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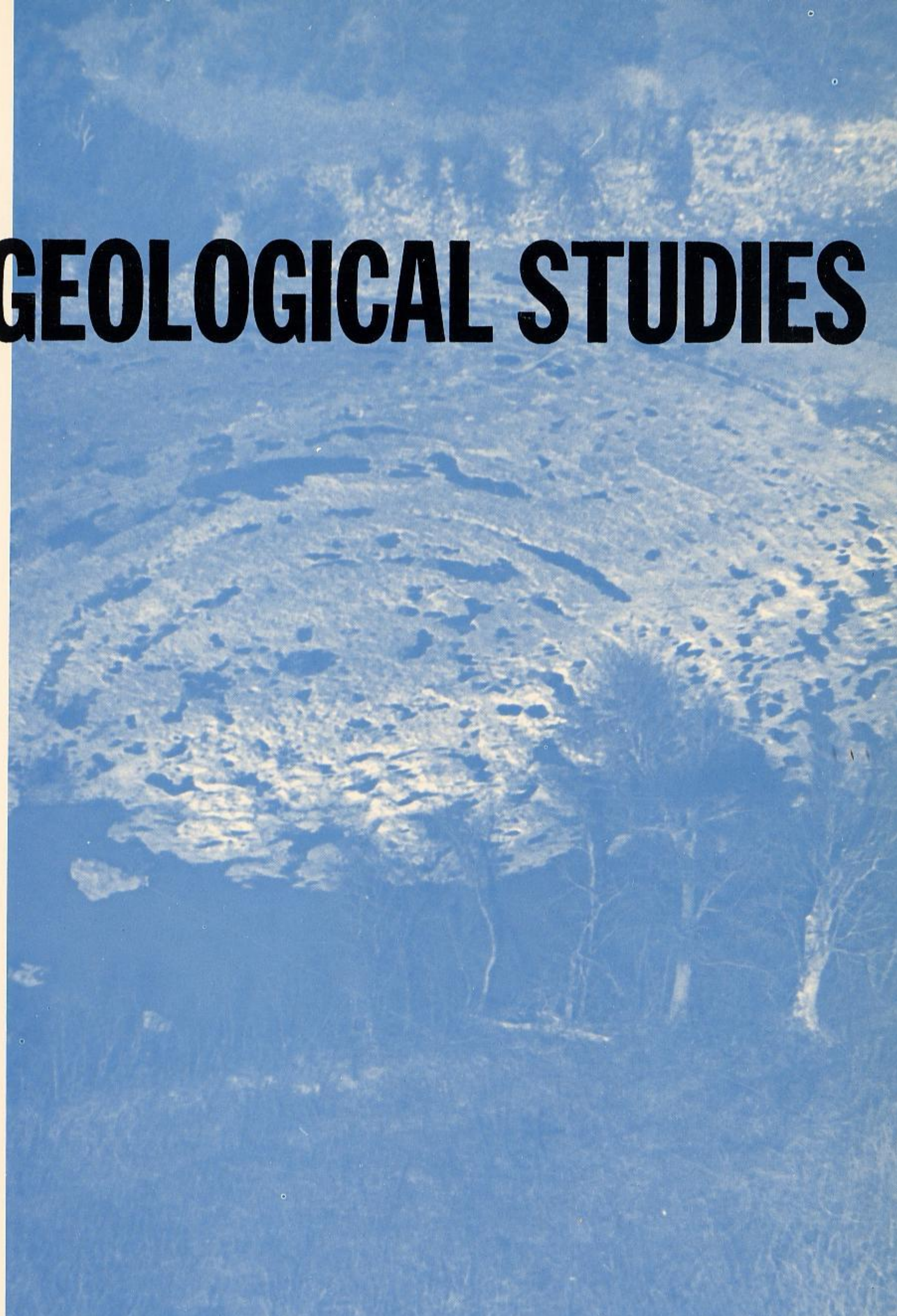

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The Paleoecology, Distribution and Significance of Circular Bioherms in the Edwards Limestone of Central Texas

DANA SHUMARD ROBERSON

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

FRANK CARNEY, PH.D.
PROFESSOR OF GEOLOGY
BAYLOR UNIVERSITY
1929-1934

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The Paleoecology, Distribution and Significance of Circular Bioherms in the Edwards Limestone of Central Texas

Dana Shumard Roberson

BAYLOR UNIVERSITY
Department of Geology
Waco, Texas
Fall, 1972

Baylor Geological Studies

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Cover photograph by John Dann.

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The Paleoecology, Distribution and Significance of Circular Bioherms in the Edwards Limestone of Central Texas

Dana Shumard Roberson

ABSTRACT

The Edwards Limestone, uppermost formation of the Fredericksburg Group in Texas, has been described in terms of three distinct lithologies (Frost, 1963): 1) a fore-reef facies, 2) a reef facies, and 3) a back-reef facies. The Edwards complex, however, grew entirely as a back-reef facies behind the Stuart City Reef of southeast Texas, which existed from late Trinity to early Washita time. Therefore, the distinctive Edwards Limestone lithologies are sub-divisions of a major back-reef province.

Within the Edwards Limestone of the study area, are several facies which differ significantly from the three described by Frost. These are small areas of the reef facies which are here classified as 1) reef facies, 2) inter-reef-biohermal facies, and 3) biohermal-mound facies, all of which exist in Frost's reef facies.

In the study area, the uppermost Edwards Limestone was deposited in a warm, shallow, hypersaline environment. Under these conditions, the caprinid form of rudist flourished and built reef foundations. Seaward assemblages grew in elongate trends forming reefs. Behind these young reefs assemblages grew in clumps or mounds.

A later assemblage consisting primarily of *Eoradiolities davidsoni* (a species of rudist) composed beds which encircled the central mounds. This assemblage was a normal marine faunal group and indicated an environmental change. The circular structure of the bioherms represents growth accumulations, periodically terminated or slowed by influxes of clay or carbonate mud. These influxes occurred at least fourteen times yielding fourteen distinct rings. The circularity of the bioherms was the result of deposition in quiet water behind a reef barrier which stopped destructive waves and currents.

Reef barriers, elongate reefs, protected the area of bioherms to the extent that talus did not form and growth occurred in all directions from a central caprinid mound. Each new ring grew only as high as the original mound and no higher than the elongate reef-barrier. The restriction barring upward growth may have been a wave base or, as the uniformity of elevation suggests, the low tide sea level. The bioherms and elongate reefs grew contemporaneously, and wash-over beds from the elongate reefs surrounded the circular bioherms.

Reef growth was terminated by a massive influx of clay, the Kiamichi Member of the Georgetown Formation, which drapes over the undulating surface of the Edwards bioherms.

INTRODUCTION*

In November, 1968, two pilots flying out of Waco Municipal Airport became curious about the circular structures they observed in the bed of Childress Creek. Their observations led to a detailed ground investigation which revealed circular biohermal mounds in the top of the Edwards Limestone.

While reefs have been recognized and studied in the Childress Creek basin for years (Nelson, 1959; Frost, 1963), no one appreciated their extreme circular geometric shape (fig. 2). These bioherms represent a distinct depositional facies of the Edwards Limestone in central Texas.

Initially, the bioherms were believed to be restricted to the Childress Creek basin. Further investigation revealed these circular bioherms to be extremely widespread (fig. 3).

Edwards Limestone bioherms characterize the southern and western edges of the north Texas-Tyler basin and extend into the subsurface along the eastern edge of the Comanche platform (fig. 4). Massive rudist reefs developed first in the southwest and transgressed eastward over the Comanche Peak Limestone, which accumulated along the western flank of the East Texas basin (Frost, 1963, p. 134). Frost (1963) divided the Edwards Limestone into three lithofacies: 1) a fore-reef facies, 2) a reef facies, and 3) a back-reef

*A thesis submitted in partial fulfillment of the requirements for the M.S. degree in Geology, Baylor University, 1971.

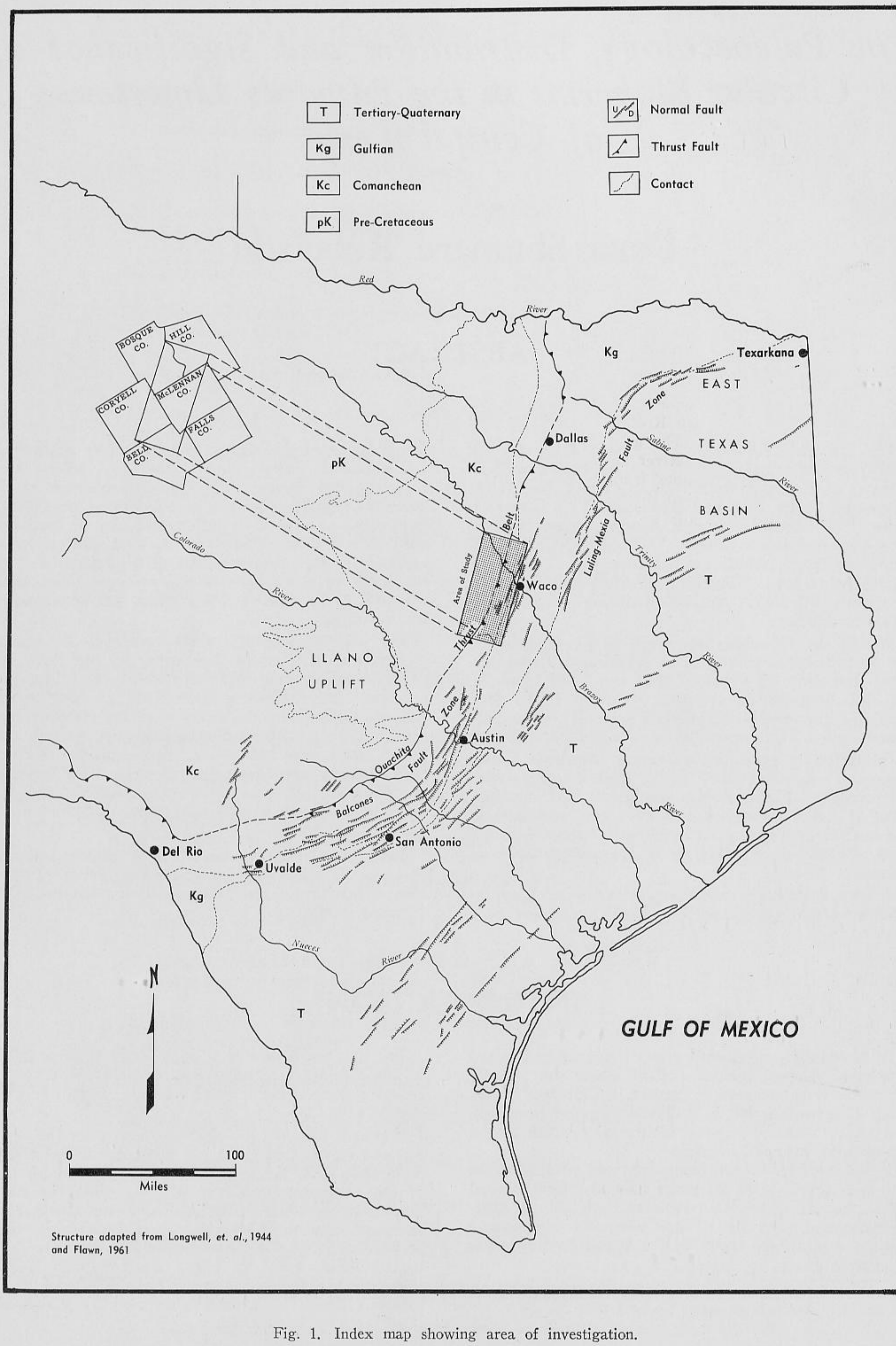

Fig. 1. Index map showing area of investigation.

facies. The area of this investigation lies within the region defined by Frost as reef facies (fig. 4). This area can be further subdivided into a major wave-resistant reef facies, an inter-reef lime-mud facies, and a back-reef, quiet water mound or bioherm facies.

This study constitutes a more detailed view of the geology in the mound and bioherm facies including, 1) distribution, 2) paleoecology, 3) environment of deposition, and 4) geologic significance of circular bioherms found in the upper Edwards Limestone.

LOCALITY

The area of study includes Childress Creek basin in northern McLennan County and southern Bosque County, North Bosque River basin in Bosque and McLennan counties, Hog Creek in Bosque and McLennan counties, Middle Bosque basin in Coryell and McLennan counties and Leon River basin in Coryell and Bell counties (fig. 3). The area is bounded on the northeast by the Brazos River and on the southwest by the Leon River. Lines from Lake Whitney to Gatesville and from Waco to Belton bound the area to the west and east respectively.

METHODS

Aerial photographs, topographic maps, electric logs, and field examination aided in mapping and describing the geology in the area of the bioherms. Of particular advantage was the utilization of a helicopter to locate and photograph from low altitude circular bioherms widely exposed over the study area. Bioherms located from the air were plotted on topographic maps and then examined in the field (fig. 3).

Samples collected were petrographically analyzed for calcite, kaolinite, montmorillonite, and dolomite. Prepared thin sections allowed microscopic determination of minerals. Slabs, acetate peels, and thin sections were necessary for petrologic and paleontologic investigation. X-ray diffraction was used to determine the mineralogy of clay and limestone samples.

TERMINOLOGY

Terminology used in this paper is defined in the following glossary. These terms, generally regional and structural in nature, will be defined in greater detail in the following sections.

Reef: A product of actively building and sediment-binding biotic organisms, which have the ability to erect rigid wave-resistant topographic structures.

Bioherm: A moundlike mass built exclusively of or mainly by sedentary organisms such as corals, algae, mollusks.

Mound: Mounds refer to circular bodies which differ lithologically from the surrounding rocks. These bodies are growth assemblages and sediment-binding organisms. In this paper, mound refers to caprinid growth accumulations and bases for biohermal rudist growth.

East Texas-Tyler Basin: A basin existing during Fredericksburg time to the east and northeast of the study area. The basin is centered near present-day Tyler, Texas.

Comanche Platform: A large flat, relatively stable area occupying the central portion of Texas during much of Cretaceous time. Sometimes referred to as the Comanche Shelf.

Two sets of geologic names will be used, one for the Comanche platform formations, and one for the East Texas-Tyler Basin formations as shown in Table 1.

TABLE 1. TERMS USED FOR SHELF AND BASIN FORMATIONS

	Shelf	Basin	Origins
WASHITA	Georgetown Limestone (1)	Georgetown Formation	1. Named by Vaughan in 1900. Type locality; San Gabriel River, Williamson Co., Texas.
	Kiamichi Clay (2)		2. Named by Hill (1891). Type locality; Kiamichi River, Choctaw Co., Oklahoma.
FREDERICKSBURG	Edwards Limestone (3)	Goodland Formation (4)	3. First called *Caprotina* Limestone by B. F. Shumard (1860) changed to Edwards Limestone in 1898, by Hill and Vaughan. Type locality; Barton Creek, Austin, Texas.
	Comanche Peak Limestone (5)		4. Hill divided the Fredericksburg into five sections in 1890. The Goodland was the uppermost. Type locality; Choctaw Co., Oklahoma.
	Walnut Clay (6)	Walnut Clay	5. Named by B. F. Shumard (1860). Type locality; Comanche Peak, Hood Co., Texas.
			6. Named by R. T. Hill in 1891. Type locality; Walnut Springs, Bosque Co., Texas.
	Paluxy Sand (7)		7. Named by Hill in 1890. Type locality; Paluxy, Hood Co., Texas.

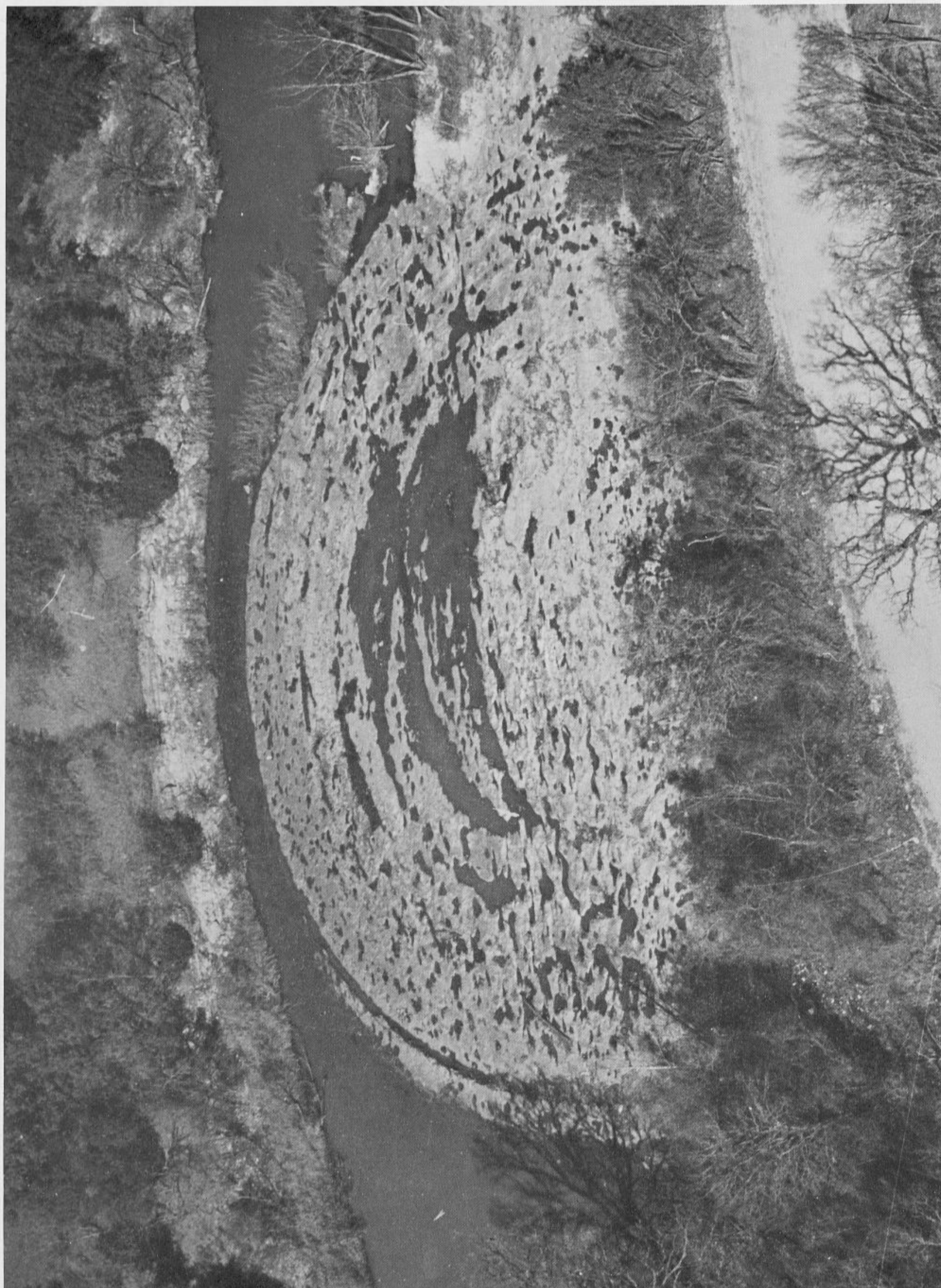

Fig. 2. Bioherm in Childress Creek bed. Circular appearance is enhanced by water in the structure (Loc. 1-3). The bioherm is approximately 150 feet in diameter. (Photo by Leach and Dann)

HISTORY OF THE NOMENCLATURE

The history of the earliest geologic nomenclature of Comanchean rocks is well documented. Early reports consisted largely of reconnaissance studies. Probably the first report significant to the immediate interest of this paper was that of R. T. Hill in 1887 (a), in which he diagrammed the correct sequence of strata of the Texas Cretaceous System. Hill provisionally divided the Comanche Series of the Cretaceous into two groups, based upon the Fort Washita (Trinity River) section. The lower group was called Fredericksburg because the paleontological features were similar to those originally described by Roemer in the Fredericksburg area. The upper group was named Washita, after the strata described by George Getz Shumard and Jules Marcou at Fort Washita. The base of the Fredericksburg Group was designated at the base of the "*Caprotina* Limestone" of Shumard (Hill, 1887b, p. 306).

In 1891 (p. 504) Hill placed the "Kiamitia Clay" in the Washita Group and named the remaining members of the Fredericksburg Group. In 1897 (p. 200) Hill and Vaughan substituted the name Edwards Limestone for "*Caprotina* Limestone" to avoid the use of a fossil name for a formation. They considered the Goodland Limestone of Oklahoma to be equivalent to the Edwards and Comanche Peak limestones. Hill and Vaughan placed the Kiamichi Clay in the Washita Group and the Paluxy Sand in the Trinity Group.

The monographic report of 1901 by Hill is the most complete work ever published on Texas Cretaceous geology. In this report, *Geography and Geology of the Black and Grand Prairies, Texas,* Hill described the extent, importance, and thickness of the Edwards and Comanche Peak limestones in Texas (p. 214). His subdivision of Comanchean rocks has been amended in part, and the term "division" has been replaced by "group," however, most of his original work remains essentially unchanged.

Little descriptive stratigraphy of Fredericksburg rocks in central Texas was published following Hill's report of 1901. In 1932, W. S. Adkins described the Cretaceous rocks and regional facies, areal distribution, and fauna (both megascopic and microscopic). In this report Adkins described the ". . . Edwards Limestone in McLennan County along Bluff Creek as pure (99 per cent $CaCO_3$), unstained rudistid limestone" (p. 340).

S. A. Thompson (1935, p. 1534) proposed the name "Gatesville Formation" to include the Walnut Clay, Comanche Peak, and Edwards as members in the central Texas area. This term was not widely accepted and has been dropped.

E. Nixon (1958) in a detailed study of a quarry near Oglesby, Coryell County, divided the Edwards Limestone into three sections: 1) upper Edwards Limestone biohermal reef rock, 2) middle Edwards Limestone inter-reef micrite, and 3) lower Edwards Limestone biostromal or "blanket" reef.

In 1959, the Texas Bureau of Economic Geology published the *Edwards Symposium,* a comprehensive study of the Edwards Limestone of central Texas. Included in this reoprt were papers by H. F. Nelson, F. E. Lozo, and K. P. Young.

Nelson (1959) studied the facies of the Edwards Limestone in Bell, Coryell, Bosque, and McLennan counties. His study involved petrography, stratigraphy, and paleontology and is the most detailed study of the formation in the central Texas area.

Stratigraphic relationships of the mid-Comanchean Cretaceous formations in north-central Texas were described by Lozo (1959). The work, describing the geology of an area from south of Waco to Fort Worth, is basically in agreement with the earlier work of R. T. Hill (1901).

Young (1959) discussed the paleoecology of the Edwards Limestone with emphasis on water depth. Young's study area included parts of Hill and Bosque counties along the Brazos River.

More recently, theses on the Edwards Limestone in various parts of central Texas have been completed by students at Baylor University, the University of Texas, and other schools. J. B. Jameson (1958) in a regional stratigraphic study of the Fredericksburg "Division" of central Texas, described the extent and nature of the Fredericksburg rocks of central Texas.

W. R. Payne (1960) mapped and described the Edwards Limestone in Bosque County, Texas. Delos Tucker (1962) described the Lower Cretaceous formations from McLennan County south to the Rio Grande. He worked with regional structures and subsequent influences on the deposition of the Edwards Limestone in south-central Texas.

J. G. Frost (1963), in a regional study, described the Edwards Limestone from Waco to Abilene, Texas. He mapped and described three Edwards facies: 1) a reef facies, 2) a patch-reef facies, and 3) a back-reef facies. G. L. King (1963) later described in greater detail the Edwards Limestone in Coryell County Texas. King described sedimentary and structural features and related the Edwards Limestone to the overlying Kiamichi Clay.

W. L. Fisher and P. U. Rodda (1967) divided the Edwards Limestone into 1) a rudist-biohermal-biostromal facies, 2) a platform grainstone facies, and 3) a lagoonal facies. They based the divisions on rudist bioherms which were constructed along the edge of the Comanche platform. They further suggested that the Edwards Limestone was deposited or grew on an extensive shallow water platform bounded by deep water basins.

In 1968, O. T. Hayward and L. F. Brown, in a summary of the Comanche Series in central Texas, stated that Comanchean sediments were deposited in six transgressive marine pulses: three Trinity, one Fredericksburg, and two Washita.

Peter Rose (1968) described in detail the Edwards Limestone in southwest Texas. The structural features described in his report relate to the depositional environment of the Edwards Formation in central Texas. M. A. Mosteller (1970) discussed the subsurface development of the Comanche Series in east-central Texas, and related the Balcones-Mexia fault zone to lithologic changes in Edwards and Comanche Peak formations.

During a 1971 (S.E.P.M.) field trip on Trace Fossils, Dr. G. M. Friedman (Rensselaer Polytechnic Institute) and Dr. B. F. Perkins (Louisiana State University) gave suggestions and references to their own work pertaining to circular mounds. Dr. Friedman studied circular mounds in Cretaceous rocks of Israel (Oral Communication, 1971). Dr. Perkins found circular mounds in the Glen Rose and Georgetown

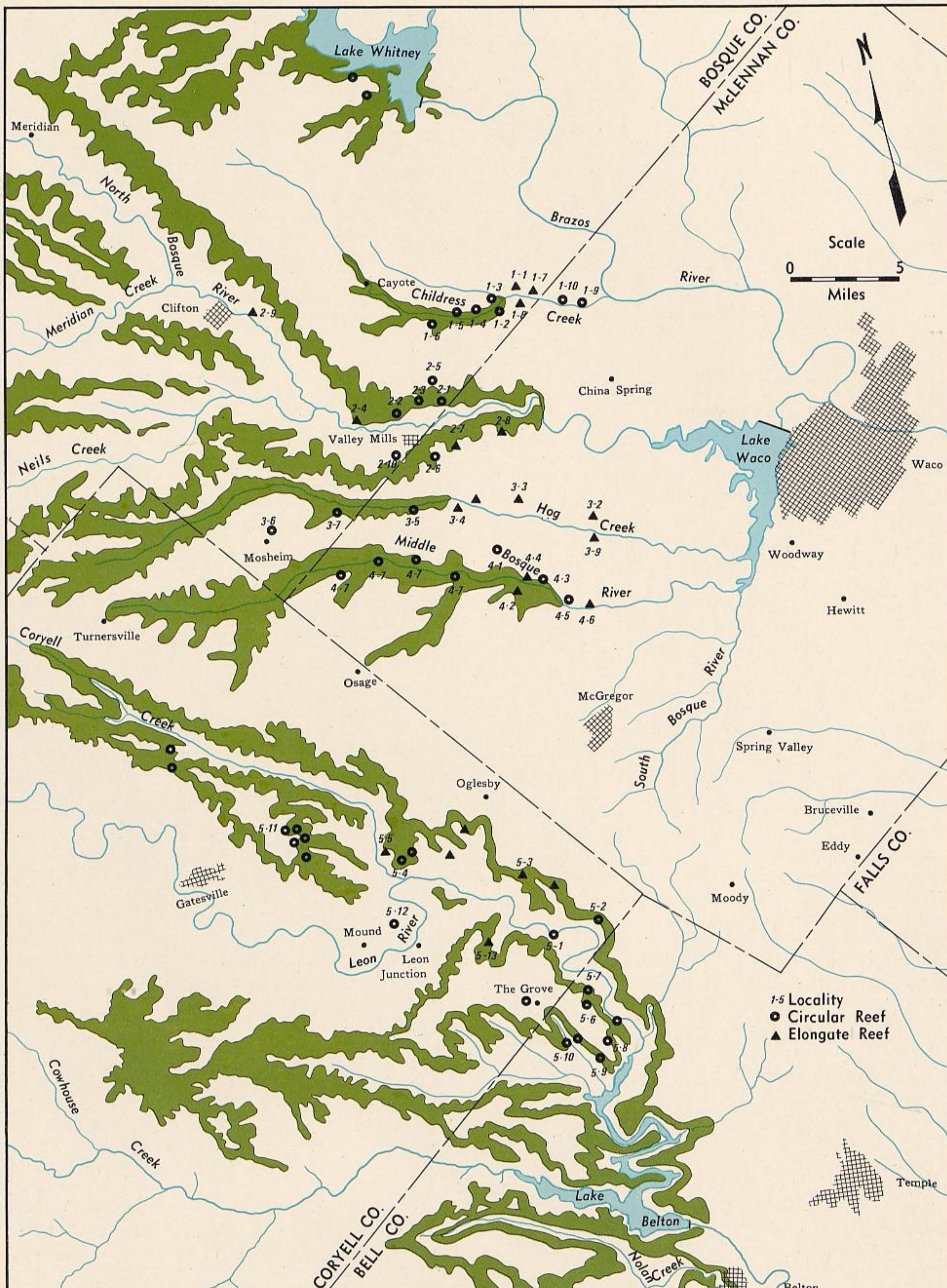

Fig. 3. Geological map showing distribution of circular Edwards Limestone Bioherms.

formations of south-central Texas (Oral Communication, 1971).

ACKNOWLEDGMENTS

The author expresses appreciation for suggestions, advice, aid in the field, and critical review to G. A. Morales and O. T. Hayward, Department of Geology, and F. R. Gehlbach, Department of Biology, Baylor University.

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EDWARDS LIMESTONE DEPOSITION

REGIONAL ASPECTS

The Edwards Limestone, uppermost formation of the Fredericksburg Group, Cretaceous Comanchean section in central Texas, has been extensively described from the area west of Waco. Though unconformably overlying the Glen Rose Limestone (Trinity Group) south of the Colorado River, the Edwards Limestone conformably overlies and interfingers with the Comanche Peak Limestone in central Texas (Nelson, 1959; Frost, 1963).

The term "Edwards Limestone" is generally restricted to the central and south-central areas of Texas. To the southeast, the Edwards Limestone has been divided into three members: the Edwards A-zone, the middle Edwards (time equivalent to the Kiamichi Clay), and the Edwards B-zone (Tucker, 1962). Northward toward Oklahoma, the Edwards Limestone and the underlying Comanche Peak Limestone correlate with and are time-equivalent to the Goodland Limestone (Table 1). In west Texas, the Edwards Limestone is equivalent with the West Nueces Formation; in south Texas, with the lower part of the Devils River Formation. The eastern extent of the Edwards Formation roughly parallels the Balcones-Mexia fault zone (fig. 4). North and east of this fault zone, the Edwards Limestone correlates with the Goodland Limestone, and then becomes part of undifferentiated Fredericksburg rocks in Louisiana.

The Edwards Limestone ranges in thickness from four feet near Benbrook, Parker County, Texas (Sellards *et al.*, 1958 p. 339) to over 1,000 feet in Terlingua, Brewster County, Texas. In northern McLennan County the Edwards Limestone is twenty-six feet thick (Loc. 2-6) and extends eastward into the East Texas basin decreasing in thickness along the Balcones-Mexia fault zone (fig. 4). This thinning roughly correlates with the Glen Rose hinge-line on the western margin of the East Texas basin (Mosteller, 1970).

The Edwards Limestone thins toward the ancient Gulf Coast geosynclinal axis (fig. 4) as the Comanche Peak Limestone thickens. Hayward and Brown (1968) and Mosteller (1970) suggest that the Balcones-Mexia fault zone served as a hinge-line where the platform slope steepened into the East Texas basin allowing Comanchean sediments to accumulate. Salt movements and basement rock warping caused regional instability and the deepening of the East Texas basin (Mosteller, 1970, p. 15).

Within the East Texas basin, along the synclinal axis, a great barrier reef, the Stuart City Reef, existed from late Trinity to early Washita time (fig. 4). The Stuart City barrier reef limited admission of ocean waters into the East Texas basin and onto the Comanche shelf. Thus, the Edwards Limestone, on a regional basis is a back-reef facies of the major Stuart City Reef complex. Mosteller (1970) suggests that the Mexia fault line was the western margin of the East Texas basin and that the Edwards biohermal limestones were deposited on and west of this line. Tucker (1962) states that (longitudinal) bioherms of the upper Edwards Limestone acted as barriers between the East Texas basin and the Austin lagoon (fig. 4). Circular bioherms apparently grew in shallow water behind longitudinal bioherms peripheral to the basin. The outlying Stuart City barrier reef protected bioherms of the platform from destructive ocean waves.

The Comanche platform was a tectonically stable region encompassing the tectonically positive Llano uplift (fig. 4). The platform was bounded by deeper water basins to the northeast, east, and south. Fisher and Rodda (1967) suggest that shallow water covered this platform and that evaporite deposits were periodically deposited in the Kirshburg lagoon, south of present day Austin, Texas (fig. 4).

The Edwards Limestone, therefore, was deposited on a shallow platform area bounded by deep water basins. The Stuart City Reef protected the developing Edwards reef from strong ocean waves while elongate Edwards reefs, parallel to the basin margins, protected areas of circular bioherms developing within protected waters.

LOCAL ASPECTS

Within the study area, the Edwards Limestone conformably overlies the Comanche Peak Limestone. This contact is usually marked by concentrations of *Cladophyllia* (Loc. 5-6) and is characterized by marked lithologic change. Overlying the Edwards Limestone is the Kiamichi Member of the Georgetown Formation. The contact between Edwards and Kiamichi rocks has been

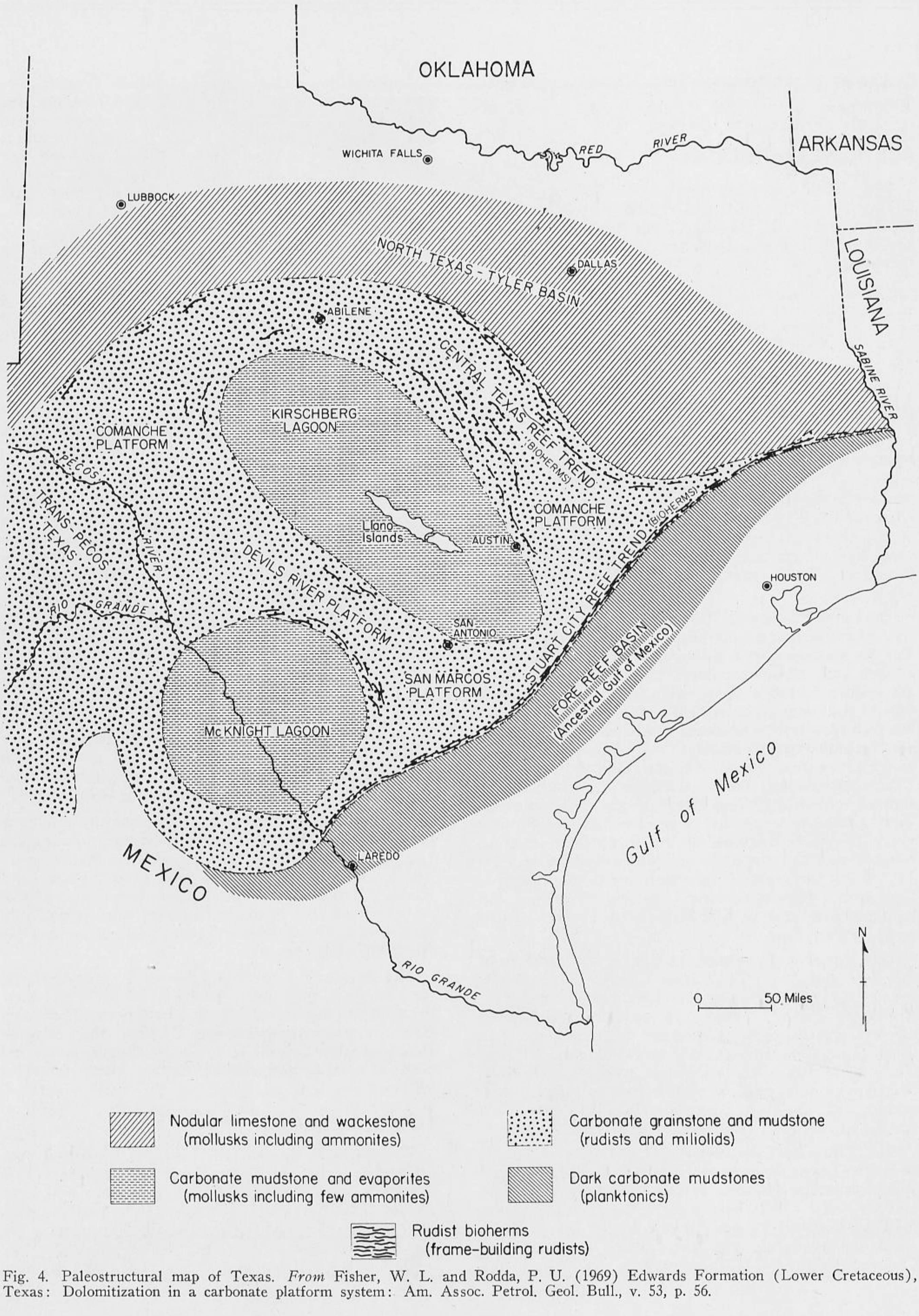


Fig. 4. Paleostructural map of Texas. *From* Fisher, W. L. and Rodda, P. U. (1969) Edwards Formation (Lower Cretaceous), Texas: Dolomitization in a carbonate platform system: Am. Assoc. Petrol. Geol. Bull., v. 53, p. 56.

described as unconformable because of the occurrence of borings and oxidized surfaces in the top of the Edwards (Frost, 1963) In the study area, however, the contact appears conformable. Clays found within the upper few feet of the circular bioherms (Loc. 1-3, sample CC-10) are similar to clays of the Kiamichi Member both petrographically and paleontologically. There was no apparent erosion of the bioherms where they are overlain by Kiamichi Clay. In the northern part of the study area, the contact between the Kiamichi and the Edwards formations is apparently diastemic in the bioherm areas. The clay in the bioherms represents the first influx of Kiamichi clays into the area of deposition. In southern Coryell County, the Edwards Limestone is directly overlain by the Duck Creek Member of the Georgetown Formation, with a thin green clay parting representing the Kiamichi Clay (Nixon, 1958, p. 7). This area, situated over the Belton High, was presumably exposed during the later stages of Edwards deposition, and thus received no Kiamichi sediments (fig. 5).

LITHOLOGY

The Edwards Formation is composed of hard, massive, grey-white reef limestone weathering grey-black. It forms ridges and bluffs along river valleys and caps hills and outliers through the central Texas area.

Chalkification (weathering to a chalky consistancy) occurs in several localities (Loc. 2-7, Loc. 5-7, Loc. 5-8). Chalky limestone erodes rapidly and forms caves beneath the resistant flat-lying reef limestone.

Clay and carbonate mud occur as partings between the micrite limestone beds within the circular bioherms and elongate reefs (Loc. 1-3, Loc. 2-5, Loc. 5-8). A six-inch clay bed (Loc. 1-3, sample CC-10) occurs *in situ* beneath the two outermost limestone "rings" of a circular bioherm. In the reef rock directly underlying the circular bioherms at Locality 2-6, chert beds containing blebs of clay (sample VM-18) and numerous echinoid spines were found. The presence of clay in the chert and in the bioherms indicates introduction of land-derived clastics during the time of deposition.

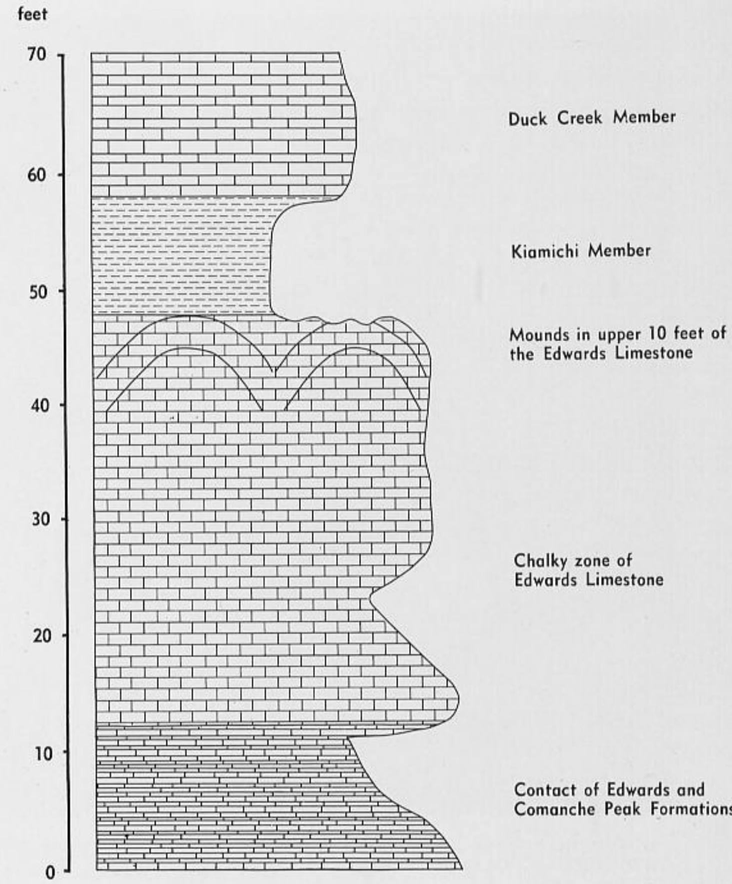


Fig. 5. Generalized stratigraphic section, Edwards Limestone, central Texas.

The Edwards Limestone ranges in thickness from fifty feet near Clifton, Bosque County (Loc. 2-9), to seventy-four feet east of Gatesville, Coryell County (Loc. 5-11). In eastern McLennan County, the Edwards Limestone is twenty-four feet thick (Loc. 2-6) and thins eastwardly as the Comanche Peak Limestone thickens.

CIRCULAR BIOHERMS

DISTRIBUTION

Circular Edwards Limestone bioherms are exposed in McLennan, Bosque, Coryell, and Bell counties along Childress Creek, Hog Creek, and the bluffs of the North Bosque, Middle Bosque, and Leon rivers (fig. 3). The bioherms are exposed in plan-section in creek beds (Loc. 1-3, Loc. 3-5) and in cross-section along river bluffs (Loc. 2-1, Loc. 5-2). Outside the study area, the bioherms are found near Cranfills Gap (Bosque County) southward to Pidcoke (Coryell County).

LITHOLOGY

The characteristic feature of these circular bioherms is the consistent circularity (figs. 6, 7, 8), in which each bioherm is composed of fourteen to fifteen concentric sedimentary rings (fig. 2). The rings weather clearly in creek beds and can be lithologically and paleontologically differentiated.

The matrix composing cores of the circular bioherms is generally homogenous biomicrite, in some localities altered to dolomite (Loc. 1-1). The dolomite stains yellow and is less resistant than the surrounding circular beds (fig. 9). Cores are as large as fifty feet in diameter and are five to seven feet thick.

The circular beds surrounding the cores are biomicrite with small amounts of sparite filling former voids and fossil molds. These beds drape away from the core at angles of five to twenty-five degrees. In cross-section, the surrounding beds drape continuously from

Fig. 6. Aerial view of Childress Creek from an altitude of approximately 300 feet, (Loc. 1-3). Six bioherms can be seen in the creek bottom. Diameter of the bioherms is approximately 150 feet. (Photo by author)

Fig. 7. Typical circular bioherms on a hilltop outside Valley Mills, Bosque County, in the northern portion of the study area (Loc. 2-1). Individual bioherms are about 175 feet in diameter. (Photo by Leach and Dann)

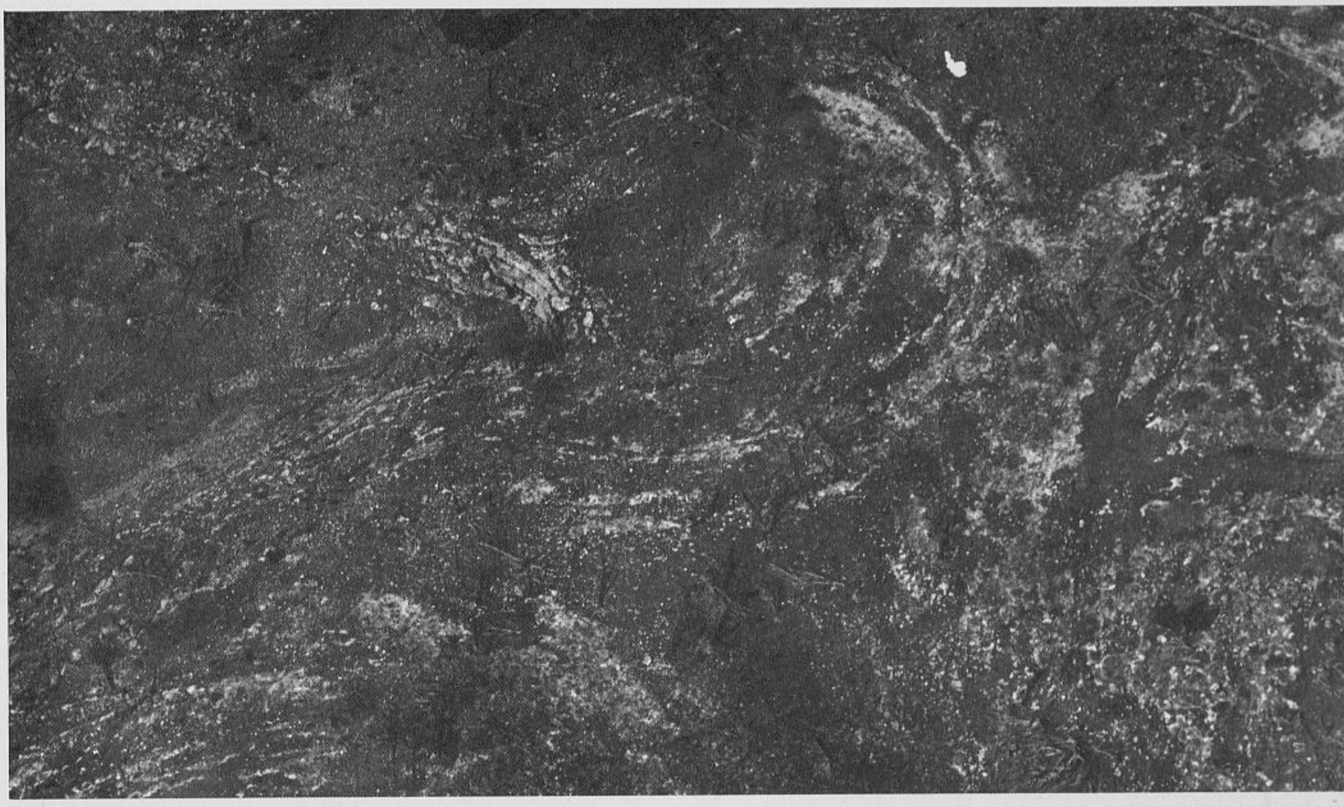


Fig. 8. Bioherms on a hilltop near The Grove, Coryell County, in the southern portion of the study area (Loc. 5-13). The bioherms are dissected and show the circular beds draping from the center. The diameter of the bioherms is approximately 150 feet. (Photo by Leach and Dann)

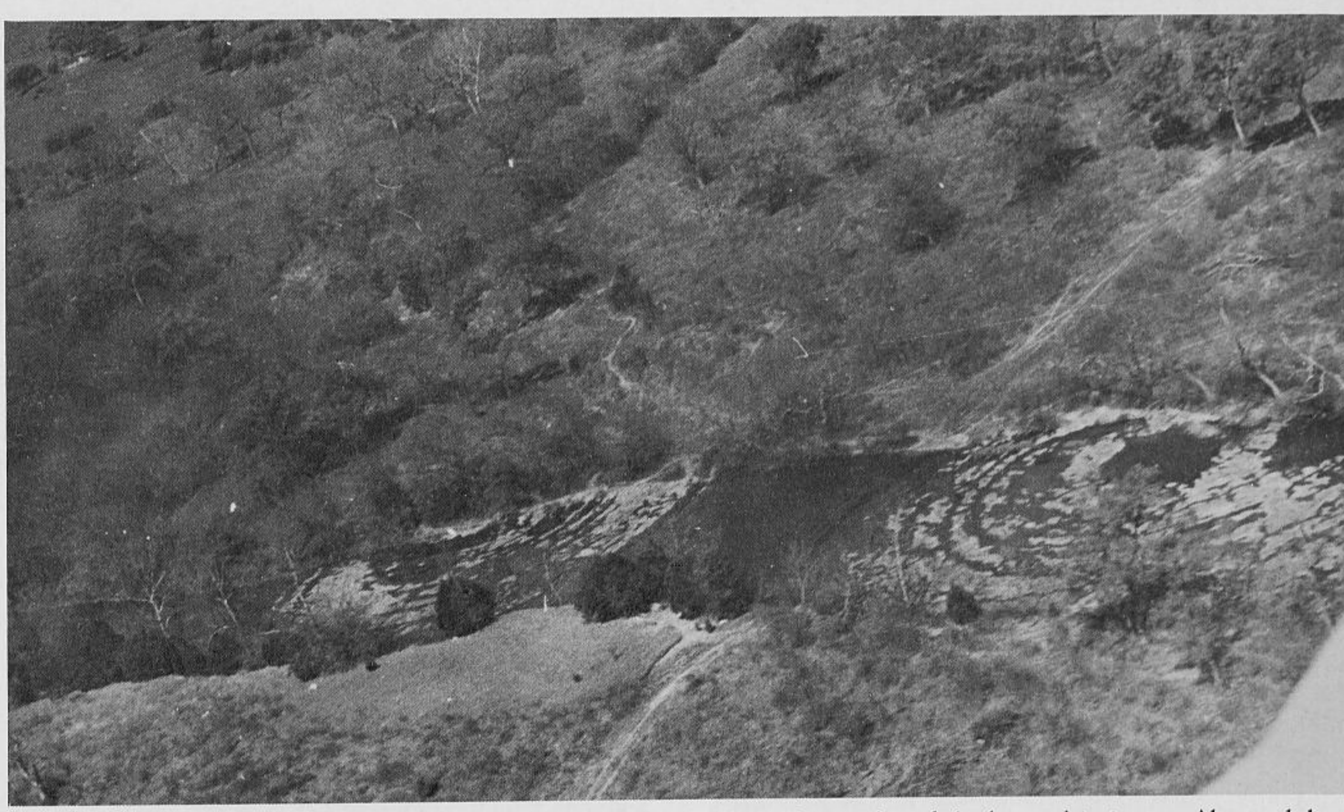


Fig. 9. Aerial view of two bioherms in Childress Creek (Loc. 1-5) illustrating erosion of the less resistant core. Also eroded are the micrite beds between the circular rudist beds. The bioherms are approximately 120 feet in diameter. (Photo by author)

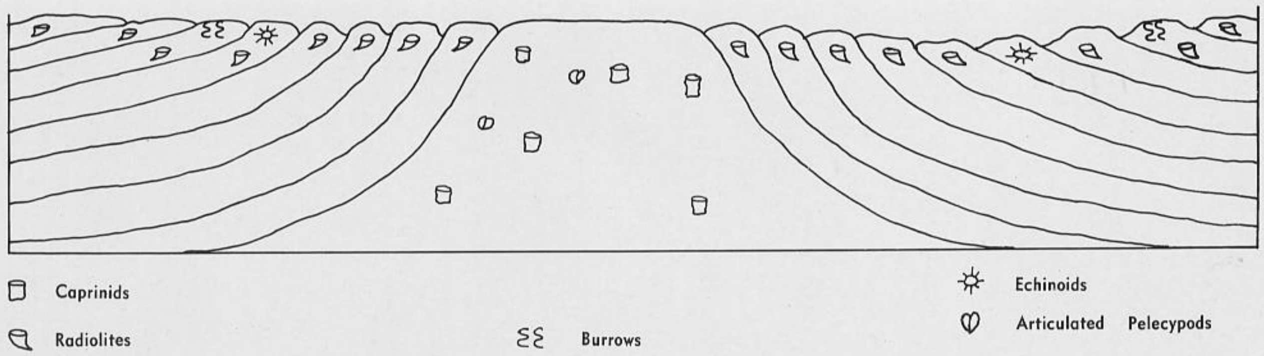


Fig. 10. Diagrammatic cross section of mound with flanking rudist beds.

one bioherm to another, thinning slightly in the trough or inner-reef area (figs. 10, 11). This inner-reef facies is composed of dense fine-grained limestone (micrite) with occasional rudists.

Clay and carbonate mud partings separate adjacent dipping ring-like beds of the bioherms. Clay, in beds six inches thick (Loc. 1-3, sample CC-10; Loc. 1-5) has been found in place separating the outermost limestone bed from the rest of the bioherm. This clay, similar in mineralogy to the overlying Kiamichi Clay (montmorillonite and kaolinite), was deposited in a marine environment as indicated by the presence of sharks teeth, echinoid spines, and ostracodes.

The flat-topped bioherms in the study area are in the upper seven to ten feet of the Edwards Limestone. The flat tops are the result of either 1) a common surface of terminated growth, or 2) extensive erosion. An absence of surface weathering characteristics and of truncated fossils tends to indicate that the bioherms were not extensively eroded. Evidence on the bioherms, such as: 1) articulated fossils, 2) whole fossils protruding above the surface, and 3) surface elevations similar to those of the elongate reefs seaward (Edwards Limestone barrier reefs), indicates that upward growth was limited either by wave base, low tide sea level surface in which the bioherms grew only as high as low tide (periodically being exposed during neap low tides), or mean water surface in a protected lagoon of little water depth fluctuation.

PALEONTOLOGY

The circular bioherms are composed of thirteen species of reef-associated fossils in a micrite matrix. The dominant genera belong to Radiolitidae, Caprinidae, Chamacae, Monopleuridae, Pectiniacea, and Ostreacea families (based on fossil counts using foot-square grids at random localities on the surface of the bioherms). Occasional echinoids and ostracodes were found in the reefs and bioherms. Fossils either retained their original composition (aragonite altered to calcite) or were replaced by sparry calcite. Original material retains the original fabric or structure of the shell. Fossils composed of original material occur most commonly within areas of reef characterized by limonite inclusions. Shells replaced by sparry calcite usually occur in association with nodules of limonite or pyrite; in some cases, however, pyrite (altered to limonite) has replaced the shell and the shell cavity is filled with spar. Burrows, feeding trails, and molds are filled with fecal pellets surrounded by fine blue-grey micrite.

In general, cores of the bioherms are composed of caprinids (*Caprinuloidea* sp.) and monopleurids (*Monopleura pinquisula*). Other species of bivalves (unidentified) and gastropods (*Tylostoma tumida*) are exposed on the surface of the reef cores. The bivalves are articulated but in random positions (vertical to horizontal).

The dominant fauna composing the bioherm cores are caprinids. These bivalves range in size from several inches up to two feet in length, and four to five inches in diameter. Numerous molds and casts of caprinids occur scattered randomly on the surface of the core (fig. 12).

Caprinids apparently did not grow in normal marine waters, as evidenced by lack of normal marine fauna in association with them (Perkins, 1969, p. 125). The great size of the caprinids suggests that the environment was less than ideal. Hostile environments tend to be occupied by a few species, those that can take the inhospitable conditions. These hostile conditions acted as a deterrent to competition, allowing the caprinids to grow to gigantic proportions (Morales, 1971, Oral Communication).

The caprinids needed solid surfaces on which to grow. The growth preference for attachment to old shells is apparently responsible for the formation of mounds, which grew contemporaneously behind the more seaward elongate reefs. Because of the elongate reefs, the mounds were slightly protected. Tops of the mounds were flat, as a result of termination of upward growth at a specific level.

The ring-like beds encircling the mounds are composed dominantly of the rudist, *Eoradiolitics davidsoni*. Other fossils in this assemblage are *Toucasia texana*, *Chama* sp., *Pecten duplicosta*, *Chondrodonta munsoni*, *Ostrea* sp., and *Gryphaea marcoui* (all bivalves), *Phymosoma* sp. (echinoid), and *Tylostoma tumida* (gastropod) all of which are normal marine (Appendix I).

Most fossils of the encircling rings occur as original material though some are replaced by spar. Most of the fossils appear to be whole and in growth position

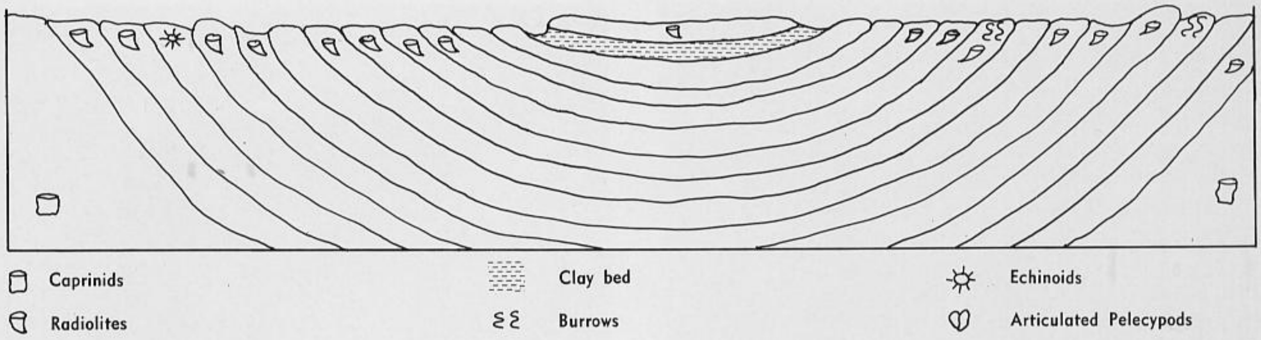


Fig. 11. Diagrammatic cross section of two mounds with rudist beds and six-inch clay bed, not to scale.

(fragments appear on a microscopic scale, Appendix II). Figure 12 illustrates the surface of a bioherm in Childress Creek (Loc. 1-3); size of the average rudist is three to four inches in length and one to two inches in diameter.

Caprinids and radiolites were reef builders, but they were not equally abundant in the same environment; one or the other usually dominated (Perkins, 1969, p. 125). An increase of radiolites, as in the encircling beds, is usually accompanied by increases of normal marine fauna. The assemblage listed above is considered a normal marine fauna; their presence with the radiolites indicates an environmental change from that existing during the formation of the reef core.

ENVIRONMENT AND GROWTH OF CORES AND ENCIRCLING BEDS

The cores and the encircling beds composing the bioherms represent two differing environments. The cores, composed of caprinids, began growth as scattered clumps of animals in abnormal marine waters, possibly hypersaline. As they built up out of the mud, they began to form mounds. These mounds, receiving the impact of waves, tended to elongate and form talus slopes. Mounds protected from the waves grew circular and cone-shaped.

Environmental changes resulted from return to normal marine salinities. Normal marine fauna flourished, including radiolites (the dominant rudist). The rudists grew radially from the now dead or dying core. Periodically, events of unknown origin caused termination or slackening of growth of the encircling rings. This change was caused either by suffocation of the fauna by mud, exposure to air, changes in salinity, climatic changes, or other factors. The result was a clear separation between successive concentric rings, giving the circular bioherms their characteristic appearance.

ELONGATE REEFS

DISTRIBUTION

Exposed along Childress Creek, Station Creek, and the Middle Bosque River in association with circular bioherms are longitudinal reefs (figs. 13, 14, 15). These may be seen in cross section on Station Creek (Loc. 5-3) and in plan section on Childress Creek (Loc. 1-1). They appear in aerial photographs as flat to gently dipping limestone beds closely associated with circular bioherms, generally on the seaward side (environment of deposition) (fig. 16).

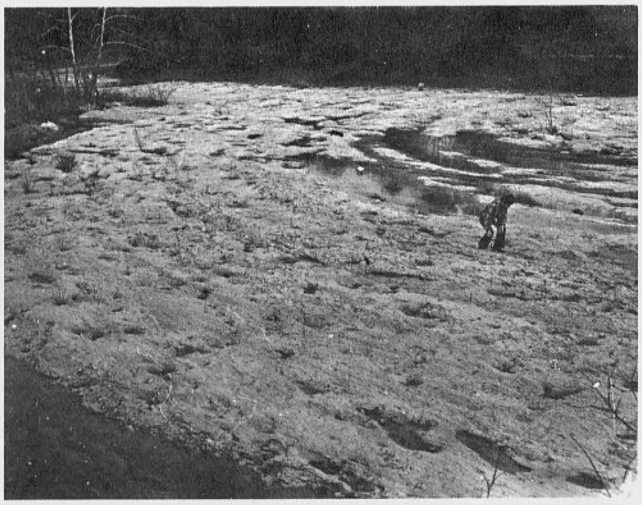
LITHOLOGY

Elongate reefs are composed of cores, accretion beds, and washover beds. They may be more than one mile long (Loc. 5-3) and are as much as several thousand feet wide (Loc 5-3, Loc. 1-1). They are anticlinal in section with the accretion and washover beds draping from a central core (fig.13).

The core consists of biomicrite altered to dolomite (Loc. 1-1, sample CC-1, CC-4). The core is lithologically homogenous at the center becoming heterogeneous toward the periphery. The core weathers rapidly in creek beds and on hilltops forming a depression.

The accretion beds drape away from the reef cores, probably toward the ancestral basin. Angles of dip range from twenty-five degrees near the core to less than one degree one-half mile seaward from the axis of the core. Accretion beds are composed of biomicrite, biosparite, dolomite, sparry calcite, and fossil fragments. Ripple marks, festooned cross-bedding, and swale marks are visible on the surface of the accretion beds (fig. 14: A, B, C). Small ripple marks occur in a biomicrite-algal mat covering the accretion beds, and on the surface of the larger ripple marks. Festooned cross-bedding occurs in the swales or troughs of the giant ripple marks. The occurrence of these three characteristic markings suggests a depositional environment of extremely shallow water, possibly at sea level at certain stages.

The surface of the accretion beds is tinted a slight reddish brown by limonite, probably derived from pyrite. The pigment is both primary (from clays and



A. Surface view of bioherm from eastern bank of stream looking to the southwest. Note the rings and obvious circularity. The bioherm is 150 feet in diameter.

B. Close up view of rudist-bearing bioherm ring. The numerous molds are *Eoradiolities davidsoni.*

Fig. 12. Surface view of bioherm in Childress Creek (Loc. 1-3).

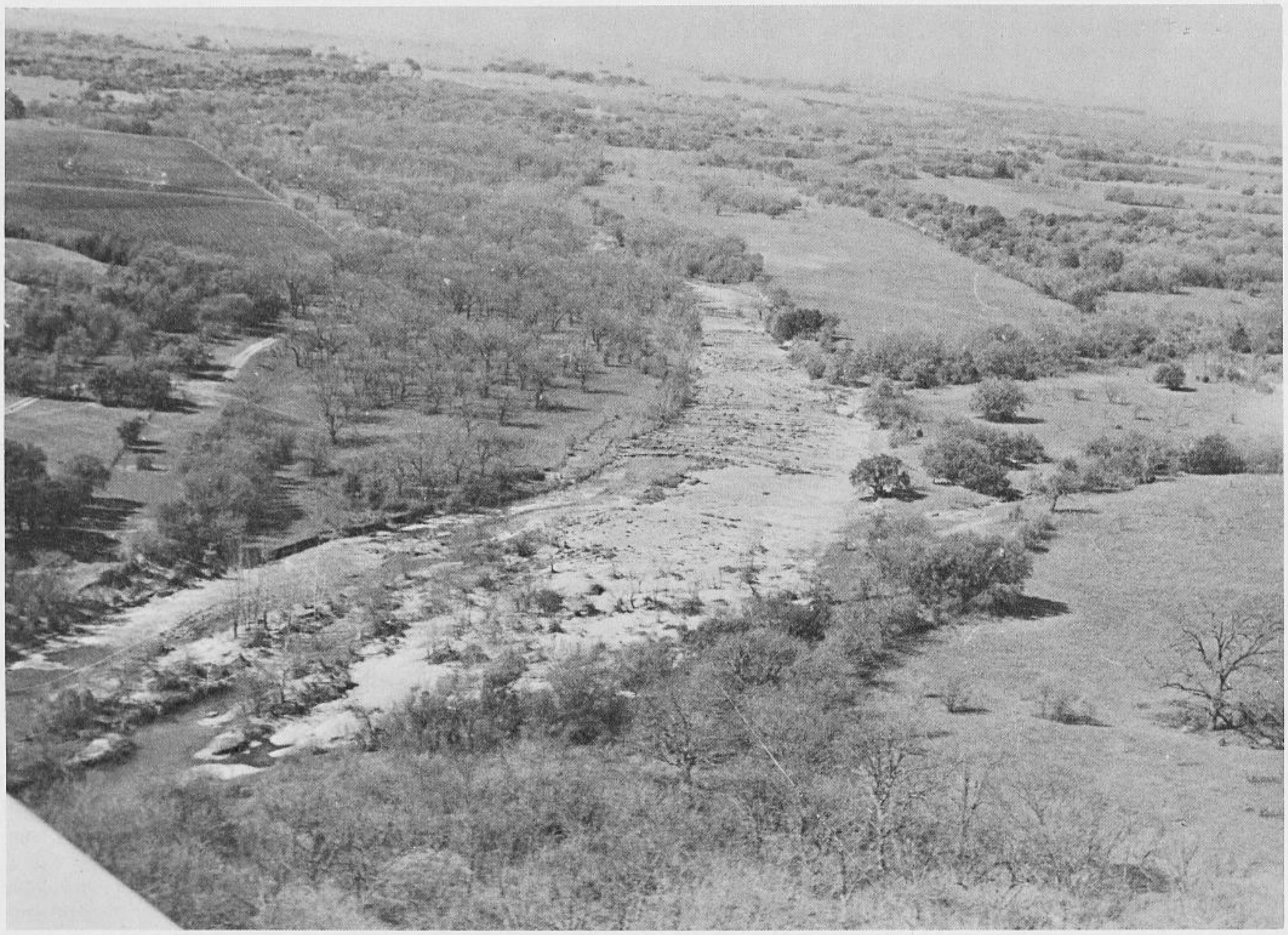
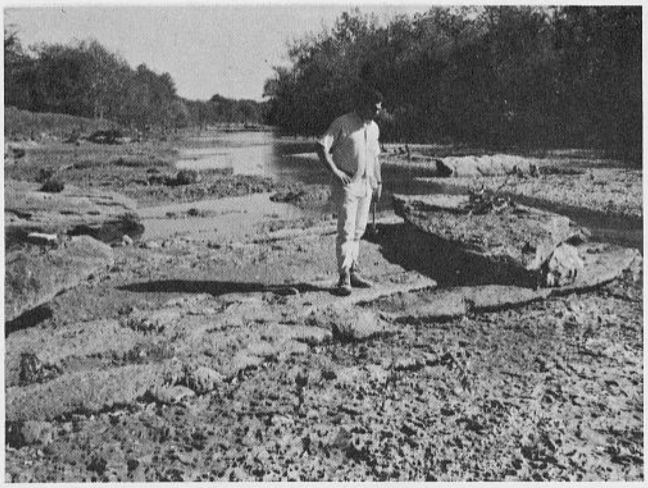
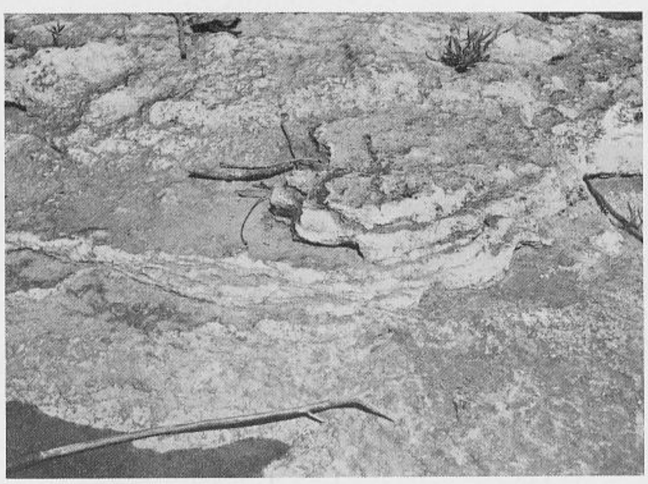


Fig. 13. Aerial view of accretion beds draping southeastward (toward ancestral basin) from the elongate reef core (top of the photograph is to the south). The beds dip at angles of twenty-five degrees near the core to less than one degree one-half mile from the core. Here the beds dip approximately fifteen degrees. Length of exposed stream channel is approximately one-half mile. (Photo by author)

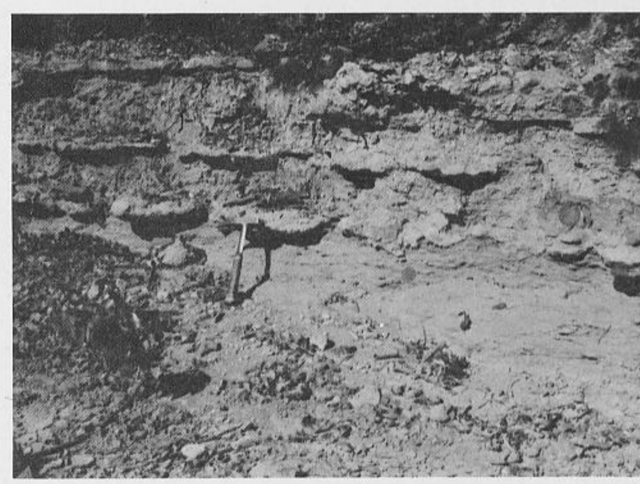


A. View of accretion beds dipping southeast at fifteen degrees. The core is approximately 200 feet northwest.

B. Close up view of the surface of the accretion beds. The surface is covered with molds of the fossil *Caprinuloides* sp. Width of view in foreground is nine feet.



C. Festooned cross-bedding occurs in the troughs of large ripple marks on the surface of the accretion beds. The stick in the foreground is approximately one and one-half feet long.



D. Kiamichi Clay—Edwards Limestone contact. The Kiamichi Clay can be seen draping over the undulating surface of the Edwards Limestone.

Fig. 14. Features of elongate reefs, accretion beds Locality 1-1, Childress Creek.

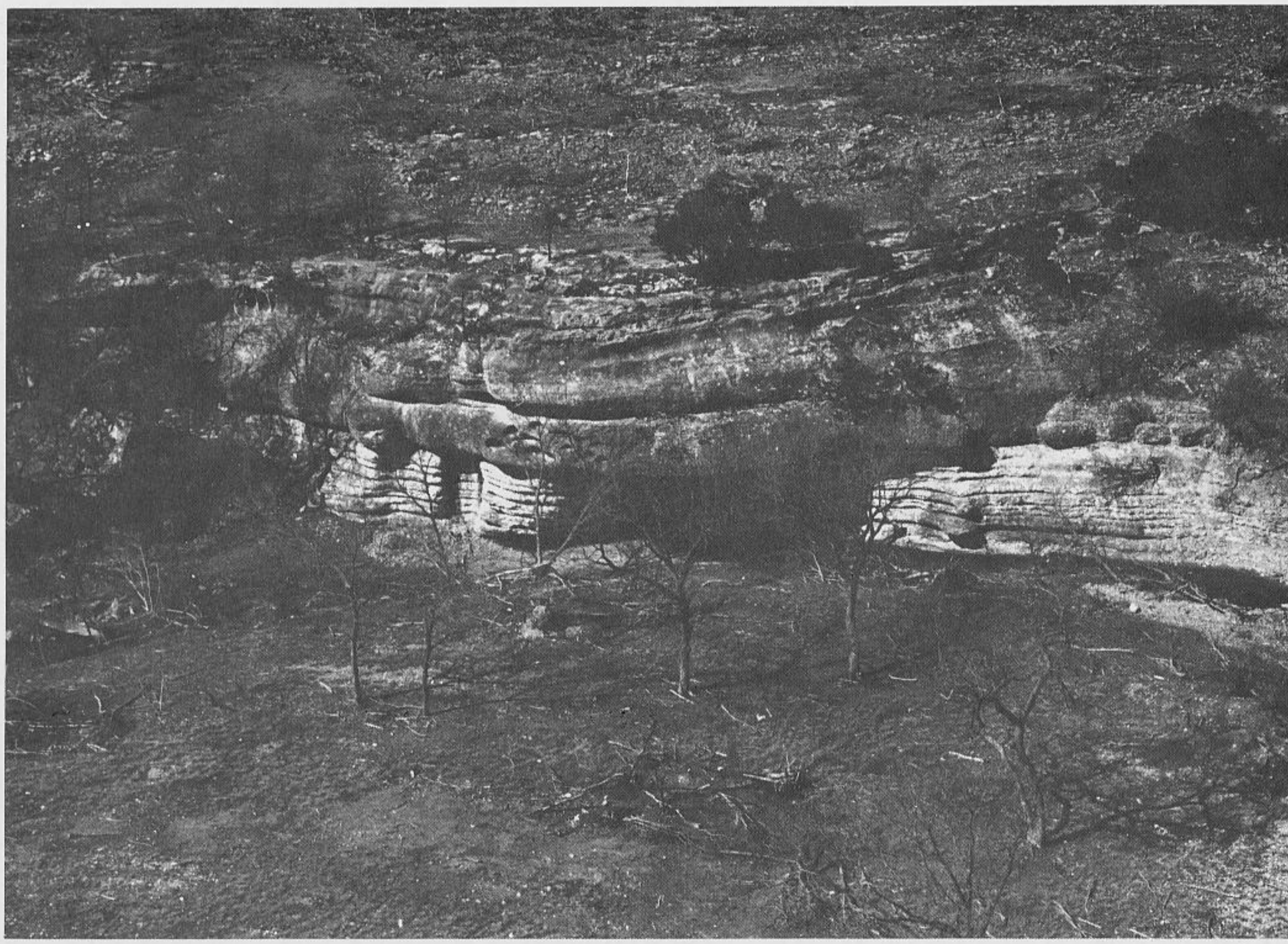


Fig. 15. Aerial view of elongate reef accretion beds (Loc. 5-3). Beds are flat lying in longitudinal section. This locality exposes reef accretion beds one-half mile south of the central core. Bluff is approximately thirty feet high. (Photo by Leach and Dann)

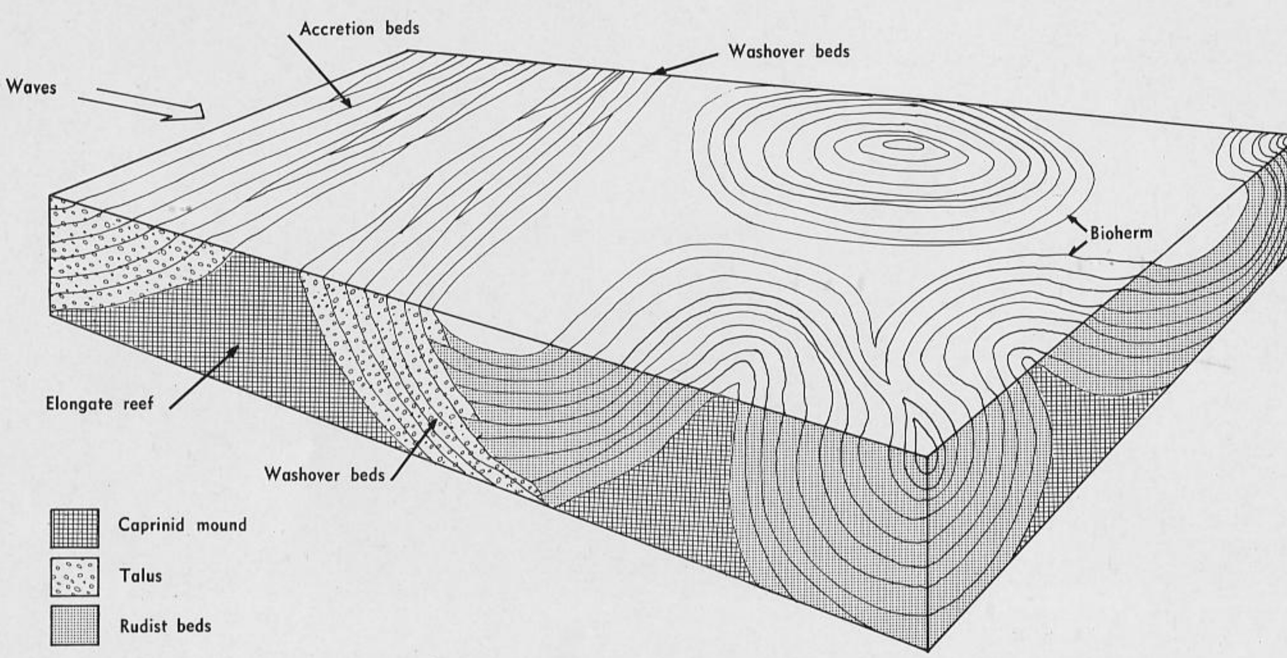
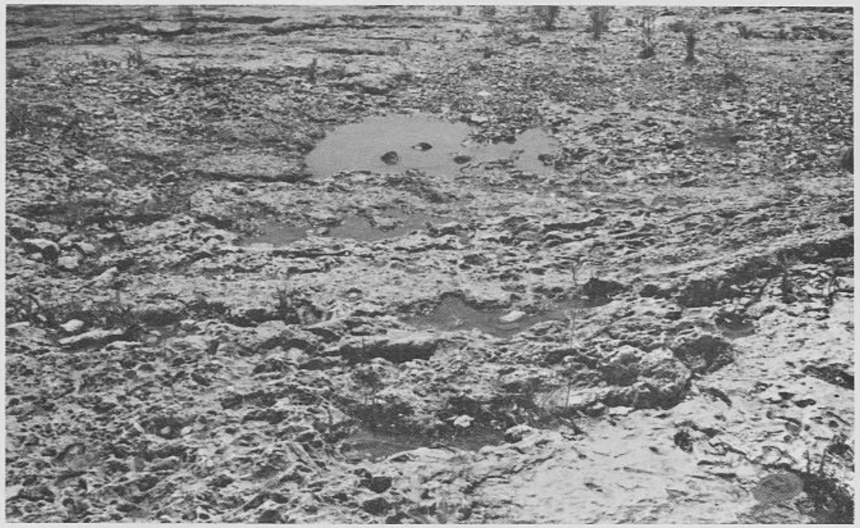
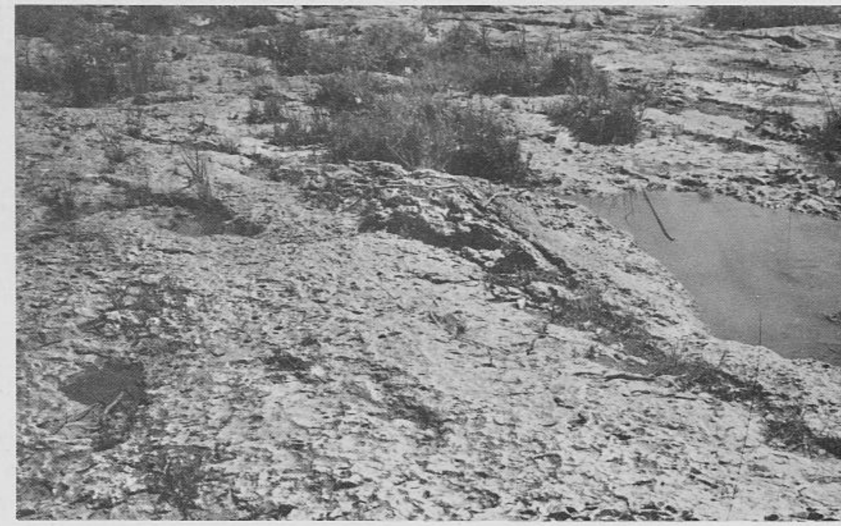


Fig. 16. Diagrammatic block diagram showing the relationship of elongate reefs to the circular bioherms (not to scale).

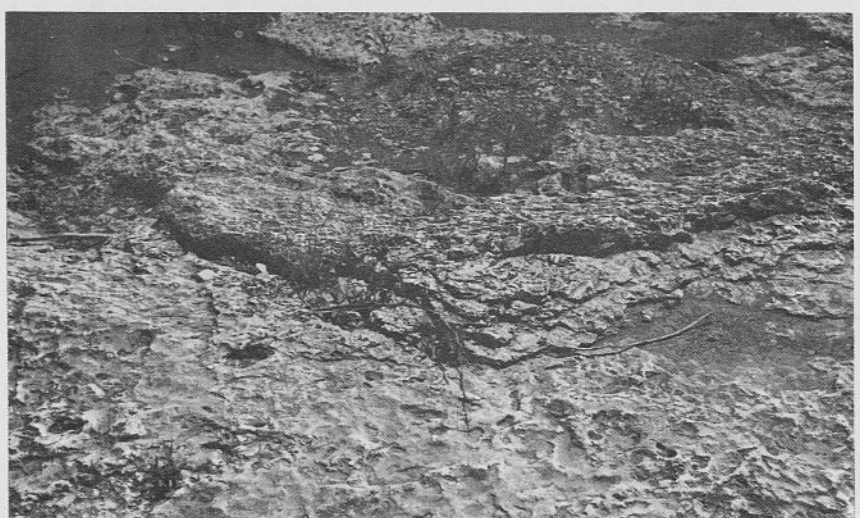
Fig. 17. Aerial view of elongate reef washover beds (northern side, Loc. 1-1). This photograph shows washover beds surrounding a circular bioherm, indicating contemporaneous growth. The stream bed is approximately 200 feet wide. (Photo by Leach and Dann)



A. View of beds dipping northeastward toward the ancestral shore.



B. Surface view of the washover beds. Swales are present with shell hash filling the troughs. Fossil molds and ripple marks are present on the surface.



C. Swales of current ripples in the dipping beds, relief is up to three feet. Small depressions in the foreground are six inches wide.

D. View showing the differences in elevation between the elongate reef core and washover beds. Ledge is two feet high.

Fig. 18. Features of elongate reefs, washover beds Locality 1-1, Childress Creek. These beds dip up to twenty-five degrees toward the circular bioherms.

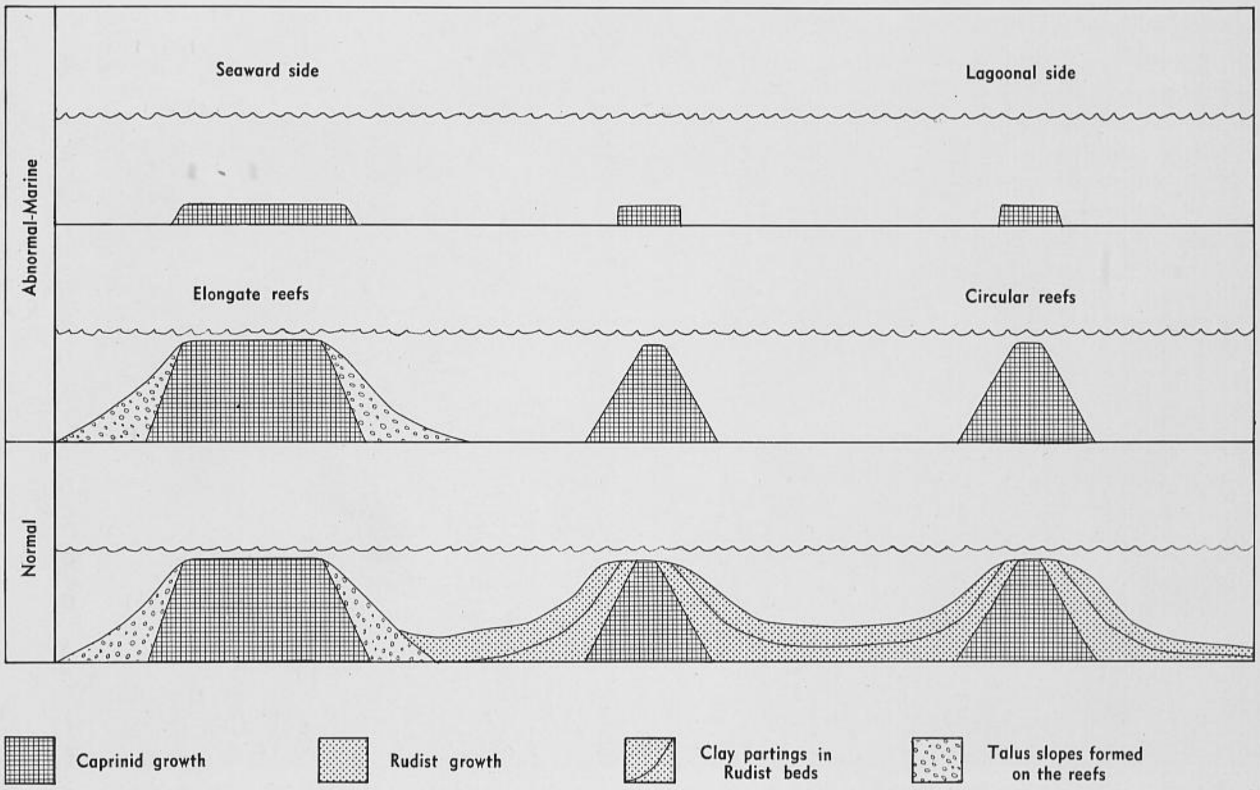


Fig. 19. Diagrammatic sketch of beginning growth of the Edwards Limestone circular bioherms and elongate reefs. Reef mounds grew in shallow, warm, and saline waters to the water surface. Reefs marginal to the platform tended to be elongate parallel to the platform edge. Mounds protected by the elongate reefs grew radially from the central core, forming circular bioherms. Influxes of clay and carbonate mud periodically terminated growth of rudist bioherms and caused lithologic differences now obvious as circular "rings" about the caprinid core.

pyrite deposited during deposition) and secondary (from weathering of the overlying Kiamichi Clay).

Washover beds, composed mainly of biomicrite with smaller amounts of biosparite, drape away from the core on the lagoonal side toward the circular bioherms (sample CC-105, VM-22). Dip angles range up to twenty-five degrees (fig. 17). Washover beds exhibit characteristics of shallow water deposition, such as giant ripple marks with small ripple marks, festooned cross-bedding, and surface algal mats. The algal mat surface exhibits extensive burrows and some borings as does the washover bed surface in general (fig. 18).

PALEONTOLOGY

On the elongate reefs, caprinids (the dominant fossil) range in size from two to four feet in length and from six inches to a foot in diameter. Rudists, other bivalves, gastropods, and algal mats compose the remaining fauna of the elongate reef.

The reef surface is covered by coquinoid limestone composed largely of shell hash (biosparite), in turn mantled by a thoroughly burrowed algal mat. The algal mat contains an abundance of fragmented shells within a micrite matrix, resting on a burrowed surface (figs. 14, 17).

Beneath the algal mat, the reef surface is composed of numerous molds and casts of the fossil *Caprinuloides* sp. with occasional casts of the open marine ammonite, *Oxytropidoceras* sp. The caprinids grew on the reef and apparently died *in situ;* the ammonites were probably washed onto the reef during storms or tidal fluctuations.

ENVIRONMENT OF GROWTH

Ripple marks, both small and large, and festooned cross-bedding on both the accretion and washover beds indicate an environment shallower than that in the area of protected circular bioherms. The elongate reefs, seaward from the bioherms, acted as barriers sheltering the circular bioherms from large waves generated in the basin to the east. The elongate reefs were themselves protected by the large Stuart City Reef to the southeast and east which barred the major waves of the open sea.

Fig. 20. Aerial view of bioherms where the central mounds grew too close together for the full complement of encircling "rings" to grow (Loc. 5-6). These bioherms show the uniform surface of upward termination typical of the Edwards bioherms. The bioherm centers here are approximately seventy-five feet in diameter. (Photo by Leach and Dann)

TABLE 2. ENERGY INDEX CLASSIFICATIONS

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

(*after* Plumley *et al.*, 1962, p. 88)

ENVIRONMENT OF DEPOSITION

Plumley, Risley, Graves, and Kaley (1962) described an environmental energy spectrum for carbonate rocks, based on mineralogy, texture, and paleontology. The result of their study is summarized in Table 2. Applying the tenets of their system to the study of the Edwards biohermal-reef complex, the circular bioherms appear to have been deposited in an environment ranging from calm to agitated waters. Petrographic and paleontologic evidence suggest an environment described as Type II, Intermittently Agitated (Table 2).

The most common rock type is micrite, or fine carbonate mud-stone, indicating a low energy environment. Agitation or current action should winnow carbonate mud leaving coarser fragments and sparry calcite. Clays, also present in the micrite matrix, tend to substantiate this conclusion. Small amounts (one to five percent) of detrital quartz (sample CC-1, CC-4) suggest periods of somewhat stronger agitation, adequate to transport land-derived quartz grains into the lagoonal area.

Swale and ripple marks suggest wave action over the reef area. Ammonite casts on the reef suggest occasional waves or currents sufficiently strong to transport large (twelve- to sixteen-inch) shells.

The abundance of fecal pellets, possibly molluscan in origin, in the reef rocks suggests limited agitation, for pellets are easily transported by moderately strong currents. Pellets occur dominantly in the reef rocks, and are associated with fossil fragments, filled burrows, and whole shells. This association suggests occasional currents which swept away unprotected pellets while leaving others trapped in shells and burrows.

Fossils of the reefs and bioherms are mostly whole and articulated. This indicates an environment of little agitation and rapid sedimentation. Normally shells would be disarticulated in areas of agitation adequate to wash either the shells or the surrounding mud away. Fragmented shells and shell hash occur only on the surface of the reef, the accretion beds, and the washover beds.

Paleontologic and petrographic evidence suggest that the elongate reefs and circular bioherms grew in an environment of intermittently agitated and calm water. The elongate reefs grew in the more agitated waters between the East Texas basin and the bioherms. Bioherms grew behind the elongate reefs in water only occasionally agitated.

The combination of two diverse environments: 1) calm waters with no substantial currents, and 2) more agitated waters with currents and waves, contributed to the formation of circular reefs composed of concentric rings of reef rock. In the shallow water, upward growth was terminated at or near the water surface. For this reason, the bioherms are flat topped, and terminate at uniform elevations over a broad area.

SUMMARY

A change in environment occurred sometime after the upward limit of growth was attained. A differing fauna, radiolites and normal marine fauna, began to flourish and dominate. This change to normal marine environment was probably caused by renewed access to the sea, reducing hypersaline conditions to that of normal salinity.

As the elongate reefs began growing laterally by addition of accretion and washover beds, the protected bioherms began growing radially from the periphery of the cores. The newly added rings of rudist limestone grew upward to the sea surface, terminating at the same plane as did the cores.

Influxes of clay and carbonate mud periodically terminated or slowed growth of the rudist rings, depositing beds of micrite peripheral to them. Fourteen times rudist growth was altered, and again resumed. Finally an influx of clay (first a six-inch bed separating the bioherms and the overlying limestone bed) marked the end of the Edwards reef growth and the beginning of Kiamichi deposition.

The flat-topped bioherms, the elongate reefs, and the inter-reef lime-mud accumulations were buried by Kiamichi Clay which draped in a suffocating blanket over the undulating surface of the bioherms and reefs.

The circular bioherms of the upper Edwards Limestone grew in a sheltered environment behind protecting elongate reefs as the terminal phase of Edwards deposition. The entire reef complex grew on the margin of the Comanche platform adjacent to the East Texas basin. This reef complex was protected from large waves by the Stuart City Reef which closed the East Texas basin on the seaward side.

The bioherms began in shallow, warm, probably hypersaline water on the eastern margin of the Comanche platform. Figure 19 illustrates the sequence of stages in the growth of bioherms and elongate reefs.

Reef growth began with accumulation of caprinid colonies randomly spaced on the shallow sea floor over a broad area near the edge of the platform. The caprinid colonies growing nearest the basin margin tended to expand in elongate trends, forming elongate reef cores. These cores then protected the mounds behind them from the brunt of the waves and currents.

At the same time, the protected mounds became cone shaped. The mounds grew by building upon the accumulated shells of the earlier reef cores, rather than by haphazard attachment to the bottom. Upward growth was terminated at a surface which was uniform over a broad area, possibly a wave base or more probably the low tide sea level. Such a limit caused the elongated and circular mounds to become flat topped and uniform in elevation.

CONCLUSIONS

1. Edwards Limestone circular bioherms occur throughout central Texas in the upper seven to ten feet of the Edwards Formation. The bioherms are best observed in plan section in creek beds (Childress and Hog creeks) and in cross section on bluffs along river valleys (North Bosque, Middle Bosque, and Leon rivers).
2. The circular bioherms grew in a sheltered environment behind protecting Edwards elongate reefs. The entire Edwards complex grew on the eastern margin of the Comanche platform, protected from large waves by the more seaward Stuart City Reef of the East Texas basin.
3. The bioherms began in shallow, warm, hypersaline waters. Caprinids, the dominating fauna at this time, formed small randomly distributed mounds.
4. Due to wave and current action, the caprinid assemblages growing nearest the deeper water tended to grow elongate, parallel to the platform edge, and protected the mounds behind them. These protected mounds grew in cone shapes.
5. Upward growth of the mounds continued to a wave base or sea surface.
6. A change in environment occurred after the upward limit of growth was attained. A differing assemblage, radiolites and normal marine fauna, began to flourish and dominate.
7. The elongate reefs began to grow laterally by addition of accretion and washover beds composed of biomicrite and fossil hash. The surface of these beds is formed of algal mats and clastic limestone showing festooned cross-bedding and both large and small ripple marks. The occurrence of these features suggests shallow water deposition.
8. The bioherms (circular mounds) grew radially from the margins of the cores by addition of rudist beds in a matrix of biomicrite with lesser amounts of sparry calcite. The rudist beds dip away from the core at angles of five to twenty-five degrees.
9. Periodic "events" caused either termination or slackening of growth of rudist beds of the circular bioherms. Either through periodic suffocation of the fauna by muds, exposure to air, or climatic changes, the result was a change in lithology which, upon weathering, reveals the characteristic circular beds.
10. Paleontologic and petrographic evidences suggest that the elongate reefs and the circular bioherms grew in an environment of intermittently agitated and calm water.
11. Throughout the area of study, the circular bioherms have fourteen or fifteen encircling beds, though in some cases the mounds grew too close for each to have a full complement of beds. Thus, fourteen times the rudist growth was slowed or terminated and new growth began.
12. Clay found in the Edwards Limestone is similar to that of the Kiamichi Clay. These clays contain sharks teeth, ostracodes, echinoid spines, expandable clays, and gypsum crystals. This influx of clay during the Edwards bioherm deposition suggests conformity between the Edwards Limestone bioherms and the Kiamichi Clay, and indicates that reef growth was ultimately terminated under an influx of land-derived clastics.
13. The Kiamichi Clay conformably overlies the Edwards Limestone circular bioherms in the study area. The Kiamichi Clay pinches out toward the Belton High, being represented only by a parting near Oglesby, Coryell County. Over the Belton High the Duck Creek Member of the Georgetown Formation unconformably overlies the Edwards Limestone. South of the Belton High, the Kiamichi Clay is time equivalent with the Edwards B-zone.

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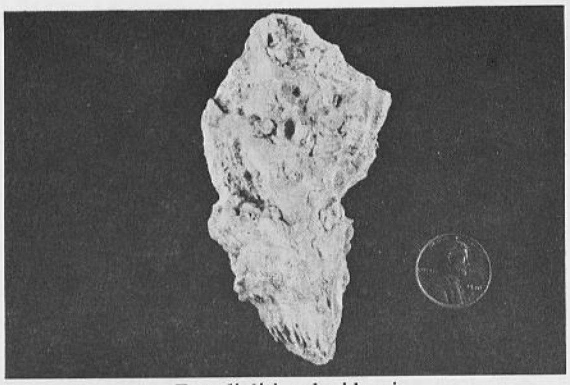
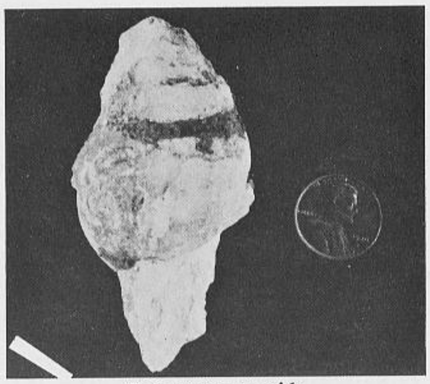
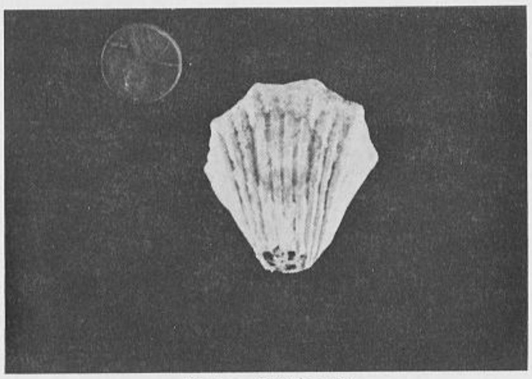


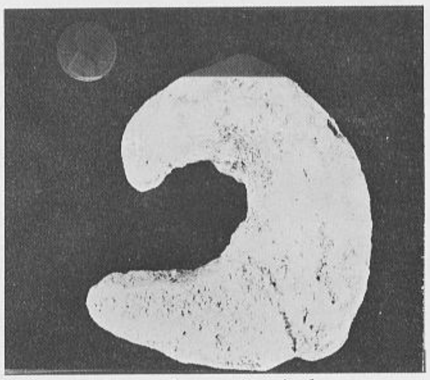
Eoradiolities davidsoni



Tylostoma tumida



Pecten duplicosta

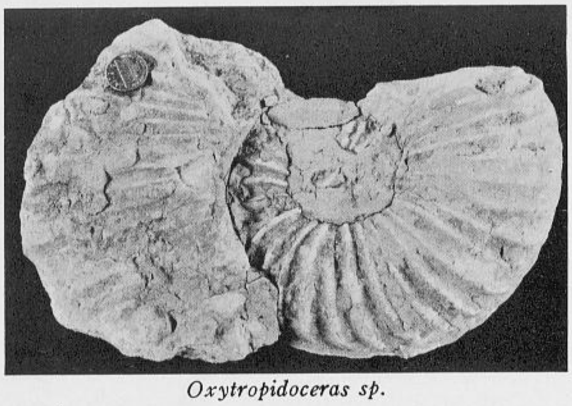


Monopleura pinquisula

Fig. 21. Fossils found on the bioherms.

Caprinuloidea sp.

Chondrodonta munsoni



Oxytropidoceras sp.

Fig. 22. Fossils found on the elongate reefs.

APPENDIX I

PALEONTOLOGY*

The limestone beds of the circular bioherms and the elongate reefs are composed of biomicrite or fossiliferous lime-mud. Rudists are the dominant fossil form and are composed of original material or re-crystallized sparry calcite. Fossils are found complete and in growth positions, with some fragments occurring on the accretion and washover beds of the elongate reefs. Molds of articulate pelecypods are numerous. Extensive burrows occur on the surface of the reefs and in the algal mat covering of the elongate reefs.

The dominant fossils, their mode of life and preservation follow:

Phylum Mollusca
Class Bivalvia Linné, 1758
Subclass Heterodonta Neumayr, 1884
Order Hippuritoida Newell, 1965
Superfamily Hippuritacea Gray, 1848
Family Radiolitidae Gray, 1848
Subfamily Radiolitinae Gray, 1848

Eoradiolities davidsoni (Hill)

Pelecypods of this species are aberrant, having unequal valves. The lower valve is conical, the upper is operculiform. The surface of the lower valve is marked by longitudinal ribs and grooves and resembles a "horn" coral. The structure of the shell wall is cellular-prismatic and at the tip of the valve, forms a network with a quadrangular mesh (Moore, *et al.*, 1952, p. 44; fig. 21).

This pelecypod was adapted to a sedentary mode of life and was confined to rocks of Cretaceous age. It was a gregarious reef builder, confined to clear, warm, normal marine seas.

Family Caprinidae d'Orbigny, 1850

Caprinuloidea sp.

This aberrant pelecypod had a conical upper valve and an elongated slightly coiled lower valve (fig. 21). *Caprinuloidea* sp. grew up to three feet in length at the centers of the bioherms and elongate reefs. It is a characteristic fauna of hypersaline or other abnormal marine waters.

Family Requieniidae Douville, 1914

Toucasia texana (Roemer)

Toucasia texana has a large left valve, a smooth keel, and a broad flat spiraled surface. *Toucasia texana* was strongly modified to a sessile mode of life, being particularly adapted to reef environments (*idem*, p. 440). It is restricted to the rudist reef facies of the Cretaceous.

Superfamily Chamacea Lamarck, 1809
Family Chamidae Lamarck, 1809
Chama sp.?

Chama sp., an equivaled pelecypod burrower, is not particularly adapted for reef life, but is found among the fossil remains. It is associated with the micrite sections of the circular bioherms.

Family Monopleuridae Munier-Chalmas, 1873

Monopleura pinquisula (White)

This pelecypod had a long, thin, and twisted right valve. In cross-section the left valve is flattened, opercular, and marked with concentric growth rings (fig. 21). This pelecypod is found with normal marine fauna, though it is also sometimes found with the caprinids.

Subclass Pteriomorpha Beurlen, 1944
Order Pterioida Newell, 1965
Suborder Pteriina Newell, 1965
Superfamily Pectinacea Rafinesque, 1815
Family Pectinidae Rafinesque, 1815
Pecten Group
Pecten (Pecten) Subgroup

Pecten duplicosta (Roemer)

Pecten duplicosta is broad, inequivalve and circular in outline, with the right valve elongated. *Pecten duplicosta* was semi-sessile, lying on the left valve. It was a normal marine fauna.

Suborder Ostreina Férussac, 1827
Superfamily Ostreacea Rafinesque, 1815
Family Chondrodontidae Freneix, 1959

Chondrodonta munsoni (Hill)

Chondrodonta munsoni has a flat shell shape through fixation and habit of growth. The shell has numerous radial plications and is confined to the rudist reef facies.

Family Ostreidae Rafinesque, 1815
Subfamily Ostreinae Rafinesque, 1815

Ostrea sp.

The superior valve of this fossil is flat and lamellar. *Ostrea* sp. adapt structurally to their environment and, therefore, taxonomic division is difficult. *Ostrea* spp. are attached during life and thrive in shallow, warm, marine, (slightly brackish) waters.

Family Gryphaeidae Vyalov, 1936
Subfamily Gryphaeinae Vyalov, 1936

Gryphaea marcoui (Hill and Vaughn)

Gryphaea marcoui is typically elongated with an unrolled nearly straight beak. The right valve is flat, opercular, and generally fitting within the left valve (*idem*, p. 220). *Gryphaea marcoui* is a sessile, warm, marine water dweller.

Subclass Palaeoheterodonta Newell, 1965
Order Trigonoida Dall, 1889
Superfamily Trigoniacea Lamarck, 1819
Family Trigoniidae Lamarck, 1819

Trigonia sp.

The surface markings of *Trigonia* consist of concentric ridges which cover the median and anterior parts of the upper valve. Its characteristic outline is emphasized by the oblique truncation of the posterior margin, and prominence of the umbonal ridge. *Trigonia* was a dweller of warm, slightly brackish, marine waters.

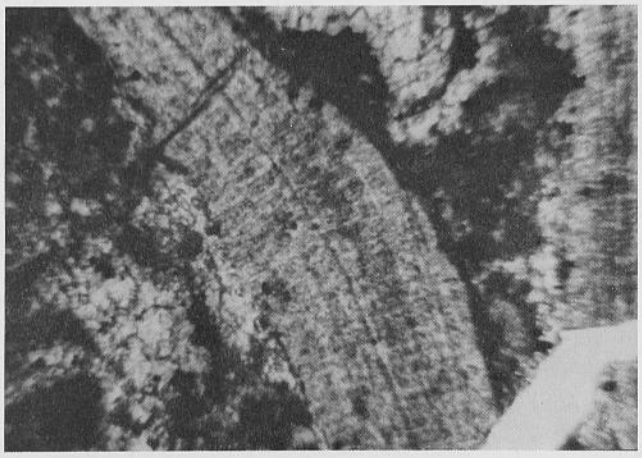
Class Gastropoda†
Order Tenibranchiata
Family Naticacea

Tylostoma tumida (Shumard)

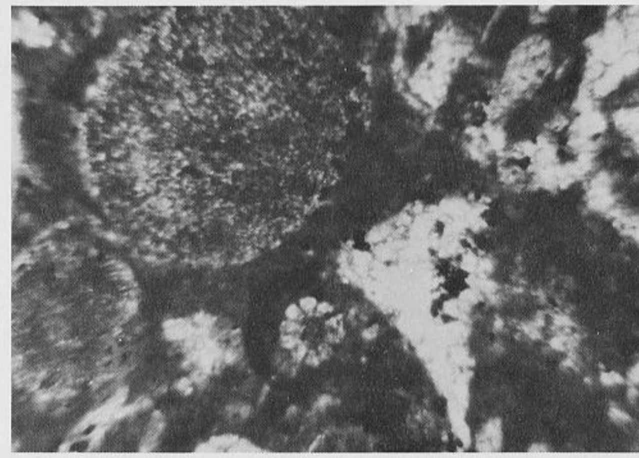
Found primarily as casts, *Tylostoma tumida* is composed of a pyramidal spiral with six whorls. *Tylostoma tumida* lived in normal marine waters (fig. 22).

*Nomenclature has been changed to agree with that proposed in the Treatise on Invertebrate Paleontology.—Ed.

†Treatise on Invertebrate Paleontology for Gastropoda not available.—Ed.

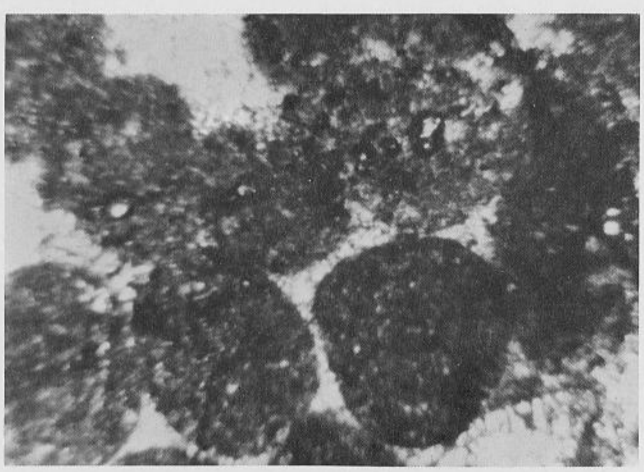


A. Sample 26, Locality 3-2. Section through rudist fragment. Dark areas surrounding fragment are limonite inclusions. Sparry calcite replaces voids around the shell fragment (x 25).

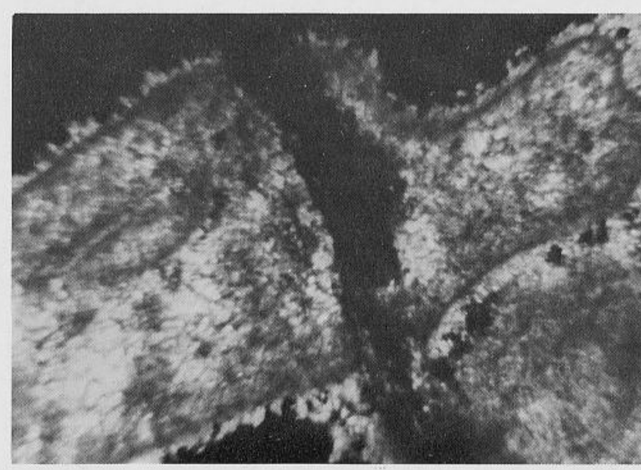


B. Sample 12, Locality 1-3. Bioherm biomicrite sample shows shell fragments and cross-section of an echinoid spine. Note the voids filled with spar (x 25).

Fig. 23. Limestone petrography of biohermal reef rocks. Both slides were taken from circular bioherms.



A. Sample 24, Locality 1-3. Bioherm biomicrite shows fecal pellets, believed to be molluscan, possibly rudist in origin. They occur around shell fragments, whole shells, and in burrows (x 25).



B. Sample 21, Locality 1-3. Calcite fills the voids in the sample. Limonite is dominant throughout the slide as dark inclusions. Note the large fecal pellet in the left center of the photograph (x 50).

Fig. 24. Limestone petrography of biohermal samples, showing fecal pellets.

Class Cephalapoda Cuvier, 1797; Leach, 1817
Order Ammonoidea Zittel, 1884
Suborder Ammonitina Hyatt, 1889
Superfamily Acanthocerataceae Hyatt, 1900
Family Brancoceratidae Spath, 1933
Subfamily Mojsisovicziinae Hyatt, 1903

Oxytropidoceras sp.

Molds of this species are found on the upper surfaces of the Edwards Limestone elongate reef at locality 1-1. Ammonites are open ocean swimmers, and appear to have been washed into the reef structures by large waves (storms). All molds are flat-lying and it is unknown whether the death of the animal was prior to or after deposition of the shell.

Phylum Echinodermata
Subphylum Echinozoa Haeckel, 1895
Class Echinoidea Leske, 1778
Subclass Euechinoidea Bronn, 1860
Superorder Echinacea Claus, 1876
Order Phymosomatoida Mortensen, 1904
Family Phymosomatidae Pomel, 1883

Phymosoma texana (Roemer)

Several specimens were found along with several club-shaped primary spines. Echinoids are restricted to marine waters, ranging from intertidal to abyssal depths.

Phylum Arthropoda Siebold and Stannius, 1845
Subphylum Mandibulata Clairville, 1798
Class Crustacea Pennant, 1777
Subclass Ostracoda Latreille, 1806
Order Podocopida, Müller, 1894
Suborder Podocopina Sars, 1866
Superfamily Cypridacea Baird, 1845
Family Paracyprididae Sars, 1923

Paracypris sp.

This ostracode is a normal marine dweller. Ostracodes generally live on the bottom or on plant stems. *Paracypris* has an elongate smooth carapace and is pointed posteriorly with a larger left valve

APPENDIX II
PETROLOGY

The bioherms and elongate reefs are composed of reef deposits varying from yellow dolomitized limestone to massive rudistid and caprinid crystalline limestone. The limestones contain abundant land-derived sediments in the form of clay, which fills burrows, borings, and shells. The clays in the limestone beds of the bioherms and within the shells contain a high percentage of expandable clays (greater than ten percent).

Original material of the fossils is well preserved in layers which exhibit large amounts of limonite-stained clay. In layers where limonite is less abundant, calcite replacement is common. Cores of the bioherms are homogenous limestone or dolomite and are composed of yellow calcitic limestone (sometimes altered to dolomite) with a few large calcite casts of fossils. The reef core limestone tends to weather in troughs parallel to the river. The surrounding beds in the bioherms are hard, resistant reef limestone, and tend to weather in alternating ridges and furrows.

Used in this study is Folk's (1959, p. 1) limestone classification somewhat modified. The term sparite encompassed samples which had a matrix consisting of more than two-thirds sparry calcite, plus whole or fragmented fossils. If the sample contained more than twenty percent fossils, whole or fragmented, the term biosparite was used.

Micrite is composed of micro-crystalline calcite containing less than ten percent whole or fragmented fossils. Biomicrite contains more than ten percent whole or fragmented fossils and constitutes the major percentage of the bioherm matrix. Original voids and pore spaces of the fossils contained either micrite, pseudomicrite, or sparry calcite.

Dolomite occurs as euhedral rhombohedra and is commonly darker than the surrounding calcite. This coloration is due to the presence of iron oxide.

Megascopically, the samples from the concentric circular beds differ, each having a seemingly different lithology. The presence of burrows and clay gives each bed a differing color. Microscopically, the samples differ only slightly, being composed of biomicrite with small amounts of biosparite.

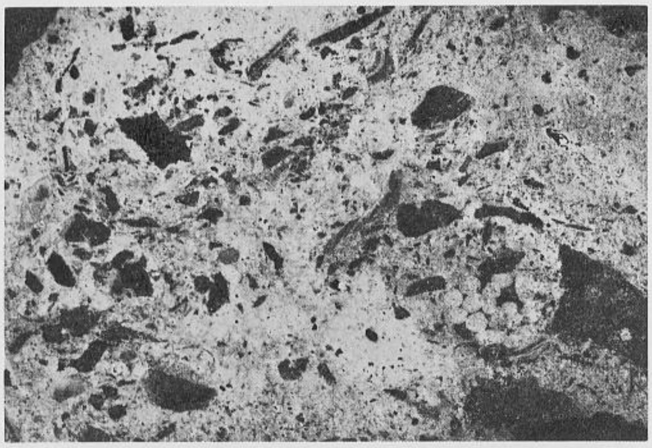
The fossils in samples with a low limonite percentage appear to be completely altered to sparry calcite. These samples with a large percentage of limonite have a lesser degree of calcite replacement and a higher proportion of original material in the shells.

Most samples consisted of calcium carbonate with inclusions of limonite, dolomite, glauconite, and pyrite. The previous figures show typical limestones, clay, fossilization, replacement, and rock types from the circular bioherms and elongate reefs.

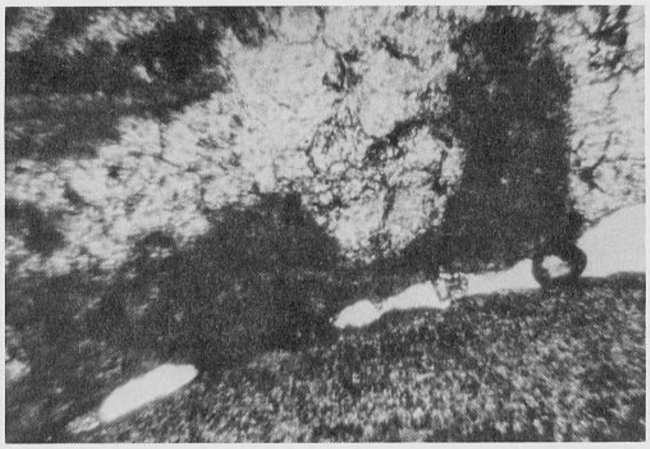
A. Sample 1, Locality 1-1. Biomicrite composed of shell fragments (shell hash), this sample is from the upper section of the core of the elongate reef (x 10). The picture is a negative image.

B. Sample 25, Locality 2-4. Calcite crystals filling voids. Dark areas are limonite inclusions. This limonite is secondary, resulting from oxidation of primary pyrite inclusions (x 15). This picture is a negative image.

Fig. 25. Limestone petrography of samples taken from central cores of elongate reefs. Negative images produced from thin sections.



A. Sample 1, Locality 2-8. Shell fragments with a sparry calcite rim. Solution has occurred and spar is filling the voids (x 15). This picture is a negative image.



B. Sample 4, Locality 1-1. Elongate reef biomicrite shows calcite and voids.

Fig. 26. Limestone petrography of samples taken from accretion bed of the elongate reef.

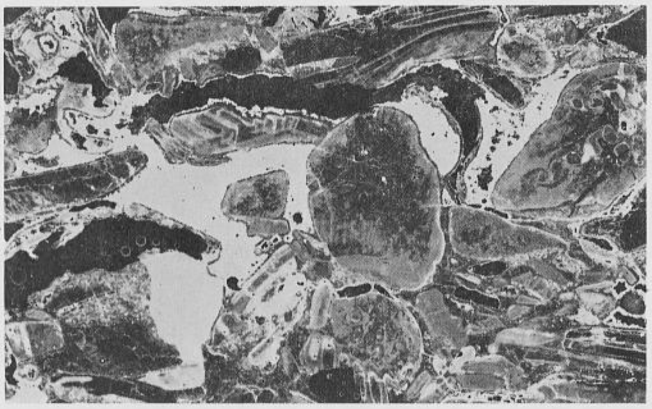


Fig. 27. Limestone petrography of washover beds of elongate reefs. Sample 21, Locality 5-8. Elongate reef sample composed of biomicrite. Included within this sample are inclusions of limonite, altered from primary pyrite (x 25).

APPENDIX III

LOCALITIES

The study area was divided into five sections or areas. Area 1 centers around the Childress Creek basin in McLennan and Bosque counties. Area 2 centers around the North Bosque River in Bosque and McLennan counties; Area 3, around the Hog Creek basin; Area 4, around the Middle Bosque basin; and Area 5, around the Leon River. Localities outside the designated study area are shown on the distribution map, Figure 3. These localities were not studied, but for purposes of distribution appear on the map.

Area One: Childress Creek Basin

LOCALITY 1-1; Lat 31°44'30" N., Long 97°21'30" W. (figs. 13, 14, 18). Exposed here in the creek bed is an elongate reef with accretion beds dipping to the southeast and washover beds dipping northwest, toward the circular bioherms. The reef rock is basically composed of biomicrite (some altered to dolomite), caprinid casts and molds, and an algal mat covering.

LOCALITY 1-2; Lat 31°43'30" N., Long 97°22'55" W. (fig. 17). This locality, upstream and northwest of locality 1-1, has washover beds from the elongate reef surrounding a circular bioherm. The main reef rock is biomicrite, and shell hash, covered with an algal mat. Swale and ripple marks dominate on the surface of the beds.

LOCALITY 1-3; Lat 31°43'15" N., Long 97°22' W. (figs. 2, 6, 12). Four bioherms are exposed in the river bed and at the ford in the stream. The bioherm just upstream of the ford represents the best example of the circular bioherms in the study area. The bioherms are composed of a core of biomicrite, altered in some places to dolomite, and encircling beds of a bivalve biomicrite, with secondary amounts of biosparite; of interest is a clay bed.

LOCALITY 1-4; Lat 31°43'20" N., Long 97°23'55" W. Two bioherms exposed in the stream bed. These bioherms are northwest of the previously mentioned locality.

LOCALITY 1-5; Lat 31°43'25" N., Long 97°24' W. (fig. 9). Four bioherms exposed in the stream, northwest of locality 1-4. The bioherms are exposed so that the area between the mounds is exposed. This locality shows the interbiohermal lime-mud facies.

LOCALITY 1-6; Lat 31°43'30" N., Long 97°34'05" W. At this locality the creek has cut a bioherm so that a slight cross-sectional view is observable. Exposed here also is the clay bed, similar to that exposed at locality 1-3.

LOCALITY 1-7; Lat 31°43'55" N., Long 97°20'55"W. This locality is downstream, southeast of locality 1-1. The flat-lying accretion beds are exposed with numerous fossil molds on the surface. Numerous limonite and pyrite inclusions are observed on the surface.

LOCALITY 1-8; Lat 31°43'30" N., Long 97°20'15" W. Bioherms exposed in the creek bed and eroded extensively by the river. These bioherms are seaward of the elongate reef and appear to have had another elongate reef seaward of them.

LOCALITY 1-9; Lat 31°43' N., Long 97°18'15" W. Bioherms exposed in the creek bed, beneath old road bridge. The bioherms are covered with river gravel and the encircling beds are outlined by troughs in the gravel. The bioherms are composed of biomicrite.

LOCALITY 1-10; Lat 31°45' N., Long 97°18'30" W. Circular bioherms in the creek bed northwest of locality 1-9. These bioherms were observed by air and were not visited on foot, but were used in the localities to show distribution.

Area Two: North Bosque River Basin

LOCALITY 2-1; Lat 31°40'25" N., Long 97°26'30" W. (fig. 7). At this locality there are several bioherms exposed on the hilltop. The presence of these hilltop bioherms is characteristic of the presence of bioherms over an extensive area.

LOCALITY 2-2; Lat 31°41'30" N., Long 97°28' W. Bioherms exposed to north of Farm Road 317, one mile west of Valley Mills, Bosque County, at crest of hill in the pasture.

LOCALITY 2-3; Lat 31°40'30" N., Long 97°27' W. Flat-lying limestone outcropping between locality 2-1 and 2-2. This limestone appears to have no circular bioherms.

LOCALITY 2-4; Lat 31°41' N., Long 97°27'24" W. Elongate bioherms exposed on the hillsides of the Hunt Farm, north of State Highway 6. These reefs are elongate and show varying zones of reef growth, accretion beds, washover beds and *Tylostoma* zones.

LOCALITY 2-5; Lat 31°41' N., Long 97°27' W. River cut north of Valley Mills on Farm Road 317, showing a cross-sectional view of limestone beds (possibly circular) overlying chert beds. The chert contains blebs of clay.

LOCALITY 2-6; Lat 31°38'45" N., Long 97°27'45" W. Railroad cut in Valley Mills, cross-sectional view of a bioherm, possibly circular.

LOCALITY 2-7; Lat 31°38'30" N., Long 97°28'45" W. Quarry off State Highway 6, southeast of Valley Mills, on the Hill Ranch. This quarry shows a cross-sectional view of aspects of longitudinal elongate reefs.

LOCALITY 2-8; Lat 31°37'30" N., Long 97°24'30" W. Quarry on the Bass Ranch, north of State Highway 6, cross-sectional view of circular bioherms. The bioherms are extremely eroded and covered with debris.

LOCALITY 2-9; Lat 31°46'30" N., Long 97°32'45" W. Near Clifton, Bosque County, to east of State Highway 6, flat-lying limestone holds up the bluffs above the river.

LOCALITY 2-10; Lat 31°38'15" N., Long 97°27'30" W. Circular bioherm exposed to the east of Farm Road 317 south of Valley Mills, Bosque County. The presence of this bioherm in such close proximity to locality 2-6 (Valley Mills railroad cut) gives support to the circularity of the bioherm there.

Area Three: Hog Creek Basin

LOCALITY 3-1; Lat 31°33'15" N., Long 97°21'45" W. Ocee, McLennan County. In the river bottom of Hog Creek is exposed flat-lying limestone with reef aspects, such as accretion beds.

LOCALITY 3-2; Lat 31°34' N., Long 97°25' W. Compton, McLennan County. In the creek bed circular bioherms are exposed. These bioherms are basically the same as the bioherms exposed in Childress Creek.

LOCALITY 3-3; Lat 31°35'30" N., Long 97°21'30" W. Circular bioherms exposed in the river bottom near the town of Shilo, McLennan County.

LOCALITY 3-4; Lat 31°36'15" N., Long 97°27'30" W. Circular bioherms exposed in the creek bed, near Patton, McLennan County.

LOCALITY 3-5; Lat 31°36' N., Long 97°27' W. This locality contains several miles of creek bottom from State Highway 317 west to the first road fording the river. In this area are several bioherms, all circular.

LOCALITY 3-6; Lat 31°38′ N., Long 97°36′15″ W. Circular bioherms exposed in the creek bed near the town of Mosheim, McLennan County.

Area Four: Middle Bosque River Basin

LOCALITY 4-1; Lat 31°34′ N., Long 97°26′45″ W. Circular bioherm exposed in pasture of ranch, north of Crawford, McLennan County. This bioherm is exposed along with several others north of an elongate reef structure at locality 4-2.

LOCALITY 4-2; Lat 31°43′15″ N., Long 97°26′45″ W. Road cut on State Highway 317, showing the flat-lying reef limestone. This limestone is presumably the washover beds of an elongate reef to the south. This entire complex is south of a group of circular bioherms.

LOCALITY 4-3; Lat 31°32′15″ N., Long 97°24′45″ W. Tonkawa Park, McLennan County. The Edwards Limestone crops out as flat-lying reef limestone. This complex is south of the circular bioherms of locality 4-1, and is presumed to be part of the reef complex seen at locality 4-2.

LOCALITY 4-4; Lat 31°43′15″ N., Long 97°25′45″ W. Circular bioherms and traces of elongate reefs are exposed in the river bottom. This locality extends over a mile of the river bottom, and is east of Tonkawa Park, locality 4-3.

LOCALITY 4-5; Lat 31°31′15″ N., Long 97°24′30″ W. Quarry on the Atkinson Ranch. Exposed in the quarry is flat-lying reef limestone. This locality is northeast of locality 4-4.

LOCALITY 4-6; Lat 31°33′45″ N., Long 97°23′45″ W. Southeast of locality 4-5, this locality is a continuation of the elongate reef of locality 4-5.

LOCALITY 4-7; Lat 31°35′30″ N., Long 97°33′45″ W. Circular bioherms exposed in the creek bottom of the Middle Bosque, south of junction of farm road and the Bosque-McLennan county line.

Area Five: Leon River Basin

LOCALITY 5-1; Lat 31°20′ N., Long 97°28′45″ W. Mother Neff Park, Coryell County, bioherms are present with elongate reefs. The erosion of the bioherms is extensive. The elongate reefs are exposed on the bluffs over the river.

LOCALITY 5-2; Lat 31°18′45″ N., Long 97°28′15″ W. Horse Creek, east of locality 5-1, the creek has cut a cross-sectional view of a circular bioherm. The bioherm is 10 feet thick and has beds draping off to the north and south. These beds thin in the trough and then drape upward. Only one bioherm is exposed.

LOCALITY 5-3; Lat 31°21′ N., Long 97°30′ W. (fig. 15). Station Creek, Coryell County. Elongate reef exposed in pasture to south of Farm Road 107, on Olinbush Ranch. This elongate reef extends in length for several miles, and in width for several thousands of feet. Station Creek has cut through the core of the reef, exposing the draping accretion and washover beds.

LOCALITY 5-4; Lat 31°23′45″ N., Long 97°36′ W. Pecan Grove, Coryell County. Circular bioherms exposed on the bluffs of the river valley. These bioherms are north of locality 5-3.

LOCALITY 5-5; Lat 31°24′45″ N., Long 97°36′30″ W. Flat-lying limestone exposed in bluffs above the junction of Coryell Creek and Farm Road 107.

LOCALITY 5-6; Lat 31°16′ N., Long 97°29′45″ W. (fig. 20). Winkler Farm, Coryell County, north of State Highway 36. Circular bioherms exposed on the hilltop, and in tangential section. These bioherms are grown together, and the encircling beds encompass two or more biohermal cores.

LOCALITY 5-7; Lat 31°20′30″ N., Long 97°29′30″ W. Circular bioherms exposed on hill slopes on the Mercer Farm, Coryell County. These bioherms are exposed in plan- and tangential-section. Also found at this locality was chert with blebs of clay.

LOCALITY 5-8; Lat 31°13′15″ N., Long 97°29′ W. Circular bioherms exposed on the hilltops of White Flint Park, south of State Highway 36. These bioherms are poorly exposed and do not afford detailed investigation.

LOCALITY 5-9; Lat 31°09′30″ N., Long 97°27′30″ W. Flat-lying limestone exposed in quarry north of State Highway 36. This quarry is east of locality 5-7.

LOCALITY 5-10; Lat 31°14′ N., Long 97°30′ W. Circular bioherms exposed on hilltops of Owl Creek Park south of State Highway 36. This locality is southwest of locality 5-7.

LOCALITY 5-11; Lat 31°25′ N., Long 97°39′ W. Mountain, Coryell County, bioherms exposed here are anamolous, in that they are 35 feet thick and over 500 feet in diameter. They are exposed on the north side of U.S. Highway 82.

LOCALITY 5-12; Lat 31°20′15″ N., Long 97°36′15″ W. Leon Junction, Coryell County, circular bioherms are exposed on the hillsides above the Leon River.

LOCALITY 5-13; Lat 31°20′30″ N., Long 97°32′30″ W. (fig. 8). Outliers in pasture are capped with Edwards reef limestone. Some traces of draping beds are observed.

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