GEOLOGY

OF

HOUSTON & VICINITY, TEXAS

WITH

Appended Guides to Fossil, Mineral, and Rock Collecting Localities

Prepared primarily as an aid in the teaching of elementary Geology in the Houston Area, Texas

By

Houston Geological Society
Academic and Library Committee

Houston, Texas
1961

Order from: Houston Geological Society
234 Esperson Building
Houston 2, Texas

Price: $2.00 per copy
$1.50 on orders of 10 or more

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FOREWORD

by

George C. Hardin, Jr., President
Houston Geological Society, 1961-62

The need for a non-technical volume on the geology of the Houston area became acute in 1959 when the Texas State Board of Education added to its "Proposed Standards for Texas Secondary Schools" a course entitled "Earth Science" for grade seven or eight, and a one-semester elective science course in Geology, Meteorology, Oceanography, and Astrophysics for grades ten through twelve. To help introduce these "new" subjects, a number of members of the Houston Geological Society lectured before groups of teachers and students during the 1960-61 school year. Repeated requests were received for information on the geology of the Houston area and for directions to localities where rocks, minerals, and fossils could be collected. In an attempt to fill this need, the Academic and Library Committee of the Houston Geological Society has prepared this publication. Preparation was rushed to make it available at the beginning of the 1961-62 school year. Although more time would have allowed certain improvements, the Committee felt that later revision would be preferable to delay in publication.

It was impossible to write about geology without using a few technical terms. These are defined in Appendix III, to which the reader is urged to refer when in doubt as to the meaning of a technical word.

Members of the Academic and Library Committee of the Houston Geological Society are listed below. They have contributed their time and information to the preparation of this publication.

George C. Hardin, Jr., Chairman

Julie E. Brock	Frank R. Hardin	DeWitt C. Van Siclen
Otto J. Buis	Shirley L. Mason	John E. Walters
Jack W. Craig	Ralph G. Nichols	John B. Williams
	E. H. Rainwater	

Mr. A. G. Winslow of the Ground Water Branch of the United States Geological Survey contributed the section "Ground Water in the Houston Region". Julie Eastin Brock, with the assistance of E. H. Rainwater, prepared the report on fossil localities and the accompanying maps showing geologic history.

INTRODUCTION

by

George C. Hardin, Jr.[1]

Geology is the science which deals with the earth and with the development of former living things. It is the study of the rocks and minerals that make up the earth, of the hills and valleys, plains and waters that occupy its surface, and of the plants and animals which inhabited it in the past. Although the Houston area is but a small part of the earth, an understanding of its geology will give one a foundation for understanding the geology of other areas.

The crust of the earth consists of igneous, sedimentary, and metamorphic rocks. Igneous rocks are formed by solidification of melted rock, some on the surface as lava flows, and some underground like granite. Sedimentary rocks are those that formed on the surface of the earth by the accumulation of material from older rocks, or from plant or animal remains. Sand and clay, limestone and coal, are abundant sedimentary rocks. Metamorphic rocks are produced by the alteration of former igneous or sedimentary rocks by the great heat and pressure deep inside the earth. Marble, slate, schist, and gneiss are common metamorphic rocks.

Around Houston we find only sedimentary rocks (mainly clay, sand, and silt), but northwest of Austin, Texas one can find many kinds of igneous and metamorphic rocks, as well as other kinds of sedimentary rocks. Localities for collecting minerals and igneous and metamorphic rocks are described in Appendix II of this booklet.

There is evidence that the earth is about four billion years old, and that life has existed on the earth for at least 600 million years. The earliest period of earth history in which we find abundant evidence of life in the form of fossils is called the "Cambrian." The time prior to this period is generally referred to as "Precambrian," and all of the time since has been divided into three eras called "Paleozoic," "Mesozoic," and "Cenozoic." Each of these eras is divided into periods. These divisions, along with the approximate age of each in years as determined by radioactivity measurements, are shown on Table I.

Rocks of all ages are found in Texas, but in the Houston area, we are concerned only with rocks deposited during the Cenozoic era. Older rocks undoubtedly underlie the area, but they do not crop out and have not been penetrated by the drill.

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[1]Consulting Geologist, Houston, Texas

TABLE I

GEOLOGIC COLUMN AND TIME SCALE

Era	System or Period	Epoch	Approximate age in Millions of years From Radioactivity*
CENOZOIC (recent life)	QUATERNARY	RECENT	
		PLEISTOCENE	1
	TERTIARY	PLIOCENE	13
		MIOCENE	17
		OLIGOCENE	25
		EOCENE	36
		PALEOCENE	58
MESOZOIC (middle life)	CRETACEOUS		65
	JURASSIC		135
	TRIASSIC		180
PALEOZOIC (ancient life)	PERMIAN		230
	CARBONIFEROUS		
	PENNSYLVANIAN		280
	MISSISSIPPIAN		310
	DEVONIAN		349
	SILURIAN		405
	ORDOVICIAN		425
	CAMBRIAN		500
PRECAMBRIAN			600

*Approximate ages from Kulp, J. L., 1961, Geologic Time Scale; SCIENCE V. 133, N. 3459, p. 1111.

SCENERY AND RECENT SEDIMENTS ALONG THE COAST

by

DeWitt C. Van Siclen[1]

Our Gulf of Mexico coast is a great laboratory in which we can see geologic processes going on today in much the same way they have been going on here for the last 100 million years. Through all these ages the rains have bathed the land and washed mud and sand into the rivers, which have carried it down to the Gulf. There it has settled out, each new layer of mud and sand pressing on those beneath, forcing the tiny grains ever closer together until they formed solid rock.

Today geologists study these rocks, laid down beside the long-ago shores of the Gulf of Mexico, because in places oil and gas occupy the tiny spaces between sand grains which did not get squeezed together too tightly. To find additional oil and gas, and to learn more about this old earth on which we live, geologists are always trying to discover more about how the ancient rocks were formed. But to understand the ancient rocks they have learned that they need to know all about the geologic processes like those going on along the Gulf Coast today. Geologists realize that knowledge of what goes on at present is the key to understanding things that happened in the past. This is such a fundamental principle of geology that it has a special name, The Principle of Uniformitarianism. You can remember it with the phrase, "the present is the key to the past."

What are the geologic processes active today along the Gulf Coast?

LARGER FEATURES OF THE TEXAS COAST

First let's think about the things we can see near Houston. Perhaps we are most familiar with the sandy beaches which fringe the Gulf. These are but the seaward margin of long narrow islands (and peninsulas) that curve along the coast. From the air and on maps these islands stand out as the most conspicuous feature of the Texas Coast. The general term for them is barrier islands. The best known barrier island is Galveston Island, shown on figure 1. They average about 30 miles long and 2 miles wide, and consist principally of fine sand that extends to a depth of about 30 feet. The barrier islands are separated from each other by tidal channels (passes), and from the mainland by shallow bays.

Did you ever notice that the bays are of two kinds? One kind is long and narrow, extending parallel to the coast behind the barrier islands, and separating them from the mainland. This type is termed a lagoon. West Bay is the lagoon that separates Galveston Island from the mainland, as can be seen on figure 1. These bays average about 3 miles wide, 20 miles long, 6 feet deep and generally have mud bottoms.

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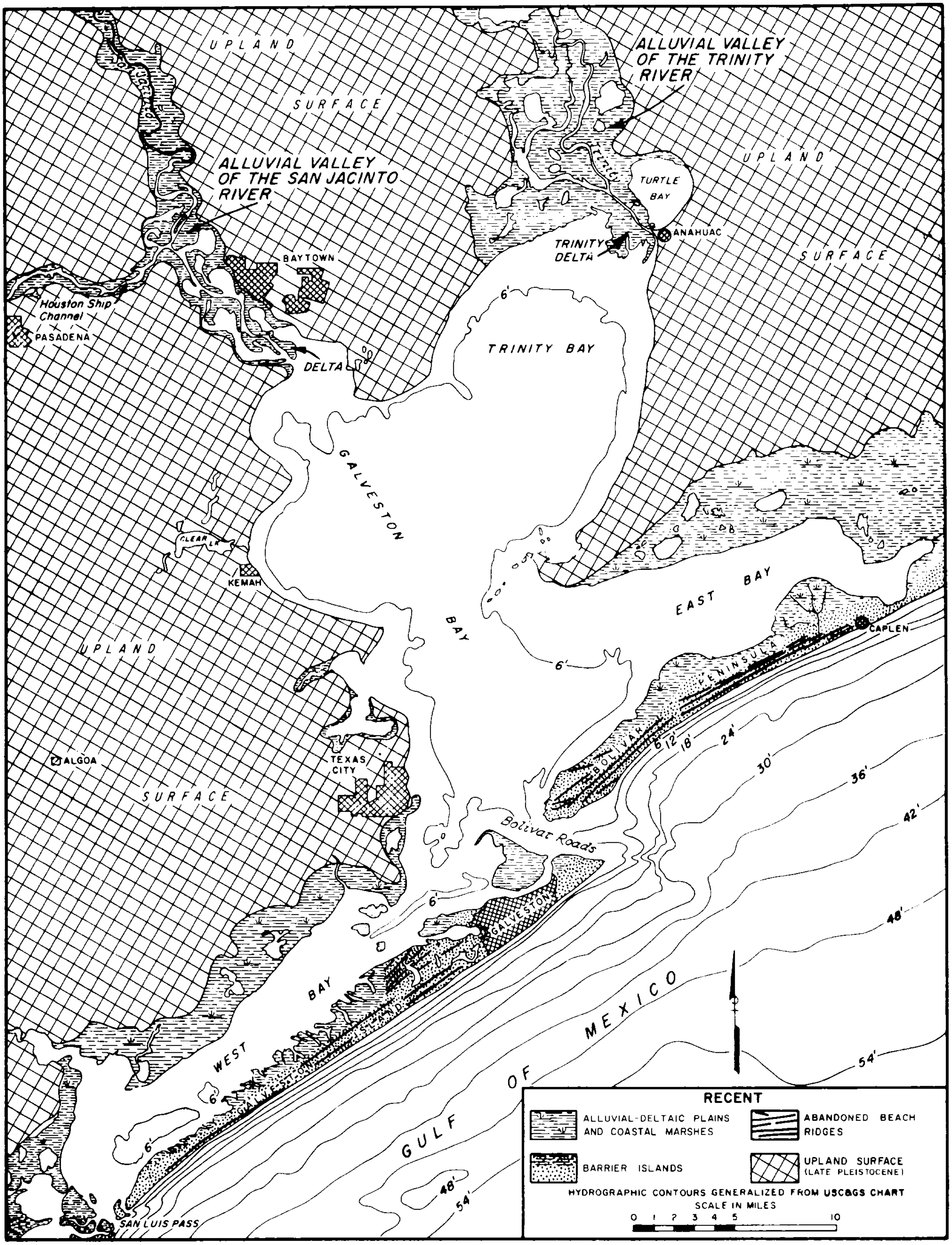
[1]Geology Department, University of Houston


UPLAND SURFACE
ALLUVIAL VALLEY OF THE TRINITY RIVER
ALLUVIAL VALLEY OF THE SAN JACINTO RIVER
TURTLE BAY
ANAHUAC
TRINITY DELTA
BAYTOWN
Houston Ship Channel
PASADENA
DELTA
TRINITY BAY
GALVESTON BAY
CLEAR LK
KEMAH
EAST BAY
CAPLEN
BOLIVAR PENINSULA
TEXAS CITY
ALGOA
Bolivar Roads
GALVESTON
WEST BAY
GALVESTON ISLAND
GULF OF MEXICO
SAN LUIS PASS
RECENT
ALLUVIAL-DELTAIC PLAINS AND COASTAL MARSHES
ABANDONED BEACH RIDGES
BARRIER ISLANDS
UPLAND SURFACE (LATE PLEISTOCENE)
HYDROGRAPHIC CONTOURS GENERALIZED FROM USC&GS CHART
SCALE IN MILES
0 1 2 3 4 5 10

The second kind of bay also is longer in one direction than in the other, but its long direction is at right angles to the coast. This is the estuary type of bay, exemplified by Galveston Bay and its continuation as Trinity Bay, on figure 1. The estuaries run about 8 miles wide, 25 miles long, and 10 feet deep, and generally have mud bottoms like the lagoons. But unlike the lagoons the estuaries extend far inland, and have streams entering at their heads.

The fourth and last of the major coastal features of Texas are the deltas that the rivers have built out into the bays. These are the swampy "new lands" which the rivers have made with the loads of mud and sand that they bring to the sea. Most of the deltas occur near the heads of estuary-type bays, like the Trinity River delta just west of Anahuac, which separates Turtle Bay from Trinity Bay, as may be seen on figure 1. However, the rivers that carry the most material - the Brazos, Colorado, and Rio Grande - long ago built their deltas right across the former estuaries into which they once emptied, filling them in to form the flat swampy lowlands that we refer to as deltaic plains. Now that these rivers have made land of their former estuaries they flow directly into the Gulf of Mexico and are trying to fill it in too! The deltaic plain near the former mouth of the Colorado River merges with that of the Brazos River, forming the broad Colorado-Brazos deltaic plain illustrated by figure 2. The Colorado River took its present course below Wharton within the last few hundred years, abandoning its former channel farther east, which now is occupied by Caney Creek.

The deltas and deltaic coastal plains continue inland without much change into more or less broad, flat valleys. These are termed alluvial valleys because they, like the deltaic plains, are underlain by a substantial thickness of mud, sand, and gravel laid down by the river, material referred to as alluvium. The size of the alluvial valley and deltaic plain of each river is proportional to the size and load (of mud and sand) which that stream carries. Large ones like the Rio Grande and Brazos River have wide valleys and broad deltaic plains that extend all the way to the Gulf of Mexico. Smaller streams like the Nueces and San Jacinto rivers flow in relatively very narrow valleys, and have built only small deltas at the very head of shallow estuary-type bays.

Figure 1. The Galveston Island - Bolivar Peninsula segment of the coast. Observe the Galveston barrier island and Bolivar Peninsula (a land-tied barrier island), separated by Bolivar Roads, a tidal channel or pass. West Bay and East Bay are long narrow lagoons that lie parallel to the barrier islands and separate them from the mainland; while Galveston Bay and Trinity Bay are estuaries which extend far inland. The San Jacinto and Trinity rivers flow into the heads of the estuaries, which they are slowly filling in by constructing deltas of mud and sand (alluvium). In this way the rivers are extending the alluvial valleys in which they flow and which lie at a lower elevation than the intervening upland surface. The upland surface slopes 2 or 3 feet per mile toward the Gulf and passes below sea level in the tidal marshes along the mainland side of the lagoons.

(Modified from Rufus J. LeBlanc and W. D. Hodgson 1959.)

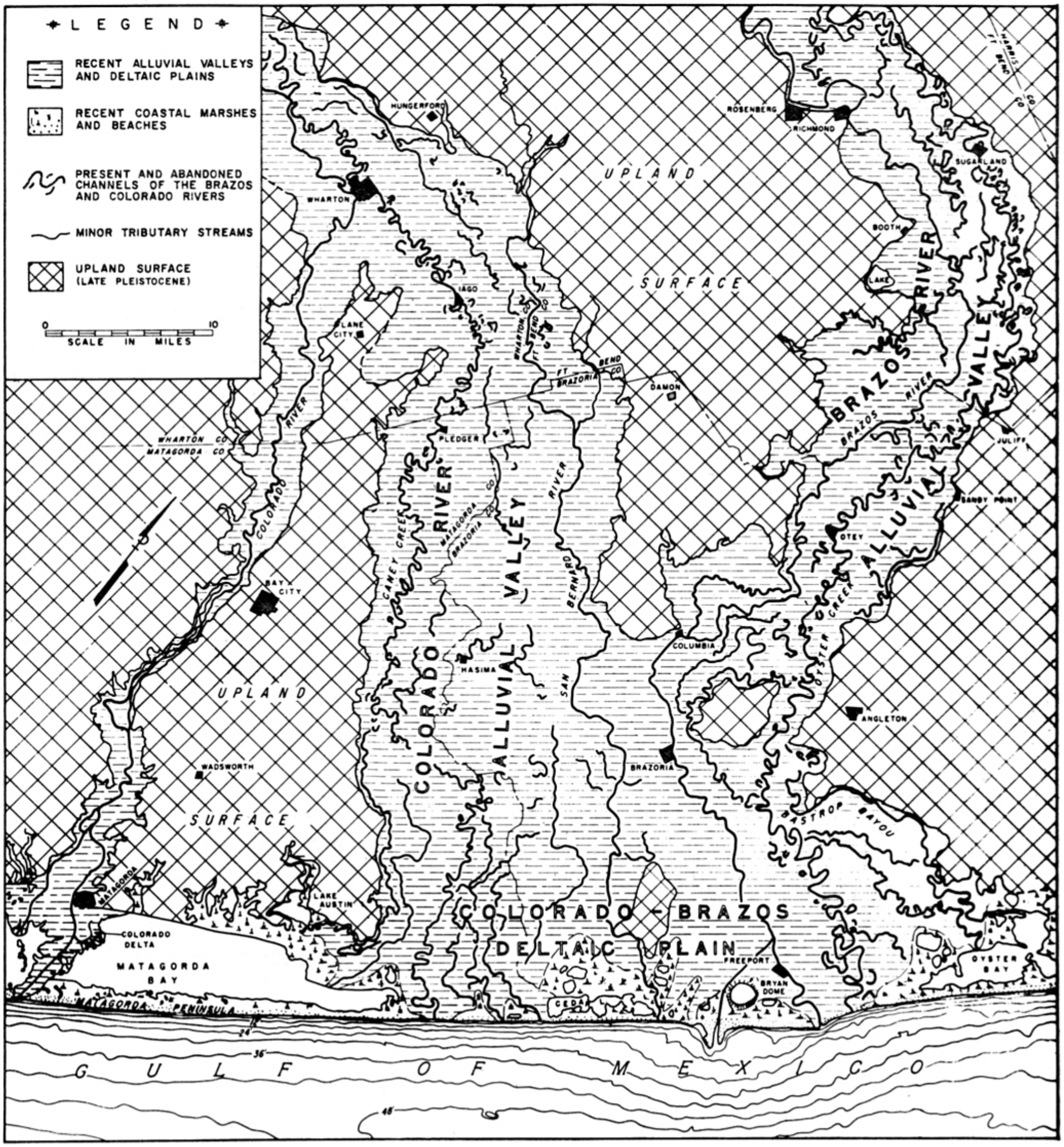


Figure 2. The Colorado-Brazos segment of the coast. The arrow shows that north is to the upper right. Observe the broad deltaic plain which the Brazos and Colorado rivers have built jointly by completely filling in their former estuaries. This is continuous inland with the alluvial valleys which interrupt the continuity of the higher upland surface. The Colorado River took its present course below Wharton within the last few hundred years, abandoning its former channel farther east (now occupied by Caney Creek). Still older abandoned channels of the Colorado and Brazos rivers can be recognized and are shown on the map. Along the Gulf the deltaic plain is flanked by barrier islands and lagoons (e.g., Matagorda Peninsula and Bay, etc.).

(Modified from Rufus J. LeBlanc and W. D. Hodgson 1959.)

THE TWO SHORELINES

Texas really has two shorelines - one along the Gulf of Mexico and another along the bays. The Gulf shoreline lies along the seaward edge of the barrier islands and deltaic plains; while the bay shoreline lies at the edge of the mainland, on the mainland side of the estuaries and lagoons. The Gulf shoreline curves along the coast in a great arc, and has broad beaches of sand. The bay shoreline is entirely different, being very irregular and generally without sandy beaches. Most of the bay shoreline is flat and marshy, though in places it has low bluffs.

THE UPLAND SURFACE

Inland from the bays the surface of the land looks almost flat, but it does rise very gently away from the coast. The river valleys rise inland less than one foot each mile for many tens of miles, but the higher land between the valleys rises inland two or three feet per mile around Houston, (and more steeply farther southwest along the coast, being about six feet per mile south of Corpus Christi). Since the river valleys have the lower slope, away from the coast they become distinct from the higher "flat" area between, which we will call the upland surface. Houston is built on the upland surface, between the Brazos and San Jacinto river valleys. The continuity of this upland is interrupted by the smaller valleys of Buffalo and other bayous. These valleys were formed by the streams that occupy them washing away the mud and sand along their banks during floods. Several times each year we can see the streams in flood still digging away at their banks (where not restrained by control measures).

GEOLOGIC HISTORY

If we wish to understand how this land received its present form, we must consider details of the features described above, and the processes active today that are able to produce such features. These processes work so slowly that we rarely are aware of their results, yet by comparing old maps with the present land we find that some streams have shifted their courses, Galveston Island has grown slightly, and other changes have occurred over the decades. Little changes like these, going on continuously for thousands of years, produce vast effects. The sequence of changes can be deciphered, and is described as the geologic history of the area and of its various features.

Geologists decipher the sequence of changes by use of a "law" so simple that it is easily overlooked, and so named that it is easily forgotten - the Law of Superposition. According to this law something can be changed only after it has come into existence; the continuity of the upland surface about Houston could be interrupted by erosion of the valleys and bayous only after the upland surface itself had formed. The sequence of events was: (1) development of the upland surface, and (2) erosion of the valleys and bayous. Hence the valleys and bayous were "superposed", or in English "placed over," the older upland surface. The same principle applies to deposition of the material removed by erosion; new layers are "superposed" or "placed over" older material. Hence, in an undisturbed sequence of sediments the lowest layer is the oldest, and each higher layer is younger than the one beneath.

In our discussion of the Law of Superposition we applied it to determining the sequence: (1) development of the upland surface, and (2) erosion of the valleys (bayous). We can carry our sequence further by observing that the upland surface slopes gently seaward and passes beneath the lagoons, and that the surface of the valleys likewise passes beneath the estuaries. Across these bays the barrier islands consist of sand and mud "superposed" on both the upland and valley surfaces. This is clearly suggested by the topography and has been confirmed by information from wells drilled on the islands. Hence the development of the present bay shoreline, and of the barrier islands and their Gulf shoreline, took place after the upland and valley surfaces had formed. Our intuition may suggest (correctly in this case) that the bay shoreline had to form first, but this is something we will have to confirm later when we have more details to work with. In the meantime let us add two more events to our sequence, (keeping in mind that we have yet to confirm their sequence): (3) development of the bay shoreline, and (4) development of the barrier islands with their Gulf shoreline.

Perhaps you are wondering why there was a sequence of events in the first place. Events imply that something changed, but what were the changes, and what caused them? To answer that we must consider how the features mentioned above were formed. We learn most readily how things formed in nature by observing similar things being formed today, following the principle of uniformitarianism mentioned already. Do you remember it, "the present is the key to the past"?

ORIGIN OF THE UPLAND SURFACE

Let's begin with the upland surface, which is the oldest feature we are considering here. How did it form? We have two major clues. The first clue may be observed on large-scale photographs taken from the air, especially of areas near the coast where the upland surface has been least disturbed. There on the photographs one may see numerous slightly darker bands of earth forming a pattern resembling the winding, interlaced stream channels of the present-day deltaic plains, (like the present and abandoned channels of the Brazos and Colorado rivers marked by heavy lines on fig. 2). Studies on the ground show that the darker bands seen on the air photographs do, indeed, have all the characteristics one would expect of former deltaic stream channels that have been largely obliterated by the rainwash of many centuries. Thus near the coast the upland surface seems to consist of former very extensive deltaic plains that grew together into one continuous deltaic coastal plain.

The second clue to the origin of the upland surface confirms in a general way the more specific conclusions drawn from the preceding clue. Along the sides of the bayous in Houston one can observe the layers of mud and sand left by streams as they built that ancient deltaic coastal plain, layer upon layer. These layers lie exactly parallel to the upland surface, this being simply the top of the highest and last layer. That means that the upland surface here was formed by the streams laying down the layers of mud and sand, not by the streams simply eroding older layers that had been left there long before. If the latter had been the case it is not likely that the layers would have been exactly parallel to the upland surface. Elsewhere stream erosion, tending always to reduce the land to the level of the sea, has formed similar broad plains. However, the plain whose remnants constitute our upland surface formed by stream deposition just like the deltaic plains of our present coast, though on a much more extensive scale. A few miles inland from Houston the layers of mud and sand do dip perceptibly toward the coast, and streams have eroded the upturned layers into gently rolling hills, among which the upland surface of the coastal region is no longer distinct.

THE VALLEYS' HISTORY

The valleys that extend as shallow, but sometimes broad notches in the upland surface are clearly "superposed," hence younger than the upland. Wells drilled in the valleys show that all of them are filled with as much as 100 feet of mud, sand, and gravel dropped by the rivers, termed alluvium. Because of this fill the valleys are called alluvial valleys, (on figs. 1 and 2). The presence of this thickness of alluvium indicates that sometime in the past the valleys were eroded to about 100 feet below their present level, then were largely filled in to form the present-day valley floors. We are referring to this now-buried surface to which the valleys were eroded as the valley surface, (and to the top of the fill as the valley floor).

Present-day streams do not erode their channels much below sea level, and there is no reason to believe that ancient streams behaved any differently. Yet the valley surface extends well below sea level, and passes seaward beneath the estuaries and barrier islands. The older material is recognized easily in wells drilled in the eastern part of Galveston Island, but a well drilled in Bolivar Roads immediately northeast of the island to a depth of more than 100 feet below sea level was still in valley fill at its total depth, (as shown on section A-A' of fig. 3). Hence the valley surface beneath Bolivar Roads lies more than 100 feet below sea level. Similarly, near the Gulf shore, the former valley of the Sabine River lies beneath at least 120 feet of alluvium. Evidence of this sort leads to the conclusion that, in the not very distant past, the level of the sea relative to the land has been at least 100 feet lower than it is today.

Evidence for lowered sea level in late geologic time is world-wide. It has been linked to the very extensive glaciers that briefly covered northern Eurasia and America, (extending south as far as New Jersey, Ohio, Illinois, and Kansas). During the times of maximum glaciation so much water was piled up on the continents as thick ice sheets, instead of being in the sea where it "belongs," that the sea level was about 450 feet lower than it is today. Interestingly, there is still enough ice on Antarctica and Greenland to raise sea level another 200 feet, if and when it should melt!

There were several intervals when the glaciers were very extensive, termed glacial stages, separated by intervals of warmer climate, the interglacial stages, during which Texas' climate was more or less like today's. The time from the first to the last interval of maximum glaciation is referred to as Pleistocene time. The time since then is called the Recent, with a capital "R."

During the several Pleistocene glacial stages, when sea level was about 450 feet lower than it is today, most of the continental shelf stood above the waves, and the shoreline was 50 to 140 miles seaward of the present shoreline. The rivers flowing

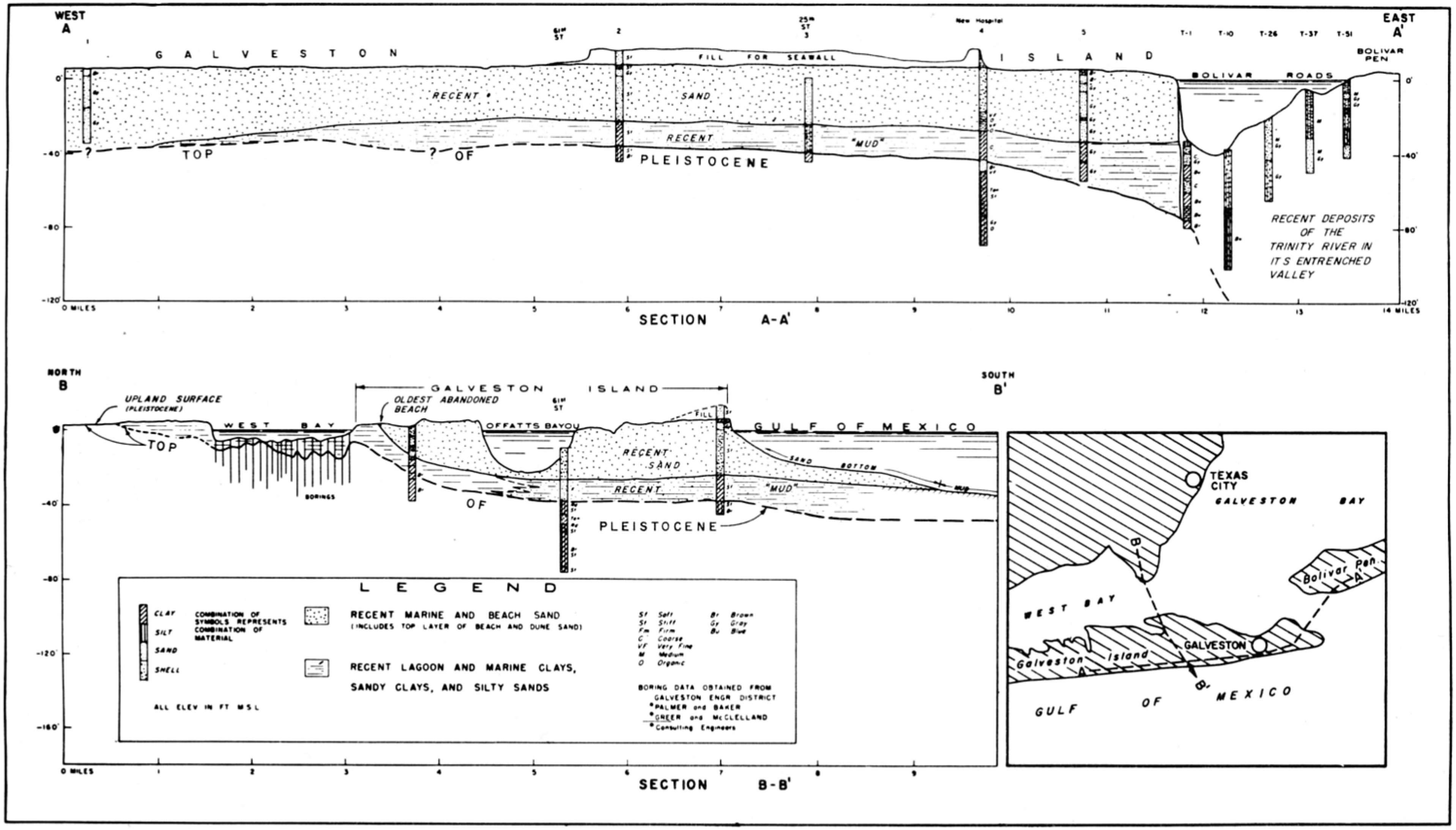


Figure 3. Cross sections along and across Galveston Island. The "top of Pleistocene" is essentially the continuation underground of the upland surface, (except near Bolivar Roads). This "surface" is irregular near the shore because it was eroded a little before the Recent sediments covered it. On section B-B' we see the upland surface (top of Pleistocene) sloping seaward and passing beneath Galveston Island. Section A-A' at its east end shows where the Trinity River once eroded its valley or "trench" well below the upland surface and more than 100 feet below present sea level. Since then the river has almost filled in its former entrenched valley, and Galveston Island has developed on the edge of the valley fill.

(Modified from Rufus J. LeBlanc and W. D. Hodgson 1959.)

across this broad plain eroded valleys more than 100 feet below the adjoining upland surface. During the last of the glacial stages the valley surface reached its final form, to be preserved beneath the alluvium that subsequently has almost filled the valleys. (Fig. 6A illustrates this situation.)

DEVELOPMENT OF THE ESTUARIES AND THEIR BAY SHORELINE

As the great Pleistocene glaciers melted and their water flowed into the sea, its level rose. This rising sea filled the lower portion of the deeply eroded valleys, forming a series of bays extending far inland, the estuaries. Thus the estuary type of bay is simply a valley cut long ago by the river that now enters at its head. The rising sea not only occupied the lower part of the valleys, but weakened the river currents to where they could not carry all their load of mud and sand, (much less gravel). This the rivers had to drop, gradually filling their valleys to the present level. Comparison of old charts with recent soundings shows that the estuaries are still filling.

Sea level reached its present position from about* 3,000 to perhaps as much as 5,000 years ago, and has remained constant ever since. This is the Recent standing sea level stage.

The bay shoreline, that on the mainland side of the bays, is essentially that which existed when the Recent standing sea level stage began. Since then some of the bay shores have been forced back by wave erosion, and other bay shores have advanced as river deltas filled in the bay heads and coastal marshes pushed out into the lagoons. The large Texas rivers, the Rio Grande, Brazos, and Colorado, have completely filled in the estuaries they once had and have constructed broad deltaic plains which protrude slightly into the Gulf of Mexico.

THE BARRIER ISLANDS AND GULF SHORELINE: DESCRIPTION

The Gulf shoreline, along the barrier islands and deltaic plains, has developed during the Recent standing sea level stage. Galveston Island and Bolivar Peninsula (a land-tied island) are the easternmost segment of a line of similar barriers which continue (with few interruptions) southward along the Texas and Mexican coast for about 600 miles. The width of Galveston and Bolivar at sea level averages 1.5 miles, and their base extends 2 miles seaward and a few hundred feet lagoonward from the islands' shore. At Bolivar Roads the long axis of Galveston Island is offset seaward relative to the axis of Bolivar Peninsula. This offset is related to the prevailing westerly longshore currents, and the resulting westward drift of sand along the shore.

*Footnote: The figures in years are based on the proportion of radioactive carbon remaining in samples of shells and wood collected from sediments believed to have been deposited at about the beginning of the Recent standing sea level stage.

Figure 4. Oblique view of Galveston Island from the air, looking northeastward toward the City of Galveston. The belts of higher ground are abandoned beach ridges, former beaches cut off from the sea by the repeated development of a new beach along the seaward side of the old beach. The dark belts are marshes that occupy the low swales between abandoned beach ridges. The bayou crossing the ridges and swales near the middle of the photograph is believed to have been scoured out by waves and currents during a major hurricane, and is kept open by floods during heavy rainfall. (From LeBlanc and Hodgson 1959.)

Galveston Island itself is about 30 miles long, 2.5 miles wide near its eastern end, and gradually tapers westward. Its surface consists principally of numerous extremely gentle ridges which trend almost parallel to the present shoreline and rise 5 to 12 feet above sea level. These are separated by low swales, which often are occupied by swamps. The ridges are abandoned beach ridges, former beaches cut off from the sea by the repeated development of a new beach along the seaward side of the old beach. Figure 4 is an oblique aerial photograph showing abandoned beach ridges and intervening marshy swales; figure 5 is a composite (mosaic) of many vertical aerial photographs showing these and other features. On the ground the ridges and swales are more difficult to recognize; they are most apparent along Eight Mile Road, at the north end of which is located the oldest beach ridge of Galveston Island. A few small sand dunes occur on the beach ridges, more commonly toward the western end of the island.

The Gulf shoreline of Galveston Island is very even, with a very broad beach. Seaward the Gulf bottom generally is smooth, and slopes approximately 13 feet per mile out to a depth of 30 feet, which is about 2 miles off shore. Beyond that the slope decreases to about 4 feet per mile out to a 50 foot depth, and farther seaward it is less than one foot per mile. The shoreline along the back side of the island is quite irregular, with many small "lakes" interrupting the continuity of the abandoned beach ridges.

West Bay, about 3 to 4 miles wide, is the lagoon that separated Galveston Island from the mainland. It generally is less than 6 feet deep and has a mud and sand bottom. It is separated from the upland surface to the north by a Recent marsh 1 to 2 miles wide.

Bolivar and San Luis passes had maximum depths of around 25 feet before the jetties were constructed. Tidal currents scouring the bottom of the passes have built delta-like sand bars (subaqueous tidal deltas) on the seaward and bay sides of both passes.

Figure 5. Aerial mosaics of: (A) central Galveston Island; and (B) western Bolivar Peninsula. As on the oblique photograph (fig. 4) the lighter-colored belts are beach ridges (abandoned except for the modern beach), while the narrower dark bands are marshes in the intervening swales. These alternating belts record stages in the development of the island and peninsula, the way rings in the wood of a tree record its growth. Galveston Island began as a single narrow beach ridge less than 2 miles long barely off the northeast part of mosaic (A), and has grown gradually wider as successive beach ridges formed along its seaward side. The younger beach ridges also lengthened the island by extending farther toward the southwest. Bolivar Peninsula has had a similar history. On the lagoon (back) side of the barriers some of the coves and marshes occupy swales between abandoned beach ridges which curve to a westerly trend near their southwest end. However, most of the water bodies cut right across the old beach ridges and are believed to have been scoured out originally by waves and currents during major hurricanes. (Courtesy of Jack Ammon Photogrammetric Engineers, Inc., San Antonio, Texas.)

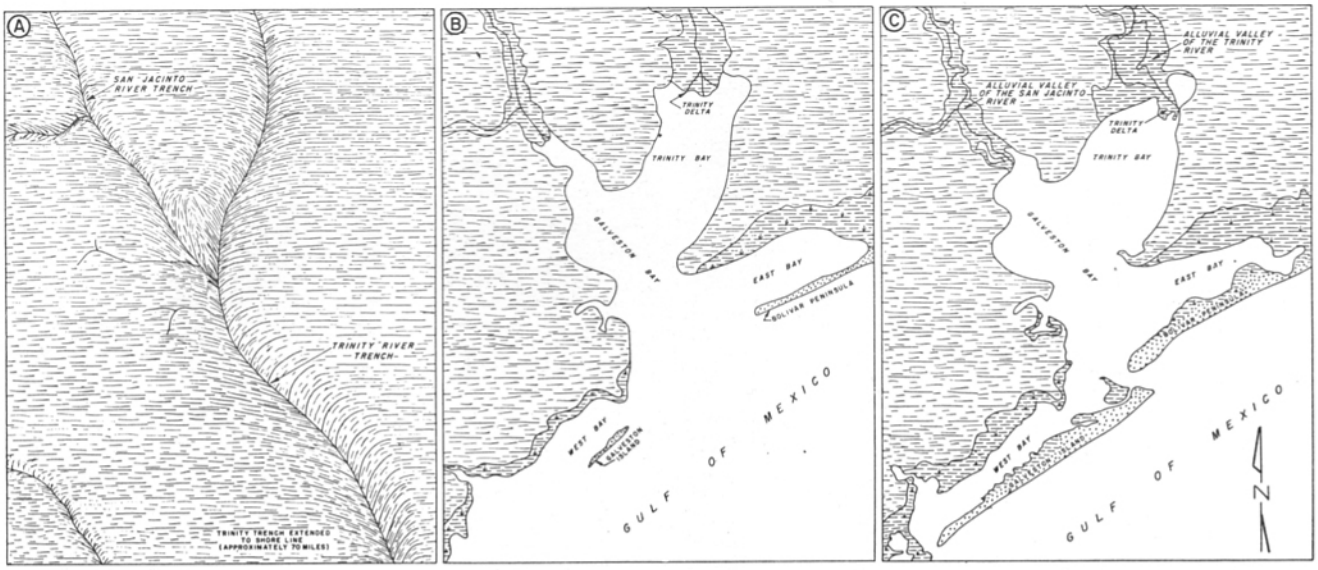


Figure 6. Diagrams showing three stages in the development of the Galveston Island-Bolivar Peninsula segment of the coast. (A) shows the deep trenches (valley surface) which the rivers eroded during the last glacial stage, while sea level was about 450 feet lower than it is today, and the shoreline lay more than 100 miles seaward of its present position. (B) shows conditions shortly after sea level had risen to its present position. One can see the early form of the bay shoreline, Galveston Island, Bolivar Peninsula, and the deltas of the San Jacinto and Trinity rivers. (C) shows the present form of these features, as illustrated in more detail on figure 1. Not only have the barrier islands and deltas expanded, but so have the estuaries, by wave erosion of their shores (as will be seen on figure 8). The marshes on both sides of the lagoons have expanded slightly, too. (From LeBlanc and Hodgson 1959.)

THE BARRIER ISLANDS AND GULF SHORELINE: ORIGIN

Galveston Island (like the other barrier islands) originated near the beginning of the Recent standing sea level stage, and has continued to grow ever since. It began as a small sandbar on the southwestern side of the mouth of the estuary now called Galveston Bay, about 4 miles offshore, in 5 to 8 feet of water. Sand piled up along the landward side of where the waves broke, forming an extremely narrow island not over 2 miles long, remnants of which today make up the most northwesterly beach ridge on the northeastern part of Galveston Island. Since that time the island has grown gradually wider by additional sand forming a succession of new beach ridges along its seaward side. The island has grown longer, too, because sand is carried southwestward along the beach by the longshore currents which usually flow in that direction, extending the beach ridges out into San Luis Pass as narrow fingers of sand, termed spits. As the continued southwestward extension of successive sand spits has restricted the pass, the water flowing through it has curved them to where the later spits trend more nearly west at their southwest end. (Fig. 5B illustrates the comparable situation at the southwestern end of Bolivar Peninsula.)

The many abandoned beach ridges disclose stages in the growth of Galveston Island, the same way rings in the wood of a tree disclose stages in its growth. Our clue to the sequence of beach ridges is the observation (on fig. 5A) that some ridges cut off the one adjoining on the northwest, (but never the one on the southeast). Applying the law of superposition, in each case the more northwesterly beach ridge had to be there first to get cut off, so is the older. Hence the beach ridges are successively younger toward the southeast. This is confirmed by observations made in shallow holes, where it is seen that each beach ridge rests on the extended base of its neighbor to the northwest. Thus the law of superposition enables us to determine the sequence of beach ridges, hence the shape of the island at stages during its growth. Also, the approximate time in years has been determined by measuring the proportion of radioactive carbon in wood and shells buried in the several beach ridges and associated sediments. In this way it has been estimated that Galveston Island reached approximately half its present size about 3,000 years ago.

Is Galveston Island still growing; and if so, where does the sand come from? Studies by the U. S. Engineers District Office at Galveston have shown that sand is being added to the beach at present, and that this has been going on for no less than 80 years. By comparing the depth of water shown on charts constructed at intervals during these 80 years, it has been found that the floor of the Gulf of Mexico off Galveston Island is being deepened in many places. The engineers have calculated that more than enough material is being removed from the floor of the Gulf to account for all the sand and finer material now being added to the island. In addition, some sand probably is brought in by long-shore currents from the Louisiana coast and from the Colorado-Brazos delta. The Trinity and San Jacinto rivers contribute important amounts of mud.

The back side of Galveston Island has a very irregular shoreline, in contrast with the Gulf shoreline, as may be observed on Fig. 5A. Those few coves and bayous on the lagoonward side of the island whose long axes trend nearly west are swales between old beach ridges which curve to a westerly trend near their southwest end. But most of the bayous, and the lakes that occur in the northern half of the island, trend nearly at right angles to the old beach ridges and are believed to have been scoured out by waves and currents during major hurricanes. They are kept open by floods during heavy rainfalls, by the tides, and by storm washovers. The island has not grown lagoonward to any important extent.

Figure 7. View of the beach several miles east of High Island, Texas. Wave erosion is forcing this part of the coast to retreat, exposing dark gray clay rich in plant remains which formed in the tidal marsh behind a former beach. The belt of sand which once separated this marsh from the Gulf has been washed away, except for the displaced remnants of shelly sand on top and in front of the clay. This suggests that the shoreline here has retreated more than 1,000 feet in the last several thousand years. (Author's photograph.)

SEGMENTS OF THE GULF SHORELINE THAT ARE RETREATING

Although most of the Gulf shoreline is advancing seaward by deposition of sand along the seaward side of the barrier islands and by the construction of deltaic plains, there are a few local exceptions. The most evident example of shoreline retreat is a 25 mile segment east of Bolivar Peninsula and west of Sabine Pass. There erosion of the beach has forced the Highway Department to relocate portions of Texas Highway 87 further inland a number of times during the last 20 years. In places along here the beach consists of two or three feet of sand resting on dark gray clay rich in plant remains. The dark clay resembles the material that forms today in the tidal marsh back of the beach. Evidently it is now exposed on the beach because the belt of sand that once separated the former marsh from the Gulf has been removed by waves and currents. The shoreline in this area must have retreated more than one thousand feet in the last few thousand years to place the present-day beach over former marsh deposits.

The shoreline along the Colorado-Brazos deltaic plain also has retreated during the late Recent, presumably since the Colorado River was diverted westward to its present mouth near Matagorda. This is shown by the abrupt way in which the shoreline cuts across the meander belts of Caney and Oyster Creeks, former channels of the Colorado and Brazos rivers, respectively, (shown on fig. 2). You can see the abrupt truncation of Oyster Creek by looking southwest from the top of the high bridge over the Intracoastal Waterway 5 miles east of Freeport. Despite this late local advance of the sea over the Colorado-Brazos deltaic plain, the net result of deltaic sedimentation in this region during the Recent has been to extend the land, making this section of the shore protrude slightly out into the Gulf of Mexico. You may have noticed how this protrusion interrupts slightly the smooth curve of the Gulf shoreline.

Figure 8. Oblique view of the Colorado-Brazos deltaic plain 20 miles southwest of Freeport. Observe the broad meanders of Caney Creek and the abrupt way in which the beach cuts off the meander belt. This suggests that the shoreline has been advancing inland here, presumably since the larger Colorado River abandoned this channel a few hundred years ago. (From LeBlanc and Hodgson 1959.)

CHANGES IN GALVESTON AND TRINITY BAYS

Significant changes have occurred also in the shoreline of Galveston and Trinity bays during the Recent standing sea level stage. Changes caused by the deposition of mud and sand have been limited almost entirely to the heads of the bays where the Trinity and San Jacinto rivers have been building their deltas. Although man-made changes related to the Houston Ship Channel make it difficult to determine the growth of the San Jacinto delta, it is evident that the Trinity River has enlarged its deltaic plain over several square miles of what was formerly the most northeasterly part of Trinity Bay. Additional mud and sand have been deposited away from the shoreline, shallowing these bays.

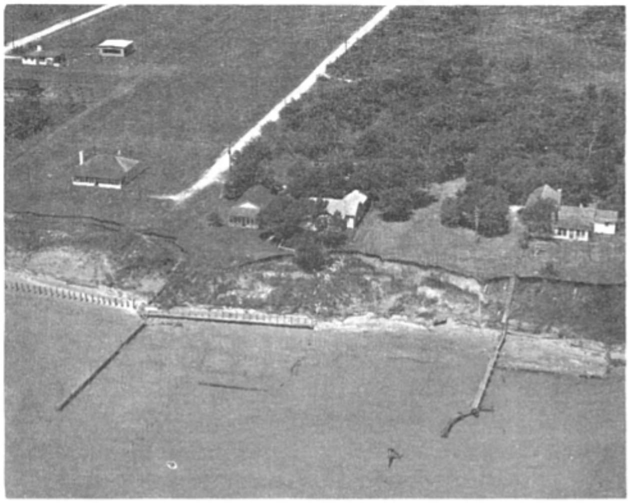


Figure 9. Oblique view of the northern shore of Trinity Bay in the summer of 1958, showing the effects of erosion by storm waves. (Courtesy of The Houston Chronicle.)

The predominant process along the shoreline of these estuaries has been erosion. The action of waves, especially during storms, is causing the shore to retreat. Much of the shoreline of Trinity Bay between Smith Point and Anahuac, and between the Trinity and San Jacinto deltas, has receded during recent years. The same is true along the west side of Galveston Bay from north of Kemah to Texas City. The broad arcs in the shoreline at Kemah and 5 miles north of Kemah are believed to have developed by wave and current erosion during the Recent standing sea level stage.

EAST AND WEST BAYS

In contrast to the estuaries, the lagoons are becoming narrower (as well as shallower), because their restricted width does not permit storm waves to become as large as those in the broader estuaries. A little sand is washed into the lagoons from the barrier islands, but most of the fill is mud derived ultimately from the San Jacinto and Trinity rivers. Much of this material is trapped by vegetation in the marshes along the shore, causing the marsh to expand slowly at the expense of the bay. East Bay has shallowed one to two feet during the past 80 years, but practically no filling was recorded in West Bay during that interval.

SURFACE GEOLOGY IN AND NEAR HOUSTON [1]

by

DeWitt C. Van Siclen [2]

The material one sees along the sides of the bayous in and around Houston is generally red to gray clay, overlain by sandy brown clay, and (near the top of the exposures) black organic clay with minor lenses of brown sand. Material of this sort, with some variation, is found along Bray's, Buffalo, White Oak, Halls, and Green's bayous, and on the divide between the first two in a road cut about 25 feet deep near the junction of Lexington and Woodhead avenues in the City of Houston. The layers (beds) like those shown on figure 10 appear to slope (dip) about three feet per mile to the southeast, parallel to the slope of the upland surface, (which seems simply to be the top of the highest layer). Because the layers have the same slope as the upland surface, and seemingly identical material is exposed in and between all the bayous around Houston, it appears that essentially the same layers of sediment are present near the surface throughout the Houston area. However, the layers do vary somewhat from place to place, so that a particular distinctive layer cannot be traced for any great distance. Also, in some places along the sides of the bayous the water has washed away the material described above and deposited in its place younger channel sands which are easily distinguished from this dominant material.

All of the clays and sands exposed near Houston are non-marine, and appear to have been deposited by distributaries of the Brazos River (and farther east the Trinity River) as they built the very extensive deltaic plain whose remnants today make up the upland surface. The conditions under which this broad plain developed were much like those that characterize the delta of the Mississippi River today. The former presence of distributary streams is disclosed especially by their channel and natural levee deposits which are more sandy and rise very slightly above the general level of the plain. These may be seen as very low topographic ridges with sandy soil that extend finger-like east and southeast across the prairie immediately south and east of Houston (in southern Harris County, and in Brazoria, Chambers, Jefferson, and Liberty counties). The former stream channel is reported to be well preserved, for example, on Blue Ridge in Brazoria County between Fresno and Alvin (D. C. Barton 1930, p. 1303).

Along Cypress Creek, about 20 miles north of Houston, the material exposed is very different from that found nearer the city, consisting of tan colored sands with only minor amounts of sandy gray clay. This difference raises a question: is the more sandy material along Cypress Creek older than that to the south in the Houston area; or was it all deposited at about the same time, with the sand tending to drop out farther upstream

[1]Footnote: The material exposed in the immediate vicinity of Houston was studied in 1960 by Gordon A. Clopine as the basis of his master's thesis at the University of Houston. The present account is based principally on Mr. Clopine's work, plus the descriptions of Donald C. Barton (1930).

[2]Department of Geology, University of Houston

Figure 10. Layers of sand and clay exposed along White Oak Bayou, 50 yards downstream (southeast) from the 18th Street bridge in Houston. The darker material in the upper third of the bank is clay (mostly red), the light material along the central part of the bank is sand (white to gray and brown), and below that the material is mostly clay again, with three to four feet of somewhat consolidated sand near the middle of it. Height of the exposure is 33.2 feet. (From Gordon A. Clopine 1960.)

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in the present vicinity of Cypress Creek, while the clay was carried farther downstream to be deposited in and south of what is now Houston? Farther north, in Montgomery County, the layers (beds) do dip more steeply toward the Gulf than does the topographic surface, so that progressively older layers are found at the surface as one proceeds northward. However, it has not been determined definitely whether or not this change inland to older, more steeply dipping layers takes place as near to Houston as Cypress Creek.

Immediately north of Houston the topography, as well as the surface material, changes slightly. The slope of the upland surface almost doubles (fairly abruptly) from about two feet per mile southeast of Houston to four feet per mile northwest of the city. At the same time local increases and decreases in the slope may be observed on the topographic maps of Harris County with a contour interval of one foot prepared by the United States Geological Survey. The slight increases in surface slope are called scarps; they are separated from each other by belts of more gentle slope. Such seaward-facing scarps are clearly evident at elevations of 60 feet and 100 feet above sea level, separated by flatter surfaces at approximately 50 feet, 85 feet and 105 feet. The scarps are so gentle that they can be recognized in the field, with some difficulty, only in uninhabited areas away from the principal valleys.

Nearly identical sediments were traced continuously along White Oak Bayou where it crosses the 100-foot scarp; and where this bayou crosses the 60-foot scarp nearly identical material is present on both sides, although the exposures are not continuous.

It appears, therefore, that the scarps are not related to some change inland in the character of the material, with older layers which dip more steeply toward the coast being exposed along the scarps. Instead, it appears that the scarps probably are due to erosion, or to displacement along small faults, although there is no obvious evidence to support either of these origins. However, movement is taking place along a number of small faults not far from Houston. Perhaps the most conspicuous active fault is one which passes beneath the southwest corner of a grade school building in Hitchcock and has caused the corner of the brick building to subside about eight inches. About one mile farther west, this same fault crosses a corner of the large paved area at the former Naval Blimp Base constructed in the early 1940's, dropping the pavement vertically as much as nine inches on the south side.

A much more conspicuous scarp, evident to even the casual traveller, crosses the northwestern corner of Harris County. This is the Hockley escarpment, which Barton (1930, p. 1302) traced from "north of Eagle Lake (Colorado County), south of Sealy, past ... Hockley ... and Tomball, south of Conroe, past Cleveland, Warren, and Kirbyville, and eastward into Louisiana." The upland surface at the foot of this scarp is 160 to 175 feet above sea level, slopes south-southeast 3 to 5 feet per mile, and is a flat, almost featureless plain. The top of the scarp lies at an elevation of 200-210 feet, and northward the terrain consists of gentle hills whose flat summits become higher toward the north at a rate of 9 to 15 feet per mile. No other scarp of this magnitude occurs in the region, except beneath the waters of the Gulf of Mexico where the seaward slope off the barrier islands (described in a previous section) constitutes a scarp of comparable magnitude. The hypothesis for the origin of the Hockley escarpment which this resemblance suggests is not supported at present by any tangible evidence.

The material exposed in the Houston area contains relatively few fossils. Vertebrate remains are the most common, and include teeth and bones of horses, elephants, buffalo, turtles, and an armadillo. The only invertebrate fossils found are land snails, of species that still live in the area.

SUBSURFACE GEOLOGY

by

George C. Hardin, Jr.[1]

Houston is situated in southern Harris County on the Gulf Coastal Plain of Texas. The discussion to follow is confined largely to the area around Houston as shown on the map, Fig. 11. This area comprises a small part of the northwestern limb of the Gulf Coast geosyncline which extends from Alabama southwestward to northeastern Mexico, and probably contains sediments on the order of 60,000 feet thick. The map, Fig. 12, shows the writer's interpretation of the thickness of sediments deposited in this large subsiding area during the Cenozoic Era. These sediments consist largely of alternating beds of sand and shale and overlie beds deposited during the Cretaceous Period (the last period of the Mesozoic Era, the age of reptiles, when dinosaurs dominated the earth) which ended about 65,000,000 years ago.

The floor of the Gulf Coast geosyncline has subsided as sediments have been deposited in it, with subsidence being roughly proportional to sedimentation. The series of cross sections through Louisiana, Fig. 13, shows the writer's concept of three stages in the formation of this large geosyncline.

STRATIGRAPHY

Beds of sand and shale of Cenozoic (Tertiary and Quaternary) age underlie Houston to a depth estimated to be about 20,000 feet. Geologists have divided these sediments into numerous formations that can be identified. The nomenclature in general use is shown on the chart, Table II. Many of the formations, or zones within a formation, are identified by the presence of "guide fossils." These guide fossils are generally species of foraminifera of microscopic size that ceased to live in this area at a time coincident with the deposition of sediments overlying the formation or zone for which they are used. Therefore, in examining the micro-fossils from the cuttings of a well being drilled, the sudden appearance of a guide fossil tells the geologist that the bit has reached the zone for which the fossil is used as a guide. The names of some of the most important species of guide fossils used by Gulf Coast geologists are shown in the right hand column of Table II opposite the zone in which they are used.

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[1]Consulting Geologist, Houston, Texas

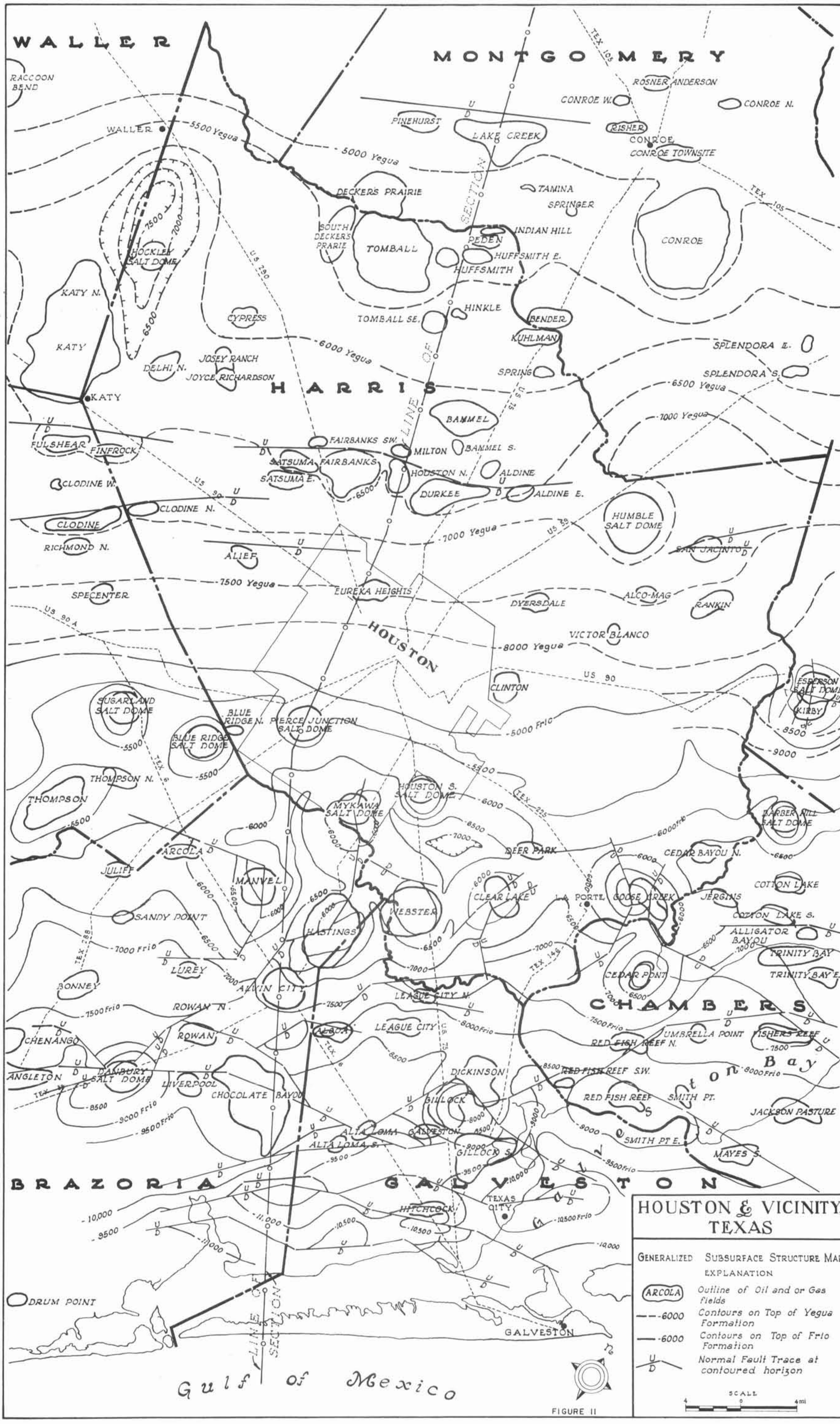
Note to Reader: It has been necessary to use a number of technical terms in writing this article, so it is suggested that, before reading it, you look through the Glossary, Appendix III, and familiarize yourself with the terms defined there.

GULF COAST GEOSYNCLINE
CENOZOIC NOMENCLATURE

ERA	SYSTEM	SERIES	GROUP	FORMATION OR MAJOR STRATIGRAPHIC SUBDIVISION	STRATIGRAPHIC SUBDIVISION OF SUBSURFACE	GENERALIZED TRANSGRESSIONS AND REGRESSIONS (LAND — SEA)	IMPORTANT MICROFAUNAL ZONES
CENOZOIC	QUATERNARY	R.		RECENT	RECENT		
		Plei.		PLEISTOCENE	PLEISTOCENE		
	TERTIARY	Pli.		PLIOCENE	PLIOCENE		Buliminella aff. curta, var basispinata
		MIOCENE		MIOCENE	UPPER MIOCENE		Bigenerina floridana Bucella mansfieldi Spiroplectammina barrowi
					MIDDLE MIOCENE (HARANG)		Bigenerina directa Bigenerina humblei Cibicides opimus
					LOWER MIOCENE (ABBEVILLE)		Amphistegina "B" Discorbis bolivarensis Siphonina davisi
		OLIGOCENE		ANAHUAC	ANAHUAC		Discorbis "restricted" Heterostegina sp. Marginulina diomorpha Marginulina howei
				FRIO	UPPER FRIO ("HACKBERRY")		Camerina "A" Cibicides hazzardi Marginulina texana Hackberry assemblage Nonion struma
					LOWER FRIO		Nodosaria blanpiedi Textularia mississippensis Anomalina bilateralis
				VICKSBURG	VICKSBURG		Textularia warreni Cibicides pippeni
		EOCENE	JACKSON	WHITSETT	WHITSETT (Rarely differentiated in subsurface)		Marginulina cocoaensis Massilina pratti
				McELROY	McELROY		Textularia hockleyensis
				CADDELL	CADDELL		Textularia dibollensis Operculina vaughani
			CLAIBORNE	YEGUA	COCKFIELD YEGUA		Nonionella cockfieldensis Discorbis yeguaensis Eponides yeguaensis
				COOK MOUNTAIN	COOK MOUNTAIN		Ceratobulimina eximia
				SPARTA	SPARTA		
				WECHES	WECHES		Textularia smithvillensis
				QUEEN CITY	QUEEN CITY		
				REKLAW	REKLAW		Cibicides "F"
				CARRIZO	CARRIZO (Rarely differentiated in subsurface)		
			WILCOX	WILCOX	WILCOX		Cytheridea sabinensis
		PALEOCENE	MIDWAY	MIDWAY	MIDWAY		Cristellaria longiforma Vaginulina robusta Vaginulina gracilis

TABLE II

This table gives the nomenclature in general use in the Gulf Coastal region of Texas and Louisiana. The arrows pointing to the left in the column titled "Generalized Transgressions and Regressions" indicate that the sea was transgressing the land, and those pointing to the right, that the land was building seaward. The right hand column lists the guide fossils commonly used to identify each horizon.



HOUSTON & VICINITY, TEXAS
GENERALIZED SUBSURFACE STRUCTURE MAP
EXPLANATION
ARCOLA Outline of Oil and or Gas fields
-6000 Contours on Top of Yegua Formation
-6000 Contours on Top of Frio Formation
U D Normal Fault Trace at contoured horizon
SCALE
4 0 4 mi
WALLER
MONTGOMERY
HARRIS
HOUSTON
CHAMBERS
BRAZORIA
GALVESTON
Galveston Bay
Gulf of Mexico
LINE OF SECTION
RACCOON BEND
WALLER
ROSNER ANDERSON
CONROE W.
CONROE N.
PINEHURST
LAKE CREEK
RISHER
CONROE
CONROE TOWNSITE
5500 Yegua
5000 Yegua
DECKERS PRAIRIE
TAMINA
SPRINGER
SOUTH DECKERS PRARIE
TOMBALL
PEDEN
INDIAN HILL
HUFFSMITH E.
HUFFSMITH
CONROE
HOCKLEY SALT DOME
KATY N.
CYPRESS
TOMBALL SE.
HINKLE
BENDER
KUHLMAN
SPLENDORA E.
KATY
6000 Yegua
DELHI N.
JOSEY RANCH
JOYCE RICHARDSON
SPRING
SPLENDORA S.
6500 Yegua
KATY
BAMMEL
7000 Yegua
FULSHEAR
FINFROCK
FAIRBANKS SW.
MILTON
BAMMEL S.
SATSUMA
FAIRBANKS
HOUSTON N.
ALDINE
SATSUMA E.
CLODINE W.
DURKEE
ALDINE E.
CLODINE N.
HUMBLE SALT DOME
CLODINE
RICHMOND N.
ALIEF
SAN JACINTO
7000 Yegua
7500 Yegua
SPECENTER
EUREKA HEIGHTS
DYERSDALE
ALCO-MAG
RANKIN
VICTOR BLANCO
8000 Yegua
CLINTON
ESPERSON SALT DOME
KIRBY
SUGARLAND SALT DOME
BLUE RIDGE N.
PIERCE JUNCTION SALT DOME
5000 Frio
BLUE RIDGE SALT DOME
THOMPSON N.
THOMPSON
HOUSTON S. SALT DOME
MYKAWA SALT DOME
BARBER HILL SALT DOME
DEER PARK
CEDAR BAYOU N.
JULIFF
ARCOLA
MANVEL
CLEAR LAKE
LA PORTE
GOOSE CREEK
JERGINS
COTTON LAKE
SANDY POINT
WEBSTER
HASTINGS
COTTON LAKE S.
ALLIGATOR BAYOU
TRINITY BAY
7000 Frio
LUREY
CEDAR PONT
TRINITY BAY E.
BONNEY
ALVIN CITY
LEAGUE CITY N.
7500 Frio
ROWAN N.
ALGOA
LEAGUE CITY
8000 Frio
CHENANGO
ROWAN
UMBRELLA POINT
FISHERS REEF
RED FISH REEF N.
ANGLETON
DANBURY SALT DOME
LIVERPOOL
DICKINSON
RED FISH REEF SW.
CHOCOLATE BAYOU
GILLOCK
RED FISH REEF
SMITH PT.
JACKSON PASTURE
9000 Frio
9500 Frio
ALTA LOMA
GALVESTON
SMITH PT E.
ALTA LOMA S.
GILLOCK S.
MAYES S.
TEXAS CITY
HITCHCOCK
10,500 Frio
DRUM POINT
GALVESTON
US 290
US 90
US 90 A
US 59
US 75
TEX 105
TEX 6
TEX 35
TEX 288
TEX 146
TEX 225

FIGURE II

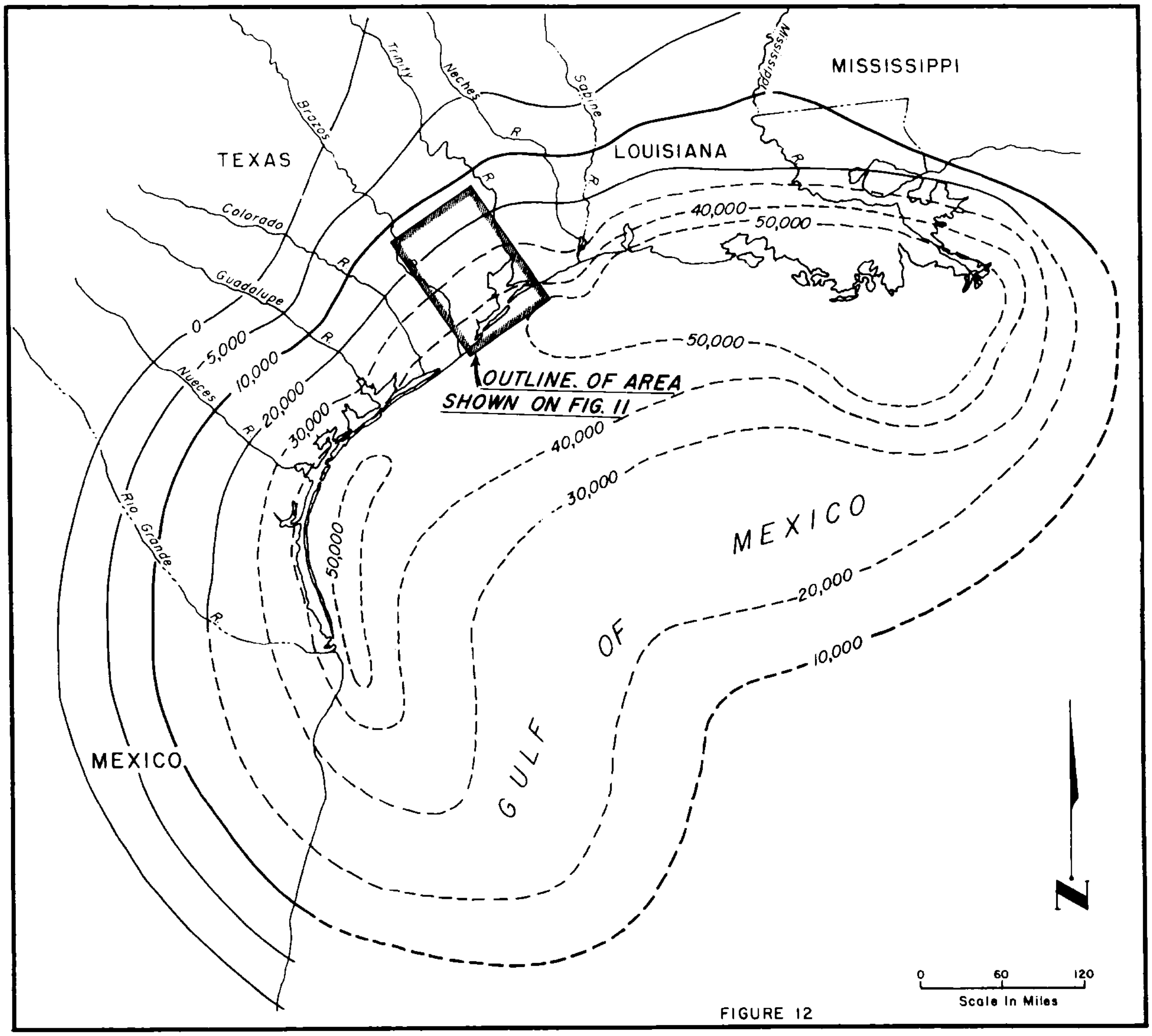


Fig. 12. Isopachous map (contours connect points of equal thickness) showing the author's interpretation of the thickness of sediments of Cenozoic age present in the Gulf Coast geosyncline. Solid contours are based upon information from wells drilled, but dashed contours are speculative. The relation of the Houston area to the geosyncline is shown.

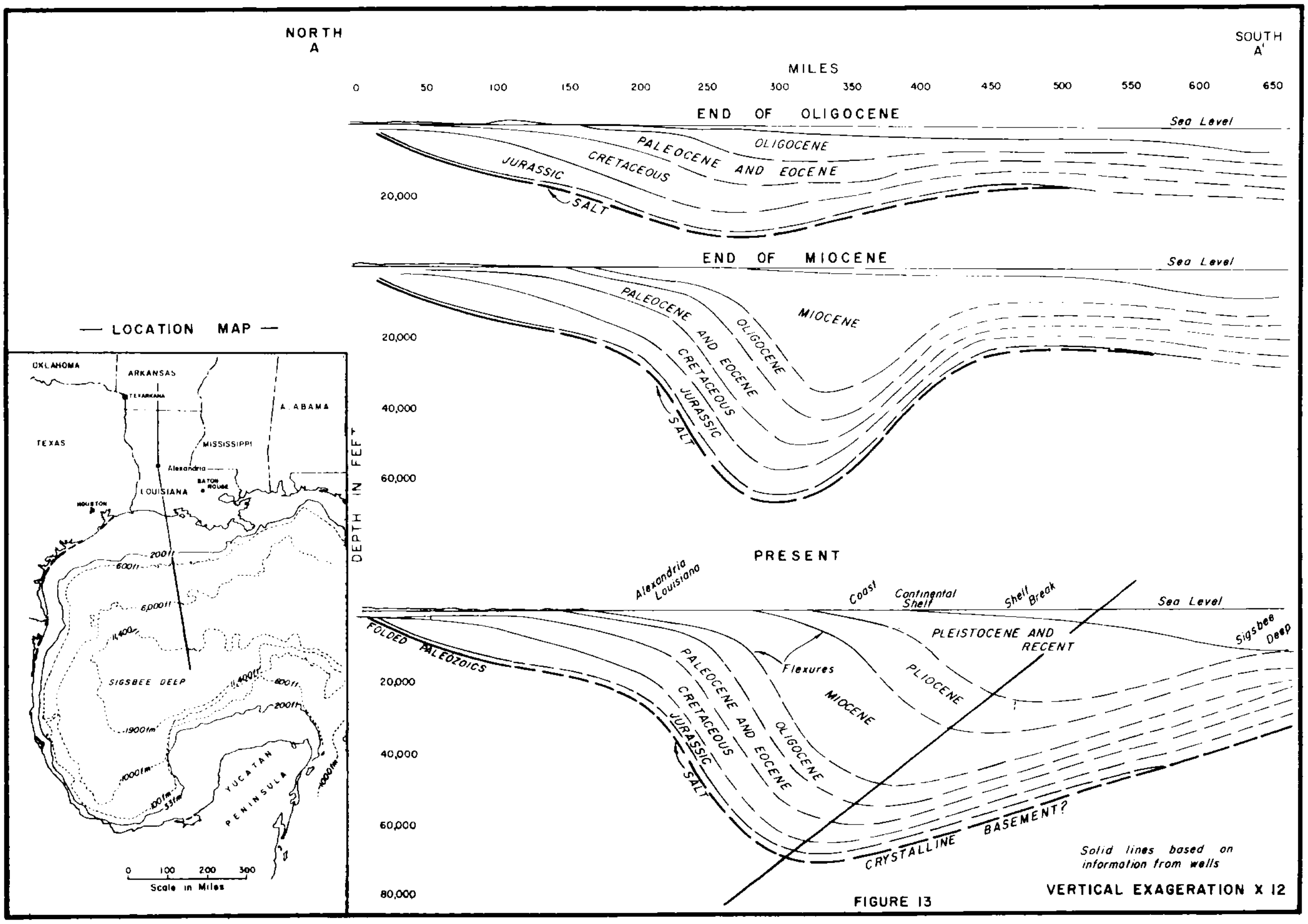


Fig. 13. Schematic cross sections showing three hypothetical stages in the development of the Gulf Coast geosyncline. The bottom cross section shows the author's interpretation of the present cross sectional shape of the geosyncline. The solid lines are based on information obtained from wells drilled in search for oil and gas, but the dashed lines are speculative.

A schematic interpretation of the structure and stratigraphy of the Houston area is shown on the cross section, Fig. 14. Near the northwestern end of the cross section, formations consisting largely of sand alternate with formations consisting largely of shale. To the southeast (downdip), the beds of sand become thinner and the beds of shale become thicker. Farther downdip, the beds of sand disappear completely, and the section consists entirely of shale. The cross section shows that in the Houston area, few beds of sand are present below depths of 15,000 to 16,000 feet.

Formations consisting of sand that gradually becomes shale in a downdip direction resulted largely from the conditions under which these sediments were deposited. Most of the beds of sand were deposited relatively near the shore of an ancient sea, and some undoubtedly comprised beaches or deltas, while most of the shales were deposited farther from the shore. The same processes that resulted in the deposition of these formations millions of years ago are at work today along the coast of the Gulf of Mexico, and are described in another part of this booklet.

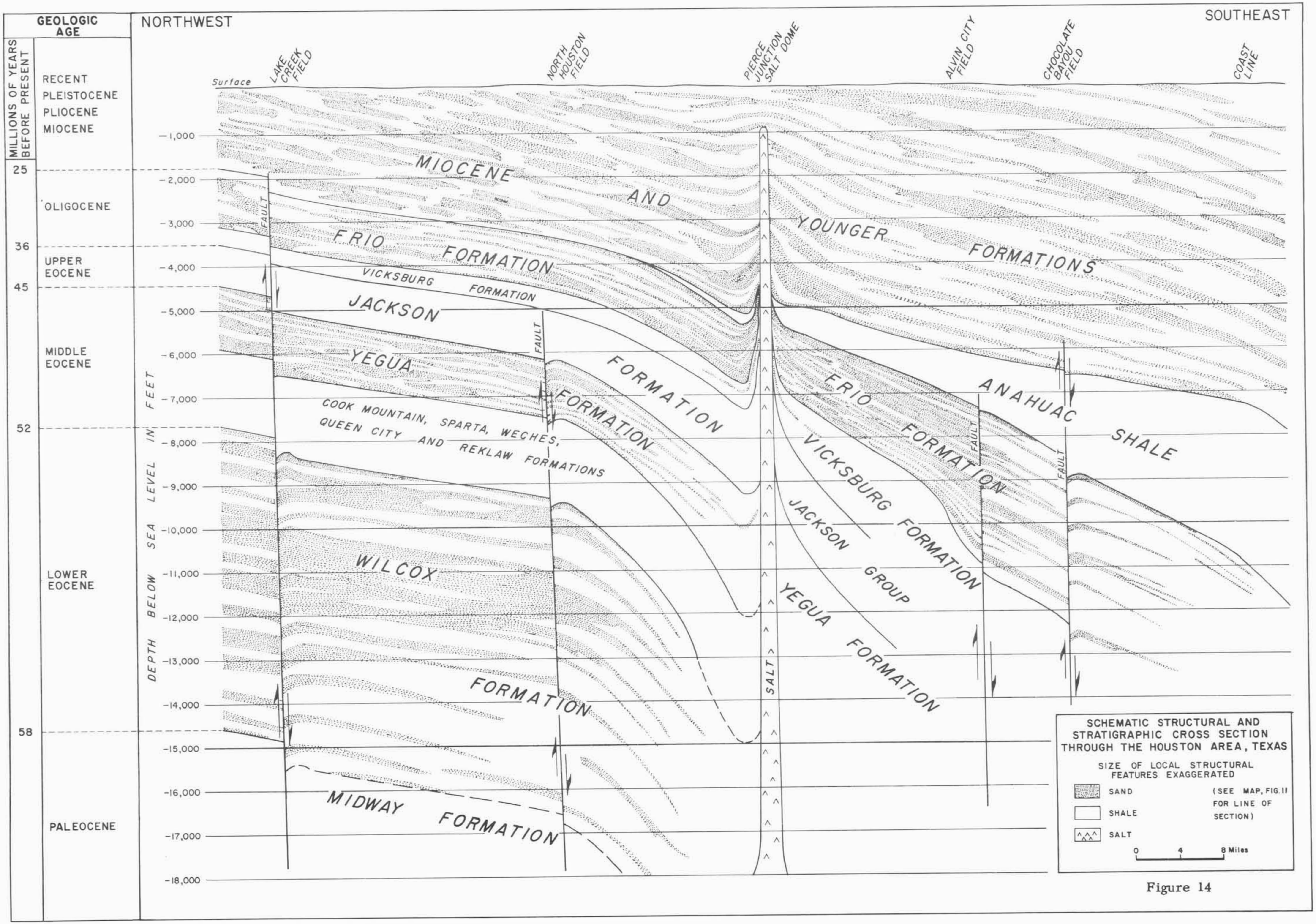

GEOLOGIC AGE
MILLIONS OF YEARS BEFORE PRESENT
RECENT
PLEISTOCENE
PLIOCENE
MIOCENE
25
OLIGOCENE
36
UPPER EOCENE
45
MIDDLE EOCENE
52
LOWER EOCENE
58
PALEOCENE
NORTHWEST
SOUTHEAST
Surface
LAKE CREEK FIELD
NORTH HOUSTON FIELD
PIERCE JUNCTION SALT DOME
ALVIN CITY FIELD
CHOCOLATE BAYOU FIELD
COAST LINE
DEPTH BELOW SEA LEVEL IN FEET
-1,000
-2,000
-3,000
-4,000
-5,000
-6,000
-7,000
-8,000
-9,000
-10,000
-11,000
-12,000
-13,000
-14,000
-15,000
-16,000
-17,000
-18,000
MIOCENE AND YOUNGER FORMATIONS
FRIO FORMATION
VICKSBURG FORMATION
JACKSON
YEGUA FORMATION
COOK MOUNTAIN, SPARTA, WECHES, QUEEN CITY AND REKLAW FORMATIONS
WILCOX FORMATION
MIDWAY FORMATION
FAULT
SALT
ANAHUAC SHALE
FRIO FORMATION
VICKSBURG FORMATION
JACKSON GROUP
YEGUA FORMATION
SCHEMATIC STRUCTURAL AND STRATIGRAPHIC CROSS SECTION THROUGH THE HOUSTON AREA, TEXAS
SIZE OF LOCAL STRUCTURAL FEATURES EXAGGERATED
SAND
SHALE
SALT
(SEE MAP, FIG. 11 FOR LINE OF SECTION)
0
4
8 Miles

Figure 14

STRUCTURE

Houston is located in an area of very little topographic relief and it could be reasoned that the formations below the surface also lie flat or parallel to the surface. However, as mentioned earlier, this region has been subsiding and the area south of Houston sank somewhat faster than the areas farther to the north. Thus, even though formations were deposited almost horizontally, they are now tilted southeastward and dip toward the coast at rates ranging from 100 to 300 feet per mile (1 degree to 4 degrees). The reader can obtain an understanding of the dip of the beds in the subsurface of the Houston area by noting that along the north edge of Fig. 11 the top of the Yegua formation is approximately 4, 700 feet deep, or 4, 600 feet below sea level (generally shown as -4, 600). To the south, the top of the Yegua formation becomes deeper, or dips, at the rate of about 100 feet per mile. A well drilled just north of the city limits of Houston found the top of the Yegua formation at a depth of 8, 050 feet, or 8, 000 feet below sea level. A well drilled 15 miles downdip on the Houston City dump south of the city found the top of the Yegua at 9, 100 feet, or about 9, 050 feet below sea level. From this illustration, it is apparent that the various formations in the subsurface around Houston are found at shallower depths as one goes north and northwest, and at greater depths as one goes south and southeast. This condition is illustrated on the cross section, Fig. 14. On the other hand, wells drilled along the direction of strike (approximately northeast-southwest) find the top of each of the Tertiary formations at about the same depth. Wells drilled in the Katy Gas Field on the western boundary of Harris County reach the top of the Yegua formation at depths ranging from 6, 200 to 6, 300 feet. Wells drilled in the Bammel Field in central Harris County, and wells drilled in the Splendora Field in western Montgomery County, find the top of the Yegua at approximately the same depth.

The subsurface geologist marks the line of strike for a formation on a map by drawing contours on the top of it. The contours are generally related to sea level, and for the horizon on which they are drawn, connect points of equal depth below sea level. Contours are determined by using the known depth to the horizon being mapped as found in wells that have been drilled to it, and extrapolating or interpreting the position of the contours between wells. The sinuosity of the contours is the result of local structural movements affecting the beds.

On the map, Fig. 11, contours have been drawn on the top of the Yegua formation in the area north of Houston, and on the top of the Frio formation in the area south of Houston. The change in datum horizons is necessary because, south of Houston, the Yegua formation lies at depths too great to have been reached by wells.

The gentle coastward dip of the beds in the subsurface is broken by many local structural features. These local structural features have resulted from movement downward (faulting) of one area relative to another area, and of movement upward by salt masses that produced the many salt domes around Houston. A study of the contoured map, Fig. 11, shows the structural configuration of the Frio formation to be more complicated than that of the Yegua formation. That is, there are more faults present and the local structural features are more complicated. In general in the Gulf Coast, the structure of beds younger than Eocene is more complicated than that of older beds. Many of the faults displacing the beds are faults along which movement took place during deposition of the sediments (called contemporaneous faults), so that the beds on the downthrown side of the fault are much thicker than the same beds on the upthrown side. This condition resulted from the filling of the low places on the downthrown side of the fault with sediment as this side was lowered by movement along the fault. Such structural movements cause very complicated structural and stratigraphic relationships. A fault of this kind is shown in the Chocolate Bayou field in the cross section, Fig. 14.

Most of the local structural features of the area are anticlines or domes where the beds have been pushed upward to a higher elevation than in the surrounding area. Many of these uplifted areas were pushed up by the rise of salt domes originating from a relatively thick bed of salt that probably lies at depths ranging from 30,000 feet to 40,000 feet beneath Houston. Some of the salt domes rise to within a few hundred or thousand feet of the surface of the ground and the salt mass has been penetrated by wells drilled in search for oil or gas. These are designated as salt domes on the map, Fig. 11. Other salt domes did not rise to depths sufficiently shallow to have been reached by the drill, but their presence is indicated by geophysical measurements.

In the vicinity of some salt domes, the withdrawal of salt from the underlying salt bed to form the dome resulted in the sinking of an area adjacent to the dome and the forming of a syncline. Such an area is outlined in the vicinity of the Hockley salt dome 30 miles northwest of Houston by the contours drawn on the top of the Yegua formation of Fig. 11. There the contours with the short line on one side indicate the presence of a depression or syncline.

When a salt bed is buried beneath thousands of feet of sediments, both the salt and the surrounding sediments behave like highly viscous liquids. Salt domes rise as a result of the forces of bouyancy because salt is "lighter" than the overlying sediments and tends to "float" up toward the top of them. Salt has a specific gravity of about 2.19, while the sediments have an average specific gravity of about 2.4. When a movement in the earth occurs to "trigger" the action, a spine or ridge of salt flows upward very slowly due to the pressure of the overlying sediments and drags the adjacent beds of sand and shale upward with it. This action has been reproduced experimentally by using viscous liquids of different specific gravities.

The causes of faulting and the formation of anticlines other than those resulting from the rise of salt domes is a subject of controversy. Some may be the result of underlying salt or shale ridges and others may be caused by the slumping and sinking of beds surrounding a stable area. Discussion of this problem is beyond the scope of this paper.

Even though the surface around Houston is relatively flat and only slightly above sea level, there have been many earth movements that affected the formations of the subsurface. The subsurface geologist can "see" on his maps the many buried "mountain peaks," ridges, and valleys. Many of these buried structural features are represented by contours on Fig. 11.

ECONOMIC GEOLOGY

by

George C. Hardin, Jr.[1]

Ground water, salt, sulphur, clay, sand, and gravel are important mineral resources of the Houston area, but the greatest income from mineral resources comes from the production of oil and gas. The petroleum industry, and the allied chemical industry, are largely responsible for the economic growth of the Houston area.

OIL AND GAS

Production of oil and gas comes primarily from porous and permeable sands of the various Tertiary formations underlying Houston and vicinity. Most of the oil and gas fields around Houston are shown on the map, Figure 11. The fields northwest of the city, where the map is contoured on the top of the Yegua formation, produce primarily from sands of the Wilcox and Yegua formations of Eocene age. Fields to the southeast of the city, where the map is contoured on the top of the Frio formation, produce primarily from sands occurring in the Frio and Vicksburg formations of Oligocene age. Although a large part of the oil and gas production of southern Louisiana comes from beds of Miocene age and younger, there is little oil and gas production from these beds in the vicinity of Houston.

ORIGIN OF OIL AND GAS

Oil and gas form from decaying animal and vegetable material that was deposited with the sediments as they accumulated and buried with them. Such material undergoes chemical changes after deep burial so that some of it becomes oil and gas. The pressure from the weight of the overlying sediments squeezes the oil and gas into porous and permeable sands or sandstones that serve as reservoirs. These sands are saturated with water, so the oil and gas move upward through them because both oil and gas are lighter than water. The upward movement continues until the oil and gas are stopped by an impermeable layer such as a shale bed. The oil and gas then move up the slope of the bed until they reach the highest point possible. There the oil and/or gas is trapped, and a field results when the trap is discovered by the drilling of a well. The trap may be a structural trap such as a dome, or an anticline, or may be a stratigraphic trap resulting from a "pinch out" of the porous sand. There are a number of different types of structural and stratigraphic traps, but discussion of all of them is beyond the scope of this paper. The search for oil and gas, therefore, involves looking for a trap in an area where porous sedimentary beds capable of serving as reservoirs are capped by impervious beds.

[1]Consulting Geologist, Houston, Texas

When a porous sand is saturated with oil and gas and becomes an oil and gas reservoir, the gas, being lighter, rises to the top and overlies the oil. Salt water, being heavier, is found beneath the oil. The contact between the gas and oil in the same reservoir is generally level, as is the contact between the oil and salt water. These fluid contacts are usually found at the same depth below sea level by all wells drilled into the same reservoir. If two reservoirs are separated by an impermeable barrier, such as a shale bed or a fault, the fluid contacts in the two are generally different.

Oil and Gas Traps in the Houston Area

The most common types of traps in which oil and gas are found in the Houston area are associated with salt domes, anticlines (possibly resulting from deep seated salt domes), and traps controlled by faults. However, a number of stratigraphic traps are known.

Anticlines:

Some of the largest reserves of oil and gas in this area are found on anticlines. Geophysical measurements indicate that many of the anticlines result from the intrusion of salt domes that reached only to within 15, 000 to 25, 000 feet of the surface. The upwarping or doming of the sediments forms a trap. Oil and gas move along the slopes of permeable beds lying beneath impermeable beds upward to the crest of the anticline, and they are trapped there and cannot escape because they float on the heavier salt water and cannot move downward through it.

In the Houston area, some of the anticlines are large but relatively simple structural features that are uncomplicated by faulting. The Katy gas field in Waller County is such a structural feature. Other anticlines, such as Conroe and Hastings fields, are broken by faults that occur in a very complicated pattern. The faults form impermeable barriers and break the fields into numerous different reservoirs. Each of these reservoirs must be produced as if it were a separate field. Dry holes are frequently drilled within the proven limits of a field when faults have formed separate segments in which oil and gas did not accumulate in commercial quantities.

Fields in the Houston area that result from oil and/or gas accumulation on antilines are Conroe, Tomball, Katy, Thompson, Goose Creek, Hastings, Webster, Dickinson, and Gillock.

Salt Domes:

When a salt mass pushes its way upward through the overlying sediments to form a salt dome, it drags the surrounding sediments upward with it to some extent, and pushes the overlying sediments upward into a domal shape. These overlying sediments then form a symmetrical anticline or dome. As oil and gas migrate through porous and permeable sands in the vicinity of a salt dome, they rise in the porous beds until they can move no farther due to the anticline formed above the dome, or an impermeable barrier resulting from the termination of the porous bed near the flanks of the salt mass, or from a fault. When this happens, oil and gas are trapped in commercial quantities in the sands, and an oil and/or gas reservoir results.

Salt domes are commonly capped by anhydrite and limestone called "cap rock." The cap rock is generally porous and is frequently found saturated with oil and gas as a result of leakage out of porous saturated sands adjacent to the cap rock. Some of the earliest oil fields discovered in the Houston area initially produced oil from the cap rock of salt domes.

The Pierce Junction oil field, located within the City Limits of Houston in the southern part of the city, is a good example of a salt dome oil field. Production comes largely from sands of the Frio and Vicksburg formations abutting the flanks of the salt mass. The schematic cross section, Fig. 15, shows the relation of the oil reservoirs at Pierce Junction to the salt dome. Other fields in the Houston area that occur on and around salt domes are Blue Ridge, Humble, Esperson, South Houston, Danbury, and Sugarland.

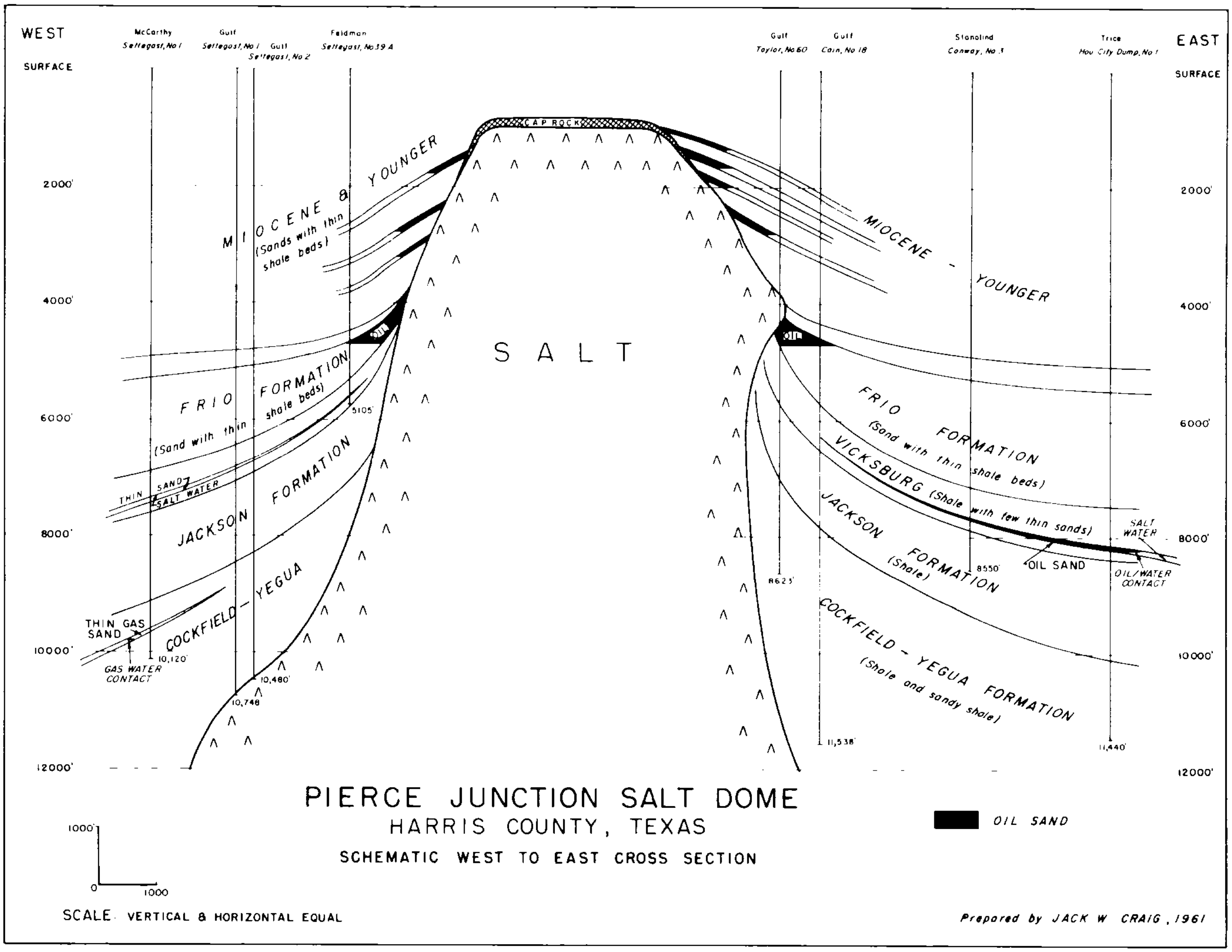


Fig. 15. Schematic cross section through Pierce Junction salt dome located south of Houston, Texas. This section shows the present position of the beds flanking the salt dome after having been dragged upward from an almost horizontal position by the intrusion of the salt mass. Oil accumulation occurs in porous sands where they pinch out against the flanks of the salt dome.

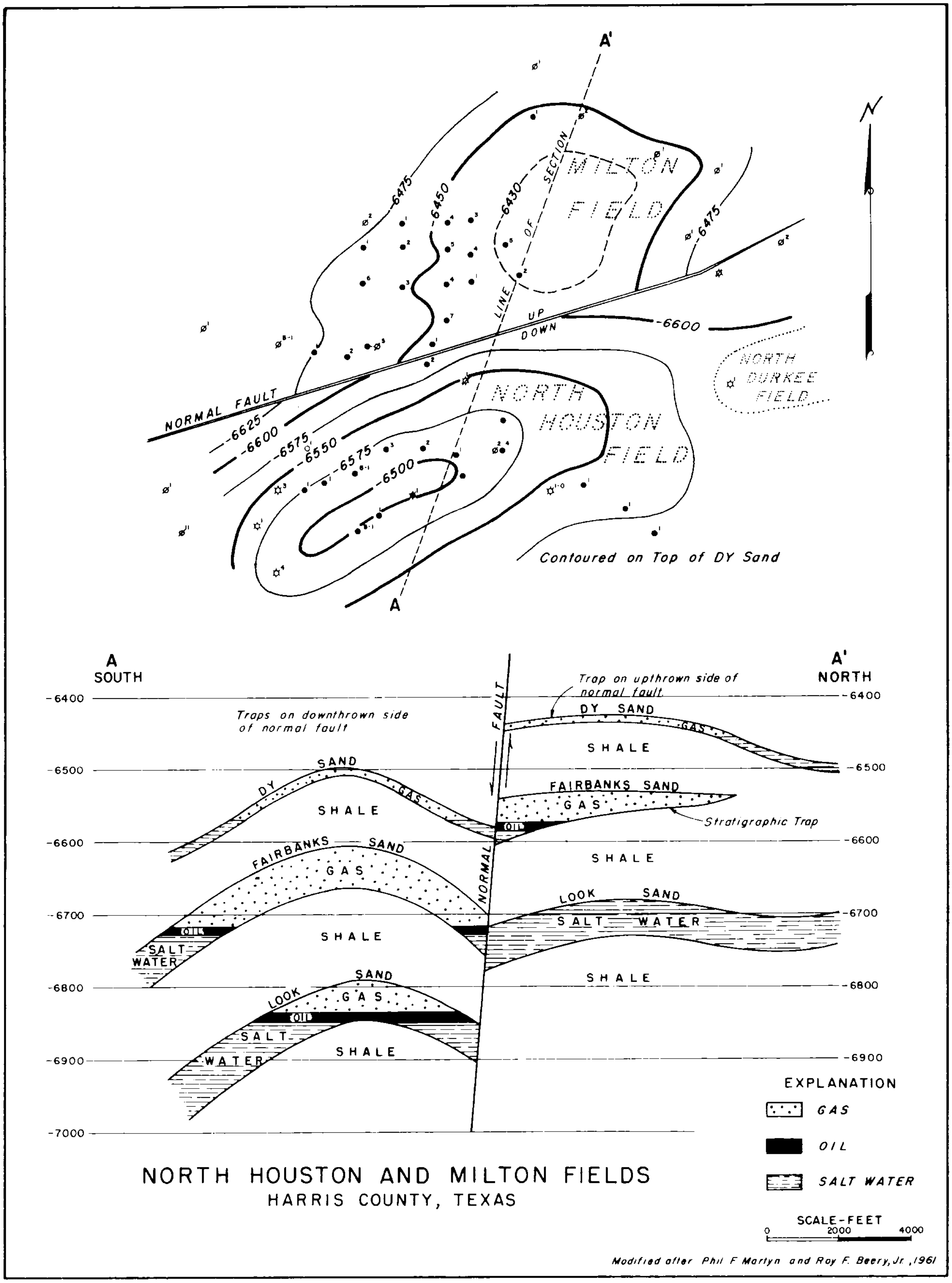


Fig. 16. Structural map and cross section through the North Houston and Milton Fields, Harris County, Texas. Oil and gas in the North Houston Field occurs in traps on the downthrown side of a normal fault. This structure is essentially an anticline with the dip of the northwest limb resulting from downward movement along the fault. In the Milton Field, gas occurs in the DY sand in a trap formed against the upthrown side of the normal fault. The oil and gas accumulation in the Fairbanks sand is in a stratigraphic trap resulting from the pinch out of the sand.

Traps Associated With Faults:

Many of the oil and gas fields of the Houston area occur in traps associated with faults; most of these are found on the downthrown side of the faults. These structural features are actually anticlines with the dip of the northwest limb resulting from dip into the downthrown side of a fault. This condition is illustrated on the map and cross section through the North Houston and Milton fields, Fig. 16. Other fields that occur under similar conditions are Fulshear, Finfrock, Satsuma, Fairbanks, Durkee, Lake Creek, Trinity Bay, Alligator Bayou, and Chocolate Bayou.

A few oil fields in the Houston area result from oil accumulation against the upthrown side of a fault. One of the reservoirs in the Milton field (Fig. 16) occurs in a trap of this type. The South Cotton Lake and Jergins fields in Chambers County are other examples of such an occurrence. In these fields, the beds dip away from the upthrown side of the fault which forms an impermeable barrier against which the oil and gas accumulate.

Stratigraphic Traps:

Although there are a number of reservoirs in the Houston area that result from stratigraphic traps, most of these traps are associated with structural features that constitute the primary cause of oil and gas accumulation. However, the Decker's Prairie, South Decker's Prairie, Bender, Kuhlman, and Milton fields are primarily the result of stratigraphic traps caused by the "pinch out" of sands. The cross section through the Milton field, Fig. 16, illustrates the accumulation of oil and gas in a stratigraphic trap.

OIL AND GAS RESERVES

Oil and gas reservoirs are finite; that is, each is of a definite size that is generally determinable by the drilling of wells and the correlation of information obtained from the wells. Although other factors are important in determining the amount of oil and/or gas that can be recovered from a reservoir, the recoverable reserve is always proportional to the volume of the reservoir. With all other conditions being identical, a reservoir covering an area of 100 acres and containing an average thickness of 30 feet of productive sand will yield the same amount of oil and/or gas as a reservoir covering 200 acres and containing an average thickness of 15 feet of productive sand. Therefore, determination of the volume of the reservoir is one of the first steps in estimating the recoverable oil and/or gas reserve.

In the Houston area, most of the oil and gas occurs in reservoir rocks consisting of porous and permeable sand. Reservoir volume is generally expressed in "acre-feet" of productive sand. An acre-foot of sand consists of that volume of sand that will cover one acre to a depth of one foot, or 43,560 cubic feet. In terms of the standard 42 gallon oil barrel, one acre-foot is equivalent in volume to 7758 barrels. The porosity, or void space, of the reservoir rock is expressed in percent. For the sands occurring in the

Houston area, porosity generally ranges from 17 percent to as much as 35 percent. Thus, an acre-foot of sand with an average porosity of 30 percent would contain 13,068 cubic feet, or 2,327.4 barrels of void space, with the remainder of the volume consisting of the sand grains. Part of this void space is filled with water originally deposited with the sand (called connate water), and the remainder is filled with oil and/or gas. Part of the oil and/or gas present in the sand cannot be recovered with our present operating techniques. By taking these and many other factors not discussed here into consideration, the geologist or petroleum engineer is able to compute a "recovery factor" for each reservoir. This factor is generally expressed in "barrels per acre-foot" for oil reservoirs, and "cubic feet per acre-foot" for gas reservoirs. In the Houston area, the recovery factor for oil ranges from about 200 to more than 1,000 barrels per acre-foot, and that for gas from 500,000 to more than 2,000,000 cubic feet per acre-foot. Thus, if an oil reservoir covers 100 acres and contains an average productive sand thickness of 30 feet, the volume would be 3,000 acre-feet. With a recovery factor of 700 barrels per acre-foot, the reservoir would be expected to yield 2,100,000 barrels of oil over its lifetime.

Because reservoirs are finite, and the amount of oil to be recovered is finite, only a finite number of wells can be drilled to produce from a reservoir, if the oil and/or gas is to be recovered at a profit. The oil production from the Vicksburg sands discovered on the flanks of the Pierce Junction salt dome within the City Limits of Houston in 1954 is a good example of overdrilling. Following the discovery of production in this area, wells were drilled on such small tracts of land that none had an appreciable drainage area. The sand comprising the reservoir was only about 15 feet thick, and the estimated recovery factor about 500 barrels per acre-foot. Therefore, a well that could only drain two acres could be expected to produce about 15,000 barrels of oil over its lifetime. This was not enough to repay the cost of drilling and completion. Because of the excessive number of wells drilled, the total withdrawal rate from the field was sufficient to deplete most of the field within a period of three or four years, and most wells did not yield enough oil to repay their cost. Had the sand comprising the reservoir been 150 feet thick, then the yield would have been approximately 10 times what it was, and even with the large number of wells drilled, production would have been sufficient to repay the cost and yield a profit. In many of the older fields of the Houston area such as Goose Creek and Humble, where wells were closely spaced, productive sand thickness was sufficient to enable most of the wells to produce enough oil to repay their cost and yield a profit.

The amount of oil and/or gas that a well can be expected to produce from a given reservoir is proportional to the number of wells producing from the reservoir, if all produce at the same rate. Therefore, the drilling of an excessive number of wells to produce from a reservoir is of no benefit to either the owners of the land or the public.

GROUND WATER IN THE HOUSTON REGION[1]

by

A. G. Winslow
U. S. Geological Survey

Geologic formations that yield water to wells in the Houston region (see index map on Fig. 17) consist of interbedded layers of sand and clay. These formations are at the surface in the northern part of the region and dip gently beneath the surface toward the Gulf of Mexico. A generalized cross section through the region illustrates these conditions (Fig. 17). The dip of the formations is greater than the slope of the land surface and therefore the formations at the outcrop are beveled by the land surface. The alternation of sand and clay layers and the structure are ideal for the occurrence of artesian water.

The predominantly sandy zones shown in Fig. 17 are the important water-producing formations. The sandy zones consist of extremely irregular beds of sand and gravel and some beds of silt and clay which may grade into each other laterally and vertically in relatively short distances. The predominantly clayey zones shown in the section are more persistent than the sandy zones and also contain many irregular sandy beds.

The cross-hatched boxes on the cross section indicate the zones now being pumped heavily in the region. Some of the deep formations are not drawn on and would yield additional large supplies of ground water to wells in the northern part of the region. Water levels in wells in these formations would be high, and some of the wells probably would flow. Supplies similar in quantity and quality to those in the present heavily pumped areas could be developed.

Rainfall is the source of the abundant supply of ground water in the region. U. S. Weather Bureau records extending back to 1889 show that the extremes in annual precipitation range from more than 70 inches in 1900 to 23 inches in 1917. The average annual precipitation is about 45 inches. Approximately 10 inches of this precipitation runs off in surface streams. Evaporation and transpiration by plants account for most of the remainder. A small part percolates down through the soil and past the root zone, eventually to reach the water table. From there the water moves slowly through the pore spaces in the ground-water formations toward pumping wells or toward areas of natural discharge.

Rainfall enters the outcrops of the sandy zones as recharge, and then the water moves down the dip of the beds to the wells. Originally, wells throughout the region tapping these zones would flow above the land surface. However, heavy pumping has caused the water levels in the wells to decline until in 1961 the water levels had dropped to as much as 270 feet below sea level in the Pasadena area (area 3 on Fig. 17), where withdrawals are most concentrated.

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[1]Publication authorized by the Director, U. S. Geological Survey

Although the heavy pumping has caused large declines in water levels locally, there is no deficiency of water in the area. Ground water cannot be obtained without a decline in water levels because decline is necessary to cause the water to flow toward the wells. The quantity of water moving toward the wells is proportional to the slope of the water surface created by the decline. Although pumping from wells has continued to increase and the water levels have declined correspondingly, the yields of the individual wells have not decreased and are still high. Pumping costs have increased, but there is still a large supply of water. If the rate of pumping is stabilized, the water levels also will be stabilized within a relatively short time.

Excessive local declines in water levels can be avoided by proper spacing of wells. The decline in water levels in the Pasadena area has been relatively great because of the concentration of wells. The annual pumping in the Houston municipal area has been about the same as in the Pasadena area, but the pumping is spread over a much larger area, and consequently, there has been less decline in water levels.

Approximately 650 large-capacity wells are in use in the region. These wells range from about 6 to 12 inches in diameter through the water-bearing zones, and many of the larger wells have surface casing as much as 30 inches in diameter. Yields range from a few hundred to about 3, 500 gallons per minute. The cost of drilling and equipping large wells ranges from about $20, 000 for a 1, 000-foot well for rice irrigation to more than $100, 000 for a 2, 000-foot well for municipal supply. The difference in cost is due to the difference in methods of construction and pumping equipment.

The temperature of the ground water near the surface in the Houston region is about the same as the average air temperature. The temperature increases about 1^{o}F. for each 100 feet of depth down to about 1, 600 feet. Below 1, 600 feet the average rate of increase is slightly greater.

Most of the ground water in the region is slightly alkaline but is generally of good chemical quality, although the quality varies somewhat with depth and location. The mineral content of the water at Houston increases with depth; the higher mineralization being due largely to increased amounts of sodium chloride. Geologic structure has an influence on the depth at which highly mineralized water occurs, especially in the vicinity of salt domes where salt water may be found at quite shallow depths. Hardness decreases with depth down to about 2,000 feet, then increases slowly; the increase becomes more rapid below about 2, 400 feet.

The cross section in Fig. 17 shows the approximate position of salt water in the formations underlying the region. This salt water probably was present in the sediments at the time of their deposition. As the land was elevated, fresh water began to percolate through the formations and tended to flush out the salt water. Incomplete flushing of the deeper formations explains the presence of salt water.

In much of the region salt water lies approximately 2, 000 feet below sea level. However, in places fresh water is found considerably deeper. In parts of eastern and northeastern Harris County fresh water occurs to depths of about 2, 800 feet below sea level. Potable water has been found to depths of about 2, 550 feet below sea level in Houston's East End municipal well field.

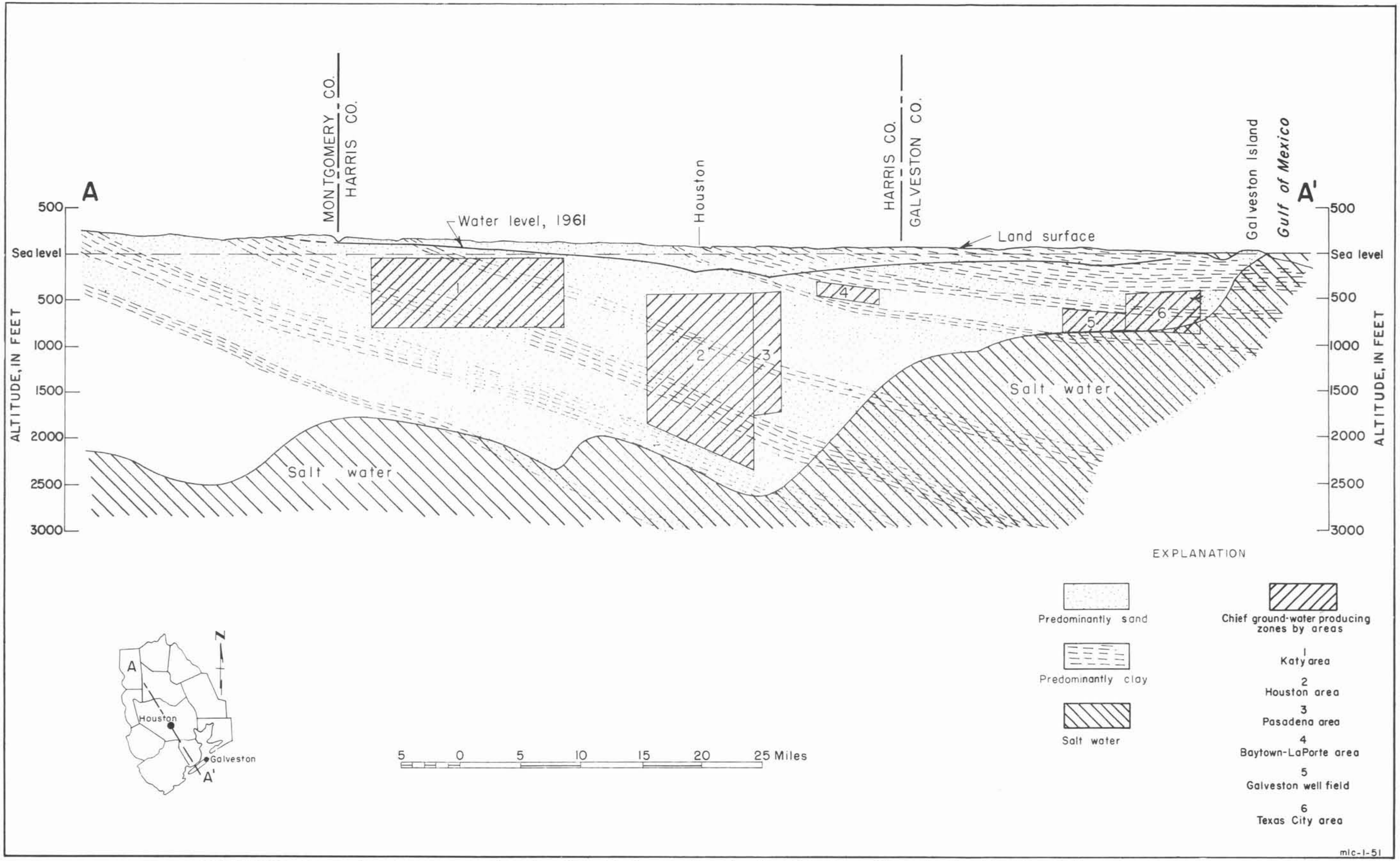


FIGURE 17.-Generalized cross section showing chief ground water-bearing formations in the Houston region.

Near the Harris-Galveston County line salt water occurs at a depth of about 1, 200 feet. The formations at that depth are the same ones that are heavily pumped in the Houston and Pasadena areas at a much shallower depth. Inasmuch as the heavy pumping in the Houston and Pasadena areas has established a slope of the water surface toward Houston and Pasadena from all directions, the salt water undoubtedly is moving northward. The rate of this movement is slow, being on the order of 1 foot per day. If the slope is not materially increased by additional pumping, salt water will not reach the Pasadena area for many years.

In the Galveston well field and at Texas City the salt-water problem is quite different. Salt water is known to occur in the lower part of the main sands drawn upon in those areas. The position of the salt water in the sands downdip, though not definitely known, probably is only a short distance southeast of Texas City. Wells drilled in the same sands on Galveston Island yield salt water. Chemical analyses of water samples indicate a certain amount of salt-water encroachment in both the Galveston well field and Texas City area. The encroachment probably has been from below rather than up the dip of the formation. It is being partly controlled by use of surface water, wide spacing of wells, and selective distribution of pumping rates to keep declines of water levels as small as possible.

Appendix I

NOTES ON SELECTED FOSSIL LOCALITIES IN EASTERN TEXAS

Compiled by

Julie Eastin Brock

"A fossil is some evidence of a prehistoric animal or plant, preserved in rock, that gives a clue to the characteristics of the organism." (Collinson - see Bibliography.) If we follow this definition of a fossil, then there are fossils in the sediments exposed in the stream banks and ditches in Houston, for in these sediments are fragments of Ice Age (pleistocene) plants, impressions of tree roots, and other rather obscure evidence of ancient life. But fossil collectors are likely to be more interested in the shells of animals which inhabited ancient seas, and marine sediments with such fossils do not appear at the surface near Houston. That is why the collecting localities shown on the Fossil Locality Map are all some distance north and west of our city.

It must be understood that in order for sea shells to occur in localities far removed from the present seashore of the Gulf of Mexico, the sea had to extend at least as far inland as the locality. That means the Gulf of Mexico, since that body of water was first formed about 125-million years ago, has been over the Houston area many times. Some of the times when the sea extended inland from its present boundary are shown on the land and sea maps. There were also times, especially in the younger geological ages, when the coast line was south of its present position. (See Pleistocene Map.) So, the features which we observe today have not always existed, and these features also are not everlasting.

No marine fossils occur near Houston because the formations, which are composed mainly of sand and clay, were deposited in nonmarine environments. Ancient streams brought the sediments from land areas to the north and west and deposited the sand and clay in coastal lakes and marshes, in deltas, and in the stream valleys. The Houston area was sinking and the newly deposited sediments were covered with even younger formations. Even though the area was sinking, there was sufficient sediment brought by the streams to fill the low coastal areas and prevent the sea from moving inland. Uplift of all parts of Texas inland from the present coast line has exposed the rocks which were deposited in the ancient seas, and it is in these rocks that sea shells occur.

Geologic history is known only through an understanding of the biological, physical, and chemical forces which are presently active. Thus we know that certain types of animals now live in the seas, and when we find fossil remains of similar animals in rocks far removed from a seashore, we know that the rocks had a marine origin. Similarly, there are animals, as the common oysters, which live mainly in brackish water, and when we find abundant oysters in old rocks, we interpret the ancient environment as brackish. Air breathing animals, such as horses and some type of snails, live on land, and rocks which have such fossils may have been deposited in land environments, though it is possible that bones and shells of land animals may be transported by streams to a brackish or shoreline environment.

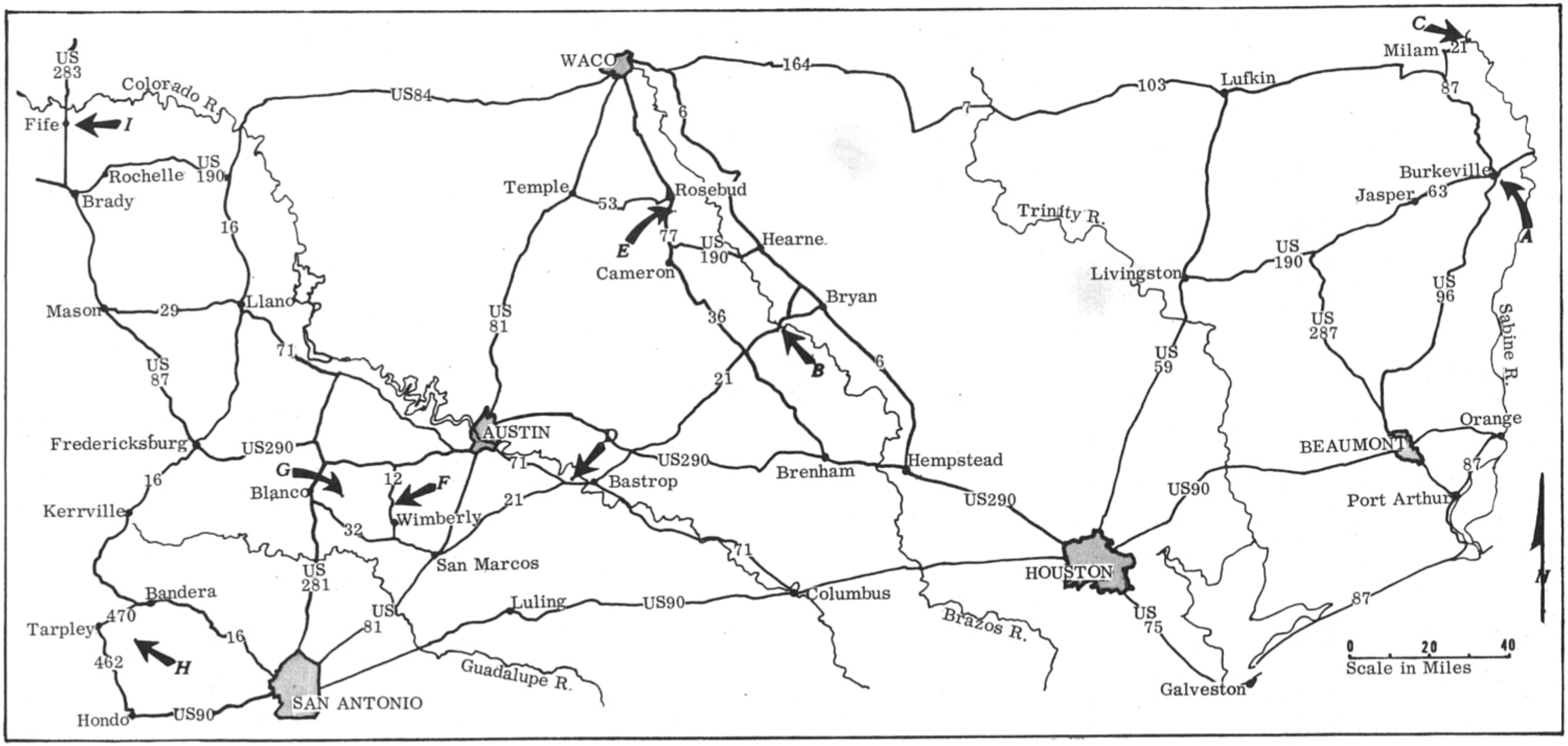
The fossil localities described here were selected to represent different environments of deposition as well as different geologic ages. Localities E, F, G, and I expose fossiliferous sediment which was deposited in shallow open seas quite far from shore; the oyster bed at Locality D almost surely grew in a bay which connected with the ancient Gulf. Some of the bones and teeth which have been found near Burkeville at Locality A are remains of land animals. However, they occur in the rock with brackish snail and clam shells so the bones and teeth were evidently transported by streams from the areas where the animals lived and died.

Respect the Landowners and Observe Safety Rules

Most fossil localities are on private land, and the owners of the land may object to individuals or groups going on the land. Permission should always be obtained from the landowner, if possible, and a courteous explanation given to the owner or his agent. Fossils are collected for their scientific interest, and usually they have little or no monetary value.

When on private property always be considerate and courteous, and do not damage fences or leave gates open when they are supposed to be closed. A small charge may be made to visit some unusual fossil locality such as dinosaur tracks.

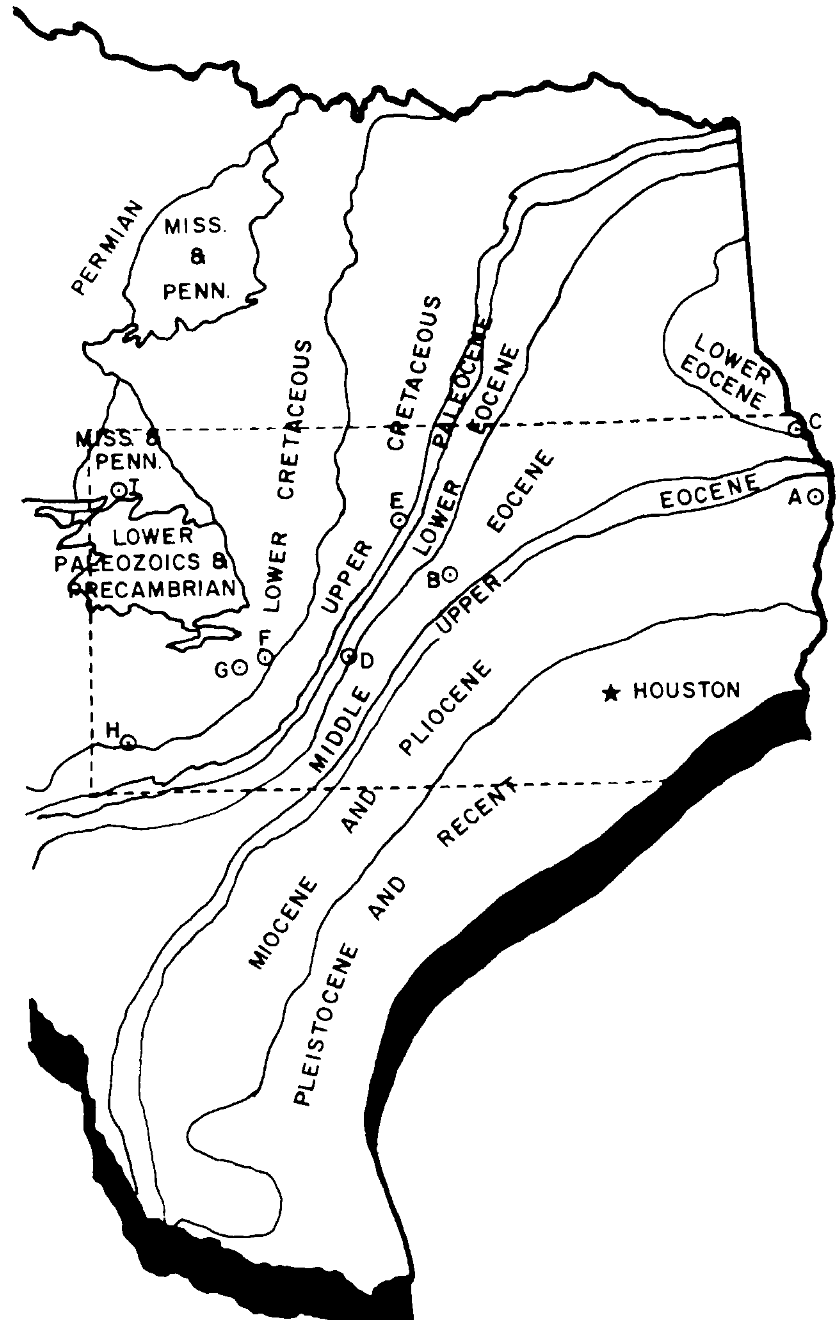
Observe all traffic rules and park well off the pavement when stopping to collect fossils.



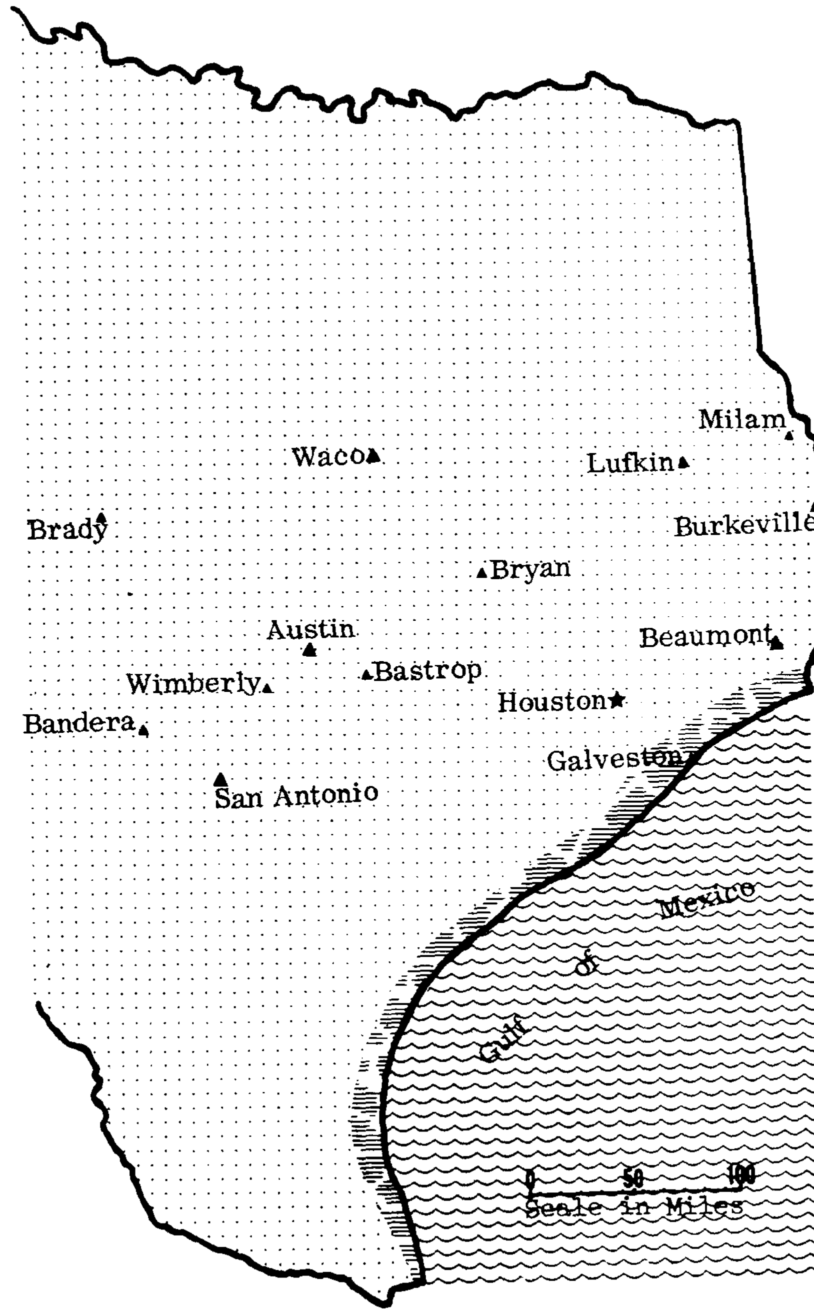
Fossil Locality Map - Localities indicated by arrows and letters.

GEOLOGIC AGE CHART

ERA (Main Divisions)	PERIODS	AGE (Approximate - in Millions of Years)
CENOZOIC (Recent Life) Age of Mammals	Recent	-
	Pleistocene	1
	Pliocene	1 - 15
	Miocene	15 - 25
	Oligocene	25 - 35
	Upper Eocene	35 - 45
	Middle Eocene	45 - 50
	Lower Eocene	50 - 60
	Paleocene	60 - 65
MESOZOIC (Middle Life) Age of Reptiles	Upper Cretaceous	65 - 90
	Lower Cretaceous	90 - 135
	Jurassic	135 - 180
	Triassic	180 - 230
PALEOZOIC (Ancient Life) Age of Invertebrates, Fishes, Amphibians	Permian	230 - 280
	Pennsylvanian	280 - 310
	Mississippian	310 - 345
	Devonian	345 - 400
	Silurian	400 - 425
	Ordovician	425 - 500
	Cambrian	500 - 600
P R E C A M B R I A N		



Geologic map of eastern Texas with fossil localities shown by letters.



LEGEND

LAND

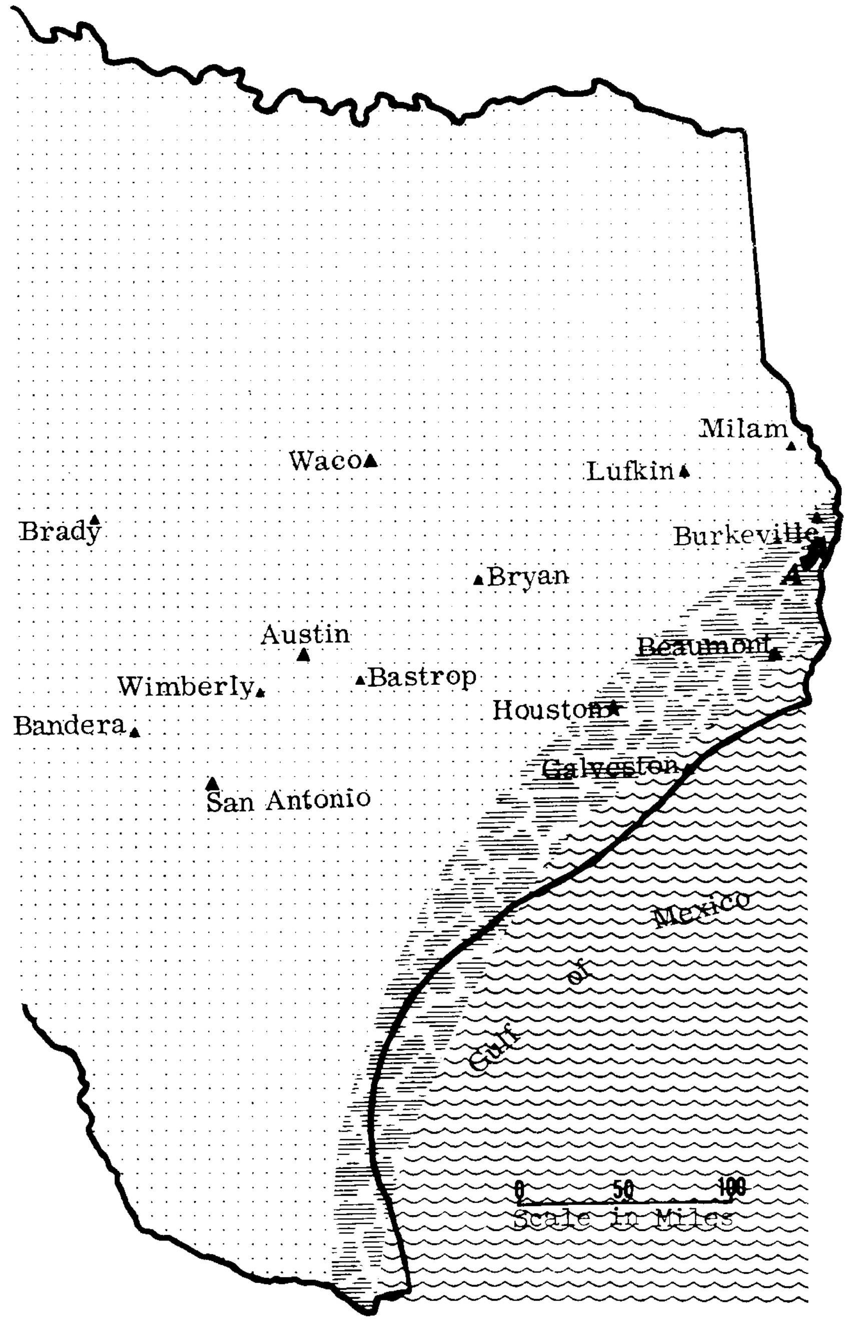
TRANSITION ZONE - Coastal bays, lagoons, marshes, deltas, beaches, etc.

SEA

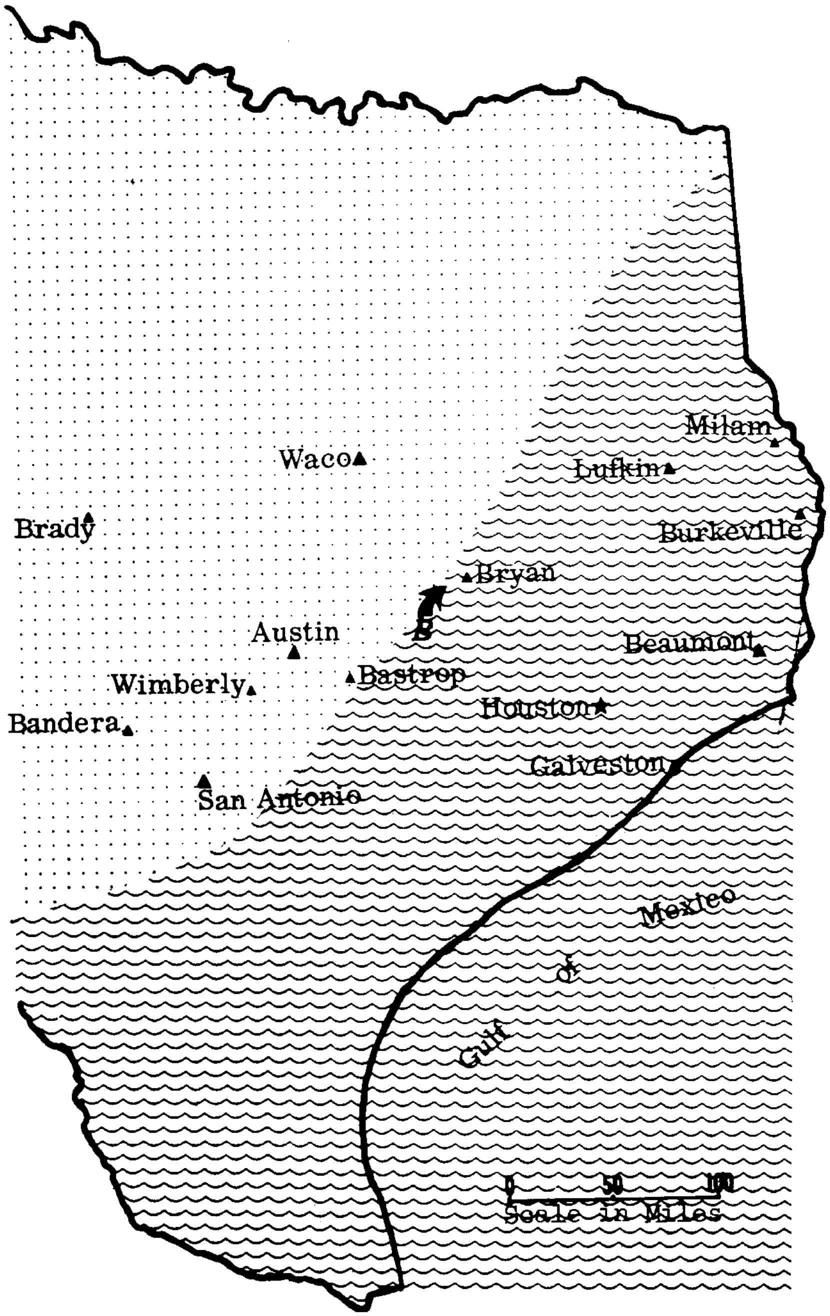
Map of eastern Texas showing the extent of the familiar features of land :::::: , transition zone and sea (the Gulf of Mexico) as we know them today.

The next six maps will show the same features as geologists know them to have existed in past geologic ages of the earth's history.

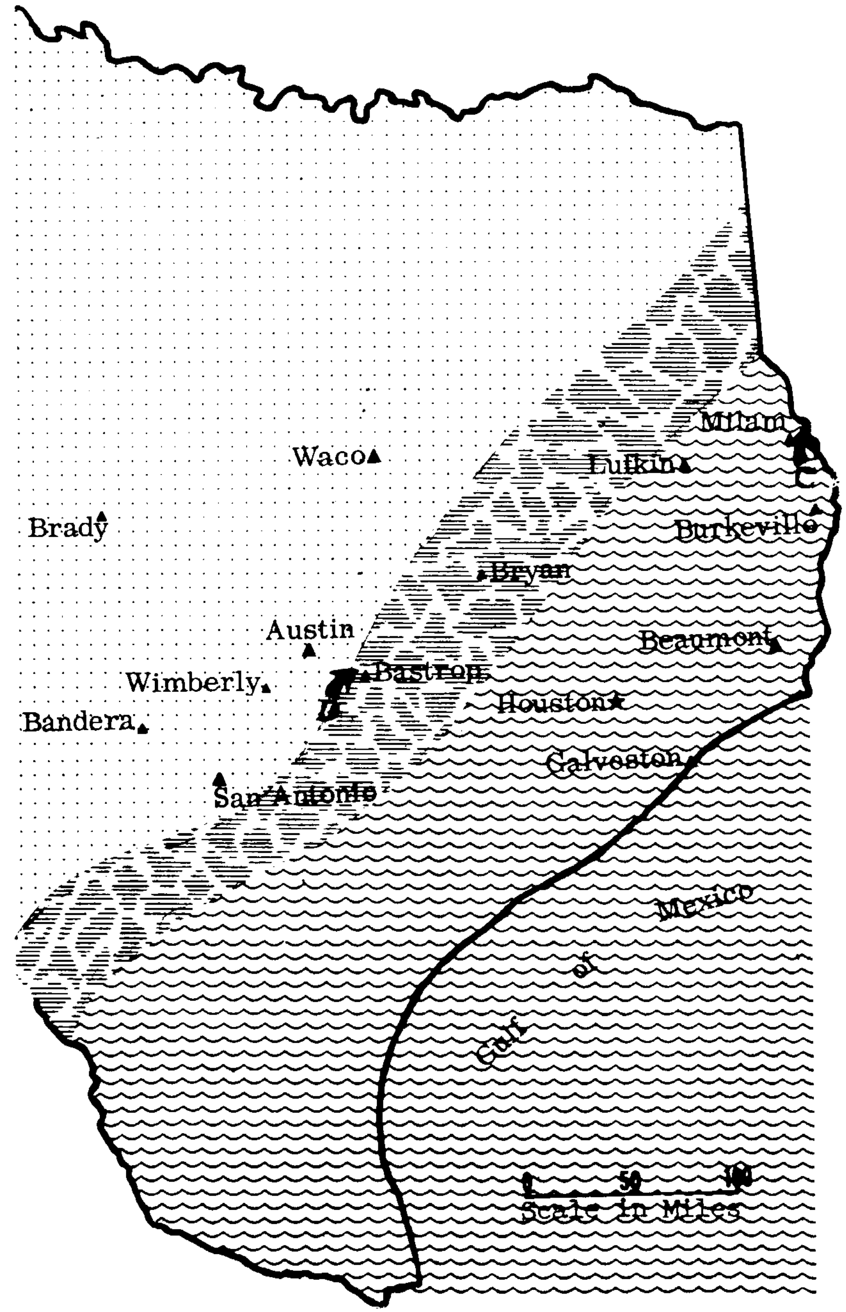
Map of eastern Texas showing extent of land ::::::, transition zone ≡≡, and sea 〰〰 during deposition of the <u>Pleistocene</u> sediments about 500,000 years ago.



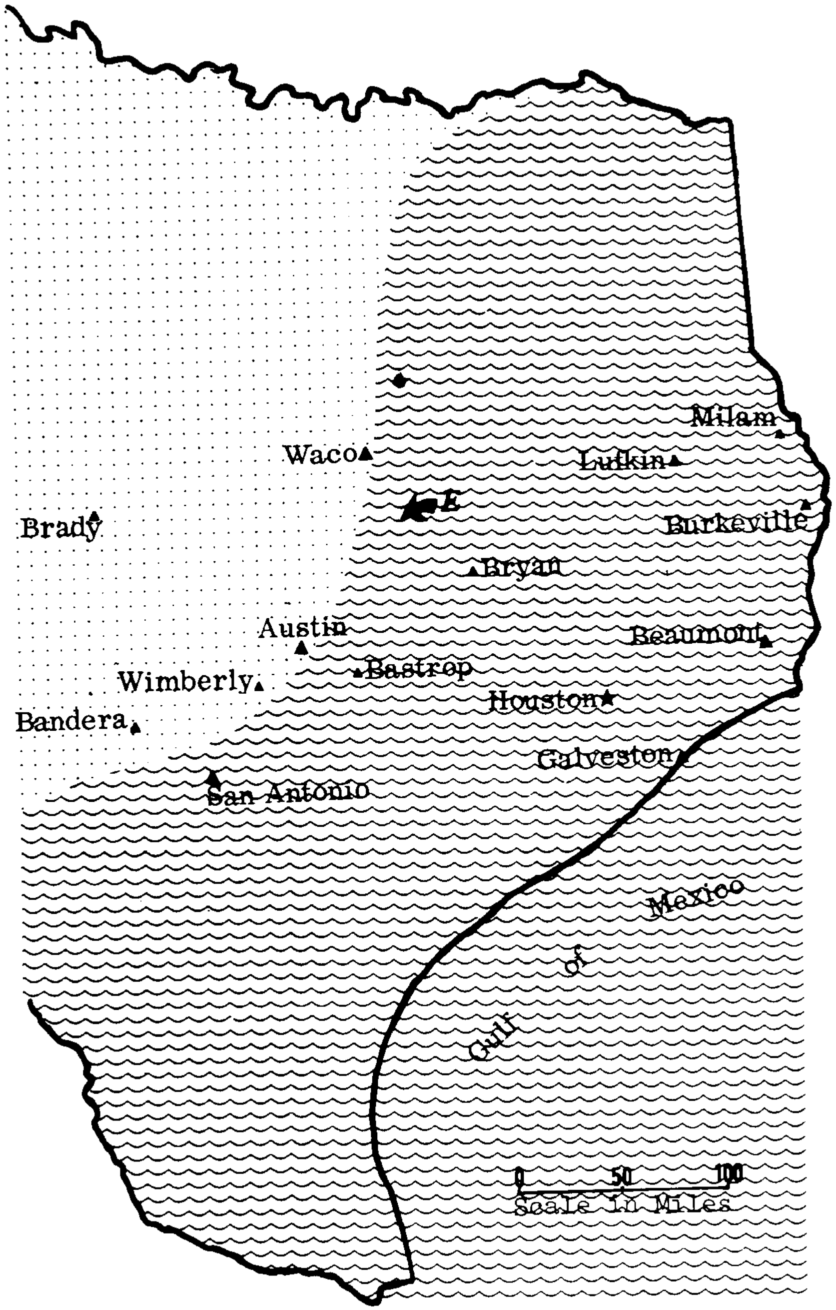
Map of eastern Texas showing extent of land ::::::, transition zone ≡≡, and sea 〰〰 during deposition of the <u>Miocene</u> (Lagarto) sediments about 30-million years ago. Note that the fossils at Locality A lived in the transition zone.



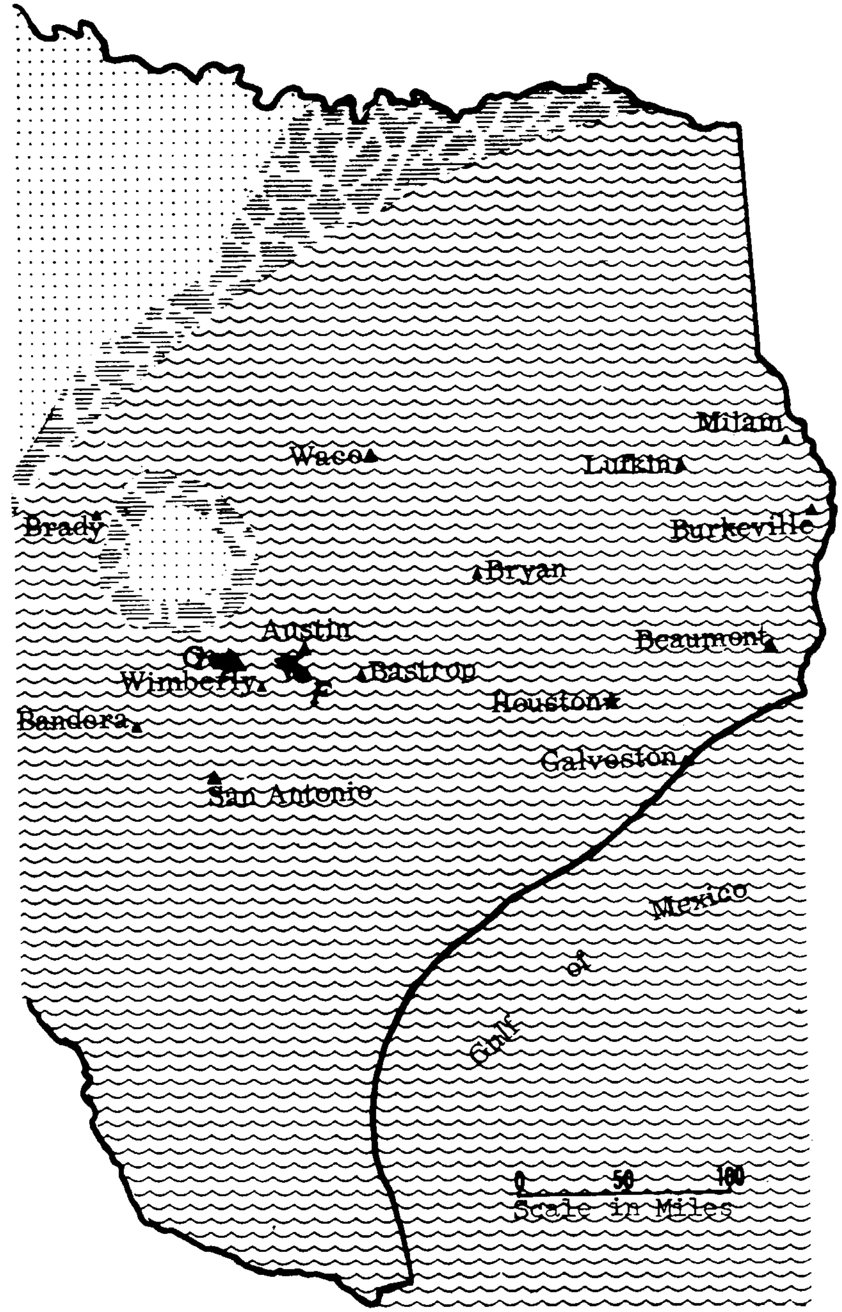
Map of eastern Texas showing extent of land ⁚⁚⁚⁚⁚ and sea 〰〰 during deposition of the Middle Eocene (Cook Mountain) sediments about 50-million years ago. Note that the fossils at Locality B lived in the sea.



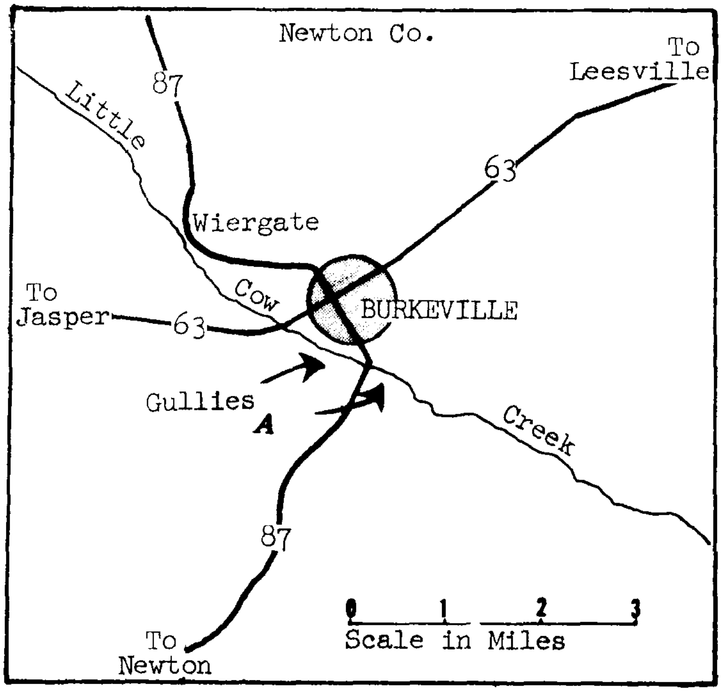
Map of eastern Texas showing extent of land ⁚⁚⁚⁚⁚ transition zone ☰, and sea 〰〰 during deposition of the Lower Eocene (Wilcox) sediments about 55-million years ago. Note that the fossils at Locality C lived in the sea and the fossils at Locality D lived in the transition zone.



Map of eastern Texas showing extent of land ⁚⁚⁚ and sea ﹏ during deposition of the <u>Upper Cretaceous</u> (Taylor) sediments about 80-million years ago. Note that the fossils at Locality E lived in the sea.



Map of eastern Texas showing extent of land ⁚⁚⁚, transition zone ≡ and sea ﹏ during deposition of the <u>Lower Cretaceous</u> (Glen Rose) sediments about 120-million years ago. Note that the fossils at Localities F and G lived in the sea.



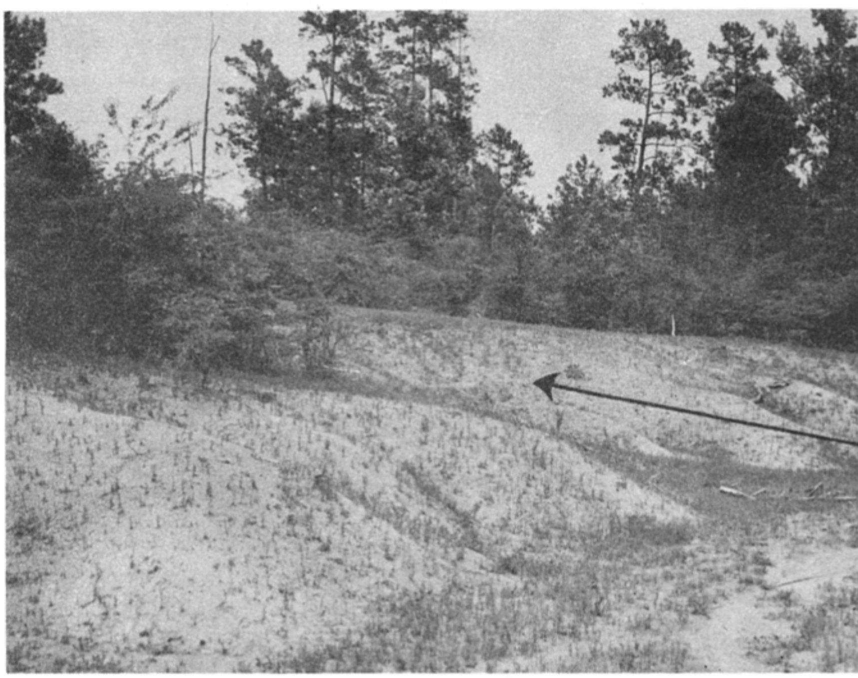
FOSSIL LOCALITY A, BURKEVILLE, NEWTON COUNTY, TEXAS. The fossil localities near Burkeville are of special interest to vertebrate paleontologists. Bone fragments and teeth of mammals, reptiles, and fish have been found in the clay which is exposed in gullies on the south side of Little Cow Creek. Oyster shells and other brackish water fossils also occur in the exposures east of Texas Highway 87.

The rock exposed in the gullies is mainly gray clay which was deposited in a coastal lagoon. Streams which drained the land area to the north during this period brought the clay and the skeletons of land animals to that ancient body of brackish water. The open sea shoreline was many miles to the south. (See map of Miocene.)

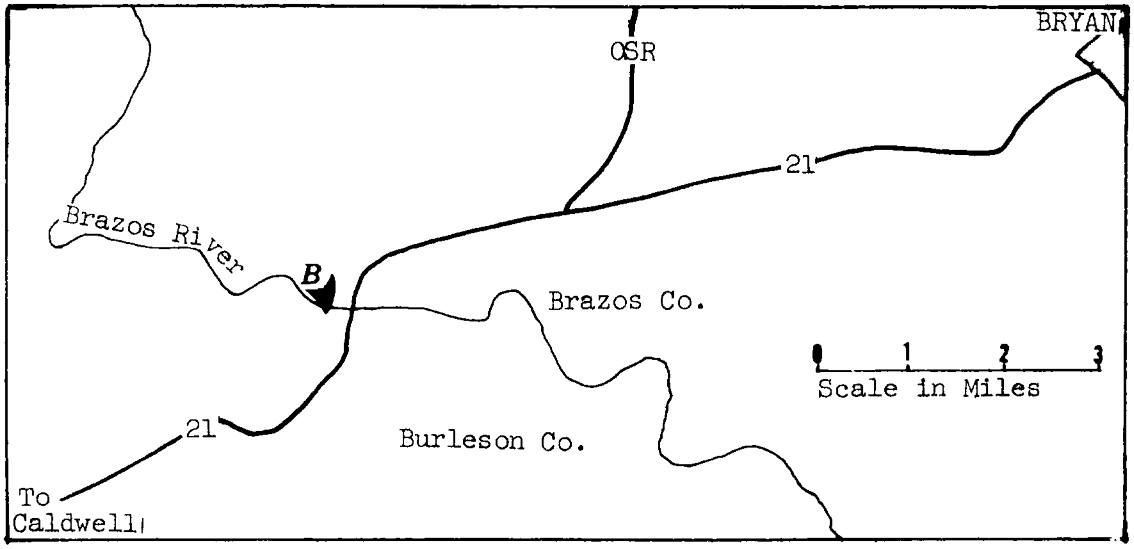
How to reach the localities on the west side of Texas Highway 87: Go south on this highway 1.4 miles from the intersection of Texas Highways 87 and 63 in Burkeville; turn right (west) onto a narrow, dirt road and follow it 0.2 mile to its end at Tom Beton's home. The gullies are about 0.5 mile farther north. In dry weather it is possible to drive to the gullies from the Beton home. Pass through wire gate and follow obscure trails across pasture and through wooded area. The gullied prairie is extensive, so there should be no doubt when the locality is reached. About 30 feet of gray clay is exposed in the gullies. White limestone nodules are abundant on the surface and in the bottom of the gullies. Fossils are rare.

How to reach the fossil locality east of Texas Highway 87: Go south on this highway 0.5 mile from intersection of Texas Highways 87 and 63 in Burkeville; turn left onto old highway, cross bridge over Little Cow Creek, and park along old highway 300 yards south of bridge in front of a home which is on the north side of the highway. Cross fence and go southeast 1/4 mile through woods to gullies in an open prairie area. About 20 feet of gray clay is exposed in the gullies. Oyster shells are abundant on the side of one of the gullies, and bone fragments are also common at this locality.

Fossil Locality A - Miocene (Lagarto) clay with vertebrate remains found in gullies on south side of Little Cow Creek, 1 mile south of Burkeville and 1/2 mile west of Texas Highway 87, Newton County, Texas.

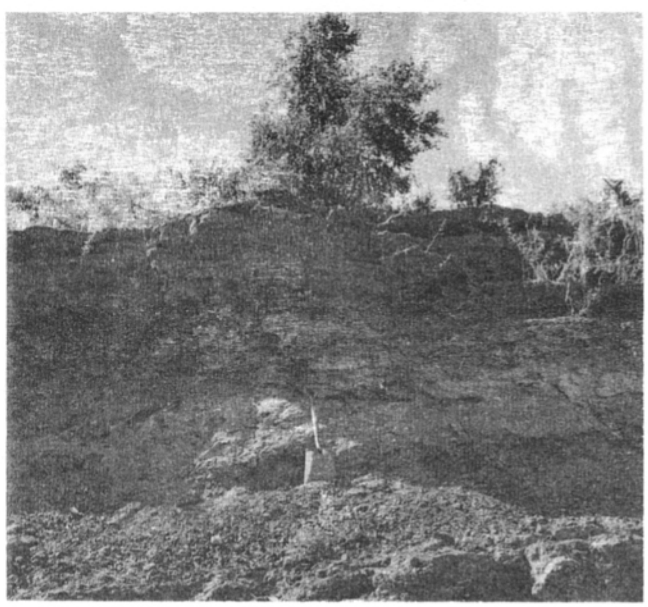


Fossil Locality A - Miocene (Lagarto) clay with oysters and vertebrate remains found in gullies on south side of Little Cow Creek, 1 mile south of Burkeville and 1/4 mile east of Texas Highway 87, Newton County, Texas.

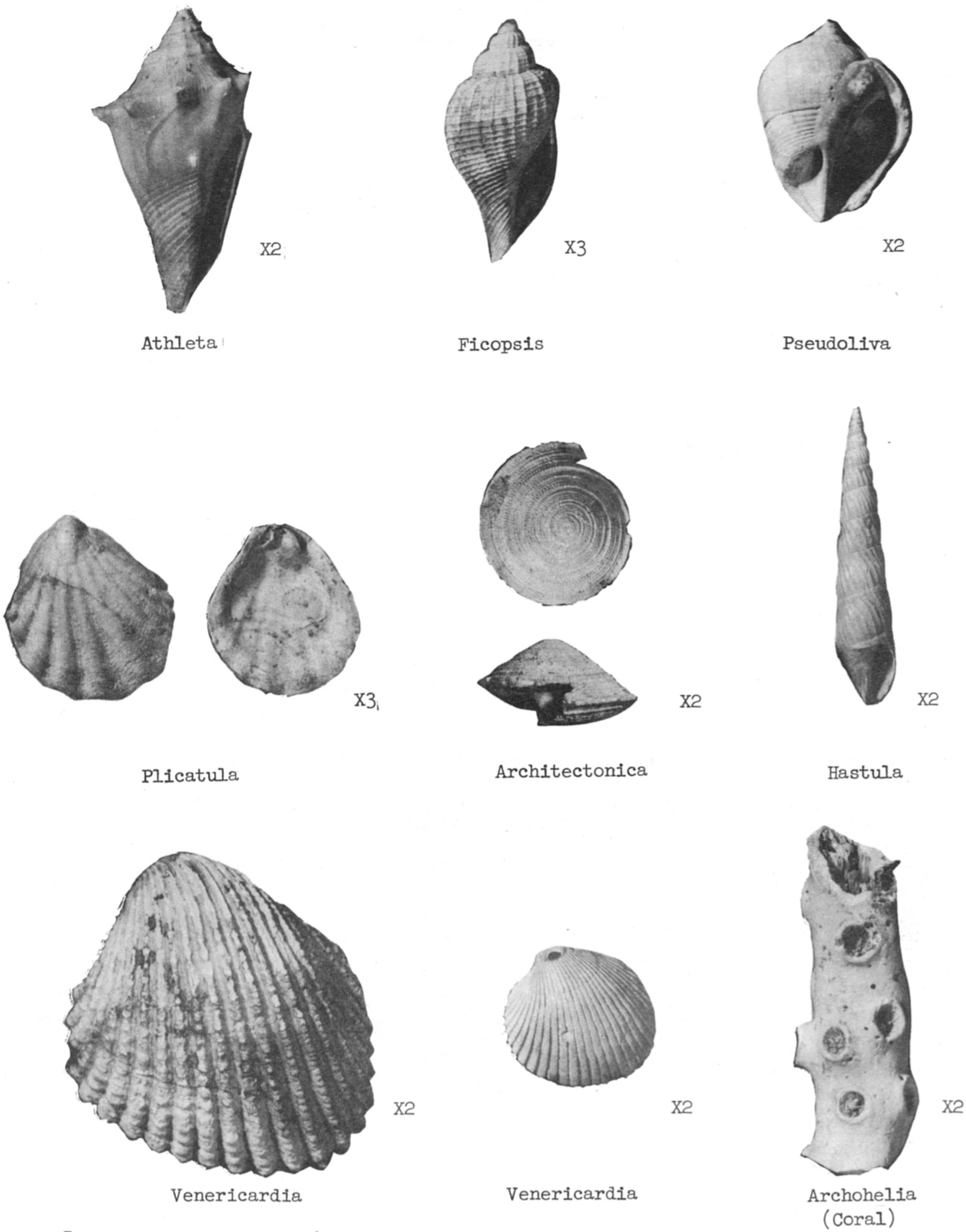


FOSSIL LOCALITY B, STONE CITY, BURLESON COUNTY, TEXAS. This locality, which has been known by geologists for more than 100 years, is perhaps the nearest exposure to Houston where abundant marine fossil sea shells can be collected. The bluff on the south side of the Brazos River, Burleson County, is located just upstream from the bridge over the river on Texas Highway 21, 12 miles west of Bryan and 14 miles northeast of Caldwell.

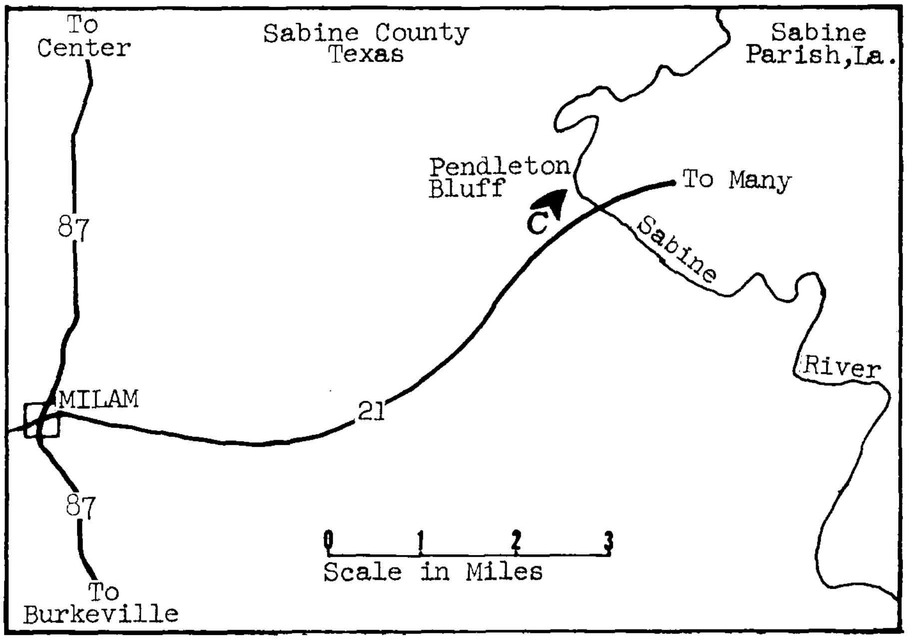
Park cars just off road on south side of bridge; go down river bank under the highway bridge, and walk upstream (west) about 300 yards, passing under railroad bridge, to bluff. About 85 feet of section is exposed at low river level. The strata are dipping to the east (downstream) so that the older beds are exposed at the western part of the bluff. The upper beds, however, a few feet below the hard limestone ledge, have the greatest number of fossils. The shells are mostly small, but many different species of gastropods (snails) and pelecypods (clams) are present in the clay and marl which was deposited in a shallow sea. (See map of Middle Eocene.)



View of bluff (Middle Eocene age) above Brazos River at Locality B, Burleson County, Texas.



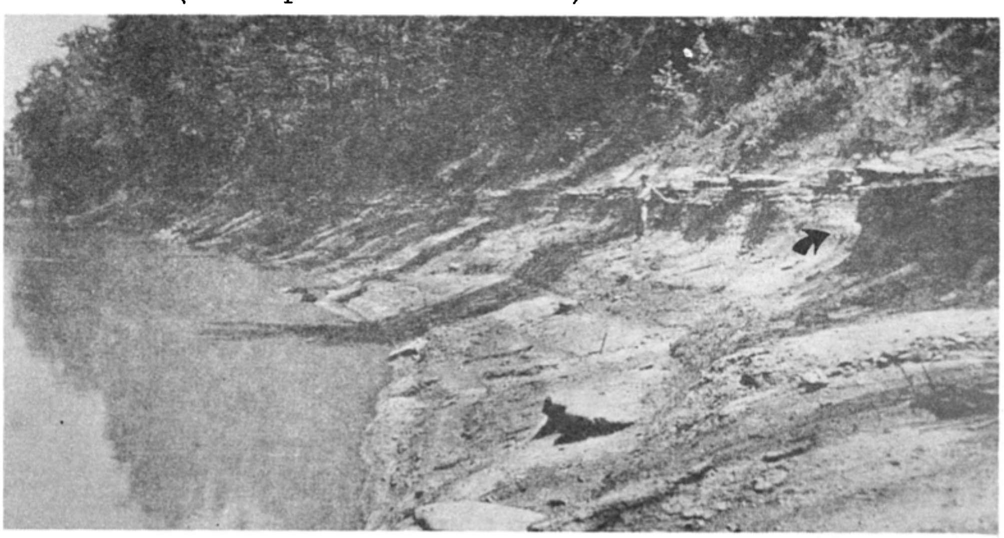
Some common gastropods (snails) and pelecypods (clams) found at Locality B, Burleson County, Texas.



FOSSIL LOCALITY C, PENDLETON BLUFF, SABINE COUNTY, TEXAS. Pendleton Bluff is on the Texas side of the Sabine River 1/4 mile upstream (to west) from Texas Highway 21 and Louisiana Highway 6 to the bridge over the river, 7.3 miles east of Milam, Sabine County, Texas. To reach the bluff, park at the west end of the bridge at C. N. McGown's grocery and gasoline station and walk along trail at the edge of the river bluff.

The fossils are in gray sandy clay near the base of the bluff at low river level, below the hard ledge. The fossils tell us that a very shallow sea extended over this area during the brief period when they lived and were covered by the sand. The sand and clay above the fossil bed were deposited in coastal environments when the sea shoreline was pushed farther south. (See map of Lower Eocene.)

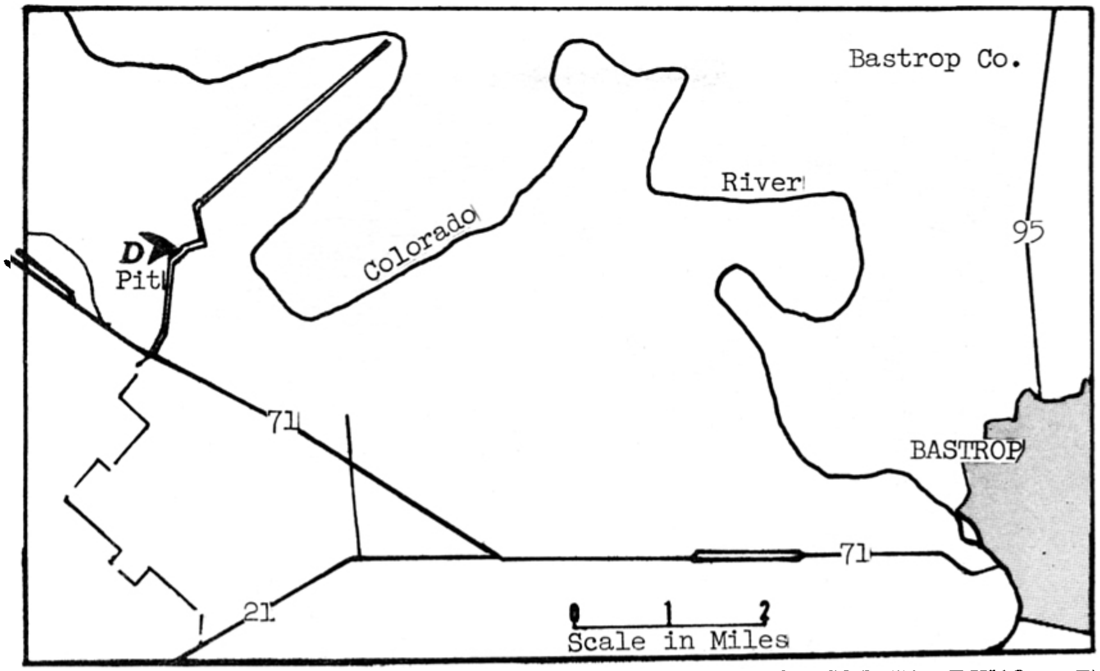
Turritella



Venericardia

View of Pendleton Bluff looking downstream (east). Common fossils found at this Lower Eocene locality are pictured at right.

Photographs reproduced with permission: Wasem, Richard and Wilbert, Louis J., Jr., 1943, The Pendleton Formation, Louisiana and Texas: Journal of Paleontology, Vol. 17, No. 2, Figure 2 and Plate 31.



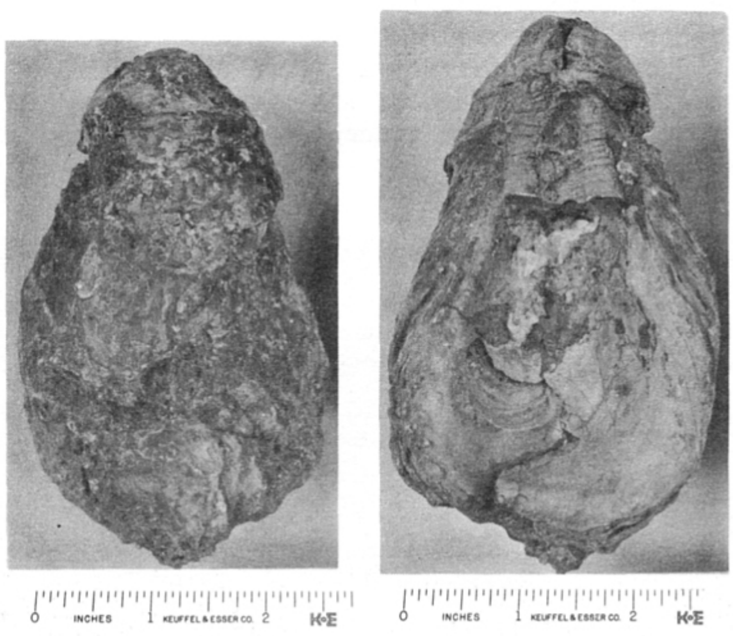
FOSSIL LOCALITY D, OSTREA DUVALI LOCALITY, BASTROP COUNTY, TEXAS. This locality, which is 10 miles west of Bastrop, in Bastrop County, is of interest because the abundant brackish oyster shells tell us that the sea reached almost to this area at least once during a long period when the shoreline was mostly far to the south. The coastal body of water in which the oysters lived must have connected with the open sea. (See map of Lower Eocene.)

Directions to locality: Go north 1.1 miles on black-top road from Texas Highway 71, 10 miles west of Colorado River Bridge at Bastrop and 4 miles west of junction of Texas Highways 71 and 21. The locality is a shallow, abandoned, and somewhat obscure quarry on the west side of the road, just across wire fence.

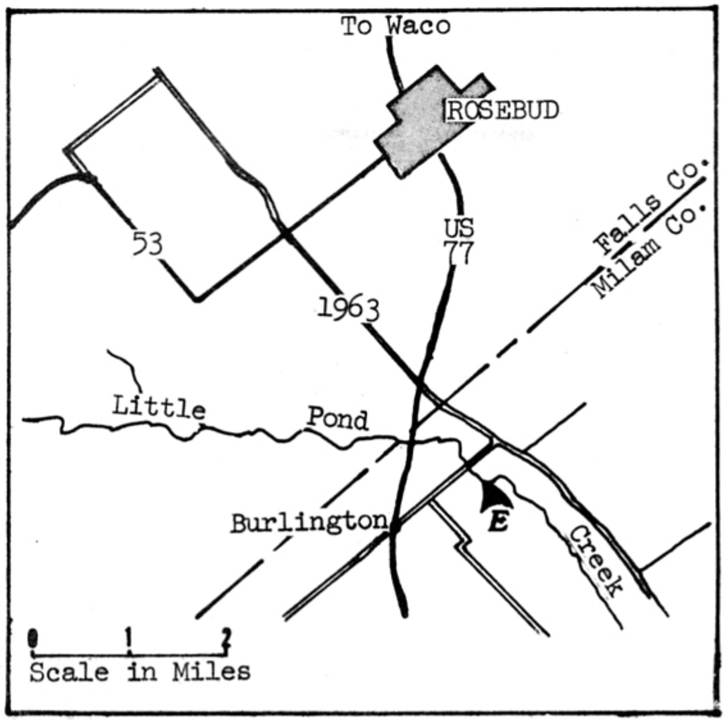
The fossil oyster shells, *Ostrea duvali*, are scattered over the surface of the shallow pit; they are also imbedded in a clayey sand which is exposed at the north edge of the pit. The large gravels on the surface at this locality were transported to this area during the Pleistocene Ice Age.

Abandoned pit showing abundant ancient oyster shells, Bastrop County, Texas.

View of abundant oysters of Lower Eocene age
to be found in pit west of Bastrop, Texas.



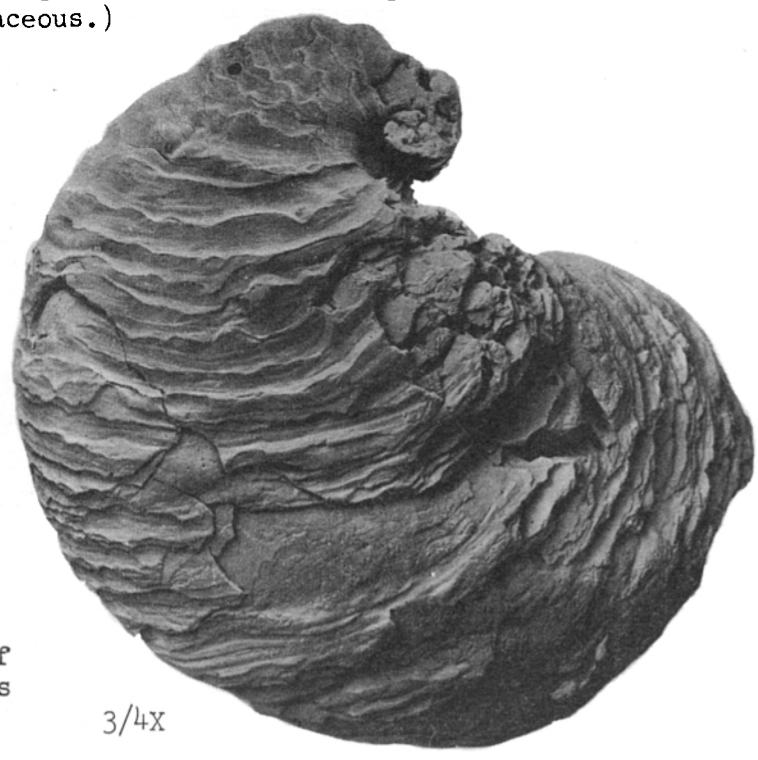
Ostrea duvali



FOSSIL LOCALITY E, EXOGYRA PONDEROSA, MILAM COUNTY, TEXAS. Fossil locality E is the bed of Little Pond Creek, 4 miles south of Rosebud and 0.9 mile northeast of the village of Burlington, at the northern edge of Milam County. Follow gravel road northeast from U. S. Highway 77 at Burlington, which is 4.3 miles south of the main crossroads in Rosebud and 11.8 miles north of the junction of U. S. 77 and U. S. 190 in Cameron. Go 0.9 miles on the gravel road and park 0.1 mile northeast of bridge over Little Pond Creek (two small bridges). Cross fence and walk 300 yards southeast across pasture to Little Pond Creek.

The large (4-8 inches) fossil marine oyster shells (Exogyra ponderosa) are abundant in the creek bed. They have been washed out of the soft clay and marl which forms the bedrock in this area. Other large fossils are rare, but the clay and marl have abundant microscopic marine fossils. The large gravels which are also abundant here were brought to this area during the Pleistocene or Ice Age. (See map of Upper Cretaceous.)

Little Pond Creek showing the large shells of Exogyras to be found at this Upper Cretaceous locality (Taylor formation).



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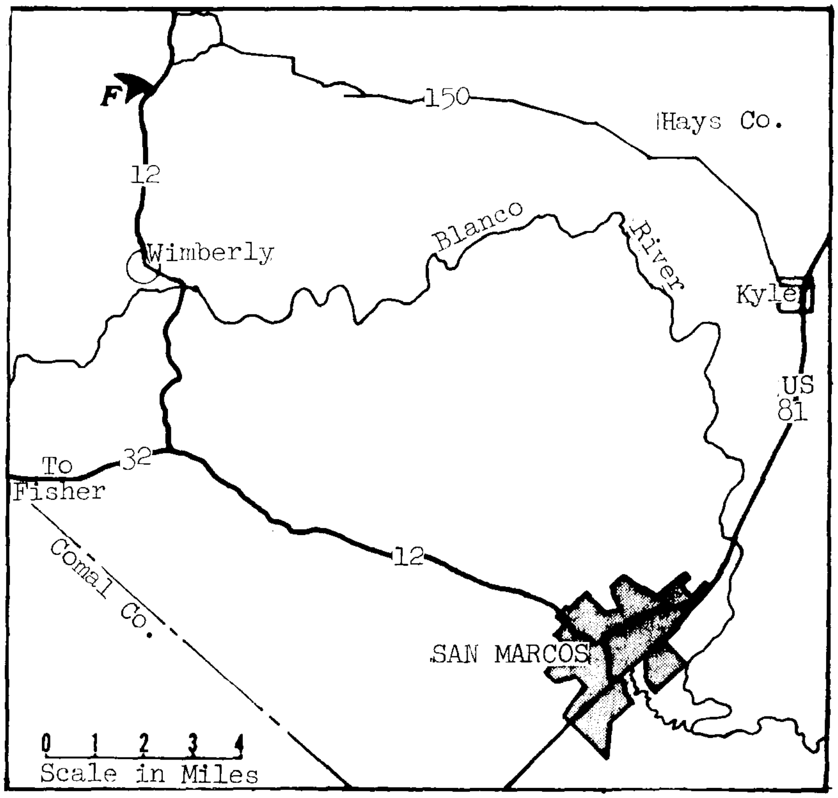
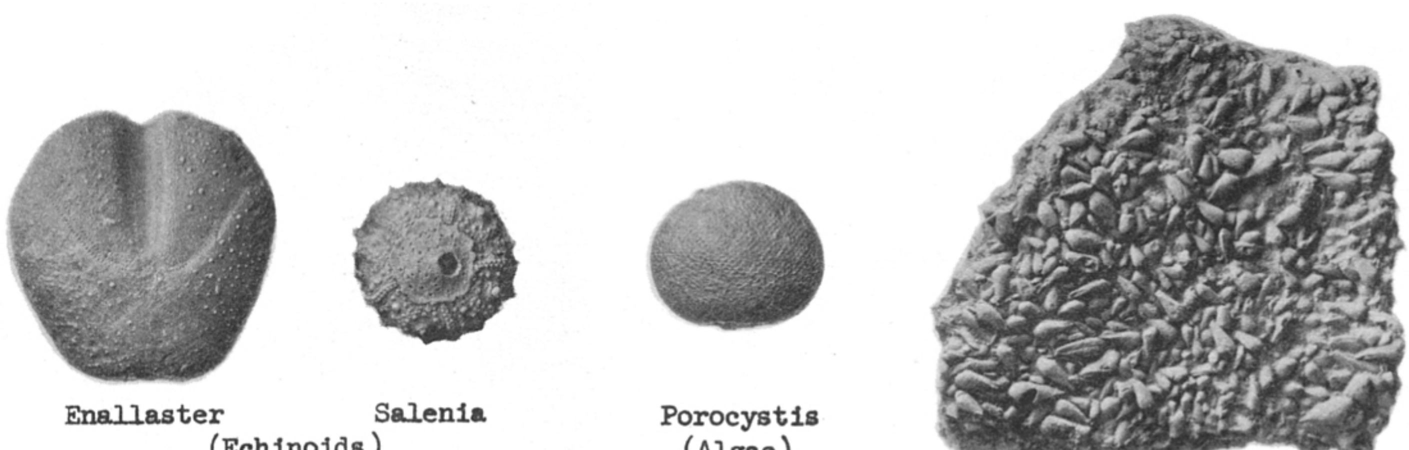
Exogyra ponderosa



FOSSIL LOCALITY F, CORBULA BED, HAYS COUNTY, TEXAS. The map of the Lower Cretaceous shows that the Corbula Beds and the associated fossils once lived in the fairly shallow seas that formerly covered this area. Here at this gently sloping roadcut, the Corbula bed is 6-10" thick, of reddish brown limestone about 8' above the level of the road. Below this thin ledge is creamy nodular limestone containing echinoids, heart-shaped clams and large sea snails.

To reach Locality F - from the junction of Texas Highway's 32 and 12 west of San Marcos, go north of Highway 12 toward town of Wimberly. From the bridge across Blanco River, continue approximately 4.7 miles to a slight roadcut on the west(left) side of the highway.

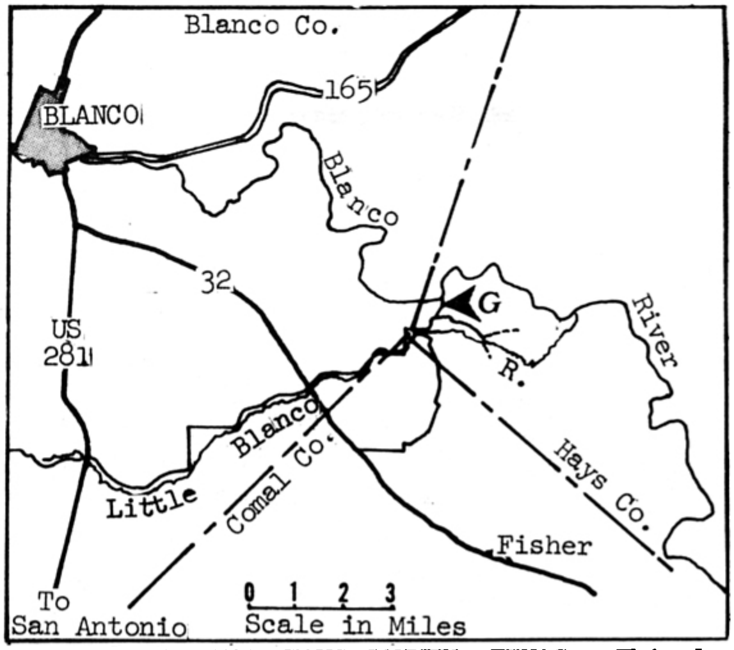


Enallaster Salenia (Echinoids)

Porocystis (Algae)

Corbula (Pelecypods)

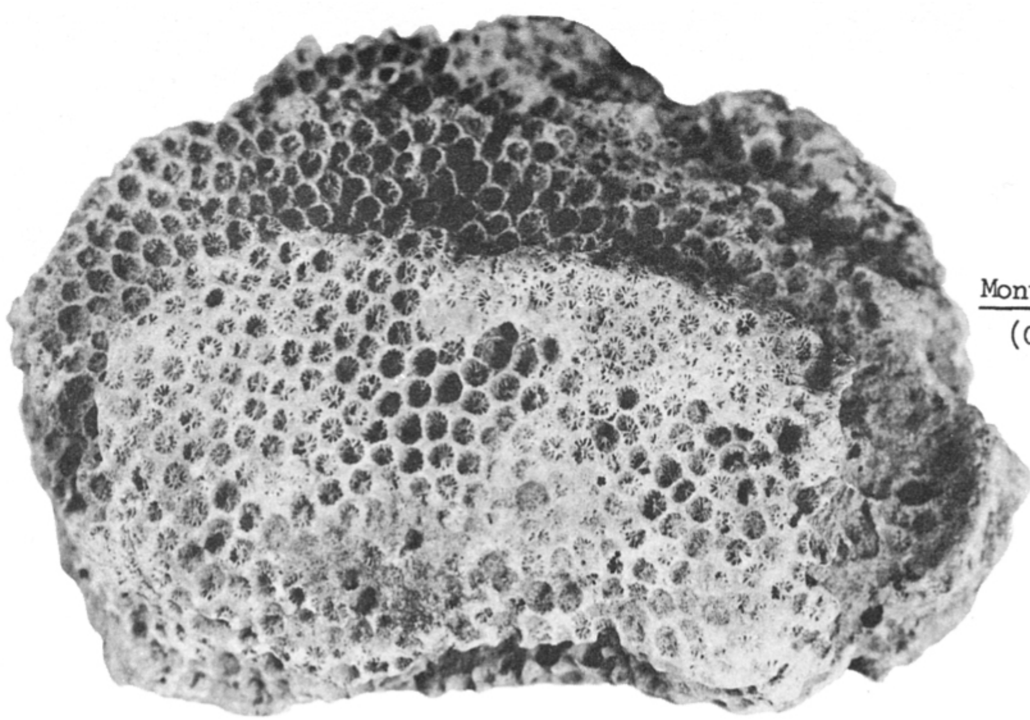
Pictured above (natural size) are some of the common fossils to be found at this Lower Cretaceous locality, Hays County, Texas.



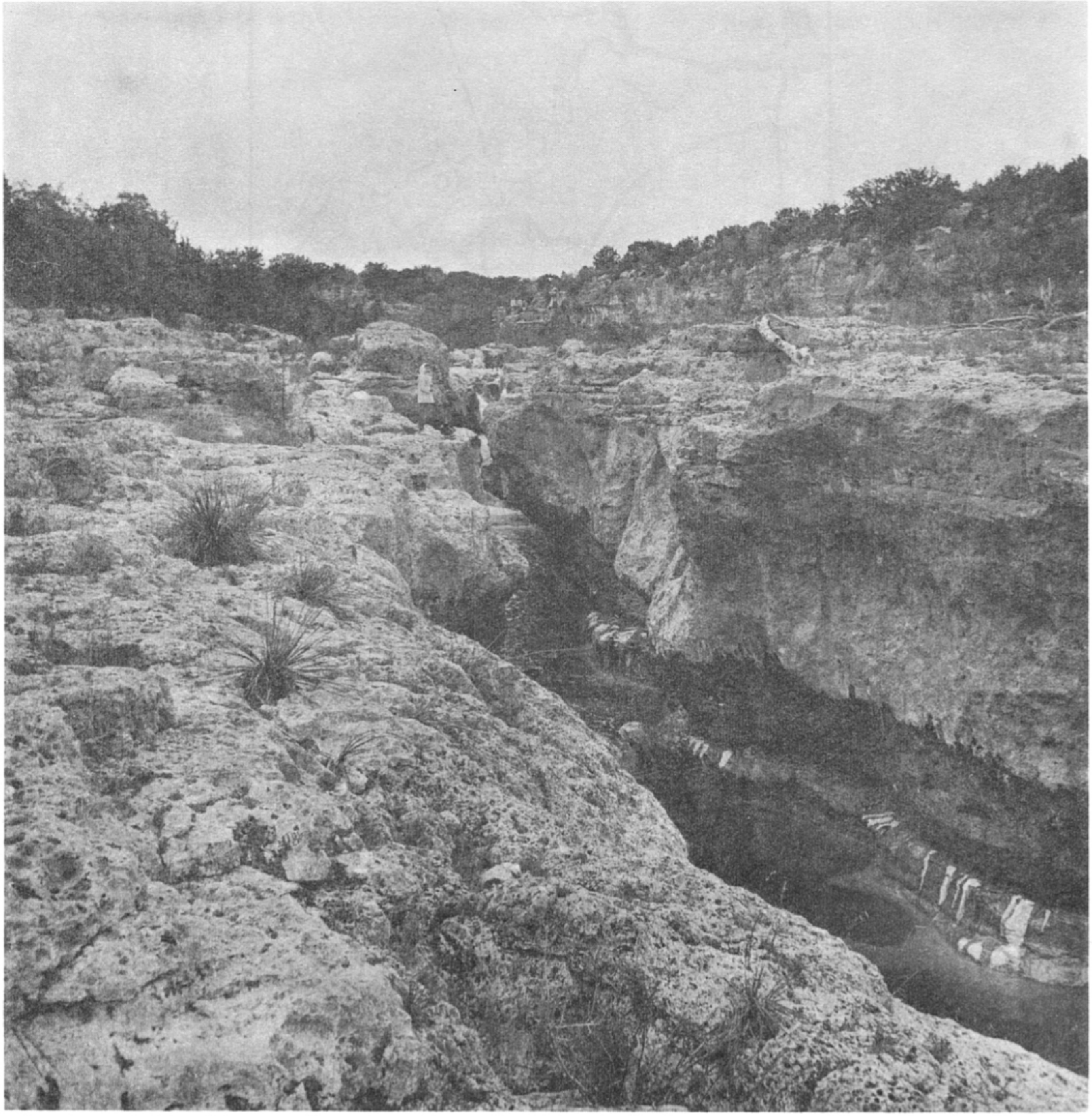
FOSSIL LOCALITY G, THE NARROWS, HAYS COUNTY, TEXAS. This locality is quite a spectacular spot in the heart of the "Hill Country". Looking at the Lower Cretaceous map one can see that the sea once covered this area during which time the coral reef formed. The importance of seeing such an exposure is that ancient reefs, such as this one, are extremely rare in Texas and the Gulf coastal area.

To reach Locality G - from the intersection of U. S. Highway 281 and Texas Highway 32 south of Blanco, go southeast on Hwy. 32, 6.3 miles to gravel road on left (east) and turn down this road following it approximately three miles to sign "Narrows" on left. This is a well known feature and most residents of the area can give additional directions if necessary.

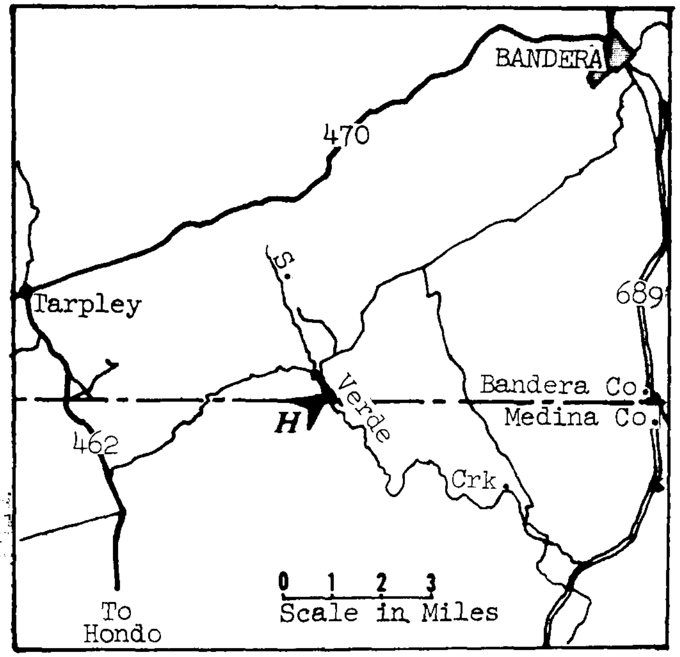
Note - this is a viewing locality - primarily because it is unlikely that the amateur collector can successfully separate a complete coral from the hard gray limestone.

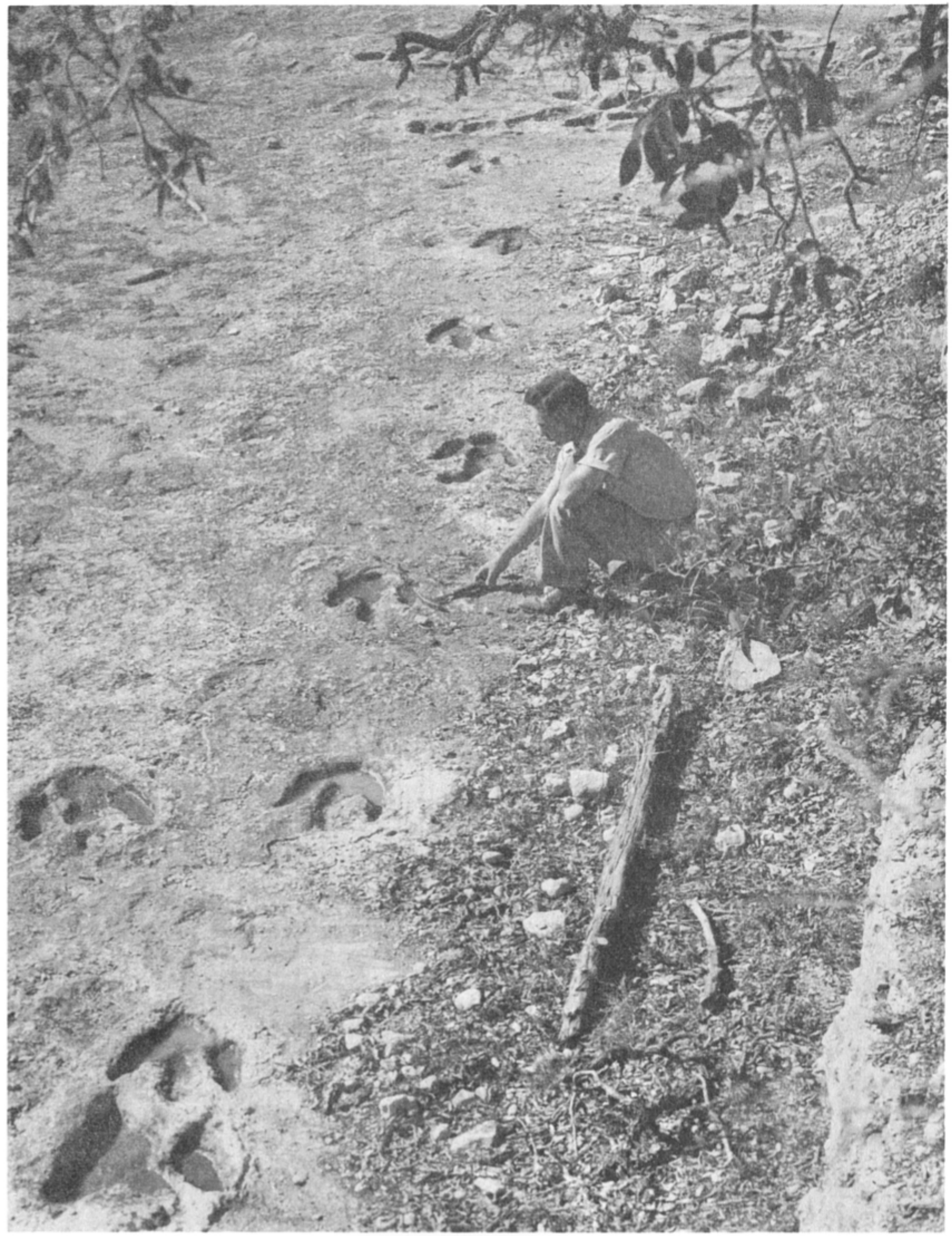


Montastrea
(Coral)



A view of the "Narrows", a coral reef of Lower Cretaceous age, Hays County, Texas.



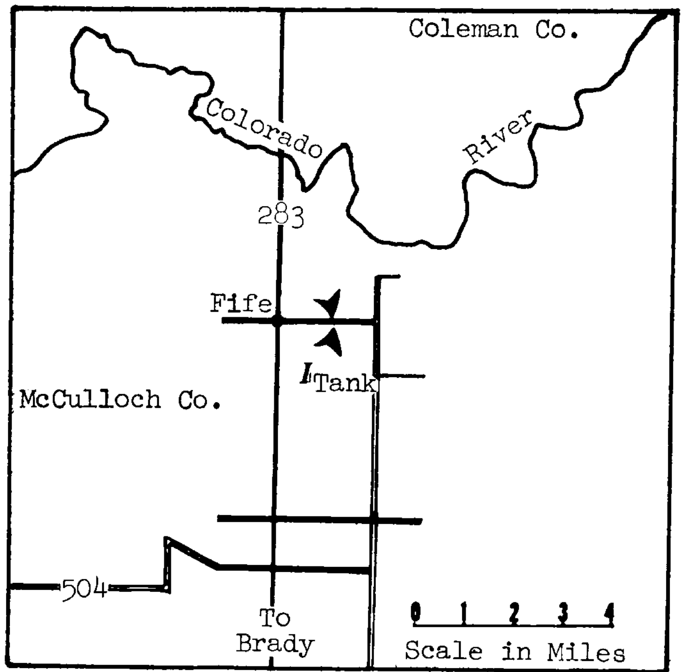


FOSSIL LOCALITY H, DINOSAUR TRACKS, BANDERA COUNTY, TEXAS. Fossil Locality H is the bed of South Verde Creek. To reach this site - from the junction of Texas highways 470 and 462 in the village of Tarpley, go south on Hwy. 462 four miles to side road on left (east) of Highway. Turn on this road and go approximately 5 miles to S. Verde Creek, turning right on ranch road on east side of creek. Tracks are visible in creek bed at low water level.

It is thought that the dinosaurs walked along near shore (in water no deeper than 5-10'), the tracks being preserved in the muddy bottom sediments of a Lower Cretaceous sea once reaching this vicinity.

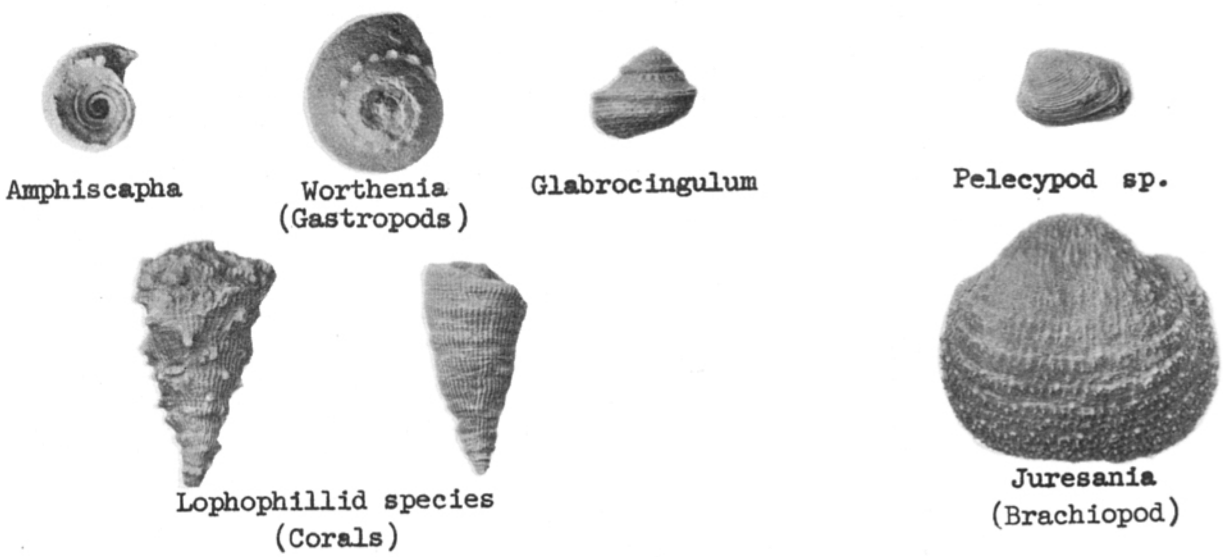
Ranch owner's permission must be obtained to visit this locality. Remember, this is a sight-seeing trip - not a collecting locality.

Photograph by L. Hinton, Jr.



FOSSIL LOCALITY I, BRADLEY'S TANK, MCCULLOCH COUNTY, TEXAS. The fossils at this locality once lived in a fairly warm shallow sea during the Pennsylvanian time. They are abundant and easily collected from the loose weathered shale which forms the sides of the tanks on the Bradley Ranch.

Locality I may be reached by traveling on U. S. Highway 283 to the village of Fife, 19 miles north of Brady. At Fife turn due east on the metal surfaced road and go one mile from the central part of town. Water tanks formed by the piles of tan shale are on either side of this road, just beyond the fences. Again, a reminder - this is private property - try to obtain permission before entering.



Pictured above (natural size) are some of the common fossils to be found at this Pennsylvanian locality, McCulloch County, Texas.

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Appendix II

THE LLANO REGION, TEXAS

NOTES ON ITS HISTORY, AND GUIDE TO SELECTED ROCK AND MINERAL LOCALITIES

by

Otto J. Buis[1]

General Statement

The Central Mineral Region, or Llano area, affords the opportunity to study many aspects of geology. Numerous rocks, minerals, and fossils may be found here and collected with ease. The excellent quality of the geologic exposures, and the many rock and mineral types present, are almost unequaled anywhere else in the United States.

The Llano region lies along the northern border of the Edwards Plateau near its easternmost extension. The area is basin-like, having been etched below the level of the Edwards Plateau. Its present form is due to a combination of structural and erosional conditions. The geologic formations present here consist of remnants of the three greatest divisions (called Eras) of earth history, the Precambrian, Paleozoic and Mesozoic (see Table I on page 60 for a listing of these units).

Descriptions of most of the rocks and minerals mentioned in this summary may be found in the booklet "Rocks and Minerals" by Herbert S. Zim and Paul R. Shaeffer, Simon and Schuster, New York, 1957, $1.00.

Summary of the Geologic History of the Llano Region

The Precambrian history of the Llano region can be determined in part. Presently, it is believed that a great mass of sediments, probably marine in origin, existed here. These sediments underwent metamorphism and during this transformation from one rock type to another were changed into the gneisses and schists found today comprising the Precambrian interval in the Central Mineral Region.

During and following this metamorphism the region also underwent extensive igneous intrusion, folding, and profound erosion. This great amount of erosion is demonstrated by the fact that igneous rocks now exposed at the surface commonly are very coarsely crystalline. This coarseness of texture implies that they were once deeply buried under miles of overlying sediments, and thus underwent slow cooling processes which were conducive to the development of large crystals (if an igneous rock exhibits a fine grained texture cooling processes were probably rapid, consequently a shallow depth of burial would be suspected).

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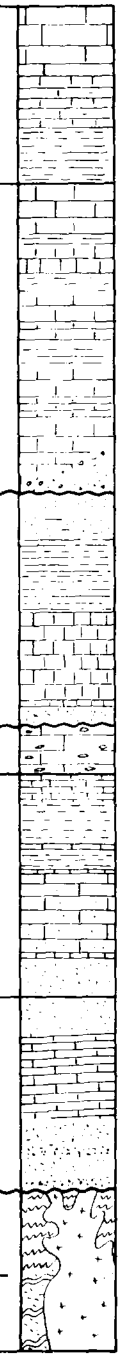
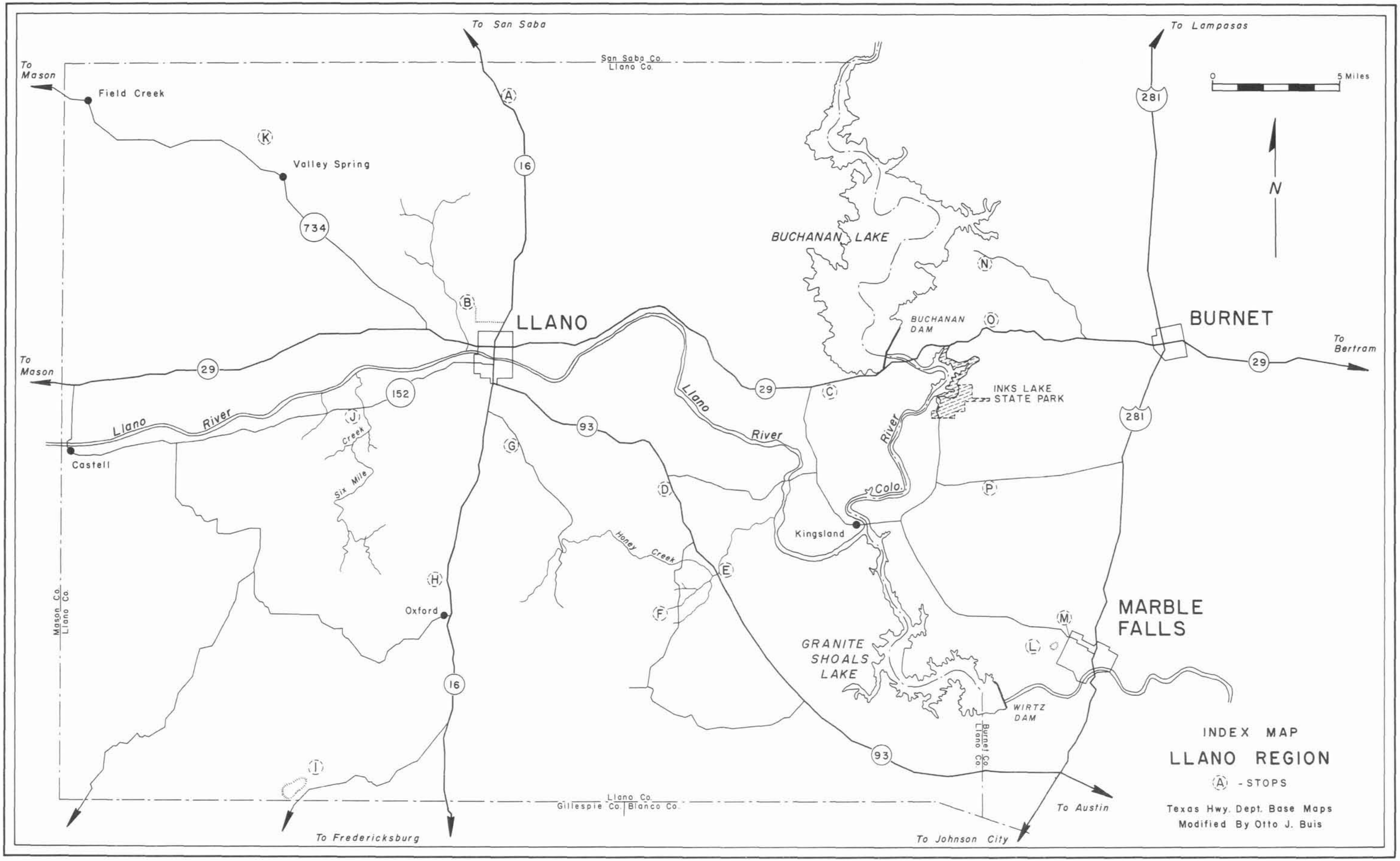
[1]Geologist, Texaco, Inc.

Table I - Generalized Geologic Column Of The Llano Region

Era	Period	Group / Formation	Units
MESOZOIC	Cretaceous	Fredericksburg Group	Edwards Comanche Peak Walnut
		Trinity Group	Glen Rose Hensel Cow Creek Hammett Sycamore
PALEOZOIC	Carboniferous (Miss. - Penn.)		Strawn Smithwick Marble Falls Barnett
	Ordovician	Ellenburger Group	
	Cambrian	Wilberns Formation	San Saba Point Peak Morgan Creek Welge
		Riley Formation	Lion Mountain Cap Mountain Hickory
PRECAMBRIAN		Packsaddle schist Valley Spring gneiss	intrusive granites (Town Mountain, Oatman, Sixmile, etc.)




To San Saba
To Lampasas
To Mason
Field Creek
San Saba Co.
Llano Co.
0
5 Miles
281
K
A
Valley Spring
16
N
734
BUCHANAN LAKE
N
B
LLANO
BUCHANAN DAM
O
BURNET
To Bertram
To Mason
29
29
152
29
C
INKS LAKE STATE PARK
Llano River
J
93
Llano River
River
281
Creek
G
Castell
Six Mile
D
Colo.
P
Kingsland
Honey Creek
E
H
F
Mason Co.
Llano Co.
Oxford
M
MARBLE FALLS
GRANITE SHOALS LAKE
L
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WIRTZ DAM
Burnet Co.
Llano Co.
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Llano Co.
Gillespie Co.
Blanco Co.
To Austin
Texas Hwy. Dept. Base Maps
Modified By Otto J. Buis
To Fredericksburg
To Johnson City

The Llano region during early Paleozoic was an area where wind blown sediments were deposited on a hilly, but gently rolling, Precambrian surface. These deposits were followed by those resulting from encroachment of Cambrian seas that flooded the area from the south, and east, towards the northwest. An almost continuous sequence of deposition, consisting first of fine grained sands, and then of limestones, was prominent until the end of Ordovician times. This sequence of events, and the resultant deposition, was followed by a period of prominent erosion during which several hundred feet of sediments were removed.

Shallow turbulent seas moved in over the freshly eroded surface and deposition of coarse grained clastics ensued. Generally speaking, the Llano area underwent alternating periods of submergence and emergence. During the periods of submergence sediments often accumulated in great quantities; however, in the following periods of emergence all, or at least portions, of these deposits often were eroded away.

The main period of uplift in the Llano region is thought to have occurred in late Paleozoic time. During this period structural forces were exerting themselves at a peak, and brought about elevation of the general area. These forces also produced and regulated the patterns displayed by most of the fault systems found here.

After a period of non-deposition and erosion Cretaceous seas transgressed and covered this area completely for the last time. Thick accumulations of limestone and marl were deposited in nearly horizontal layers over the entire region. Following removal of the sea, due to a widespread general uplift, erosion removed the Cretaceous covering over the main portion of the Llano uplift. Erosion continued with removal of Paleozoic sediments. The resultant picture is what you view today in this area, a Precambrian basement complex, surrounded and overlain by Paleozoic, and Mesozoic rocks.

Selected Stops

A brief description of some of the more interesting localities in this area have been tabulated by counties on the following pages. (Please refer to enclosed map for location of stops). These sites are often visited by geologists traveling through, or making formalized studies of, the Llano area.

Llano County

Stop A

Llanite Dike - 10 miles North of Llano on Highway 16

This dike, or ridge-like exposure, of granite porphyry represents the last episode of granitic intrusion into Precambrian sediments. The term "Llanite" was first applied to this rock because of its unique characteristics and its close proximity to the town of Llano. More accurately described this rock would be termed a quartz-feldspar-porphyry. It is mottled red and gray, and shows many red feldspar, and blue quartz phenocrysts, in an aphanitic groundness. The blue color of the quartz phenocrysts appears to be due to reflection of blue light-waves from small colorless inclusions.

Stop B

Tourmaline and Rose Quartz outcrop - 1 mile north of Llano town square off Highway 16

Crystals of tourmaline and rose quartz from a weathered pegmatite may be found in this area. Look alongside a ranch road approximately one mile west of the first gravel pit on the west side of Highway 16. (Permission should be obtained from local ranch owner for access to area.)

Stop C

Badu Pegmatite - 13 miles west of Llano on Highway 29

This pegmatite has served as a commercial source of feldspar (a mineral used in ceramics for the making of pottery, both in the body of the ware and in the glaze; this mineral is also commonly used as an abrasive). Quartz crystals may also be found here.

Stop D

Road Cut Hickory Sandstone - 8.6 miles southeast of Llano on Highway 93

Excellent examples of faulting exist here in the Hickory sandstone (Upper Cambrian in age). This ferruginous sandstone member also contains some ripple marks. A nearly vertical fault may be noted approximately 100 feet from the north end of the road cut. The drag on the displaced beds indicates that the northern side moved down.

Stop E

Honey Creek - 12.7 miles southeast of Llano on Highway 93

Several excellent geologic features may be noted here as you proceed downstream (NE) along the southeast bank of Honey Creek.

100 yards downstream, granite pegmatite dike one foot thick intrudes dark colored schists and gneisses. Since the dike breaks across the bedding of these Precambrian rocks it must be the younger rock.

150 yards farther, to light-colored bed of sugary marble approximately 20 feet thick. Originally this was a sedimentary limestone deposited in sea water but metamorphism change it into a low-grade marble.

300 yards farther to a large outcrop of pink rock jutting into the creek. This is the Kiam pegmatite, a coarse-grained, granitic dike of feldspar, quartz, and muscovite mica. At one time this area was prospective for molybdenite, a soft gray, metallic mineral. You may find specimens of this mineral in the white quartz on the hill to the right.

Stop F

Limonite Mine - 13.3 miles southeast of Llano off Highway 93

A deposit of limonite was once exploited here (limonite is the commonest form of iron ore, but is also of the lowest grade and usually quite impure; manufacturers of some of the cheaper grades of yellow and brown paints commonly use this mineral). Pyrite, or fool's gold, may also be found here. The prominent escarpment in this area, essentially parallel to the road near the mine workings, is the surface expression of the Honey Creek Fault.

Stop G

Magnesite and Marble Quarries - 3.8 miles south of Llano off Highway 16

Metamorphism of impure limestone and dolomite resulted in the formation of the two products mined here. The magnesite is of high quality containing as much as 93-97% magnesium carbonate (the best quality is slightly translucent and varies in color from blue-white to light green). Some other minerals found here are chlorite, talc, calcite, pyrite, pyrrhotite and serpentine.

Stop H

Serpentine Quarry - 8 miles south of Llano on Highway 16

Quarry is located west of road near prominent dumps now overgrown with grass. It exposes an intrusive of Precambrian magnesium-rich rocks that were altered by metamorphism into serpentine, talc, chlorite, and tremolite. The dark green material which makes up most of the quarry is serpentine. At the left-hand end of the quarry, up the wall, lenses of coarse-grained talc may be found. At the other end of the quarry are veins of green chlorite. Above the quarry rim are masses of light green soapstone and tremolite. These minerals are all magnesium silicates.

Stop I

Enchanted Rock - 21 miles southwest of Llano off Highway 16

Here you have a batholith in evidence at the surface. Approximately 10 square miles of this pluton is exposed. The predominent rock here is that of a quartz monzonite grading outwardly into a granodiorite. Note the prominent spalling, or exfoliation, of this granitic mass. A great deal of historical significance may also be attached to this feature. The name "Enchanted Rock" comes from the original Indian name. Numerous Indian legends exist here based on the eerie sounds often heard at night. Actually these sounds are due to contracting of the rock mass on a cool night following an extremely hot day (the Indians attributed these sounds to spirits). Another historical event that happened here occurred in the fall of 1841. At that time Capt. John C. (Jack) Hays, while surrounded by Comanche Indians, who had cut him off from his Ranger company, repulsed the whole band, and inflicted such heavy losses among the Indians that they fled.

Stop J

Sixmile Granite - 5 miles west of Llano on Highway 152

Excellent exposures of the Sixmile granite are found at this stop. This intrusive, commonly containing xenoliths of the Town Mountain granite, is pointed out due to its fine-grained texture as compared with the other area granites. Relatively speaking, the Sixmile granite must have cooled in a much shorter length of time than most of the other granites, thus indicating a shallow depth of burial. Another thing noted here is that the feldspar making up this granite is gray in color rather than pink which is so common in the Llano region.

Stop K

Magnetite Mine - 12.2 miles northwest of Llano off Highway 734

This is the site of an abandoned magnetite mine. Samples of this mineral can still be obtained here in some of the talus dumps. This mineral is a very pure, and valuable, source of iron; it is strongly attracted by a magnet and sometimes is magnetic itself.

Burnet County

Stop L

Granite Mountain Quarry - .5 mile west of Marble Falls off Highway 281

Granite Mountain quarry was originally opened in 1882; it is currently active and is operated by the Texas Granite Corporation. The rock quarried here comes from an intrusive mass of Precambrian granite. This rock is composed mostly of feldspar and quartz, with some biotite and hornblende. A distinctive feature of this rock is its texture (it is very coarse-grained; note the large feldspar crystals - some are more than two inches across).

Although granite is a common rock there are few places where it may be quarried on a profitable basis for building stone. Primarily this is due to either a complete lack of natural fractures which would require excessive blasting to remove the stone, or a profusion of close, irregular fractures exist that would hinder the removal of a large piece of stone intact. However, in this quarry the conditions seem ideal, as widely spaced, horizontal fracturing allows the removal of large blocks. Once removed, these blocks may be cut to the desired dimensions. The granite from this quarry, commonly referred to as "Texas Pink," has been used for the facings of buildings not only in Texas, but in many of the major cities of the United States, and even in some foreign countries.

Stop M

Marble Falls Fault - .25 mile west of Marble Falls near city limits off Highway 281

Pennsylvanian limestone has been down faulted on the southeast, against Precambrian granite on the northwest. Note how the bedding in the limestone is steepened by drag against the fault. Crinoid stems, small cylindrical fossils, may be found in the limestone. Chert, a type of silica, may also be obtained. It is the dark colored, hard, thin layered beds dispersed irregularly through the limestone.

Stop N

Southwestern Graphite Mine - 9 miles northwest of Burnet off Highway 29

The graphite produced here is from the Packsaddle schist. The mine is a narrow, open pit more than 1000 feet long, with steep walls in excess of 100 feet high. All the graphite produced here has been sold for industrial use except during the years 1948-53 when some of it was government stockpiled. It has been estimated that a 20 years' supply of open-pit ore remains. Some of the main uses of graphite are for foundry facings, batteries, lubricants, crucibles, and pencils. Other rocks in the Packsaddle sequence found in this area are mica schist, hornblende schist, tourmaline schist, amphibolite and marble.

Stop O

Sheridan Copper Prospect - 8 miles west of Burnet off Highway 29

The outcrop here is Packsaddle schist surrounded by Valley Springs gneiss. The ore deposits at this locality are associated with the many pegmatites and aplite dikes (and their associated hydrothermal fluids) that cut across these formations. Active mining ventures have been going on in this area since 1912, however, economic production has never been established. Some of the minerals that may be found here are sphalerite, chalcopyrite, galena, arsenopyrite, magnitite, flourite, and mica (two varieties of mica may be collected here, muscovite and biotite).

Stop P

Longhorn Cavern - 9.8 miles southwest of Burnet off U. S. Highway 281

A great length of time and enormous amounts of water have eroded and etched Lower Paleozoic limestone into the winding passageways and immense chambers seen today in this cavern. Guided tours are conducted daily through this geologic wonder.

This cave is also steeped in historical significance. It has been used by outlaws as a hiding place, and during the Civil War it was used by the Confederate Army as a place where they manufactured and stored gun powder.

Appendix III

GLOSSARY OF TECHNICAL TERMS

(Many of the definitions given below are modified from those given in "Glossary of Geology and Related Sciences" by J. V. Howell et al; the American Geological Institute, Washington, D.C., 1957.)

ANTICLINE	An upfold in the rocks of the earth where the beds dip in opposite directions from a common ridge or axis.
APHANITIC	Having a texture so fine that the individual grains, or crystals, cannot be distinguished with the naked eye.
APLITE	A fine grained granite.
BATHOLITH	Vast irregular masses of igneous rocks that crystallized at depth and have been exposed by erosion (usually they have a surface area of 40 square miles or more).
BED	The smallest division of a stratified series of rocks, and marked by a more or less well defined divisional plane from its neighbors above and below.
BUOYANCY	Power of supporting a floating body; the upward force exerted upon an immersed or floating body by a fluid.
CLOSURE	Structure of beds as shown by contour lines when one or more contour lines "closes," or is continuous and encircling. For an anticlinal structure, the amount of closure is the vertical distance between the top of the structure and the lowest level at which a continuous encircling contour can be drawn.
CONTOUR	Line connecting points of equal value on a map; in this booklet most commonly points of equal elevation.
DEPOSITION	The laying down of potential rock-forming material; sedimentation.
DIP	The angle at which a bed, fault, (or any planar feature), is inclined from the horizontal. The elevation of the bed becomes lower in the direction of dip.
DOME	A (roughly symmetrical) upfold or anticline with beds dipping in all directions more or less equally.
EXFOLIATION	A process whereby successive sheets of rock are split, or peeled, off the parent mass.

EXTRUSIVE	Igneous rock that solidified from melted rock (lava) after it reached the surface of the earth. It is distinguished from intrusive igneous rock by its glassy to fine-grained texture.
FAULT	A fracture in the rocks of the earth along which there has been displacement of the two sides relative to one another parallel to the fracture. Fault classification is very complex and will not be discussed here. However, almost all of the faults in the Houston area are classified as "normal faults," which means that the fault plane is inclined and that the side that overhangs has moved downward relative to the other side.
FORMATION	An assemblage of rocks that have some character in common that permits the geologist to identify and map it as a unit.
FRACTURE	An open break of any dimensions.
GEOSYNCLINE	An elongated area of regional extent that subsided more or less continuously for a very long period of time, and was filled with sediments almost as fast as it subsided so that a thick section of sedimentary rocks accumulated.
GNEISS	A metamorphic rock having the minerals arranged in more or less massive bands.
GRANITE	An igneous rock consisting primarily of quartz and feldspar, is granular, and usually light colored.
HYDROTHERMAL FLUIDS	Hot mineral waters associated with igneous intrusions.
IGNEOUS	Rock that solidified (crystallized) from hot liquid rock (magma).
IMPERMEABLE	Impervious; term applied to strata having a texture that does not permit the penetration of water, petroleum, or natural gas.
INTRUSIVE	Igneous rock that solidified without reaching the surface. It is distinguished from extrusive igneous rock by its coarse-grained texture.
LITHOLOGY	The study of the composition and texture of rocks.
MARL	A sedimentary rock consisting of roughly equal proportions of clay and calcium carbonate (limestone).
METAMORPHIC	Rocks that formed by the alteration of older rocks beneath the earth's surface due to heat, pressure, and/or chemically active fluids.
MINERAL	A naturally-occurring substance produced by processes of inorganic nature, usually having a definite chemical composition and a characteristic atomic structure.

PEGMATITE	A coarse grained granite.
PERMEABLE	Pervious; having communicating pores or interstices that permit fluids to move through the rock.
PERMEABILITY	The capacity of a rock to transmit fluid.
PHENOCRYSTS	Individual crystals embedded in a fine grained groundmass of igneous rock. The crystals are usually visible to the naked eye.
PINCH OUT	When a stratum becomes thinner and thinner as it is traced in some direction, until it finally disappears, the stratum is said to pinch out.
PLUTON	Any body of igneous rock that crystallized at depth, regardless of the shape of the rock mass.
POROSITY	The ratio of the volume of all pore space to the total (bulk) volume of a given sample of rock, usually expressed in percent.
POROUS	Containing voids, pores, interstices, or other openings which may or may not be connected.
PORPHYRY	An igneous rock in which large crystals (phenocrysts) are set in a fine grained groundmass.
RESERVOIR	A natural underground container of fluids, such as oil, water, or gas. Also that portion of a trap which contains oil and/or gas in a single hydraulically connected system.
ROCK	Any naturally-formed aggregate or mass of mineral matter constituting an essential and appreciable part of the earth's crust.
SALT DOME	A dome resulting from the upward movement or intrusion of a salt mass.
SCHEMATIC	Diagrammatic; constituents of a pattern placed according to a scheme or explanatory design.
SCHIST	A foliated metamorphic rock (made up of minerals that have been elongated or flattened into a flaky-like mass).
SEDIMENT	Solid material settled from suspension or solution in a liquid.
SEDIMENTARY	Rocks that have been formed at the surface, either by the accumulation and cementation of fragments of rocks, minerals and organisms, or as precipitates from sea waters.
SHALE	A laminated sediment in which the constituent particles are predominantly clay; a laminated claystone.

SPECIFIC GRAVITY	The ratio of the weight of a substance to the weight of an equal volume of water.
STRATIGRAPHIC TRAP	A type of trap which results from variations in the lithologic character of the reservoir rock.
STRATIGRAPHY	The branch of Geology which treats of the arrangement of strata; the formation, composition, sequence, and correlation of the stratified rocks as parts of the earth's crust.
STRIKE	The line formed by the intersection of a stratum or planar feature with a horizontal plane. The direction of strike is at right angles to the direction of dip.
STRUCTURE	The sum total of the structural features of an area.
STRUCTURAL FEATURE	Features produced in the rock by movements after deposition.
SUBSIDENCE	Sinking of a part of the earth's crust.
SYNCLINE	A downfold in rocks of the earth where the strata dip inward from both sides toward the axis.
TEXTURE	Size and shape of the constituent particles of a rock.
TRAP	A body of reservoir rock occurring underground under structural and/or stratigraphic conditions that result in the trapping of migrating oil and/or gas.
XENOLITH	A fragment of older rock enclosed in a younger body of igneous rock.