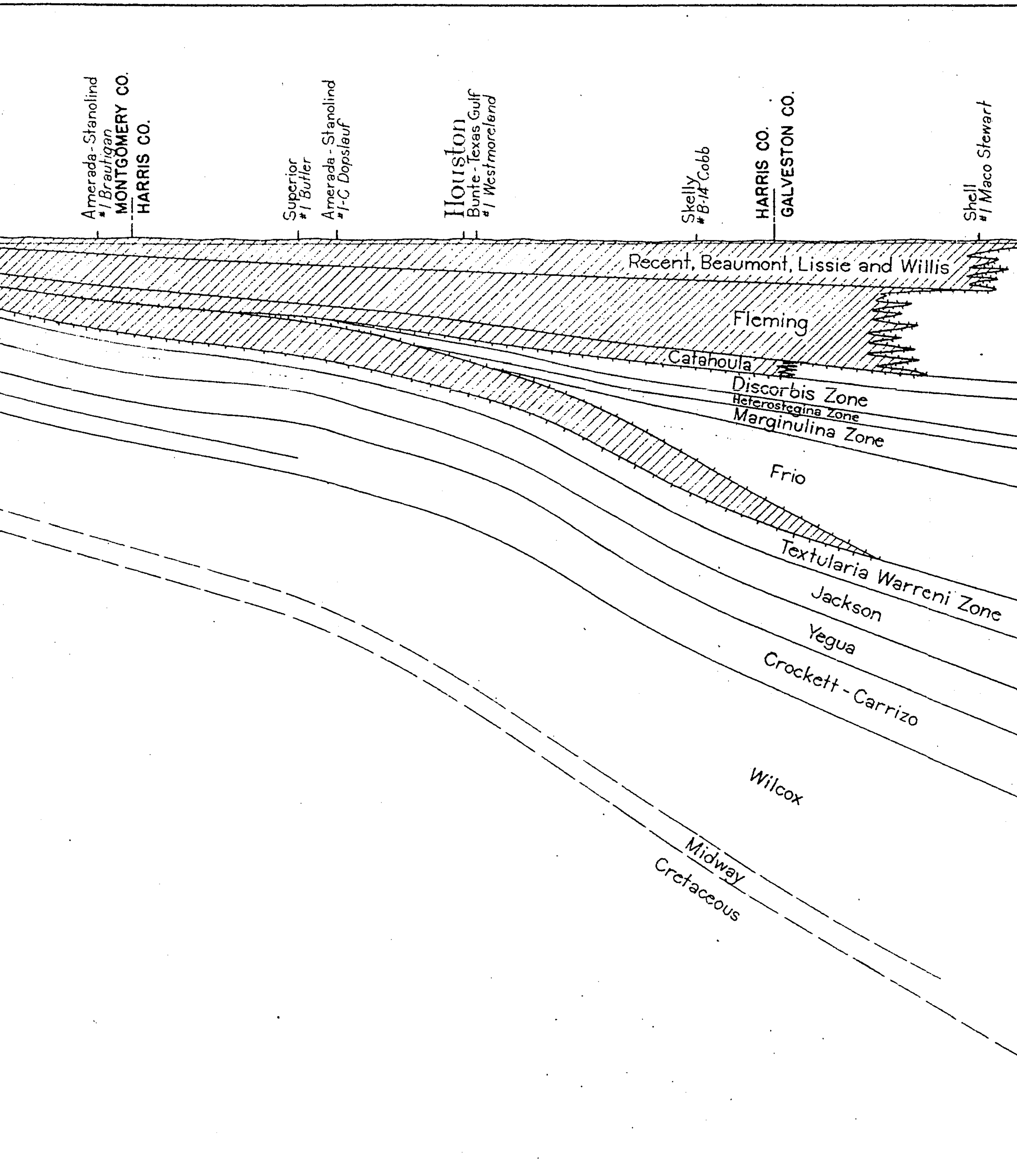
To explain this excessive sinking of the area along the coast by postulating a similar amount of sinking over the entire area of the Gulf of Mexico involves two serious difficulties. First, such excessive depressions of the earth's surface have been achieved in so short a time only in relatively long, narrow belts and do not involve areas of the magnitude and shape of the Gulf of Mexico basin. Such movements, in other words, are not epeirogenic

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.



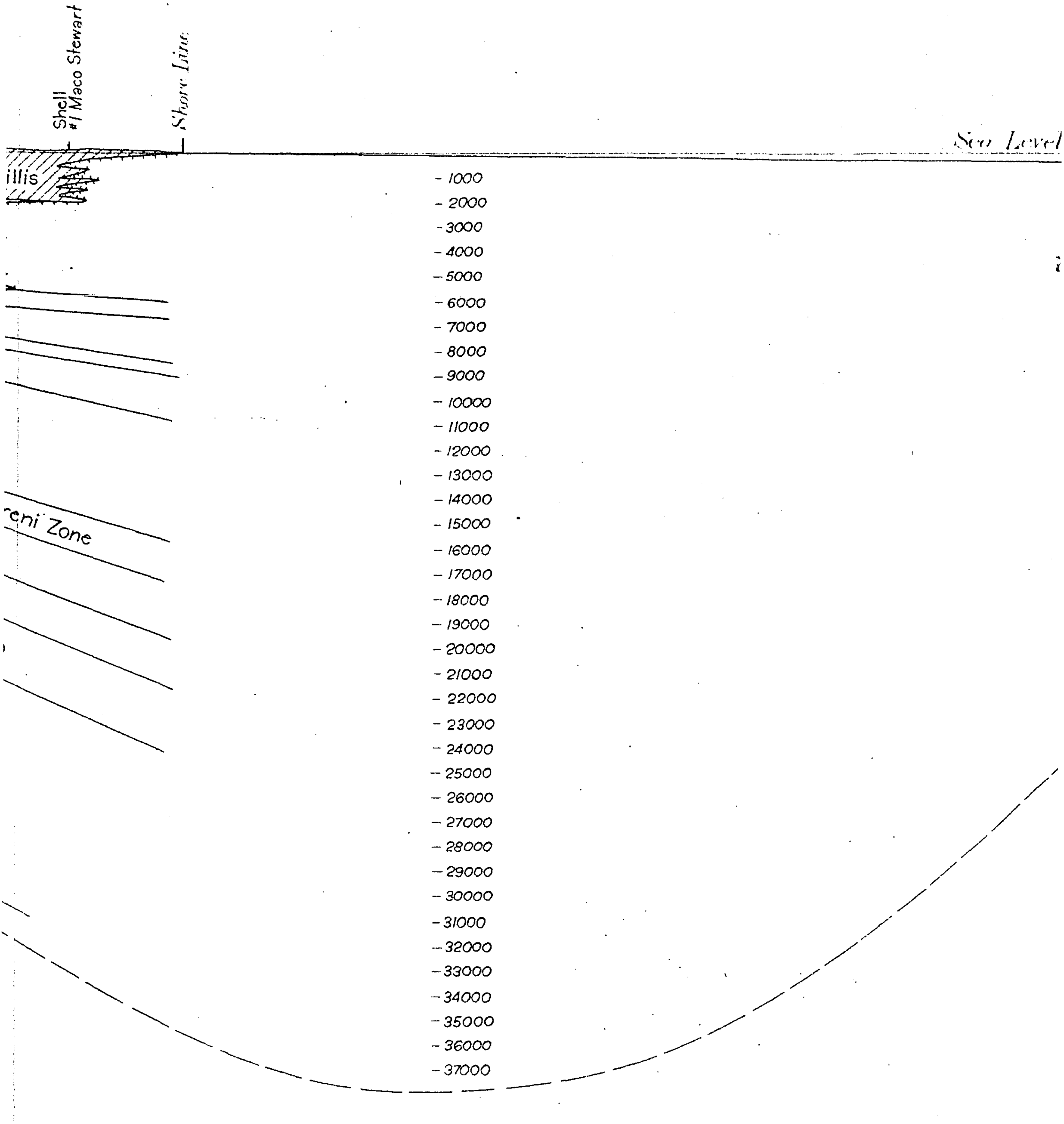
Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.



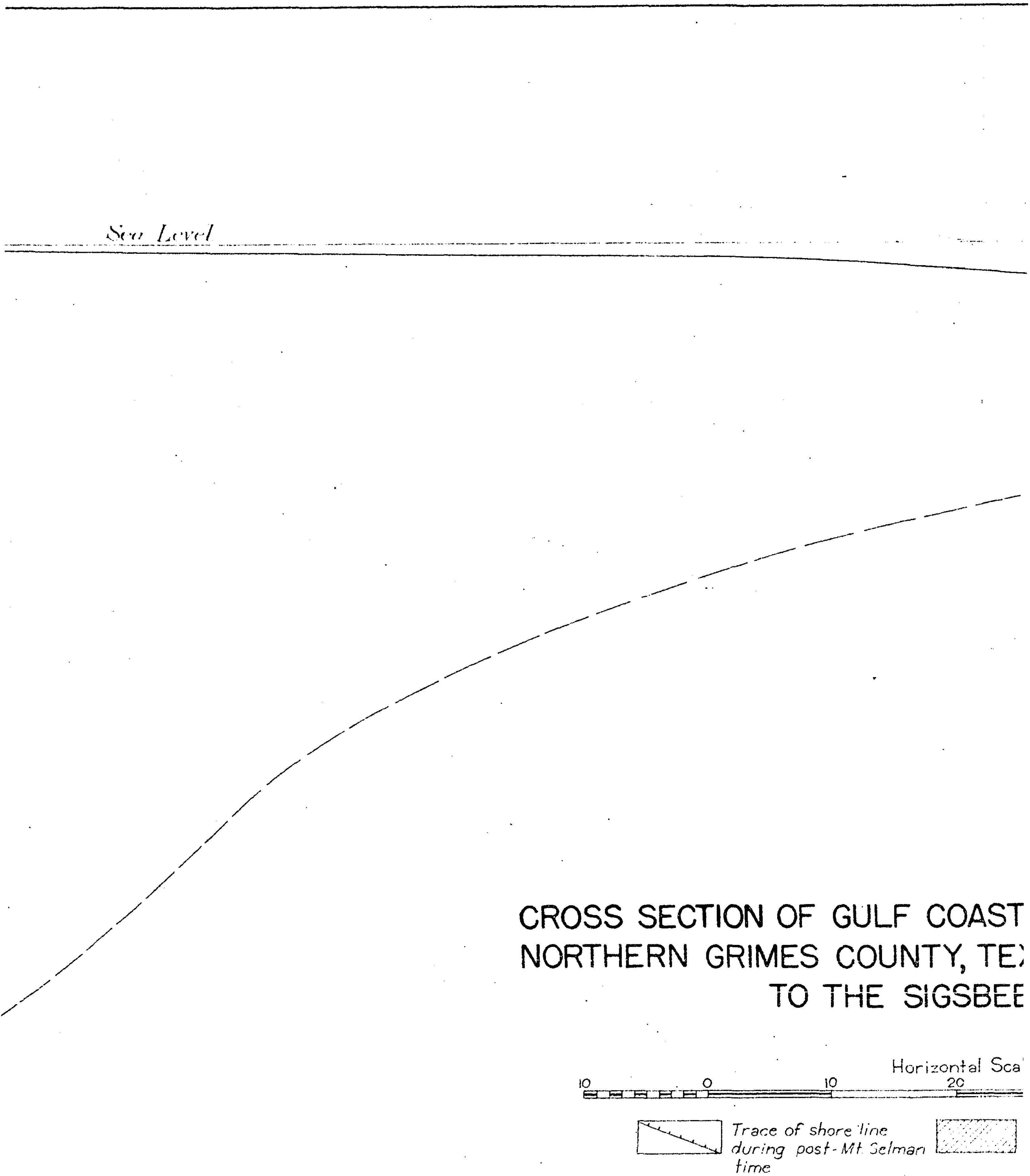
Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.



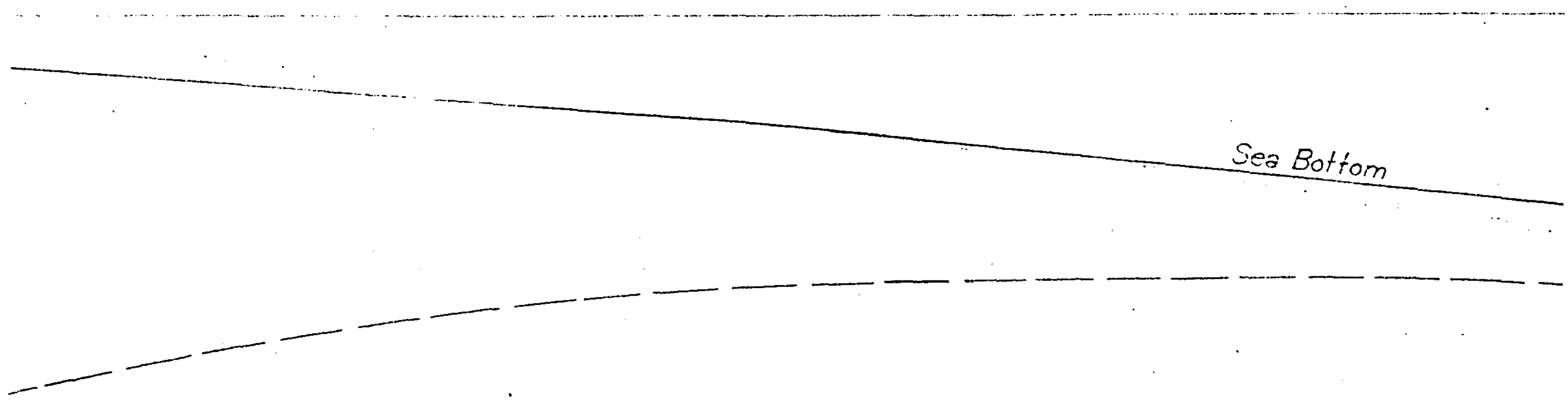
Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.



Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.



;EOSYNCLINE FROM
\S, THROUGH HOUSTON
DEEP

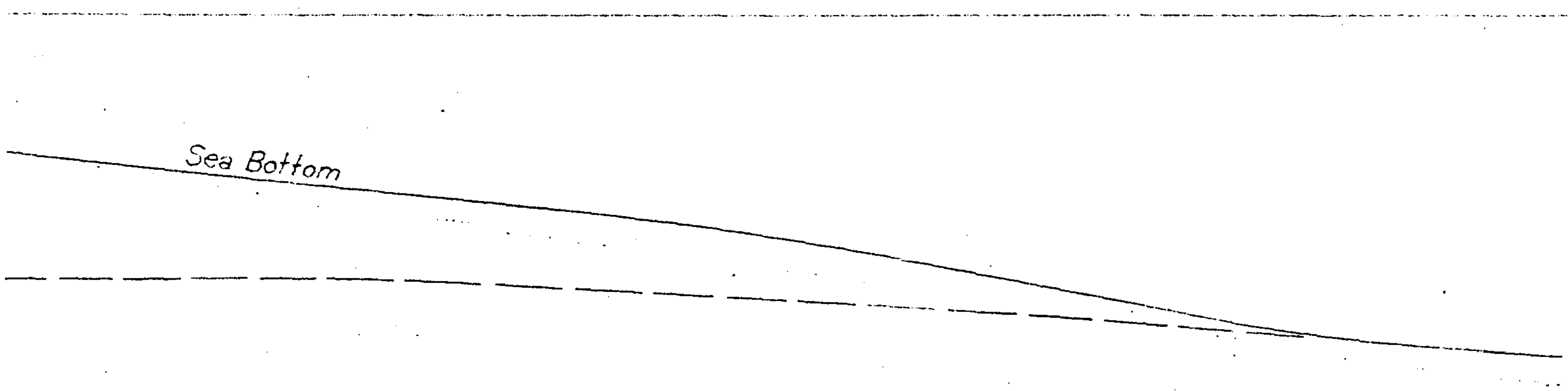
30 40 50 Miles

ı-Marine
ɔosits

Marine
deposits

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.



Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

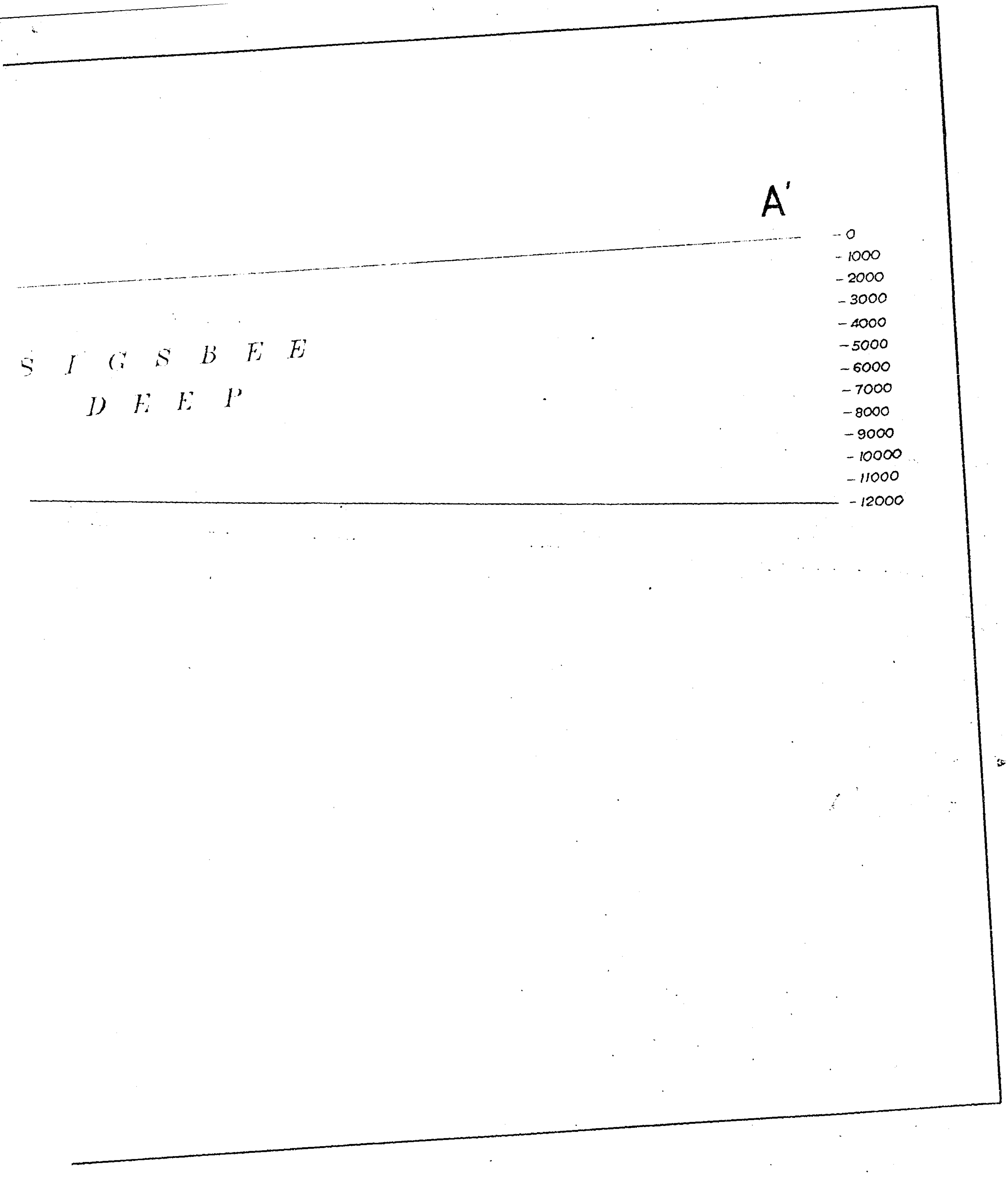
Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

A′

S I G S B E E
D E E P

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.



Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

but are the initial stage of an orogenic cycle. Second, if the entire Gulf of Mexico basin was depressed 30,000 feet, a block of sediments 20,000 or 25,000 feet thick, covering an area of 700,000 square miles would be required to fill the Gulf to its present mean level. Much of this would have to come from the basins of the Mississippi River and adjacent smaller streams. These streams would have had to furnish a wedge of sediments more than 30,000 feet thick at the coast and more than 18,000 feet thick in the region of the Sigsbee Deep. This seems unlikely in view of the fact that deposition instead of erosion occurred over much of the Great Plains and in the Lower Mississippi valley during Tertiary time.

That the degree of formational thickening increases markedly within 50 miles of the present shore line has been shown previously. Dips in southern Harris County and in Galveston and Matagorda Counties are much greater than in northern Harris County and in Montgomery County. These excessively steep dips are found not only in this area but in a long belt adjacent to the shore line in eastern Texas and Louisiana.

This sudden increase in the regional dip together with the excessive thickness of the Tertiary sediments indicate the presence of a geosyncline of major dimensions with its axis essentially parallel to the shore of the Gulf of Mexico. Geophysical evidence of the existence of this great geosyncline has been presented by Barton, Ritz, and Hickey[1]. In this important paper, the authors

—6

1. Barton, Donald C., Ritz, C. H., and Hickey, Maude, Gulf Coast Geosyncline: A. A. P. G. Bull. vol. 17, no. 12, pp. 1446-1458, 1933.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

give indubitable geophysical evidence of this geosyncline the axis of which they place approximately at the site of the present shore line.

Although the western limit of this structure is unknown, isopach maps show a distinct thinning of some of the formations in the longitude of Matagorda and Wharton Counties, Texas, and subsurface structural maps show a gulfward component to the strike at about the same place. While there is thus some reason to believe that the structure becomes less pronounced west of Matagorda County, the possibility that it does continue southwestward but with gentler dips or that the axis diverges from the present shore must be considered. It is also possible that this formational thinning reflects only a northwest-striking, anticlinal ridge.

Recent studies on the Gulf Coast geosyncline in Louisiana have been made by Howe[1], Russell[2], McGuirt and Moresi[3]. Howe estimates

---

1. Howe, Henry V., Louisiana Petroleum Stratigraphy: La. Dept. of Conserv. Bull. no. 27, 1936.

2. Russell, Richard Joel, Physiography of Lower Mississippi River Delta: La. Dept. of Conserv. Geol. Bull. no. 8, 1936.

3. Note: See bibliography in Bulletin no. 27 for papers by McGuirt, Moresi, and previous papers by Howe.

---

the maximum thickness of the Cenozoic in southern Louisiana to be approximately 31,000 feet.

The picture of the structure paralleling the coast is complicated by the north-striking Mississippi embayment and by other much smaller north-striking synclines and anticlines. The exact

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

relationship of the Gulf Coast Geosyncline to the Mississippi embayment is yet to be determined.

The Cenozoic history of this part of the Gulf Coast is largely the pouring of sediment into this sinking trough. Both the sinking and the sedimentation was interrupted for relatively brief periods of time by reversals of movement which exposed to erosion the region now occupied by the Gulf Coast.

Origin of Geosynclinal Depression.

Geosynclines are elongated, sediment-filled depressions in the earth's surface. They may come into existence in one of two ways. Either the surface was depressed by the weight of accumulating sediments, or its lowering is due to independent forces arising beneath the surface. The one hypothesis places the cause on the earth's surface; the other places the cause beneath the earth's surface. The one accounts for the pattern of the mobile belts in the fortituous wanderings of the major streams; the other accounts for the pattern of the mobile belts in the manner of crustal yielding to stresses which are caused by forces originating in the subcrustal part of the earth.

The idea that geosynclinal depression is due to sedimentary loading has found many champions in the past and present. Russell[1]

1. Russell, Richard Joel, loc. cit., pp. 180-193.

gives an historical review of contributions on this problem. He himself attributes the sinking of the Gulf Coast Geosyncline to this

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

cause. Other proponents of the theory are Howe[1], and to a less extent, Barton, Ritz and Hickey[2].

---

1. Howe, Henry V., loc. cit.

2. Barton, Donald C., Ritz, C. H., and Hickey, Maude, loc. cit.

The case for this theory rests largely on the observation that much of the sediment in the Gulf Coast geosyncline accumulated near sea-level, that maximum subsidence is at the site of the great deltas, on the fact that the mean of observed gravity readings on the Mississippi delta is almost zero, and on the belief that the theory of isostasy supports it.

The proponents of this theory contend that the deposition of thousands of feet of Tertiary and Quaternary strata under near sea-level conditions proves that the rate of subsidence is a function of the rate of sedimentation. The subsidence must, therefore, be a result of the sedimentation for it would be highly improbable that the effects of two unrelated factors, such as the rate at which streams brought down sediment to the site of the geosyncline and forces arising in the earth's interior, would proceed at the same rate. Russell[3] states that it would be a "miracle that sedi-

---

3. Russell, Richard Joel, loc. cit., p. 180.

---

mentation should occur at a rate just sufficient to deposit all materials filling the trough neither far above nor far below sea-level".

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Miocene, Pliocene, and Pleistocene deposits are thicker in the Mississippi delta region than anywhere else in the Gulf Coast, and some geologists take this to mean that the great weight of these deposits caused the increased depression which is found here. Furthermore, the lack of an observed gravity anomaly is considered to indicate a compensated column which means that a mass of rock below, equal to the mass of sediment deposited above, has been removed. If this is true, then causal relationship is inferred.

Finally, some proponents of the sedimentary load hypothesis assume the validity of the theory of isostasy and maintain that their hypothesis is a valid deduction from the general case to the particular.

Indeed, a beautifully simple explanation of geosynclinal deformation appears to be supported by these arguments, and the idea has proven to be attractive to most writers on the Gulf Coast geosyncline. But before accepting this theory, a more critical examination of the arguments supporting it should be made as well as a consideration of alternative hypotheses.

The presence of tens of thousands of feet of sediment in the geosyncline, all deposited approximately at sea-level, is a fact of prime importance. If this means that the volume of sediment brought to the site of the Gulf Coast geosyncline during any interval of time just equals the increase in the volume of the geosynclinal trough during that same interval of time, then a weighty argument has indeed been advanced to support the idea that deformation is caused by the weight of the sediment. It is highly improbable that

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

tensional stresses in the crust or other forces below the earth's surface just happened to cause a rate of subsidence exactly sufficient to accomodate all the sediment being brought down by the streams. However, the assumption that sea-level deposition in the geosyncline means that the rate at which sediment is transported to this area equals the rate of depression rests on a failure to consider all possibilities. The rate of sedimentary accumulation along the Gulf border and in the margin of the Gulf of Mexico may be less than the rate of geosynclinal depression, it may equal the rate of geosynclinal depression, or it may exceed the rate of geosynclinal depression. The first case would, of course, result in deep-water deposition. Eocene beds in the geosyncline may be deep-water deposits, but most of the post-Vicksburg beds were surely deposited near sea-level or wave-base. The second case would result in near sea-level deposition, and proponents of the sedimentary load theory conclude, therefore, that the shallow water deposits in the geosyncline indicate that geosynclinal depression did necessarily proceed at the same rate as the transportation of sediment to the Gulf of Mexico. A consideration of the third possibility, however, shows the fallacy of this conclusion. If sediment was brought to the Gulf of Mexico faster than the rate of geosynclinal depression, then the trough would be filled to sea-level or wave-base, depending upon the exact position of the strand line with respect to the geosyncline, and the excess load would be carried by wave action and currents beyond the geosyncline since it borders upon an open basin. Under these conditions, then, near sea-level deposition would occur in the structural trough and the appearance of the stratigraphic column would be the same as though the

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

volume of sediment brought down at any particular interval of time did equal the increase in the volume of the trough during that same interval of time.

The large amount of sand in the marine, post-Heterostegina formations at the modern shore line shows that sediment was by-passed beyond the axis of the trough. Furthermore, the gentle slope of the sea floor south of the geosyncline suggests a depositional surface as far as the 100 fathom line which, in places, is 150 miles south of the supposed position of the axis of the geosyncline. The fact that salt comes as elevated topographic features on the sea floor are largely, if not entirely, absent from this gentle slope, but are conspicuously present beyond it, is best explained by assuming that they have been truncated by wave and current action and covered by recent sediment. This substantiates the interpretation of this gentle slope as a depositional surface. Good reason thus exists for believing that a greater volume of sediment was transported to the Gulf shore line during Tertiary time than the geosyncline proper could hold and that the excess was carried by waves and currents beyond the geosyncline into the open basin of the Gulf of Mexico, and the conclusion that near sea-level deposition of large amounts of sediment in the geosyncline indicates that geosynclinal depression proceeded at the same rate as the transportation of sediment to the site of the geosyncline is not justified.

This condition of an excess of sediment existed in other geosynclines. The Appalachian geosyncline was not able to accomodate all the sediment brought to it during the Paleozoic era. The

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Paleozoic, clastic sediments in the area now occupied by the states west of the Appalachian Mountains represents the excess eroded from Old Appalachia and carried seaward beyond the geosyncline. If the weight of accumulating sediment could cause deformation, there would be no deposition of coarse clastic sediments seaward from the structural trough. This fact itself refutes the main argument frequently advanced by proponents of the sedimentary load theory.

The fact that Miocene, Pliocene, and Pleistocene deposits are thickest in the Mississippi delta region does not require, as proponents of the sedimentary load theory contend, that the superior weight of this great body of sediment caused the excessive subsidence. Equally possible is the alternative - that the Mississippi River and the delta got their positions as a result of excessive subsidence. The thick sedimentary accumulation could, therefore, be the result of down-warping rather than the cause of it.

The fact that geophysical investigations have shown that the observed gravity anomaly on the delta is almost zero is very impressive until allowance is made for variations in surface densities. Bucher[1] has shown the important influence of abnormal densities close

---

1. Bucher, Walter H., Deformation of the Earth's Crust: Princeton Univ. Press, pp. 30-33, 1923.

---

to the surface on observed values of gravity. He points out that "since gravitative attraction varies inversely as the square of the distance, a heavy rock mass immediately beneath a station will register an excess of gravity over that of surrounding crustal columns of equal elevation and equal mean density". A light rock

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

mass at the surface will, of course, have the opposite effect on the observed gravity values.

This effect of variations in rock density upon observed gravity values has been recognized, as Bucher observes, by geologists and geodesists for some time, and it must not be ignored in the interpretation of observed values. The gravity readings on the Mississippi delta must be considered in the light of this fact.

In discussing the Mississippi delta, Bucher[1] states that "if the

1. Bucher, Walter H., loc. cit., p. 33.

column beneath the delta were in isostatic equilibrium, the light, unconsolidated sediments of at least the upper part of the delta should register a strong negative anomaly - . . . If the delta constituted a local, essentially equidemensional body, the absence of such strong negative anomalies would mean that there is an excess of mass below, that is, the crust is not in equilibrium and that the delta constitutes an excess load. If, on the other hand, its shape approached that of a thin sheet of large horizontal dimensions, its differential effect on the value of gravity would be negligible". The fact that the Mississippi delta has a great thickness is admitted by proponents of the sedimentary load theory. Since the observed gravity readings approach zero (-0.005 dyne)[2], it would appear that

2. Bucher, Walter H., loc. cit., p. 33.

the whole column which includes the Mississippi delta is not com-

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

pensated. The sedimentary load theory, however, requires near compensation at all times. Subcrustal movement and subsidence must keep pace with sedimentation. Failure to do so would result in a progressive, seaward movement of the shore line and no localization of sedimentation over long periods of time would result. The fact that the Mississippi River has built out its delta as much as 100 miles south of the position of the shore line on the east and west shows clearly that subsidence has not recently kept pace with sedimentation. Gravity studies on the Mississippi delta, therefore, do not support the idea that the weight of accumulating sediments causes the depression of the geosynclinal trough.

Some geologists believe that the sedimentary load theory is necessarily a consequence of the theory of isostasy. The reality of isostatic changes is not questioned here. The controversy about isostasy is the extent to which the deformation of the earth's crust can be attributed to it.

That the mechanism of sedimentary loading as the cause of deformation requires almost perfect compensation at all times is conceded by proponents of this theory[1]. But such a mechanism is predicated

1. Russell, Richard Joel, loc. cit., p. 184.

upon a lack of inherent strength in the crust of the earth. Even geodesists concede that the crust is able to bear an excess load of 600 feet of rock before failing. Geologic data indicate that this load is more likely to be measured in thousands of feet rather than

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

hundreds[1]. Russell[2] points to the subsidence of the continent under

1. Bucher, Walter H., loc. cit., pp. 34-35.

2. Russell, Richard Joel, loc. cit., p. 189.

the weight of an ice cap as direct evidence that a superficial load causes crustal subsidence. However, the depression of the crust in a long, narrow belt for tens of thousands of feet cannot be compared to the relatively slight subsidence of the nearly equidimensional, glaciated regions. The very fact that the ice spread out over large areas on the continent rather than depressed the crust along deep, narrow troughs adjacent to the focal points of the glacier is evidence against the thesis that subsidence is the effect of sedimentation.

While isostasy can restore equilibrium, there is no evidence to show that it can effect the reverse. When equilibrium has been established and the geosyncline has been filled to sea-level, the site of deposition should change. This is not the case in the Gulf Coast geosyncline for depression has been localized in this one place throughout most, if not all, of Tertiary time.

The case against the sedimentary load theory does not rest entirely on the failure of the arguments intended to support it; there are at least four other facts which are not compatible with the theory. First, if the weight of accumulating sediments causes down-warping, the maximum thickness of a formation which has both a marine and non-marine facies should be at the shore line of that

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

formation. A substantial portion of the Tertiary formations reach their maximum thickness far south of the shore line of that time. Second, the sedimentary load theory does not account for the reversals of movement evident during Tertiary and Quaternary time. Third, this theory does not account for the oceanic deeps which are geosynclines without a sedimentary fill. Fourth, it does not account for the failure of a geosyncline to develop around the margins of the Canadian Shield even though this was a persistent land mass and shore line sedimentation must have occurred.

Formational thickening as far south as Bammel in north-central Harris County has been proven for formations as old as the Cook Mountain. The Bammel area is sufficiently close (approximately 15 miles) to the edge of the geosyncline in southern Harris County where the remarkable increase in the degree of formational thickening begins that one may safely assume that Cook Mountain beds are involved in the geosyncline.

The maximum thickness of the Cook Mountain formations at the outcrop in eastern Texas where the group is part marine and part non-marine is 700 feet, whereas, in the Bammel area 75 miles south, where it is entirely marine, the group is more than 1500 feet thick. The Yegua beds are from 1200 to 1240 feet thick in northern Montgomery County which is the average position of the shore line during Yegua time. In central Harris County, 50 miles from the shore line, the Yegua is more than 1400 feet thick. The average position of the shore line for the Jackson is at the outcrop or a short distance landward. The Jackson is approximately 900 feet thick there but it

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

is 1380 feet thick in southwestern Harris County 80 miles from the old shore line. The sea retreated throughout the deposition of the *Textularia warreni* Beds and their exact continental equivalent is not definitely known. The shore line during Frio time was in the geosyncline. The *Marginulina*, *Heterostegina*, and *Discorbis* zones were deposited in a transgressive-regressive sea and there probably is no continental equivalent of the upper part of these beds. The Catahoula shore line was in the geosyncline but the Catahoula does not thicken appreciably toward it; the thickness of this formation remains nearly constant. The shore line for Fleming and post-Fleming deposits was in the geosyncline. Thus, for all post-Weches formations, there seems to be no relation between formational thickening and paleogeography. Whenever the shore line was not in the geosyncline, the formation thickened toward the geosyncline and not toward the shore line. This would not be expected if subsidence was due to sedimentation.

A yet more striking case than this of lack of relationship between shore lines and maximum subsidence is the Wichita geosyncline of Oklahoma. The Arbuckle limestone thins without a change of facies from its maximum thickness of 6000 or 8000 feet at the site of the mountains to 1000 feet or less southward in Texas and northward in Kansas. Certainly the maximum thickness of this formation is not obtained in a deltaic or shore line facies but attains its maximum instead in the marine limestone and dolomite facies. Though Howe and Russell[1] confidently believe "that drainage patterns determine

---

1. Russell, Richard Joel, loc. cit., p. 193.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

future courses of mountains", early Paleozoic drainage patterns had nothing whatever to do with determining the position of the Wichita Mountains.

The mechanism pictured by the sedimentary load theory cannot account for the epochs of uplift in areas where subsidence and sedimentation has been the general rule. The history of all geosynclines has been marked by relatively short periods of uplift during the initial stage of the orogenic cycle when down-warping was predominate. That this is also true of the Gulf Coast geosyncline and the Gulf Coast in general is shown by unconformities in the section, by fluctuations in the shore line, and by the presence of submarine canyons in the Gulf of Mexico. The unconformities in the section and the succession of paleogeographies have been treated elsewhere in this paper. Notable retreats of the sea occurred just after the close of the Jackson and during Upper <u>Heterostegina</u> and <u>Discorbis</u> time. The basal Catahoula contact is marked by a major unconformity and the region occupied by the geosyncline must have been uplifted considerably. Recent uplift is shown by the entrenched streams found everywhere on the coast. Streams in northern Harris County are entrenched as much as 85 feet. The paleogeographic studies of Moody[1] in Louisiana

---

1. Moody, C. L., Tertiary History of Region of Sabine Uplift, Louisiana: A. A. P. G. Bull. vol. 15, no. 5, pp. 531-551, 1931

---

show that the shore line there fluctuated hundreds of miles and must indicate reversals of movement of hundreds of feet.

The submarine canyon south of the mouth of the Mississippi River

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

is evidence of uplift.[1] Shepard relates this trough to eustatic

1. Shepard, Francis P., "Salt" Domes Related to Mississippi Submarine Trough: Bull. G. S. A. vol. 48, pp. 1349-1362, 1937.

changes in sea-level due to glaciation and deglaciation and subsequent subsidence of the region, but the relief of the canyon is too great to be accounted for in this way. A cross-section drawn where the 2400-foot contour crosses the bottom of the canyon shows more than 1800 feet of relief. Shepard accounts for the flat bottom of this trough by mud fill, pointing out that the profile slope is the same as the angle of repose for mud. A projection of the slope of the canyon walls shows that the bottom of the canyon must have been at least 600 feet below the present level of the mud. This gives a relief of 2400 feet for the canyon at this point. Farther south the relief was probably greater. If this is to be accounted for by changes in sea-level due to glaciation, a lowering of sea-level of more than 2400 feet is required. Since the oceanic areas are 2.6 times the land areas and since only a small fraction of the land areas not now covered by glaciers were covered by Pleistocene ice sheets at any one time, it is obvious that the average thickness of the ice sheets would have to be many times 2400 feet to cause the erosion of the submarine canyon south of the mouth of the Mississippi River. A thickness many times greater than that indicated by present ice sheets and by physiographic observations in the northern mountain regions would be required. An appeal to uplift of the geosynclinal area seems inevitable.

These epochs of reversal of movement in the geosyncline, in-

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

dicated by unconformities, shore line migrations, entrenched streams, and the submarine canyon are opposed to the basic tenets of the sedimentary load theory.

An obvious argument against this theory is that many structural troughs could not have been caused by the weight of accumulating sediments because they contain no sediment. These, of course, are the ocean deeps.

It is interesting to note that Russell[1], in looking to "the great laboratory of Nature" which he recommends in preference to the "lesser laboratories of man", appealed to the relatively slight continental subsidence under the weight of an ice sheet when he could have had the Sigsbee Deep which is much more comparable to the Gulf Coast geosyncline in shape, amount of subsidence, and geographic position. In fact, the Sigsbee Deep and the Gulf Coast geosyncline may be cognate structures. On the south side of the Sigsbee Deep, the slope is more than 11,000 feet in less than 50 miles. Yet there is no sedimentary load to depress this structure. Obviously the theory fails in this case and has to be limited to structures filled with sediment. The fact that a structural trough is or is not filled with sediment depends only upon its geographic setting and there is no reason to suppose that different causes must be attributed to the formation of each. If one has to appeal to a different cause for the oceanic deeps, a cause that could also account for all the types of

1. Russell, Richard Joel, loc. cit., p. 189.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

geosynclines, then the case in favor of that theory is strong because dualism in science has rarely, if ever, conformed with reality.

Finally, the failure of a geosyncline to develop around the margins of the Canadian Shield is unaccountable by the sedimentary load theory. There were four main land masses in North America during Paleozoic time - Appalachia, Cascadia, Llanoria, and the Canadian Shield. Epeiric seas repeatedly lapped up on the flanks of all of these structures. Streams carried sediment from each of these land masses into the seas. Deltas and other shore line features must have been formed on the margins of each. All the requirements for the formation of a geosyncline, according to the sedimentary load theory, were present at the margins of all four land masses. Yet no geosyncline was formed adjacent to the Canadian Shield. One cannot escape the conclusion, therefore, that something more than a sedimentary load is required to originate and develop a geosyncline.

Contrary to this latter thesis, one might contend that there was no great amount of sediment removed from the Canadian Shield during Paleozoic time and that the boundaries of this land mass lacked definition with the result that the shore line fluctuated widely preventing long-continued localization of sedimentation. There is no reason, however, to assume that a great deal of the inorganic sediment throughout the central part of the continent was not derived from the Canadian Shield. If sediment could depress the crust, a geosyncline would surely have originated at the site of the early Paleozoic shore lines around the Canadian Shield and this would have given definition to the land mass. Instead, however, the Wichita geosyncline was

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

formed hundreds of miles south of the shore line as is shown by the Arbuckle limestone.

In view of the failure of the sedimentary load theory to account for the observed facts and the apparent absence of any other cause on the earth's surface, we must look for a cause of geosynclinal depression beneath the surface.

Many hypotheses have been formulated concerning the nature of the processes below the earth's surface which lead to the formation of geosynclines. Here again two alternatives exist. Either geosynclines arise as concommitant features more or less simultaneously with the formation of folded mountains in the course of a continuous process of crustal deformation, or they come into existence independently, through a set of forces different from and possible opposed to those which cause the folding of mountains. Most geologists favor the former view. But the presence of so conspicuous a geosyncline as that here discussed without a corresponding "welt"[1] of mountains adjoining it, seems to the writer to be convincing proof that not all geosynclines, and certainly not this one, have formed as a by-product of the process which raises welts.

1. Bucher, Walter H., loc. cit., pp. 4-5.

Of attempts to account for the presence of geosynclines independently of welts and folded mountains, the writer wishes to mention two which follow radically different lines.

Geosynclines form on the margins of earth "blisters" according

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

to Rich[1], which result from local subcrustal heating possibly due to local excess of radioactive matter. Isostasy comes into play when erosion removes the top from the high area (in the case of the Gulf Coast geosyncline presumably the adjoining part of the continent). Geosynclines result from the local withdrawal of subcrustal matter at depth from the foreland towards the high land to restore isostatic equilibrium.

1. Rich, John L., A Mechanism for the Initiation of Geosynclines and Geo-Basins: Abstracts of papers offered at the fiftieth annual meeting of the G. S. A., 1937.

If there were little or no friction in the flow of subcrustal matter, the withdrawal of matter from beneath the vast foreland would be distributed over its whole area. But because of the very large internal friction which opposes movement, material is withdrawn at first only nearest the point of deficiency of mass, i.e. along the edge of the "blister". If no sediment accumulated in it, the depression would gradually vanish as surface equilibrium is established by the sluggish flow of the viscous subcrustal matter. But when sediment fills the trough, it is perpetuated and its sinking even accentuated while it forms.

Bucher, on the other hand, points out that geosynclines deepen during "anorogenic" times, that is, during those epochs of the earth's history when relief on the earth's surface dwindles to a minimum and when the seas transgress widely over the continents; whereas they tend to shallow or even emerge completely during "orogenic" times, i.e. when relief on the earth's surface increases and mountain folding is active.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

From this contrast he infers that geosynclines result from forces opposed to those which make mountains. If the latter are due to compression in the earth's crust, geosynclines should be the result of tensional stresses in the crust, comparable to the hollows formed on an inhomogeneous rubber sheet under tension, which stretches and thins most at the weakest points. This hypothesis accounts equally well for geosynclines on ocean floors, as for those on the continental platforms, and for reversals in movement, so characteristic of geosynclines. According to it, the depressions localize the drainage of the land and the deltas. Furthermore, the failure of a geosyncline to develop around the margin of the Canadian Shield and the fact that a number of the formations involved in the Gulf Coast geosyncline attain their maximum thickness far seaward from the shore line offer no difficulty to it.

This hypothesis requires essential simultaneity of all major epochs of geosynclinal and of orogenic phases over the whole earth, which is at present hard, if not impossible, to prove. Furthermore, no plausible cause has been suggested for the alternation of compression and tention in the crust. These seem to be the chief difficulties of this hypothesis.

Studies of the Gulf Coast geosyncline do not appear to the writer, at the present time, to justify the final acceptance of any of the hypotheses for the origin of geosynclines thus far advanced. Sufficient evidence does appear to exist, however, to justify the abandonment of the sedimentary load theory and also those hypotheses which require the formation of folded mountains or welts concomitant with geosynclines. The field of speculation seems to be limited to

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

forces arising within or beneath the earth's crust. Furthermore, any hypothesis of world-wide application must account for geosynclines which are formed independent of excessively high elevations as well as those which are associated with such elevations.

Whatever may be the primary cause of the formation of the Gulf Coast geosyncline, isostatic adjustment to the weight of accumulating sediments may have been an important secondary factor. The Sigsbee Deep suggests the possibility that the Gulf Coast geosyncline was a similar structural and topographic basin in early Tertiary time when the strand line was far inland. After this basin had come into existence, it offered an opportunity for the accumulation of thousands of feet of sediment. The weight of the first several thousand feet of Tertiary deposits may have been sufficient to overcome the inherent strength of the crust and to cause further sinking. This phase in the evolution of the Gulf Coast geosyncline could not have extended later than Vicksburg time because Frio deposits in the geosyncline were deposited near sea-level, and henceforth there was probably no opportunity for the accumulation of a sufficient excess of mass to overcome the inherent strength of the crust. From this time on, the forces acting within or beneath the crust must have been the sole cause of deformation.

It is to be emphasized that with such a history of this structure as outlined above, the writer assumes that at first there was a mass deficiency and that compensation was reached by the beginning of Frio time, that is, when near sea-level deposition occurred. This assumption is based on the belief that pre-Frio deposits in the geosyncline

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

are of the deep-water type. This condition is suggested but not proven by paleogeographic data already given.

Physiographic History.

Two physiographically distinct areas are present in the margin of the western Gulf Coastal Plain. One is an embayed area adjacent to the shore line, and the other is an entrenched area located farther inland. The embayed area is limited to a very narrow belt and has an excessively gentle slope. The profile from the shore line to northern Harris County indicates a physiographic unconformity about 50 miles from the shore line. The slope from Galveston to Houston, a distance of 50 miles, is 1 foot per mile. The slope from the 50-foot contour to the base of the Hockley scarp, a distance of 25 miles, is 4.6 feet per mile, and in northwestern Harris County elevations as high as 275 feet are recorded. In the area north of the 50-foot contour, streams are actively downcutting, whereas the area south of the line is embayed. Streams are entrenched all the way to the estuaries and in many cases are slightly entrenched in the areas between the bays.

Recent uplift is shown by the entrenched streams present everywhere on the Texas Gulf Coast. In northern Harris County, Spring Creek is entrenched 85 feet, and most of the streams in the vicinity of Harris County are entrenched from 25 to 75 feet. The profile described above shows that the uplift was greater north of the 50-foot contour than south of it.

The numerous drowned valleys and long tidal areas which mark

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

the outer margin of the Coastal Plain have commonly been interpreted as the result of subsidence. Professor Walter H. Bucher has suggested to the writer, however, that the drowning of the valleys may be the result solely of a rise of sea-level due to the deglaciations of the last 20,000 years. He points out that drowning is a universal phenomenon except in those regions where recently lifted terraces demonstrate that the land has been rising faster than the sea-level.

The profile of the present surface appears to support the latter hypothesis. As stated previously, the slope is very gentle south of Houston and is relatively steep north of there. This is the exact opposite of the curve described by the dip of the Tertiary beds which is steepest between Houston and the shore line and is gentlest northward from Houston. Since the dip of the Tertiary beds is definitely the curve for geosynclinal sinking, one would not expect that the mirror image of this curve, which is the present land slope, would also be the result of geosynclinal sinking. If the present land slope were the result of geosynclinal depression, the axis would have to be situated at least 50 miles north of the axis of deformation during Tertiary and Quaternary time. This is highly improbable. The present slope seems to be best explained by upward deformation along an axis north of the 50-foot contour. Such an uplift together with deglaciation will explain the present profile, the entrenched streams, the estuaries and also such an anomaly as the elevated beach at Corpus Christi. The slightly entrenched streams near the shore line are the result of a relatively small amount of uplift. They are not drowned because they

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

have not cut down as far as the main streams which form the estuaries.

If this is the recent history of the Gulf Coast, then the submerged canyon south of the mouth of the Mississippi River and the present alluvium-filled canyon of the Mississippi were formed in a cycle of uplift and subsidence which antedates the uplift represented by the entrenched streams in Texas.

Significance of Barrier Beaches. --The coast of Texas is bordered with barrier beaches. Padre Island and Matagorda Island are excellent examples. Behind these barrier beaches are equally well-developed estuaries.

Russell[1] states that many geologists believe the Texas coast

---

1. Russell, Richard Joel, loc. cit., pp. 162-174.

---

to be emergent because of the presence of these barrier beaches. He says that the use of barrier beaches as a criterion of coastal emergence "has had such impressive sponsorship that today most geologists accept it without question". While this statement is debatable, he is correct in concluding that barrier beaches are not necessarily indicative of an emergent shore line. Russell's treatment of the barrier beach problem, however, is noteworthy for its failure to show the significance of these topographic features.

Professor N. M. Fenneman first pointed out to the writer that barrier beaches are a device to correct an excessively flat offshore profile. Just as streams build up or cut down their bed to

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

establish grade so there is an off-shore profile of equilibrium toward which waves and currents will direct their energy. If this slope from shore line to wave base is too steep, a cut-and-built-terrace will be formed to correct this deviation from the profile of equilibrium. If the slope is too gentle, the waves will expend their energy in dragging over this excessively flat surface and break before reaching the shore. An off-shore bar, or barrier beach, will be formed at the line of breakers. The lagoon will soon be filled, and the barrier beach will then represent the new shore line. In this way the shore line will be moved seaward, the off-shore slope increased, and the profile of equilibrium established.

After a new cycle is inaugurated, then, the presence or absence of barrier beaches will depend upon the slope of the initial off-shore profile and not upon the condition of emergence or submergence. When a gently-sloping surface like the Texas Coastal Plain is subsiding or when sea-level is rising upon such a surface, an excessively flat off-shore profile may be inherited since the slope from the shore line northward to the 50-foot contour is much less than from the shore line southward to the 100-fathom line. Barrier beaches and estuaries would then be formed simultaneously.

Russell[1] has proposed that a classification of shore lines on

1. Russell, Richard Joel, loc. cit., p. 174.

the basis of advance and retreat be substituted for the basis of

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

submergence and emergence. The inadequacy of this proposal is apparent when one considers that a shore line cannot advance appreciably without subsidence once the profile of equilibrium is established. When the profile of equilibrium is established, the energy of the waves is exhausted just as they reach the shore and they are without ability to attack the continent. Most of the features which mark the progressive changes incident to the evolution of a shore line are directly or indirectly a result of an off-shore profile which is not in equilibrium. Since only diastrophism can alter an off-shore profile once it is in equilibrium, the classification of shore lines on a basis of submergence and emergence has more real significance than a classification on a basis of advance and retreat.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Bibliography

A very complete list of papers on Texas geology has been published recently by Sellards, Adkins, and Plummer. A similar list for Louisiana has been prepared by Howe. The following is a select list of the more important papers and books relating to the subject of this paper:

Bailey, Thomas L., The Geology and Natural Resources of Colorado County: The Univ. of Texas Bull. no. 2333, 1923.

Bailey, Thomas L., The Gueydan, a New Middle Tertiary Formation from the Southwestern Coastal Plain of Texas: The Univ. of Texas Bull. no. 2645, 1926.

Barton, Donald C., Deltaic Coastal Plain of Southeastern Texas: G. S. A. Bull. vol. 41, 1930.

Barton, Donald C., Mechanics of Formation of Salt Domes with Special Reference to Gulf Coast Domes of Texas and Louisiana: A. A. P. G. Bull. vol. 17, no. 9, 1933.

Berry, Edward Wilber, The Flora of the Catahoula Sandstone: U. S. G. S., Prof. Paper no. 98, 1916.

Brown, Levi S., Age of the Gulf Border Salt Deposits: A. A. P. G. Bull. vol. 18, no. 10, 1934.

Bucher, Walter H., Deformation of the Earth's Crust: Princeton Univ. Press, 1932.

Deussen, Alexander, Geology of the Coastal Plain of Texas West of Brazos River: U. S. G. S. Prof. Paper no. 126, 1924.

Deussen, Alexander, Geology and Underground Waters of the Southeastern part of the Texas Coastal Plain: U. S. G. S. Water Supply Paper no. 335, 1914.

Dumble, E. T., The Geology of East Texas: The Univ. of Texas Bull. no. 1869, 1918.

Ellisor, Alva Christine, Jackson Group of Formations in Texas with Notes on Frio and Vicksburg: A. A. P. G. Bull. vol. 17, no. 11, 1933.

Galliher, E. Wayne, Geology of Glauconite: A. A. P. G. Bull. vol. 19, no. 11, 1937.

Howe, Henry V., Louisiana Petroleum Stratigraphy: La. Dept. of Conserv. Bull. no. 27, 1936.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Howe, Henry V., Russell, Richard J., McGuirt, James H., Geology of Cameron and Vermilion Parishes: La. Dept. of Conserv. Geol. Bull. no. 6, 1935.

Howe, Henry V., Moresi, Cyril K., Geology of Iberia Parish: La. Dept. of Conserv. Geol. Bull. no. 1, 1931.

Moody, C. L., Tertiary History of Region of Sabine Uplift, Louisiana: A. A. P. G. Bull. vol. 15, no. 5, 1931.

Powers, Sidney, Interior Salt Domes of Texas, Geology of Salt Dome Oil Fields: Amer. Assoc. Petrol. Geol., 1926.

Renick, B. Coleman, The Jackson Group and the Catahoula and Oakville Formations in a part of the Texas Gulf Coastal Plain: The Univ. of Texas Bull. no. 3619, 1936.

Rich, John L., A Mechanism for the Initiation of Geosynclines and Geo-basins: Abstracts of papers offered at the fiftieth annual meeting of the G. S. A., 1937.

Russell, Richard Joel, Physiography of Lower Mississippi River Delta: La. Dept. of Conserv. Geol. Bull. no. 8, 1936.

Schuchert, Charles, Historical Geology of the Antillean-Caribbean Region: John Wiley and Sons, Inc., 1935.

Sellards, E. G., Adkins, W. S., and Plummer, F. B., Geology of Texas: The Univ. of Texas Bull. no. 3232, 1932.

Shepard, Francis P., "Salt" Domes Related to Mississippi Submarine Trough: G. S. A. Bull. vol. 48, 1937.

Spooner, W. C., Oil and Gas Geology of the Gulf Coastal Plain in Arkansas: Ark. Geol. Surv. Bull. no. 2, 1935.

Trowbridge, A. C., Tertiary and Quaternary Geology of the Lower Rio Grande Region, Texas: U. S. G. S. Bull. no. 837, 1932.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.