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Symposium on Edwards Limestone in Central Texas

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The benefits of education and of useful knowledge, generally diffused through a community, are essential to the preservation of a free government.

SAM HOUSTON

Cultivated mind is the guardian genius of Democracy, and while guided and controlled by virtue, the noblest attribute of man. It is the only dictator that freemen acknowledge, and the only security which freemen desire.

MIRABEAU B. LAMAR

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Foreword

Publication of this symposium was made possible through the establishment in 1951 of the East Texas Geological Fund of the Bureau of Economic Geology, the nucleus of which came from sales of The University of Texas Publication 5116, "The Occurrence of Oil and Gas in Northeast Texas." This publication was a cooperative effort between the East Texas Geological Society and the Bureau of Economic Geology in which sixty-nine members of the Society prepared papers describing 135 oil and gas fields in northeast Texas.

Publication 5116 was been very useful to many people interested in oil and gas development, and it records information of permanent value to science and industry. The project which produced it is an outstanding example of cooperation between the petroleum industry, represented by members of the Society, and a public geological agency. The fund which was made possible through the project is dedicated to publication of papers of mutual interest to the Society and the Bureau of Economic Geology. The present volume is the first of this kind.

JOHN T. LONSDALE
Director, Bureau of Economic Geology

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Stratigraphic Relations of the Edwards Limestone and Associated Formations in North-Central Texas

FRANK E. LOZO[1]

ABSTRACT

Salient stratigraphic relationships of the mid-Comanche Cretaceous formations in north-central Texas are analyzed with reference to regional genetic and diastrophic factors. Based on historically significant outcrop sections in this classic area of Cretaceous investigations, a southern complex of the Edwards, Comanche Peak, and Walnut formations is indicated to pass northward into a complex composed of the Goodland, Walnut, and Paluxy formations. Classification of the included stratigraphic interval as the "Fredericksburg division" follows R. T. Hill's early nomenclature and concept of an integrated subseries representing a major and distinct cycle of sedimentation.

INTRODUCTION

Salient stratigraphic relations of the mid-Comanche Cretaceous formations are well displayed in the historically significant, classic area of north-central Texas, where R. T. Hill, J. A. Taff, S. Leverett, and later, W. S. Adkins, W. M. Winton, and others worked to elucidate the stratigraphic succession and enlosed faunas. As a consequence the type localities of many of the formations involved are in this area —a factor that has tended to make a study of this area the more interesting.

LOCALE

The geographic setting of this investigation is a triangular area in north-central Texas with the apex westward of Waco and the base an approximate north-south line extending from the vicinity of Fort Worth to the Austin area (fig. 1).

SCOPE OF REPORT

The repeated study which the Cretaceous stratigraphy of this area has received by various workers has resulted in various concepts of the formational units, nomenclatural applications, and presumably genetic associations of rock units. A comparison of these differences of opinions and interpretations is of interest in the light of additional data, principally subsurface. The proximity of mechanically logged borings to outcrop reference sections affords an immediate tie between the outcrop and the adjacent subsurface. The larger area of study and increased density of data permit an evaluation of significant regional relationships. An appreciation of these relationships may serve as an introduction to the geologic setting. The papers in this volume treat of detailed studies within this area and are only the first of many detailed studies which need to be made.

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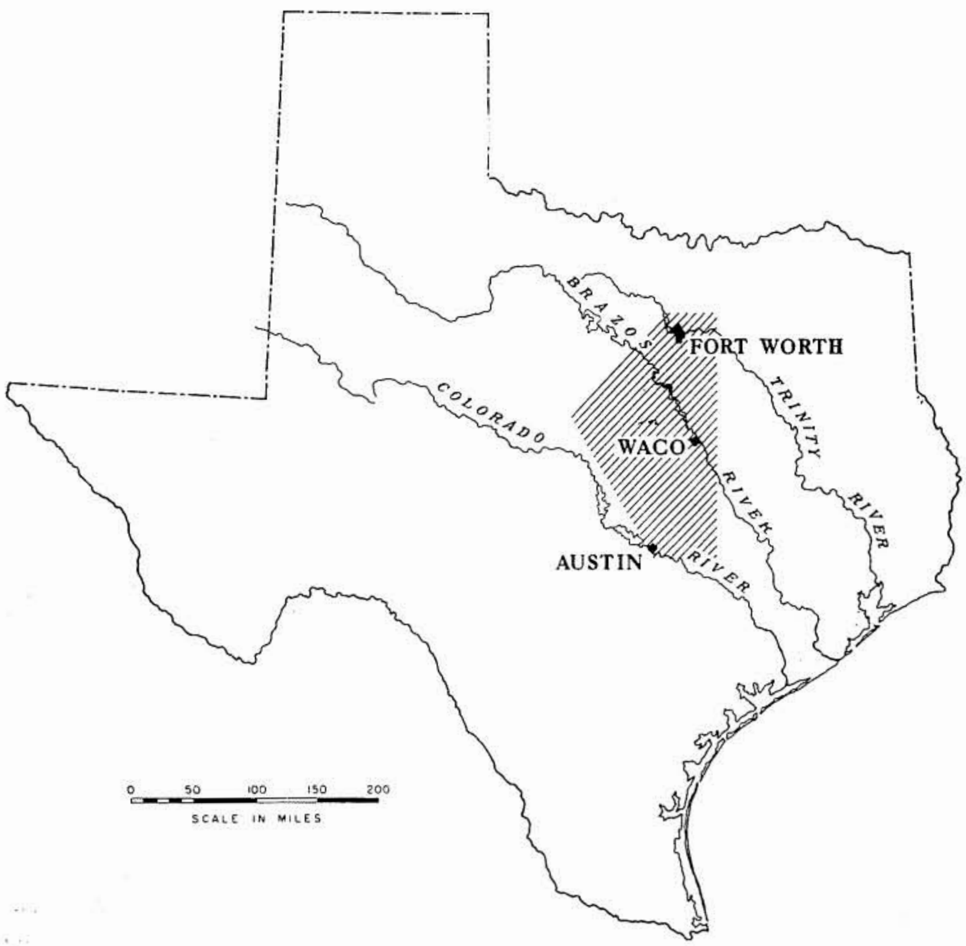

FIG. 1. Area of investigation in north-central Texas.

STRATIGRAPHIC UNITS

Formation Names and Local Sequences

The stratigraphic units and successions discussed in this report are tabulated in figure 2. The total agreement on the limits of the Fredericksburg "group" or "division" in the southern part of the area is in contrast to the lack of general agreement (as shown by the brackets in fig. 2) in the northern area.

The differing interpretations indicated by the numbered brackets are:

(1) The Goodland-Walnut-Paluxy combination is based on concepts of genetically related cyclic sedimentation.

(2) The Kiamichi - Goodland - Walnut combination is based on paleontologic affinities.

(3) The Goodland-Walnut combination is a lithologic grouping that separates predominantly calcareous beds from differing contiguous lithologies.

(4) The Kiamichi-Goodland-Walnut-Paluxy complex results from a mixture of the three basic concepts of stratigraphic grouping or combining noted above.

Synopses of Lithic Units

The Cretaceous in Texas was initially recognized by Ferdinand Roemer in 1847–48. The first tabulated section of named units was presented by B. F. Shumard in 1860. Most of Shumard's units such as "Caprina Limestone," "Exogyra arietina Marl," and "Caprotina Limestone" were named for paleontologic traits. Other units, e.g., "Comanche Peak Group" and "Austin Limestone," received geographically derived names or were named for a lithologic feature, e.g., "Arenaceous Group" and "Blue Marl." In 1889 the Texas Geological Survey under the direction of E. T. Dumble initiated systematic reconnaissance studies, and R. T. Hill was placed in charge of the Cretaceous. By 1891 mapping and knowledge of the local sections were sufficiently advanced to define most of the main cartographic units under consideration in the present paper. In a paper entitled "The Comanche Series of the Arkansas-Texas Region," Hill (1891) formally introduced most of the formation names in present use. Later investigations by Hill and T. W. Vaughan, as Federal Survey geologists, resulted in the naming of the Edwards (1898) and Georgetown (1900–

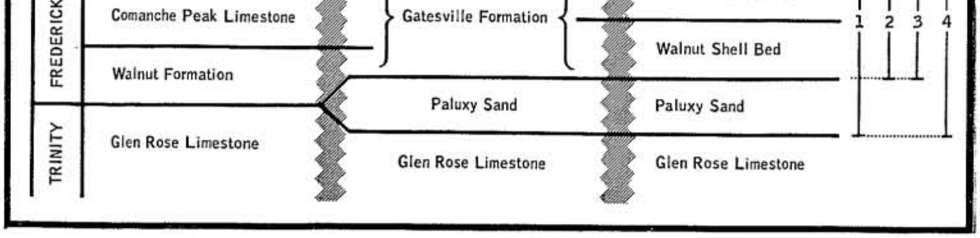

Fig. 2. Local sequences and interpretations of "Fredericksburg."

1901) limestones. Of the nomenclatural proposals since 1901, only the Gatesville formation of Thompson (1935) is pertinent to this discusion. Notes on the origin and application of the formational names are given below.

Georgetown limestone.—Named after occurrences at Georgetown, on the San Gabriel River, Williamson County (Hill, 1901, p. 262), the Georgetown is composed of thinly bedded somewhat nodular limestone typically containing tiny calcispheres of presumed planktonic organisms. The name is applied south of the Brazos River to the thinned correlative of numerous limestone and shale formations (Kiamichi to Main Street inclusive) occurring to the north. The formation thins from 150 feet at Waco to less than 75 feet at Austin. Southward thinning is associated with facies change (argillaceous into calcareous material), decreased rate of deposition, intraformational hiatuses, and basal onlap on the disconformable top of the Edwards in and south of McLennan County.

Duck Creek formation.—The formation was named (Hill, 1891, pp. 504, 516) from exposures along Duck Creek, north of Denison in Grayson County, at the valley edge of Red River. The Duck Creek consists of alternating marly limestones and marls concordantly overlying the Kiamichi from McLennan County northward. The formation thickens from 30 feet at Waco to 65 feet at Fort Worth to more than 100 feet in the type area. The lower part of the Georgetown limestone contains a similar if not identical fauna.

Kiamichi formation.—The Kiamichi was named (Hill, 1891, pp. 504, 515) after occurrences on the plains adjacent to the Kiamichi River near Fort Towson, eastern Choctaw County, Oklahoma. Dark clays or shales with gryphaeate oyster beds or shelly limestones are prominent in the type area. The outcrop thickness decreases from 50 feet or less (not 150 as reported) in Oklahoma west of the type area to about 30 feet at Fort Worth to 5 feet or less southeast of Gatesville, Coryell County. The Kiamichi is absent at the outcrop by onlap south of the Coryell-Bell County line, with the exception of the Williamson County outlier near Round Rock.

Goodland limestone.—The Goodland was named (Hill, 1891, pp. 504, 514) after the old settlement of Goodland (= present site of Good Switch on the St. Louis and San Francisco Railroad, 3 miles north of Hugo, not the present-day Goodland, 3 miles southwest of Hugo), Choctaw County, Oklahoma. Twenty feet thick in the type area, the formation is characterized by thin marl partings between fossiliferous beds of gray nodular chalky or white crystalline limestone. The facies is the same as that developed in the type area of the Comanche Peak limestone. East of the type area, the Goodland in McCurtain County thickens to 50–75 feet of more massive and purer limestones and rudists common in the upper portion and is in part the same facies developed in the Edwards limestone of the Brazos River valley. Along the outcrop south of Red River the formation thickens to about 125 feet west of Fort Worth. Near the Tarrant-Johnson County boundary, the upper portion is again marked by massive beds containing rudists, the lower portion becomes more argillaceous, and the formation passes by transition into the Edwards, Comanche Peak, and upper Walnut of the Brazos valley sections.

Edwards limestone.—The geographic name Edwards, from the Edwards Plateau of southwestern Texas, was applied (Hill and Vaughan, 1898a, p. 2; 1898b, pp. 227–235) to the cherty, caprinid- and other rudist-bearing strata intermediate between the Georgetown or Kiamichi and the Comanche Peak formations and replaced the earlier paleontologic designation of "Caprina Limestone" (Shumard, 1860). The name change was substituted under false impressions of the actual stratigraphic relations between the Edwards Plateau section and the Caprina Limestone sections originally described from occurrences in the Colorado and Brazos valleys. The type locality of the Edwards was subsequently assigned to central Texas (Barton Creek, near Austin) by Adkins (1933). The Edwards is composed of several different limestone types but is distinct from adjacent formations in physiographic expression, nature of soil, and differences in vegetation; it varies from 30 feet or less in the north to more than 200 feet in the Colorado Valley. Southward thickening results from successively older intercalations or facies change at the expense of the underlying strata.

Comanche Peak limestone.—Hill (1891, pp. 504, 512–513) emended the Comanche Peak formation to exclude most of the older strata (Walnut and Glen Rose) originally included in the Comanche Peak group by Shumard. The white chalky limestone of the type section is 100 feet thick at Comanche Peak, the famous early landmark southwest of Fort Worth, and is essentially the same facies represented by the Goodland limestones from Tarrant County north. The Comanche Peak thins to the south as the Edwards thickens, and finally, in the Colorado Valley area, encroaches on the underlying marly limestones of the Walnut with stratal replacement analogous to the Edwards-Comanche Peak transition mentioned previously.

Walnut formation. — Named (Hill, 1891, pp. 504, 512) after occurrences near the town of Walnut (now called Walnut Springs) in Bosque County, the alternating clays, nodular marly limestones, and shell beds were previously called "*Exogyra texana* clays," "*Gryphaea* rock," or "Texana beds." Transitional into the overlying Comanche Peak, the Walnut in the type area is in abrupt contact with the Paluxy sands below. The Walnut interval varies with different concepts of the formation north and south. In the area of Goodland limestone recognition to the north, only the gryphaeate shell beds common in the lower part of the type Walnut are customarily assigned to the Walnut. South of the type area, the formation expands stratigraphically at the expense of the Paluxy, then decreases as the chalky limestones of the Comanche Peak replace from the top downward the marls and nodular limestones of the type section. The thin clay ordinarily recognized as the central Texas Walnut is a lateral equivalent of Paluxy sands underlying the type Walnut.

Paluxy sand.—Initially confused (Hill, 1891, pp. 504, 510–511) in the area west and northwest of Fort Worth with older sands, the irregularly bedded, friable packsand section intermediate between the Walnut and Glen Rose was subsequently recognized as a distinct unit following studies in the Brazos Valley adjacent to Comanche Peak. The Paluxy sands were named from characteristic occurrences along the headwaters of the Paluxy River in Erath County and on the highlands adjacent to the village of Paluxy, Hood County. Typically developed between the valleys of the Trinity and Lampasas rivers, the formation merges into the greater interval of the Antlers sand outcrop northwest of Fort Worth. The southern limit of quartz sand concentration, roughly along a line bearing northeast from Lampasas toward Waco, marks the passage of the Paluxy into the calcareous and argillaceous strata assigned to the Walnut. This latter relation is contrary to older notions that the Paluxy was totally represented in the upper Glen Rose of the central Texas or southern area.

Glen Rose limestone.—Named (Hill, 1891, pp. 504, 507–509) from the typical development at and near Glen Rose on the Paluxy River, Somervell County, the so-called "Alternating Beds" are characterized by a variety of argillaceous or dolomitic limestones alternating with more indurated limestones that result in a pronounced bench - and - terrace topography. The formation interval thickens from 200 feet plus in the type area to more than 600 feet in the Colorado Valley outcrops.

Gatesville formation. — From vertical and lateral gradation relationships observed in a series of outcrop sections from Red River south into central Texas, the Edwards, Comanche Peak, and Walnut were treated as facies of a single sedimentation unit, reduced in rank from formations to members, and grouped into the proposed Gatesville formation (Thompson, 1935, pp. 1531–1534). The type locality was designated near Gatesville, Coryell

County, where the three subdivisions are exposed with characteristic facies. Concerned with the ambiguous application of the name Edwards to the entire sedimentation unit (Gatesville equivalent) in distant areas to the west and southwest, and noting in turn that stratal intervals different from those of the type Comanche Peak and Walnut sections were recognized elsewhere, the intent of the new proposal was to confine an area of consistent, non-ambiguous usage based on the representative or type sections as developed in north-central Texas. Thompson rejected the Goodland formation as a synonym of the Comanche Peak and considered the Kiamichi and Gatesville formations as constituting the Fredericksburg group from Coryell County northward.

LOCAL STRATIGRAPHIC SECTIONS

Certain outcrop sections have been repeatedly studied and consequently have become the local reference sections. In other areas shallow core-borings at damsites serve the same purpose. The lithic units in these reference sections, as locally recognized by the writer, may be projected with reasonable certainty into the adjacent subsurface and the subdivisions indicated on mechanical logs. These logs show typical local relationships and serve as subsurface standards for a network of log-to-log correlations on which the regional relations presented are based.

Investigations that provide details and previous interpretations of local sections include Texas Geological Survey regional studies by Taff (1892, 1893) and Hill (1901); county geological reports in the northern area by Winton (1920, 1922, and 1925) and on the southern counties by Adkins (1924; Adkins and Arick, 1930); U. S. Army Corps of Engineers damsite investigations (Colligan, 1951; Hull, 1951); reports of investigations by other organizations (Thompson, 1935; Lozo, 1949; and Leggat, 1957); and thesis studies (Ikins, 1941) or other open-file reports, mostly unpublished.

Tarrant County Control Section

Reference outcrop sections of the Fredericksburg and adjacent formations are well exposed in the Benbrook area, southwestern Tarrant County, and in the vicinity of Lake Worth dam, northwest of Fort Worth (fig. 3). Taff and Hill used data originally obtained in the Benbrook area. Winton and Adkins first presented details of the Lake Worth dam abutment exposure and Thompson later utilized data from this locality and others nearby. Leggat clarified mistakes of measurement in Taff's original compilation of the section in the Benbrook vicinity by combining data from outcrops and Benbrook dam-site borings of 1945.

The subdivision boundaries indicated on the log in figure 3 are those in recent common use and date from Gayle Scott's early works (1930; Scott and Armstrong, 1932; Armstrong and Scott, 1930) in Parker and Wise counties to the west and northwest of Tarrant County.

Stratigraphic annotations. — Taff, in part through erroneous matching of partial sections, never fully understood the relation of this locality to others either south or north. Relying mostly on the range of *Exogyra texana* (="Texana Beds") and occurrences of rudists (= "Caprina Beds"), he considered the intervening Comanche Peak to be the upper 18 feet of the section below the Kiamichi with the uppermost 4 feet, from which he reported a caprinid, representing the "Caprina Limestone" which occurs to the south.

Hill, using Taff's erroneous data, extended the Goodland from the north, as the "Caprina" plus Comanche Peak equivalent, but erred in his correlation of the Walnut interval as recognized to the south.

Winton and Adkins (1920) extended the Goodland down to the top of the main Walnut shell beds, the position subsequently accepted by most workers in the northern area. Their placement of the lower limit of the Walnut, to include upper Paluxy sands different in character from those below, was influenced by mis-identification of lenticular fossiliferous limestones just above the proposed boundary as Walnut rather than Glen Rose as later determined by Scott (1930, 1940). The top of the Paluxy has since been recognized as the shell bed-sand contact, following Taff's usage.

Thompson considered the name Goodland as a synonym of Comanche Peak but this conclusion is debatable. Advocating a consistent nomenclature usage, he correctly placed the Comanche Peak-Walnut-Paluxy boundaries at the positions recognized in the respective type localities to the southwest. It may be noted that the nomenclature and boundary positions recommended by Thompson could be used as

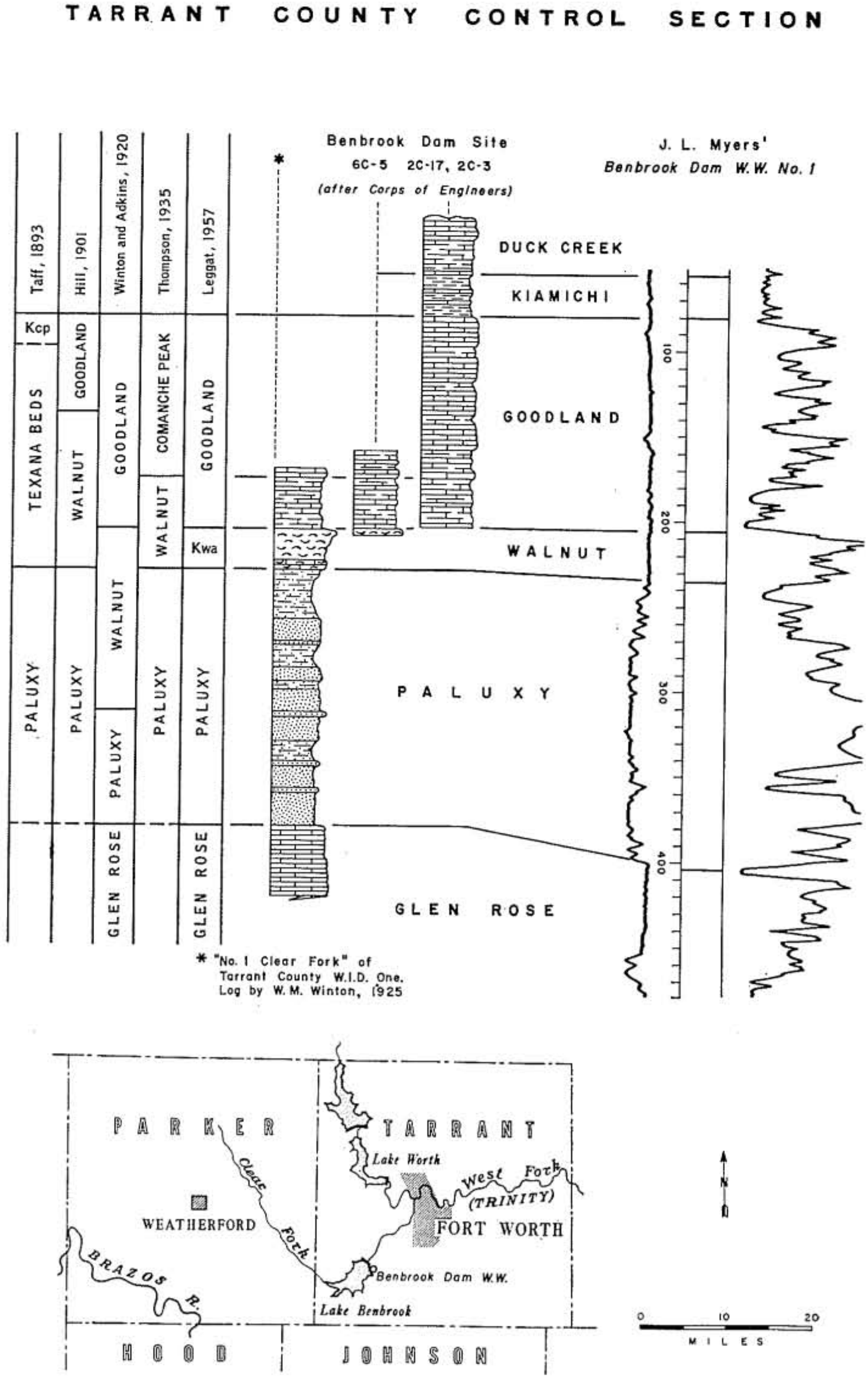

Fig. 3. Tarrant County control section.

logically in the transitional area of Tarrant County as those currently accepted through usage.

Hood-Johnson County Control Section

Comanche Peak, the famous Indian landmark south of Granbury, Hood County, was examined in reconnaissance by Shumard prior to the Civil War. This Edwards-capped topographic prominence rising 200 feet above the Paluxy sands which encircle its base has become the classic exposure of the Fredericksburg in the northern Brazos Valley. The section exposed at the peak is typically represented in logs at Cleburne, Johnson County, about 25 miles to the east (fig. 4).

Taff, Hill, Thompson, and Ikins have referred to the Comanche Peak locality with general agreement on the section excepting the limits of the Comanche Peak formation. This strange situation, with reference to the type section of the unit, is traceable in part to Hill's ambiguous statements of thickness in his original definition.

Stratigraphic annotations. — The Edwards-Comanche Peak contact is uniformly determined at the base of the scarp-forming, massive, rudist-bearing limestone capping the peak. Taff's "Caprina Limestone" is Shumard's early paleontologic designation of the Edwards.

Hill, in both his 1892 and 1901 reports on the section at Comanche Peak, gave ambiguous thicknesses of 66 and 99 to 100 feet in his treatment of the type Comanche Peak unit. The lesser interval conforms to Taff's Comanche Peak, as indicated. The greater thickness, however, is more consistent with Hill's emendation of the "Texana Limestone" in the type Walnut section to the south. Consistent practice would result in placing the Walnut-Comanche Peak contact 100 feet below the base of the Edwards, at the position recognized by Thompson and as projected on the log.

Ikins' upper limit of the Walnut here and at other localities to the south was determined at the highest occurrence of chalky or marly limestones bearing the keeled, flat ammonite *Oxytropidoceras.* This questionable criterion would result in assigning almost all of the Goodland formation in Tarrant County to the Walnut.

Thompson described the Paluxy-Walnut contact as abrupt and disconformable, as it is to the north. Taff and Hill placed the contact at the base of a 15-foot transitional interval of "arenaceous lime marls with *Gryphaea.*" This transitional interval has not been confirmed, in this area, by later work.

The Kiamichi, absent by denudation from the top of the peak, is given an average outcrop thickness of 18 feet in Johnson County (Winton and Scott, 1922). At Comanche Peak, the Paluxy sands have been estimated by Hill and others to be 100 to 125 feet thick. These intervals approximate those determined in the Cleburne log.

Bosque-Hill County Control Section

Sections in the area of Bosque and Hill counties (fig. 5) introduce changes from the stratigraphic relations observed to the north. These differences relate specifically to the nature of the Kiamichi-Edwards contact and the changing position of the Walnut-Paluxy boundary. Evidence of a disconformity on the top of the Edwards increases in significance in the Coryell-McLennan area to the south. Of similar significance is the lateral intercalation of sand (Paluxy) and argillaceous or calcareous strata (Walnut) that results in the complete replacement of the sand by calcareous strata in southern Coryell and McLennan counties.

Outcrop data in the Walnut Springs area were detailed originally by Taff. The type section of the Walnut formation was defined by Hill from these data and Thompson added later observations in the same area. Cores from dam-site investigations (Hull, 1951) along the Brazos River (near Kopperl, northeastern Bosque County, and at Lake Whitney Dam 15 miles south-southeast) provide basic data on the Walnut-Paluxy relations. Observations on the Kiamichi-Edwards contact in the vicinity of Whitney Dam have been re-

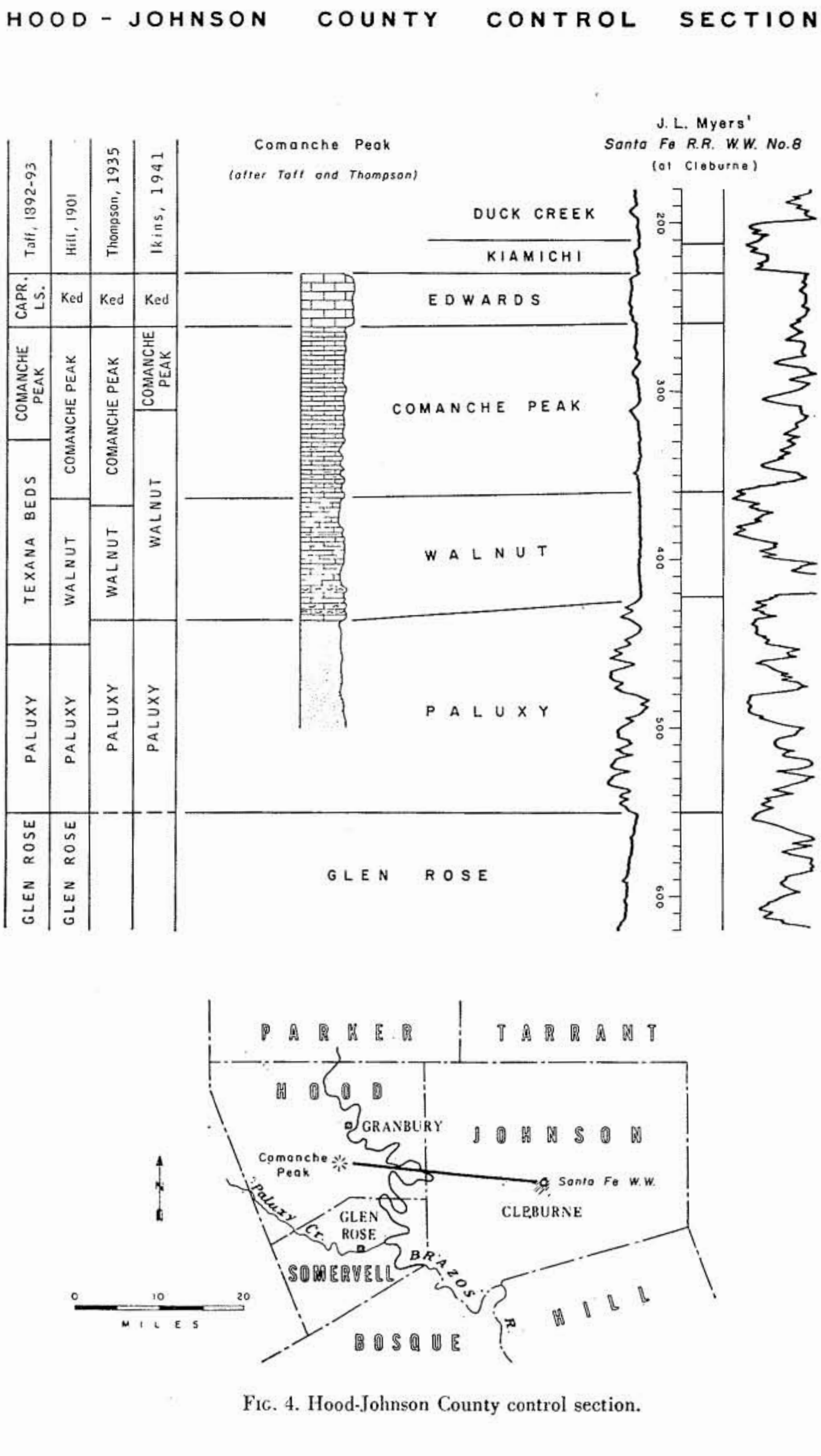

FIG. 4. Hood-Johnson County control section.

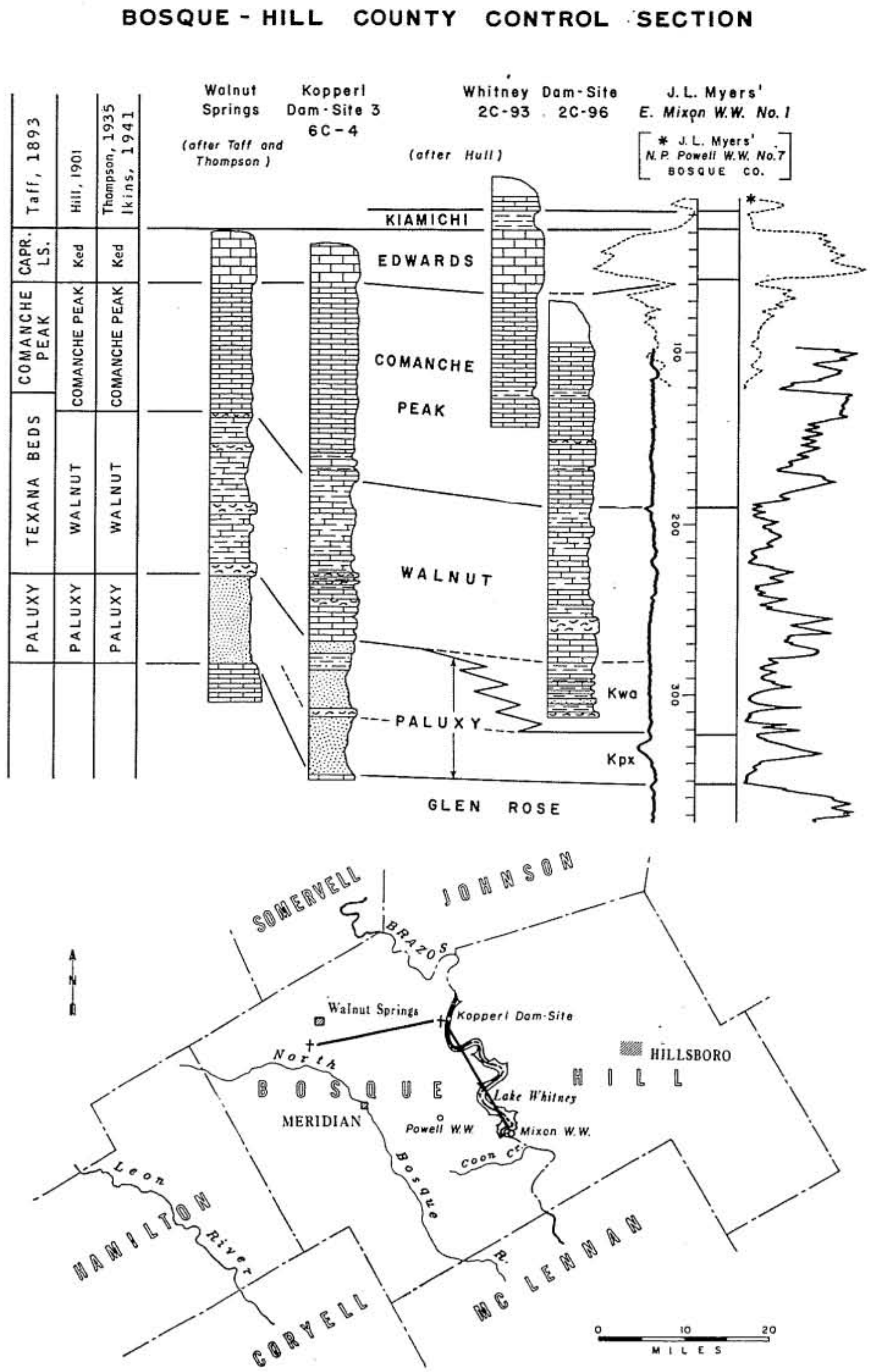

FIG. 5. Bosque-Hill County control section.

corded by Taff, noted by the writer in the company of Corps of Engineers geologists, and treated in detail by Shelburne (1956).

Stratigraphic annotations.—Hill emended Taff's "Texana Limestone" to exclude 10 to 15 feet of fossiliferous chalky limestone at the top and thus defined the type section of the Walnut formation. With this slight change, all boundary determinations of later investigators are in agreement with those of Taff, are readily recognized in the Kopperl core 15 miles east, and can be accurately projected into logs of wells in northwestern Hill County.

At Kopperl and at Lake Whitney Dam the Walnut and Paluxy interval at both sites is about 165 feet. Correlations between the two localities can be closely controlled by persistence of lithologies, or interval matching when necessary. Without question, it is evident that the upper Paluxy sands of Kopperl pass laterally into calcareous shales and thin shelly limestones at Whitney to be assigned to the Walnut formation. This argillaceous-calcareous facies, of Walnut aspect lithologically and paleontologically, in turn is transitional into the underlying Paluxy sand through a few feet of interbedded sand and shell beds. The result is a stratigraphic lowering of the Walnut-Paluxy contact by lateral and vertical intercalation as diagrammed.

A mile and a half north-northeast of Whitney Dam, the upper surface of the Edwards is vertically bored and the elongate cylindrical holes, 0.1 to 0.5 inch in diameter, are locally filled with sand from the overlying basal Kiamichi. The basal sand is a foot thick. Similar evidence of a possible interruption in deposition at the Kiamichi-Edwards contact was noted by Taff a few miles southeast of the dam (on Coon Creek in Bosque County) where he observed a "commingling" of Kiamichi gryphaeas and Edwards caprinids "at the contact on the surface of the hard Caprina limestone." Advancing a case for paleontologic affinity between the two formations, he did not suggest the possibility of reworked fossils.

Coryell-McLennan County Control Section

Within Coryell County, the Kiamichi and Paluxy disappear as mappable units and the Edwards probably increases abruptly in thickness. Despite the strategic location of the county in the mid-Comanche outcrop belt, stratigraphic progress in the form of outcrop data sufficiently controlled to demonstrate the nature of these important relations has been negligible. Recent work by O. B. Shelburne on the Kiamichi and H. F. Nelson on the Edwards are notable exceptions.

Continuous outcrop sections of the total interval, Kiamichi to Paluxy inclusive, are confined to the area north of Gatesville and east of the Leon River (fig. 6). The section exposed near the State Reform School has been generalized by Thompson and reviewed by Ikins. A composite of two sections by McBride (1953) in the southeastern corner of Hamilton County, just north of the Hamilton-Coryell County boundary, is in gross agreement with the Gatesville section and includes the Paluxy, overlooked by Thompson in the area of his section (Lozo, 1949).

The Gatesville reference section is basically the same as the Whitney Dam section and the same structural-stratigraphic relations continue into northern McLennan County. Southward of Gatesville, near the Coryell-Bell County line, the southern limit of the continuous Kiamichi outcrop is reached and the replacement of the Paluxy by the Walnut is completed. The same stratigraphic relationships are maintained in southern McLennan County, and the log of the well at Moody was selected as typical of these developments.

Stratigraphic annotations.—The Kiamichi thins to zero by basal onlap, a conclusion independently derived from outcrop observations by Shelburne to the north, deduced from subsurface relations to the southeast by the writer, and supported by ammonite zonal studies of Young (1956).

By projection of relations observed in Bell County and to the south, the remnant Edwards exposures in western Coryell

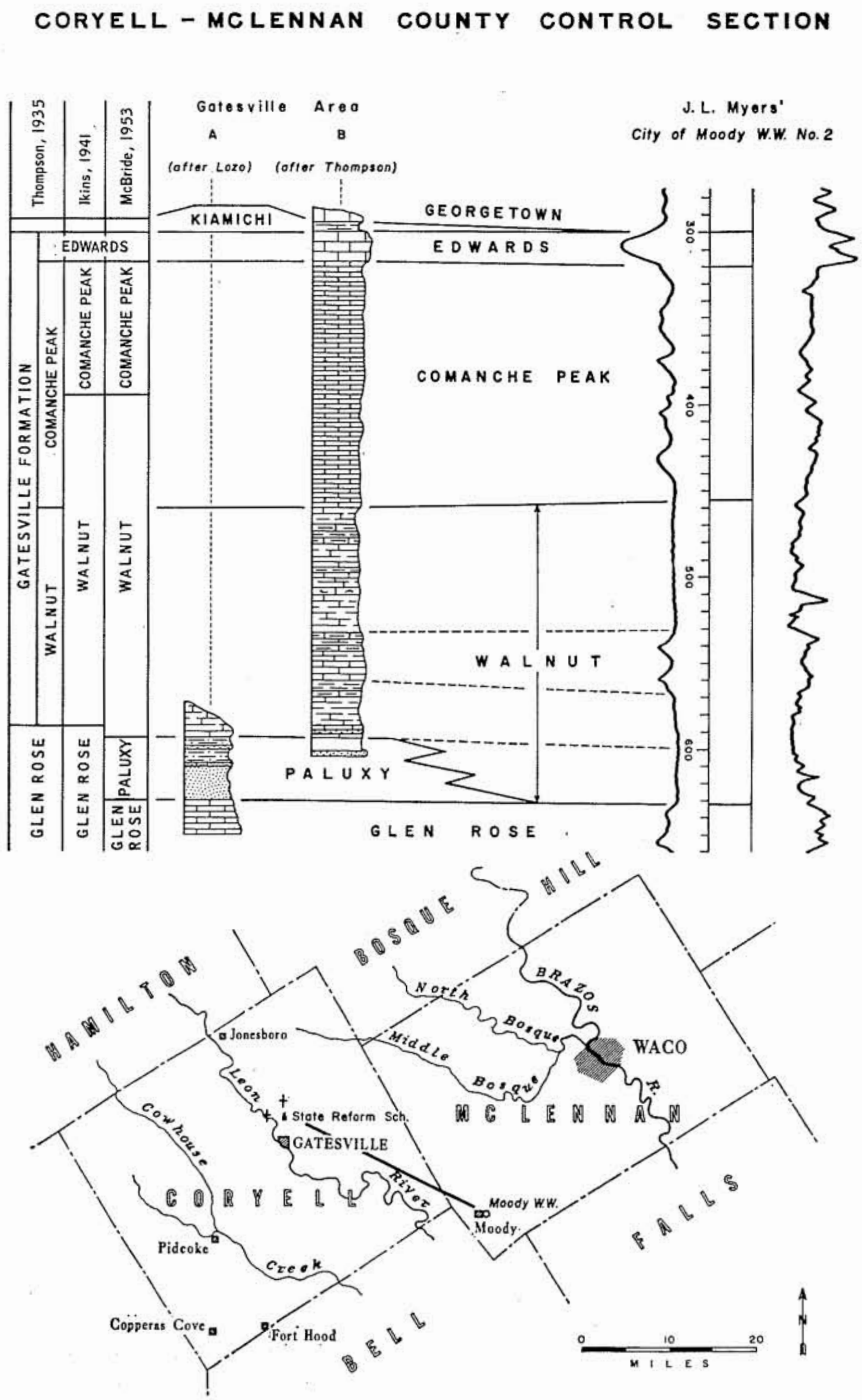

FIG. 6. Coryell-McLennan County control section.

County (on the divides adjacent to Cowhouse Creek) probably represent stratigraphically lower rocks than the Edwards to the east. This interpretation remains to be checked in the field.

The Comanche Peak-Walnut boundary of Thompson and the writer is that of the type Walnut section. McBride's agreement with Ikins' placement is fortuitous; in a northern Hamilton County section, his determination approaches the lower stratigraphic position.

The Paluxy at Gatesville was not recognized by Thompson and Ikins who placed the uppermost few feet of sand observed in the Glen Rose. This follows an earlier error of Hill who presented two versions of the Paluxy outcrop in Coryell County. In Hill's "Black and Grand Prairies" report of 1901, one map (Pl. LXVI, dated 1899) shows the Paluxy outcrop terminated at Jonesboro, just south of the Hamilton-Coryell County line. On another map (Pl. LXX, dated 1900), he correctly extended the outcrop down both sides of the Leon Valley to a position just south of Gatesville. Other Paluxy outcrops, not shown by Hill, occur to the west along Cowhouse Creek and its tributaries. It is from these outcrops, in the Pidcoke-Copperas Cove-Fort Hood village area, that the Paluxy-Walnut relations indicated can be demonstrated in the field.

The Gatesville formation of Thompson is a cartographic "group" in present stratigraphic taxonomic practice and warrants consideration if the existing ambiguity attached to the name "Fredericksburg" can be clarified.

Central Bell County Control Section

Within Bell County, the major development in the Edwards-Comanche Peak-Walnut sequence is the steplike southward replacement of chalky Comanche Peak limestone by Edwards limestones of various types. This feature and other observations derived from study of the exposures in western Bell County were reported by Adkins and Arick (1930). Their generalized outcrop data on the Fredericksburg formations are in agreement with the more detailed information based on cores at the Belton dam-site (Colligan, 1951). The core data, augmented by sample data from a well at the dam-site, control the units indicated on the log (fig. 7).

Stratigraphic annotations.—The nature and position of the upper and lower limits of the Fredericksburg interval, as developed in southern McLennan County, continue without change through Bell County. Of the total interval, the Walnut formation comprises approximately the lower half and is essentially of constant character throughout the area. With some uncertainty in regard to the regional relations of the lowermost 20 to 25 feet of the Walnut, the total thickness indicated on the log is comparable to the outcrop interval of 165 to 170 feet determined by Adkins and Arick.

The Edwards limestone varies from 30 to 40 feet in the north to approximately 100 feet at the Bell-Williamson County line. The increase is known to be abrupt and at the expense of the underlying Comanche Peak in certain places; in other instances, mound or ridge build-ups by increased rate of calcareous deposition in the upper part of the Edwards may be a contributing factor. With respect to compensating thickness changes betwen the Edwards and Comanche Peak, the relative importance of lateral intercalation and gradational facies remains to be determined.

Central Williamson County Control Section

In northern Williamson County (fig. 8) intermediate between the county line and the city of Georgetown, the Edwards continues to thicken at the expense of the Comanche Peak, and the Comanche Peak, in turn, encroaches on the upper part of the Walnut. These changed relations result in the formation intervals and contact positions at Georgetown indicated on the log and are confirmed by sample data.

The logged section is controlled by exposures west-northwest of Georgetown. In the area of Pilot Knob (U.S.C.G.S. Station "Gabriel"), an Edwards-capped prominence 15 miles distant, Taff and Ikins are

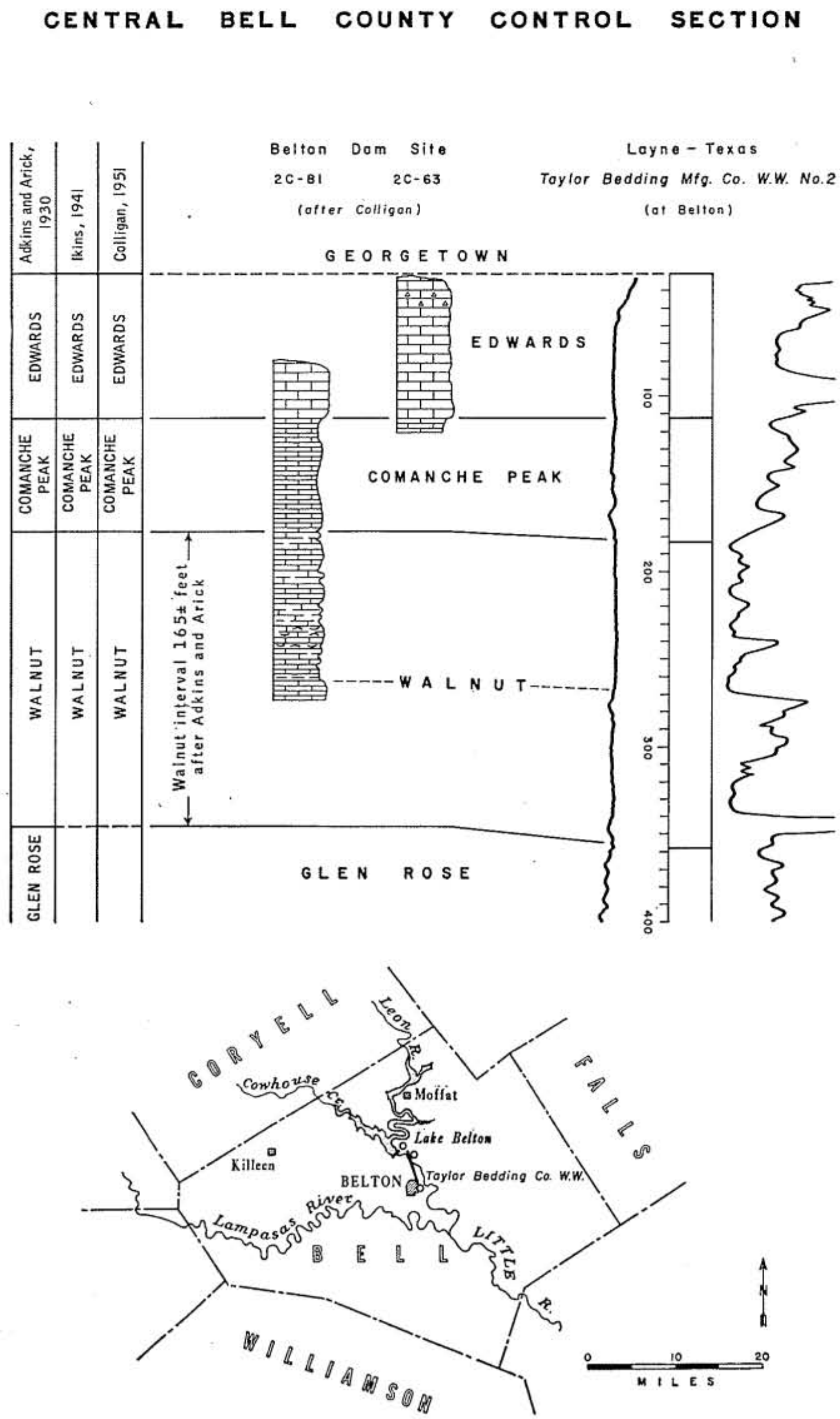

FIG. 7. Central Bell County control section.

CENTRAL WILLIAMSON COUNTY CONTROL SECTION

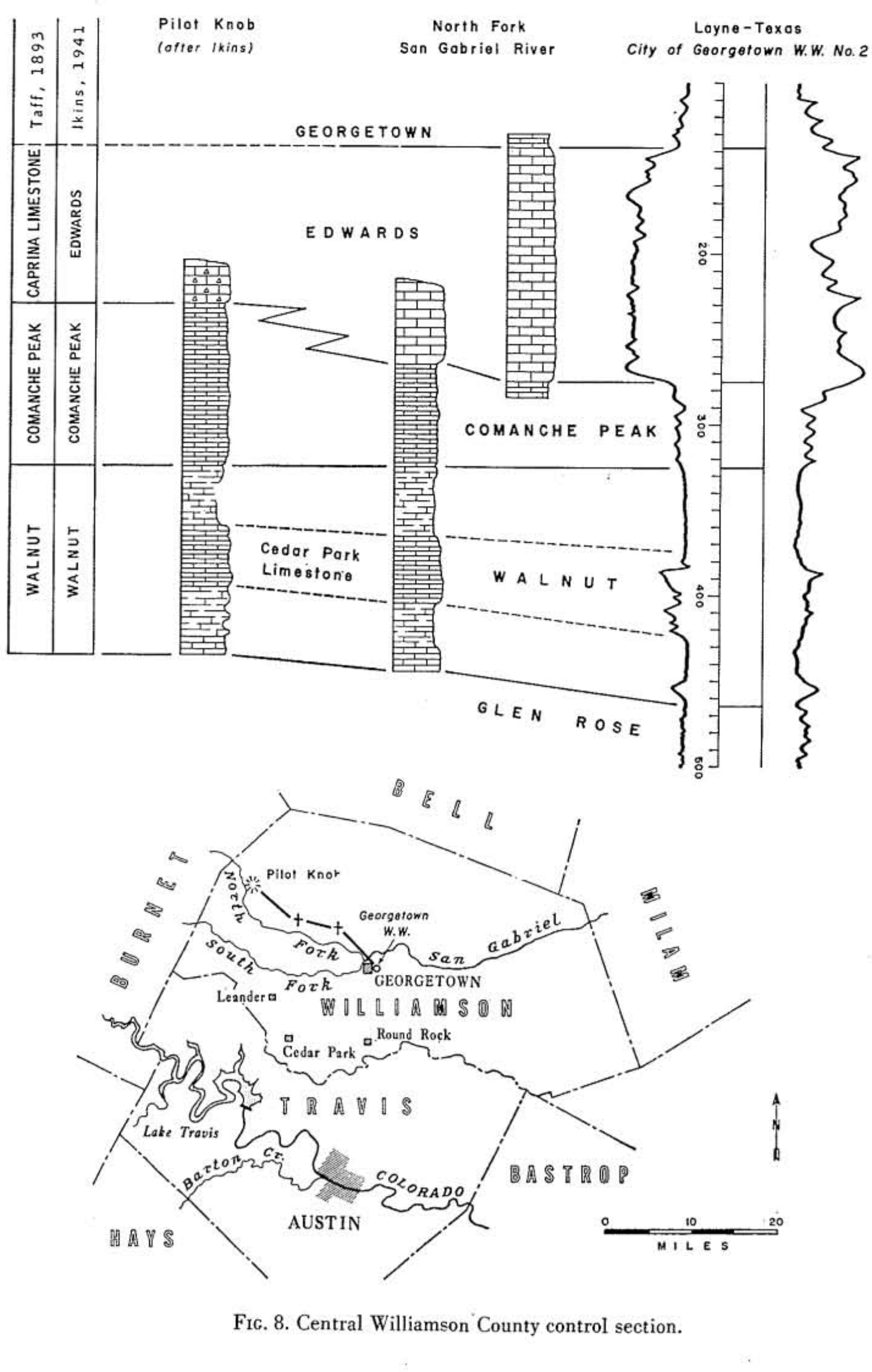

FIG. 8. Central Williamson County control section.

in basic agreement on the Comanche Peak-Walnut boundary and the thickness of each formation. Midway between Pilot Knob and Georgetown, in the vicinity of the westernmost outlier of the Georgetown limestone, outcrops in the valley of North Fork of San Gabriel River permit compilation of the total Fredericksburg section. The subdivisions recognized in the compiled section are essentially those of the subsurface log.

Stratigraphic annotations.—Ikins detailed the Walnut section at Pilot Knob, and the three approximately equal subdivisions recognized can be matched in the San Gabriel and Georgetown sections of the Walnut. With the middle member, the Cedar Park limestone of Adkins (1933), used as a datum, the base of the Comanche Peak is indicated to be essentially constant in stratigraphic position. Whether or not the stratal ascent of the base of the Edwards west of the San Gabriel section can be projected any significant distance beyond Pilot Knob is entirely conjectural.

A possible disconformity at the Walnut-Glen Rose contact is present 3 miles north-northwest of Leander, at the Austin-Lampasas highway (US 183) crossing of the South Fork of San Gabriel River. The uppermost bed of the Glen Rose is extensively riddled by pholad borings. The same feature with the same possible interpretation was noted by Adkins and Arick (1930) in a Bell County contact taken to be the top of the Glen Rose. The extent and significance of this possible surface of disconformity northeast of the Llano uplift are problems for future study.

REGIONAL STRATIGRAPHIC RELATIONS

In preceding pages local outcrop or cored reference sections, showing well-defined formation units, have been matched with nearby logs to identify the electric log units. The interpreted relations of these formations, as indicated on these and additional logs, are illustrated on the regional cross sections (fig. 10). The line of section, adjacent to the outcrop, is from the vicinity of Fort Worth southward toward Austin (fig. 9). On Section A-B, from Benbrook to South Bosque, the major features concern the southward onlap of the Kiamichi and the relation of the Paluxy to the Walnut. On Section B-C, from South Bosque to south of Georgetown, the major change is the increase in thickness of the Edwards. In summary, the following points may be emphasized.

(1) Between the Kiamichi or Georgetown above and the Glen Rose below, each mappable unit (Goodland, Edwards, Comanche Peak, Walnut, and Paluxy) is locally transitional into the contiguous unit, laterally or vertically, or both.

(2) The disconformable Georgetown-Edwards contact in the southern area passes northward into the conformable but abrupt contact of the Kiamichi on the Edwards or Goodland. Similarly, the probably disconformable Walnut–Glen Rose contact in the southern area passes northward into the probably conformable but abrupt contact of the Paluxy on the Glen Rose. These continuous surfaces are considered datum planes that in effect bracket a genetically and diastrophically related interval of the stratigraphic record. The included interval is herein termed the Fredericksburg division.

(3) Classification of the Fredericksburg as a division follows the early usage and concept of R. T. Hill, emphasizing a major and distinct cycle of sedimentation producing an integrated subseries. In stratigraphic nomenclature, a *division*, thus defined, is distinct from both the paleontologically defined *stage* and the cartographic, lithologically defined association of formations usually called a *group*.

(4) In the area of the regional cross section (A-B-C), the total Fredericksburg interval is about 325 feet thick in which the Paluxy sand composes up to 50 per cent of the total interval. This may be a significant indication of the probably minor importance of the Walnut-Paluxy disconformity in the area from Hill County northward. The disconformity, reflecting marine transgression, is conceived to result from rhythmic progression of successive minor onlaps of marine on nonmarine strata. Implied is the interpretation that the underlying Paluxy, at any one locality, is but slightly older than the overlying Walnut at the same locality. In the regional setting, the Paluxy is essentially a phase of dominantly nonmarine deposition contemporaneous with the offshore marine deposits of the lower Fredericksburg.

(5) The Edwards limestone is a geometric analogue of the Paluxy sand within the total Fredericksburg interval but is geographically opposed in direction of increasing thickness and in area of occurrence. The sedimentary cycle initiated by the influx of terrigeneous clastics (Paluxy) from the northwest and north suggests a rejuvenation in these source areas possibly accompanied by a change in climatic conditions. The terminal phase of the cycle, marked by shallow and clear water free of land-derived detritus, is reflected in the calcareous carbonate deposits, locally zoogenic, of the Edwards limestone.

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Deposition and Alteration of the Edwards Limestone, Central Texas

HENRY F. NELSON[2]

ABSTRACT

The Edwards limestone is the uppermost formation in the Fredericksburg group (Early Cretaceous epoch). In the vicinity of the Red River, the group is composed predominantly of terrigenous clastic sediments. To the south, the terrigenous sediments grade into the marls, shell beds, and nodular limestones of the Walnut and Comanche Peak formations. The latter, in turn, grade into the Edwards formation farther south. Near Austin, the Edwards formation constitutes most of the Fredericksburg group.

At various localities in Bell, Coryell, and McLennan counties, the Comanche Peak limestone grades into the Edwards limestone by (1) an increase in grain size, (2) a gradual increase in the number of rudistids in the upper part of the Comanche Peak limestone, (3) transition of massive nodular limestone into well-bedded limestone, and (4) intertonguing of nodular limestone with rudistid limestone.

The Edwards formation is 16 feet thick north of Gatesville in Coryell County. It increases in thickness to the south and east reaching a maximum thickness of 124 feet near Moffat in northern Bell County. South of Moffat, it decreases in thickness. It is 68 feet thick at locality 14-T-8 southwest of Belton. Variations in thickness of the Edwards formation are due primarily to facies changes of the Edwards limestone into the Comanche Peak limestone. However, topographic relief, due either to local reef growth in the Edwards limestone or erosion of the limestone prior to deposition of the overlying formations, probably caused some variation in thickness.

The Edwards formation is unconformably overlain by the Kiamichi and Duck Creek formations. Evidence for an unconformity includes (1) oxidation and case-hardening of the top of the Edwards limestone, (2) occurrence of small pits and bore holes filled with Kiamichi shale in the top of the Edwards limestone, (3) onlap of successively higher lithologic units of the shale upon the Edwards formation, and (4) onlap and pinchout of the shale around rudistid reefs. There is no evidence of gradation between the two formations. The Kiamichi shale pinches out in southeastern Coryell County along a line extending from Whitson toward Gatesville.

In the area of this study, the Edwards formation is a reef complex made up of massive rudistid biohermal and biostromal reefs that grade laterally into well-bedded inter-reef deposits. Biohermal reefs are composed of a mass of rudistids and associated organisms embedded in a very fine-grained matrix. Three faunal zones can be frequently recognized. A coral zone in which *Cladophyllia* is prominent occurs at the base of the reefs. The *Cladophyllia* zone grades upward into a zone of *Toucasia* and *Monopleura*. The *Monopleura*-*Toucasia* zone grades upward and outward from the reef core into the zone of *Caprinuloidea*, *Eoradiolites*, and *Chondrodonta*. The biohermal reefs range from a minimum thickness of 9 feet to a maximum known thickness of 55 feet. The reef cores grade laterally into more fragmental flank beds that dip away from the cores with inclinations as great as 35°. In some places, the biohermal reefs apparently stood at least 20 feet above the surrounding sediments.

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The inter-reef sediments are composed of well-sorted calcilutites, calcarenites, and poorly sorted shell debris. Most particles are well rounded and are composed mainly of "original" shell fragments, recrystallized shell fragments, and opaque grains. The particles are cemented with clear calcite that is believed to be an original precipitate rather than a product of recrystallization. The chert in the inter-reef facies is a primary deposit.

Primary dolomite occurs as beds and as crystals disseminated in limestones and chert. Dolomite also occurs as a diagenetic mineral in the matrix of limestones, in the body chambers and shell walls of fossils, in bore holes, and in voids in reef limestones.

In Bell and southeastern Coryell counties, south of the pinchout of the Kiamichi shale, the Edwards formation has been altered by post-lithification processes which include solution, recrystallization, cavity filling, dolomitization, and silicification. The resulting limestones are characteristically mottled shades of brown, yellow, and pink. They are hard dense crystalline limestones that occur as beds, concretions, and irregular-shaped masses. Post-lithification dolomite is soft, very finely crystalline, and has excellent intercrystalline porosity, except where it has been cemented by subsequent precipitation of calcite in the pores.

This study and a previous study (Feray and Nelson, 1956) have shown that post-lithification dolomite occurs where the Kiamichi shale is thin or absent and that dolomitization took place prior to deposition of the Duck Creek limestone. The time when the crystalline and silicified limestones formed has not been positively established. Some of them formed after dolomitization. Extensive chalkification of the Edwards limestone appears to be related to present-day topography.

During the Early Cretaceous epoch, the rudistids and associated organisms formed one of the most extensive reef complexes in geologic history. At the beginning of Fredericksburg time, the fauna began to migrate northwestward from the main reef trend. As they migrated, they transgressed the Fredericksburg group and formed a reef complex along the west side of the Tyler basin. The reef complex, which is described in this study, effectively subdivided the lagoon behind the main reef trend into two parts: the Austin lagoon in which rudistid biostromes, granular limestones, and chert (Edwards) were formed and the Tyler lagoon in which the Paluxy, Walnut, and Comanche Peak formations were deposited. The Fredericksburg age was brought to a close by regional uplift, but before uplift took place, reef growth had ceased and sedimentation had essentially filled the inter-reef basins to the crests of the reefs. Uplift was apparently not very great. Following uplift, the Edwards limestone was subjected to post-lithification alteration that developed new types of carbonate rocks.

INTRODUCTION

The Edwards formation in north-central Texas is made up of many types of relatively pure limestones and dolomites. This paper describes the various types of rocks and attempts to show their relation to each other and to their environments of deposition. The paper is limited primarily to the physical features of the rocks and to the stratigraphic relationship of the Edwards formation to adjacent formations. A detailed study of the faunal features of the Edwards formation is beyond the scope of this report. Such a study from an adjacent area is presented by Young in another paper in this volume.

The area discussed in this paper is located in the western parts of McLennan and Bell counties and the eastern part of Coryell County (fig. 11). It is bounded on the north by Bosque County, on the west by the Leon River and a line extending north from Gatesville to the Coryell County line, on the south by U.S. Highway 190, and on the east by the downdip limit of the Edwards outcrop.

The paper is based upon field mapping of the Edwards formation in McLennan County and a reconnaissance study in Bell and Coryell counties. The investigation went through four phases: (1) a preliminary survey to determine the nature of the problems which might be encountered, (2) mapping the rudistid and the inter-reef facies of the Edwards limestone on aerial photographs of McLennan County. (3) mapping the various types of lithology on photographic mosaics of representative outcrops of the Edwards formation, and (4) a petrographic study of hand specimens and thin sections. The latter phase was accompanied by X-ray diffraction and chemical analyses in order to determine the relative abundance of calcite and dolomite.

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Dr. Keith Young visited outcrops with the writer and identified many of the fossils.

Mr. A. B. Craig and Mr. A. A. Buford cut and polished many of the rock specimens, and Mr. L. O. Price prepared the samples for X-ray analyses. Analysis of the samples was done by Mr. Everett Glover.

Messrs. J. W. Macon, Joseph Walton, Dan F. Scranton, and J. M. Tabor drafted the maps and illustrations.

Mr. D. R. Miller assisted in preparing the photographs and Mr. A. S. Pearce helped prepare the plates.

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FIG. 11. Index map of Texas showing location of area.

TERMINOLOGY

In the course of writing this paper, standard terminology has been used as often as possible. Frequently, because of conflicting opinions regarding the meaning of terms, the writer has found it necessary to apply his own definition to a term or to introduce a new one. Insofar as possible, these terms and definitions are descriptive rather than genetic. The terms and their definitions are as follows:

Bank—see skeletal limestone.
Bioherm—see skeletal limestone.
Biostrome—see skeletal limestone.
Bedding—no attempt has been made to measure the absolute thickness of beds.
  Terms denoting thickness have the following general meanings:
    thin-bedded—less than 6 inches thick.
    medium-bedded—6 inches to 1 foot thick.
    thick-bedded—1 to 2 feet thick.
    massive—more than 2 feet thick.
In addition, bedding is described as even, wavy, and irregular. These terms have the following meanings:
    even—bedding formed by essentially smooth bedding planes that have no relief. Adjoining bedding planes may or may not be parallel.
    wavy—bedding formed by undulatory bedding planes. Beds vary in thickness. The undulations of adjoining bedding planes may intersect to produce a nodular structure.
    irregular—bedding formed by bedding planes which have extremely variable relief. As a result, individual beds vary considerably in thickness.
Calcarenite—see rock terms.
Calcilutite—see rock terms.
Cementation—the process by which sediments become harder by the chemical precipitation

of a mineral in the interstices.

Chalkification—the conversion of rock to soft white microgranular calcite by weathering processes.

Chalky—see rock terms.

Clastic—see rock terms.

Dense—refers to rock which is very hard, usually fine-grained, and has low porosity.

Detrital—see rock terms.

Diagenesis—"those changes of various kinds occurring in sediments between the time of deposition and the time at which complete lithification takes place" (Howell, 1957).

Dolomitization—the process whereby a rock becomes dolomite by substitution of magnesium carbonate for a portion of the original calcium carbonate.

Granular—see rock terms.

In situ—strictly speaking, this term means "in its natural position." In this paper, it means "essentially in its natural position." Thus, a reef-building organism, though torn from its growth position, is considered to be in situ so long as it remains at its growth site.

Inter-reef facies—"the sediments deposited between reefs" (Nelson, Brown, and Brineman, in preparation).

Lime-mud—an aggregate of sand, silt, and clay-sized particles of calcium carbonate having a high water content.

Lime-sand—an aggregate of calcium carbonate particles which are more than 0.06 mm in diameter.

Lime-silt—an aggregate of calcium carbonate particles which are less than 0.06 mm in diameter.

Lithification—"the complex of processes that converts a newly deposited sediment into an indurated rock" (Pettijohn, 1957, p. 648).

Particle terms—many types of particles make up the Edwards limestone. Among these are microfossils, sponge spicules(?), oolites, and other fragmentary particles of calcium carbonate. With the exception of the last-named group, each is referred to by its proper name. The remaining particles, which make up most of the Edwards limestone, are subdivided into three types:

"original" shell fragments—fragments considered to be the original material secreted by the organism. On polished rock specimens, "original" shell material is tan to gray in color. In thin sections, this material is colored various shades of gray and may exhibit slight tinges of brown or green. Minute structures, such as striations and laminations, are characteristic of "original" shell material. Under crossed nicols, it may have a prismatic, lamellar, or fibrous structure and exhibit undulose extinction.

recrystallized shell fragments—fragments composed of a mosaic of clear crystalline calcite. They may or may not be surrounded by a dark "dust" rim in thin sections. They have the appearance of white sand grains in the outcrop. Strictly speaking, not all grains having this appearance are recrystallized shell fragments. Small particles are in part well rounded. They exhibit neither the structure nor an external shape which would identify them as shells. However, because of their structural similarity to larger grains which have external shapes that identify them as shell fragments, and because a complete gradation exists between these particles, the small well-rounded ones are classified as recrystallized shell fragments.

opaque grains—dark structureless particles which are composed of microgranular calcite. Generally, they are silt-sized and have very fuzzy outlines.

Penecontemporaneous—formed at essentially the same time as deposition of the surrounding sediments.

Primary—"characteristic of or existing in a rock at the time of its formation" (Rice, 1951).

Recrystallization—"the formation of new mineral grains in a rock while in the solid state. The new mineral grains may or may not have the same chemical and mineralogical composition as the original rock" (Howell, 1957).

Reef complex—"the aggregate of reef, fore-reef, back-reef, and inter-reef deposits which are bounded on the seaward side by the basin sediments and on the landward side by the lagoonal sediments" (Nelson, Brown, and Brineman, in preparation). This is essentially the same concept as that expressed by Henson (1950).

Replacement—the process by which one mineral or chemical substance takes the place of another, often preserving the structure or crystalline form of the original substance.

Rock terms—a generalized classification of carbonate rocks is shown in figure 12. On the basis of textures and composition, most of which can be observed in the field, the following types of rock lithology have been mapped or are discussed:

calcarenite—a limestone composed of detrital grains which range from 0.06 to 2 mm in diameter. Synonymous with granular limestone.

calcilutite—a limestone composed of detrital grains which are smaller than 0.06 mm in diameter. Synonymous with fine-grained and microgranular limestone.

calcitic dolomite or calcitic chert—dolomite or chert which contains from 10 to 50 percent calcite.

chalky limestone—limestone which has been partially altered to microgranular calcite. It is softer and lighter colored in the outcrop than the normal limestone; in thin sections, however, it has a very dusty appearance. In extreme cases, the original texture may be almost completely obliterated.

chert—a microcrystalline or microgranular variety of silica.

clastic (fragmental) limestone—a limestone formed from the fragments of older or contemporaneously formed limestone. It does not necessarily imply transportation of the fragments from their site of formation. Synonymous with detrital limestone.

coarse shell debris—a type of limestone composed predominantly of large shell fragments and in which whole shells may be abundant. The fragments are frequently

Rock terms (continued)

large enough to permit the identification of the organism from which they were derived.

crystalline limestone or crystalline dolomite—a limestone or dolomite which has a crystalline texture as observed in the field. An original clastic texture may be apparent in thin sections.

detrital limestone—synonymous with clastic limestone.

dolomite—a rock of which 90 percent or more is the mineral dolomite.

dolomitic limestone or dolomitic chert—limestone or chert containing 10 to 50 percent of the mineral dolomite.

fine-grained (fine granular)—limestone composed of particles (other than crystals) which are less than 0.06 mm in diameter. Synonymous with calcilutite.

fine shell debris—a type of limestone in which small shell fragments are the conspicuous component (though not necessarily the most abundant). Generally, the fragments range in size from 2 to 10 mm. The organisms from which the fragments were derived can rarely be identified except by diagnostic structures within the fragments.

granular limestone—limestone composed of particles (other than crystals) which range from 0.06 to 2 mm in diameter. Synonymous with calcarenite.

marl—a poorly indurated deposit of calcium carbonate in which there is a conspicuous amount of clay. No attempt has been made to set a definite limit on the relative abundance of the two minerals.

microgranular (micrograined) limestone or microgranular (micrograined) chert—limestone or chert composed of grains or crystals which can be discerned only under a microscope. In general, such particles are less than 0.004 mm in diameter.

miliolid limestone—a limestone composed predominantly of Foraminifera of the family Miliolidae.

pulverulent chalk—a white unindurated deposit of very fine-grained or microgranular calcium carbonate. In the area of this study the chalk is the result of weathering action.

rudistid limestone or rudistid dolomite—limestone or dolomite in which rudistids or large identifiable fragments of rudistids are prominent.

silicified limestone or silicified dolomite—limestone or dolomite containing 10 to 50 percent of crystalline quartz deposited as a replacement product or cavity filling.

skeletal limestone—"a limestone which consists of or owes its characteristics to essentially in situ accumulation of calcareous skeletal matter" (Nelson, Brown, and Brineman, in preparation).

Rudistid—a collective term used in this paper to include the aberrant sessile pelecypods belonging to the Rudistacea and Chamacea; mostly thick shelled, highly inequivalved, and coral-like in form.

Rudistid facies—that group of rocks characterized by the prominence of rudistids or large identifiable fragments thereof.

Secondary—"a general term applied to rocks and minerals formed as a consequence of the alteration of pre-existing minerals" (Howell, 1957).

Skeletal limestone terms—terms applicable to skeletal limestone deposits as the term has been defined are as follows:

bank—"a skeletal limestone deposit formed by organisms which do not have the ecologic potential to erect a rigid wave-resistant structure" (Nelson, Brown, and Brineman, in preparation).

bioherm—". . . a reef, bank, or mound; for reeflike, moundlike, or lenslike or otherwise circumscribed structure of strictly *organic origin*, embeddel in rocks of different lithology" (Cumings, 1932, p. 333).

biostrome—". . . purely bedded structures such as shell beds, coral beds, et cetera, consisting of and built mainly by sedentary organisms, and not swelling into moundlike or lenslike forms . . . , which means a bed or layer" (Cumings, 1932, p. 334).

reef—"a skeletal limestone deposit formed by organisms possessing the ecologic potential to erect a rigid wave-resistant topographic structure" (Nelson, Brown, and Brineman, in preparation).

reef core—"that portion of the reef within the rigid growth lattice formed by the framebuilding organisms" (Nelson, Brown, and Brineman, in preparation).

reef flank—"that portion of the reef which surrounds, interfingers with, and sometimes even overlies the reef core" (Nelson, Brown, and Brineman, in preparation). This is a gradational zone where the biologic force of reef expansion contends with the physical and biologic forces of reef destruction. As a result, the sediments exhibit properties of both the reef core and the mechanically deposited inter-reef sediments.

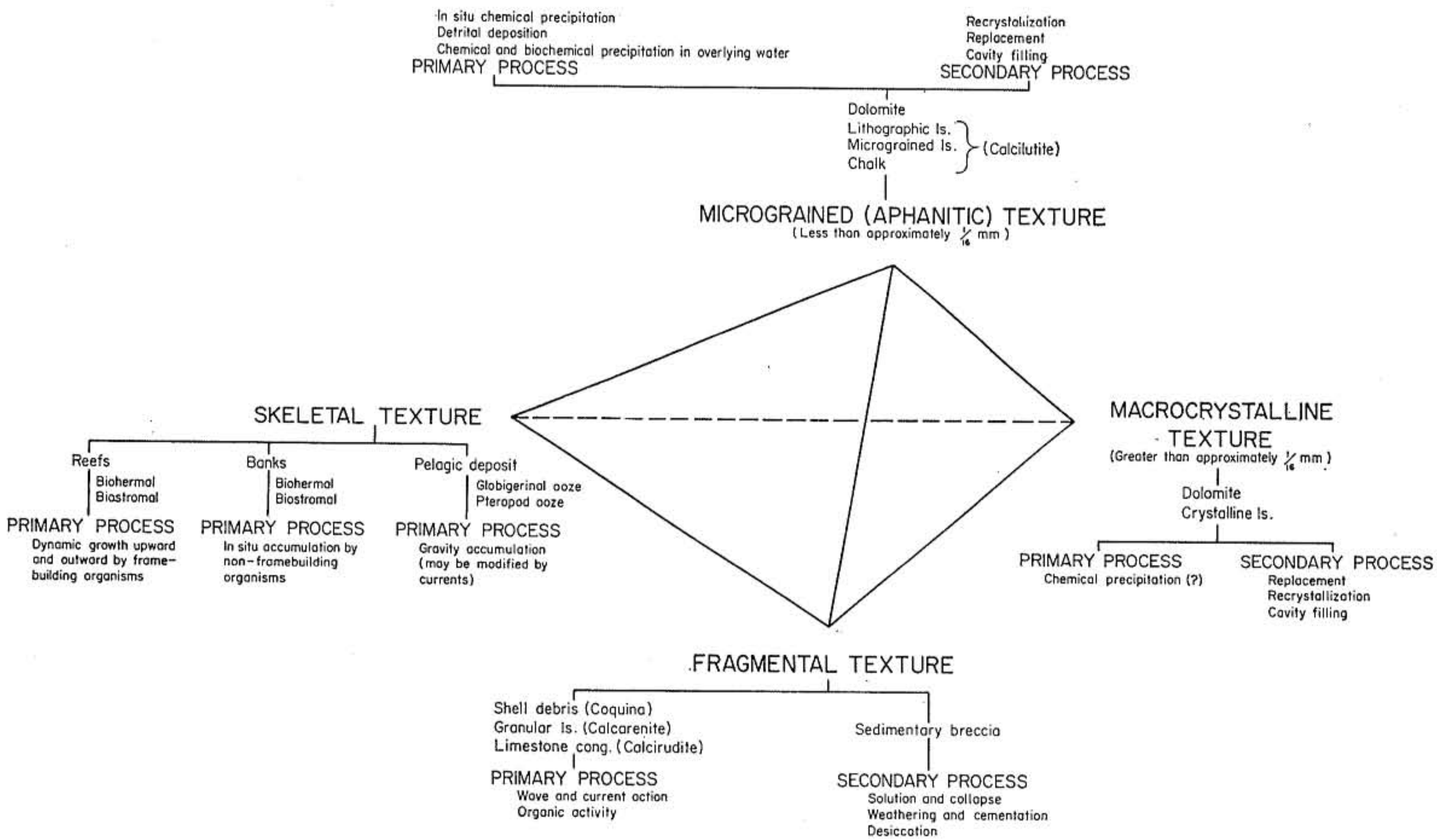

FIG. 12. Schematic diagram of classification of carbonate rocks (modified from Nelson, Brown, and Brineman, in preparation).

REGIONAL GEOLOGY

Structural Setting

The area discussed in this paper is located on the west side of the Tyler basin. The tectonic structure is simple. Beds dip southeastward into the basin at an average rate of 20 feet per mile. Flexures perpendicular to the regional strike of the beds are present but insignificant. Normal faults and flexures which are part of the Balcones fault system in Bell County have been described by Adkins and Arick (1930, pp. 71–74) and Colligan (1951, p. 33). Small faults with a throw of 1 to 3 feet have also been observed by the writer. Locally, the top of the Edwards formation is undulatory owing to reef growth.

Stratigraphic Relations

The formations which crop out within or immediately adjacent to the area are all of Early Cretaceous age and are parts of the Trinity, Fredericksburg, and Washita groups (fig. 13). The regional stratigraphic features of the Edwards formation have been discussed by other writers (Hill, 1891, 1901; Taff, 1892; Taff and Leverett, 1893; Adkins, 1924, 1933; Adkins and Arick, 1930; Thompson, 1935; Lozo, 1944, 1949) and are also discussed by Lozo and Shelburne in this volume. Nevertheless, despite some repetition, it is necessary to discuss the relations of the Edwards limestone to the underlying and overlying formations in this area in order to fully understand the origin of many of the lithologic features of the formation.

THICKNESS OF EDWARDS FORMATION

The Edwards formation ranges in thickness from a minimum of 13 feet to a maximum of 124 feet.

In McLennan County, the Edwards limestone ranges in thickness from 13 to 23 feet in the valley of the North Bosque River east of Valley Mills (fig. 14). It gradually increases in thickness to the southwest. In Hog Creek it is 25 feet thick. Along Bluff Creek and the Middle Bosque

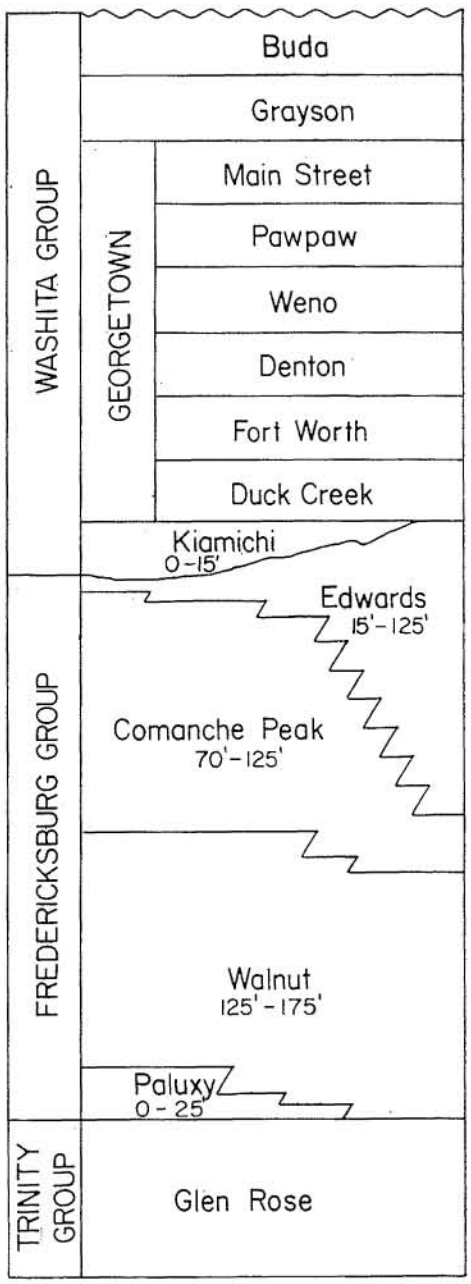

Fig. 13. Columnar section of Early Cretaceous formations in this area.

River near Crawford the thickness ranges from 36 to 45 feet. It reaches a maximum thickness of 56 feet in the northwest corner of the county.

The greatest thickness in Coryell County occurs east of Gatesville near Mountain where it is at least 73 feet thick (fig. 14). The formation decreases in thickness in all directions from this point. It has a minimum thickness of 16 feet at locality 50-T-1 north of Gatesville and is 33 feet thick south of Whitson near the Bell County line (fig. 14).

A marked increase in thickness of the Edwards formation takes place in Bell County as a result of a facies change into the Comanche Peak formation (fig. 14). The formation is approximately 30 feet thick on the west side of the Belton reservoir at locality 14-T-16. On the east side of the reservoir, near White Hall, 43 feet of Edwards limestone is exposed. Three miles to the south, at Moffat, the Edwards limestone is 124 feet thick. South of Moffat, the Edwards formation becomes thinner, but there are no complete stratigraphic sections to indicate the manner of thinning. Two miles southeast of Moffat, near the point where Cedar Creek flows into the Belton reservoir, 105 feet of Edwards limestone is exposed; the top of the formation is estimated to be 5 or 10 feet higher in the section. Eighty-five feet of Edwards limestone was recovered in a core at the southwest end of Belton Dam (Colligan, 1951); the top of the formation was not present. Four miles southwest of Belton, at locality 14-T-8, approximately 25 feet of the lower part of the Edwards formation is exposed. The remainder of the formation and the contact with the overlying Duck Creek limestone are very poorly exposed but, on the basis of topography and vegetation, the contact is believed to be 65 to 75 feet above the base of the Edwards formation. It is possible, however, that faulting has eliminated part of the section and the true thickness of the formation may be greater than indicated.

From the data presented, it is clear that the Edwards formation varies in thickness to a considerable extent. The variation is a result of: (1) a regional facies change of the Comanche Peak limestone into the Edwards limestone, (2) local facies changes of the Comanche Peak limestone into the Edwards limestone, (3) local doming of the Edwards formation owing to reef growth, and (4) erosion of the Edwards limestone prior to deposition of the overlying Kiamichi shale.

RELATION OF EDWARDS FORMATION TO COMANCHE PEAK FORMATION

The lateral equivalence of the Comanche Peak and the Edwards formations on a regional scale has been noted by others and needs no further discussion. The manner of transition, however, warrants some consideration. In this area there are four types of relationships between the two formations: (1) The two formations are in sharp contact with no apparent gradation. In any one outcrop, even in a long continuous exposure, this relationship is the type most frequently observed. If no other relationship were present, there would be no reason to believe that the Comanche Peak and Edwards formations are lateral equivalents. (2) Comanche Peak limestone grades into Edwards rudistid limestone as indicated by the occurrence and gradual increase in abundance of rudistids in the upper few feet of typical Comanche Peak limestone. This type of faunal gradation is not common. (3) Comanche Peak limestone grades into Edwards limestone by a slight increase in grain size, a decrease in the nodular structure, and in places by a better development of distinct beds in the upper few feet of the formation. This relationship occurs rather frequently and may be seen at locality 50-T-12. (4) Beds of "typical" Edwards limestone are intercalated with beds of Comanche Peak limestone (Pl. 1). This feature occurs rather frequently. It may be seen at localities 50-T-7 and 154-T-3 and is the reason for the marked increase in thickness of the Edwards limestone near Moffat in Bell County (Pl. 1; fig. 14). At locality 14-T-3, south of Moffat, the Edwards limestone is 124 feet thick and is marked at the base by 5 to 6 feet of coarse granular and conglomeratic limestone. Three miles to the northwest, at locality 14-T-16, 7 feet of massive conglomeratic *Cladophyllia*-bearing limestone occurs in the Comanche Peak formation. The base of this bed is 117 feet below the top of the Edwards limestone. Lithologically and stratigraphically, this bed appears to correlate with the base of the Edwards limestone south of Moffat and it is therefore considered to be a northwestward-extending tongue of the Edwards formation.

RELATION OF EDWARDS FORMATION TO OVERLYING FORMATIONS

The top of the Edwards limestone is a gently undulatory surface as a result of reef growth. It is unconformably overlain by the Kiamichi shale in McLennan and northeastern Coryell counties. In Bell and southeastern Coryell counties it is unconformably overlain by the Duck Creek limestone (Washita). It is beyond the scope of this paper to dwell at great length upon the stratigraphic relations of the Kiamichi shale to contiguous formations. However, the following features, which have been observed during this study, are worth noting because they have a bearing upon any interpretation of the position of the Kiamichi shale in the Cretaceous section: (1) The Kiamichi shale decreases in thickness to the south and pinches out in southeastern Coryell County (figs. 14, 15). Within this area it has a maximum thickness of 19 feet. (2) The Kiamichi shale onlaps the Edwards formation to the south as demonstrated by the pinchout of successively higher lithologic units in the shale. (3) The Kiamichi shale thins locally over some Edwards reefs and may be totally absent over others. In places, not only the Kiamichi shale but also the lower beds of the Duck Creek limestone are compressed around topographic highs on the Edwards limestone surface. This may be due to primary deposition, later compaction, or both. (4) Two exposures of the contact between the Kiamichi shale and the inter-reef beds of the Edwards formation (loc. 50-T-4 and a roadcut on State Highway 22, approximately 3.7 miles west of Whitney Dam, Bosque County) indicate that the top 1 to 2 feet of the Edwards limestone is argillaceous and contains thin laminations of dark gray shale similar to the lower part of the Kiamichi shale. These two localities are the exception rather than the rule. Normally, the contact between the Edwards limestone and Kiamichi shale is very sharp and the top of the Edwards formation is no more argillaceous than the rest of the formation. (5) Approximately 3 miles east of Valley Mills in a tributary of the North Bosque River, the Kiamichi shale overlies an Edwards reef and contains many abraded and rounded pebbles of Edwards limestone, thereby indicating that the reef was eroded after lithification of the limestone. (6) The upper surface of the Edwards formation is covered with numerous small pits at many places and the top few inches of limestone are oxidized to shades of yellow, brown, and purple. Oxidized nodules of pyrite are common and bore holes frequently penetrate the upper surface of the Edwards limestone. The bore holes, as much as 4 inches long and one-fourth of an inch in diameter, are filled with Kiamichi shale.

The magnitude of the unconformity between the two formations is not definitely known. It has been traced as far north as Whitney Dam where it is still present. Regional stratigraphic studies have shown that the unconformity probably extends for a considerable distance to the south (Feray and Nelson, 1956). Similar studies indicate that it does not extend far into the Tyler basin.

Erosion of the Edwards formation was either not very great or it was uniform over a large area because there is no evidence of channels at the top of the formation. Thinning of the formation south of locality 14-T-3 in Bell County may be due either to truncation of the Edwards limestone or to a facies change of the limestone into the Comanche Peak formation. Such a change would be counter to the normal

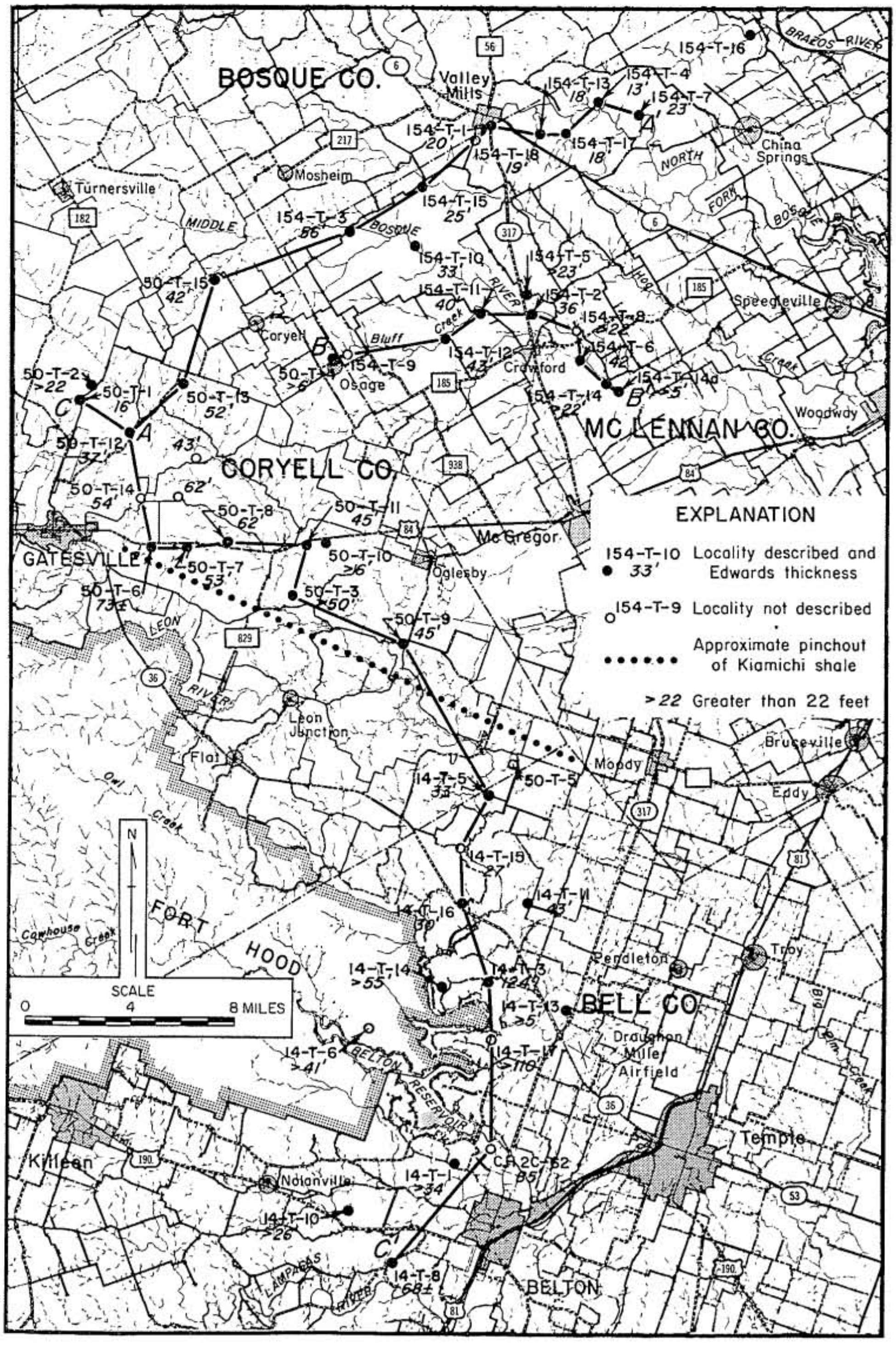

Fig. 14. Map of area showing location of localities and regional stratigraphic cross sections, thickness of Edwards formation, and approximate geographic position of pinchout of Kiamichi shale.

regional transition but it cannot be discounted. Further investigations, both surface and subsurface, are necessary to determine the reason for thinning of the Edwards formation in Bell County.

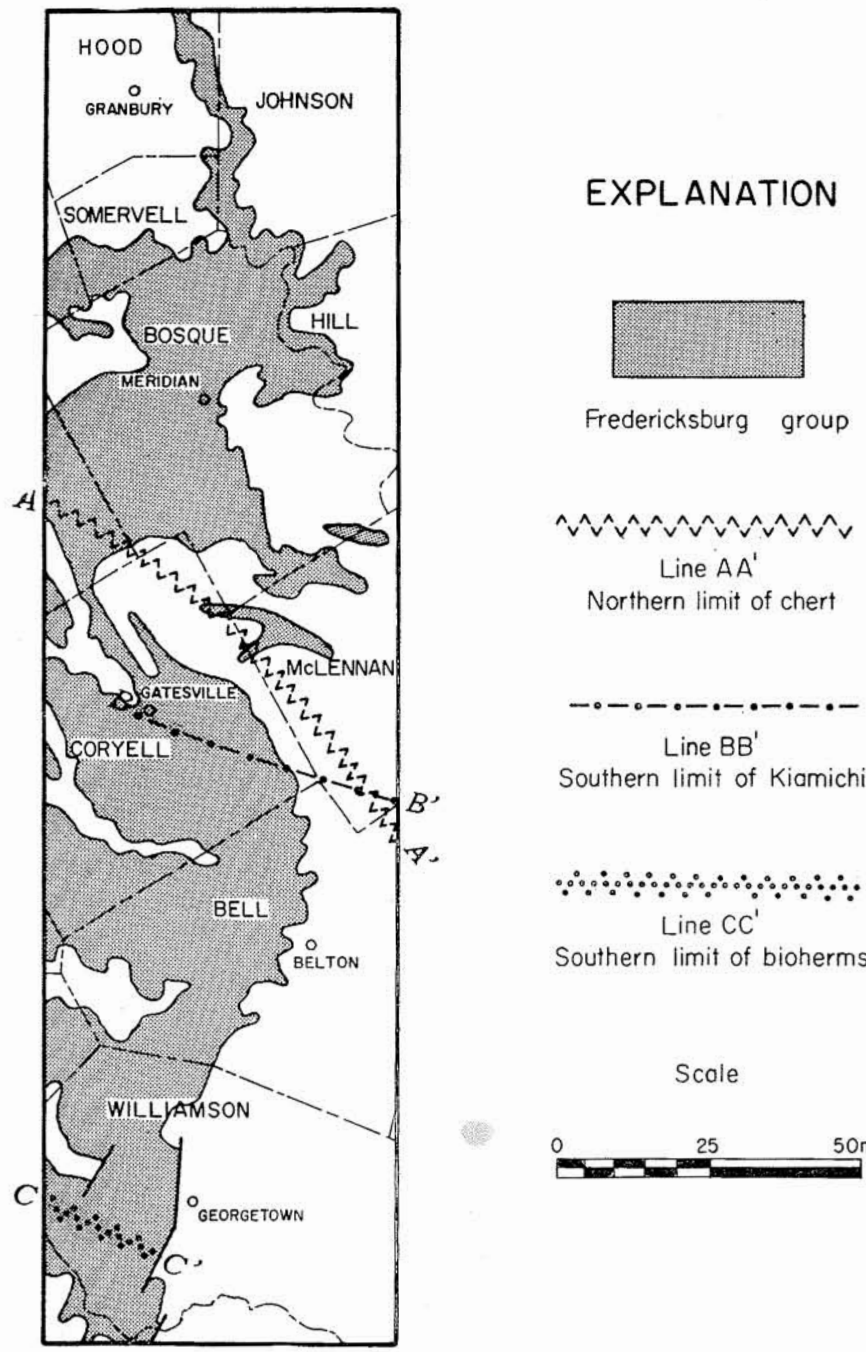

FIG. 15. Outcrop pattern of Fredericksburg group (after U. S. Geological Survey, 1933) showing approximate northern limit of chert in the Edwards limestone (AA′), approximate southern limit of Kiamichi shale (BB′), and approximate southern limit of biohermal reefs in the Edwards formation (CC′).

LITHOLOGY OF THE EDWARDS FORMATION

The Edwards formation in central Texas is composed of six principal types of carbonate rocks: (1) massive rudistid reef limestone; (2) shell debris consisting of various proportions of whole rudistids, coarse shell fragments, and comminuted shells in a fine-grained matrix; (3) medium- to fine-grained limestone (calcarenite and calcilutite); (4) chalk and marl; (5) dolomite; and (6) many types of secondary limestones. All combinations of these types occur. In addition, chert and silicified carbonate rocks are common in some places.

The discussion which follows deals with local outcrops that form examples of one or more lithologic features of the Edwards formation. Collectively, they represent most of the lithologic characteristics which have been seen in the area. In this discussion, one important fact should be kept in mind: the Edwards limestone in this area was subjected to alteration prior to deposition of the Duck Creek formation. The limestone has been further altered since that time. In places, it has been altered so completely that none of the original lithologic features remain. For this reason, caution must be exercised when the original conditions of deposition are interpreted from lithologic features which exist today.

McLennan County

The Edwards limestone in McLennan County crops out in steep bluffs along the major streams (Pl. 2). Only in the northwest part of the county does it form a broad outcrop. The top of the formation is marked by a narrow treeless band which corresponds to the distribution of the Kiamichi shale. The base is marked by contact with either the Comanche Peak limestone or with alluvial deposits.

TRAVERSE ALONG MIDDLE BOSQUE RIVER, TONK CREEK, AND BLUFF CREEK

Relation of Edwards Formation to Contiguous Formations

A good concept of the lithologic and structural features of the Edwards limestone can be obtained on a traverse that begins west of Windsor at locality 154-T-14a and extends up the Middle Bosque River and Bluff Creek to Osage in Coryell County where it terminates at locality 50-T-4 (Pls. 1, 2; fig. 14). Along this traverse, the rudistid facies, which constitutes the entire Edwards limestone at the beginning of the traverse, gradually decreases in thickness until it either disappears or occupies only a small part of the section at locality 154-T-6. Upstream, it again builds up until it occupies the entire formation at localities 154-T-8 and 154-T-9.

Complete sections of the Edwards limestone are exposed only along the center of the traverse from locality 154-T-2 to locality 154-T-12. Along this part of the traverse, the formation ranges from 36 to 45 feet in thickness. In all exposures, the contact with the underlying Comanche Peak limestone is sharp, but variations in thickness of the Edwards limestone suggest that the two formations may grade into each other.

Relation of Edwards formation to Kiamichi formation.—The contact with the overlying Kiamichi shale is sharp and all evidence clearly indicates that it is an unconformable contact—not a facies change. In all outcrops where the contact can be seen, the upper few inches of the Edwards limestone are oxidized to shades of red, brown, and yellow, and the top of the formation is case-hardened.

At locality 154-T-14a and at the ford across Tonk Creek east of Crawford, the upper surface of the Edwards formation is covered with numerous small pits (Pl. 5, D). The pits are a very characteristic feature of this contact. In many places they are so abundant that they give the limestone a honeycombed appearance. The pits are as much as half an inch deep and range from less than one-sixteenth to one-fourth of an inch in diameter. Their equal abundance on both the rock matrix and fossils suggests that they were formed after lithification. Their presence beneath the Kiamichi shale indicates that they are not related to development of the present-day stream channel.

Bore holes filled with Kiamichi shale are common at localities 154-T-2 and 50-T-4. Most are less than one-fourth of an inch in diameter and are only a few inches long. At locality 50-T-4, the bore-hole zone is overlain by the *Gryphaea navia* bed at the base of the Kiamichi shale. This bed consists of whole fossils and comminuted shells. Many of the fossils are finely pitted and most of the fragments are abraded. Many fragments also have a chalky surface. The shell debris resembles the shell banks and beach deposits which occur in the Gulf of Mexico today.

The top of the Edwards limestone in places is undulatory, though regionally it is very flat. At locality 154-T-14a the reef core is directly overlain by 2.5 feet of Kiamichi shale and nodular limestone. Both the Kiamichi shale and the overlying Duck Creek limestone, which are exposed in the bluff, show the effect of slight relief on the Edwards limestone surface. The greatest amount of relief on this surface, however, occurs at locality 154-T-8. Here, several biohermal reefs are exposed in the creek bed. Seven feet of Kiamichi shale is exposed upstream from the bioherms. Toward the reefs, the formation becomes thinner. The contact of the shale with the crest of the reefs is not exposed; therefore the exact relationship between the two formations cannot be determined. By projection, however, it is evident that the shale either pinches out around the reefs or is only a few inches thick on the crests. It is quite possible that the lower beds of the Duck Creek limestone pinch out or drape over the reefs as they do in Neils Creek southwest of Hurst Springs in Coryell County.

Rudistid Facies

Stratigraphic and structural relations.— The rudistid facies consists of the reef core and the reef flank deposits. The core is exposed at locality 154-T-14a only. The flank deposits are exposed at all other localities along the traverse with the exception of localities 154-T-6 and 50-T-4.

Locality 154-T-14a is one of the best localities where an impression of a reef surface during Fredericksburg time can be obtained. At the extreme southeast end of the outcrop, the rudistids built a reef which has a very undulatory upper surface. The reef core is exposed in the riverbed at the base of the bluff that exposes Georgetown limestone. At the bend in the river, reef flank beds crop out and dip 10° in an upstream direction. Around the bend to the north, the river has cut down several feet into the core. Here, reef flank beds, which range from 6 inches to a few feet in thickness, dip as much as 30° toward every point of the compass (Pl. 5, A). Several hundred feet farther upstream, the reef core is again exposed (Pl. 5, C). The overlying beds dip very gently both up and downstream and their eroded edges form small cuestas across the stream.

Near the north end of the outcrop (loc. 154-T-14), the river has cut down approximately 22 feet into the limestone to expose 12 feet of the reef and 10 feet of inter-reef deposits (Pl. 5, B). Near the south end of the vertical bluff on the west side of the river, the rudistid facies is essentially biostromal and consists of two very massive beds of rudistids separated by a thin bed of coarse rudistid debris. To the north, the thin bed pinches out and is then represented by an obscure bedding plane. Incipient bedding planes in the rudistid beds indicate that they represent the flank rather than the true core of the reef. Two basin-like depressions interrupt an otherwise flat upper surface of the reef.

Another rudistid reef is present at locality 154-T-8. Because the lower part of the Edwards formation is not exposed between localities 154-T-14 and 154-T-8, it is impossible to determine whether this reef is a separate one or another vertical manifestation of the same reef that is exposed at locality 154-T-14. At locality 154-T-8 the rudistids built several biohermal reefs. The reefs have smoothly convex outlines, and flank beds consisting of whole rudistids and rudistid debris dip as much as 25°. Downstream, toward the Middle Bosque

River, the rudistid facies is very massively bedded and forms a biostromal reef.

In the bluff along the Middle Bosque River north of Crawford, the rudistid facies is a massive biostromal reef 8 to 9 feet thick (Pl. 4, B). At localities 154-T-11 and 154-T-12, the rudistid facies is 20 and 27 feet thick, respectively. It consists of two massive beds at locality 154-T-11 (Pl. 4, H) and a single massive bed at locality 154-T-12 (Pl. 4, D). At both localities incipient bedding is present and indicates that the rudistid facies is the flank of a reef.

A rudistid biohermal reef is partially exposed near the top of the hill at locality 154-T-9.

Lithology of the reef core.—The reef core is composed of an interlocking mass of rudistids, caprinids, and associated organisms embedded in a matrix of very light gray to cream-colored microgranular calcium carbonate (Pl. 13, B).

Fossils are preserved as "original" shell material and clear crystalline calcite casts.

The matrix is composed of microgranular calcium carbonate. Generally, individual grains cannot be discerned, even under high magnification. However, some individual grains can be recognized and are shown to be very irregular-shaped clusters, of still finer grains of calcium carbonate. All grains are cemented by clear calcite. Tiny angular shell fragments composed of clear crystalline calcite are also present in the matrix.

Very fine irregular hairlike tension cracks are present in the matrix. Normally, the cracks are filled with clear calcite, but dolomite was found in one of them. They are similar to cracks which are produced when a piece of wet clay is pulled apart; by analogy, the cracks in the matrix are believed to have formed prior to complete lithification of the sediment.

Coarse crystalline calcite is abundant in the reef. It occurs most conspicuously as fillings in the body cavities of the fossils, between the tabulae of the outer shell wall, and in vugs. It may fill the cavities completely or merely line the walls. Casts of shells, vein fillings, and inter-granular filling have been noted already.

Dolomite is present, though not abundant, in the rudistid facies along the Middle Bosque River and Bluff Creek. It occurs as tan irregular-shaped patches in the reef rock at localities 154-T-2 and 154-T-11 (Pl. 12, A, B, D). All patches are made up of rhombohedral crystals which range from 0.01 to 0.10 mm in diameter. The patches of dolomite grade imperceptibly into the surrounding matrix. Dolomite is also concentrated along a stylolite at locality 154-T-11 (Pl. 15, E). Dolomite has been found in one tension crack. The rhombohedrons are embedded in the coarse crystalline calcite cement that fills the crack. The relationship clearly indicates that the dolomite and calcite formed penecontemporaneously.

Dolomite also occurs in the top of the Edwards limestone at locality 154-T-14a. It fills some of the body cavities of the fossils, has replaced the inner shell wall of some rudistids, and partially fills the interstices in some flank beds (Pl. 13, A, B). The dolomite crystals, unlike most dolomite crystals in the Edwards formation, are iron-stained around the edges and vary greatly in size. The crystals have two distinct sizes. Large euhedral crystals 0.5 mm in diameter are embedded in a fine mosaic of dolomite composed of crystals approximately 0.003 mm in diameter. Frequently, the centers of the large rhombohedrons are absent and an external mold of iron oxide is the only vestige of the original crystals. Many of the iron oxide molds are partially or completely filled with an anisotropic mineral believed to be calcite or a second generation dolomite (Pl. 15, F).

Stylolites are fairly common in some exposures of reef rock and are particularly abundant at locality 154-T-14a. They occur mainly along the contact of shell fragments and matrix or between two shell fragments. The amplitude of the stylolites seldom exceeds 1 mm.

Lithology of the reef flank.—In general, the reef flank sediments are a poorly sorted accumulation of whole shells, large shell fragments, and finely comminuted shells all of which are preserved as "original" shell material and crystalline calcite casts.

of shells (Pl. 12, C, D). Most shell fragments are extremely angular. The matrix is similar to that in the reef core.

Beds of debris which show the effect of current action do occur. In these beds, elongated shells and shell fragments are oriented parallel to the bedding and the matrix is chiefly crystalline calcite (Pl. 13, A).

Paleontology.—Eoradiolites and *Caprinuloidea* are by far the most abundant forms identified in the reef core and flank deposits. They appear to make up most of the rock at exposures of the rudistid facies. *Chondrodonta* is fairly common. *Monopleura* and *Toucasia* have also been identified but are not abundant. The coral *Cladophyllia* is present but rare. The foraminifer *Dictyoconus walnutensis* is very abundant in the reef flank deposits but is either absent or extremely rare in the reef core. In the biostrome at locality 154-T-2, it is so abundant that the matrix in many places appears to be a coarse sand.

In considering the relative abundance of the reef organisms, it should be kept in mind that a complete section of a reef is not exposed along this traverse. Only the upper part of the reef core is exposed at locality 154-T-14a and only the flank beds are well exposed at the other localities. It is very possible that other forms of rudistids are just as abundant as *Eoradiolites* and *Caprinuloidea* but they cannot be seen.

Inter-reef Facies

Stratigraphic and structural relations.—The inter-reef deposits which are exposed along the Middle Bosque River and Bluff Creek were deposited in a basin that extended from locality 154-T-14 to a point west of locality 154-T-12. The deepest part of this basin was in the vicinity of locality 154-T-6 where approximately 40 to 45 feet of inter-reef sediments is now exposed.

The inter-reef deposits are characteristically very well bedded (Pl. 4, B). Beds range in thickness from 6 inches to 3 feet and have an average thickness of approximately 1 foot. All beds are essentially horizontal. When viewed from a distance, as at locality 154-T-14, it is apparent that the beds are comparable to the foreset beds of a delta; each bed, traced laterally, drops from a position at the top of the Edwards formation to a position lower in the inter-reef section.

Cross-lamination within individual beds is a common feature. Where it is developed, most elongated grains are oriented parallel to the laminations. Grain size varies somewhat from bed to bed, but most of the grains are well sorted within individual beds. Small patches of coarse grains are present in some of the fine-grained limestone. Despite the variation in grain size, the inter-reef deposits can be subdivided into three lithologic units: (1) fine-grained limestone (calcilutite) at the base, (2) fine- to medium-grained limestone (calcarenite) in the middle, and (3) fine to coarse shell debris at the top of the formation. Contacts between the units are gradual. Comparison of the lithologic sequence at each locality indicates that the units are most clearly defined at localities 154-T-6 and 154-T-2, are poorly defined at localities 154-T-14 and 154-T-12, and that unit 3 is the most widespread. The approximate thickness of each unit is shown in table 1.

Lithology of the inter-reef deposits.—The lowest unit is light gray to tan fine-grained limestone (Pl. 13, D). In a fresh outcrop, the granular texture is almost indiscernible, but in a weathered outcrop, on a polished rock specimen, or in a thin section the texture is readily apparent (Pl. 14, C). The limestone is composed of well-sorted moderately rounded "original" shell fragments, opaque grains, and recrystal-

TABLE 1. *Thickness of lithologic units in the inter-reef facies along the Middle Bosque River, Tonk Creek, and Bluff Creek, McLennan County.*

<table>
<tr><th>Lithologic Unit</th><th>Loc. 154-T-14a</th><th>Loc. 154-T-14</th><th>Loc. 154-T-6</th><th>Loc. 154-T-2</th><th>Loc. 154-T-11</th><th>Loc. 154-T-12</th><th>Loc. 154-T-9</th></tr>
<tr><td>3</td><td>—</td><td rowspan="2">10</td><td>15</td><td>7</td><td>3</td><td rowspan="2">15</td><td>—</td></tr>
<tr><td>2</td><td>—</td><td>10</td><td>13</td><td>13</td><td>—</td></tr>
<tr><td>1</td><td>—</td><td>—</td><td>16</td><td>6</td><td>5</td><td>—</td><td>—</td></tr>
</table>

lized grains embedded in a cement of fine crystalline calcite (see section on "Terminology" for definitions of these terms). Opaque grains predominate. The average grain size is approximately 0.06 mm; thus, the limestone is texturally equivalent to a coarse siltstone. The borders of the opaque grains are generally very fuzzy and often it is difficult to differentiate between grains and cement (Pl. 15, D).

Unit 1 grades into unit 2 by (1) an increase of grain size, (2) a greater degree of rounding of grains, (3) a somewhat lesser degree of sorting, (4) more sharply defined grain boundaries, (5) a decrease in abundance of opaque grains, and (6) an increase in abundance of "original" shell fragments and recrystallized shell fragments. Unit 2 is largely white to cream-colored granular limestone (calcarenite). Grain sorting varies somewhat from bed to bed, but most beds, as seen in the outcrop, would be considered well sorted. Microscopically, however, the limestones are obviously not as well sorted as in the unit below (Pl. 14, D). The average grain size in various beds ranges from 0.1 to 0.7 mm. Most grains are fairly well rounded. The three types of particles which make up unit 1 also make up unit 2, but "original" shell material and recrystallized grains predominate in unit 2. As in unit 1, the cement is crystalline calcite; however, the calcite is not as dusty as in unit 1 and is more coarsely crystalline.

Lithologically, unit 3 varies to a greater extent than the units below. Most of the unit is a poorly sorted fine shell debris (Pl. 13,C), but at locality 154-T-2 whole fossils showing very little evidence of abrasion are fairly abundant in a coarse granular matrix. Opaque grains, "original" shell fragments, and recrystallized grains constitute the shell debris. Though it is more coarse-grained, the shell debris microscopically resembles the coarse granular limestone shown on Plate 14, E, F. Recrystallized grains are the most abundant components, especially at locality 154-T-6. All particles are very well rounded.

Many shell fragments are only partially recrystallized (Pl. 15, B). The original shell structure of these fragments is still present, but it is ramified by a mosaic of crystalline calcite. This relationship indicates that recrystallization took place in the solid state. Recrystallization may be uniform throughout a fragment or it may be spotty. In places it has almost obliterated the original fragment.

The "dust" rims around the recrystallized shell fragments have partially disappeared in some places. Where this has happened, the cement and crystalline calcite cores of the grains are indistinguishable.

The cement is clear calcite. Most interstices are filled with a mosiac of coarse anhedral calcite, but some are filled with (1) a layer of relatively small crystals of calcite that coats the particles and (2) a mosaic of coarse crystalline calcite that fills the remainder of the voids.

Weathering of the top of the Edwards limestone is pronounced at locality 154-T-6 (Pl. 13, C). Here, solution by ground water has produced a vuggy type of porosity. The vugs are as large as half an inch in diameter and tend to be elongated in a vertical direction. Many vugs are partially filled with brown calcium carbonate deposited under subaerial conditions. This calcite has an earthy appearance similar to caliche. It may be massive or fibrous; if the latter, the fibers are oriented in a vertical direction. In many vugs the filling is microconglomeratic as a result of fragments of "roof rock" having fallen to the bottom of the vug where they are now incorporated in the new vug filling. Vugs are also filled with brown crystalline calcite deposited as microstalactites hanging from the roof of the vug.

The inter-reef sediments at the west end of the traverse are part of a cherty inter-reef facies which is discussed in more detail in this paper (locs. 50-T-7, 50-T-8). At locality 50-T-4, north of Osage, these sediments consist of 6 feet of gray hard thin-bedded very fine-grained limestone (calcilutite) and chert.

Some of the limestone beds are very thinly laminated. A few chert nodules have been found in the vicinity of locality 154-

T-9 and one nodule has been seen in the Tonk stone quarry at Crawford. Other than these rare occurrences no chert has been found in McLennan County. The dark gray microcrystalline chert occurs as flattened nodules concentrated in one bed. In plan view, the nodules have a smoothly irregular outline (Pl. 6, A). They range from 2 to 6 inches in thickness and are as much as 2 feet in diameter. Most of the nodules are only loosely held in place by the surrounding limestone and often they may be plucked out with ease. The present-day stream has done this in many places to produce a pock-marked surface.

MIDDLE BOSQUE RIVER FROM BLUFF CREEK TO THE BOSQUE COUNTY LINE

Most of the Edwards formation along the Middle Bosque River northwest of its junction with Bluff Creek is made up of the inter-reef facies (Pl. 2). Near the mouth of Bluff Creek, the rudistid facies and the inter-reef facies are present in approximately equal proportions. The section at locality 154-T-11 is representative of this area. Here, 20 feet of massive rudistid facies is overlain by 21 feet of well-bedded granular limestone and fine shell debris (Pl. 4, H). The inter-reef facies is cross-bedded on a very large scale, a feature which can be seen in the bluff across the creek from locality 154-T-11.

A short distance northwest of Bluff Creek the rudistid facies makes up most of the Edwards limestone. Several biohermal reefs are present in this area but most of the rudistid facies is biostromal.

The rudistid facies predominates for a distance of 2 miles up the Middle Bosque River. Beyond this point, the inter-reef facies makes up most of the Edwards limestone and the rudistid facies is either absent or forms only a thin biostrome at the base of the formation. At locality 154-T-10 the rudistid facies is absent and the inter-reef facies consists of white to light buff well-bedded fine- to medium-grained limestone (calcarenite). The contact with the Comanche Peak limestone is somewhat gradational as shown by a slight increase in grain size in the upper few feet of that formation. Only 25 feet of the Edwards limestone is exposed but the formation is estimated to be approximately 35 feet thick.

The entire Edwards limestone is exposed at locality 154-T-3 where an intertonguing relationship between the Edwards and Comanche Peak formations may be seen (Pl. 1). The base of the Edwards formation is marked by a rudistid biostrome 4 feet thick. It consists of whole and broken rudistids. Six feet of nodular fine-grained limestone similar to the Comanche Peak limestone overlies the rudistid limestone. Above this is 8 feet of marly nodular limestones interbedded with fine-grained limestones.

The remaining 38 feet of Edwards limestone is composed of cream-colored well-bedded granular limestones and coarse shell debris. Whole rudistids are common in the coarse shell debris which makes up the upper 13 feet of the formation.

HOG CREEK

The Edwards limestone is exposed in two places in Hog Creek: (1) in the bed of the creek upstream from State Highway 317 and (2) in the bluffs near the ford on the Valley Mills-Coryell road where the formation is 25 feet thick.

The top of a rudistid reef is exposed near State Highway 317. It is gently undulatory and dips in all directions. It is pitted in the same manner as the top of the reef at locality 154-T-14a. *Caprinuloidea* appears to be the dominant organism in the reef core.

Four feet of Kiamichi shale and nodular limestone overlies the Edwards limestone. There is no gradation between the two formations. Bedding within the Kiamichi shale is parallel to the undulatory surface of the reef.

Three biohermal reefs are exposed in the bluffs on the west side of the creek below the ford on the Valley Mills-Coryell road. The reef cores are massive and show no evidence of bedding. Because of their inaccessibility, they could not be examined closely.

Flank beds dip away from the reef cores with inclinations of 15° to 20°. The beds are several feet thick and, from across the stream, appear to be lithologically similar to the reef cores.

Part of another biohermal reef is exposed on the east bank of the creek north of the ford (Pl. 4, C). The reef core, like those south of the ford, is very massive. The flank beds which have inclinations of 15° to 20° are structurally similar to the foreset beds of a delta. They are thickest where they dip with the greatest inclination. The upper ends of the beds are not exposed. The lower ends pinch out away from the reef. They appear to be somewhat more fragmental that the reef core.

NORTH BOSQUE RIVER

The Edwards formation in the North Bosque River valley is composed predominantly of the rudistid facies (Pl. 2). At localities 154-T-4 and 154-T-7 the entire Edwards formation consists of biostromal reefs 13 and 23 feet thick, respectively. The contact with the Comanche Peak limestone is sharp in both outcrops.

Biohermal reefs are exposed at a number of places in this area and some of them are noted on the map of McLennan County (Pl. 2). At locality 154-T-13, 7.5 feet of reef core is overlain by 10.5 feet of reef flank deposits. The upper part of the reef core that is equivalent to these deposits is not exposed. The flank beds dip approximately 15°.

A biohermal reef 18 feet thick is exposed at locality 154-T-17. Most of the reef core is exposed. The massive reef flank beds dip 18°.

LOCALITY 154-T-1

The Santa Fe Railroad cut southeast of Valley Mills exposes reef and inter-reef deposits in two outcrops (Pls. 3; 4, A). The Edwards limestone overlies a thick section of Comanche Peak limestone and is in turn overlain by the Kiamichi shale. The Duck Creek limestone caps the hill.

Relation of Edwards Formation to Contiguous Formations, Outcrop No. 1

Relation of Edwards formation to Comanche Peak formation.—Twenty-six feet of Comanche Peak limestone is exposed. The basal 5 feet forms a single massive bed of gray fine-grained limestone (calcilutite). Texturally, it is similar to the overlying beds; however, it lacks the nodular structure which is so characteristic of the upper part of the Comanche Peak limestone. Because it has features which are characteristic of both the Comanche Peak (texture) and Edwards (structure) formations, this bed is believed to be an attenuated tongue of Edwards limestone that extends eastward from a much thicker section near locality 154-T-3 (Pl. 1).

The remainder of the Comanche Peak formation consists of two massive beds of gray compressed nodular limestone. A shaly limestone zone separates the two beds. The highest bed is more argillaceous than the bed below; the uppermost 2 feet is thinly laminated. A few rudistids are present near the top of the bed.

Relation of Edwards formation to Kiamichi formation.—The contact with the Kiamichi shale is unconformable. Evidence for an unconformity is derived from the lithologic character of the beds adjacent to the contact. The top of the Edwards limestone is case-hardened and oxidized to a depth of 4 to 6 inches. Bore holes one-eighth of an inch in diameter and 1 to 2 inches long are abundant in the top of the formation. The upper surface is covered with many small pits.

As a result of reef growth, the Edwards limestone is approximately 2 to 3 feet thicker above the reefs than above the inter-reef area. The resulting relief decreases upward through the Kiamichi shale until it becomes imperceptible at the base of the Duck Creek limestone. All beds within the Kiamichi shale extend over the top of the easternmost reef. Thinning of the shale over the top of the reef is due therefore to compaction or slower deposition rather than non-deposition or erosion of individual beds.

Effect of present-day weathering.—Chalkification resulting from present-day weathering is especially pronounced in this outcrop. All beds have been affected, some more than others. Unit 4 is so chalky toward each end of the outcrop that the original texture has been almost obliterated. Bedding within the unit is still apparent, however. In unit 5 and the more argillaceous parts of the Kiamichi shale, rock structure, texture, and composition have all been destroyed. At these horizons, white pulverulent chalk extends inward from the present-day surface for distances as great as 120 feet. White consolidated chalk extends still farther toward the center of the outcrop. In the transition zone between the pulverulent chalk and the original sediment, iron-staining and clay seams are quite prominent and irregular-shaped concretions of secondary limestone are abundant.

Rudistid Facies

Stratigraphic and structural relations, outcrop no. 1.—The base of the Edwards limestone is the base of the rudistid facies (discounting the few rudistids in the top of the Comanche Peak limestone). It is a conformable and horizontal contact across the entire exposure. The rudistid facies forms two biohermal reefs connected by a biostrome (Pl. 3). The core of each reef is a structureless mass of interlocking rudistids broken only by one growth surface in the center of the reef at the west end of the railroad cut. The remainder of each biohermal reef and the biostrome are composed of whole and fragmented rudistids that accumulated essentially in situ. The westernmost reef is 11 feet thick and the easternmost reef is 9 feet thick. Each has a smoothly convex upper surface. The maximum dip on this surface is approximately 15°. The crest of each reef is a disconformable surface that has a maximum relief of 6 inches. The crest of each reef is also casehardened and oxidized to various shades of brown and pink. Many bore holes filled with the overlying limestone are present on top of the westernmost reef. These features indicate that the crests of the reefs were subjected to erosion and weathering for a brief period of time. The weathering is thought to be subaerial.

Lithology of the reef core, outcrop no. 1.—Masses of rudistids embedded in a microgranular matrix make up the reef cores (Pl. 16, A). The fossils are preserved as "original" shells and calcite casts (Pl. 18, A). In spite of extensive chalkification, the original structure of many of the shells is still apparent (Pl. 18, B). Some shells have a mosaic texture superimposed upon the original shell structure, thereby indicating direct recrystallization to coarse crystalline calcite. The time of recrystallization is unknown.

Coarse crystalline calcite, in addition to occurring as casts of shells, fills the body chambers and voids in the outer shell walls of the fossils, fills small vugs, and is believed to be the cementing agent in the matrix. Some vugs and body chambers completely filled with crystalline calcite are lined with small crystals of calcite. This feature indicates that the voids were filled during two stages of calcite precipitation.

The matrix, as seen on polished rock specimens or in the field, is very fine-grained. It is made up of silt-sized particles of calcium carbonate cemented with calcite. The particles are in turn made up of still finer grains of calcium carbonate.

Microscopically, the matrix has a mottled texture because the fuzzy silt-sized particles are only vaguely distinguishable from the dusty crystalline calcite cement. The dusty appearance is due to chalkification. Irregular patches of relatively clear crystalline calcite ramify much of the matrix. They are believed to have been formed by reprecipitation of calcium carbonate following chalkification. Tiny shell fragments, most of which are crystalline calcite casts, are distributed throughout the matrix (Pl. 18, A).

Lithology of the reef flank, outcrop no. 1.—The reef cores grade laterally and vertically into essentially in situ deposits of whole rudistids and coarse rudistid debris. No bedding planes separate the reef cores from their flank deposits.

The principal differences between the flank deposits and the reef cores, as seen in thin sections, are the greater abundance of medium to coarse shell fragments in the fine-grained matrix of the reef flank and the more frequent occurrence of irregular patches of coarse crystalline calcite (Pl. 18, C). The former is, of course, a result of fragmentation at the time of reef growth. All fragments are exceedingly angular and show no evidence of transportation. The more frequent occurrence of irregular patches of coarse crystalline calcite is due to more extensive chalkification and re-precipitation of calcium carbonate during weathering. Indirectly it is probably due to the greater porosity that existed in the flank beds.

An interesting feature of the westernmost reef is the concentration of dolomite in the bottom of some of the bore holes on top of the reef (Pl. 16, C). The dolomite consists of an interlocking mass of crystals that has a sharp contact with the walls of the bore holes. There is no evidence of wall rock alteration. The space above the dolomite in the bore holes is filled with clear crystalline calcite. Inter-reef limestone is depressed into one bore hole and rests upon the clear calcite cement. This indicates that the reef was lithified before the overlying beds were deposited. It is evident that the dolomite was deposited in the bore holes or was an in situ alteration of some pre-existing material prior to or penecontemporaneous with deposition of the crystalline calcite cement. Therefore, it is considered to be a diagenetic deposit.

An irregular growth surface several feet long marks the top of the flank deposits on the west side of the reef core in the westernmost reef. It extends downward from the crest of the reef and disappears into the coarse flank deposits to the west. It is overlain by rudistid limestone similar to the reef core. This is believed to be a tongue of the reef core that extends out from the main core behind the outcrop.

Lithology of the biostrome, outcrop no. 1.—Laterally, the reef flank deposits become a massive rudistid biostrome. It is 2.5 feet thick between the reefs but is considerably thicker on the opposite sides of the reefs (Pl. 3). The biostrome is the time equivalent of the biohermal reefs. Lithologically, it is like the reef flank sediments (Pl. 16, D). Both whole and broken fossils are abundant. There is no evidence of rounding or sorting of the components to suggest that the biostrome was formed by transportation and deposition of the constitutents (Pl. 18, D). On the other hand, whole fossils do not appear abundant enough to have formed a rigid framework. The biostrome is believed to have been formed by the in situ accumulation of organisms that were not sufficiently abundant to build a rigid structure above the surrounding sediments.

Lithology of the reef flank, outcrop no. 2.—The flank deposits of another rudistid reef are exposed in a second outcrop around the bend of the railroad to the southeast (Pls. 3; 16, B). They are lithologically similar to the flank deposits in outcrop no. 1. Some of the rudistids in the west wall of the railroad cut appear to be oriented in a near-horizontal attitude. The writer is uncertain as to whether this is due to sorting action of waves and currents or to organic growth.

Paleontology.—*Caprinuloidea*, *Eoradiolites*, and *Chondrodonta* are the most abundant fossils in the rudistid facies. *Toucasia* is also present.

The coral *Cladophyllia* is fairly common in the basal parts of the biohermal reefs.

Inter-reef Facies, Outcrop No. 1

Stratigraphic and structural relations.—The rudistid facies is overlain and flanked by well-bedded generally fine-grained limestones, marls, and pulverulent chalk (Pls. 3; 4, A). The Edwards formation is 17 feet thick between the reefs and approximately 20 feet thick at each reef. Thus, the present-day relief on top of the Edwards limestone is 3 feet. Prior to deposition of the inter-reef sediments, the relief on top of the rudistid facies was approximately 7.5 feet.

The basal part of unit 4 is confined to the floor of the inter-reef basin. Higher beds in the unit progressively onlap the reefs, and the highest beds in the unit pass over them. At the present time, the relief on the upper surface of unit 4 is 3.5 feet. It has not been determined whether the dip on this surface is primary, secondary, or a combination of both. Higher lithologic units pass over the reefs with only a slight change in thickness and no apparent change in the primary lithologic features of the units. However, as will be shown in the subsequent discussion, the reefs may very well have had some indirect effect upon the present lithologic features of units 5 and 6.

Lithology of the inter-reef deposits.—A thin brown calcareous shale (unit 3) 2 to 4 inches thick overlies the rudistid facies. It is thinnest over the reefs and is oxidized to a red color near the westernmost reef.

Unit 4 is a gray moderately hard limestone which ranges in thickness from 6 inches above the westernmost reef to almost 5 feet between the reefs. Except for post-lithification alteration, there is no lateral variation in lithology. Vertically, the unit is divisible into three parts. The lower part is a fine-grained argillaceous limestone 9 inches thick that has a honeycombed surface because of weathering. The middle part is a thinly laminated very fine-grained argillaceous limestone which forms the most prominent part of the unit (Pl. 17, A). Elongated particles and small pelecypods are oriented parallel with the bedding; fine clay seams bend around the shells (Pl. 18, E). Some of the particles are elongated shell fragments, but many appear to be fragments of limestone laminations; the resulting fragments were reworked prior to final deposition. Most of the shells are calcite casts; coarse crystalline calcite fills the small pelecypods. The upper part is 1 foot thick and composed of light gray very thin-bedded fine-grained argillaceous limestone. In many places the thin beds are crumpled and broken. At one point, a block of limestone lithologically similar to unit 6 is tilted at a steep angle and emplaced in these beds. The thin beds are bent and broken beneath the block. Several joints filled with red limonitic granular limestone cut across this part of the unit and in places mark its base.

All parts of this unit become more chalky and less argillaceous near the reefs. This is due to present-day weathering rather than to original deposition.

Unit 5 is an argillaceous limestone breccia (Pl. 17, B). All of the fragments consist of very fine-grained limestone texturally similar to units 4 and 6. Though a few fragments have rounded edges and smooth outlines, most of them are angular and have very ragged edges. Some fragments are long and rectangular suggesting fragmentation of thin beds of limestone. Many of the fragments contain small and very irregular calcite-filled cracks like those described in the discussion of the reef core in the Middle Bosque River (p. 35).

Unit 6 is a very light gray chalky extremely fine-grained limestone which grades into the unit below (Pl. 17, C). Very small angular recrystallized shell fragments are abundant. Bedding is very irregular, particularly above the reefs where it is so irregular that it produces a nodular structure.

Unit 7 is a very light gray hard thin-bedded miliolid limestone (Pl. 17, D). Miliolids make up approximately 90 percent of the sedimentary particles (Pl. 18, F). The remaining 10 percent is made up of well-rounded recrystallized shell fragments. All miliolids have been converted to chalk. Chalkification has almost obliterated the structure of many tests.

Clear crystalline calcite forms the cement in the limestone of unit 7 and fills the chambers of the miliolids. Many interstices are lined with tiny crystals of calcite which were deposited before the major portion of the calcite cement filled the void.

Origin of the limestone breccia.—Discussion of the origin of the lithologic features within the Edwards formation is largely reserved for the latter part of this paper. However, because locality 154-T-1 is the only known occurrence of this type of breccia in the Edwards formation, the origin of the breccia is discussed at this time.

In seeking a solution to brecciation several factors should be kept in mind: (1)

The upper part of unit 4, the fragments in unit 5, and the limestone of unit 6 are lithologically similiar. (2) Some fragments in the breccia are well rounded but most are angular and have extremely ragged edges. (3) Thin beds in the top of unit 4 are wavy or crumpled in many places and are broken beneath a rounded block of limestone embedded in them. (4) Bedding in unit 6 is very irregular, particularly above the reefs. (5) Unit 4 onlaps the reefs, and the uppermost beds of the unit pass over them. The relief on top of unit 4 is approximately 3.5 feet at the present time. Unit 5 thins slightly over the reefs but, like units 6 and 7, exhibits no lithologic change over them.

Considering all these features, the writer believes the following interpretation to be the mode of brecciation. The fine texture and thinly laminated structure of the limestones in unit 4 indicate that sedimentation occurred in quiet water. Fine-grained sediments deposited in this environment probably had a high moisture content and underwent a loss of volume as a result of either dessication or compaction. The reefs, being rigid masses, acted as buttresses around which compaction took place. Brecciation occurred in those beds which occupied the position where the greatest amount of vertical and possibly horizontal movement took place. This position was on a level with the crests of the reefs. Unit 5 and the beds at the top of unit 4 occupied this position.

Compaction and brecciation took place before lithification, as indicated by the ragged edges of many fragments and the wavy or crumpled bedding at the top of unit 4. The lithologic similarity of unit 6 to the fragments in unit 5 and the irregular character of the bedding in unit 6 indicate that brecciation occurred subsequent to or during the deposition of unit 6. Unit 7 was not affected by brecciation, therefore brecciation occurred prior to deposition of the unit.

Rounding of many of the fragments is attributed to movement of the fragments during brecciation or to circulating waters. During brecciation, joints were formed both across and along some of the bedding planes at the top of unit 4. Later, they were filled with limonitic carbonate sand.

If the interpretation of the mode of brecciation is correct, this outcrop provides an interesting example of the effect that topography or structure may have upon the lithologic features of a stratigraphic unit. The reefs stood in boldest relief at the beginning of deposition of unit 4 and should therefore have had the greatest effect upon the lithologic characteristics of the unit. No effect is apparent, however. Unit 4 was merely deposited around and over the reefs; thus, their influence was stratigraphic, not lithologic. Later, when there was either no relief or no more than 3 to 4 feet of relief, the reefs were indirectly the cause of brecciation. At this time, their influence was almost entirely lithologic and led to post-depositional alteration of the sediments.

CHILDRESS CREEK

Only the upper 3 to 4 feet of the Edwards limestone is exposed in Childress Creek. Throughout most of the exposure, the Edwards formation consists of a series of biohermal reefs or, more probably, a single large reef which has an undulatory surface. The reef flank beds dip toward all points of the compass. Maximum dips range from 10° to 15°. In many places the present-day course of the creek is controlled by the reefs.

The reef cores are composed of a tightly interlocking mass of rudistids embedded in a fine-grained matrix. *Caprinuloidea* and *Eoradiolites* are the most abundant forms. *Chondrodonta* and *Monopleura* are present. The reef flank deposits consist of beds of rudistids and coarse rudistid debris.

Just north of the small tributary which flows into Childress Creek from the northwest, the formation is made up of granular well-bedded inter-reef limestone. The thickness of the inter-reef facies is unknown.

Relief on the Edwards-Kiamichi contact is approximately 1 foot. This is considerably less than the present-day relief on the bioherms and indicates that, before the end of the Fredericksburg age, the interbiohermal areas were filled to the level of the reef crests. At all points where the contact is exposed, the top of the Edwards formation is oxidized and case-hardened to a depth of several inches. Like many other localities, it is covered with small pits and contains many bore holes filled with Kiamichi shale. Oxidized pyrite nodules are abundant on this surface.

An interesting feature of the Edwards limestone in Childress Creek is the occurrence of dolomite (Pl. 4, E, G). The dolomite is composed of an interlocking mass of crystals all of which are coated with ferric oxide. Average crystal size is approximately 0.15 mm. This is considerably larger than the crystals of most dolomite in the Edwards formation. Large patches of dolomite are gray, but small patches and the borders of large patches are brown.

The dolomite occurs as fillings in cracks in the reef rock, in the body chambers of fossils, and as replacements of shells (Pl. 19, A, B). It may fill all the body chambers in a fossil or only some of them. As a replacement of shells, it may occupy all the space formerly occupied by the shell or only the inner shell wall and the divisions between the body chambers. In all cases the contact between dolomite and wall rock is sharp and in many places it is lined with iron oxide. There is no evidence of penetration of dolomite crystals into the wall rock. In many cases the dolomite only partially fills the void it occupies. The remainder of the former void is filled with a mosaic of clear crystalline calcite cement which in many places surrounds individual dolomite crystals. The relation of dolomite to crystalline calcite cement and to the surrounding rock indicates that the dolomite was emplaced at approximately the same time as cementation occurred. The dolomite is believed to have originated by crystallization in a void rather than by recrystallization of shells or cement.

Coryell County

The Edwards limestone is present only in the eastern part of Coryell County where it crops out in steep bluffs along the Leon River and along the major streams east of the river. Complete sections can be obtained only east of a line extending from Seattle through Gatesville to Jonesboro. West of this line only the basal part of the formation remains.

The Edwards limestone in Coryell County is similar to that in McLennan County. It consists of numerous biohermal reefs separated by biostromes and inter-reef deposits. Some reefs are known to be 55 feet thick and may be as much as 70 feet thick. Good examples of biohermal reefs may be seen near Turnersville; along Coryell, Greenbriar, and Clear Creeks; near Pecan Grove Church; and near Mother Neff State Park.

The inter-reef deposits are composed of coarse rudistid debris, granular limestones (calcarenites), and fine-grained cherty limestones (calcilutites). A line extending approximately from Whitson toward Gatesville marks the southern limit of the Kiamichi shale and the northern limit of extensive post-lithification alteration of the Edwards limestone. In general, primary rock textures are readily apparent north of this line. South of the line, post-lithification alteration is pronounced.

Three outcrops which show the relationship of the various lithofacies crop out along U.S. Highway 84 east of Gatesville. All have been altered by chalkification which has partially obscured the original textures.

Locality 50-T-6

A good example of a reef core may be seen in an abandoned quarry on the south side of U.S. Highway 84, 3.3 miles east of the railroad station in Gatesville (Pl. 3). A small subsidiary quarry is located at the edge of the highway. The main quarry, which is located behind the subsidiary quarry, is not visible from the road but can be reached by means of a path west of the quarry.

Relation of Edwards Formation to Contiguous Formations

The Edwards limestone lies in sharp contact with the Comanche Peak limestone on the west side of the quarry. Forty-four feet of Edwards limestone is exposed. The top of the hill along the highway east of the quarry is 63 feet above the Comanche Peak contact; the top of the Edwards limestone is not present, however. The hill rises another 10 to 15 feet along the ridge northwest of the highway. Reef core or reef flank deposits are present but are poorly exposed near the crest of the hill. The top of the formation is not exposed. It is evident from the measurements cited that the Edwards formation is at least 73 feet thick in this vicinity. This is believed to be close to the maximum thickness, however, because the formation is thinner north and east of this locality.

Rudistid Facies

Reef core, Cladophyllia zone.—The lower 21 feet of the reef core is composed of a homogeneous mass of *Cladophyllia* (Pl. 27, D). Many *Cladophyllia* colonies are present, but most of them appear to be broken though not abraded. Rudistids are present in this zone but are definitely subordinate to *Cladophyllia*. The *Cladophyllia* zone grades upward into the rudistid zone.

Reef core, rudistid zone.—The remainder of the reef core consists of a mass of rudistids embedded in a white fine-grained chalky matrix (Pl. 6, C). There is no bedding in the reef core. A slightly undulatory bedding plane separates the core from the flank deposits (Pl. 6, D). It extends across most of the quarry but disappears in the center and at the east end where the reef core builds up to the top of the exposure.

The rudistids show no particular orientation except *Caprinuloidea* which is oriented in a more or less horizontal position. It has not been determined whether the organisms occupied this position during life or whether the shells assumed this position after the organisms died.

This outcrop is especially interesting because of the variety of ways in which the fossils are preserved. Most are preserved as molds but "original" shells and clear calcite casts of shells also occur. "Original" shell material is uncommon, however, and completely preserved "original" shells are very rare.

Molds are more abundant here than in any other outcrop which has been studied. Both internal and external molds are present. However, the internal mold is missing in most molds owing to solution of the surrounding shell. Most molds have a thin coating of small crystals of calcite covering the walls.

Good natural casts of the original shells do not occur. Usually, only part of the original shell is preserved as a cast. The remainder has been dissolved away and only a cavity remains. Casts have been formed by recrystallization of the original shell and by cavity filling. Strictly speaking, the latter is a replica of the cavity rather than a natural cast of the shell. Filling of the cavity is accomplished by the uniform growth of crystals inward from the shell walls which they coat and by construction of bridges. Bridges are constructed by irregular growth of crystals across the cavity to form pillars and plates that have a great variety of shapes (Pl. 30, C). Eventually they coalesce to fill the cavity.

The matrix, as seen in the outcrop, is composed of fine-grained limestone and fine shell debris. In thin sections, however, because chalkification has destroyed or obscured much of the original texture, the matrix is a dusty extremely fine-grained groundmass of calcite. Small irregular-shaped patches of clear calcite formed by reprecipitation following chalkification occur throughout the matrix. The contacts between these patches and the groundmass are very indistinct.

All stages of alteration of shell fragments to chalk are present. Large shell fragments are least affected. Small fragments, however, are often only barely discernible. Conversion to chalk usually proceeds from the edge of the shell inward but in a few shell fragments, chalk has developed preferentially along some of the internal layers within the shell walls.

Reef flank.—Coarse poorly sorted shell debris and whole fossils constitute the reef flank deposits. Whole fossils are abundant but are clearly less abundant than in the reef core. These sediments grade laterally into the reef core indicating deposition simultaneous with reef growth.

The flank deposits are massive and not bedded in the main quarry, but in the small quarry adjacent to the highway, they are well bedded. The beds range in thickness from 2 to 4 feet and are inclined to the northeast with an apparent dip of 35°.

Paleontology.—As already noted, the basal zone of the reef is composed predominantly of *Cladophyllia*. The floor of the quarry, which is near the base of the rudistid zone, is paved in places with *Toucasia*. In the quarry wall, *Caprinuloidea* and *Eoradiolites* are the most abundant forms. *Caprinuloidea* appears to be dominant.

LOCALITY 50-T-7

Locality 50-T-7 includes two roadcuts that expose two and possibly three levels of the rudistid facies and their associated inter-reef deposits. The roadcuts are located on U.S. Highway 84 about 4.5 miles east of the railroad station in Gatesville (fig. 14). The easternmost outcrop, designated as outcrop no. 1, is located just west of the roadside park in the tributary valley of Coryell Creek; the westernmost exposure, designated as outcrop no. 2, is the deep roadcut on the crest of the hill.

Relation of Edwards Formation to Contiguous Formations

Relation of Edwards formation to Comanche Peak formation.—The Edwards limestone is 50 to 55 feet thick at this locality and most of the formation is exposed. The lower part of the formation is intercalated with the upper part of the Comanche Peak limestone. Outcrop no. 1 exposes 13 feet of typical Comanche Peak nodular limestone and 6 to 8 feet of the Edwards rudistid facies. A sharp change in lithology marks the contact.

Another 2 to 3 feet of the rudistid facies is exposed at the base of the north wall in outcrop no. 2. It is overlain, with sharp contact, by approximately 3 feet of gray compressed nodular limestone which is, in turn, overlain by 6 inches of marl (Pl. 3). The marl was formed by weathering rather than by primary deposition. The thickness of the nodular limestone is included in the thickness of the Edwards formation because it constitutes only a small percent of the entire Edwards limestone section. It is considered, however, to be a tongue of the Comanche Peak limestone projecting into the Edwards limestone. The direction from which it came is unknown.

Relation of Edwards formation to Kiamichi formation.—The contact of the Edwards and Kiamichi formations is exposed at the top of the hill just west of outcrop no. 2. An entire section of Kiamichi shale is present but is poorly exposed. It is 10 feet thick and is overlain by the Duck Creek limestone.

The Edwards and Kiamichi formations lie in sharp contact with each other. The top of the Edwards limestone is oxidized, case-hardened, and pitted like the top of the formation at many other localities.

Rudistid Facies, Outcrop No. 1

Outcrop no. 1 exposes 6 to 8 feet of well-bedded rudistid limestone. Beds range in thickness from 2 inches to 2 feet and are composed of a mass of whole and broken rudistids that show no evidence of transportation. The top of this outcrop appears to be stratigraphically equivalent to the base of the lowest rudistid facies at the east end of the north wall of outcrop no. 2.

The origin of the rudistid facies in this outcrop is undetermined. Well-developed bedding indicates that the deposit is not the core of a rudistid reef. It could be the flank of a reef, however. On the other hand, it may be an incipient reef formed by the in situ accumulation of rudistids which grew under conditions that did not permit the construction of a massive reef core.

Rudistid Facies, Outcrop No. 2, South Wall

Stratigraphic and structural relations.—The south wall of outcrop no. 2 exposes 11 feet of a rudistid reef, the true thickness of which is unknown. The reef has an asymmetrical shape and consists of the core and the surrounding flank deposits (Pls. 3; 7, A).

The reef core is massive compared to the flank deposits. Three irregular and discontinuous growth surfaces, none of which pass completely through the core, mark levels where reef growth was temporarily interrupted. Similarly, a thin irregular bed of coarse granular limestone near the base of the outcrop indicates that, for a brief period of time, reef growth was not only interrupted but gave way to the physical deposition of sediment.

The reef core grades laterally and upward into more fragmental deposits. No sharp line of demarcation can be drawn between these sediments. On the east side and above the core, the flank sediments form only a thin zone between the core and the bedding plane which marks the limit of the reef. The flank deposits on the west side of the core are thick to massively bedded. Bedding is very irregular but becomes more uniform away from the reef. The flank sediments grade laterally into the interior-reef sediments. The boundary between these sediments (Pl. 7, A) is based primarily upon petrographic evidence that the particles in the inter-reef sediments are rounded and sorted to some extent, thereby indicating deposition by mechanical processes.

The rudistid facies near the top of the formation at the west end of the outcrop is the flank of another reef which lies to the west. It is probable that this rudistid facies is the highest part of the same reef which is exposed at the east end of the outcrop.

Lithology of the reef core.—The reef core is composed of a structureless mass of interlocking fossils preserved as "original" shell material, recrystallized shell material, and molds (Pl. 19, C). Cells within the outer shell wall are usually filled with either crystalline calcite or lime detritus but some are empty (Pl. 21, A). Body chambers of many of the fossils are filled with lime detritus. Some, however, are partially or completely filled with clear crystalline calcite. Where partially filled, they are vugs lined with calcite crystals. Body chambers filled with clear calcite often exhibit a layer of small calcite crystals lining the chambers and an irregular mosaic of larger crystals filling the remainder of the chambers. This feature indicates two stages of cavity filling. There is no evidence to show that a long period of time separated the two stages of crystallization.

The matrix of the reef core is microgranular limestone in which tiny angular shell fragments are abundant. On a polished surface, the matrix has a very fine detrital appearance. Microscopically, it is an extremely dusky groundmass composed of grains which have an average size of 0.003 mm.

Stylolites are abundant throughout the reef core and in the adjacent flank deposits. They occur along bedding planes, at the contact between the internal and external molds of the fossils, and throughout the matrix. The amplitude of the stylolites ranges from one-thirty-second to half an inch. At most places a coating of iron oxide is present on the surface of the stylolites.

Lithology of the reef flank.—The reef flank deposits are composed of a poorly sorted mass of whole and broken rudistids embedded in a microgranular matrix similar to that in the reef core. There is very little evidence of transportation of the components. Shells and shell fragments are preserved as "original" shell material and recrystallized material.

The flank deposits of the reef west of the roadcut are made up of whole and broken rudistids embedded in a granular matrix. Coarse rudistid debris is not as abundant as in the flank sediments of other reefs. The deposit is massive and grades laterally into the well-bedded cherty inter-reef facies.

Rudistid Facies, Outcrop No. 2, North Wall

Stratigraphic and structural relations.—Three feet of rudistid limestone is exposed at the base of the east end of the outcrop (Pl. 3). The beds dip 15° to the east and grade laterally, to the east as well as the west, into finer shell debris. The beds appear to be truncated by the overlying nodular limestone, but it is not known whether this represents true truncation or merely nondeposition.

The massive rudistid facies which overlies the nodular limestone is the flank of an unexposed reef which is believed to have been located to the east or southeast of the outcrop (Pl. 7, B). Weathering has revealed the presence of incipient bedding which dips very gently to the northwest. To the west, the entire deposit, as well as individual beds, thins out and grades into inter-reef sediments. The upper few feet of the rudistid facies grades into the lower part of the cherty inter-reef facies.

The rudistid facies at the west end of the outcrop is structurally and lithologically like that in the south wall.

Lithology of the reef flank.—Lithologically, the reef flank in the north wall is very similar to the flank deposits in the south wall. It is composed of a poorly sorted mass of whole and broken rudistids embedded in a microgranular matrix. Fossils and fossil fragments are preserved as "original" shell material and recrystallized calcite casts. There is very little evidence of abrasion of the components.

The coarse debris and whole shells grade laterally into finer shell debris which is better sorted and shows some evidence of rounding of shell fragments.

Paleontology.—*Chondrodonta*, *Caprinuloidea*, and *Eoradiolites* are the predominant organisms in the reef core and reef flank deposits. *Eoradiolites* is especially abundant in the flank deposits in the north wall. *Caprinuloidea* appears to be the dominant form in the flank deposits at the west end of the outcrop. *Toucasia* is also present.

Dictyoconus walnutensis is abundant in places in the flank deposits on the west side of the reef core in the south wall.

Inter-reef Facies, Outcrop No. 2, North and South Walls

Stratigraphic and structural relations.—The massively bedded inter-reef deposits on the east side of the reef in the south wall lie against the reef flank (Pls. 3; 7, A). Near the core the sediments dip as much as 30°; 50 feet away they are essentially horizontal. The beds are truncated at the top by the thin-bedded cherty inter-reef facies. The inter-reef sediments on the east side of the core are believed to be the lateral equivalent of a part of the reef located behind the outcrop or of a part which was eroded away prior to deposition of the cherty limestones. The beds are several feet thick and increase in thickness away from the reef.

The inter-reef sediments west of the reef core are thick to massively bedded. They are laterally equivalent to the reef and dip away from the core with a maximum inclination of 12°. The beds are marked at the top by the low-relief disconformable surface that extends westward from the top of the reef.

The inter-reef sediments in the upper part of the outcrop consist of a lower cherty limestone zone and an upper nodular limestone zone which contains no chert. In the cherty zone, bedding planes are well developed, and beds maintain a fairly uniform thickness in the center of the outcrop except where chert nodules are present. In the zone above, bedding is wavy and produces a nodular structure. Bedding in both zones becomes discontinuous and finally disappears into the rudistid facies at the west end of the outcrop.

From the center of the outcrop to its eastern extremity, the entire facies decreases in thickness owing to pinchout and thinning of individual beds. In the north wall the inter-reef facies grades into the top of the reef flank as already noted.

Chert occurs as both beds and nodules (Pl. 8, B). The nodules have various shapes but most of them are flat and elongated parallel to the bedding. The lowest chert bed in the north wall is honeycombed and approximately 1 foot thick. To the east, it becomes a thin wavy bed which finally breaks up into nodules concentrated along a bedding plane. This bed is not present in the south wall.

Chert beds range in thickness from 0.5 of an inch to 6 inches. Some have flat surfaces but more commonly they have knobby or wavy surfaces. In places, the beds thicken to form large protuberances. These, in turn, often coalesce with the next chert bed above. Locally, where weathering has etched them out, laminations in the limestone can be seen bending around and pinching out against chert nodules in the same manner that sediments onlap a mound (Pl. 8, C). Small shells and shell fragments are oriented parallel to the chert boundaries. The honeycombed chert horizon at the base of the inter-reef sediments is overlain by a bed of pelecypods. A few organisms in this bed secreted shells which conformed to the shape of the nodules on which they grew. The relation of the chert to the adjoining limestones clearly indicates that the chert originated as a primary deposit.

An interesting feature of the sediments in the north wall is the occurrence of tiny faults and joints. Their presence suggests fracturing prior to lithification because none of them cross the bedding planes (Pl. 8, D). Displacement on the faults ranges from one-sixteenth to one-eighth of an inch and it may be vertical, horizontal, or a combination of both.

Lithology of the inter-reef deposits, east end of south wall.—The inter-reef deposits at the east end of the south wall are composed of white poorly sorted fine to coarse shell debris (Pl. 20, A). These sediments are extremely chalky as a result of present-day weathering. On a fresh surface very little texture is evident, but on a weathered surface the shell fragments are etched into relief and reveal the true nature of the deposit.

Detailed features of the shell debris are obscure owing to chalkification. In thin sections, the chalk is a dark microgranular groundmass through which the clastic texture can be barely seen (Pl. 21, E). Large shell fragments are composed of "original" shell material but most small fragments have been converted to chalk. A large amount of the shell material also occurs as coarse crystalline calcite casts. *Dictyoconus walnutensis* is very abundant in places, but many specimens are so completely altered to chalk that they are barely recognizable (Pl. 21, F).

Clear crystalline calcite, in addition to forming casts of shell fragments, occurs as irregular-shaped patches and ramifies the entire matrix. Small veins of crystalline calcite cut across shell fragments as well as matrix. Some of the calcite was undoubtedly deposited as a cement shortly after deposition, but most of it probably originated by reprecipitation of calcite following chalkification.

Evidence of boring organisms in the shell debris is found in many instances (Pl. 21, D). The borings have shapes which range from small indentations in the shells to long slender sinuous holes.

Lithology of the inter-reef deposits west of the reefs, north and south walls.—West of the reef core, the flank deposits grade into shell debris in which whole shells are scarce. The effects of wave and current action become apparent with increasing distance from the reef core. Individual particles are slightly abraded. The matrix, which is extremely fine-grained and almost opaque in thin sections of reef core and reef flank limestones, is composed of both microgranular calcite and relatively coarse crystalline calcite (Pl. 21, C).

An interesting feature is the occurrence of dolomite. It is found in many small bore holes that penetrate the top of these sediments and as dolomite casts of original shell fragments. The dolomite is tan and coarsely crystalline like that described at localities 154-T-1, 154-T-14a, and 154-T-16.

Lithology of the cherty inter-reef facies.—The inter-reef limestones overlying the core and its equivalent deposits to the west are microgranular chalky limestones (Pl. 20, B). Most of the beds appear to be structureless, but weathering reveals the presence of very thin laminations and cross-laminations. The top of the outcrop is a marl or caliche.

In thin sections, these limestones have a dusty finely mottled texture (Pl. 22, A). The dusty silt-sized particles have very indistinct outlines and are composed of microgranular calcite. No organic structures are apparent in them. Slightly coarser crystalline calcite fills the interstices. Irregular-shaped patches of clear crystalline calcite containing ghosts of the dusty silt-sized particles are the result of chalkification and reprecipitation of calcite.

Calcite casts of small rod-like particles (replaced sponge spicules?) are very abundant (Pl. 22, B). In laminated limestones they are oriented parallel with the laminations. Small round spheres (cross sections of sponge spicules?) are equally abundant. Miliolids, all of which have been converted to dark microgranular calcite, are present throughout these sediments. "Original" shell material is almost totally absent.

The inter-reef deposits near the west end of the north wall contain a large number of hard tubes or rods of fine-grained limestone. Fragments of limestone lithologically similar to the surrounding limestone are associated with them. *Pecten duplicostata* is very abundant in this area. The origin of the limestone rods is unknown; they may be casts of bore holes. The limestone fragments are believed to have originated from fragmentation of the surrounding limestone prior to complete lithification. Both features may be the result of organisms; if so, they indicate great organic activity.

The microgranular limestones grade laterally into coarse granular limestone, fine shell debris, and, finally, into rudistid limestone at the west end of the roadcut.

Paleontology.—*Pecten duplicostata* and the unidentified pelecypod which forms the bed on top of the lowest chert horizon are the only macrofossils which are very common.

Dictyoconus walnutensis is abundant in the deposits at the east end of the south wall and miliolids are abundant in the remainder of the inter-reef deposits.

Correlation of Outcrops

It is rather difficult to correlate the outcrops at this locality. From evidence which has been presented, it appears that several centers of reef growth controlled sedimentation in this vicinity. Actually, they were probably individual mounds or lobes projecting upward and outward from the same reef core.

The core of one of these reefs is exposed at the east end of the south wall. A tongue of rudistid limestone is believed to have extended northeastward from this reef to form the flank deposits at the base of the north wall. It was buried beneath a tongue of Comanche Peak limestone which did not extend to the south side of the highway. Upward growth of this reef behind the south wall shed debris over the lower part of the reef to form the coarse sediments at the east end of the south wall.

A second center of reef growth existed east of the main roadcut above the Comanche Peak tongue. The flank of this reef is exposed in the north wall. This reef and the reef core in the south wall became coextensive and their flank deposits extended to the west as a single unit.

The youngest reef to affect sedimentation was located west of the outcrop. A tongue of this reef extended eastward and is exposed at the west end of the roadcut. Sediments derived from this reef were swept to the east and inundated the older reefs.

LOCALITY 50-T-8

A long roadcut on U. S. Highway 84 west of Greenbriar Creek exposes the flank deposits of two reefs and the intervening inter-reef deposits (fig. 14; Pls. 3; 7, C). The Edwards-Kiamichi contact is not exposed, but the top of the hill at the west end of the outcrop is thought to be very close to the top of the Edwards formation.

Relation of Edwards Formation to Contiguous Formations

Relation of Edwards formation to Comanche Peak formation.—The contact between the Edwards and Comanche Peak formations is texturally very sharp. Faunally and structurally, however, it is somewhat gradational. A few rudistids scattered through the upper few feet of the Comanche Peak limestone and an incipient development of even bedding in the upper part of the formation indicate that environmental conditions favorable for deposition of the Edwards limestone were established before the end of Comanche Peak deposition.

An unusual feature of this outcrop is the occurrence of a small syncline near the 300-foot mark (Pl. 3) in both the Edwards and Comanche Peak formations near the east end of the roadcut. Because this is the only known occurrence of such a feature and because it is only partially exposed, its origin is difficult to determine. Tectonism seems unlikely for there is no other evidence of disturbance in the immediate vicinity. Pre-Edwards erosion must be ruled out because incipient bedding in the Comanche Peak limestone is also deflected downward in the syncline. The rubble zone near the syncline and another solution channel a few hundred feet farther west in addition to an abundance of stylolites indicate that some solution of the limestone has occurred. It is conceivable, therefore, that solution near the Edwards-Comanche Peak contact followed by slow adjustment of the overlying limestone could have produced the syncline.

Rudistid Facies

Stratigraphic and structural relations.—The rudistid facies at the extreme east end of the outcrop is biostromal and consists of very gently undulatory beds which range from 4 inches to 2 feet in thickness. To the west along the outcrop, the rudistid facies develops into a series of bioherms that have dips as great as 30°. Bedding planes are less pronounced but are still apparent in the bioherms. Individual beds maintain approximately the same thickness as far as the 450-foot mark where several of them combine to form thicker beds. The remaining beds continue from this point to the 600-foot mark where they disappear. The rudistid facies is massive from the 600-foot mark to the 900-foot mark where it passes beneath the outcrop.

Stylolites are conspicuous on many of the bedding planes. They are developed equally well on the crests, flanks, and in the troughs between the bioherms. Irrespective of their location, they are always oriented in a vertical direction. The amplitude of the stylolites ranges from one-sixteenth to three-fourths of an inch but is most commonly one-fourth of an inch.

The rudistid facies at the west end of the outcrop overlies the inter-reef beds with a sharp contact. Most of the rudistid facies is massive, but it becomes bedded toward the east. It is quite probable that the inter-reef beds could be seen grading laterally into the rudistid facies if the roadcut were deeper.

Lithology of the reef core.—Only two small patches in the outcrop are considered to be reef core. Both are patches of *Caprinuloidea* which occur between the 450- and 550-foot marks. Classification as reef core is based primarily upon the better state of preservation of the fossils as compared to the preservation of fossils in the surrounding rock. Both patches may be either tongues of the reef core extending into the flank deposits or merely small local colonies of *Caprinuloidea.*

Lithology of the reef flank.—The eastern half of the roadcut (to the 1,000-foot mark) exposes the flank of a reef which is believed to be located behind the outcrop.

The flank deposits consist of a poorly sorted accumulation of whole fossils and coarse rudistid fragments embedded in a microgranular chalky matrix (Pl. 20, C, D). All components are very angular and show no evidence of abrasion (Pl. 22, D, E). Near the 300-foot mark elongated shell fragments and whole shells are preferentially oriented parallel to the bedding. Shells and shell fragments are composed of "original" material and recrystallized calcite (Pl. 22, E).

On polished rock specimens, the rudistid limestone is a heterogeneous mass of broken material. The matrix and the shells are cut and offset by many small very irregular hairlike cracks. The microgranular fillings in the body chambers and in the cells of the outer shell wall have fallen out of some of the fossils or down into the cavity formed by solution of the original shell. The entire mass of whole shells, shell fragments, and displaced fillings is cemented by clear coarse crystalline calcite. The latter appears to constitute a greater volume of the rock than it does in similar deposits elsewhere. The abundance of irregular cracks that cut shell fragment as well as matrix indicates that compaction played an important part in the development of the flank deposits of this locality and that it occurred prior to cementation.

The great volume of clear calcite cement suggests that a more than normal amount of matrix material was winnowed out of the accumulating flank deposits. This caused the remaining material to be fragmented and compacted to a greater extent than usual.

Paleontology.—*Eoradiolites* is the most abundant fossil in the flank beds. *Chondrodonta* and *Caprinuloidea* are fairly common. A few isolated specimens have been tentatively identified as *Monopleura.*

Inter-reef Facies

Lithology and stratigraphic relations.—Reef flank sediments grade laterally and vertically into inter-reef limestones. Near the 500- and 900-foot marks these sediments are poorly sorted chalky fine shell debris. The shell fragments are angular and most of them are recrystallized calcite. The matrix is very fine grained and chalky. The chalky appearance of the limestone and the large amount of recrystallization of the shells are due to weathering. The contact between the fine shell debris and the overlying inter-reef deposits near the 900-foot mark is defined by a thin oxidized marly limestone bed which thins to the west. The bed contains many shell fragments and broken "tubes" of hard fine-grained limestone.

Between the 900- and 1,200-foot marks the inter-reef deposits are well-bedded cherty limestones (Pl. 6, B). Beds range from 0 to 3 feet in thickness. The beds at the east end of the inter-reef facies are even bedded. To the west, they become wavy bedded and interfinger with other beds of similar lithology.

The chert is both bedded and nodular. Most of it occurs in two prominent beds. The remainder occurs as both flat and irregular-shaped nodules most of which are concentrated in the limestone beds rather than along the bedding planes.

Lithologically, the limestone and chert are like the cherty inter-reef facies at locality 50-T-7.

Bell County

The Edwards formation crops out in a narrow belt along the Leon River north of Moffat. Between Moffat and the Williamson County line, the Edwards outcrop increases in width until it eventually forms a broad belt several miles wide between Prairie Dell and Ding Dong.

The most conspicuous feature of the Edwards formation in Bell County is the great variety of carbonate rocks which make up the formation. All previously described rock types are present. Many more, formed by alteration of the original limestone, also occur. Though secondary processes have altered the primary constituents of the Edwards limestone throughout the area, they have not been severe enough to destroy completely the original primary textures and form new rock types north of Moffat. South of Moffat, on the other hand, alteration of the Edwards formation has been so severe in some places that none of the original texture remains. Two well-exposed outcrops which illustrate various degrees of alteration are discussed.

Locality 14-T-1

Locality 14-T-1 is an abandoned quarry approximately 2 miles northwest of Belton (fig. 14). The quarry face is cut by a fault zone near the point where the dirt ramp descends into the quarry. In this zone a heterogeneous mass of dense crystalline and honeycombed limestone is embedded in a matrix of white iron-stained chalk. The fault block west of the fault has dropped 6.5 feet measured on the base of unit 2.

Contacts of the Edwards formation with contiguous formations are not exposed, but the quarry floor is believed to be close to the base of the formation.

Extreme East End of Quarry Wall

The extreme east end of the quarry wall is particularly interesting because of the occurrence of dolomite. The dolomite is interbedded with coarse granular limestones, fine shell debris, and dolomitic limestones (Pl. 9, A). Dolomite beds range from 0 to approximately 1 foot in thickness; limestone beds may be thicker. Each bed is penetrated by bore holes that are filled with the overlying type of rock (Pl. 9, B-D). In general, the limestone beds contain more bore holes than do the dolomite beds. This suggests that organic activity was greater on the lime-sand bottoms than on the dolomite bottoms. In places, bore holes ramify the rock to such a great extent that it is difficult to differentiate between bore-hole fillings and host rock.

The dolomite is hard, dark gray, and composed of a tightly knit mass of crystals which have an average size of 0.01 mm. Microscopically, there appears to be very little porosity in this dolomite. Some beds of dolomite are cross-laminated and consist of alternating layers of crystals, the lighter colored laminations being more coarsely crystalline (Pl. 24, D).

Bore holes in the dolomite beds are filled with more coarsely crystalline dolomite that contains many well-rounded grains of "original" and recrystallized shell material. Most of the grains do not touch each other; instead, they appear to be floating in the dolomite. Dolomite crystals penetrate the "dust" rim of many of these grains, and "ghosts" of particles in the dolomite suggest that the grains were originally more abundant than at present. It seems unlikely, however, that dolomitization of the particles could have produced the open-packed texture that now exists. In the writer's opinion, this was produced by lime-sand being deposited in bore holes in which dolomite was crystallizing. Some of the grains were then dolomitized.

Some limestone beds have a dolomite matrix or cement similar to the filling of the bore holes. The principal difference between the bore-hole fillings and the limestone beds is the greater proportion of grains to matrix in the latter. The grains occur in a normal close-packed state.

Mapped Portion of Quarry Wall

Approximately 30 feet of the Edwards formation is exposed in the quarry wall (Pl. 3). This is divisible into seven lithologic units which can be traced across the entire length of the quarry, a distance of more than 1,200 feet. Only that portion of the quarry wall west of the fault zone has been mapped, however. The following discussion deals with the mapped portion of the quarry wall only, unless otherwise stated.

Unit 1.—Unit 1 is a massive gray dolomitic limestone characterized by a variety of textures. The lower part of the unit is poorly sorted shell debris and contains many dolomite-filled bore holes. It grades upward into thinly laminated fine shell debris and coarse granular limestone (Pl. 23, A). Very thin clay seams are common in this part of the unit, and many of them terminate in minute stylolites. Stylolites are common at the contact of individual grains and between the grains and matrix.

Most of the sedimentary particles are "original" shell material, recrystallized grains, and opaque grains (Pl. 25, A). Recrystallized grains are the most abundant. *Dictyoconus walnutensis*, miliolids, and well-rounded fragments of the coral *Cladophyllia* are common in some places. All grains are very well rounded. Many are coated with brown oolitic growth rings which, in a few cases, have cemented several particles together (Pls. 25, B; 26, D).

The state of packing of the particles is quite variable. The grains occur in either a close-packed or an open-packed state (Pl. 25, A).

Dolomite and clear crystalline calcite constitute the matrix or cement. However, the two minerals are not uniformly distributed through the matrix. Some interstices are filled with calcite that was deposited during two stages of precipitation (Pl. 26, D). Others are filled with calcite that was deposited during only one stage of precipitation. Part of the calcite was deposited subsequent to formation of the dolomite as indicated by large crystals of calcite that surround rhombohedrons of dolomite.

Dolomite varies considerably and may either partially or completely fill the interstices. In places, dolomite has encroached upon the particles (Pl. 26, A-C). Analyses of six samples (table 2) indicate that dolomite ranges from 5 to 65 percent.

A bore hole zone marks the top of the unit (Pl. 9, B). The bore holes form a reticulate network 1 foot thick. The bore hole fillings are lithologically similar to those in sediments at the extreme east end of the quarry with which they are stratigraphically equivalent. Analyses of one bore hole filling and the adjoining host rock show that the filling is 65 percent dolomite as compared to 15 percent in the host rock (table 2).

Unit 2.—A thin bed of rudistids forms unit 2 (Pl. 10, B). Though both the top and bottom contacts of the unit are sharp, neither is a bedding plane. Apparently, conditions of deposition in each case changed too rapidly for a bedding plane to develop.

Both whole and fragmented fossils are present (Pl. 23, B). They vary in relative abundance laterally so that the unit may be composed of either whole fossils or fossil fragments. "Original" shell material and calcite or dolomite casts are both present. The casts appear to have been formed by cavity filling rather than by recrystallization. All are very angular and show very little, if any, evidence of abrasion. Some fragments contain small tubelike bore holes (Pl. 26, E).

The composition of the matrix is extremely variable. It is composed of various proportions of microgranular calcite, coarse crystalline calcite, and dolomite. Analyses of two samples indicate that 50 percent of the rock is dolomite, part of which is in the casts of the shell fragments. The clear coarse crystalline calcite surrounds the dolomite and microgranular calcite and therefore was emplaced subsequent to their formation (Pl. 26, F). The origin of the microgranular calcite is problematical. It may be either an original lime-mud which was not completely replaced by dolomite and coarse crystalline calcite, or the result of post-lithification chalkification.

Unit 3.—Tan well-sorted very dolomitic fine-grained limestone (calcilutite) grades upward into well-sorted slightly dolomitic granular limestone (fine calcarenite) (Pl. 25, C). The unit ranges from 2.5 to 4.5 feet in thickness and forms a single massive but thinly laminated bed. Bedding planes within the unit are only a few tens of feet long.

Opaque grains, "original" shell material, and recrystallized grains make up the particles. Opaque grains and "original" shell fragments predominate. Most grains are well rounded.

The matrix or cement is calcite in the upper part of the unit. In the lower part it is dolomite and calcite. The dolomite consists of euhedral rhombohedrons and in places constitutes the entire matrix.

Flat nodules of gray microcrystalline chert are present near the center of the outcrop. They are 3 to 6 inches thick and as much as 10 feet long. Laminations in the surrounding limestone bend around the nodules thus demonstrating that the chert was emplaced before lithification of the limestone. Therefore, it is a primary deposit. Thin sections of the chert indicate that dolomite rhombohedrons are abundant. Most of them are corroded or abraded and many have been partially replaced by silica. They occur in clusters and as laminations arranged parallel to the bedding (Pl. 22, F). Long slender siliceous objects occur with the dolomite and are oriented parallel to the laminations. The siliceous rods are believed to be recrystallized sponge spicules.

Unit 4.—White to tan thinly laminated granular limestone forms unit 4 (Pl. 23, C). Well-developed cross-laminated bedding is a prominent feature of this unit (Pl. 10, C). Bedding is lenticular and, as a result, few beds can be traced across the length of the outcrop. Most beds are 3 to 6 inches thick. The entire unit gently pinches and swells from a minimum thickness of 4 feet to a maximum thickness of approximately 8 feet.

The limestone is made up of well-sorted and well-rounded "original" and recrystallized shell fragments embedded in a crystalline calcite cement. The "original" shell material is unusual in that it is composed predominantly of straight or slightly curved rodlike organic fragments of unknown origin. The anhedral calcite that forms the center of the recrystallized grains is more finely crystalline than usual and the grain boundaries are less distinct than normal. In places, recrystallization of individual grains is so complete that no "original" shell material is evident (Pl. 25. D).

A characteristic feature of this unit is the abundance of molds of grains. Most of them are bordered by the "dust" rim that surrounds most recrystallized grains. It is uncertain whether the molds were formed by natural phenomena or by the process of thin-sectioning.

Large flat nodules of gray microcrystalline chert similar to those in unit 3 occur at the base and along bedding planes within the unit. Laminations in the limestone bend around the nodules as they do in unit 3. Organic debris is abundant in the chert. A large amount of it consists of remnants of sponge spicules(?). The organic debris in some nodules is cross-laminated on a very small scale, thus demonstrating the effect of current action upon the debris prior to lithification of the chert (Pl. 24, C). Because of the great dissimilarity of the cross-laminations in the limestone and chert, and because limestone laminations bend around the chert nodules, the writer believes the chert is syngenetic.

Dolomite is an interesting constituent of the chert in unit 4. The dolomite rhombohedrons are distributed irregularly through the chert as well as along the cross-laminations. Most of the crystals are corroded or abraded. The occurrence of dolomite in this chert is anomalous because it does not occur in the surrounding limestones, as shown by analyses of eleven samples (table 2). The significance of this dolomite is discussed later.

Unit 5.—Unit 5 is approximately 7 feet thick. The thickness varies slightly owing to undulations on top of unit 4. The larger undulations of unit 4 are reflected on top of unit 5 but to a lesser degree.

The contact of units 4 and 5 is sharp. Strictly speaking, there is no bedding plane between the units in the western part of the quarry. Instead, the contact is marked by a very sharp gradation from fine-grained limestone in unit 4 to rudistid limestone in unit 5. The contact develops into a bedding plane to the east, however. Below the collapsed zone, the contact drops 1 foot in the stratigraphic sequence; thus, the top of unit 4 in the western part of the outcrop is laterally equivalent to the base of unit 5 in the eastern part of the outcrop.

Bedding planes are undulatory but are generally parallel to the top and bottom of the unit in the western part of the outcrop. In contrast, the limestones in the eastern part exhibit well-developed cross-bedding which dips very gently to the west. Beds range from a few inches to several feet in thickness. Most of them are not continuous for a great distance even though the lithologic subdivisions of the unit continue across the quarry.

Unit 5 is composed of several types of rocks; these include rudistid limestone and coarse shell debris, granular limestone and fine shell debris, crystalline limestone, and silicified limestone. In general, the unit can be subdivided into three parts: rudistid limestone at the base, granular limestone and fine shell debris in the middle, and crystalline limestone at the top. Patches of silicified limestone are also present.

The rudistid limestone is composed of coarse poorly sorted shell fragments embedded in a granular matrix (Pl. 23, D). The cement is crystalline calcite. Almost all constituents are recrystallized shell material; very little "original" shell material is present.

It is evident that this rudistid limestone was formed by mechanical processes of deposition rather than by organic growth in place. All components of the limestone are well rounded and have the "dust" rim that typifies medium to coarse transported or reworked particles. The rudistid limestone is bounded above by a distinct bedding plane in some places; in other places, it interfingers with and grades into fine shell debris and granular limestone along the foreset beds.

The fine shell debris and granular limestone (calcarenite) that form the middle of the unit are made up of well-rounded grains embedded in a cement of crystalline calcite (Pl. 25, E). Most grains are recrystallized, but particles of "original" shell material are fairly common. Many grains are represented by molds. In general, this part of the unit is poorly sorted, but some beds are composed of well-sorted grains. Cross-lamination is well developed in many beds and elongated grains are oriented parallel to the laminations.

Specimens of *Dictyoconus walnutensis* which have altered to microgranular calcite are common.

Recrystallization has affected all of unit 5, but only the upper 6 to 12 inches has been converted to a new rock type. In the outcrop, the limestone is extremely dense, vuggy, and very finely crystalline. It is mottled shades of brown and yellow (Pl. 24, B). For the most part, recrystallization has not completely erased the original texture. Polished rock specimens and thin sections indicate that the rock was originally a well-sorted granular limestone. The grains are now represented by very thin "dust" rims. In places, even these have been partially destroyed. The calcite within the grain boundaries is more coarsely crystalline than the matrix. Some grains now consist of a single large crystal of clear calcite. The writer is uncertain whether this calcite was formed by recrystallization in the solid state or by precipitation of calcite in the molds of grains. Very few molds occur in the recrystallized limestone. A small amount of "original" shell material remains. The contact with the overlying unit is sharp but very irregular.

Secondary silicification has formed large patches of extremely hard dense silicified limestone (Pl. 10, D). The patches have a lenticular shape and are as much as 25 feet long. All are elongated parallel to the bedding. The long dimensions may be bordered by bedding planes or by gradational contacts with the surrounding limestone. The contacts at the ends of the silicified limestone lenses are always gradational though they often appear to be sharp in the field. In sample GG (Pl. 3), for example, the gradation extends over a distance of 1 inch.

Silicification is largely confined to the fine shell debris and coarse granular limestone. Silica occurs in the grains and shells as well as in the matrix. It has replaced the centers of many "original" shell fragments while still preserving the original structure of the shell. During the process of silicification very little of the original texture was destroyed and as a result, original bedding, cross-lamination, and fabric are well preserved.

Unit 6.—Soft brown microcrystalline dolomite overlies unit 5. Intercrystalline porosity is well developed. Microscopically, the dolomite is a loosely knit mass of small euhedral crystals 0.03 mm in diameter.

Molds of fossils are very abundant throughout the dolomite. Most of them are unidentifiable, but a few appear to be fragments of rudistids. The abundance of fossil fragments throughout the dolomite suggests that unit 6 was a rudistid biostrome prior to post-lithification dolomitization. The very rubbly surface of the outcrop suggests that the biostrome was thicker originally and that it collapsed following dolomitization.

Nodules of chert are abundant in the top of the unit across the entire length of the outcrop. In the field, they appear to be lithologically similar to nodules lower in the stratigraphic section; they differ primarily in having a more equidimensional shape than the other nodules. Thin sections indicate, however, that the chert is actually silicified dolomite and was formed by precipitation of microcrystalline silica in the interstices (Pl. 30, D).

Unit 7.—Unit 7 is composed of interbedded crystalline limestone, chalk, and dolomite (Pls. 3; 10, A). All are believed to have been formed by post-lithification alteration of pre-existing limestone. The characteristics of the original limestone are unknown.

When viewed from across the quarry, the unit appears to be composed of regular continuous beds. Close inspection, however, demonstrates that very few beds are continuous across the entire quarry. They either pinch out or coalesce laterally with another bed. Individual beds are as much as 2 feet thick. Contacts between beds are generally sharp but very irregular and undulatory. In some beds, the lithology changes laterally, but the upper and lower contacts continue beyond the point of lithologic change.

The dolomites are soft, microcrystalline, and vary in color from light gray to brown. They have excellent intercrystalline porosity. In places, the dolomite beds are finely laminated.

The limestones are extremely hard, microcrystalline, and mottled shades of brown and gray. They may be dense and massive or dense and laminated.

The limestones in unit 7 have a texture which has not been seen in thin sections of any other limestone. The texture is a mosaic of very irregular-shaped interlocking calcite crystals that have serrated edges. A "dust" of very fine irregular-shaped particles of unknown origin is disseminated

TABLE 2. *Relative abundance of calcite, dolomite, and quartz, locality 14-T-1.* Determined by X-ray diffraction analyses.

Lithologic unit	Sample number	Calcite	Dolomite	Calcite and dolomite (total)	Quartz
7, bed 7	BBB		100	100	
7, bed 5	VV[a]	100		100	
7, bed 5	VV[b]		100	100	
7, bed 4	AAA		100	100	
7, bed 3	ZZ	95	5	100	
7, bed 2	YY		100	100	
7, bed 1	XX	70	30	100	
6	PP		100	100	
6	DD		100	100	
6	G		100	100	
5	OO	100		100	
5	F	100		100	
4	TT		Tr.		100
4	QQ				100
4	LL	100		100	
4	KK	100		100	
4	JJ	100		100	
4	Z	100		100	
4	Y	100		100	
4	X	100		100	
4	N	100		100	
4	M	100		100	
4	L	100		100	
4	J	100		100	
4	H	100		100	
3	RR		5	5	95
3	HH	70	30	100	
3	W	60	40	100	
3	V	40	60	100	
3	Q	95	5	100	
3	P	50	50	100	
3	E	95	5	100	
3	D	50	50	100	
2	U	50	50	100	
2	C	71	29	100	
1	SS[c]	85	15	100	
1	SS[d]	35	65	100	
1	R	50	50	100	
1	B	95	5	100	
1	A	83	17	100	

[a], [b] Interbedded limestone and dolomite.
[c] Host rock.
[d] Bore hole filling.

throughout the mass of interlocking crystals. The larger particles appear to be corroded dolomite crystals, and X-ray analyses of two crystalline limestone beds confirm the presence of dolomite (table 2, samples XX, ZZ). Bed 3 demonstrates that calcification and complete conversion to crystalline limestone have taken place. In this bed, patches of dolomite occur in the limestone. The contact between the dolomite and the limestone is always sharp, but it may be very irrgeular.

Origin of Dolomite

The dolomite in this quarry was formed as both a primary deposit and a post-lithification alteration product. The quarry is believed to be an exposure of the transition zone between the site of dolomite deposition (east of quarry) and the site of limestone deposition (west of quarry) that existed when units 1, 2, and 3 were formed.

At the eastern end of the quarry, precipitation of dolomite was periodically replaced by mechanical deposition of lime detritus. When the influx of lime detritus was great, the grains were deposited in a close-packed state to form beds which later became limestone. During these periods, dolomite often continued to precipitate out of solution to form the matrix in the limestones. When the influx was small, however, the grains were deposited in an open-packed state in the dolomite mud. Benthonic organisms preferred the lime-sand bottom sediments, as suggested by the greater number of bore holes in limestone beds.

Deposition of lime detritus was the dominant type of sedimentation in the mapped portion of the quarry. The interstitial water was evidently saturated with magnesium, because the mineral dolomite crystallized out of solution to form the cement in some limestones and partially replace some of the grains. Grain replacement by dolomite is considered to be very early diagenetic alteration which took place at the same time as dolomite was precipitated as a primary mineral elsewhere in units 1, 2, and 3. In places, dolomite crystallized out of solution to form individual crystals that were then reworked and transported with the other particles. By the time unit 3 was deposited, precipitation of dolomite in the limestones had ceased, but it persisted into unit 4 in the silica deposits.

The argument may be advanced that the dolomite in units 1, 2, and 3 is a secondary deposit and was formed by dolomitization of some particular type of limestone. As noted above, some of the dolomite did originate by diagenesis of particles subsequent to deposition of the lime detritus, but this is true of only part of the dolomite in these units. The writer believes that the dolomite beds at the extreme east end of the quarry and most of the dolomite in units 1, 2, and 3 in the mapped portion of the quarry are primary deposits for the following reasons:

(1) Field evidence, such as bore holes and cross-laminations, suggests that the dolomite mud was subjected to the same physical processes of sedimentation as the lime detritus. It is very questionable whether the cross-laminations in the dolomite would have been preserved through the process of post-lithification dolomitization.

(2) The presence of laminations and cross-laminations of abraded dolomite crystals in primary chert nodules indicates that the crystals were transported or reworked by currents prior to lithification of the chert. Their occurrence in the chert nodules in unit 4 is particularly significant. Inasmuch as no dolomite is present in the limestone of unit 4, dolomite in the chert must have originated by crystallization from solution at the present site of the nodules. It could not have been transported from other areas without some rhombohedrons being deposited in the surrounding limestones, and it is extremely unlikely that post-lithification dolomitization would have formed dolomite rhombohedrons in chert nodules

while failing to dolomitize the limestones.

Dolomite in units 6 and 7 originated by post-lithification alteration of pre-existing limestone. The possible conditions of alteration are discussed later in this paper.

LOCALITY 14-T-8

Primary limestones and post-lithification alteration products crop out at locality 14-T-8. The outcrop is located on F. M. 1670 southwest of Belton (fig. 14). Approximately 70 feet of the Edwards formation is present at this locality, but only the lowest 22 feet is well exposed. The remainder appears to be largely secondary limestone and dolomite.

Comanche Peak Formation

Comanche Peak limestone.—A thick section of Comanche Peak limestone underlies the Edwards formation. In the outcrop, it is a light gray very fine-grained slightly argillaceous compressed nodular limestone (calcilutite). Fine clay seams separate the compressed nodules. Microscopically, it is composed of clay-sized particles of calcium carbonate that are clustered into indistinct silt-sized grains (Pl. 29, A). The cement appears to be crystalline calcite. Angular recrystallized shell fragments are fairly common. Small angular fragments of "original" shell material and miliolids are also present.

Comanche Peak dolomitic limestone and post-lithification dolomite.—The upper 10 to 15 feet of the Comanche Peak formation is dolomitic limestone and dolomite. Four feet below the contact with the Edwards formation, the limestone contains 18 percent dolomite (table 3). The dolomite rhombohedrons are approximately 0.01 mm in diameter and are concentrated between the silt-sized grains (Pl. 29, B).

The limestone becomes progressively more dolomitic toward the top of the formation (Pl. 29, A-D). At first, the increase in abundance of dolomite crystals between the grains produces a more sharply defined granular texture. Ultimately, however, the original granular texture is destroyed. Large shell fragments are the last components to be dolomitized.

The top of the formation is 87 percent dolomite and is almost indistinguishable from the overlying Edwards formation which is 100 percent dolomite (table 3, sample X). The rock is brown in color and the nodular structure which is so characteristic of the Comanche Peak limestone is only faintly apparent. The dolomite is a loosely knit mass of small rhombohedrons. It has a crystalline texture and excellent intercrystalline pinpoint porosity (Pl. 29, D).

Edwards Formation

Primary limestone.—Primary limestone is present at the top and near the west end of the outcrop (Pl. 3). It is hard cream-colored chalky fine shell debris (Pl. 27, A).

The poorly sorted shell debris is composed of fragments of "original" shell material and recrystallized shell fragments (Pl. 28, A). All are very angular.

The matrix is fine-grained limestone. The texture is largely obscured, however, as a result of chalkification and reprecipitation of coarse crystalline calcite.

Dolomitic limestone and post-lithification dolomite.—The primary limestone grades into dolomitic limestone and dolomite in all directions as a result of post-lithification alteration (Pl. 3). The gradation extends over either a short or a long distance. Samples N (0.00 percent dolomite) and T (17 percent dolomite) are 10 feet apart. The dolomite crystals are concentrated in the matrix of dolomitic limestones (Pl. 28, B). As the dolomite content increases, the original texture gradually disappears (Pl. 28, A-C).

The dolomite is soft, massive, and microcrystalline (Pl. 27, B). In general, the crystals are uniform in size and average 0.01 mm in diameter. Crystals as large as 0.04 mm are present, however. They usually occur around the edges of pores (Pl. 28, D).

Intercrystalline porosity is very well developed in the dolomite. It apparently develops after the dolomite content exceeds 50 percent. Porosity which is visible in thin sections does not appear to change until this value is exceeded.

Shell material is almost totally absent in the dolomite, but molds of fossils and fossil fragments are very abundant (Pl. 28, E). The upper part of the outcrop is a mass of molds of rudistids and caprinids which are believed to have formed the core of a reef (Pl. 3). The molds are well preserved and, as far as can be determined, there has been very little deformation of individual shells as a result of dolomitization. It is possible, however, that the entire mass of fossils has undergone a change in volume as a result of dolomitization.

Post-lithification calcitic dolomite.—A considerable part of the dolomite in this outcrop is cemented by secondary calcite which was precipitated in the intercrystalline voids. The resulting masses of calcitic dolomite have very irregular shapes (Pls. 3; 11, A). They range in size from small concretions only a few inches in diameter to large masses several tens of feet across. Their contact with the dolomite is sharp but very irregular (Pl. 11, B). Pockets of dolomite and dolomitized rudistids occur in the calcitic dolomite.

Near the 80-foot mark (Pl. 3), the calcitic dolomite is brecciated and oxidized to a pink color. Brecciation and oxidation are located near a vertical fracture that is present at this point. Brecciation appears to have occurred after dolomitization but prior to secondary cementation.

Cementation was apparently controlled to some extent by primary bedding in the rocks. At the east end of the outcrop, calcitic dolomite is interbedded with dolomite. Below the mass of dolomitized rudistids, several concretions and one long bed of calcitic dolomite are elongated approximately parallel to bedding in the Comanche Peak limestone.

The calcitic dolomite is extremely dense, finely crystalline, and mottled shades of gray, brown, and pink (Pl. 27, C). Color banding along the contacts is common. Deposition of calcite in the intercrystalline voids reduced the porosity of the dolomite considerably. Porosity which remains consists of disconnected vugs and small irregular-shaped patches of intercrystalline porosity that escaped cementation.

Table 3. Relative abundance of calcite, dolomite, and quartz, locality 14-T-8.
Determined by X-ray diffraction analyses.

Sample number	Calcite	Dolomite	Calcite and dolomite (total)	Quartz
A		100	100	
B	33	67	100	
C	43	57	100	
D	79	21	100	
E	28	69	97	3
F		100	100	
G		100	100	
H		100	100	
J		100	100	
K		100	100	
L		100	100	
M	33	67	100	
N	100		100	
O	9	91	100	
P	100		100	
Q	76	24	100	
R	100		100	
S	54	46	100	
T	83	17	100	
U	86	14	100	
V*	100		100	
W	75	25	100	
X		100	100	
Y	100		100	

* Fifteen feet below sample U.

During the process of pore-filling, many dolomite crystals were completely embedded in larger calcite crystals which occasionally grew in optical continuity with the dolomite (Pl. 28, F). Corroded crystal boundaries suggest that some dolomite was removed by solution at the time of cementation. Not much dolomite was lost, however, because the original voids now filled with calcite appear to occupy approximately the same area in a thin section as do the voids in thin sections of adjoining dolomites.

Chert.—Light gray irregular-shaped nodules of chert occur in the dolomite and calcitic dolomite. Near the 175-foot mark, one nodule contains some silicified rudistids.

The chert in this outcrop is generally lighter gray in color and has a more irregular shape than chert found elsewhere in the area. Up to the present time, the origin of this chert has not been determined.

A small amount of silicification has taken place in the primary limestone. In this limestone, a few "original" shell fragments are partially silicified. Small botryoidal masses of chert occur in the centers of the shells. Remnants of the original shell structure are still apparent.

RESUMÉ OF STRATIGRAPHIC AND LITHOLOGIC FEATURES OF THE EDWARDS FORMATION

Stratigraphic Relations

The Edwards limestone is the uppermost formation in the Fredericksburg group. From north to south, the Edwards limestone gradually replaces the Comanche Peak limestone; however, the regional trend may be reversed and the Comanche Peak limestone may locally replace the Edwards formation. The Edwards-Comanche Peak contact is unquestionably gradational over a large area, but in a single outcrop it is usually a sharp contact characterized by a marked change from very fine-grained nodular limestone below to well-bedded granular or rudistid limestone above.

The Edwards limestone is overlain unconformably by the Kiamichi shale in McLennan and northeastern Coryell counties. The shale pinches out along a line extending from Gatesville to the eastern corner of Coryell County (fig. 15). South of this line the Edwards formation is overlain unconformably by the Duck Creek formation.

The thickness of the Edwards formation varies considerably owing to the facies change into the Comanche Peak formation. It ranges from a minimum of 15 feet north of Gatesville to a maximum of 124 feet near Moffat in Bell County. Local variations in thickness due to reefing have been observed in several places.

Rudistid Facies

REGIONAL ASPECTS

The most conspicuous feature of the Edwards limestone in this area is the extensive development of rudistid biohermal and biostromal reefs. Biohermal reef growth reached its maximum development in Bell, Coryell, and McLennan counties. South of these counties, reefs with a biohermal shape occur less frequently. Reconnaissance studies show that biohermal reefs are either absent or very rare in surface exposures of the Edwards formation in the vicinity of Austin and southern Williamson County (fig. 15). In these areas, the rudistid facies is biostromal and constitutes but a small part of the Edwards formation.

North of McLennan and Coryell counties, the rudistid facies makes up most of the Edwards formation and forms extensive biostromal reefs. Though well-developed biohermal reefs are present at least as far north as Johnson County, there is a general tendency for the biohermal shape to be less pronounced than in Bell, Coryell, and McLennan counties. In addition, reef and inter-reef deposits are often only poorly differentiated.

STRATIGRAPHIC AND STRUCTURAL RELATIONS

The true shape of the rudistid reefs in plan view is unknown. In Childress Creek and the Middle Bosque River where the upper surface of the Edwards limestone can be seen, the rudistid facies forms a series of coalescing mounds. All have only a few feet of relief and are probably nothing more than small pinnacles on biostromal reefs of much greater extent.

In contrast to the very limited information about the horizontal shape of the rudistid reefs, evidence of the vertical shape is much more abundant. Biostromal reefs range in thickness from 1 foot up to the total thickness of the Edwards formation; reefs 45 feet thick have been measured. Some are very massive and exhibit only a faint trace of bedding but others are subdivided into many thin beds. The latter are usually the flank of a reef. Bedding may be either horizontal or slightly undulatory.

Biohermal reefs range from a minimum thickness of 9 feet to a maximum known thickness of 55 feet. Biohermal or biostromal reefs could be 120 feet thick near Moffat in Bell County.

As seen in the field, biohermal reefs exhibit considerable variation in their struc-

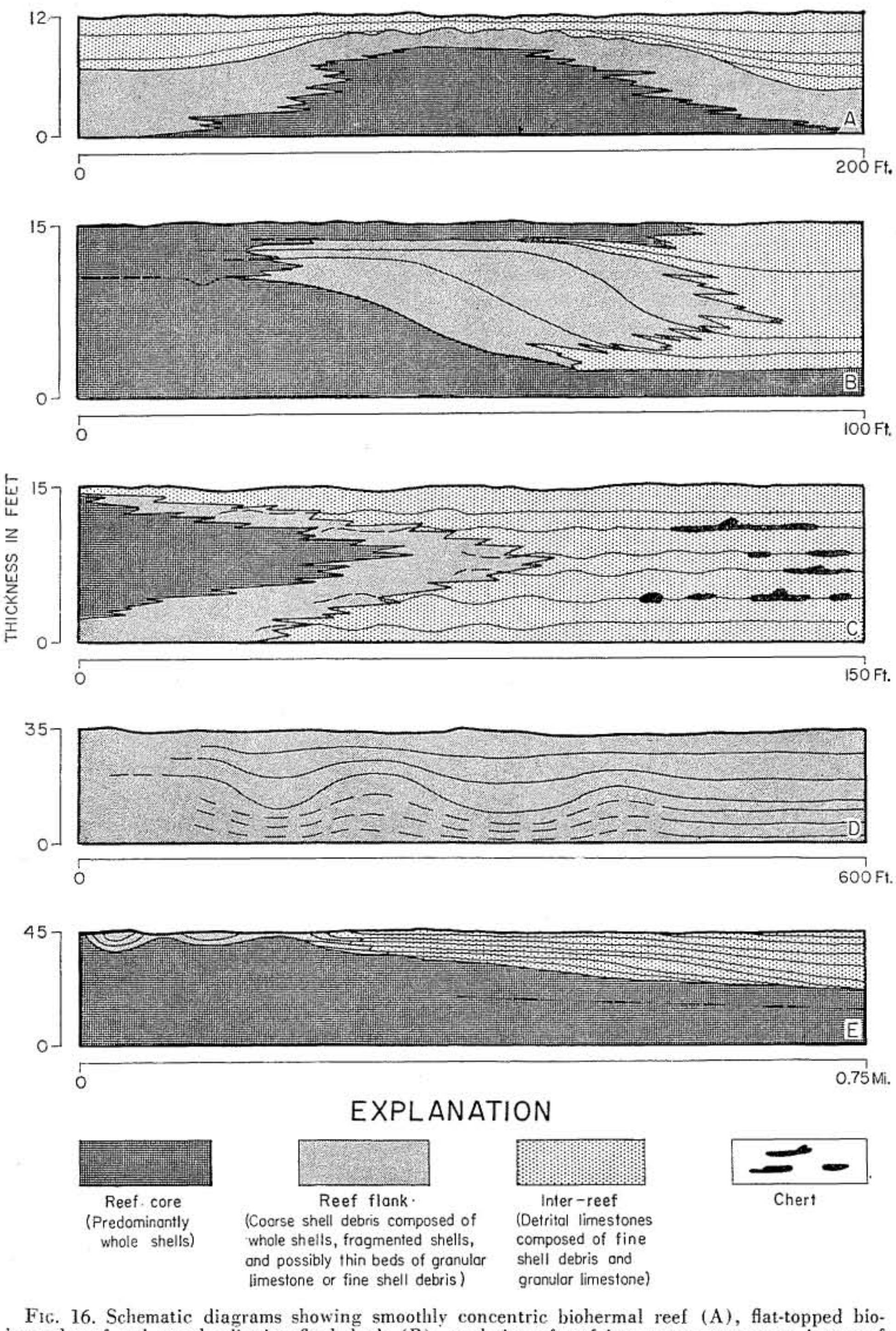

FIG. 16. Schematic diagrams showing smoothly concentric biohermal reef (A), flat-topped biohermal reef and steeply dipping flank beds (B), gradation of reef into contemporaneous inter-reef sediments (C), coalescing bioherms (D), and biostromal reef with small bioherms on the crest (E).

ture (fig. 16). The reef core in most reefs is very massive, but in some it is broken by one or more irregular growth surfaces. In places a series of coalescing well-bedded bioherms may be seen in long outcrops (fig. 16, D). Close examination of the beds usually indicates that they have a fragmental texture, thereby suggesting that they are reef flank deposits.

Most biohermal reefs have a fairly symmetrical shape. They are either smoothly convex upward (fig. 16, A) or flat-topped (fig. 16, B). The entire bioherm may be the "time" equivalent of the biostrome and the overlying granular limestones (fig. 16, B). The flank beds extend out from the reef core at various inclinations up to a maximum of 35°.

LITHOLOGIC FEATURES

Biohermal and biostromal reefs are composed of a mass of rudistids and associated organisms embedded in a very fine-grained dense matrix. In general, the matrix of the reef core consists of silt- and clay-sized particles of calcium carbonate. Patches of sand-sized particles also occur in the matrix but they are not common. The matrix cement, which may be seen only under high magnification, is crystalline calcite.

The flank deposits are composed of poorly sorted coarse angular shell fragments and whole shells embedded in a matrix similar to that in the reef core. In places the flank beds have a lineated fabric owing to orientation of large fragments and whole shells parallel to the bedding. In many places it is difficult, however, to determine whether this is due to sorting action of currents or to the growth habit of the organisms. Because the whole fossils and the fossil fragments are closely packed, the reef flank sediments in many places appear to be more fossiliferous than the reef core. Tongues of reef core and inter-reef sediments may be interbedded with coarse shell debris and, as a result, a sharp line of demarcation can seldom be drawn between the reef flank deposits and the adjoining sediments.

The thin rudistid biostromes that extend outward from the base of the biohermal reefs are lithologically similar to both the reef core and the reef flank deposits. Some biostromes are obviously fragmental and cannot be differentiated from the normal reef flank deposits. Other biostromes exhibit very little fragmentation of the fossils and resemble the cores of biohermal reefs. There is little evidence of transportation of material in any of the biostromes, though in some, there is lineation of the larger constituents.

INTER-REEF FACIES

REGIONAL ASPECTS

The Edwards formation in the vicinity of Austin consists predominantly of well-bedded granular limestone, chert, and post-lithification alteration products. To the north where the rudistid biohermal reefs are developed, this facies is restricted to the inter-reef basins and becomes more coarse grained. The chert and fine-grained thin-bedded limestones (calcilutites) that characterize this facies in central Texas extend as far north as a line that curves southeastward from Hamilton to Osage in Coryell County where it then passes into the subsurface (fig. 15). North and east of this line, the inter-reef facies consists predominantly of granular limestone (calcarenite) and shell debris.

STRATIGRAPHIC AND STRUCTURAL RELATIONS

The inter-reef sediments are characteristically well bedded. Beds range from a few inches to a few feet in thickness. In general, fine-grained limestones (calcilutites) are more thinly bedded than coarse-grained limestones (calcarenites and shell debris). Beds maintain a fairly uniform thickness in the centers of the inter-reef areas. Near the reefs, however, the beds (1) thicken rapidly as they grade into the reef flank deposits, (2) pinch out or thin over the reefs, or (3) develop a nodular structure as they grade into the reefs (fig. 16, A-C). Long outcrops reveal the presence of cross-bedding on a very large scale (fig. 16, E). Many individual beds are thinly laminated and cross-laminated.

Inter-reef beds which onlap the reefs are often separated from the reef deposits by a small disconformity. In many places the top of the reef beneath the disconformity is oxidized, case-hardened, and contains bore holes.

Chert in the inter-reef facies is both nodular and bedded. Most beds break up into nodules as they approach the reefs. Neither the nodules nor the beds extend into the reef flank deposits. The contact between the chert and the surrounding limestone is sharp and is marked by a thin zone of weathered chert. In many places the laminations in thinly laminated limestones bend around or onlap protuberances on the chert nodules in a manner which indicates that the chert was a rigid mass before lithification of the limestone.

LITHOLOGIC FEATURES

Lithologically, the inter-reef sediments are composed of fine-grained limestones (calcilutites), medium- to coarse-grained limestones (calcarenites), shell debris and chert. The fine- to medium-grained limestones are well sorted. Individual particles tend to be well rounded. However, all limestones become poorly sorted and individual particles become more angular near the reefs.

Detrital material is composed primarily of "original" shell material, recrystallized shell fragments that are surrounded by "dust" rims. and opaque grains. The recrystallized shell fragments are most abundant in the medium- to coarse-grained limestones; opaque grains are most abundant in the fine-grained limestones. Minor components include oolites, micro-fossils, and small unidentifiable particles that appear to be calcified sponge spicules. The cement, when it can be distinguished from the detrital particles, is clear crystalline calcite.

FAUNAL ASSOCIATION

Though a detailed study of the fauna in the Edwards formation has not been made, the distribution of the major faunal elements has been noted. It is similar to that described by Young (1955 and this volume), but faunal zones do not appear to be as sharply defined. It is possible, however, that a detailed faunal study would show the zones to be more distinct than has been noted.

Cladophyllia occurs most abundantly at the base of the rudistid facies. It appears to be more abundant at the base of the biohermal reefs than in the adjoining biostromes, but this observation needs further study to determine its validity. The *Cladophyllia* zone is gradational into the overlying faunal zone.

The *Monopleura-Toucasia* zone overlies the *Cladophyllia* zone. It seems to be best developed in the middle of the reef core.

Caprinuloidea, *Eoradiolites*, and *Chondrodonta* form the uppermost faunal zone. They are also the dominant organisms in the reef flank deposits. In these deposits they extend down to the base of the Edwards limestone and are associated with *Cladophyllia*.

Two other organisms which appear to be important as indicators of the environment of deposition are *Dictyoconus walnutensis* and the miliolids. Neither has been found in the reef core. *Dictyoconus* occurs most frequently in the reef flank deposits. It is also abundant in coarse-grained inter-reef sediments. Miliolids are confined to the inter-reef facies and in most places are more common in fine-grained than in coarse-grained sediments. In only a few places do they occur in great abundance.

MODE OF SHELL PRESERVATION

Shell material, including whole shells and fragments, is preserved in a variety of forms:

(1) Whole shells and large fragments that exhibit the original structure of the shell (Pl. 30, A). The inner shell wall is composed of clear crystalline calcite, an early diagenetic replacement product of the original shell material. The shell substance of the outer wall has a tan or light gray color in thin sections and on polished rock surfaces. Most of the shell substance exhibits various types of internal shell structures that characterize the organ-

isms. This substance is considered to be the shell material which was secreted by the organisms. The voids within the outer wall are filled with either secondarily deposited clear calcite or lime-mud deposited at the time of reef growth (Pl. 21, A).

(2) Clear crystalline calcite casts of original shells (Pls. 14, A; 18, A). A complete gradation exists between such casts and "original" shell material. The casts are formed by direct recrystallization of the "original" shell material, as shown by a mosaic of anhedral calcite superimposed upon the original structure of the shell (Pls. 15, B; 22, C; 30, B), and by solution of the shell followed by cavity filling of the mold (Pl. 30, C). The end product of both processes can rarely be differentiated. Because direct recrystallization appears to be the more common process, clear crystalline calcite casts are frequently referred to as recrystallized shell material. This type of shell preservation is especially common in those outcrops which have been altered by chalkification.

(3) Molds of shells. With the exception of locality 50-T-6, well-preserved molds occur almost exclusively in post-lithification dolomite (Pl. 28, E). At locality 50-T-6, all gradations between molds and calcite casts may be seen (Pl. 30, C).

(4) Dolomite casts of shells. The inner shell wall of many rudistids at localities 154-T-14a and 154-T-16 are partially replaced by dolomite which is believed to be of diagenetic origin (Pls. 19, A, B; 30, F).

(5) Chalkified shell material. The Foraminifera and many small shell fragments are partially or completely altered to chalk (Pls. 18, F; 21, F; 30, G). Microscopically, chalkified shell material consists of opaque microgranular calcite.

(6) Silicified shell material. Locally, silica in the form of chert and clear anhedral quartz has replaced the shells to form silica casts (Pls. 15, C; 30, E).

(7) Silicified dolomite molds of shells. At locality 14-T-1, chert fills the molds of fossils in post-lithification dolomite (Pl. 30, D).

Post-Lithification Effects

Post-lithification alteration of the Edwards limestone has occurred to some extent throughout the area, but its effect is most pronounced in southeastern Coryell and Bell counties where the Kiamichi shale is absent. In these counties, post-lithification alteration has formed the following types of rocks: chalk, crystalline limestone, silicified limestone, and dolomite. In addition, there has been a considerable amount of solution of the limestone. Post-lithification dolomite is discussed under the heading "Occurrence of Dolomite."

Solution

Solution of the Edwards limestone has been especially pronounced west of Belton as indicated by the widespread occurrence of post-lithification alteration products and extensively honeycombed primary limestones. Colligan (1951, pp. 32–33) noted that the limestone strata near Belton Dam are porous and vuggy, but he concluded from bore-hole data and examination of surface exposures that there is no evidence of large continuous channels or caves. At the same time, however, he showed pictures of an excavated channel approximately 100 feet long (Colligan, 1951, Pls. 20, 21).

Honeycombed limestones are prominent as far north as Station Creek near Mother Neff State Park in Coryell County. Their occurrence is discontinuous, however.

The top of the Edwards formation is locally rather vuggy along Bluff Creek and the Middle Bosque River in McLennan County. Stalactites and patches of recrystallized limestone are frequently found beneath the overhanging bluffs along these streams.

Most vuggy limestones are impregnated with iron oxide, and in many places soil has been carried several feet into the limestone to fill the vugs.

CHALK AND CHALKY LIMESTONE

Recrystallization of limestone to soft white microgranular calcite is referred to as chalkification. The process tends to destroy the original texture and to reduce the limestone to a mass of pulverulent chalk. This has occurred in only a few places, however. Pulverulent chalk is found most often in the Kiamichi shale.

Chalks and chalky limestones occur most frequently in areas of great relief. Localities showing the greatest effect of chalkification are 154-T-1, 50-T-6, 50-T-7, and 50-T-8. Fine-grained limestones (calcilutites) and shell debris appear to be most susceptible to chalkification. In places, the base of the rudistid facies is chalky, probably because the relatively impermeable Comanche Peak limestone prevents water from percolating downward and forces it to move laterally, thereby increasing its ability to dissolve the limestone.

Microscopically, chalk consists of microgranular calcite; it forms a dark groundmass that partially or completely obliterates the original texture of the rock. Chalkification is usually accompanied by reprecipitation of some of the dissolved calcite. The reprecipitated mineral forms irregular-shaped anastomosing patches of clear coarse crystalline calcite. Contacts between these patches and the surrounding rock are very indistinct. Large shell fragments in chalk are usually recrystallized.

CRYSTALLINE LIMESTONE

Crystalline limestones occur almost exclusively in Bell County. These rocks are characteristically mottled shades of brown, yellow, and pink. They are very hard and dense and usually have a fine crystalline texture. Crystalline limestones occur as beds, concretions, masses of coalescing concretions, and irregular patches. They are vuggy, honeycombed, or nonporous. The contact between these limestones and the surrounding rocks in most places is sharp but is very irregular.

Most polished rock specimens and thin sections of crystalline limestones reveal the texture of the original rock. In some, however, replacement has destroyed the original texture and the crystalline limestones are composed of a mosaic of crystalline calcite.

Field relations and petrographic evidence indicate that crystalline "limestones" were formed by (1) secondary precipitation of calcite in the interstices of granular limestones and dolomite without destroying the original texture of the rock (loc. 14-T-8), (2) recrystallization that partially or completely destroyed the original rock texture (loc. 14-T-1), and (3) solution of the original limestone followed by cavity filling (this process has not been definitely established; possible examples are the concretionary horizon in the roadcut near Frank's Landing west of Belton Dam and the crystalline limestone near the base of the Edwards formation south of Moffat).

SILICIFIED LIMESTONE

Silicified limestone and dolomite have been found only in the vicinity of Belton and Moffat. However, they are known to occur in the Edwards formation south of this area.

Secondarily deposited silica occurs in two forms: as medium to coarse crystalline quartz and as microcrystalline chert. The latter forms the nodules at the top of the quarry at locality 14-T-1 and was precipitated in the intercrystalline voids of the dolomite. Medium to coarse crystalline quartz has replaced the original shell material and fills the interstices of the silicified rocks. The original textures are still preserved.

OCCURRENCE OF DOLOMITE

Field and petrographic evidence indicates that dolomite originated as a primary deposit, a diagenetic mineral, and as a post-lithification alteration product.

Occurrences of primary dolomite include (1) beds of dolomite intercalated with limestone, (2) dolomite in the matrix of the interbedded and laterally equivalent limestones, (3) dolomite crystals in chert nodules in dolomitic limestones, and (4) dolomite crystals in chert nodules in non-dolomitic limestones. All are found at locality 14-T-1. Actually, the matrix dolomite (item no. 2) is in part early diagenetic because it replaces some of the particles.

Diagenetic dolomite occurs as fillings or partial fillings of (1) bore holes (locs. 154-T-1, 50-T-7), (2) pre-lithification cracks in the matrix of reefs (loc. 154-T-16), (3) interstices in coarse reef flank deposits (loc. 154-T-14a), and (4) the body chambers and shell walls of the fossils in reefs (locs. 154-T-16, 154-T-14a). In each of these occurrences, the dolomite is surrounded by or interfingers with the clear crystalline calcite cement of the rock. There is no evidence of replacement of the surrounding rock. These occurrences are considered to be diagenetic because the dolomite was emplaced after deposition but before lithification of the host rock.

Primary and diagenetic dolomites are similar in that they are composed of a tightly interlocking mosaic of dolomite crystals. As a result, the characteristic rhombohedral shape of the crystals is poorly developed and there is very little intercrystalline porosity. Iron oxide commonly surrounds individual crystals of diagenetic dolomite. The occurrence of iron with dolomite seems to be a characteristic feature of early diagenetic dolomite (Udluft, *in* Fairbridge, 1957, p. 158).

Most dolomite in the Edwards formation originated subsequent to lithification. It occurs as both beds and irregular masses of dolomite that grade laterally into the adjoining limestones. It also occurs as individual crystals or masses of crystals in the matrix of dolomitic limestones as previously described by Hanna (1931, pp. 47–55). The dolomite is characteristically very soft and is composed of a loosely knit mass of euhedral crystals. Fossils in dolomitized rocks are preserved as molds. With the exception of its occurrence in the rudistid facies along Bluff Creek, post-lithification dolomite is found only in Bell County. Regional studies have shown that this dolomite extends into south Texas and is present only where the Kiamichi shale is very thin or absent (Feray and Nelson, 1956).

Along Bluff Creek, irregular patches of dolomitic limestone are found in the rudistid facies. Crystals of dolomite are also found along stylolites in the rudistid limestone. Both occurrences are believed to have originated after lithification, but the writer is not certain whether dolomitization took place prior to or after deposition of the inter-reef sediments.

GEOLOGIC HISTORY

General Statement

The geologic history of an area is a study of geologic processes, their sequence, and the relation of one to another. Many processes were involved in forming the lithologic features of the Edwards formation. Among these processes were organic growth, transportation and deposition of sediment, cementation, solution, replacement, and post-lithification cementation. Organic growth was unquestionably the foremost process in developing the primary features of the Edwards formation. It led to formation of the rudistid reefs which in turn controlled the surrounding environment to a considerable extent. These reefs have interested many geologists during recent years and some have undoubtedly questioned the classification of these skeletal masses as true reefs. It is pertinent, therefore, that the reasons for classifying them as true reefs be critically examined.

Reef Definition

The term *reef* has many meanings. In a recent review of terminology of reefs and reef-like masses, Nelson, Brown, and Brineman (in preparation) showed how varied are the concepts of the constitution of a reef. These writers expressed their concept of a reef and defined it as "a skeletal deposit formed by organisms possessing the ecologic potential to erect a rigid wave-resistant structure." As a parallel, a bank was defined as "a skeletal deposit formed by organisms which do not have the ecologic potential to erect a rigid wave-resistant structure." Skeletal limestones were defined as "deposits which consist of or owe their characteristics to essentially in situ accumulation of calcareous skeletal matter." The writers' concept of a reef follows that of Lowenstam (1950, p. 433), who defined a reef as ". . . the product of the actively building and sediment-binding biotic constituents, which, because of their potential wave-resistance, have the ability to erect rigid, wave-resistant topographic structures."

In the present writer's opinion, there is no question that rudistid reefs meet these qualifications. This opinion is based upon evidence that (1) the organisms could construct a rigid framework, (2) they were able to do so in the zone of wave action, and (3) the organisms controlled their environment.

Rigid framework.—Numerous writers (Palmer, 1928; Adkins, 1930; Young, 1955) have discussed the morphology of the rudistids and speculated upon their growth habit. They have shown that the organisms grew attached to each other and therefore had the potential to erect a rigid framework. The writer has found specimens of several rudistids attached to and oriented parallel with a larger rudistid. Polished rock specimens from reef cores have shown individual rudistids crowded so closely together that their exterior shape was modified by the adjacent organisms. Despite this evidence of an attached growth habit, their ability to construct a true reef is doubted by some geologists, probably because the effectiveness of the small point of attachment to anchor the organisms is questionable. This is a valid question but the writer believes that even if the period of attachment was brief, it would not have prevented the construction of a rigid wave-resistant structure. Many rudistids are large and have very irregular shapes. The irregular-shaped shells interlocked together could have formed a very rigid framework even though the individual shells were unattached. In addition, there is good evidence that the interstices in the reefs were filled and the reef was lithified almost as rapidly as the organisms grew. These processes would have helped to rigidify the skeletal mass.

Evidence of wave-resistance.—Growth of the organisms within the zone of wave action is clearly demonstrated. The fact that the reef cores (that part within the growth lattice) grade laterally into an unsorted debris of angular whole and broken shells is not in itself proof of wave-resistance because fragmentation of the shells could have been accomplished by predatory organisms below wave-base. Proof that the rudistid reefs actually grew in the zone of wave action is based upon (1) lateral transition of the reefs into well-sorted, bedded, and cross-laminated granular limestones and (2) local disconformities on the crests of the reefs at localities 154-T-1 and 50-T-7. It may be argued that local disconformities are not proof of reef growth but are actually evidence of erosion. This is certainly true but it is extremely unlikely that reefs having such disconformities could have been uplifted into the zone of wave action (and above sea level at locality 154-T-1), eroded, and then depressed below wave-base without some evidence of the movement being developed in the sediments. None is apparent.

Growth in the zone of wave action is also suggested by faunal zonation in the reefs. Young (1955 and in this volume) attributed this zonation to organic adaptation to more shallow-water conditions as the reefs grew upward. This is a logical interpretation. In the writer's opinion, a benthonic fauna would be most sensitive to changes in depth if it were living in shallow water. A fauna living in water 10 feet deep, for example, would seem to be more sensitive to a variation of 5 feet in depth than would a fauna living in water 50 feet deep. If this view is correct, the rudistid reefs must have been formed in shallow water and in the zone of wave action.

Environmental control.—Evidence of local environmental control by the rudistids is demonstrated by the marked contrast between the reef and inter-reef facies. Not only did the rudistids provide a source from which the inter-reef sediments were derived, but in doing so they established new environments which became inhabited by organisms that otherwise might not have lived in the area.

Regional control of the environment by the rudistids is not quite so striking as their local control but, in the writer's opinion, it is just as certain. Regional stratigraphic studies have shown that the rudistid reef complexes in Early Cretaceous time were barriers between the basin and lagoon depositional areas. At various times during the period, the barrier became so effective that it led to evaporite deposition in the lagoon. In addition, as will be shown, an extension of the reef complex into the lagoon served as a barrier that further subdivided the lagoon into contrasting lithofacies.

Considering all this evidence, there would seem to be little doubt that the rudistids were true reef-building organisms.

Development of the Rudistid Facies

Regional studies of Early Cretaceous deposits in southern United States and Mexico demonstrate that the rudistids and related organisms formed one of the most extensive reef complexes in geologic history. In fact, if the reef complexes of the Trinity, Fredericksburg, and possibly the Washita groups are considered as a unit, it would be rivaled in size and extent by few, if any, known reef trends. Of this vast complex only a small part is exposed in the United States. One part extends northwestward as a thin tongue of the main barrier reef complex in Brazos and other counties to the southwest and is the subject of this paper.

Transgression of the Rudistid Facies

At the beginning of Fredericksburg time a vast lagoon, herein named North Texas lagoon, covered north and central Texas (fig. 17). Sands (Paluxy) were deposited in the northern part of the lagoon, and marls, shell beds, and nodular limestones (Walnut) in the southern part (fig. 18, A). The southeast end of the lagoon terminated in the rudistid reef complex (Edwards). With the passage of time, deposition of each of these lithofacies shifted northward and the rudistids began their transgression which did not cease until the close of the age (fig. 17).

Because the west flank of the Tyler basin was the site of optimum environmental conditions, the rudistids migrated to the northwest from the main reef trend and invaded the present area of reef development by way of Williamson and other counties to the south. By the time approximately 35 percent of the Fredericksburg

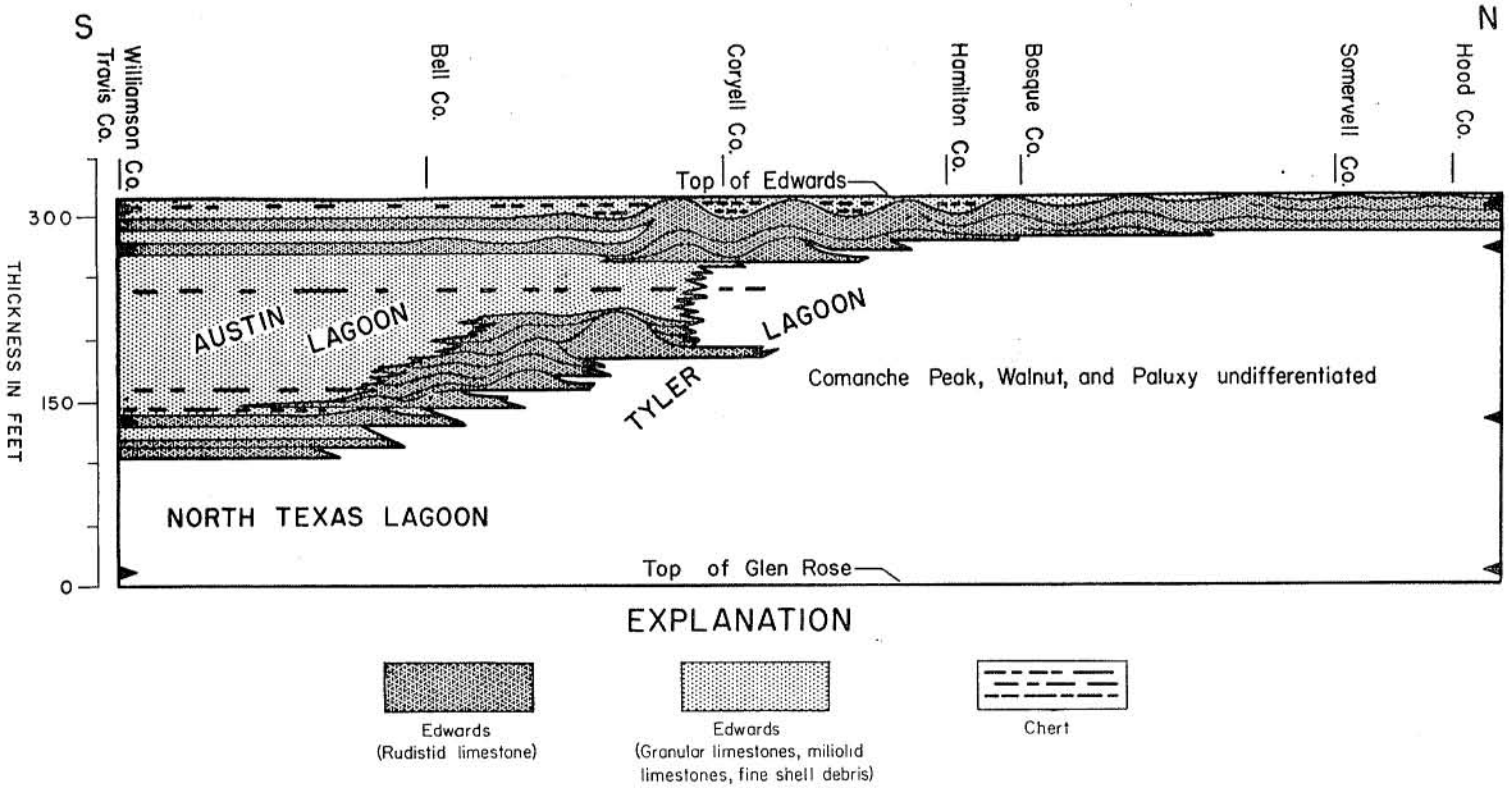

FIG. 17. Schematic diagram showing inferred transgression of rudistid facies from south to north along the west side of the Tyler basin. Compiled from data of Hill (1901), Adkins (1933), Thompson (1935), Ikins (1941), Lozo (1949), Atchison (1954), and personal observations. The abrupt facies change near the Bell-Coryell County line occurs between localities 14-T-3 and 14-T-16. The upper and lower rudistid horizons probably coalesce east of locality 14-T-3 in the subsurface. Triangles at the ends of the profile mark levels of maps shown in figure 18.

age had transpired (assuming a constant rate of deposition), the rudistids reached southern Williamson County where they formed thin biostromes (fig. 18, B). Sediments deposited with them include bedded granular limestones and chert.

When the rudistids reached central Williamson County, they began to build biohermal reefs. The reason for the change in form of reef growth is unknown. The writer can only speculate that it was due (1) to an increased rate of subsidence (or rise of sea level) that caused the rudistids to grow upward rather than laterally or (2) to a new combination of physicochemical conditions. Biohermal reef growth reached its greatest development in Bell, Coryell, and McLennan counties (Nelson, 1949, pp. 92–94). Here, the reefs are most sharply delineated from inter-reef sediments. The reef complex that was formed now divides the North Texas lagoon into two lagoons which are named Austin and Tyler, after towns in their geographic vicinity (figs. 17; 18, C). The Edwards limestone was deposited in the Austin lagoon; the Paluxy, Walnut, and Comanche Peak formations in the Tyler lagoon.

Near the end of the age when the rudistids had reached the approximate vicinity of Bosque and Hamilton counties, the environmental conditions again changed. Apparently the change resulted in more optimum conditions, for the rudistids tended to secrete a more robust shell and to grow laterally to form massive biostromal reefs that constitute most of the formation from these counties northward (figs. 17; 18, D). Though biohermal reefs were also constructed they were, in general, less pronounced and less sharply delineated from the inter-reef sediments than in Bell, Coryell, and McLennan counties. In effect, the rudistids not only controlled their environment, they dominated it.

Thus, at the close of the Fredericksburg age there were, along the site of the present-day outcrop in north and central Texas, three coextensive areas of deposition which were characterized by (1) a dominance of mechanical processes of sedimentation (the Austin lagoon), (2) a dominance of biological processes of reef formation (the reef complex north of Coryell and McLennan counties), and (3) an approximately equal co-mingling of both processes (reef complex in Bell, Coryell, and McLennan counties).

MANNER OF RUDISTID TRANSGRESSION

It is evident from the stratigraphic relations of the Comanche Peak and Edwards formations that the rudistids in most instances advanced by recurring surges that quickly populated a new area. Occasionally, however, they moved but slowly into a new area, as demonstrated by the occurrence of individual rudistids in the top few feet of the Comanche Peak limestone. Such invasions were the exception rather than the rule. Floods of lime-mud (Comanche Peak and Walnut) intermittently inundated the fauna and temporarily halted its advance. In places, the rudistids paused for extra long periods of time before they continued their migration northward, as shown by the abrupt decrease in thickness of the Edwards formation near Moffat. Increases in thickness of the Edwards limestone in a northerly direction, which is counter to the normal trend, and variations in thickness in an east-west direction suggest that the fauna did not advance as a solid front but rather as a series of northward-probing tongues. It is very possible that the offspring of the rudistid and coral fauna, like the oysters on the oil-well platforms in the Gulf of Mexico, were carried northward by currents and established colonies well ahead of the main advance. This is no more than an opinion, however, because local variations in thickness may also be explained by reef building above the level of the surrounding sediments and by pre-Kiamichi erosion of the Edwards formation.

REEF GROWTH

The initial deposit of the Edwards formation throughout most of the area is rudistid limestone. In general, it appears to be an in situ accumulation of whole organisms, but locally it is made up of a

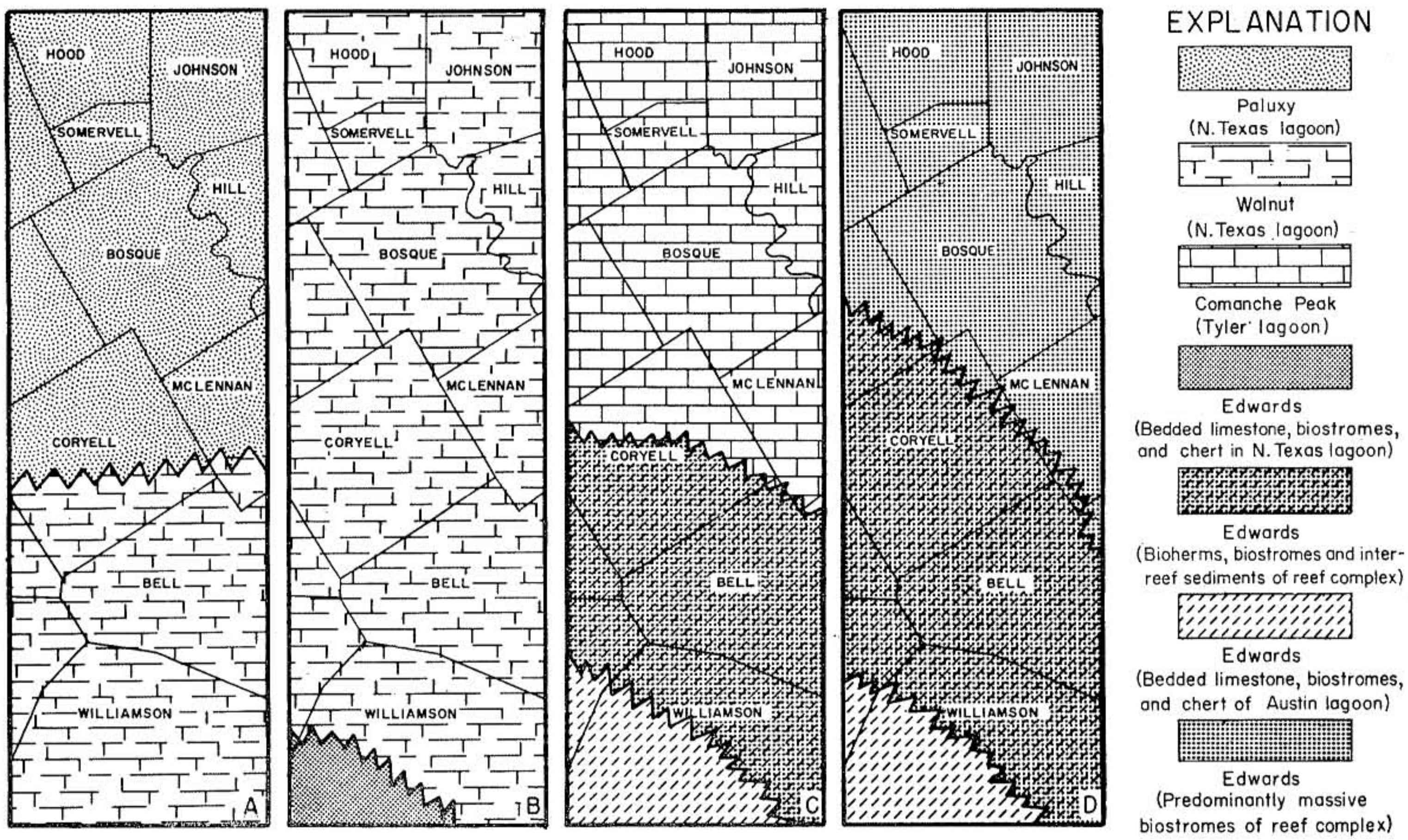

FIG. 18. Geologic history of Fredericksburg age. A, Beginning of the age. B, Sedimentation after approximately 35 percent of the age had passed. C, Sedimentation after approximately 90 percent of the age had passed. D, Close of the age.

coarse debris of whole shells and shell fragments. However, the latter show very little evidence of transportation. In places, the limestone does have a fabric that suggests some sorting of the components by waves or currents.

The rudistids and the associated fauna grew rapidly upward to form prominent biohermal reefs at numerous places. The factor controlling or leading to formation of biohermal reefs is unknown, but a possible factor is suggested by the apparent distribution of the branching coral *Cladophyllia*. It appears to be more abundant at the base of the bioherms than in the adjoining biostromes. Conceivably, it formed a mat upon which the rudistids were able to grow rapidly above the surrounding sediments. As the fauna grew upward, it gradually adapted itself to changing environmental conditions in the manner described by Young (this volume).

The rate of biohermal reef growth is indeterminable; usually it was several times as fast as the rate of accumulation of contemporaneously deposited inter-reef sediments.

Faunal and lithologic evidence of reef growth in the zone of wave action has been presented already. An approximation of the depth of reef growth may be obtained by considering two lines of structural evidence:

(1) Evidence of subaerial exposure of the reef crests at locality 154-T-1. The most reasonable explanation for this feature would place the reefs in water only slightly deeper than their thickness, which is 9 and 11 feet. Under this condition only a slight drop of sea level would be necessary to expose the crests of the reefs. A water depth of 12 to 15 feet would seem to be a reasonable estimate for the beginning of reef growth at this locality.

(2) If bedding planes in the flank deposits are geologic "time" lines (as the writer considers them to be), the greatest relief on a single bedding plane is a measure of the minimum depth of water that existed at the time the bedding plane was formed. The upper end of each bedding plane becomes horizontal as it passes into the reef core and shows that upward reef growth had almost ceased when the bedding plane was formed. Because most reefs exhibit this feature, there must have been a regional controlling factor. On the basis of comparison with modern reefs, the writer believes that the surface of the water prevented further upward growth and the tops of the reefs were, therefore, close to sea level. The lower end of the lowest bedding plane usually marks the top of the rudistid biostrome flanking the reef. The greatest known relief is approximately 20 feet and the average thickness of the thin biostromes that extend out from the base of the bioherms is about 4 feet. A depth of water of 25 feet is therefore suggested for the beginning of growth of many reefs. Considering the possible variables that enter into this calculation, a range of 10 to 30 feet would seem to be a reasonable estimation of the depth of water at the beginning of reef growth. However, the water could have been deeper in the areas where the rudistid facies is more than 30 feet thick.

The end product of organic growth in this area was a multitude of mounds or ridges each consisting of a rigid core and the surrounding flank deposits. In general, upward growth of the core was uninterrupted during the period of reef formation. There were brief periods when physical sedimentation replaced organic growth, but these interruptions were usually confined to the reef flank.

In contrast to the reef core which was formed almost exclusively by organic growth, the reef flank deposits were formed or modified by many processes. In the writer's opinion, however, organic growth was dominant in their formation. The flank of the reef is visualized as a zone in which modifying and destructive forces were allied against organic growth that tended to expand the reef. The total effect of all forces produced a group of rocks that have structural and lithologic features common to the reef core and inter-reef sediments. The modifying and destructive forces were shell fragmentation, winnowing action of waves and currents, and compaction of the resulting shell debris. The writer believes that predatory organisms probably played the major role in fragmentation of the shells. Petrographic studies have revealed the presence of shell fragments containing bore holes (Pl. 21, D). Personal observations of modern carbonate sediments in the Gulf of Mexico have shown that predatory and boring organisms are fragmenting, comminuting, and weakening the framework or shells of carbonate-secreting organisms. Along the reefs of the Florida Keys, for example, one can seldom find a large shell or piece of coral that does not show evidence of boring by some organism. Similar observations have been reported many times (Gardiner, 1903; Hedley, 1925; Otter, 1937; Ginsburg, 1953).

Though the reefs grew in the zone of wave action, waves and currents played a secondary role in the development of the reef flank deposits. They acted primarily as agents that sorted the sediments to some extent, winnowed out some of the fine material, and intermittently planed the surface of the accumulating debris, thereby producing the bedding in the flank deposits. In the writer's opinion, the abundance of coarse poorly sorted unabraded shell debris embedded in a microgranular matrix indicates that waves and currents did not deposit most of the sediment in the reef flank. Only at infrequent intervals did waves and currents sort the sediments and sweep lime-sands onto the growing reef.

Compaction is a process of lithification and its effect in the development of the reef flank deposits is discussed subsequently.

ORIGIN OF THE MATRIX

Many writers have discussed the origin of the microgranular calcareous mud which forms the groundmass in coarse fragmental limestones and covers much of the shallow sea floor in environments favorable to the deposition of calcium carbonate. The various opinions, which have been summarized by Crickmay (1945, pp. 233–235) and Johnson (1957, pp. 180–181), include attrition of shells, biochemical precipitation, physico-chemical precipitation, and disintegration of fine organic debris. This study provides no information as to the origin of the fine particles. It indicates only that the microgranular matrix, which is so characteristic of the reef core and associated flank deposits, has a clastic texture and was deposited as a lime-mud in the voids of the reefs.

The mud apparently filled the voids in the reefs as rapidly as they grew. There are no interstices lined with encrusting layers of crystalline calcite or with organic growth to suggest that the voids remained open for a long period of time. Many reefs are overlain by medium- to coarse-grained limestones, but only rarely does the lime-sand fill the interstices in the reef and then it does not extend far into the reef core.

DEVELOPMENT OF THE INTER-REEF FACIES

As a result of reef growth, numerous small basins of depositions were created. Some may have been completely isolated, but most were probably inter-connected.

Lime detritus was swept into the basins from the surrounding reefs. In McLennan County and other counties to the north, the detritus consisted predominantly of lime-sand and shell debris. Similar sediments were deposited in Bell and Coryell counties, but lime-mud was also deposited. Beds and nodules of chert formed in the fine sediments where the water was quiet. Usually, the detritus in the inter-reef areas is well bedded, well sorted, and frequently cross-laminated, thus indicating deposition in the zones of wave action.

The inter-reef sediments were deposited both contemporaneously with and subsequent to the reefs with which they are in contact. Stratigraphic and petrographic evidence clearly indicates that some of the older reefs were lithified and even eroded before the overlying inter-reef sediments were deposited (loc. 154-T-1).

If the abundance of fossils is a measure of organic activity, the inter-reef basins were rather barren areas. Most evidence of organic activity, either in the form of faunal remains or bore holes, is concentrated in the reef core and reef flank deposits or on the depositional surface upon which the fine-grained inter-reef sediments were deposited. The principal exceptions to this observation are the inter-reef basins where chert is abundant and locality 14-T-1 where there is an extensive bore hole zone in inter-reef deposits. Petrographic examination of chert nodules, which are believed to be of primary origin, indicates that many nodules contain sponge spicules(?) and other unidentified organic remains. The enclosing limestones also contain objects which appear to be calcified sponge spicules. On the basis of these observations, the writer believes that sponges may have lived in great abundance in those inter-reef basins where lime-muds were deposited.

ORIGIN OF THE PARTICLES

The inter-reef sediments are composed primarily of "original" shell fragments, recrystallized shell fragments, opaque grains, and microgranular calcite. Microfossils, macrofossils, sponge spicules (?), pellets, and oolites also contribute to the sediments, but they are important constituents in only very local areas.

The rudistid reefs are the ultimate source of the "original" shell material and recrystallized shell fragments. This is demonstrated by gradation of reef into inter-reef sediments and by similarity of the internal structure of "original" shell fragments to shell structures of reef-building and accessory organisms. The similarity is often so close, the writer believes, that one could frequently identify the particular organisms from which the particles were derived if a detailed study of the structure of individual organisms were made.

The same cannot be said of recrystallized shell fragments. The belief that they were derived ultimately from the reef organisms is based upon the fact that complete gradations between "original" shell material and recrystallized shell material have been observed. Recrystallized fragments in the inter-reef sediments characteristically have "dust" rims of microgranular calcite. Three hypotheses are advanced to explain the origin of the recrystallized shell fragments:

(1) They are recrystallized fragments of "original" shell material. Mosaic patterns of anhedral calcite superimposed upon the prismatic and lamellar structure of "original" shell material clearly demonstrate that some of the grains have originated in this way (Pl. 30, B). This mode of origin is also shown by recrystallization of shells of *Rangia cuneata*, a late Pleistocene or early Recent brackish-water pelecypod which has been collected in the Gulf of Mexico (Pl. 30, H). Both of these examples indicate that recrystallization occurred in the solid state.

(2) They are recrystallized opaque grains (the origin of these grains is discussed subsequently). Complete gradations between opaque grains and recrystallized shell fragments have been observed. This hypothesis applies to the small (fine sand- and silt-sized) recrystallized shell fragments. It does not apply to the large recrystallized grains because very few sand-sized opaque grains have been observed.

(3) They may be detrital grains derived from break-up of the recrystallized inner shell wall, the calcite fillings of the voids in the outer shell wall of the rudistids, or both. This possibility is indicated by the occurrence of a few grains composed of parts of both walls. It is questionable, however, whether there was enough of this material available to form the great volume of re-

crystallized grains which occurs in the Edwards formation.

There are two possible explanations for the "dust" rim around the recrystallized grains:

(1) Microgranular calcite accumulated on the particles during their transportation and deposition as suggested by Cullis (1904, p. 402).

(2) It is a disintegration rim formed on the "original" shell fragment prior to recrystallization.

There is no evidence that strongly favors either hypothesis. The occurrence of oolitic growth rings on the outside of the "dust" rims (Pl. 26, D) in one bed at locality 14-T-1 indicates that the "dust" rims were present when the grains were still subject to current action.

On the basis of the type and size of particles. fine-grained inter-reef limestones (calcilutites) are subdivided into two types: (1) a coarse-grained calcilutite composed of opaque grains, "original" shell fragments, and recrystallized shell fragments and (2) a very fine-grained calcilutite composed of a dark groundmass of microgranular calcite.

Opaque grains generally predominate in coarse-grained calcilutites. Possible modes of origin of the grains are:

(1) They are chalkified "original" shell material. Complete gradation between "original" shell material and opaque grains favors this view. Known occurrences of shells altering to chalk in Recent and Pleistocene sediments also support this explanation. The fuzzy outline of the particles suggests chalkification after deposition. The reefs were the ultimate source of these particles.

(2) They are chalkified shells of organisms indigenous to the inter-reef areas. The occurrence of chalkified microfossils indicates that inter-reef organisms were the source of some grains. They are not considered to be a major source, however.

(3) They are cemented or agglutinated microgranular calcite. Illing (1954, pp. 26–27) noted the occurrence of friable aggregates of lime-silt in the Bahaman sands that appear to be similar to the opaque grains.

The microgranular calcite that constitutes the very fine-grained calcilutites is lithologically similar to the matrix in the reef core. Theories regarding the origin of fine lime-mud have been presented already. In the writer's opinion, the origins of the matrix and the very fine-grained calcilutites are probably closely related.

Lithification

Lithification has been defined as ". . . that complex of processes that converts a newly deposited sediment into an indurated rock." (Pettijohn, 1957, p. 648). Many post-depositional processes have left their imprint upon the Edwards formation but only two, compaction and cementation, seem to have been significant factors in converting the sediments to indurated rock. Of these, cementation was dominant.

Compaction

Except for locality 154-T-1, compaction was confined primarily to the reef flank deposits. The accumulating debris of whole and fragmented shells compacted as some material was winnowed out by waves and currents. In the process, many fragile shells were broken, thus compounding the effects of other agents of shell fragmentation. The fine-grained partially consolidated matrix also compacted and developed numerous hairlike tension cracks. Similar cracks have been attributed to shrinkage during dehydration (Crickmay, 1945, p. 237). This explanation cannot be applied to the Edwards limestone. If shrinkage alone were the cause of the tension cracks, they should be as abundant in the reef core and fine-grained inter-reef sediments as they are in the reef flank deposits. Petrographic evidence indicates that they are not. Compaction, combined with the winnowing action of currents, is believed to be partially responsible for inclination of the flank beds.

There is no evidence of compaction in the reef core and relatively little in the inter-reef sediments. Microfaults in the inter-reef sediments at locality 50-T-7 suggest compaction, but they are limited to individual beds and there is no other evidence of compaction. Limestone laminations which bend around chert nodules also suggest compaction. However, the laminations may also drape over the nodules as a result of initial deposition of the sediment.

CEMENTATION

Granular limestones (calcarenites) and shell debris of the inter-reef facies were lithified by precipitation of calcium carbonate from solution. The resulting cement is a mosaic of clear anhedral calcite. The fine-grained limestones (calcilutites) of the inter-reef facies and equally fine-grained matrix of the reef core and reef flank deposits are presumed to have been lithified in a similar manner. Under high magnification, a fine reticulate network of calcite, which is slightly coarser than the fine detritus, is sometimes barely perceptible in these rocks and suggests that cementation was brought about by precipitation of calcite in the minute interstices.

Richards and Hill (1942, p. 63) showed that carbonate sands on Heron Cay are being cemented by aragonite in the intertidal zone. Emery, Tracey, and Ladd (1954, pp. 148–149) concluded that cementation takes place at or below low-tide level. Ginsburg (1957, pp. 95–96) believed that cementation takes place in those carbonates that are ". . . subaerially exposed or in the zone of meteoric waters." The present study indicates that cementation occurred very early in the history of the rocks. This is demonstrated by localities 154-T-1 and 50-T-7 where bore holes are present at the top of the reefs in the middle of the formation. It is doubtful that the bore holes could have remained open if the sediments had not been semi-consolidated or completely lithified. That the reef at locality 154-T-1 was actually lithified before the overlying sediments were deposited is indicated by the occurrence of bore holes filled with clear anhedral calcite into which the overlying limestone was compressed (Pl. 16, C).

The environmental conditions under which cementation took place cannot be positively determined. The writer believes that it occurred in very shallow water. In the reef at locality 154-T-1, cementation could have occurred in that part which was subaerially exposed while the remainder of the rudistid facies remained unconsolidated. Later, when the Edwards limestone was uplifted prior to deposition of the Kiamichi shale, the entire formation could have been subaerially exposed and cemented. The only alternative to this hypothesis, if one feels that cementation must take place under subaerial conditions, is repeated exposure of the sediments to the atmosphere as they accumulated. In the writer's opinion it is unnecessary to appeal to this mode of origin for the cement in limestones. The environmental conditions necessary for calcite precipitation would appear to exist in very shallow water. In this environment, the carbon dioxide content of the water fluctuates considerably due to temperature changes, agitation, organic activity, and other processes. These fluctuations could cause calcium carbonate in the connate water to crystallize out of solution in the interstices of the sediment. This would probably occur a short distance below the surface of the sediments where the particles are not in motion. As noted previously, the Edwards limestone is believed to have been deposited in shallow marine water.

It seems unlikely that the clear calcite cement was formed by recrystallization of a fine-grained matrix. Recrystallization of an original lime-mud has been noted by many writers (Skeats, 1903, p. 110; Cullis, 1904, p. 399; Crickmay, 1945, pp. 238–241; Fischer, 1953, pp. 50–51; Emery et al., 1954, p. 89; and Johnson, 1957, p. 182). However, only Crickmay felt that it was an important process in lithification. Most writers (Cullis, 1904, p. 396; Bergenback and Terriere, 1953, pp. 1019–1028; Emery et al., 1954, p. 149; Newell, 1955b, p. 308; Myers et al., 1956, p. 19; Ginsburg, 1957, pp. 95–96; Moore, 1957, p. 119) thought that clear crystalline cement was formed by precipitation of calcite or aragonite from solution. The following evidence indicates that the clear anhedral calcite cement in the Edwards limestone was formed by precipitation from solution rather than by recrystallization of an original fine-grained matrix:

(1) The calcite was deposited in two stages. During the first, it was precipitated on the walls of the interstices; during the second, it filled the remainder of the voids.

(2) Contacts between cement and constituents are generally very sharp in the medium- to coarse-grained limestones.

(3) The fine-grained matrix in the reefs and the fine-grained limestones (calcilutites) in the inter-reef facies are not recrystallized except where there is obvious disintegration (chalkification) as a result of weathering. If an original lime-mud matrix could have recrystallized to clear calcite, it is reasonable to expect that the matrix in the reef and the calcilutites in the inter-reef areas would have recrystallized.

(4) It is improbable that lime-mud would be deposited with the well-rounded and frequently well-sorted grains of the medium-grained limestones and shell debris.

(5) A sample of a modern carbonate deposit has shown that cementation is a natural process of lithification and has produced petrographic features similar to features in the Edwards limestone. Plate 30, I, shows a shell agglomerate of *Rangia cuneata* collected in the Gulf of Mexico in approximately 75 feet of water. *Rangia* is a brackish-water pelecypod and the shell agglomerate, therefore, is not indigenous to the environment in which it is found. The matrix is composed of comminuted shells. The entire mass of shells is cemented by clear crystalline calcite which completely fills some interstices while only lining others with a coating of acicular crystals. No lime-mud is present. The environment of cementation has not been determined. The specimen is believed to be either late Pleistocene or early Recent in age.

End of the Fredericksburg Age

The Fredericksburg age was brought to a close by regional uplift (or recession of the sea) that exposed the Edwards limestone to subaerial weathering. Uplift apparently was not great, for there is no evidence of pronounced erosion. The exposed surface was fairly flat and indicates that the inter-reef basins were filled to the level of the reef crests prior to uplift. Decrease of dips in successively higher flank beds around the biohermal reefs shows that reef growth had ceased before regional uplift. Possible reasons for arrested reef growth are (1) the rudistids had reached the surface of the water and could no longer grow upward or (2) the rudistids were inundated by their own shell debris. In a few places reefs protruded through the surrounding sediments to form low mounds around which succeeding formations were deposited. By the time the next formations were deposited on the Edwards formation, it was lithified and, in many places, completely altered to new types of rocks.

Post-Lithification Alteration

The beginning of alteration of the Edwards limestone or its individual components cannot be sharply defined. Boring organisms, waves, and currents began to destroy the rudistid reefs soon after growth started. Recrystallization of shell fragments apparently started before lithification and, locally, dolomite replaced the shell wall of the rudistids prior to complete lithification.

After lithification and regional uplift, the Edwards limestone was subjected to alteration throughout the area. Pronounced alteration took place south of the pinchout of the Kiamichi shale in Bell and Coryell counties. This would suggest that post-lithification alteration is related to pre-Washita exposure of the Edwards limestone. However, Bell and Coryell counties are also the location of the Balcones fault system and the well-developed drainage system formed by the Leon and Lampasas rivers. Both of these features could have had as much effect on alteration of the Edwards limestone as pre-Washita exposure.

Because only a reconnaissance study of Bell and Coryell counties has been made, it is not possible to definitely associate post-lithification alteration products with the geologic features and processes that led to their formation. Insofar as possible, the origin of the various secondary features of the Edwards formation has been discussed (with the exception of the origin of dolomite which is discussed subsequently), but the time of origin has not been positively established.

Oxidation and case-hardening of the top of the Edwards limestone clearly took place before deposition of the Kiamichi shale and Duck Creek limestone.

Chalkification is going on today, as suggested by the close relationship between the severity of chalkification and the amount of present-day topographic relief. Some chalkification could have occurred prior to deposition of the Washita group, but it probably was not great.

The time of development of crystalline limestones and post-lithification calcitic dolomites is more difficult to determine. Cementation of post-lithification dolomite obviously postdates dolomitization. Similarly, recrystallization of some limestones took place after dolomitization of adjoining beds. Recrystallization apparently resulted from percolation of ground water downward through the dolomite and into the less porous limestone where the velocity of water movement was decreased. Recrystallization of the limestone then followed. The time of origin of crystalline limestones in nondolomitic areas has not been determined.

Solution of the Edwards limestone is most certainly going on today, as indicated by the occurrence of springs at the base of the formation and by the presence of stalactites beneath overhanging cliffs of the limestone. The time when solution of the limestone began has not been determined.

Origin of Dolomite

The present study indicates that dolomite in the Edwards formation was formed by primary and diagenetic processes of deposition and by diagenetic and post-lithification alteration of pre-existing limestone. Many theories have been advanced to explain the origin of dolomite. In view of the excellent discussions of the dolomite problem (Van Tuyl, 1916, Twenhofel, 1932, pp. 330–351; Cloud and Barnes, 1948, pp. 89–95; and Fairbridge, 1957), the writer considers it unnecessary to present another review at this time. It is pertinent, however, to review recent studies which deal with modern carbonate sediments, because only these studies can definitely prove or disprove that dolomite is precipitated as a primary rock-forming mineral. Many geologists have been hesitant to postulate a primary origin for dolomite, probably because dolomite had not been found in modern sediments. Cloud and Barnes (1948, p. 92), for example, concluded that ". . . it is not advisable to assume a primary origin for a dolomite that can otherwise be explained as well as the result of penecontemporaneous alteration." Even more recently, Fairbridge (1957, p. 164) concluded that dolomite ". . . is not found in rock-forming accumulations on the sea floor today, or at shallow depth in Recent marine sediments." He noted, however, that isolated dolomite rhombohedrons, apparently authigenic, have been found in the deep sea environment (500 to 2,000 fathoms) and in Recent intertidal deposits.

In 1957, subsequent to Fairbridge's discussion, the results of two studies pertinent to the origin of dolomite were published. In the first study, Alderman and Skinner (1957, pp. 561–567) conclusively proved that dolomite is being formed today in Kingston Lake and in a shallow inlet of the sea in the South-East province of Australia. They noted that dolomite is also forming in other lakes in the area. Analyses showed that the water in Kingston Lake has essentially the same composition as sea water. Their study demonstrated that (1) the dolomite rhombohedrons possess no morphological evidence of organic origin, (2) precipitation of dolomite in the water is directly related to the abundance of plant growth, and (3) the water has a pH of 9.2. They ascribed the elevated pH to plant growth.

The second study showed that dolomite forms as an early diagenetic mineral in the sediments of the northwestern part of the Black Sea (Tageeva and Tikhomirova, 1957, pp. 61–63). These writers concluded that dolomite is precipitated by a lowering of the carbonic acid content of organic acid. They also noted that pyrite is formed by microbiological reduction of the sulfates. They classified both minerals as products of early diagenesis. It is interesting to note that pyrite is also associated with diagenetic dolomite in the Edwards formation at localities 154-T-1, 154-T-14a, and 154-T-16.

Both studies thus demonstrated that dolomite forms in an environment of restricted circulation which has an elevated pH. These conditions had been suggested previously by several writers (Pfaff, 1895; Udluft, 1929; Koehler, 1931; and Linck, 1937: *in* Fairbridge, 1957, p. 137).

Post-lithification dolomitization of pre-existing sediments has been described by many writers. In his excellent summary of the origin of dolomite, Fairbridge (1957, pp. 164–170) suggested that metasomatic dolomite may originate under the following conditions:

(1) A large amount of dolomitization does not take place on the sea floor or the seashore, but there is a considerable amount of fixation of Mg-rich calcite. Later, this may become mobilized to form dolomite (p. 166).
(2) Isolated crystals of authigenic dolomite have been found on the sea floor in deep water. They may have formed in situ by alteration of Mg-rich calcite or they may have been transported to the present site of deposition (p. 166).
(3) In the intertidal zone, Mg-rich calcite may alter to dolomite in warm water where there is a high concentration of Mg^{++} brought about by increased alkalinity (p. 166).
(4) In soft sediments, metastable aragonite and Mg-rich calcite may alter to dolomite when they become buried providing there is an adequate supply of Mg^{++} (pp. 167–168). Dolomitization takes place preferentially in the fine-grained sediments.
(5) Dolomitization may also take place after lithification as Mg^{++}-saturated waters circulate through permeable limestones (p. 168). Dolomitization probably would not take place if the limestones were low in magnesium.
(6) Dolomite may form under continental conditions (p. 169). The Mg^{++} would be derived from pre-existing dolomite.

The present study and the review of previous studies suggest to the writer that dolomite in the Edwards formation originated in the following manner:

During deposition of the Edwards limestone, the mineral dolomite precipitated out of solution to form beds of dolomite in local areas (lóc. 14-T-1, for example) where the alkalinity of the water was abnormally high (greater than pH 9). The high alkalinity was probably due to many factors; these are thought to be loss of CO_2 by elevated temperatures, and putrefaction brought about by restricted circulation and organic decay.

Primary precipitation of dolomite also produced individual rhombohedrons which became dolomite detritus in border areas where lime detritus was being deposited. In these border areas, dolomite also crystallized out of solution to form the cement and partially dolomitize the lime detritus. In effect, the dolomite was both primary and diagenetic with respect to deposition of lime detritus in the Edwards formation.

Highly alkaline micro-environments were formed in many places in the rudistid reefs and, in particular, on the upper surface of the reefs. These micro-environments included tension cracks in the matrix of the reefs, bore holes on top of the reefs, the body chambers of fossils, and the voids that were formed by solution of the shell walls of the fossils. Usually, only the inner shell wall was removed by solution. This wall was composed of an unstable mineral which was destroyed either by solution or by recrystallization to coarse crystalline calcite soon after lime-mud filled the reef interstices but before the mud was lithified. Dolomite crystallized out of solution in these voids. To date, the writer has found very little evidence to indicate that the alkaline solutions which filled the voids dolomitized the surrounding rock. Reducing conditions apparently prevailed at the top of the reefs because pyrite nodules are usually found on the reef surfaces. Stratigraphic evidence, which has been presented previously, indicates that the reef surfaces on which the micro-environments developed were fairly flat surfaces and were exposed to subaerial weathering for an unknown period of time.

During the time of deposition of the Kiamichi shale, when the Edwards limestone was either exposed or was covered by only very shallow water, Mg^{++}-bearing waters circulated through the Edwards formation and dolomitized the limestones south of the area where the Kiamichi shale was deposited. Dolomitization began in the fine-grained part of the rocks. Fairbridge (1957, p. 147) suggested that dolomite preferentially develops in the lime-mud near coral reefs because magnesium is more abundant in the interstitial mud than in the calcite lattice of the corals. He believed that high-magnesium constituents serve as nuclei for the growth of dolomite crystals. This explanation may possibly account for the preferential occurrence of dolomite in the matrix of the Edwards limestone, but the present writer does not believe it is the only explanation. It would seem most probable that the matrix was the most permeable part of the limestone and was, therefore, the path followed by the circulating fluids. Though the writer cannot clearly disprove that high-magnesium constituents served as nuclei for crystallization of post-lithification dolomite in the Edwards, it seems unlikely. Chemical and X-ray analyses have demonstrated that many limestones, lithologically similar to slightly dolomitic primary limestones, contain no magnesium or only trace amounts. It seems probable then that either high-magnesium constituents were not necessary for post-lithification dolomitization of the Edwards limestone or that trace amounts were sufficient to initiate it.

The direct relationship between the absence of the Kiamichi shale and the occurrence of post-lithification dolomite, which was pointed out and related to pre-Washita weathering (Feray and Nelson, 1956), most certainly exists, but the present writer suggests another possible relationship. In 1956 the writer was unaware of the possible occurrence of primary dolomite in the Edwards formation. This study has shown that dolomite, which is interpreted to be of primary origin, does occur. It has been found at only one locality (14-T-1), but it probably occurs in other places. The writer suggests that the primary dolomite may extend southward behind the main trend of the rudistid reef complex from locality 14-T-1. If so, it could have been the source of magnesium for later dolomitization at the time the Edwards was subjected to pre-Washita weathering. The occurrence of dolomite (time of origin unknown) behind other reef complexes has been noted in the Glen Rose (Early Cretaceous) formation by the writer, in the Permian reef complex by Newell et al. (1953, pp. 178–180), and in the Triassic sediments of southern Tyrol by Newell (1955a, p. 105).

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APPENDIX. MEASURED SECTIONS

The following sections, all measured from top to bottom, are shown by locality number on figure 14.

Localities in Bell County

Localities 14-T-2, 14-T-4, 14-T-7, 14-T-9, and 14-T-12 were not used in this study.

Locality 14-T-1

Abandoned railroad metal quarry approximately 2 miles northwest of Belton, on north side of road that parallels the G. C. & S. F. Railroad and just west of the road that crosses Belton Dam, Bell County.

This locality is discussed on pages 52–59.

Locality 14-T-3

Roadcut along the road that descends into the valley of the Belton reservoir, 1 airline mile west-southwest of Moffat, Bell County.

	Thickness (*feet*)
Edwards—	
10. White to light buff, thick- to massive-bedded granular limestone and fine to coarse shell debris. The top of the formation is oxidized to a brown color and honeycombed. Though the contact with the overlying Duck Creek is not exposed, it is believed to be close to the top of the highest exposed limestone	67.0
9. Moderately hard, buff, honeycombed, thick-bedded, granular limestone. The lower 4 inches contains patches of hard, gray, fine-grained limestone	2.0
8. Hard, light gray, stylolitic, honeycombed, microgranular limestone; the holes are partially filled with limestone like the unit above	1.0
7. Moderately hard, thick- to massive-bedded, fine- to medium-grained limestone that is mottled light gray and buff. Buff-colored mottlings are soft and porous. The lowest 8 feet is honeycombed	33.0
6. Extremely hard, dark brown, thick-bedded, microcrystalline limestone. Grades downward to unit below	6.5
5. White, pulverulent chalk mottled with brown chalk. The upper part of the unit contains nodules of the limestone above	3.5
4. Hard, gray, thick-bedded rudistid limestone	6.0
3. Interlaminated gray and brown marl	0.5
2. Hard, gray, medium- to coarse-grained conglomeratic limestone	5.0
Comanche Peak—	
1. Moderately hard, gray, argillaceous, microgranular, compressed nodular limestone. Exposed	24.0

Locality 14-T-5

Bluff on the east side of Leon River, 1 airline mile due west of Meador Grove, Bell County.

	Thickness (*feet*)
Duck Creek—	
5. Very hard, gray, medium-bedded, spherulitic, microgranular limestone. Exposed	5.0
Edwards—	
4. Very hard, light brown, honeycombed, microcrystalline limestone	2.0
3. Hard, white, massive rudistid limestone. This is the core of a biohermal reef. It grades laterally into shell debris and granular limestone. Beds dip away from the core with inclinations of 15° to 20°. The base of the reef is not exposed. Exposed	27.0
2. Covered interval	3.0 – 5.0
Comanche Peak—	
1. Moderately hard, light gray, argillaceous, microgranular, massive, compressed nodular limestone. This exposure is located 200 yards south of main exposure. Exposed	5.0

Locality 14-T-6

Because of construction of Belton Dam and flooding of the area behind the dam, this locality is no longer accessible. Prior to flooding, 41 feet of Edwards limestone and dolomite was measured.

Locality 14-T-8

Roadcut on F. M. 1670 where road descends into the valley of Stillhouse Hollow Creek, southwest of Belton, Bell County.

This locality is discussed on pages 59–61.

Locality 14-T-10

Prominent bluff just north of U. S. Highway 190, 2.6 miles east of Nolanville, Bell County.

	Thickness (*feet*)
Edwards—	
10. Single bed of very hard, brown, microcrystalline limestone. Exposed	1.0
9. Soft, gray-brown, thick-bedded, finely porous, microcrystalline dolomite containing a few fossils	9.0
8. Very hard, light buff, nodular, microcrystalline limestone; poorly exposed. This unit has a limited extent for, laterally, unit 7 is in contact with unit 9. Maximum thickness	1.4
7. Lithologically similar to unit 9	2.8
6. Soft, buff, granular dolomitic(?) limestone	1.2
5. Hard, buff, thick-bedded, fine- to medium-grained limestone	7.3
4. Moderately hard, gray to light buff, thin-bedded, fine- to medium-grained limestone containing a few fossils and gradational into the units above and below	1.3
3. Hard, gray and brown, thin-bedded, fine-grained limestone interbedded with soft calcareous shale and gradational into the unit below	1.4
Comanche Peak—	
2. Moderately hard, mottled gray and brown, massive, microgranular, argillaceous, compressed nodular dolomitic(?) limestone	4.2
1. Moderately hard, gray, thick- to massive-bedded, argillaceous, microgranular, compressed nodular limestone. Exposed	45.0

Locality 14-T-11

Bluff on the east side of Stampede Creek, 1.6 miles west-northwest of White Hall, Bell County.

	Thickness (*feet*)
Duck Creek—	
6. Very hard, light gray, microgranular, nodular limestone; poorly exposed	2.0
Edwards—	
5. Hard, white, massively bedded rudistid limestone. Base of unit is not exposed. Exposed	31.0
4. Covered interval; believed to be Edwards limestone	12.0
Comanche Peak—	
3. Moderately hard, light gray, argillaceous, microgranular, massive, compressed nodular limestone. Exposed	3.0
2. Covered interval	18.0
1. Lithologically similar to unit 3	12.0

Locality 14-T-13

Cedar Creek just west of State Highway 317 bridge over creek, Bell County.

	Thickness (*feet*)
Duck Creek—	
4. Very hard, light gray, microgranular, nodular limestone. Exposed	4.0
3. Limestone as above grading up into gray and buff calcareous shale which contains nodules of limestone	3.7
2. Two beds of limestone as above interbedded with shale as above. A shale bed 2 inches thick marks the base of the formation	2.5
Edwards—	
1. Very hard, iron-stained, massive rudistid limestone. Pyrite nodules are abundant. Exposed	5.0

Locality 14-T-14

Bluff overlooking Belton reservoir, approximately 1.6 miles due west of locality 14-T-3, Bell County.

An unknown amount of the upper part of the Edwards formation has been removed by erosion.

	Thickness (*feet*)
Edwards—	
6. Moderately hard, tan, massively bedded, honeycombed, granular dolomitic(?) limestone. Exposed	22.0

5. Secondary limestone zone. Consists of hard, brown, crystalline limestone and soft honeycombed limestone. Patches of brown calcite are common. Some of the original granular texture is still evident. The contact with the underlying unit is sharp; the contact with the overlying unit is gradual	8.0
4. Very hard, light gray, thick-bedded, fine-grained limestone	5.0
3. Hard, gray, massively bedded rudistid limestone. The unit is more fragmental at the top than at the bottom	15.0
2. Gray, massive, granular limestone. Gradational contact with the Comanche Peak	5.5
Comanche Peak—	
1. Moderately hard, light gray, argillaceous, massively bedded, compressed nodular limestone. Exposed	18.0

Locality 14-T-15

Outcrop at head of creek near country road west of Leon River valley and north of State Highway 36, 2.6 airline miles southeast of The Grove, Coryell County.

A rudistid biohermal reef 27 feet thick is exposed at the head of the creek on the west side of the road. This is a complete section of the Edwards limestone. The outcrop was not described.

Locality 14-T-16

Roadcut at west end of State Highway 36 bridge over Belton reservoir, Bell County.

	Thickness (*feet*)
Duck Creek—	
8. Hard, gray, microgranular, nodular limestone. Exposed	3.0
Edwards—	
7. Hard, very light gray, thick-bedded, slightly fossiliferous, microgranular limestone gradational into the unit below. The top of the limestone is pitted and contains many limonite nodules	15.0
6. Hard, massively bedded rudistid limestone. Sharp contact with the Comanche Peak	15.0
Comanche Peak—	
5. Moderately hard, very light gray to cream-colored, massively bedded nodular limestone. Color is lighter than the normal color of the Comanche Peak and the nodular structure is not as well developed. Chert nodules are present 13 feet below the Edwards. Exposed	31.0
4. Covered interval	46.0
3. Lithology similar to unit 5	10.0
2. Hard, gray to tan, massively bedded, poorly sorted granular and conglomeratic limestone becoming fine grained in upper part of unit. Particles are well-rounded fragments of fossils, most of which are unidentified. Fragments of *Cladophyllia* have been found. Gradational contacts at the top and bottom of the unit	7.0
1. Moderately hard, light gray, argillaceous, massively bedded, nodular limestone. Exposed	15.0

Locality 14-T-17

Roadcut on road that descends into the valley of the Belton reservoir near Hill's Bait House; approximately 2 miles due west of State Highway 317 and south of the mouth of Cedar Creek, Bell County.

One hundred and ten feet of Edwards limestone is exposed. On the basis of the topography, another 10 to 15 feet of Edwards limestone is believed to be present. The section has not been described.

Localities in Coryell County

Locality 50-T-1

Roadcut on road to White Hall. 2.2 miles north of Gatesville School for Boys. Coryell County.

	Thickness (*feet*)
Duck Creek—	
4. Very hard, gray, medium-bedded, microgranular, nodular limestone. Exposed	5.0
Kiamichi—	
3. Soft shale mottled gray and brown. Contains pseudomorphs of limonite after pyrite	4.8

Edwards—	
2. Moderately hard, light gray to white, massively bedded rudistid limestone. Top of formation is oxidized to a brown color and case-hardened. Contact with Comanche Peak is sharp	16.0
Comanche Peak—	
1. Moderately hard, light gray, argillaceous, massively bedded, microgranular, compressed modular limestone. Exposed	72.0

Locality 50-T-2

Roadcut 1 mile north-northeast of locality 50-T-1, Coryell County.

	Thickness (*feet*)
Edwards—	
3. Extremely hard, gray, thin- to medium-bedded, microgranular limestone interbedded with light gray marls and chert. The chert occurs as beds continuous through the entire outcrop, discontinuous beds, and nodules; it is generally black in color. Exposed	15.0
2. Alternating beds of moderately hard, light gray, thin- to medium-bedded limestones and light gray, soft, thin- to medium-bedded fissile limestones or marls. Vertical gradations from one lithologic type into the other are the rule. The contact with the underlying Comanche Peak is gradational and has been arbitrarily placed at the level where the massive marl below begins to assume a well-bedded character	7.0
Comanche Peak—	
1. Light gray, massive marl. Exposed	4.0

Locality 50-T-3

Prominent bluff behind Pecan Grove Baptist Church, 9 airline miles south-southeast of Gatesville, Coryell County.

	Thickness (*feet*)
Edwards—	
4. Moderately hard, very light buff, massive rudistid limestone thickening to the north; approximately 10 feet is exposed at the point measured	10.0
3. Moderately hard, white, massive rudistid limestone thickening to the north. At the point measured, this unit is 13 feet thick and contains several nodular chert beds which thin out and disappear in the center of the reef	13.0
2. Light buff, hard, massive rudistid limestone; the upper half of the unit is more clastic than the lower half	7.0
Note: This section of Edwards was measured on the southwest side of the biohermal reef where 30 feet of Edwards is exposed; all units thicken toward the center of the reef and are represented by approximately 50 feet of white, massive, rudistid limestone which becomes more clastic toward the top.	
Comanche Peak—	
1. Moderately hard, light gray, argillaceous, massively bedded, microgranular, compressed nodular limestone; the Edwards-Comanche Peak contact is sharp. Exposed	20.0

Locality 50-T-4

Ford over Bluff Creek north of Osage, Coryell County.

	Thickness (*feet*)
Duck Creek—	
7. Very hard, gray, microgranular limestone. Poorly exposed at bend in road just south of ford. Exposed	3.0
Kiamichi—	
6. Gray and brown, thinly laminated shale. Mottled with white pulverulent chalk in upper 1.5 feet of unit	3.5
5. Gray and brown, thinly laminated shale grading upward into hard, light gray, irregular-bedded limestone	1.0
4. *Gryphaea navia* bed. Comminuted shells are abundant. *Kingena wacoensis* and *G. corrugata(?)* also present. Shells are pitted and coated with a thin film of calcium carbonate	0.5
Edwards—	
3. Light gray, microgranular, very irregular-bedded limestone filled with bore holes that contain Kiamichi shale	0.5
2. Light gray, thin-bedded, microgranular limestone. Beds are separated by thin	

argillaceous limestones	1.5
1. Very hard, gray, thin-bedded, microgranular limestone containing many large flat nodules of dark gray chert at top of unit. Exposed	4.3

Locality 50-T-5

Grove Creek bed just west of Meador Grove-Whitson road bridge, 1.8 miles north of Meador Grove, Bell County.

Duck Creek limestone overlies an Edwards rudistid reef. The top of the reef is case-hardened, oxidized to a brown color, and contains many pyrite nodules.

Locality 50-T-6

Vicinity of abandoned quarry on the south side of U. S. Highway 84 where the highway descends into the Leon River valley, 3.3 miles east of the railroad station in Gatesville, Coryell County.

	Thickness (*feet*)
Edwards—	
4. The Edwards formation is discussed on pages 44–46. Approximately 73 feet of Edwards limestone is present	73.0
Comanche Peak—	
3. Soft, white, massive, microgranular limestone grading upward into compressed nodular limestone having a similar texture. The contact with the Edwards is sharp	31.0
2. Ferruginous limestone zone. This zone is made up of three extremely hard, ferruginous-coated beds of pelecypod shells and two beds of soft, buff-colored marl or limestone containing hard, white limestone concretions and mottlings of white, pulverulent chalk. The base of the unit is marked by a 6-inch thick ferruginous pelecypod shell bed that has an undulatory upper surface. The remaining two ferruginous beds are 2 inches thick; one is near the middle and the other at the top of the unit	3.9
Walnut(?)—	
1. Soft, buff-colored marl or limestone grading upward into moderately hard, white, microgranular, equidimensional nodular limestone. Exposed	10.0

Locality 50-T-7

Roadcuts on U. S. Highway 84, 4.5 miles east of the railroad station in Gatesville, Coryell County.

This outcrop is discussed on pages 46–50. Approximately 53 feet of Edwards limestone is present.

Locality 50-T-8

Long roadcut on U. S. Highway 84 on the west side of Greenbriar Creek, Coryell County.

	Thickness (*feet*)
Edwards—	
10. The Edwards formation is discussed on pages 50–52. Approximately 62 feet of Edwards limestone is present	62.0
Comanche Peak—	
9. Moderately hard, light gray, microgranular, compressed nodular limestone. Bedding is poorly developed. A few rudistids are present in the top of the unit. Exposed	40.0
8. Covered interval	15.0
7. Gray to buff-colored, thin- to medium-bedded, granular limestone	4.0
6. Massive limestone similar to unit 7. Grades into unit below	5.5
Walnut(?)—	
5. White to cream-colored, microgranular, chalky, massively bedded, equidimensional nodular limestone. Bore hole fillings(?) and fossil fragments (gastropods and pelecypods) are abundant. Gradational into unit below	6.5
4. *Gryphaea* limestone. Grades into unit below	1.0
3. Similar to unit 5. Grades into unit below	3.5
2. Similar to unit 4, but fossils are more abundant. Grades into unit below	1.5
1. Similar to unit 5 but contains some *Gryphaea* in upper part. Exposed	27.0

Locality 50-T-9

Long roadcut on road that descends into Leon River valley, 3.8 miles south of Oglesby, Coryell County.

	Thickness (*feet*)
Duck Creek—	
4. Very hard, gray, nodular, medium-bedded, microgranular limestone. Exposed	3.0

Kiamichi—	
3. Soft, greenish-gray shale mottled with white, pulverulent chalk. The shale becomes thinly laminated and oxidized near the top. Limonite occurs as mottlings, along seams, and between the laminations in the shale	1.5
Edwards—	
2. Hard, cream-colored, thin- to massive-bedded, poorly sorted fine and coarse shell debris. Some beds of granular limestone are also present. The top of the formation is case-hardened and iron stained	45.0
Comanche Peak—	
1. Moderately hard, very light gray to cream-colored, massive compressed nodular limestone. Sharp contact with the Edwards. Exposed	27.0

Locality 50-T-10

Roadcut on U. S. Highway 84, 2.3 miles west of intersection of that highway and F. M. 185 northwest of Oglesby, Coryell County.

	Thickness (*feet*)
Duck Creek—	
3. Very hard, light gray, nodular microgranular limestone. One and one-fourth feet above the base of the formation is a thin bed of light gray to brown shale. Exposed	4.0
Kiamichi—	
2. Interlaminated greenish-gray and yellowish-brown shale mottled with white, pulverulent chalk grading upward into light gray marl which is iron stained and mottled with white pulverulent chalk. The chalk makes up a large portion of the upper part of the formation	4.0
Edwards—	
1. Hard, light gray, thin- to medium-bedded granular limestone. The top of the limestone contains bore holes and is iron stained, case-hardened, and contains limonite concretions	6.5

Locality 50-T-11

Roadcut on U. S. Highway 84 where highway descends into the valley of Coryell Creek, Coryell County.

	Thickness (*feet*)
Duck Creek—	
14. Very hard, gray, microgranular nodular limestone. Exposed	3.0
Kiamichi—	
13. Soft, gray and buff-colored shale. Section not measured in detail	3.5
Edwards—	
12. Very hard, brown, case-hardened, fine-grained limestone containing many specimens of *Chondrodonta*. All specimens are oriented parallel to the bedding. Limonite concretions are abundant. This bed pinches out laterally	0 – 1.0
11. White, chalky, massive rudistid limestone. *Eoradiolites* and *Chondrodonta* appear to be most abundant forms. Most are broken but not abraded. They are preserved as "original" shells and calcite casts. The matrix is fine lime detritus. The top of this unit has 1 foot of relief on it. The upper half of the unit has incipient to well-developed bedding planes. Beds are 1 to 3 feet thick. Exposed	23.0–24.0
10. Covered interval	2.0
9. Interbedded buff-colored granular limestone and marl. Thin to medium bedded. Exposed	3.0
8. Hard, cream-colored, massive, granular limestone and fine shell debris. Gradational into unit below. The top of the unit is convex upward, but the thickness of the unit is uniform across the outcrop	2.5
7. Soft, buff-colored marl containing some fragments of rudistids	0.9
6. Hard, white rudistid limestone. The upper part of the unit is more fragmental and massive than the lower part. The lower part exhibits incipient bedding. The beds are slightly undulatory and range from 6 to 10 inches in thickness	11.0
5. Single massive bed of limestone similar to unit above. Sharp contact below	2.0
Comanche Peak—	
4. Moderately hard, light gray, massive, microgranular, compressed nodular limestone. Grades downward into the unit below	17.0
3. Very soft, light gray, massive microgranular limestone which contains several discontinuous and slightly harder microgranular limestone beds	14.0
2. Ferruginous limestone zone. Three extremely hard, ferruginous-coated, pelecypod shell beds are separated by two beds of soft, buff-colored, microgranular	

limestone which are mottled with white, pulverulent chalk and contain hard, white, microgranular limestone concretions. A ferruginous-coated shell bed 4 to 6 inches thick marks the base of the unit. The remaining two shell beds are discontinuous and are 2 inches thick. One marks the top of the unit; the other is 7 inches below the top of the unit	3.9
Walnut(?)—	
1. White, microgranular, equidimensional nodular limestone. Exposed	6.0

Locality 50-T-12

Roadcut on F. M. 929 where road descends into the valley of Coryell Creek, approximately 2.5 miles northeast of Gatesville School for Boys, Coryell County.

	Thickness *(feet)*
Duck Creek—	
9. Very hard, light gray, medium-bedded, microgranular limestone. Exposed	5.0
Kiamichi—	
8. Soft, gray and brown shale	4.0
Edwards—	
7. Hard, gray to tan, thin-bedded, granular limestone. The top of the formation is oxidized to a brown color and the upper surface is covered with small pits. Beds in the lower part of the unit dip 8° to 10°. The upper surface of the Edwards dips 3°	16.5
6. Interbedded rudistid limestone and fine to coarse shell debris. Beds range from 9 to 18 inches in thickness. Beds dip 15° in the lower part of the unit; the dip decreases to 8° at the top of the unit	12.0
5. Interbedded fine-grained limestone; argillaceous, microgranular, nodular limestone; and marl	7.5
4. Hard *Cladophyllia*-bearing limestone	0.9
Comanche Peak—	
3. Moderately hard, very light gray, microgranular, compressed nodular limestone grading downward into soft massive microgranular limestone. Several thin (2 to 3 inches) slightly harder limestone beds are present near the base of the unit. The lower part of the unit is mottled with white pulverulent chalk. A hard, thin, ferruginous shell bed that grades laterally into soft ferruginous limestone is present 8 feet above the base of the unit	39.0
2. Ferruginous limestone zone. Interbedded ferruginous shell beds and soft massive microgranular limestone which is mottled with white pulverulent chalk. A 6-inch ferruginous shell bed marks the base of the unit. The remaining two ferruginous shell beds are 2 inches thick and are 7 and 18 inches above the base of the unit. These two beds are discontinuous and grade laterally into soft ferruginous limestone	1.5
Walnut(?)—	
1. White, microgranular, equidimensional nodular limestone. Exposed	2.5

Locality 50-T-13

Roadcut along F. M. 929 near Coryell Valley Church, approximately 1.5 miles east of locality 50-T-12, Coryell County.

	Thickness *(feet)*
Edwards—	
4. The Edwards limestone at this locality appears to be primarily rudistid limestone. It is 52 feet thick. Because it is poorly exposed the formation has not been described	52.0
Comanche Peak—	
3. Moderately hard, very light gray to white, slightly argillaceous, compressed nodular limestone grading down into soft microgranular limestone that contains several thin slightly harder limestone beds. The soft limestone is mottled with white, pulverulent chalk	31.0
2. Ferruginous limestone zone similar to that at locality 50-T-12. Four ferruginous shell beds are present	1.7
Walnut(?)—	
1. White, microgranular, equidimensional nodular limestone. Exposed	7.0

Locality 50-T-14

Roadcut 0.8 mile west of Rainier School, which is 1.5 miles due north of the village of Mountain on U. S. Highway 84, Coryell County.

Approximately 54 feet of Edwards limestone is present in the roadcut. However, because the limestone is poorly exposed, it has not been described.

Locality 50-T-15

Roadcut on the north side of the valley of the South Fork of Middle Bosque River, 2.3 miles due north of Coryell, Coryell County.

Approximately 42 feet of Edwards limestone is present in the roadcut. However, because the limestone is poorly exposed, it has not been described.

Localities in McLennan County

Locality 154-T-1

Santa Fe Railroad cut on southeast side of Valley Mills, Bosque County.

The Edwards limestone ranges from 17 to 20 feet in thickness at this locality. It is discussed on pages 39–43.

Locality 154-T-2

Roadcut 1 mile north of Crawford on State Highway 317, McLennan County.

	Thickness *(feet)*
Duck Creek—	
11. Very hard, gray, microgranular, medium-bedded nodular limestone. Exposed	4.0
Kiamichi—	
10. Brown shale mottled with pulverulent chalk at the top	1.8
9. Light gray, fine-grained, nodular limestone interbedded with brown, slightly sandy and shelly shale	3.3
8. Dark gray slightly sandy fissile shale. Sharp contact with the Edwards limestone	1.4 1.4
Edwards—	
7. White to light gray, massively bedded, very fossiliferous granular limestone. The top of the limestone is oxidized, case-hardened, and contains bore holes filled with Kiamichi shale	7.0
6. White to light gray, medium to massively bedded, fine- to medium-grained limestone. Beds are cross-laminated and composed of "original" shell particles, recrystallized shell fragments (predominant), and opaque grains. Generally well sorted, but patches of coarse granular to fine shell debris limestone are present. Elongated grains are oriented parallel to cross-laminations. Cement is clear crystalline calcite. Limonite concretions are abundant in the top of this unit	13.0
5. Gray, massive, microgranular limestone composed predominantly of well-sorted opaque grains. Cement is crystalline calcite (Pl. 13, D)	6.3
4. Soft, gray, argillaceous, microgranular nodular limestone	1.5
3. Hard, light gray, granular limestone. Contains bore holes filled with brown lime-sand (dolomitic?). Pinches out laterally	0–1.0
2. Massive rudistid limestone. Composed of a mass of fossils and fossil fragments embedded in a very fine-grained matrix. Fossils are preserved as "original" shell material and calcite casts. Lower part of biostrome is composed predominantly of *Eoradiolites*; upper part is largely *Caprinuloidea*. *Dictyoconus walnutensis* is very abundant. Dolomitic in patches. Body chambers of *Caprinuloidea* are filled with brown lime-sand (dolomitic?). Sharp contact with Comanche Peak limestone	8.7–7.7
Comanche Peak—	
1. Light gray, argillaceous, massively bedded, microgranular, compressed nodular limestone. Exposed	24.0

Locality 154-T-3

Roadcut west of crossing of Middle Bosque River in McLennan County, approximately 6.4 airline miles southwest of Valley Mills, Bosque County.

Base of measured section is 67 feet above level of ford.

	Thickness *(feet)*
Kiamichi—	
7. Soft gray shale. Only the basal few inches is exposed at the top of the hill	0.5
Edwards—	
6. White to light cream-colored, medium- to thick-bedded, vuggy, fine and coarse shell debris. Whole fossils are common. The top of the formation is oxidized, case-hardened, and pitted	13.0
5. Cream-colored, thin- to medium-bedded, well-sorted granular limestone. This unit and unit 7 form the prominent beds exposed along the top of the bluff	10.5

4. Hard, light gray, fine-grained limestone alternating with beds of marl and soft, fine-grained limestone. Thin to thickly bedded. At approximately 8 feet above the base of this unit, the grain size increases slightly	22.5
3. Light gray, argillaceous, microgranular, nodular limestone. Grades into unit above	6.0
2. Rudistid limestone. Whole and broken fossils in a microgranular matrix. Sharp contacts with units above and below	4.0
Comanche Peak—	
1. Light gray, argillaceous, microgranular, massive, compressed nodular limestone. Exposed	7.0

Locality 154-T-4

Bluff on the north side of the North Bosque River, 4.3 airline miles due east of Valley Mills, Bosque County.

	Thickness (*feet*)
Edwards—	
2. White, soft, chalky, massive rudistid limestone. The contact with the Comanche Peak is sharp. The contact with the Kiamichi is not exposed. Exposed	13.0
Comanche Peak—	
1. Light gray, argillaceous, microgranular, massive nodular limestone. Exposed	15.0

Locality 154-T-5

Prominent bluff on the north side of the Middle Bosque River just west of the Santa Fe Railroad bridge, 1.2 miles north of Crawford, McLennan County.

	Thickness (*feet*)
Edwards—	
4. Hard, buff-colored, medium- to thick-bedded granular limestone grading upward into shell debris. Exposed	14.5
3. Covered interval	4.3
2. Hard, medium- to thick-bedded rudistid limestone. Sharp contact with Comanche Peak. Exposed	5.0
Comanche Peak—	
1. Light gray, argillaceous, massively bedded compressed nodular limestone. Exposed	20.0

Locality 154-T-6

Vertical bluff at bend in Tonk Creek, 0.5 mile above the mouth of the stream and 1.5 miles east-southeast of Crawford, McLennan County.

	Thickness (*feet*)
Edwards—	
3. White, honeycombed, medium- to thick-bedded fine and coarse shell debris (Pl. 13, C). The top of the formation is not exposed but is believed to be less than 5 feet above highest exposure of limestone. This is suggested by the presence of the treeless band which corresponds to the distribution of the Kiamichi shale. Top of limestone is iron stained. Exposed	15.0
2. White to cream-colored, well-sorted, medium- to thick-bedded granular limestone which grades into the units above and below (Pl. 14, D). Particles made up of "original" shell material, recrystallized shell fragments, and opaque grains. Cement is crystalline calcite	10.0
1. Hard, cream-colored, thin- to massive-bedded fine-grained limestone. This unit is similar to unit 5, locality 154-T-2. The base of the unit is not exposed; it is estimated to be near the bed of the creek. Exposed	16.0

Locality 154-T-7

Bluff at the head of a small stream north of the North Bosque River, approximately 4 airline miles due west of China Springs, McLennan County.

	Thickness (*feet*)
Edwards—	
2. Hard, white to very light gray, massive rudistid limestone. Sharp contact with Comanche Peak. The contact with the Kiamichi is not exposed, but this exposure is believed to represent a complete section of the Edwards	23.0
Comanche Peak—	
1. Moderately hard, light gray, argillaceous, microgranular, massive, compressed nodular limestone. Exposed	12.0

Locality 154-T-8

Small tributary of Middle Bosque River approximately 0.3 mile due north of F. M. 185 bridge over the river east of Crawford, McLennan County.

Several biohermal rudistid reefs are exposed in the creek. The section has not been described in detail.

Locality 154-T-9

Bluff on south side of Bluff Creek, approximately 0.3 mile downstream from ford over Bluff Creek north of Osage, Coryell County.

A biohermal rudistid reef is poorly exposed at this locality. The section has not been described in detail.

Locality 154-T-10

Along ranch road descending into the valley of the Middle Bosque River, 2.3 miles downstream from ford over river on Valley Mills-Coryell road, McLennan County.

	Thickness (*feet*)
Edwards—	
3. Covered interval. Kiamichi shale estimated to be 5 to 8 feet above unit 2	5.0 – 8.0
2. Hard, buff-colored, medium- to thick-bedded granular limestone	25.0
Comanche Peak—	
1. Moderately hard, light gray, argillaceous, microgranular, massive compressed nodular limestone. The Comanche Peak grades into the Edwards by an increase in grain size and development of a well-bedded structure. Exposed	13.0

Locality 154-T-11

Prominent bluff just west of bridge over Bluff Creek on the Crawford-Coryell road, 2 miles northwest of Crawford, McLennan County.

	Thickness (*feet*)
Edwards—	
5. White, honeycombed, thin- to medium-bedded coarse granular and fine shell debris limestone (Pl. 14, E). Composed predominantly of "original" and recrystallized shell material. Cement is crystalline calcite. Gradational into unit below. The contact with the Kiamichi is not exposed, but the top of the exposed limestone is considered to be very close to the top of the formation. Exposed	3.0
4. White to light buff, well-sorted, medium- to thick-bedded granular limestone. Gradational into unit below	13.0
3. White to light buff, well-sorted, medium- to thick-bedded, fine-grained limestone. Sharp contact below	5.0
2. Hard, light gray to buff, very massively bedded rudistid limestone (Pl. 12, D). Fossils are preserved as "original" shells and calcite casts. Matrix is very fine-grained limestone. *Eoradiolites* predominates. Dolomitic in patches. This limestone is considered to be the flank of a rudistid reef. Sharp contact below	19.5
Comanche Peak—	
1. Moderately hard, light gray, argillaceous, microgranular, massively bedded, compressed nodular limestone. Exposed	31.5

Locality 154-T-12

Overhanging bluff at Bluff Creek crossing of abandoned Crawford-Coryell road, McLennan County.

	Thickness (*feet*)
Edwards—	
3. Hard, white to light buff, medium- to thick-bedded granular limestone and fine to coarse shell debris. Individual beds pinch out and are overlapped to the west by higher beds. The contact with the Kiamichi is not exposed, but the treeless band and terrace above the outcrop indicate that the highest exposed limestone is close to the contact. Exposed	15.0
2. Hard, gray, massively bedded rudistid limestone. Beds dip very slightly to the east. Incipient bedding and major bedding suggest that the rudistid limestone is the flank of a reef. Sharp contact with Comanche Peak	27.0
Comanche Peak—	
1. Moderately hard, light gray, argillaceous, microgranular, massive, compressed nodular limestone. Exposed	20.0

Locality 154-T-13

Bluff just north of State Highway 6, 1.6 miles east of Valley Mills, Bosque County.

	Thickness *(feet)*
Edwards—	
4. Hard, white, thick-bedded rudistid limestone. Beds dip approximately 15°. The contact with the Kiamichi is not exposed, but the top of the exposure is probably close to the contact. Exposed	10.0
3. Hard, white, massive rudistid limestone. The contact with the Comanche Peak is exposed downstream from the main outcrop. The contact is approximately 1 to 2 feet below the base of the main outcrop. Exposed	7.0
2. Covered interval	1.0
Comanche Peak—	
1. Moderately hard, light gray, argillaceous, microgranular, massive, compressed nodular limestone. The Comanche Peak is exposed downstream from the main outcrop. Exposed	8.0

Locality 154-T-14

Bluff on the west side of the Middle Bosque River, 3 airline miles southeast of Crawford, McLennan County.

	Thickness *(feet)*
Edwards—	
2. Interbedded white well-sorted granular limestone, poorly sorted coarse granular limestone, and fine shell debris (Pls. 13, A; 14, F). Bedding is well developed. The contact with the Kiamichi is not exposed, but it is believed to be very close to the top of the exposed limestone. This unit varies in thickness owing to variations in thickness of the underlying rudistid facies. Just west of the bend in the road these beds are approximately 10 feet thick. Downstream, they pinch out completely	0 – 10.0
1. Hard, white, massive rudistid limestone (Pls. 5; 13, B). This unit is discussed on pages 34–36. Maximum exposure	12.0

Locality 154-T-15

Bluff along Hog Creek near ford over creek on the Valley Mills-Coryell road, McLenna County.

The Edwards limestone is approximately 25 feet thick along the creek. The formation is discussed on pages. 38–39.

Locality 154-T-16

Childress Creek, approximately 4 airline miles north of China Springs, McLennan County.

Only the top of the Edwards limestone is exposed at this locality. The formation is discussed on pages 43–44.

Locality 154-T-17

Head of small tributary of North Bosque River north of State Highway 6, approximately 2 miles due east of Valley Mills, Bosque County.

	Thickness *(feet)*
Edwards—	
2. Hard, white, massive rudistid limestone. Beds dip 18°. The contact with the Kiamichi is not exposed, but the terrace and treeless band that are associated with the Kiamichi shale indicate that the contact is close to the top of the exposed limestone. Exposed	18.0
Comanche Peak—	
1. Moderately hard, light gray, argillaceous, microgranular, massive, compressed nodular limestone. The contact with the Edwards is sharp. Exposed	8.0

Locality 154-T-18

Roadcut in front of cemetery on country road south of Valley Mills, Bosque County.

Nineteen feet of Edwards limestone is present at this locality. The section has not been described.

Edwards Fossils as Depth Indicators

KEITH YOUNG[3]

Abstract.—The Edwards limestone is 20 to 25 feet thick along the Brazos River in Hill and Bosque counties, Texas, where it constitutes a single tabular reef. Biologically it consists of four zones which are related to bottom depth at the time of their deposition. The *Cladophyllia* zone is at the base; this small coral grew in about 20 to 25 feet of water. Then in ascending order are the *Monopleura-Toucasia*, the *Caprinuloidea* zone, and the *Eoradiolites-Chondrodonta* zone. The top of the *Eoradiolites-Chondrodonta* zone is thought to have occupied a depth slightly above that of mean low spring tide.

To the northeast this Edwards limestone tabular reef interfingers with the Goodland formation, and to the southwest it is cut out by erosion. The southwest front of the tabular reef was to windward and the northeast to leeward.

Introduction.—Reef complexes of all ages have been intensely studied in recent years. For most of these ages the reef-building organisms have received a parallel but much less intense study. The results of ecologic studies of organisms of Paleozoic (Newell et al., 1953; Lowenstam, several papers) and Recent (many authors) reefs are spread through many papers. A few authors (Bonet, 1952; Wells, 1932, 1933) have discussed and described Mesozoic reefs and the peculiar molluscs that were rock builders only during the Jurassic and Cretaceous Periods. True paleoecology of these animals has been neglected almost completely in English geological literature. The writer at this time does not desire to review the extremely scattered data in many languages concerning the ecology of Rudistaceae and Chamaceae. The former superfamily has no modern relatives. The latter has a modern counterpart and relative in the numerous species of the genus *Chama*, but too little is known concerning the ecology of this modern genus (Ricketts and Calvin, 1952). Wells (1932) has pointed to the definite growth relationship in reef masses between corals and caprinids in the Glen Rose formation of Texas.

Certain observations at the outcrop of the Edwards limestone in northern Hill and Bosque counties, Texas, along the Brazos River, furnish information that may bear on present and future paleoecological interpretations concerning Rudistaceae and Chamaceae, and some associated fossils.

In the summer of 1950 the writer and M. E. Dehlinger were surface mapping for the Bureau of Economic Geology in northern Hill, northern Bosque, and southern Johnson counties. The writer returned to this area with E. T. Ashworth in the summer of 1952 for several weeks. During these periods a number of sections of the Edwards limestone were measured and surface mapping of the Edwards limestone and adjacent strata was carried on. The photographs on Plate 32 were made by J. S. Pittman, Jr., and the writer.

Stratigraphic setting.—In northern Hill and Bosque counties the Edwards limestone crops out in bluffs along the Brazos River; it varies from 18 to 30 feet thick, being the attenuated northern end of a thicker limestone prism to the south. The Hill County side of the Brazos River (fig. 19) consists of a continuous bluff with Comanche Peak limestone in the lower part, Edwards limestone capping the bluff, and the Grand Prairie flattening out on the softer Kiamichi and Duck Creek formations. The Edwards limestone is overlain by the Kiamichi formation, which is mostly shale; the contact between the two is rarely well exposed. The contact between the Edwards limestone and the underlying Comanche Peak limestone is sharp along

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the Brazos River but more difficult to pick immediately east of the Brazos along various tributaries. At several localities near Blum, Hill County, there is no Edwards limestone present, and the Kiamichi formation rests on Comanche Peak limestone, which is then called Goodland limestone.

Lithology.—In this area the Edwards limestone consists of four principal lithologies: (1) the most prominent is a light tan, extremely hard, fossiliferous limestone containing rock-building organisms in place, accompanied by minor amounts of scattered organic debris; (2) a thin but persistent, phaneric, pulverulitic limestone; (3) a restricted, tan, hard, calcirudite composed of organic debris; and (4) through part of the area an extremely hard, tan, phaneric limestone caprock (a biosparite); this caprock has borings of animals extending from 8 inches to 2 feet into it from the top. The Comanche Peak facies is a white, nodular, aphanitic, unevenly bedded limestone (biomicrite), quite distinct from the different facies of the Edwards limestone.

Faunal associations.—The fauna of the Edwards limestone is very incompletely described. Adkins (1933) has pointed to the almost complete mutual exclusion of species and genera of the Edwards limestone from other equivalent Fredericksburg facies and vice versa. Mathews (1951, 1956) has discussed some of the reef localities and the associated faunas, and the fauna listed by Young (1952) is a typical reef-type fauna although also incomplete. Except for the Deep Eddy locality, most of the Fredericksburg fossils described by Stanton (1947) are non-reef type. Typical of the Edwards limestone facies of the Fredericksburg group in Hill and Bosque counties are the following, some of which are illustrated in Plates 31 and 32.

- Gastropoda
  - Nerineacea
    - Ceritellidae
      - *Ceritella* sp.
- Pelecypoda
  - Rudistaceae
    - Radiolitidae
      - *Eoradiolites* sp.
  - Chamaceae
    - Caprinidae
      - *Caprinuloidea* sp.
    - Diceratidae
      - *Toucasia* sp.
    - Monopleuridae
      - *Monopleura* sp.
- Scleractina
  - Stylinidae
    - *Cladophyllia furcifera* Römer

Typical of the Comanche Peak limestone facies are:

- Gastropoda
  - *Turritella*
  - *Alipes*
- Pelecypoda
  - *Gryphaea*
- Cephalopoda
  - Ammonoidea
    - *Oxytropidoceras* sp.
    - *Engonoceras* sp.

These two faunas are almost mutally exclusive, and in the Bosque County area the writer has never seen any of the one group intermingled with those of the other. Some mixing of similar types of fossils has been observed in certain beds in the Glen Rose formation and at rare localities in the Georgetown limestone. The exclusion of ammonoids from the reef-type habitat has hindered stratigraphic correlations between the reef and non-reef facies of the Fredericksburg and Washita groups.

In addition to the fore-mentioned lithologic facies, the Edwards limestone along the Brazos River in northern Hill County contains a peculiar zonation of the reef-type fossils listed above (fig. 20). Along the river near Kimball Bend at Bee Mountain and at Robinson's Bluff, Bosque County, and across the river in Hill County, the following zonation is realized or approached; as one departs from the river in either direction this zonation changes. For the purpose of the present paper the Comanche Peak limestone facies of the Fredericksburg group can be called the *Gryphaea* zone. Lying very sharply on the *Gryphaea* zone of the Comanche Peak limestone is the *Cladophyllia* zone of the Edwards limestone facies. This zone is a counterpart of lithology (2) of the Edwards limestone and constitutes a single pulverulitic bed; *Cladophyllia* sp. and *Ceritella* sp. are the only fossils observed by the writer in this zone. Fossils are rare because of the alteration of the original limestone to pulverulite. The *Gryphaea* and

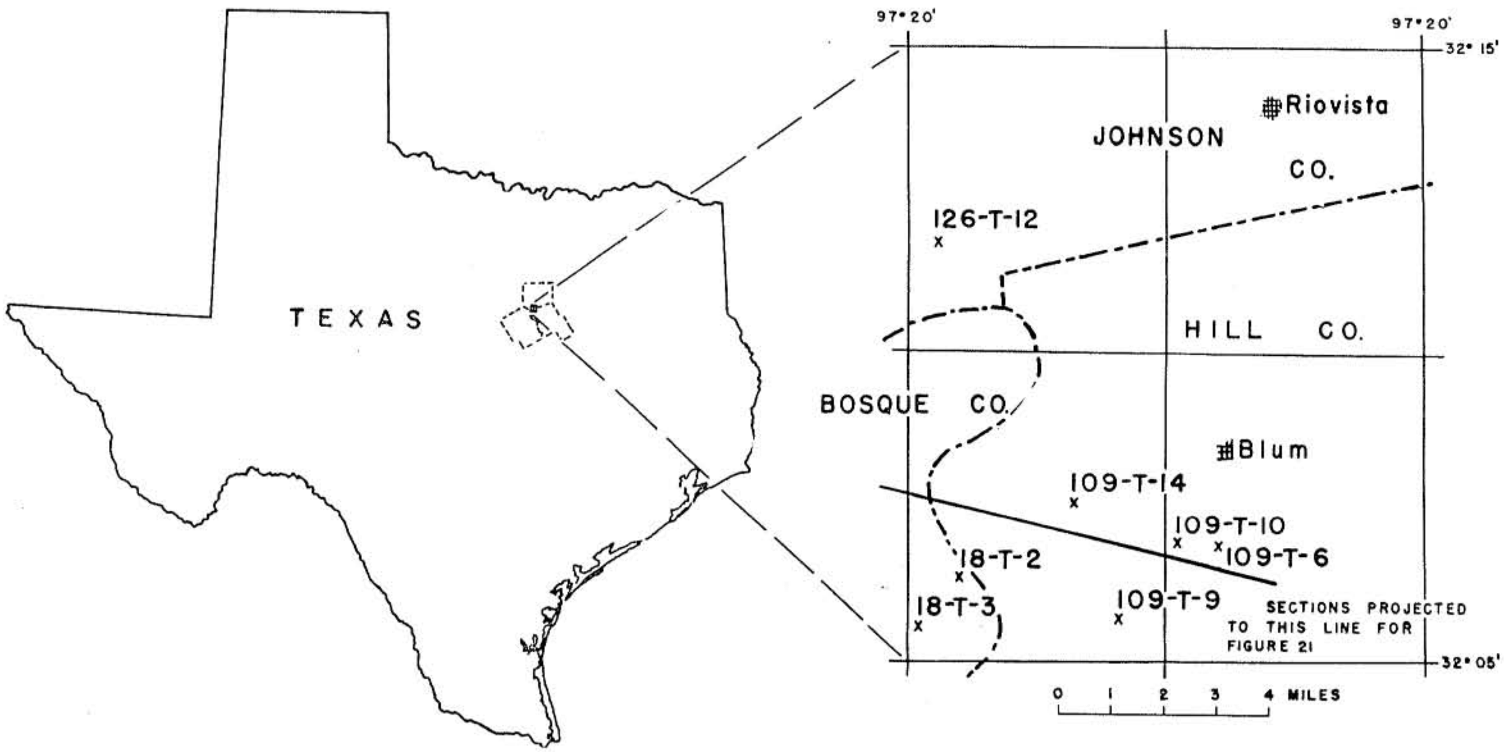

FIG. 19. Locality map of Johnson, Hill, and Bosque counties. Locality numbers and descriptions are those of the Bureau of Economic Geology.

Cladophyllia zones are distinct and their mutual boundary is a plane with no lithologic gradation observed. The *Cladophyllia* zone varies from 0.7 to 2.5 or 3.0 feet thick.

As the underlying *Gryphaea* zone is sharply delineated from the *Cladophyllia* zone, so is the overlying Diceratidae-Monopleuridae zone sharply delineated from the *Cladophyllia* zone. The dominant and characteristic fossils of this zone are the diceratid *Toucasia* and the monopleurid *Monopleura*. Other fossils occur, but the above may be identified from outlines on the rock surface (e.g., see Bonet, 1952, figs. 19, 34). This zone varies from about 3.5 to 7 feet thick. It is not sharply delineated from the overlying zone but instead grades into the Caprinidae zone by the gradual upward numerical increase in *Caprinuloidea* until this genus is the dominant fossil in the rock. The Caprinidae zone is 4 to 8 feet thick and gives way gradually to the zone of Radiolitidae and *Chondrodonta*. *Eoradiolites* and *Chondrodonta* have not been observed as low in the section in this area as has *Caprinuloidea*. In the Caprinidae zone a few individuals of *Eoradiolites* appear, and they gradually increase in number upward in the rocks. At some position they become a more important part of the rock-building suite than is *Caprinuloidea;* this position marks the base of the zone of Radiolitidae and *Chondrodonta*. *Chondrodonta* has not been observed as low in the rock as *Eoradiolites* but is always abundant at higher levels, occupying a most conspicuous place in the

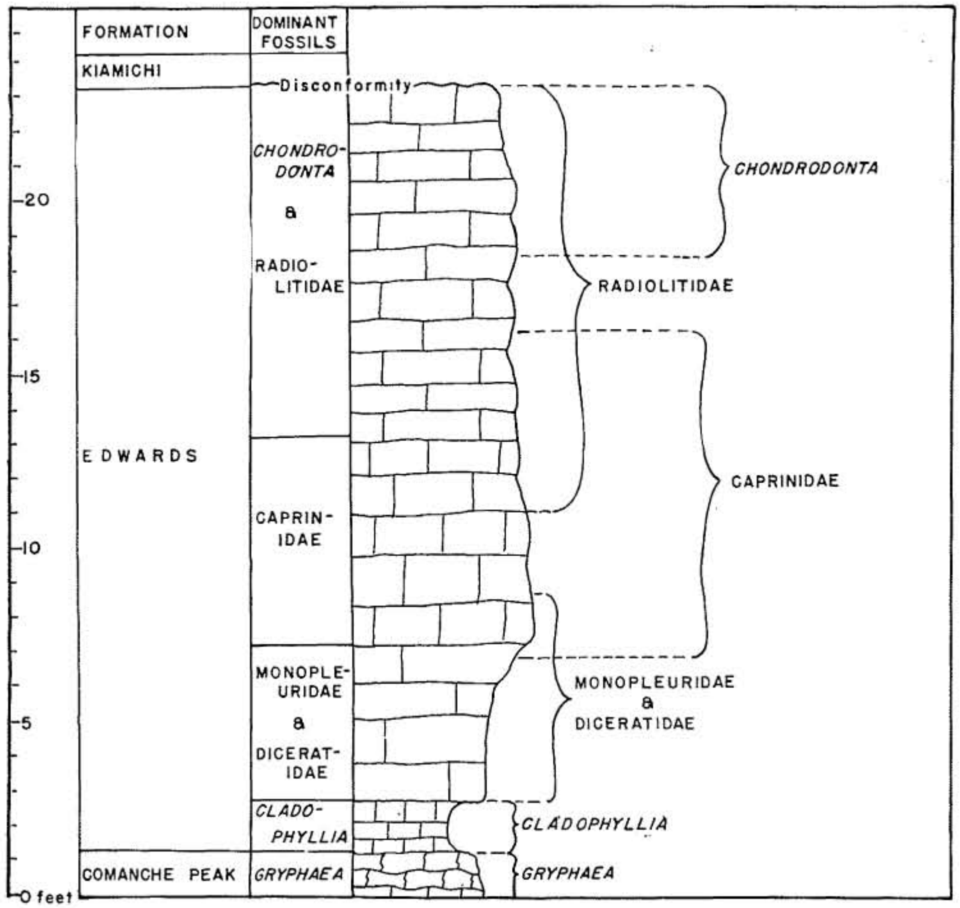

FIG. 20. Diagrammatic section near section 109-T-14 (fig. 19) showing dominant zones and ranges of the fossils. A single fossil observation outside of the range was regarded as not significant.

upper part of the zone which bears its name. This last observation is at variance with Mathews (1956), but we have yet to study in the same area.

Changes do occur in the section toward Blum, eastward (in Hill County). To the west in Bosque County the section has been mostly removed by erosion; in figure 21 a section from southern Johnson County has been projected to the line of cross section and may represent the changes which occur in a westerly or southwesterly direction.

Eastward, toward Blum, the *Cladophyl-*

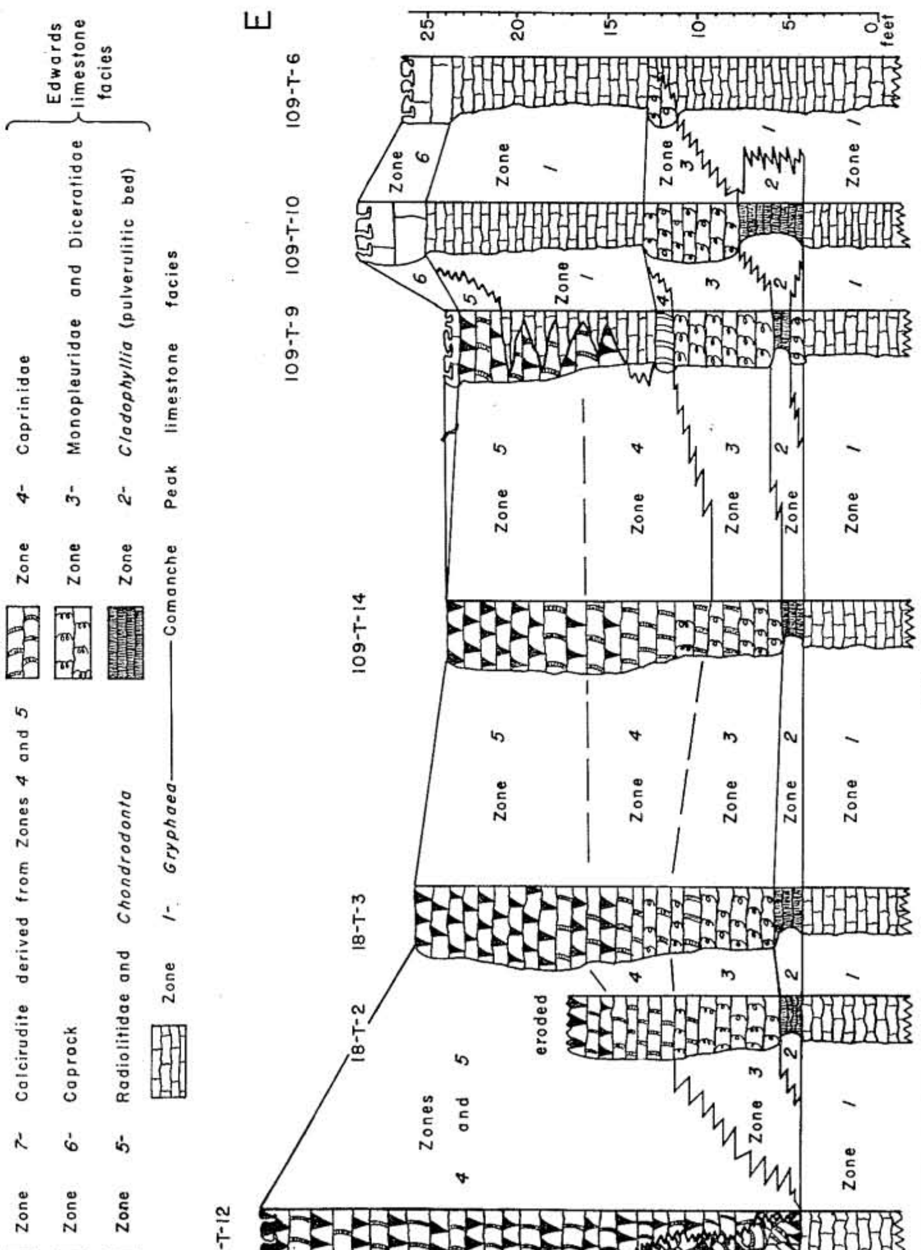

FIG. 21. Diagram showing relationship of sections of Edwards tabular reef from localities shown on figure 19. The areas between sections 109-T-9, 109-T-10, and 109-T-6 were walked out bed-by-bed and these relations are reasonably accurate. Because of topography and brush cover, the left-hand side of the diagram is partly assumed.

lia zone (zone 2) is persistent for some distance, and the Monopleuridae-Diceratidae zone (zone 3) increases in thickness. In a distance of about half a mile up Rock Creek from its mouth at Nolan's River, zone 3 gradually changes to zone 1 (Edwards limestone facies changes to Comanche Peak limestone facies). The top of zone 3 in this area is the last bedding plane of definite Edwards limestone that can be walked out into the Comanche Peak facies. Zones 4 and 5 change to zone 1 along Rock Creek between the mouth of Rock Creek and 3/16 mile upstream. This likewise is easily observed and walked out on the outcrop. In this area the Edwards limestone facies seems to have added an afterthought, the caprock (zone 6). This zone does not occur at the top of the Edwards facies farther west nor does it occur at the top of the Comanche Peak (Goodland) facies where this facies directly underlies the Kiamichi formation, a few hundred yards east, or in the town limits of Blum.

The southwestern Johnson County section illustrates that west from Kimball Bend the *Cladophyllia* and *Monopleura*-Diceratidae zones (zones 2 and 3) can be expected to be replaced by a mixture of zones 4 and 5 (zones of Caprinidae and Radiolitidae and *Chondrodonta*). Here zones 4 and 5 are not differentiated. In this area also were observed the only good examples of lithology (3) (zone 7). Here is an exposure which quite definitely illustrates the growth of zones 4 and 5 out over the calciluditic rock (zone 7), the latter having been eroded from previous growth of zones 4 and 5 and consisting of all sizes of unoriented fragments of *Eoradiolites* and *Caprinuloidea*.

General morphology. — The zonation might just as well be in morphologic terms as in taxonomic terms provided more definite terms existed; the morphologic terms are too relative to be practical for a zonation. The individuals of *Gryphaea* in zone 1 (Comanche Peak limestone facies) are isolated, scattered, and not in banks. For this reason they do not form the solid structure which the intertwining, rambling, colonial hexacorals of the *Cladophyllia* zone build. An individual coral of *Cladophyllia* is not as robust as an individual *Gryphaea*, but woven together in a bed they form a fairly solid framework compared to the scattered *Gryphaea* of zone 1. *Monopleura* and *Toucasia* make up the framework of zone 3. These are medium-thick-shelled pelecypods in which the spats were attached to the growing adults; thus a continual framework could be developed which is stronger than the *Cladophyllia* of zone 3. *Caprinuloidea* is another sessile, "coral-like" pelecypod with a very thick shell which appears to have a vesicular structure in cross section but which is actually a structure of many elongate open canals, usually filled with lithified lime mud in the fossils. The shell wall may be up to three-fourths inch thick. These individuals then are even more robust than the individuals of *Toucasia* and *Monopleura*; they would seem to have been strong enough to withstand wave action. *Eoradiolites* possesses a shell of the same maximum thickness as *Caprinuloidea*, but the entire animal is more massive and sturdier. The shell is denser and less porous. *Chondrodonta* is unlike the associated pelecypods in that it is ostreiform in habit and appearance but according to Dechaseaux (1952) is a specialized offshoot of the Mytilaceae. It occurs in the Kimball Bend region only in the upper part of the Edwards limestone, being abundant in the upper one-half to two-thirds of zone 5.

Relations of gross lithology to fossils.— The restriction of the genus *Gryphaea* (zone 1) to the Comanche Peak limestone facies has already been described. The Edwards limestone facies generally starts at the bottom with the *Cladophyllia* biostrom (zone 2) consisting of a pulverulitic bed which is in part a solution-redeposition phenomenon. The outward appearance of this bed is the result of vadose water percolating downward and encountering the less permeable Comanche Peak limestone. The water then flows laterally through this bed (zone 2) above the Edwards—Comanche Peak interface.

Zones 3, 4, and 5 consist typically of a tan, massive, phaneric Edwards-type limestone of the tabular reef facies. Zone 3 weathers slightly more readily than do zones 4 and 5 in the Kimball Bend area. The differences in zones 3, 4, and 5 are primarily the differences in weathering of selected surfaces of the rock (e.g., Bonet, 1952, figs. 10, 16, 34 are typical of zone 3 and figs. 14, 15, 18, 38 are typical of zones 4 and 5). On the rock surfaces these appear as differences of shell structure and as differences in gross shape of the unoriented sections of the animals. The diceratids and monopleurids have a typical molluscan shell structure consisting of overlapping lamellae of prisms of the prismatic layer (Pl. 32, figs. 3, 6, 9, 10). *Caprinuloidea* and some relatives have a pseudocellular structure which consists of many elongate tubes of many sizes. These were usually filled with mud when the animal died. In transverse section the tubes are circular or oval in section, whereas in *Eoradiolites, Durania*, and other Radiolitidae the cells are box-shaped (Pl. 32, figs. 1, 2, 8) and filled, forming a solid structure rather than a vesicular structure. In the Radiolitidae the spaces formed by the vertical and transverse partitions are usually filled each with several crystals of sparry calcite.

Zone 7 has been observed only in large amounts as debris from zones 4 and 5, but calcirudite of mixed or other nature is certainly possible, although it appears that only fossils of zones 4 and 5 grew in the zone of really active wave erosion. This may also account for the absence of nerineid-type gastropods in zone 5—the waters were too rough.

Possible depositional interpretation.—The area represented by the line of section (fig. 21) probably represents a single tabular reef mass. To the east is the leeward side with the gradation to fine carbonate sediment (e.g., Comanche Peak facies) and with the less robust animals of zones 1 and 3 extending higher in the reef. To the west (e.g., supposed windward side) the more robust animals of zones 4 and 5 replace the less robust animals of zones 2 and 3 in the lower part of the reef, and the only large amount of calcirudite (zone 7) occurs in this side of the reef.

Walls (1950) reported and photographed in the calcarenite of the Coniacian part of the Austin chalk of Williamson County, especially along Mansky Branch, cut-and-fill channels about 150 to 200 feet wide, all trending about N. 30° E. In the Glen Rose formation in Hays County, the writer has observed the positions of numerous of the small shells of the Pelecypoda in the *Corbula martinae* bed (this is the key rock of Whitney; see Scott, 1940). The average shell alignment of a sample studied in Hays County is between N. 25° E. and N. 35° E. The small ends of the pelecypods are to the northeast, indicating current direction from the southwest. The currents thus indicated by Austin chalk and Glen Rose limestone depositional features agree roughly with the back-reef—fore-reef areas of Edwards limestone deposition in Hill County.

Ecologic interpretation of the fossils.—None of the genera used for zonation in this report is extant. All of the forms except the Radiolitidae (Rudistaceae) have living relatives at the superfamily level (Chamaceae) in the modern genus *Chama. Chama* is the form which is most closely related to the pelecypods of zone 3. The habitats of the recent species of *Chama* are incompletely documented (Ricketts and Calvin, 1952). Pacific coast species are known to occupy rocky coasts so high as to occur between mean low tide and mean low spring tide. Few living sessile marine pelecypods thrive this high. The morphology of the Cretaceous fossils of zones 4 and 5 indicates that these robust animals might have been able to compete as high as mean low tide in fairly rough seas, and the relations of the reef mass (zones 4 and 5) to the calciruditic zone 7 suggest that animals of zones 4 and 5 were competing with wave-eroding agents during their growth.

Chondrodonta (a pernid) is a maverick to its group. If the Chamaceae in the Edwards limestone had a habitat at all similar to their near relatives (*Inoceramus*), then *Chondrodonta* should not be a brackish-water form as interpreted by Mathews (1951) on its shape and ostreiform habit; all of these animals in the high-energy zone must be tolerant of euryhaline conditions. *Chondrodonta* was adapted to the more rugged zoogene environment, lying flat and attached to areas on which also were growing the elongated coral-shaped rudistids. This euryhaline environment requires animals with a high tolerance of oxygen.

The *Cladophyllia* (coral) bed is not understood. The only explanation at this time is that a mat of these small, ramose, scleractinid corals introduced the reef environment in this area. Some such environment and mat may have been necessary before the pelecypod spats could attach and grow successfully.

Zone 6 is a caprock which is restricted to the lee side of the reef. It is only from 1½ to 3 feet thick. It is coquinal calcarenite and has been bored by some marine animals, probably boring pelecypods. It seems to have been an afterthought at the end of reef deposition, deposited in a quiescent area, perhaps while the main part of the reef mass to the southwest was undergoing pre-Kiamichi erosion. The duration of the Edwards-Kiamichi break is of course unknown, but by modern standards, if the borings are molluscan, to reach the stage of the life cycle indicated by these holes would require several months after lithification and prior to Kiamichi clay deposition.

Conclusions.—The interpretation of available evidence indicates that the Edwards limestone of northern Hill and Bosque counties has a zonation of fossils that can be interpreted as depth adaptation of the animals. The top of the reef mass may have been at or near mean low spring tide.

How far such an interpretation can be carried from the Kimball Bend area of Hill County is uncertain. That the sea was this shallow in every area of Pachyodonta reef deposition and at every horizon of such reef deposition might require too many changes of sea level; hence other interpreations may also be necessary. It seems improbable that Caprinidae-Rudistidae growth associated with calcirudite deposition ever occurred except in extremely shallow water.

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A Stratigraphic Study of the Kiamichi Formation in Central Texas[4]

ORVILLE B. SHELBURNE[5]

ABSTRACT

Twenty stratigraphic sections of the Lower Cretaceous Kiamichi formation were measured and described from surface exposures in the southern Fort Worth Prairie in Hill, Bosque, Coryell, McLennan, and Bell counties, Texas.

The Kiamichi formation is composed of silty shale, nodular limestone, calcareous clay, and *Gryphaea* beds. The Kiamichi shale is the uppermost formation in the Fredericksburg group and is enclosed by the Edwards limestone below and the Georgetown limestone above. The Kiamichi is 25 feet thick near Blum in Hill County. It thins southward along the outcrop and disappears in southern McLennan County.

Corrosion, pitting, and burrowing, and presence of an iron oxide zone at the top of the Edwards formation indicate that the Edwards-Kiamichi contact in unconformable. The characteristic megafossils of southern outcrops, where the Kiamichi is thin, are *Gryphaea navia, Exogyra plexa,* and *Heteraster adkinsi.* This fauna is characteristic of the upper Kiamichi of northern outcrops, where the formation is thick. The lower part of thick sections of the Kiamichi is characterized by *Gryphaea mucronata, Exogyra texana,* and *Cyprimeria texana.* This distribution suggests that the formation thins from the bottom and that it onlaps the unconformable surface at the top of the Edwards limestone affecting regional thinning to the south.

Local variations in thickness of the Kiamichi are a result of the topography at the top of the underlying Edwards formation during Kiamichi time. Thinner and more calcareous sediments were deposited over the topographically high reef facies of the Edwards limestone.

INTRODUCTION

The Lower Cretaceous (Comanchean) rocks of Texas are mainly limestone, marls, shales, and sands of shallow-water origin. The Comanche series is divided into three groups; from bottom to top they are the Trinity, Fredericksburg, and Washita. The Fredericksburg group is characterized by several lithologic facies owing to the variety of depositional environments that existed during Fredericksburg time. Use of facies terms rather than formational divisions has been proposed for this group (Adkins, 1933; Thompson, 1935), but the formations recognized are, in ascending order, the Paluxy sandstone, Walnut clay, Comanche Peak limestone, Edwards limestone, and Kiamichi clay. Surface and subsurface work by Lozo (1949) demonstrated that the Paluxy sandstone is the lowermost formation of the Fredericksburg group rather than the uppermost formation of the underlying Trinity group as it is usually classified. The Kiamichi consists of marls with thin limestone seams and shell aggregates. The stratigraphic relationships and group assignment of this formation are controversial, and the writer undertook a field study of the Kiamichi of central Texas in an effort to resolve some of these problems.

Nature of problem and purpose of study.—The thickness of the Kiamichi decreases southward. Central Texas is a critical pinch-out area where the formation thins from 25 feet in the north and is absent in the south. The purpose of this study was to determine the nature of the

[4] Modified from thesis submitted in partial fulfillment of the requirements for Master of Science degree at The University of Wisconsin.

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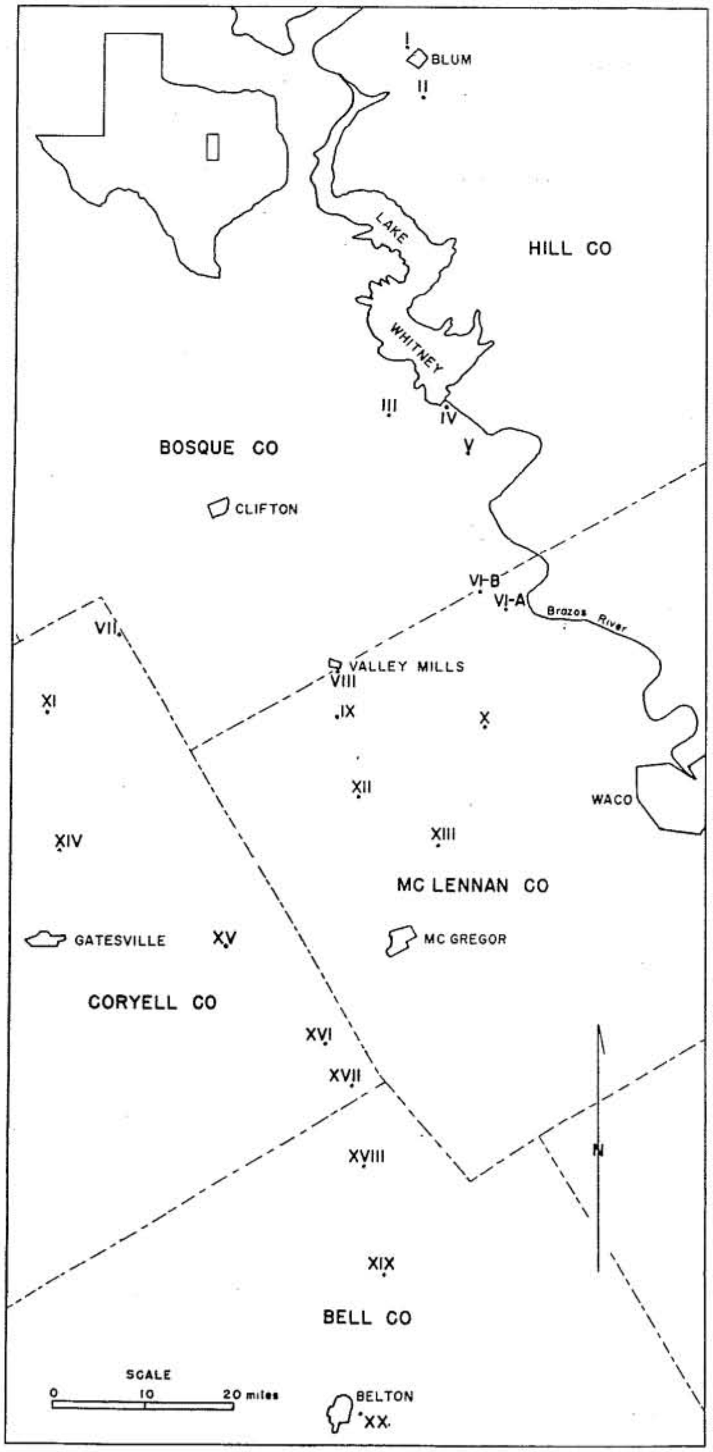

Fig. 22. Stratigraphic section location map.

thinning, to ascertain the agency which produced the thinning, and to resolve the general stratigraphic relations in central Texas. The writer proposed to obtain these goals by a field study of the stratigraphy with consideration of the processes which might control thickness of the formation. Near Goodland, Choctaw County, Oklahoma, Hill (1901) reported a thickness of 150 feet for the Kiamichi. On the Red River west of Denison, Texas, it is approximately 40 feet thick, decreasing southward in Texas to 27 feet near Fort Worth and to 11 feet at Whitney Dam and finally disappearing south of Waco near the southern tip of McLennan County. Winton (1925) ascribed this southward thinning to replacement of the shales of the Kiamichi away from the shore line by the limestones of the Edwards formation. Thompson (1935) attributed the thinning to differential uplift during a post-Kiamichi, pre-Washita erosional interval. The writer has attempted to solve this problem by means of stratigraphic studies in central Texas.

Location of the area.—The area investigated is the southern Fort Worth Prairie of central Texas (fig. 22). This study is concerned with that part of the Fort Worth Prairie which lies south of Blum, Hill County, and north of Belton, Bell County; this includes parts of Hill, Bosque, Coryell, McLennan, and Bell counties. The Fort Worth Prairie is the westernmost subdivision of the Grand Prairie and is underlain mainly by the limestones of the Washita group. The Walnut Prairie subdivision of the Lampasas Cut Plain lies west of the Fort Worth Prairie in central Texas and is underlain by the soft marls of the Walnut formation of the Fredericksburg group.

Previous work.—Outcrops of the Kiamichi in north and west Texas have been studied, but the Kiamichi as a specific object of study is relatively untouched in central Texas. Hill (1901) produced a monumental work on the "Geography and Geology of the Black and Grand Prairies of Texas," which included a detailed description of the outcropping Cretaceous formations. Hill described exposures of the Kiamichi south of Brazos River in Bosque County. Adkins (1923) described exposures of the Kiamichi in his report on the geology of McLennan County. Later Adkins (Adkins and Arick, 1930) mentioned the Kiamichi in his discussion of the Fredericksburg-Washita contact in the "Geology and mineral resources of Bell County." In a study of the Fredericksburg group, Thompson (1935) measured and described stratigraphic sections from Red River to Colorado River. Three of Thompson's sections are located in Coryell County and lie within the area of this study. In a report on the geology of the Whitney reservoir area of Brazos River in Bosque and Hill counties, Hull (1951) described surface and subsurface exposures of the Kiamichi of that area.

Field and laboratory procedure.—In the summer of 1955 the writer studied and measured 20 stratigraphic sections of the Kiamichi formation in central Texas. These sections were measured vertically with a carpenter's rule and an eye-level. The lithology of each unit was described directly in the field with the aid of a hand lens. The faunal content of each unit was described in the field and megafossils were collected for later identification and comparison in the laboratory. The lithology and faunal content of each stratigraphic section was plotted to facilitate comparison with other sections.

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STRATIGRAPHY

History of Nomenclature

In central Texas the Kiamichi formation is a calcareous shale alternating with thin stringers of wavy-bedded limestone. It lies between two resistant limestone units, the Edwards limestone below and the Duck Creek member of the Georgetown formation above. The classification most generally accepted at present refers the Kiamichi to the uppermost formation of the Fredericksburg group of Lower Cretaceous (Comanchean) age. The formation was first called "Kiamitia Clays" by Hill (1891). The present spelling is the result of action by the Board of Geographic Names. The type locality is the plains of Kiamichi River near Fort Towson, eastern Choctaw County, Oklahoma. The proper classification of the Kiamichi formation has been controversial. Hill classed the Kiamichi as basal Washita when he proposed the name "Kiamitia Clays" in 1891. In a report on the Cretaceous rocks north of Colorado River, Taff (1892) disagreed with Hill and referred the Kiamichi to the top of the Fredericksburg group. Taff based his assignment on the occurrence of Fredericksburg forms such as *Oxytropidoceras* and *Exogyra texana* in the Kiamichi. In 1901 Hill recognized Taff's assignment but defended his original definition of the Kiamichi as the basal member of the Washita group. He stated that the Kiamichi clearly belonged in the Washita group on lithologic grounds and although it contained some conspicuous Fredericksburg fossils, it also contained the initiatory species of the Washita faunas. Hill's usage was generally adopted but caused much confusion in the marginal areas of outcrop. Later Adkins (1927) in a report on the geology of the Fort Stockton quadrangle returned to Taff's definition, which placed the Kiamichi in the Fredericksburg group. Adkins' views were supported by S. A. Thompson and others; however, a correlation chart of the Cretaceous formations (Stephenson et al., 1942) retained the Kiamichi in the Washita. More recently, the United States Geological Survey has adopted the Fredericksburg classification of the Kiamichi (Imlay, 1944).

Areal Distribution and Correlation

The Kiamichi crops out in north-central Texas, southeastern and western Oklahoma, southeastern Arkansas, Trans-Pecos Texas, the Llano Estacado, and the Panhandle. The easternmost outcrop of the Kiamichi is at Cerrogordo, Arkansas; its westernmost outcrop in Texas is near El Paso. This is a large lateral extent of a relatively thin formation. The Kiamichi has been correlated with the Kiowa shale of southern Kansas (Bullard, 1928) and may be analogous to part of the Tucumcari shale member of the Purgatoire formation in southeastern New Mexico (Brand, 1953). Possible equivalents also occur in central Kansas, Colorado, northeastern New Mexico, and eastern Mexico. In the subsurface the Kiamichi is usually recognized near the outcrop and also in east and south Texas. In east Texas the subsurface Kiamichi is mainly a black shale which becomes more calcareous to the east and south. It thins southward on the flanks of the San Marcos arch and disappears in Burleson County (Imlay, 1944).

Outcrops in central Texas.—The Kiamichi crops out in a narrow tortuous belt on the boundary between the Fort Worth Prairie and the Lampasas Cut Plain. Streams cut through the Georgetown formation to expose the underlying Kiamichi within the Fort Worth Prairie. Isolated erosional remnants of the Kiamichi formation occur within the Lampasas Cut Plain. The Kiamichi is relatively soft and erodes rapidly at the outcrop. It is enclosed between resistant limestones above and below and therefore forms a receding zone. Good exposures are limited to vertical outcrops such as road cuts and stream banks. Most streams flow down the regional dip at an angle less than the dip; therefore, outcrop patterns "vee" downstream, and the streams flow over progressively younger formations. Some smaller streams and headwaters of larger streams maintain a gradient which exceeds the dip of the beds. Near Turnersville in Coryell County, the Middle Bosque with a steep gradient cuts through the Kiamichi and descends into the Edwards. Farther downstream it enters the underlying Comanche Peak limestone. As the gradient decreases, the stream climbs the stratigraphic column, and the Kiamichi is again exposed near Windsor more than 20 miles downstream from Turnersville. The best exposures of the Kiamichi are usually in the banks of streams at the point where the Edwards-Kiamichi contact is at water level. Because the soft shales of the formation are rapidly removed from the stream bed, a consequent stream which crosses the Edwards-Kiamichi contact tends to flow upon the top of the Edwards for long distances. The Kiamichi is exposed in the banks with the Edwards in the stream bed for more than 5 miles above the mouth of Childress Creek. A similar situation was observed in the banks of Middle Bosque River near Windsor.

Upland exposures of the formation are rare, but a few were seen along the upper margin of stream valleys. The contact of the Edwards and Kiamichi is usually marked by a large bench caused by the rapid erosion of soft shale overlying resistant limestone. The Kiamichi slopes gently back from this bench and is usually concealed by overwash. Attempts to reveal these outcrops by removal of the overwash were not successful.

Outcrops of the Edwards limestone usually have a larger growth of trees than the overlying Kiamichi and Georgetown outcrops. If the approximate outcrop area of the Kiamichi is known, it can be rather precisely located by examination of the distribution of trees. This may be accomplished by aerial photographs or the recent photogrammetric map of the Waco area prepared by the United States Geological Survey. The Edwards is the controlling factor in the determination of locations of the Kiamichi based on the distribution of trees. The Kiamichi is found only because it lies at the margin of the Edwards outcrop, and the Edwards-Georgetown contact can be determined in Bell County where the Kiamichi is absent.

Structure

The Lower Cretaceous rocks dip uniformly toward the east at small angles. Surface exposures of the Kiamichi in central Texas dip south of east at a rate of 20 to 50 feet per mile. At Whitney Dam the formation strikes N. 10° E. and dips to the east at 24 feet to the mile (Hull, 1951). Local variation in dip is due to domical reef structure in the underlying Edwards limestone and usually is the only structure apparent in outcrops.

Lithology

The Kiamichi is composed of silty and calcareous shales, calcareous clay, and thin wavy-bedded and nodular limestones. Color varies from dark gray to light yellow depending on the degree of weathering. The lithology gradually changes from the bottom to the top, but three general lithologic divisions are usually recognized in outcrops. In ascending order they are silty shale, limestone, and calcareous clay. The clastics become finer grained and more calcareous from the base upward. Relatively non-calcareous silty shale and siltstone in the lower part grade into calcareous clay in the upper part of the formation. The shales are composed of silt-size quartz poorly cemented with calcium carbonate. Sand-size crystals of selenite are often abundantly disseminated throughout the shale and occur along fractures in the calcareous clay. Limestones are more abundant in the upper portion where they occur as wavy-bedded layers 1 to 2 feet thick with small shaly partings. In the lower silty shale, thin limestone stringers 2 to 4 inches thick are common. A calcareous clay is usually found at the top of the Kiamichi. This clay contains macerated oyster shells which are scattered throughout the unit and also occur in thin laminae of shell debris. The bed is usually 1 to 2 feet in thickness, although near Valley Mills a thickness of 6 feet was measured. This unit is well developed in McLennan County, and a typical exposure is located in the road cut north of the town of Crawford.

Stratigraphic contacts.—Both the upper and lower boundaries of the Kiamichi are sharp and easily determined. The lower contact is unconformable and very sharp with silty shale of the Kiamichi directly overlying dense limestone of the Edwards. The contact is almost always characterized by a rust color, which is the result of oxidation of iron at the top of the Edwards and does not affect the color of the Kiamichi. Pebble-size concretions of marcasite occur in the porous tops of rudistid reefs in the Edwards. The top of inter-reef limestones contain irregular masses of marcasite and iron-stained worm burrows. Although the character of this iron-stained surface changes with variations in the lithology of the Edwards limestones, it is persistent and may be recognized throughout central Texas. At Blum in Hill County this zone is marked by iron-stained fucoids an inch in diameter. Southward it contains marcasite concretions and iron stains into northern Bell County where the Kiamichi is absent. This iron-stained surface was also observed at the type locality of the Kiamichi formation near Fort Towson, Oklahoma.

The contact of the Kiamichi with the overlying Georgetown formation is sharp. It usually involves the contact of calcareous clay and dense limestone. Often a thin bed of shell debris 1 to 3 inches marks the contact. This debris is composed of poorly cemented fragments of oyster shells and with increasing cementation grades into the overlying limestone. These local concentrations of shell fragments probably represent a decrease in the amount of clay being deposited which preceded the deposition of the overlying limestone.

Bedding.—Stratification in the Kiamichi is thin and wavy. Individual beds range from 1 to 18 inches in thickness and are usually about 6 inches thick. Vertical variations in bedding correspond to the three lithologic divisions of silty shale, wavy-bedded limestone, and clay. The dark shales are fissile and often form units up to 18 inches thick which may be divided by thin stringers of limestone. The bedding units of the wavy limestones are usually about 6 inches thick and are separated by thin marly partings. These partings curve uniformly, producing a wavy bedding or vary in thickness, producing a nodular type of bedding. With an increasing thickness of marl, wavy limestone may grade into a nodular limestone or even into a marl containing isolated lens-shaped nodules of limestone. The calcareous clay division contains thin beds of nodular limestone and light-colored laminae of high calcium carbonate content. Although lithologic zones may be followed for great distances, the individual beds are not continuous, and rapid lensing occurs adjacent to reef structures in the Edwards.

Attempts at detailed correlation of closely adjacent exposures is usually futile. Small receding or projecting zones may be correlated in exposures 1 to 2 miles apart even though the type of bedding within the zone has changed. The Kiamichi is affected by a facies change in the underlying Edwards limestone; therefore, the difficulty of correlation is proportional to the distance between exposures and the rate of facies change. Exposures a mile or more apart may be closely correlated, but exposures 50 yards apart are difficult to correlate if one lies over a reef and the other lies over an inter-reef facies.

Shell beds.—Interesting accumulations of shells were observed in many outcrops and are of two general types: *Gryphaea* beds and shell debris. The *Gryphaea* beds are commonly about 6 inches thick and are composed almost entirely of unbroken shells of the oyster genus *Gryphaea*. *Exogyra texana* and *Cyprimeria texana* are also found in these beds but they are rare. The shells commonly occur in a matrix of dark shale; however, they may form a coquinoid limestone in places. *Gryphaea* beds were observed in the railroad cut near Valley Mills and in outcrops north of that place near Whitney Dam and Blum. They are limited to the lower part of the formation and are associated with the lower silty shale. These beds were found only in the thicker sections of the Kiamichi (over 12 feet) and usually overlie inter-reef facies of the Edwards. In a road cut west of Whitney Dam, a prominent *Gryphaea* bed lies a foot above inter-reef limestones of the Edwards. In a quarry 100 yards south of the road cut where the Kiamichi thins over a rudistid reef, this bed is represented by a thin zone of abundant *Gryphaea* at the top of the reef.

Limestone pebbles are associated with a *Gryphaea* bed exposed in the railroad cut near Valley Mills. These pebbles are rounded and irregularly tabular in shape with maximum dimensions of about 3 inches. The entire surface of the pebbles is highly etched, and sand grains fill depressions in the top. The pebbles are composed of sublithographic limestone which is penetrated by burrows filled with crystalline calcite. The limestone contains abundant miliolid-type foraminifera which commonly occur in the Edwards. Pebbles are found where the Kiamichi is locally thick and become absent as it thins toward an adjacent reef. The pebbles occur within a *Gryphaea* bed and in an underlying silty shale and argillaceous limestone. The *Gryphaea* bed and silty shale are separated by a thin limestone in the thicker parts of the formation but are in contact in thinner parts. The writer believes the pebbles were derived from adjacent topographically higher reef flank limestones of the Edwards during times of high current activity.

At favorable times during the deposition of the Kiamichi, gryphaeas were common on the muddy bottom and after death their shells were washed to lower parts of the bottom by currents. The relief of the depositional interface roughly corresponded to the relief of the underlying Edwards; therefore, shells were washed from above reef structures to be concentrated above inter-reef areas. Association of limestone pebbles and coquina suggests that they both were affected by the depositional slope and current action. This association may seem to suggest an erosional origin for the *Gryphaea* beds, but it is noted that an unfossiliferous shale also contained these pebbles. Although some erosion undoubtedly occurred, the writer does not believe the *Gryphaea* beds were produced by erosional concentration of large amounts of sparsely fossiliferous strata.

Shell debris is composed of macerated oyster shells. These beds vary from resistant limestones 2 inches thick to uncemented shell laminae a fraction of an inch in thickness. Thin laminae are often red due to oxidation of iron. Shell debris with an argillaceous limestone matrix is usually casehardened in weathered outcrops. These resistant beds show a violet color on freshly broken surfaces and also contain small cubes of pyrite. This shell debris was probably formed during periods of slow deposition of clay. Some may have been formed by current action which caused by-passing of finer clastics and winnowing of previously deposited material. Shell debris occurs throughout the Kiamichi but is most common in the upper portion.

Effects of weathering.—The silty shales and clays of the Kiamichi are poorly indurated and will disintegrate in two or three minutes upon being wetted after drying. This lack of lithification causes rapid erosion at outcrops. The most striking feature produced by weathering of the formation is a color change from black to yellow. Silty shales and clays are dark gray to black in fresh exposures. Lighter shades of gray are common in highly calcareous shales. Unweathered limestones are light gray to gray depending on the amount of argillaceous material which they contain. Fresh exposures of the Kiamichi are rare and are limited to the banks of major streams and deep road cuts. Most exposures are quite different in color from the grays mentioned above. The shales and clays are buff to orange yellow due to the oxidation of contained iron. The limestones are dull white to light buff in color.

Weathering tends to destroy bedding of the formation. A prominent limestone bed in a moderately weathered zone may grade into a disseminated chalky layer in a highly weathered zone. Interbedded limestone and clay may have the appearance of marl after intensive weathering. The effects of weathering extend deep into the exposures, and unaltered material is usually not revealed by removal of a foot or two of weathered material. Highly weathered exposures which are within a few feet from the ground surface often show a buff and white color combination. This coloring is due to the presence of white specks of calcium carbonate which was concentrated by the weathering process. Locally, the specks increase in size and induration, resulting in calcite concretions.

Thickness

Distribution.—The thickest stratigraphic sections in the area studied by the writer were found in northern outcrops near Blum in Hill County. Two measured sections in that area revealed thicknesses of 25 and 23 feet. The character of the Kiamichi at Blum is frequently described as a yellowish clay 19 feet thick, but the writer did not observe this exposure. North of Blum in Johnson County the Kiamichi is reported to be 18 feet thick (Winton and Scott, 1922, p. 22). South of Blum in the vicinity of Whitney Dam in Bosque County, the formation varies from 10 to 14 feet in thickness. Southward in McLennan County the outcrops average about 7 feet. The thickest exposure is 15 feet near Valley Mills, and the southernmost exposure in the county is a 3-foot section in the bed of Middle Bosque River.

Outcrops of the Kiamichi formation in Coryell County display a large range in thickness. This is caused by a long distance of outcrop (30 miles) which is approximately parallel to the direction of thinning and by the presence of an abnormally thick stratigraphic section in the northern tip of the county. The writer has studied this section and assigns it a thickness of 20 feet, but Thompson (1935, p. 1524) recorded a thickness of 25 feet for a similar exposure. This discrepancy may be due to a difference in assignment of the Edwards-Kiamichi contact, which is of an unusual nature at this locality. Above thin-bedded Edwards limestones is 3 feet of buff shale, and resting on this shale is a 1-foot bed of sublithographic limestone. This limestone has an iron-stained upper surface and contains abundant miliolid foraminifera. Thompson probably referred the contact to the top of the thin-bedded limestones, but the writer referred the contact to the top of the sublithographic limestone. The writer realizes that this assignment refers a considerable thickness of shale to the Edwards formation, but the lithology, thickness, iron stain, and fauna of the limestone bed indicate an Edwards affinity.

The southernmost outcrop of the Kiamichi in central Texas is on Horse Creek near Whitson in the eastern tip of Coryell County. At this locality the formation is composed of 15 inches of buff shale. The thinnest exposure of the formation is northwest of Horse Creek at Eagle Springs. The Kiamichi here is 8 inches of marl which lies at the contact of the Edwards and the Duck Creek. This thin marl was assigned to the Kiamichi because it contains the Kiamichi variety of *Kingena wacoensis*.

Isopach map.—Data obtained from the measurement of 20 complete stratigraphic sections was used in constructing a map (fig. 23). A smooth sigmoid pattern indicating a general trend of thinning to the southeast resulted. The rate of thinning is usually one-half to 1 foot per mile, but it decreases as the zero isopach is approached and is less than half a foot per mile south of the 8-foot isopach line. A uniform rate of thinning is indicated by the smoothness and spacing of the isopach lines. Local and rapid variations in thickness occur adjacent to reef structures in the underlying Edwards. Usually these thickness changes are not of sufficient magnitude to change the general pattern of the isopach lines; however, an abnormally thick section of the Kiamichi exposed near Valley Mills (Stratigraphic Section VIII) causes a change of trend in that area. This local thickening is due to the position of the Kiamichi which is over a thin inter-

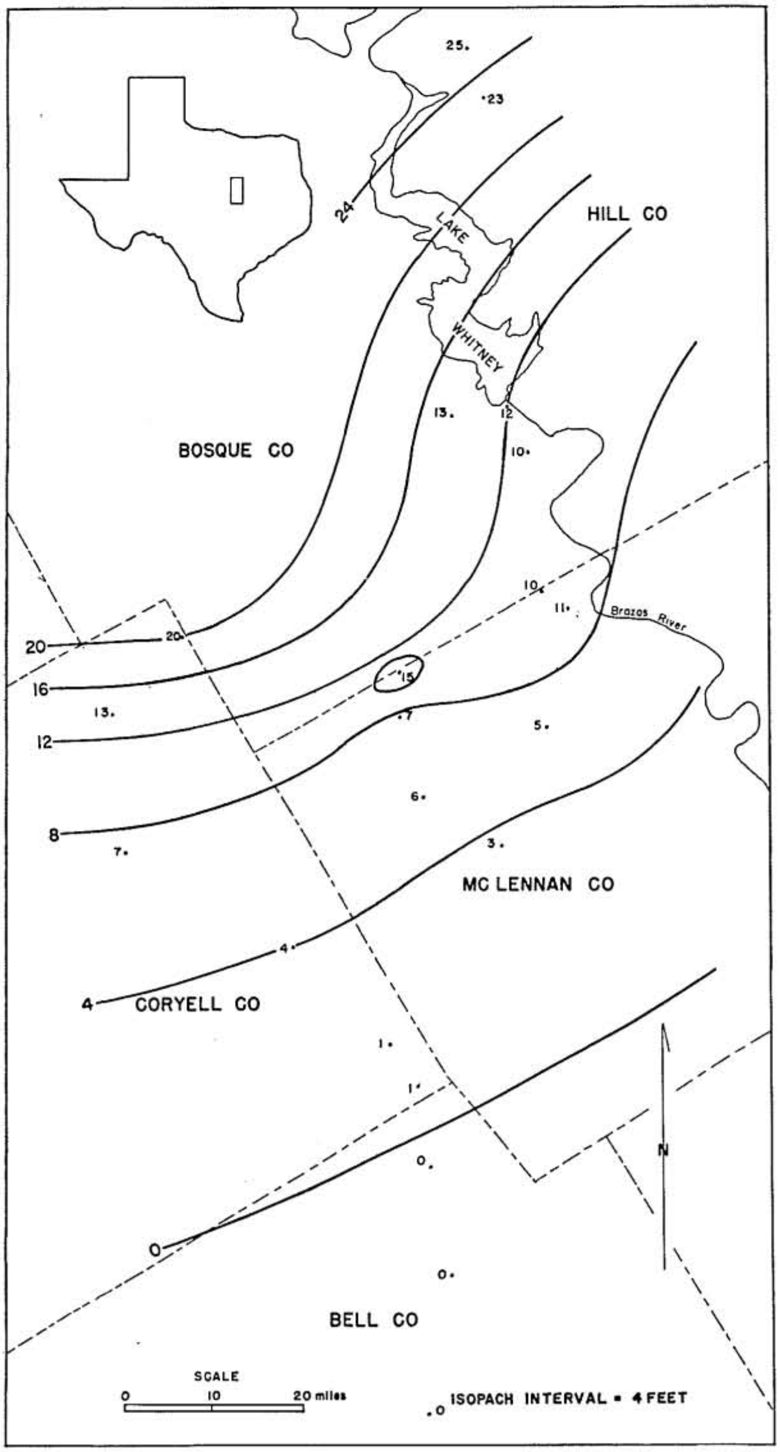

FIG. 23. Isopach map of the Kiamichi formation.

reef facies of the Edwards. At localities in which the formation lies above the reef facies and an adjacent exposure lies above an inter-reef facies, the two thickness measurements obtained are averaged.

Relation to adjacent formations.—Perhaps the most significant result of this study is a recognition of the detailed relationship of the Kiamichi to the Edwards formation. The regional thickness changes in the Kiamichi are the reverse of those in the Edwards. This relationship has been known by geologists for 60 years. An example will acquaint the reader with the dimensions of these thickness changes. In Tarrant County, Winton and Adkins (1920) recorded a thickness of 16 feet for the Edwards and 27 feet for the Kiamichi. Southward the Edwards thickens and the Kiamichi thins until in Bell County the Edwards is 55 feet thick (Adkins and Arick, 1930) and the Kiamichi is absent.

Local thickness changes in the Kiamichi also are the reverse of those in the Edwards. This relation is excellently displayed in central Texas due to the abundance of reef structures in the Edwards which cause local thickening of the Edwards and thinning of the overlying Kiamichi. Local variation in thickness has been observed in north Texas. Bybee and Bullard (1927, p. 23) stated: "Another point that has been noted, although its significance is not clearly understood, is that in the southern part of the county [Cooke] where the Goodland limestone is greatly increased in thickness the Kiamichi clay is relatively thin."

In central Texas, small but rapid thickness changes are superimposed upon the regional thinning. These changes are related to facies change in the underlying Edwards formation. During Kiamichi time the depositional interface maintained a topography which corresponded to the topography at the top of the Edwards formation. The Kiamichi was deposited on a gently rolling surface on which the reefs rose as highs and the inter-reef areas were topographic lows. The relief of the bottom affected the thickness and type of sediment being deposited throughout Kiamichi time, although the effects were less pronounced in the upper Kiamichi due to filling of the inter-reef areas. Small differences in elevation may control sedimentation, and at the present time in the Gulf of Mexico a change of 1 foot in elevation of the bottom may cause a change in the type of sediment being deposited (H. F. Nelson, oral communication, 1955). Exposures of the Kiamichi which lie above reefs are characterized by a thin stratigraphic section, thick limestone units, thin shale units, and thin *Gryphaea* beds. A change from reef to inter-reef areas with consequent change of character of the Kiamichi may occur within 100 yards; in a railroad cut near Valley Mills some of these changes can be observed in a single exposure. The bedding of the Kiamichi is draped over the bottom topography and has an initial dip where it lies on the flanks of reefs. This initial dip has been increased by diagenetic compaction to form the present structure. An initial dip during sedimentation is indicated by the thickening of limestone units over the reefs and the prominence of *Gryphaea* beds above the inter-reef facies. These features must have been localized by the topography of the bottom. Some compaction occurred during deposition, and this would tend to maintain the relief of the bottom because the thickness and shale-limestone ratio of the lower parts of the bottom would cause more compaction to take place in these areas.

The writer constructed a nonspecific lithofacies map of the Kiamichi in the area of study. This was done by plotting the shale-limestone ratio of each stratigraphic section on a base map. It was found that this ratio often increased as much as 30 percent from the reef to inter-reef areas of adjacent exposures; therefore, the local variations masked the regional variations. The random distribution of stratigraphic sections in relation to reef and inter-reef areas resulted in a meaningless map which showed no significant trend but was rather a measure of local sedimentation.

An interesting regional relationship exists between the Kiamichi and the Denton and Pawpaw members of the overlying Georgetown formation. These units are the first three shales above the Edwards, each of which is separated from the others by the limestones of the Georgetown. These units show a similar rate of thinning from north to central Texas. In Cooke County, the Denton and Pawpaw members are each 50 feet thick, and the Kiamichi is 36 feet thick. These three shales thin southward into McLennan County where the Denton and Pawpaw are about 5 feet thick and the Kiamichi is 7 feet thick. The limestones of the Georgetown also thin southward but not as rapidly as the shales.

Unconformity at the top of the Kiamichi formation.—One purpose of this study was to determine the cause of thinning of the Kiamichi. The presence of an unconformity at the top of the formation is probably the most widely accepted explanation for this thinning. During observations in the field and study of data and samples in the laboratory, the writer searched for indications of unconformity at this level. Although local diastems probably occur, the writer does not believe the local or regional thickness changes in the Kiamichi of central Texas are due to the presence of an unconformity at the top of the Kiamichi.

Thompson (1935, p. 1529) stated that an unconformity is present at the top of the Kiamichi in north-central Texas. He based this assignment on an explosive development of a different ammonite fauna in the Duck Creek member of the overlying Georgetown formation, variation in thickness of the Kiamichi in north Texas and its absence farther south, the presence of pebbles at the contact of the Kiamichi and Duck Creek in Westover Hills at Fort Worth, and the increase in porosity of the Edwards limestone south of Coryell County where the Kiamichi is absent. Scott and Armstrong (1923, p. 59) found evidence of an unconformity or a diastem at the top of the Kiamichi in Wise County. The wavy contact of the Kiamichi and Duck Creek is marked by a "rusty" seam in which one of the authors found a rounded quartz grain almost half an inch in diameter. Adkins and Arick (1930, p. 40) stated that the position of the Kiamichi at the Edwards-Duck Creek contact in Bell County is marked by an unconformity. They observed that the top of the Edwards was irregularly corroded and pitted and locally scoured out to a depth of a foot.

The writer believes that the presence of an unconformity at the top of the Kiamichi in central Texas is untenable and that the local and regional thinning cannot be explained by erosion of the Kiamichi during a post-Kiamichi, pre-Duck Creek interval. The teilzones of the megafossils of the Kiamichi in central Texas may be divided into two general groups. The lower group (more than 10 feet below the top) is characterized by *Gryphaea mucronata*, *Exogyra texana*, and *Cyprimeria texana*. The upper group contains *Heteraster*, *Gryphaea navia*, and *Exogyra plexa*. If the Kiamichi thins due to erosion from the top, thin exposures should contain the lower group of fossils. The reverse is true, and all exposures which are less than 10 feet thick contain only the upper group. This indicates that the thinning is from the bottom and not from the top.

The Kiamichi-Duck Creek contact appears conformable in central Texas. There is a faunal break at this contact where *Oxytropidoceras* and *Gryphaea navia* cease their upward range and are replaced by a rapid development of large ammonites in the Duck Creek. This change in fauna is obvious but may be due to a change from clay to limestone as much as to difference in age. Commonly there is a thin shell debris at the base of the Duck Creek, but these are common throughout the Kiamichi and are usually found in other formations at the contact of a fossiliferous shale and a limestone. The shell debris probably indicates slow deposition which preceded deposition of the overlying limestone. The occurrence of quartz pebbles in north Texas, which have been reported from only two localities and are found only after diligent search, do not necessarily indicate an unconformity but only that the transporting medium was competent enough to move a pebble to that area.

Unconformity at the base of the Kiamichi formation.—The Edwards-Kiamichi contact (base of Kiamichi) is unconformable in central Texas. Throughout central Texas the top of the Edwards is iron stained and contains marcasite which weathers out leaving a corroded and pitted surface. The tops of reefs are commonly porous and contain marcasite concretions. Worm borings are present at the top of some inter-reef limestone. These indications of unconformity remain at the top of the Edwards and cross the zero isopach line of the Kiamichi without apparent change. The writer examined the surface at the top of the Edwards on Leon River east of Belton where distinct evidences of unconformity have been reported (Adkins and Arick, 1930, p. 40). This surface appears unconformable and is similar to the top of an inter-reef limestone exposed on Childress Creek near the McLennan-Bosque County line. At the top of the Edwards in both these exposures is a limestone bed which is about 16 inches thick. The surface of this resistant layer is corroded, iron stained, and penetrated by worm borings which extend downward to a maximum of 7 inches in the exposure on Childress Creek. There is more than 10 feet of Kiamichi above the Edwards on Childress Creek and the Kiamichi is absent on Leon River. Thus the unconformity is at the top of the Edwards limestone regardless of the presence or absence of the Kiamichi.

Cause of thinning.—The Kiamichi formation onlaps the unconformable surface at the top of the Edwards limestone. This southward onlap produces the observed regional thinning of the formation. Onlap is indicated by the presence of an unconformity at the base of the Kiamichi and by evidence that the formation thins from the bottom.

It also appears that the Duck Creek member of the Georgetown formation onlaps the Edwards in the area where the Kiamichi is absent. A zone of *Kingena wacoensis* which is usually found about 1 foot above the top of the Kiamichi in McLennan and Coryell counties is found resting on the Edwards in the first stratigraphic section in which the Kiamichi is absent and is not found in exposures south of that place.

Local variations in thickness, as explained on page 114, are due to the uneven topography upon which the Kiamichi was deposited.

Paleontology

Faunal aspect.—The fossils of the Kiamichi are closely related to the Fredericksburg, and forms such as *Exogyra texana* and *Oxytropidoceras* are distinctly Fredericksburg in affinity. Its relation to the overlying Washita division is less apparent, but one connecting species is *Kingena wacoensis* which is found in the uppermost Kiamichi and basal Duck Creek in McLennan County.

Abundance of fossils.—Locally gryphaeas are of such abundance that coquinas are formed and fossils are common in most exposures. The shales are usually more fossiliferous than the limestones, but this may be more apparent than real due to the relative resistance of the lithology, and most limestones reveal cross sections of recrystallized shells when a fresh surface is exposed normal to the bedding. Usually the lower silty shales of the formation are relatively unfossiliferous, but intercalated *Gryphaea* beds are present in some localities.

Fauna of enclosing formations at the stratigraphic contacts.—The Kiamichi is paleontologically distinct and a rapid change in fauna as well as lithology occurs at both the lower and upper contacts. The lower contact at the top of the Edwards commonly exposes a pelecypod reef which is composed of coral-like rudistids, chamids, and mytilids such as *Eoradiolites, Monopleura,* and *Chondrodonta.* Megafossils are usually rare in inter-reef Edwards but small gastropods occur locally. A thin section of inter-reef limestone prepared by the writer contained foraminifera of the genus *Miliolina* and *Dictyoconus walnut-*

ensis (Carsey). As previously stated, limestone pebbles found in the lower Kiamichi near Valley Mills also contain miliolids.

The upper contact of the Kiamichi with basal Duck Creek marks the beginning of a rapid development of ammonites in the Duck Creek. *Idiohamites fremonti* (Marcou) and *Kingena wacoensis* (Roemer) occur at the base of this ammonite zone with large forms of *Eopachydiscus* Wright and *Pervinquieria* a few feet higher. The zone of *Idiohamites* and *Kingena* is very persistent and can be recognized in almost every exposure. *Kingena* usually occurs about 1 foot above the top of the Kiamichi and often forms a thin coquinoid limestone at this horizon. On Stampede Creek in Bell County, which is a short distance south of the southernmost exposure of the Kiamichi, this zone of *Kingena* is a discontinuous 1-inch coquinoid limestone which rests directly upon the iron-stained top of the Edwards. It is absent farther south at the Fredericksburg-Washita contact on Cedar Creek and Leon River.

Fauna.—Common fossils of the Kiamichi of central Texas are shown in Plates 37 and 38, and their stratigraphic relationships are shown in the correlation charts (Pl. 39). The most characteristic and abundant fossil of the formation is *Gryphaea navia* Hall. It occurs only in the Kiamichi and is common in most exposures. It is usually found in thin exposures or in the upper part of thick exposures. *Oxytropidoceras* sp. aff. *boesei* Knechtel is common throughout the formation and usually occurs in the shales. Complete specimens of this large ammonite are rare because of rapid weathering of the first exposed surfaces, but only a portion of the coil is necessary for identification.

Gryphaea mucronata Gabb was found only in the lower part of thick exposures of the Kiamichi and is the dominant species of *Gryphaea* beds. This species forms thick argillaceous coquinas at the base of the formation near Blum. *Gryphaea navia* Hall is common in the upper part of the exposure; a form which appears transitional between *Gryphaea mucronata* and *Gryphaea navia* occurs in the intervening beds.

Exogyra texana Roemer is often found in the lower part of thick sections of the Kiamichi where it is commonly associated with *Cyprimeria texana* (Roemer). One specimen of *Exogyra texana* was found within 3 feet of the top of the Kiamichi on Childress Creek, and *Cyprimeria* was found as high as 8 feet below the top.

Exogyra plexa Cragin and *Heteraster adkinsi* Lambert usually occupy a zone about 2 or 3 feet thick at the top of the formation. This zone is rather persistent and can be recognized from Blum to southern McLennan County. *Pecten irregularis* Böse occurs sparingly throughout the Kiamichi.

In southern McLennan County and eastern Coryell County a variety of *Kingena wacoensis* Roemer is found in the upper few inches of the Kiamichi. These kingenas are smaller and more symmetrical than the ones which are about 1 foot above in the basal Duck Creek. The shape of the two varieties is shown in Plate 38.

Since the Kiamichi thins from the bottom, the lower and upper fossil zones are present in areas in which the Kiamichi is thick, but only the upper zones persist into areas in which the formation is thin. Fossil zones are condensed in areas where the Kiamichi formation is thin. This is probably due to less deposition in these relatively positive areas during the time spanned by the fossil zone.

CONCLUSIONS

Observations made in the field and results of the laboratory work led the writer to the following conclusions in regard to the Kiamichi formation in central Texas.

1. Because outcrops of the Edwards limestone usually have a larger growth of trees than the overlying Kiamichi or Georgetown outcrops, the position of the Kiamichi may be estimated by inspection of the distribution of trees on an aerial photograph or photogrammetric map.

2. Stratigraphic sections of the Kia-

michi can usually be divided into three general lithologic divisions. In ascending order they are dark silty shale, thin wavy-bedded and nodular limestone, and calcareous clay.

3. *Gryphaea* beds composed of large oyster shells of the genus *Gryphaea* are present in the thicker sections of the Kiamichi and are more prominent in exposures which overlie inter-reef limestones of the Edwards. These beds thin as a reef structure is approached. The accumulations were formed by washing of the shells to the lower parts of the bottom which were above the inter-reef facies of the Edwards.

4. The presence of limestone pebbles in the lower Kiamichi near Valley Mills which contain abundant miliolid foraminifera indicates that parts of the Edwards were topographically higher and exposed to erosion during Kiamichi time.

5. An isopach map of the Kiamichi formation shows a general trend of thinning to the southeast at rates of one-half to 1 foot per mile.

6. Local variations in thickness of the Kiamichi formation are due to the topography at the top of the underlying Edwards which affected deposition during Kiamichi time. The pelecypod reefs of the Edwards were topographic highs and the inter-reefs areas were lows. This relief resulted in thinner and more calcareous deposits over the reef facies.

7. The Edwards-Kiamichi contact is unconformable in central Texas. The top of the underlying Edwards limestone is corroded, pitted, and burrowed and contains marcasite concretions. These indications of unconformity are present in central Texas where the Kiamichi is present and in northern Bell County where the Kiamichi is absent.

8. The regional relation of fossil zones to distribution of formational thickness indicates that the Kiamichi thins from the bottom.

9. The Kiamichi formation onlaps the unconformable surface at the top of the Edwards limestone. This southward onlap produces the observed regional thinning of the formation.

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APPENDIX. DESCRIPTION OF STRATIGRAPHIC SECTIONS

Section I

North side of bridge over Nolan River, 0.25 mile north of Blum, Hill County, Texas; longitude 97°24'17", latitude 32°09'00".

	Feet	*Inches*
Comanche series		
Washita group		
Georgetown formation		
Duck Creek member		
22. Limestone; thin bedded	5	
21. Limestone; very resistant, massive, shell fragments abundant near the bottom, small coiled ammonites rare, *Kingena wacoensis* rare		11
Fredericksburg group		
Kiamichi formation		
20. Covered; buff-colored shale exposed in a few places and at the top	5	10
19. Shale; buff, poorly exposed, *Oxytropidoceras* sp. aff. *boesei* Knechtel rare	3	9
18. Limestone; resistant, shell fragments abundant, violet on fresh fracture		3
17. Shale; calcareous, buff	1	2
16. Limestone; with interbedded shale, thin shale near the top contains abundant shell debris and some *Gryphaea navia*	3	7
15. Limestone; with shaly partings	1	3
14. Shale; calcareous, buff	1	4
13. Shale; tan, thin limestone bed at top and botton		10
12. Shale; calcareous, receding		5
11. Limestone; resistant, shell fragments abundant in upper half, *Gryphaea* sp., *Pecten* sp., and small oysters common		5
10. Shale; calcareous, gray		10
9. Limestone; resistant		3
8. Shale; silty, gray and buff	1	2
7. Limestone; resistant, gray when fresh		3
6. Shale; calcareous, gray and buff	1	3
5. Limestone; resistant		6
4. Shale; calcareous, rust and gray		9
3. Limestone; violet on fresh fracture, coquinoid with *Gryphaea mucronata* Gabb, small oysters, and *Exogyra texana* rare		4
2. Shale; silty, calcareous, buff, *Gryphaea* sp. common (Pl. 37, figs. 7–9)	1	3
Total Kiamichi	25	5
Edwards formation		
1. Limestone; resistant, massive, gray, iron oxide-stained fucoids or burrows about one-fourth inch in diameter are present at the top	5	

Section II

Banks of Rock Creek, 2.2 miles south-southeast of Blum, Hill County, Texas; longitude 97°23'24", latitude 32°06'33".

	Feet	*Inches*
Comanche series		
Washita group		
Georgetown formation		
Duck Creek member		
18. Limestone; massive, weathers white, resistant, shell fragments rare, *Exogyra* sp. rare	1	3
17. Limestone; white, fucoidal weathering, small *Pervinquieria* sp. rare, *Exogyra plexa* common, contains two shaly partings	2	1
Fredericksburg group		
Kiamichi formation		
16. Limestone; shell debris, gray soft shell debris at the base contains large *Gryphaea navia, Exogyra plexa,* and small *Gryphaea* sp.		9
15. Shale; gray, with nodular limestone and thin wavy beds of limestone, *Exogra plexa* and *Oxytropidoceras* sp. aff. *boesei* Knechtel common	3	1
14. Limestone; resistant, fucoidal at top		5
13. Shale; gray, with some white limestone	1	11
12. Limestone; resistant, evenly bedded		3
11. Shale; calcareous, with nodular limestone, *Gryphaea navia* abundant in two continuous limestone beds, *Oxytropidoceras* sp. aff. *boesei* Knechtel and *Exogyra plexa* common in the upper part	3	1

	Feet	Inches
10. Limestone; a shell debris composed of *Gryphaea* and other oyster shell fragments		3
9. Shale; silty, calcareous, thin limestone shell debris at the base, *Gryphaea navia* common, *Pecten* sp. rare	1	4
8. Limestone; shaly, *Oxytropidoceras* sp. aff. *boesei* Knechtel rare	2	11
7. Limestone; resistant, gray, shaly parting at the base		8
6. Limestone; sandy, resistant, buff		3
5. Shale; silty, gray, nodular limestone in the middle, *Cyprimeria texana* and *Oxytropidoceras* sp. aff. *boesei* Knechtel rare	4	5
4. Limestone; shaly, shell bed at the base containing *Gryphaea mucronata* Gabb (Pl. 37, figs. 4–6) and *Exogyra texana*	1	10
3. Shale; gray, silty shell debris in the middle contains abundant *Gryphaea mucronata* Gabb	1	5
2. Limestone; shell debris, gray, lower contact irregular and sharp		9
Total Kiamichi	23	4
Edwards formation		
1. Limestone; massive, resistant, iron-stained fucoids and borings filled with iron-stained shell debris occur at the top	5	

Section III-A

North side of road cut 2.2 miles east of intersection of farm 215 and State Highway 22 between Clifton and Whitney Dam, Bosque County, Texas; longitude 97°25′09″, latitude 31°51′28″. (Pl. 34)

	Feet	Inches
Comanche series		
Washita group		
Georgetown formation		
Duck Creek member		
21. Limestone; thick wavy bedded with thin shaly partings	6	
20. Limestone; resistant, projecting, massive, thin shell debris at the base with wavy lower surface, *Idiohamites* sp. common, a zone of abundant *Kingena wacoensis* occurs 1 foot above the base	1	10
Fredericksburg group		
Kiamichi formation		
19. Shale; buff and gray, some thin layers of limestone occur, *Exogyra plexa* and *Heteraster* sp. common, *Alectryonia?* sp. rare	1	10
18. Limestone; resistant, violet on fresh fracture, small shell fragments abundant		5
17. Shale; tan, gray when fresh, oyster shell fragments and *Exogyra plexa* common		2
16. Limestone; resistant, violet on fresh fracture, small shell fragments abundant		3
15. Shale; tan, gray when fresh		8
14. Limestone; wavy bedded, gray, weathers to tan, contains shaly partings with *Gryphaea navia* common	2	8
13. Limestone; an iron-stained laminae of shell debris at the base		6
12. Limestone; with silty shale, tan	1	11
11. Limestone; tan after weathering and gray when fresh, *Gryphaea mucronata?* and internal molds of *Turritella?* sp. common		4
10. Shale; with limestone, tan, silty, gray when fresh	2	6
9. Limestone; silty, gray weathering tan, wavy bedded		4
8. Shale; silty, gray weathering tan		8
7. Limestone; argillaceous, tan		3
6. Shale; silty, gray weathering tan		5
5. Limestone; coquinoid with *Gryphaea mucronata* Gabb		4
4. Shale; dark gray, small fragments of oyster shells abundant		4
3. Shale; silty, dark gray		8
Total Kiamichi	14	3
Edwards formation		
2. Limestone; inter-reef facies, thin bedded, clastic, fine grained, iron stained at the top	7	5
1. Limestone; reef facies, massive, vuggy, *Chondrodonta munsoni* and *Eoradiolites* sp. abundant	9	

Section III-B

Small quarry 100 yards south of Section III-A.

	Feet	Inches
Comanche series		
Washita group		
Georgetown formation		
Duck Creek member		
14. Limestone; massive, saccharoidal, gray when fresh turning white after exposure to weathering, projecting, shell fragments	1	3
Fredericksburg group		
Kiamichi formation		
13. Limestone; coquina of small *Gryphaea* sp.		2
12. Shale; clayey, buff and gray with white specks which become more numerous near the top, 3-inch shale at the base is followed by a 5-inch ledge of limestone, contains *Heteraster* sp., *Exogyra plexa*, and *Alectryonia?* sp.	2	4
11. Limestone; resistant, projecting, a shell debris, violet on fresh fracture, contains small cubes of pyrite		3
10. Shale; calcareous, receding, buff with white specks, *Exogyra plexa* and *Gryphaea navia* common, *Pecten* sp.	1	
9. Limestone; wavy bedded, indistinct shale partings, *Gryphaea navia* common, *Homomya?* sp. and *Heteraster* sp. rare in the upper part	2	
8. Limestone; an oyster shell debris, iron strained		1
7. Limestone; with shaly partings, limestone contains shell fragments, *Gryphaea navia* common in shale	1	1
6. Shale; calcareous, buff with white specks, abundant *Gryphaea* sp., internal molds of *Turritella?* sp. common		6
5. Limestone; a *Gryphaea* bed, loosely cemented in places, *Gryphaea mucronata* Gabb abundant	3	
4. Shale; calcareous, silty, buff, *Gryphaea mucronata* Gabb and internal molds of *Turritella?* sp. common		1
3. Shale; calcareous, silty, with wavy-bedded limestone, buff with white specks, gray when fresh	3	5
2. Shale; calcareous, silty, weathers to a buff color with white specks, *Gryphaea mucronata* Gabb coquina at the base	1	2
Total Kiamichi	12	4
Edwards formation		
1. Limestone; reef facies, vuggy, red zone at the top, *Monopleura* sp. and *Chondrondonta munsoni* abundant	5	

Section IV

Two-tenths mile east on road which turns off State Highway 22 at the west end of Whitney Dam, Bosque County, Texas; longitude 97°17'08", latitude 31°51'51".

	Feet	Inches
Comanche series		
Washita group		
Georgetown formation		
Duck Creek member		
7. Limestone; tan, resistant, in places this unit thickens downward and causes unit 6 to thin, *Idiohamites* sp. rare		7
6. Limestone; gray, shaly parting at the top and bottom, unidentified shell fragments, *Kingena wacoensis* rare		9
5. Limestone; resistant, gray, tan on weathered surface		7
Fredericksburg group		
Kiamichi formation		
4. Shale; rust and white, *Exogyra plexa* and *Gryphaea navia* common, *Alectronia?* sp. rare	1	7
3. Limestone; a shell debris, violet on fresh fracture, 2-inch shaly parting in the middle contains *Exogyra plexa* and *Holectypus* sp.		7
2. Shale; weathered to a rust and white color, bottom part poorly exposed, *Gryphaea navia* zone 27 inches below top, *Exogyra plexa* common in the upper part, two iron oxide-stained laminae of shell debris in the upper part	9	8
Total Kiamichi	11	10
Edwards formation		
1. Limestone; massive, with indistinct bedding developed by weathering, pink due to iron oxide stain	8	4

Section V

On Coon Creek 200 yards upstream from concrete ford on Smith's Bend road, 3 miles southeast of Whitney Dam, Bosque County, Texas; longitude 97°20'51", latitude 31°49'38".

	Feet	Inches
Comanche series		
Washita group		
Georgetown formation		
Duck Creek member		
9. Limestone; thin shell debris at the base contains small *Gryphaea* sp., zone of *Kingena wacoensis* 10 inches above base, small *Pervinquieria* sp. rare	1	8
Fredericksburg group		
Kiamichi formation		
8. Shale; *Exogyra plexa* and *Alectryonia?* sp. common		7
7. Limestone; *Gryphaea navia* common, *Oxytropidoceras* sp. aff. *boesei* Knechtel rare		1
6. Shale; clayey, buff, *Exogyra plexa, Heteraster adkinsi,* and *Oxytropidoceras* sp. aff. *boesei* Knechtel	1	1
5. Limestone; argillaceous, shaly partings in the middle, *Gryphaea navia* common	2	3
4. Shale; clayey, shell debris at the top with *Gryphaea navia* common		3
3. Limestone; argillaceous, light gray		5
2. Shale; clayey, rust and gray, small *Gryphaea navia* rare near the top, two thin beds of limestone near the base	4	10
1. Covered by stream gravel. The top of the Edwards is probably within a foot of the base of the above unit. A short distance downstream from the concrete ford is an exposure of the lower 8 feet of the Kiamichi with *Gryphaea navia* near the top.		

Section VI-A

On Childress Creek 2 miles upstream from its mouth, McLennan County, Texas; longitude 97°18'37", latitude 31°42'21". (Pl. 34)

	Feet	Inches
Comanche series		
Washita group		
Georgetown formation		
Duck Creek member		
14. Shale; calcareous, forms a slightly receding zone		2
13. Limestone; coquinoid with *Kingena wacoensis* (Pl. 38, figs. 9, 10) and small shells, resistant, massive, projecting	1	3
Fredericksburg group		
Kiamichi formation		
12. Limestone; coquina of *Kingena wacoensis* and small *Gryphaea* sp., loosely cemented		3
11. Limestone; wavy bedded, shaly parting at the top, receding, *Exogyra plexa* rare	2	1
10. Shale; calcareous, in some places a nodular limestone is present in the middle of this unit, *Gryphaea navia* common		7
9. Limestone; wavy bedded, with shaly partings	2	1
8. Limestone alternating with calcareous shale	1	11
7. Shale; calcareous, receding	1	
6. Shale; dark gray, silty		6
5. Limestone; nodular, argillaceous, gray when fresh, tan on weathered surface		3
4. Shale; dark gray, silty	1	
3. Limestone; nodular, argillaceous, gray on fresh surface and tan on weathered surface		4
2. Shale; dark gray, silty		8
Total Kiamichi	10	8
Edwards formation		
1. Limestone; massive, resistant, reef facies, contains *Monopleura* sp. and marcasite concretions	5	

Section VI-B

On Childress Creek 2.2 miles upstream from its mouth, near McLennan-Bosque County line, in McLennan County, Texas; longitude 97°19'30", latitude 31°42'30".

	Feet	Inches
Comanche series		
Washita group		
Georgetown formation		
Duck Creek member		
12. Limestone; shaly parting at the bottom, fucoidal weathering, *Gryphaea* sp. rare	1	9

	Feet	Inches
11. Limestone; resistant, shaly parting 7 inches above base contains *Kingena wacoensis* and *Idiohamites* sp. common	1	7
Fredericksburg group		
Kiamichi formation		
10. Limestone; impure, upper part shaly and contains *Exogyra plexa, Gryphaea navia, Heteraster* sp.	2	6
9. Shale; shell debris, large *Gryphaea navia* common		2
8. Limestone; impure	6	
7. Shale; shell debris, contains shark teeth, *Exogyra texana*, small *Gryphaea* sp., large *Gryphaea navia*		2
6. Limestone; impure, *Pecten* sp. rare	1	
5. Shale; silty, gray, with impure wavy-bedded limestone	4	10
4. Limestone; impure		4
3. Shale; gray, silty		9
Total Kiamichi	10	3
Edwards formation		
2. Limestone; calcarenite, resistant, massive yet weathering thin bedded in places, pyritiferous zone at the top, 0.1-inch diameter borings extending down from the top to a maximum of 7 inches, a thin section of this unit contained miliolid foraminifera and *Dictyoconus walnutensis* (Carsey)	1	4
1. Limestone; massive, soft, white, contains *Dictyoconus walnutensis* (Carsey)	3	

Section VII

Six and a half miles northeast of Turnersville on Farm Road 182, Coryell County, Texas; longitude 97°40'22", latitude 31°40'50".

	Feet	*Inches*
Comanche series		
Washita group		
Georgetown formation		
Duck Creek member		
8. Limestone; poorly exposed, resistant, gray, unidentifiable shell fragments common, shaly parting in the middle in places	1	5
Fredericksburg group		
Kiamichi formation		
7. Shale; calcareous, buff and white, *Exogyra plexa* and *Gryphaea navia* common	2	
6. Limestone; resistant, gray purple on fresh fracture, contains many small shell fragments		5
5. Shale; with thin layers of limestone, silty near the base, *Gryphaea* sp. rare	11	
4. Shale; clayey, buff and gray, *Exogyra texana* (Pl. 38, fig. 8) and *Gryphaea* rare	6	2
Total Kiamichi	19	7
Edwards formation		
3. Limestone; sublithographic, light tan, iron oxide-stained zone at the top, *Nerinea* sp. rare, small flat brachiopods and rudistids rare, miliolid foraminifera abundant	1	1
2. Shale; reddish buff and white, severely weathered, *Monopleura* sp. very rare	3	6
1. Limestone; thin bedded, resistant, thin shaly limestone partings	7	1

Section VIII-A

Center of north side of railroad cut, 200 yards east of intersection of State Highway 317 and Santa Fe Railroad tracks near Valley Mills, Bosque County, Texas; longitude 97°28'00", latitude 31°39'04". (Pl. 35)

	Feet	*Inches*
Comanche series		
Washita group		
Georgetown formation		
Duck Creek member		
15. Limestone; gray, massive, resistant, *Kingena wacoensis* zone 1 foot above the base	1	4
Fredericksburg group		
Kiamichi formation		
14. Shale; calcareous, buff becoming lighter near top, resistant ledge of limestone occurs 42 inches above base, *Oxytropidoceras* sp. aff. *boesei* Knechtel (Pl. 38, fig. 1), *Exogyra plexa* (Pl. 38, fig. 5), *Gryphaea navia*, and *Heteraster adkinsi* (Pl. 38, figs. 2, 3) in the upper part	6	10

	Feet	Inches
13. Shale; buff		7
12. Limestone; coquina of *Gryphaea* sp.		4
11. Shale; tan		8
10. Limestone; buff, contains shaly partings	2	8
9. Shale; dark gray		10
8. Limestone; gray, argillaceous		3
7. Limestone; a *Gryphaea* bed, with some dark silty shale, contains *Gryphaea mucronata* Gabb abundant, *Exogyra texana* and *Cyprimeria texana* rare, contains limestone pebbles which contain miliolid foraminifera		5
6. Limestone; gray; this unit pinches out as the formation thins toward an adjacent reef		3
5. Shale; silty, dark gray, contains limestone pebbles		7
4. Limestone; argillaceous, gray, contains limestone pebbles	1	
3. Shale; silty, dark gray		9
Total Kiamichi	15	3
Edwards formation		
2. Limestone; massive, resistant, projecting, iron oxide-stained upper surface, shaly parting at the base	2	9
1. Limestone; massive, fine grained, weathers to a chalky texture	2	

Section VIII-B

Thirty yards east of Section VIII-A.

	Feet	Inches
Comanche series		
Washita group		
Georgetown formation		
Duck Creek member		
11. Limestone; resistant, massive, projecting, *Kingena wacoensis* zone a foot above the base	1	4
Fredericksburg group		
Kiamichi formation		
10. Shale; calcareous, buff becoming lighter near the top due to more intensive weathering, resistant flag about halfway up from the base, *Exogyra plexa* common	7	6
9. Limestone; tan, coquina of *Gryphaea* with some *Cyprimeria texana* and internal molds of *Turritella*? sp.		3
8. Shale; buff, contains internal molds of *Turritella*? sp.		5
7. Limestone; wavy bedded, buff	3	11
6. Shale; with shaly partings, tan, *Gryphaea mucronata* Gabb abundant, *Exogyra texana* and *Cyprimeria texana* rare		3
5. Shale; buff with white specks		3
4. Limestone; tan, becoming gray near the top	1	9
3. Shale; buff, clayey		2
Total Kiamichi	14	6
Edwards formation		
2. Limestone; massive, resistant, projecting, red zone at top caused by iron oxide stain	2	9
1. Limestone; massive, fine grained	2	

Section IX

On Hog Creek 0.25 mile upstream from bridge on State Highway 317, McLennan County; longitude 97°27′48″, latitude 31°36′52″. (Pl. 36)

	Feet	Inches
Comanche series		
Washita group		
Georgetown formation		
Duck Creek member		
12. Limestone; resistant, coquinoid with *Kingena wacoensis*		3
11. Limestone; massive, resistant, in places units 12 and 11 are one unit		7
Fredericksburg group		
Kiamichi formation		
10. Shale; gray and rust	1	1
9. Limestone; a shell debris		3
8. Shale; buff, *Exogyra plexa* common, *Alectryonia?* sp. rare	1	4
7. Limestone; shaly parting at the base, *Oxytropidoceras* sp. rare		7
6. Limestone; shaly parting at the base, *Gryphaea navia* abundant (Pl. 37, figs. 1–3)		6

5. Limestone; gray, nodular		7
4. Shale; silty, gray, receding, small *Gryphaea* sp. rare		7
3. Limestone; nodular, with gray shale, *Gryphaea* sp. and *Oxytropidoceras* sp. rare	1	2
2. Shale; silty, black, soft iron sulfide concretions rare	1	
Total Kiamichi	7	1
Edwards formation		
1. Limestone; resistant, gray, saccharoidal, marcasite nodules common at top	3	

Section X

On North Bosque River 1.5 miles upstream from bridge which is 2.5 miles north of intersection of State Highway 6 and County Road 46N, McLennan County, Texas; longitude 97°19′45″, latitude 31°36′20″.

	Feet	Inches
Comanche series		
Washita group		
Georgetown formation		
Duck Creek member		
7. Limestone; massive, resistant, coquinoid *Kingena wacoensis* zone 1 foot above the base	1	6
Fredericksburg group		
Kiamichi formation		
6. Shale; calcareous, light gray, some nodular limestone, receding, *Kingena wacoensis,* small *Gryphaea* sp., *Heteraster* sp.		9
5. Limestone; irregular thickness, projecting, resistant, gray		5
4. Shale; gray, with nodular limestone in the middle, *Gryphaea navia* common in shale		8
3. Limestone; irregular thickness, resistant		5
2. Shale; dark gray, silty, with two or three thin beds of gray limestone	2	6
Total Kiamichi	4	9
Edwards formation		
1. Limestone; resistant, massive, reef facies, iron oxide-stained upper surface, crops out at water level	2	

Section XI

Gully 10 yards south of Farm Road 182 where road crosses creek on east side of Turnersville, Coryell County, Texas; longitude 97°44′18″, latitude 31°36′58″.

	Feet	Inches
Comanche series		
Washita group		
Georgetown formation		
Duck Creek member		
6. Limestone; light gray, resistant, *Kingena wacoensis* rare, unidentified shells common, shaly parting at the base		11
5. Limestone; resistant, saccharoidal, basal part softer and is a shell debris		6
Fredericksburg group		
Kiamichi formation		
4. Shale; calcareous, buff and white due to severe wethering, *Exogyra plexa* common, *Pecten* sp. and internal molds of *Turritella?* sp. rare	2	
3. Limestone; wavy bedded, with calcareous shale, *Gryphaea navia* common near top	5	
2. Shale; calcareous, some thin layers of limestone, buff	6	
Total Kiamichi	13	
Edwards formation		
1. Limestone; thin bedded, resistant, shaly partings, iron oxide-stained upper surface	8	2

Section XII

Road cut 1 mile north of Crawford on State Highway 317, McLennan County, Texas; longitude 97°16′48″, latitude 31°33′06″. (Pl. 33)

	Feet	Inches
Comanche series		
Washita group		
Georgetown formation		
Duck Creek member		
8. Limestone; resistant, shaly parting at the bottom, *Kingena wacoensis* rare		7
7. Limestone; *Gryphaea* sp. and *Kingena* sp. common		4

	Feet	Inches
Fredericksburg group		
Kiamichi formation		
6. Shale; with nodular limestone, small *Gryphaea* sp. rare, *Exogyra plexa* and *Alectryonia* sp. common	2	2
5. Limestone		4
4. Shale; buff, calcareous, nodular limestone in the middle, upper shale contains *Exogyra plexa, Heteraster* sp., and *Kingena wacoensis*		10
3. Limestone		7
2. Shale; dark gray, silty	1	6
Total Kiamichi	5	5
Edwards formation		
1. Limestone; massive, resistant, vuggy, calcitized rudistids, iron oxide stained at the top	3	

Section XIII

On Middle Bosque River 0.5 mile upstream from bridge which is 1.5 miles west of Windsor, McLennan County, Texas; longitude 97°22'18", latitude 31°30'44".

	Feet	Inches
Comanche series		
Washita group		
Georgetown formation		
Duck Creek member		
8. Limestone; resistant, coquinoid *Kingena wacoensis, Idiohamites* sp. rare, thin shaly parting at the bottom		5
7. Limestone; projecting, *Kingena wacoensis* rare		6
Fredericksburg group		
Kiamichi formation		
6. Shale or shaly limestone; contains symmetrical *Kingena wacoensis, Pecten* sp., and *Exogyra plexa*		8
5. Limestone; shaly, small oyster shell fragments abundant		5
4. Shale; gray, *Gryphaea navia* and *Exogyra plexa* common		4
3. Limestone; nodular		4
2. Shale; dark gray, silty, slightly calcareous, *Exogyra texana* rare		10
Total Kiamichi	2	7
Edwards formation		
1. Limestone; massive, resistant, contains marcasite nodules, *Monopleura* sp. and *Chondrodonta munsoni* common, *Exogyra texana* rare	5	

Section XIV

Road cut near top of escarpment 2 miles north of intersection of State Highway 36 and road to White Hall Church, Coryell County, Texas; longitude 97°43'30", latitude 31°30'18".

	Feet	Inches
Comanche series		
Washita group		
Georgetown formation		
Duck Creek member		
6. Broken limestone and soil	1	
5. Limestone; resistant, unidentified shell fragments abundant, *Idiohamites* sp. rare		8
Fredericksburg group		
Kiamichi formation		
4. Shale or shaly limestone; not well exposed, *Exogyra plexa* common	1	8
3. Limestone; tan, shaly at the base		7
2. Shale; calcareous, weathering white, resistant zone of shaly limestone shell debris halfway up from the base contains *Gryphaea navia*	4	7
Total Kiamichi	6	10
Edwards formation		
1. Limestone; massive, reef facies, iron oxide stained at the top, *Chondrodonta munsoni* common	5	

Section XV-A

One mile east of Coryell Creek on U. S. Highway 84, Coryell County, Texas; longitude 97°35'08", latitude 31°25'45".

	Feet	Inches
Comanche series		
Washita group		
Georgetown formation		
Duck Creek member		
7. Limestone; massive, resistant		9
6. Limestone; shaly, receding		7
5. Limestone; gray on fresh surface, shell fragments abundant, very resistant, massive, *Idiohamites* sp. common		6
4. Limestone; shaly, receding		2
3. Limestone; resistant, tan, shaly limestone shell debris at the base		7
Fredericksburg group		
Kiamichi formation		
2. Shale; calcareous, severely weathered, buff with tan and white areas, limestone shell debris in the middle, abundant oyster shells especially right valves, *Exogyra plexa* plicate and nonplicate forms common, *Gryphaea navia, Heteraster* sp., *Kingena wacoensis,* and *Pecten irregularis* rare	4	11
Total Kiamichi	4	11
Edwards formation		
1. Limestone; calcarenite, thin bedded, resistant, reddish tan, 1-foot bed at top	3	4

Section XV-B

Two hundred yards west of Section XV-A, in north face of highway cut.

	Feet	Inches
Comanche series		
Washita group		
Georgetown foormation		
Duck Creek member		
5. Limestone; gray, resistant, unidentified shell fragments common		8
4. Limestone, shaly, light gray		2
3. Limestone; resistant, in places one unit but locally two units with a shaly parting, receding shaly limestone at the base		10
Fredericksburg group		
Kiamichi formation		
2. Shale; calcareous, severely weathered to rust and white, 19 inches above the base is a zone of common *Kingena wacoensis, Gryphaea navia, Exogyra plexa, Oxytropidoceras* sp., internal molds of *Turritella* sp.	3	2
Total Kiamichi	3	2
Edwards formation		
1. Limestone; reef facies, massive, iron oxide stained at the top, *Eoradiolites davidsoni* and *Chondrodonta munsoni* common	5	10

Section XVI

Eagle Springs, 8.5 miles west of Moody on Farm Road 107, Coryell County, Texas; longitude 97°28'36", latitude 31°21'10".

	Feet	Inches
Comanche series		
Washita group		
Georgetown formation		
Duck Creek member		
6. Limestone; massive, blocky fracture, *Eopachydiscus* sp. common	2	5
5. Limestone; resistant, massive, light gray		10
4. Limestone; shaly, receding, light gray		2
3. Limestone; resistant, massive, zone of common *Kingena wacoensis* 7 inches above base, small *Pervinquieria?* sp. rare		11
Fredericksburg group		
Kiamichi formation		
2. Shale; calcareous, 3-inch nodular limestone in the middle, symmetrical *Kingena wacoensis* common		8
Total Kiamichi		8
Edwards formation		
1. Limestone; reef facies, resistant, massive, crops out at water level of creek	2	

Section XVII

On Horse Creek 200 yards upstream from bridge which is 1.3 miles south of Whitson, Coryell County, Texas; longitude 97°27'52", latitude 31°18'55". (Pl. 36)

	Feet	Inches
Comanche series		
Washita group		
Georgetown formation		
Duck Creek member		
8. Limestone; light gray, thin marly partings	17	
7. Limestone; resistant, light gray, *Idiohamites* sp. common (Pl. 38, fig. 4)	1	1
6. Limestone; resistant, zone of common *Kingena wacoensis* 5 inches above base, small *Pervinquieria?* sp. rare		8
Fredericksburg group		
Kiamichi formation		
5. Limestone; coquina of small fragments of oyster shells, *Kingena wacoensis* (Pl. 38, figs. 6, 7) and small *Gryphaea* sp. common		3
4. Shale; calcareous, gray, receding, *Inoceramus* sp. rare	1	
Total Kiamichi	1	3
Edwards formation		
3. Limestone; with shaly partings	1	3
2. Limestone; shaly, receding		9
1. Limestone; massive, resistant, white	6	

Section XVIII-A

Road cut 50 yards south of Stampede Creek, 3.3 miles north of White Hall, Bell County, Texas; longitude 97°26'19", latitude 31°15'07".

	Feet	Inches
Comanche series		
Washita group		
Georgetown formation		
Duck Creek member		
4. Limestone; resistant, shaly parting at the bottom, *Eopachydiscus* sp. rare	1	7
Fredericksburg group		
Edwards formation		
3. Limestone; buff, light violet when fresh, very resistant, pyrite zone at the top, calcitized gastropods common	1	4
2. Limestone; shaly, small low-spired snails common	1	1
1. Limestone		10

Section XVIII-B

One mile upstream from concrete ford, Stampede Creek, 3.3 miles north of White Hall, northeastern Bell County, Texas; longitude 97°25'46", latitude 31°15'28".

	Feet	Inches
Comanche series		
Washita group		
Georgetown formation		
Duck Creek member		
6. Limestone; shaly, *Gryphaea washitaensis* abundant	1	5
5. Limestone; "Georgetown lithology," some shaly partings, blocky weathering	5	5
4. Limestone; resistant, *Eopachydiscus* sp. common		9
3. Limestone; this bed occurs only in places, *Kingena wacoensis* abundant		1
Fredericksburg group		
Edwards formation		
2. Limestone; resistant, blocky weathering, contains pyrite, top has many solution holes to one-half inch deep, *Nerinea* sp. and other gastropods common		11
1. Limestone; resistant	3	4

Section XIX

One hundred yards downstream from bridge over Cedar Creek on State Highway 317, 1 mile north of intersection of State Highways 317 and 36, Bell County, Texas; longitude 97°25'16", latitude 31°10'03".

	Feet	Inches
Comanche series		
Washita group		
Georgetown formation		
Duck Creek member		
8. Limestone; resistant, shaly partings	1	7

	Feet	Inches
7. Limestone; resistant, coquinoid with *Gryphaea washitaensis* in places near the bottom		6
6. Limestone; with interbedded shale, becoming more shaly near the top	3	9
5. Limestone; resistant, projecting, large ammonites common	1	
4. Shale; calcareous, buff and white		3
3. Limestone; lithographic, very resistant, contains unidentified crystalline calcite shells, internal mold of large *Eopachydiscus* sp., small *Idiohamites* sp., *Ampullina?* sp., *Nerinea* sp.		11
2. Shale; calcareous, buff		2
Fredericksburg group		
Edwards formation		
1. Limestone; reef facies, iron-stained zone at the top, *Monopleura* sp. common	3	4

Section XX

On Leon River, below bridge on U. S. Highway 81, east of Belton, Bell County, Texas; longitude 97°26′32″, latitude 31°03′22″.

	Feet	*Inches*
Comanche series		
Washita group		
Georgetown formation		
Duck Creek member		
4. Limestone; argillaceous, *Pervinquieria* sp. common, *Gryphaea washitaensis* abundant	1	8
3. Limestone; typical Georgetown lithology, irregular bedded with thin shaly limestone partings, blocky weathering, *Eopachydiscus* zone 1 foot from base with internal molds up to 15 inches in diameter, *Inoceramus* sp. rare	5	5
Fredericksburg group		
Edwards formation		
2. Limestone; shaly parting at the bottom, very resistant, small brachiopods, internal mold of *Nerinea?* sp. and other crystalline calcite shells	1	4
1. Limestone; massive, resistant, becoming chalky near the top	5	

A Review of Edwards Limestone Production with Special Reference to South-Central Texas

JOHN R. SANDIDGE[6]

ABSTRACT

The discovery in 1922 of oil in the Edwards formation of south-central Texas was of great importance because it opened a large area for exploration and development. Much credit is given to Edgar B. Davis, who pioneered the discovery, and to many other oil men who have carried Edwards exploration and development from the Sabine to the Rio Grande. The more re cent discoveries of gas in the Edwards have established substantial reserves and created much interest in additional exploration.

INTRODUCTION

The discovery of oil in the Edwards formation of south-central Texas opened a chapter in the history of the oil business which was as important locally as were the great discovery at Spindletop for the Gulf Coast, Yates for west Texas, and "Dad" (C. M.) Joiner's No. 3 Daisy Bradford well for east Texas. It lifted a large part of the population from marginal farming and subsistence living in the towns to positions of comfort and in some cases to luxury. After the excesses accompanying the boom days had subsided, cultural improvements and general progressiveness characterized the community life, and both the countryside and the urban centers have continued to become more attractive. The economic impact has been of major importance throughout the main productive area, extending from Caldwell to Webb counties, a distance of 165 miles, and over a period of thirty-six years.

ACKNOWLEDGMENTS

The writer has obtained information through a period of twenty-five years from sources too numerous to mention, but conversations with geologists and operators together with various published accounts of activities and Magnolia Petroleum Company records have furnished a large part of the factual data. Among the many veterans of the oil business in south Texas who have contributed general information are E. Vernon Woolsey, H. Miller Ainsworth, John Mowinkle, H. A. Pagenkopf, Wm. H. Spice, Jr., Carey Dauchy, Leslie Harlow, and Grady Kirby.

With reference to Luling field, the booklet entitled "Citizen of Luling," prepared by the noted columnist Kenneth Foree, Jr., for the Magnolia Petroleum Company on the occasion of the Luling Silver Anniversary Oil Jubilee, August 9, 1947, has been drawn upon freely. Dilworth Hager furnished first-hand information regarding the discovery at Darst Creek. Noah Smith, Jr., President, and Charles Edgerton, Chief Geologist, of the Luling Oil and Gas Company, contributed facts relating to Salt Flat field. Henry D. McCallum, of the Humble Oil & Refining Company, assembled data regarding the discovery of Imogene, Jourdanton, and Charlotte fields; George H. Clark of The Texas Company also furnished information on Charlotte. J. B. Souther and Porter Montgomery of Pan American Petroleum Company; Charles E. Kimmell, consulting geologist; Edman R. Zink of the Standard Oil Company of Texas; Robert M. Knebel and Franklin Jones of the Lone Star Producing

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Company; and Robert E. Wills of the Magnolia Petroleum Company have been the chief sources of information on the intermediate and deep Edwards trends. Thomas H. Walker and John Mulligan of Magnolia's Tyler office furnished data on east Texas, while Homer Noble, Gilbert A. Fabre, and A. J. Bauernschmidt of the Company's Houston office contributed facts about fields in the northeastern Gulf Coast. Production statistics are mainly from the files of the Texas State Railroad Commission.

The map (Pl. 40) showing Edwards fields was produced by Raymond Lightsey, draftsman in the San Antonio geological office of Magnolia Petroleum Company. Miss Elsie Bryan, Geological Secretary in Magnolia's San Antonio office, prepared the manuscript. The writer expresses deep appreciation to the management of Magnolia Petroleum Company for the privilege of presenting this paper, which is intended to enlighten the citizens of Texas regarding a phase of the oil business to which the Company made an important early contribution.

EARLY DISCOVERIES

Luling Field

The history of the discovery of oil in the Edwards formation is a story of skepticism, disappointment, dogged persistence, and fabulous success. It had its inception in the mind of a man guided by firm "FAITH"[7] who, although he passed to his heavenly reward only seven years ago, already has attained the status of a legendary character. Even while living, because of his retiring attitude and deeply religious nature, he was regarded by many of his associates as a man of mystery. This remarkable individual who first discovered oil in the Edwards was Edgar B. Davis, late "Citizen of Luling."

The saga of Edgar B. Davis will live because it is unique in the annals of the oil business. Stories are common of swashbuckling promoters discovering oil by sheer luck and of "poor boy" wildcatters spending their last dollar to bring in an elusive gusher. A generally rough and ready lot they are, but not so in the case of Edgar B. Davis. Here is a man in strong contrast, a member of an old New England family, reared with all the niceties of the gay nineties. He had traveled the world, associated with royalty, played golf, excelled at bridge, loved music and art. Admitting no church affiliation, he nevertheless considered himself a "Steward of the Lord," ordained to improve the lot of his fellow man.

This extraordinary person at 35 years of age left a promising business career as co-founder and sales executive of the Walk-over Shoe Company of Brockton, Massachusetts, to regain his impaired health on a world tour. In Singapore he met a Dutch rubber plantation manager who induced him to interest the United States rubber companies in cultivating rubber trees in Sumatra. This proved to be a highly successful venture for Davis and resulted in his acquiring $4,000,000 in rubber company stocks and cash. Upon his return to New York he declined attractive offers to become president of the United States Rubber Company, because it would have confined his activities too much. Instead he betook himself at the age of 50 from his luxurious New York environment to the impoverished farming community of Luling, Texas. His immediate mission was to salvage whatever could be retrieved from a $75,000 investment in a shaky wildcat venture made by his elder brother and some associates. Little did he realize the involvements to which this would lead.

Possessed with the spirit of a true entrepreneur, fascinated by the idea of prospecting for oil, and imbued with the impassioned desire to bring prosperity to the inhabitants of his newly adopted home community, he acquired the interests of his brother and associates and dedicated himself wholly to his new-found task.

The first step in this task led to the assumption of lease obligations held by the Texas Southern Oil and Lease Syndicate in the Luling area. This syndicate had assembled leases covering most of what is now the Salt Flat and Darst Creek fields as well as about 85 percent of the Luling field. Many of these leases had to be dropped for lack of finances, but the Luling block was retained on the basis of a fault exposed in the San Marcos River and the mapping of an inlier of lower Wilcox against it. The fault discovery is credited to Vernon E. Woolsey; additional work by him, Carroll E. Cook, Roy A. Dobbins, and others resulted in definition of the lower Wilcox inlier on this up-to-the-coast fault. The Syndicate's first well was drilled in 1920 on the Thompson lease in the George C. Kimball survey, Caldwell County. It was abandoned as a dry hole in the Buda limestone, 150 feet above the Edwards, but shows of oil and gas in the

[7] The use of "FAITH" is in deference to Edgar B. Davis who always capitalized the word in his writing. H. Miller Ainsworth, Chairman of the Board, First National Bank in Luling, and Mrs. Joe Davis, private secretary to Edgar B. Davis, personal communication, September 1958.

Eagle Ford furnished encouragement for additional drilling.

Edgar Davis named his new enterprise, organized March 18, 1921, United North and South Oil Company, Inc., as a Yankee gesture of friendship toward the unregenerated planters of a colloquial southern agricultural community. After taking over the holdings of Texas Southern Oil and Lease Syndicate, a well was started on the Cartwright farm, about a quarter of a mile closer to the surface fault trace than the Syndicate's Thompson hole. It had a small show of oil in the Edwards, as did No. 2 Cartwright drilled about 500 feet up dip. On May 5, 1921, No. 3 Cartwright was spudded and was completed as a dry hole on June 16. Cartwright No. 4 followed at a nearby location and also was dry. Then No. 2 Thompson proved to be a failure.

Undaunted by six disappointing dry holes and with little left of the $1,300,000 on which he started his venture, Edgar Davis made a seventh location on the Rafael Rios 126-acre farm in the John Henry survey. This well was spudded June 19, 1922, and according to Foree (1947, pp. 2–3) the hot afternoon of August 9, 1922, found a depressed if not totally discouraged group of three United North and South people, Edgar Davis, Agnes Manford, and W. F. Peale, watching the hypnotic rotary grinding away at 2,100 feet. Just as Peale, at the wheel of their car, was about to drive away, Miss Manford is reported (Foree, 1947) to have pointed and shouted in a most undignified way:

> "Look, Boys, look!" A black column was rising from Rafael Rios No. 1; the crew was scattering. The column was rising higher, higher, like an aroused giant snake. Miss Manford and Peale quickly piled out of the car as the black column rose higher, rose up above the crown block, and began to spray the black, gummy stuff of which millions are made.[8]
>
> No one knows exactly what was said after that. Peale and Miss Manford were a bit hysterical. For the charming bachelor who had furnished so many pleasant evenings at cards or talk; for the employer of Peale who had never looked back, never faltered, never lost his beatific smile; for the strange man who seemed half of the present material world and half of the heavenly world to come, they were overjoyed.
>
> And Davis himself? That gentle smile grew a bit more expansive perhaps, he was quieter, if anything, and he retained that ever present dignity. Yes, the foreordained had come to pass. The Lord, though the instrument of Edgar B. Davis, had achieved another objective, and in the end Davis, drenched with oil, reminded that he must go to town.
>
> To Luling went the oil spattered trio and when the giant Davis was asked if he wanted to go to the hotel to change clothes he said, "No, first to Mackey's Drugstore." And they called for J. R. Mackey, who had been sure Davis was chasing a will-o'-the-wisp and had said so. Mackey came out, stared, threw up his hand and said with awe, "The drinks are on me. Anything you want. Anything."
>
> Thus the story of Luling is in a way the story of Edgar B. Davis, who would walk into a fiery furnace if his Lord ordered, yet belonged to no church, who is Luling's godfather, but who at 77 had never married; the Yankee who has walked with princes and kings, but who has spent his happiest years among the descendants of Rebels who love him.

On August 10, 1922, the Luling boom began, gaining momentum slowly at first, because oil men were skeptical of Edwards production. Magnolia Petroleum Company came forward with an offer to buy 1,000,000 barrels of oil in the ground at 50 cents a barrel. Edgar Davis and his associates accepted with alacrity, and the $500,000 provided by this deal financed early development of the Luling field. Extension from the discovery area northeastward, a distance of 1.6 miles, was established on March 13, 1923, by Caldwell Oil Company No. 1 Hardeman, which made gas. On May 23, 1923, Royal Oil Company completed a well for over 1,000 barrels a day on their W. H. Tabor lease of 40 acres, later acquired by Grayburg Oil Company. This extended the field 2½ miles northeast of the Rios No. 1 discovery well. The rate of drilling increased after these extensions, and many wells were completed with initial production of 1,000 barrels a day or more.

According to Ernest W. Brucks (1929, p. 261):

> By December 31, 1923, about 90 producers had been completed. One of the most significant developments in the field during 1923 was the

[8] John E. Mowinkle, who was General Superintendent of the United North and South Oil Company, in personal conversation says Foree is in error on this statement. The Rios No. 1 made mostly black sulfur water, and it was No. 1 Merriweather, drilled several months later, which was being swabbed when it blew oil over the car occupied by Davis, Peale, and Miss Manford.

completion of the United North and South Oil Company's Marines No. 1 in Guadalupe County, an extension of nearly four miles southwest of the Rios discovery well. The Marines well was located about 800 feet southeast of the fault and came in as a 300-barrel producer. On December 31, 1924, the field had 391 producing wells, and by the end of the year 1926, the total number of wells was 502.

In the spring of 1926, display advertisements appeared on the financial pages of several well-known newspapers stating that the Luling field properties of the United North and South Oil Company were for sale. It is reported that several major oil companies considered the deal and made offers, but probably because the production was from limestone, and many of the fabulous Mexican fields of the same type were suddenly beginning to make salt water, no trade was consummated immediately. The Magnolia Petroleum Company, having bought the first production from the field and with pipeline facilities in place, met the advertised price of $12,-100,000. The deal was consummated on June 11, 1926, on a basis of half cash and half in oil as produced.

As Kenneth Foree, Jr. (1947) says in his booklet:

That should have been the end of the saga of Edgar B. Davis. The man of 56 had more money than any man would ever need. But the strange New Englander recognized something that not many men do, an obligation to those who help them make fortunes. And the benevolent, unusual man of vision went about it in the more unusual way. First he announced a barbecue to which Luling, Caldwell County, Guadalupe County, former employees, friends over the world, and—well practically everyone—were invited. He bought a herd of beeves, all the soda water and ice cream in Central Texas, imported entertainers from New York, and purchased and cleared for the jubilee 100 acres of land white with cotton at harvest time.

Come one, come all, advertised Davis. And pretty nearly everyone did, or so it seemed. The most conservative authorities estimated 15,000 while others looking at the sea of faces, swore not less than 40,000 were there. And the 15,000 or 40,000 were not only fed but electrified. Every employee drew a bonus. Those who had been with him one year drew 25 per cent of total salaries paid them, two years' service brought 50 per cent, and four years 100 per cent. Most of them got dollar for dollar, and five men on his firm's management committee, K. C. Baker, W. F. Peale, J. E. Mowinkle, S. H. Rabon and B. Rayner, received checks for $200,000 each.[9]

The youngest clerk and toughest roughneck were rich over night. Some bought farms or businesses or capitalized on it like loyal Miss Kate Nugent, who went off, studied chiropractic and came back to practice in Luling. But much of it, the easy-come easy-go type, went for fast living.

A couple of million it must have cost Luling's benefactor for bonuses alone. But there was more to come, a $50,000 golf course later built on that $150,000 cleared cotton patch, a $50,000 Negro athletic clubhouse, a $150,000 total endowment for the upkeep of both. Not even the Texas wildflowers, particularly those beautiful bluebonnets that had nodded and smiled the mystic on, were forgotten. An annual $10,000 wildflower painting contest was announced on which was ultimately spent $50,000.

But something bigger was in the mind of the town's benefactor who later put into writing approximately what he said that day and which best reveals the magnificent obsession of the man. "Believing that the kind and generous Providence, Who guides the destinies of all humanity, directed me in the search for the discovery of oil . . ." he wrote, "And believing that the wealth which has resulted has not come through any virtue or ability of mine, but has been given to me in trust; and desiring to discharge in some measure the trust which has been reposed in me; and in consideration of the opportunity which the resources of Texas gave me; and of my interest in the welfare of the citizens of the city of Luling, Caldwell, Guadalupe and Gonzales Counties; . . . and realizing the evils of the one-crop system; and in the hope through research of experimental work in diversified crops of aiding the tillers of the land to secure a larger return for their labor. . . ." With such a promise a man who has something of the ethereal in him proceeded to establish the Luling Foundation for the benefit of agriculture with $1,000,000. In another breath he gave his native town of Brockton $1,000,000 for the charitable Plymouth Foundation, at the same time disclosing that he would live and die in Luling.

Of the $6,050,000 cash paid by Magnolia, thus at least $4,000,000, possibly $5,000,000 had been given away.

Much more has been written about Edgar B. Davis and far more could be written if the man of mystery had left written records or if he had communicated more freely with his associates, but here there is occasion to point out only a few phases of his later years.

The greatest monument to his memory undoubtedly is the Luling Foundation.

[9] In recent conversation, John E. Mowinkle relates that there were two entertainment areas, one for Negroes attended by 15,000 and one for whites attended by 20,000. He also states that the amounts received by the administrative officers were as follows: K. C. Baker, $500,000; W. F. Peale, $250,000; J. E. Mowinkle, $250,000; S. H. Rabon, $100,000; C. B. Rayner, $100,000.

Regarding it he is quoted[10] as having said in Board Meetings of the Foundation: "We builded better than we knew." And under the Presidency of H. Miller Ainsworth this has proved to be literally true. The institution is a recognized service organization beneficial to the agricultural community of all south-central Texas. The Foundation still is worth over a million dollars, notwithstanding many donations and contributions to worthy projects in the area, and is entirely self-supporting.

Another philanthropy was Edgar Davis' support of "The Ladder," a religious play written by a boyhood friend on the theme of reincarnation. A million and a half dollars are said to have been spent in maintaining this theatrical on Broadway for over a year where the average paid attendance was half a dozen persons at each performance.

Probably the most distressing event of his life was the instigation of a suit for income taxes by the State of Massachusetts which claimed him a citizen years after he had established his home at Luling and had declared his intention of living and dying there. The case could have been settled at one time, after long and costly litigation, for $25,000, but the obstinate Davis said no; he would pay nothing. The estate was forced to make a final settlement after his death.

Income from the oil produced at Luling went into new exploration by the newly organized United North and South Develment Company which resulted in the finding of some good production in the Darst Creek field. This property was sold to the Louisiana Oil and Gas Company in 1928 for $500,000 in cash and $1,500,000 in oil, but when the depression hit and the price of oil dropped to ten cents a barrel the deal fell through. Davis took back the Darst Creek leases and agreed to pay back ten cents a barrel on produced oil until the Louisiana Company recovered the purchase price.[11] Income from this property and a residue of the income from Luling production went into additional exploration leading to the discovery of the Buckeye field in Matagorda County. Development of this field proved so costly (production was from below 10,000 feet) that resurces of the United North and South Development Company were depleted in 1935. Edgar B. Davis again demonstrated his "FAITH" and determination by refusing to sell this property for the $1,000,000 offered him.

He is quoted as having said (Foree, 1947): "No. It is worth $100,000,000." As to quitting exploration the magnificent man disclosed his most magnificent obsession by saying simply, "The Lord is going to reward my "FAITH" with another fortune greater than I have ever seen. It is up to me to maintain "FAITH" so I can receive it and reward others less fortunate than I."

One regrets to reveal that Fate proved cruel in the end by removing the great man from the scene, on October 10, 1951, before the United North and South Development Company was able to recoup and realize the second vast fortune Edgar B. Davis had dreamed about. Who knows but that it was for the best, thus sparing him vicissitudes such as were imposed by his earlier spectacular success. His complete saga when it is written will reveal a depth of faith totally unfazed by difficulty.

In the original purchase from United North and South, Magnolia acquired approximately 60 percent of the Luling field. Later acquisition of other properties increased the Company's ownership to better than 90 per cent. Producing problems required much attention during the four or five years following the purchase from United North and South, and it was not until the late thirties that appreciable new drilling was attempted. The total number of producers in 1939 was 593, and in 1946 the number was 675 (Davis and Goode, 1957). A late surge in development activity occurred in 1946 when cooperative effort between United North and South Development Company and Magnolia led to the drilling of a deep test on the northeast end of the field. This well, while unsuccessful

[10] H. Miller Ainsworth, personal communication, September 1958.
[11] John E. Mowinkle, personal communication, August 1958.

in the beds below 3,000 feet on which the United North and South had retained all rights, cut a fault which defined a previously unknown fault segment productive in the Edwards. A total of 230 new wells were drilled after 1946, of which 42 were in the new segment. All of this development was carried on by Magnolia. Infill drilling to complete spacing patterns contributed much additional oil from undrained portions of the reservoir, mainly from the less porous and more permeable dolomitic beds of the producing section. Working over old wells in these zones also improved their performance. At present there are about 550 producing wells in the field.

It is estimated that at least 1,200 wells have been drilled in Luling field. The productive area approximates 2,300 acres. Peak production was obtained in July 1924 with an average of about 47,000 barrels daily from 350 wells. In 1926 daily production averaged around 20,000 barrels, and the yield per acre at that time amounted to about 15,000 barrels. The rate declined gradually until 1946 when the daily take was about 3,000 barrels a day. This increased, as a result of new drilling and workover operations, to 6,700 barrels a day in 1955. Since then there has been a general decline, and the present rate (June 1958) is 5,400 barrels daily. Brackish sulfur water has been produced with much of the oil since the first discovery on the Rios lease. In the early days this water after separation from the oil was allowed to follow natural drainage into the San Marcos River. In 1948 a salt water disposal system, which returns the water to the Edwards below the producing zone, was installed by Magnolia at a cost of $1,341,-000. Currently, over 300,000 barrels of water daily are being injected.[12]

The comeback at Luling is due in large measure to the aggressiveness of Russell Clymer, Magnolia's District Production Superintendent, who in 1946 was transferred to Luling from the limestone-producing area of Kansas and who worked in close cooperation with the San Antonio District geological office. Cumulative production of record is approximately 110,-000,000 barrels. It is interesting to note that Brucks (1929, p. 281) in June 1927 gave a cumulative figure of 31,672,000 barrels as of December 31, 1926, and estimated total ultimate recovery in excess of 40,000,000 barrels. Since that time numerous reserve estimates have fallen short, and it is very difficult to arrive at a sound figure.

Luling field and its discoverer merit much more time and space than can be allotted in this paper, but their importance can scarcely be overestimated. A new production trend was opened which has been actively explored for 36 years.

Larremore Field

Activity grew apace along the Luling fault trend following the United North and South discovery, and many tests were drilled before additional commercial production was obtained. A surface structure and fault were mapped during 1926 in an area about 3 miles west of Lockhart, Caldwell County (Weeks, 1930). Half a dozen tests were drilled in this general locality by various operators; one test, the Wilford et al. No. 1 Schroeder, had a good show in the Edwards lime. Roxana Petroleum Corporation (now Shell Oil Company) assembled a lease block around the A. W. Jolly farm in the C. Crenshaw survey and refined the structural picture by means of core holes.

Their Jolly No. 1 was spudded in May 12, 1928, and was completed a month later for 25 barrels of oil a day with considerable sulfur water from the Edwards at a depth of 1,351 feet. Roxana's No. 2 Jolly encountered the Edwards at 1,268 feet, or 37 feet structurally higher than No. 1, and had an initial production of 300 barrels of oil daily. It flowed about 15 barrels a day but was completed as a pumper. This field is small; a total of only ten producing wells had been completed prior to 1948. At this time the Southern Producing Company took over the properties, which were

[12] Oscar Goode, District Engineer, Magnolia Petroleum Company, Luling, personal communication, September 1958.

no longer producing, and started a new development program. They drilled 22 wells, 19 of which were completed as producers in the top few feet of the porous Edwards.

In 1948 when all wells had been abandoned total recorded production amounted to 360,000 barrels. Following the new drilling program a peak production of 125 barrels a day from 18 wells was attained in 1952. As of January 1, 1958, 17 wells had produced 22,944 barrels during 1957, and the cumulative production since 1948 amounted to 266,175 barrels. The area of the field is about 250 acres.

Salt Flat Field

The fault line play led to speculation regarding the source of salt water which was seeping to the surface in an area immediately northeast of the town of Luling. That it probably came up along a fault seemed patent, and the presence of lower Wilcox, where terrace and alluvial deposits which cover the country roundabout permitted bedrock to be observed, led to test drilling in the area. According to McCollum, Cunningham, and Burford (1930, p. 1402) the first production obtained here was from the Austin at 2,450 feet in the Sullivan et al. (later Bruner et al.) No. 1 Davis on May 28, 1928. However, a log filed by the Luling Oil and Gas Company with the Texas Railroad Commission indicates that their No. 1 Carter well in the Gerron Hinds league was spudded February 2, 1927, and reported shows in the Austin from 2,430 to 2,460 feet. Their No. 2 Carter was started May 8, 1928, and drilled into the Edwards with minor oil shows. Several other Austin wells were completed in the area including Golden West Oil Company No. 1 Malone, which had an initial production of 500 barrels daily. The Sun Oil Company drilled their No. 1 Malone in search of the same pay, but it had only a small Austin showing and they deepened the hole to the Edwards. This well made the Edwards discovery on October 19, 1928, with an initial production of 720 barrels a day flowing through a slotted liner at a depth of 2,712 to 2,742 feet. It is located about a mile northeast of Luling townsite in the A. Floyd survey. Peak production in the field was reached in mid-1929 at about 50,000 barrels a day. It dropped off rapidly and by January 1, 1930, the figure was 30,000 barrels daily. This resulted in much discouragement as to the prospects at Salt Flat, but production levelled off in the thirties and in 1957 the Edwards probably accounted for one-third of the 781,500 barrels of oil produced during the year. A total of about 360 wells had been drilled for Edwards production over an area of approximately 2,000 acres. The field reached a low point in 1953, with 177 producing wells and cumulative production at 33,000,000 barrels (Hendy, 1957, pp. 23–29). Since 1954 about 100 new wells have been drilled for Austin, Eagle Ford, and Buda production. Cumulative production to January 1, 1958, is 35,046,914 barrels. Daily production in April 1958 was 2,050 barrels average of which one-third, or about 700 barrels, is estimated to be Edwards oil. The Edwards wells at Salt Flat may be making better than 98 percent water, which is slightly higher than the ratio at Luling and Darst Creek.

Darst Creek Field

The Luling fault system is shown on a generalized map of the Coastal Plain of Texas (Deussen, 1924, p. 132). The faulted belt extends southwestward across Guadalupe River and terminates south of San Antonio in Bexar County. Although there is nothing on the map to localize the fault in the immediate area of Darst Creek in Guadalupe County, Roscoe E. Schutt[12a] stated that he recognized faulting in the Darst Creek area in 1923 but many other faults were found, some of them much more pronounced than the one at Darst Creek. Independent search of drainage courses by the late A. B. Bauchman resulted in the discovery, or perhaps the rediscovery, of slickensides and steep dips in a tributary gully of Darst Creek. Educated as a lawyer but qualifying as a first-rate

[12a]Personal communication, July 24, 1928. Mr. Schutt was a geologist for Roxana Petroleum Company at the time of the fault-line activity; he now is a consultant at Tulsa, Oklahoma.

amateur geologist, Mr. Bauchman recognized the significance of his find and brought it to the attention of the well-known surface geologist Dilworth Hager, who at the time was mapping in the vicinity of Lockhart, Caldwell County. The late Hilmer H. Weinert, with whom Bauchman was associated, joined in support of detailed surface work in the faulted area, and Dilworth Hager, with the assistance of Robert Frank, prepared a geologic map in September 1928. When the work revealed closure against a typical up-to-the-coast fault, a large lease block was assembled by Weinert, Bauchman, and Hager, parts of which were then sold to various companies for development.

The scientific methods used in exploring the Darst Creek area and the planned location of the first well near the center of the closure against the fault led to a spectacular discovery on the initial test. This was The Texas Company No. 1 Dallas Wilson, which this company had an obligation to drill as part of the lease consideration. It was completed on July 18, 1929, flowing over 1,000 barrels of oil a day from open hole in the Edwards at a depth of 2,603 to 2,610 feet.

Development in this field at first was slow due to the generally depressed economy and particularly because of the overproduction of oil in south-central Texas. In an attempt to forestall the erratic drilling and heavy flush production which occurred at Luling and Salt Flat, the operators agreed to conduct development in an orderly and systematic manner under the direction of an umpire. On January 1, 1930, he issued the first schedule for 15,369 barrels to be prorated among the operators according to their proven 20-acre units and the average potential production of wells in each unit. This daily allowable was 68 percent of the 22,397 barrels of the field's potential at that time. Drilling accelerated greatly following this agreement, and the daily potential increased during early 1930 to a peak of 245,864 barrels on May 1. The continuing state of overproduction in the industry made it necessary for the umpire to reduce the allowable to 9 percent on the latter date. The voluntary proration gradually broke down after so stringent a restriction, and pipeline runs increased from a daily average of 28,201 barrels in June to 50,763 barrels a day in October. The Texas Railroad Commission then took over regulation of the field and beginning on October 29, 1930, restricted the daily allowable to 30,000 barrels. This volume was continued until March 14, 1931, when it was reduced to 20,000 barrels. On October 17, 1931, the allowable was cut back to 18,000 barrels, which figure was maintained through December 1931 (McCallum, 1933).

Darst Creek has been one of the best regulated fields as a result of being placed under proration early in its development, and as a whole the operators cooperated very satisfactorily. This prevented calamitous overproduction and brought about systematic development of the field. Undoubtedly this has kept producing costs lower and will result in much greater ultimate per-acre-foot recovery than will be true of the earlier Edwards fields.

Several wells of phenomenal initial production were completed, such as John Camp No. 1 Sue Denman, which made 6,000 barrels of oil a day, and The Texas Company, Sun, and Gulf Knoblock wells, which are reported to have had very large initial production. Most prolific of all was Magnolia Petroleum Company No. 1 M. E. Roamel, which blew out while drilling and made a proration test of 41,928 barrels daily. It flowed 1,621 barrels of oil the first hour and 1,747 barrels the second hour through 6⅝-inch casing from a crevice in the Austin. The oil is thought to have come from the Edwards reservoir. This well was exhausted in a very short time, and the offset location had a potential of only 750 barrels daily. Two other wells drilled on the lease were dry.

At the time that Railroad Commission control was imposed there were 250 producing Edwards wells. These increased to 350 by January 1937 and to 500 at present. The maximum yearly production of

11,550,000 barrels was reached in 1930 but declined precipitously immediately thereafter because of strict proration and stood at about 2,000,000 barrels in 1940. During World War II the rate was increased, reaching 3,425,000 barrels in 1944, then declining to around 2,500,000 barrels in 1951 (Hendy, 1957, p. 32). New drilling and workovers starting at this time brought the field to a new peak of 3,200,000 barrels of Edwards oil in 1955. Production in 1957 was 3,380,307 barrels. In April of 1958 Darst Creek was producing at the rate of 281,148 barrels monthly, which includes about 10 percent of oil from beds younger than Edwards. Total cumulative production to January 1, 1958, is 95,613,140 barrels, of which 92,500,000 is estimated to have come from the Edwards. The area of the field is approximately 2,000 acres.

Water has been produced with the oil from many wells since they were first brought in, and water disposal has been a serious problem. Water formerly was retained in a large surface reservoir, but as the quantities increased this became impracticable. All produced water now is injected by disposal wells into the Edwards formation below the oil zone. The ratio of oil to water now is 96 percent, but production is likely to last for another ten years.

Branyon Field

Branyon field in Caldwell County is included with Luling in the Railroad Commission reports, but it is a relatively new producer from the Edwards on the Luling trend. The presence of faulting northeast of the Luling field has been known since the earliest exploration along this trend, and Brucks (1927, p. 837) defined the Burdett Wells and Cibolo faults in 1927. Drilling was attempted as early as 1928 and some Austin chalk production resulted. It was not until 1955 that a trap in the Edwards was discovered. Hoxey Oil Company No. 3 Ross in the Samuel Shupe survey was the first completion on March 2, 1955. It pumped 91 barrels a day from perforations in the Edwards at 2,328 to 2,358 feet. Since the discovery, 32 wells have been completed in the Edwards. Their productive rates have varied from 20 to 91 barrels per day (Hendy, 1957, pp. 32–33). Cumulative production to date is estimated at 450,000 barrels. The field has an area of 175 acres.

INTERMEDIATE FIELDS

Surface geology received much attention during the later twenties and the early thirties down dip from, but generally on strike with, the Luling fault trend. One of the best-defined and most promising prospects resulting from the work is the Pearsall anticline in Frio County. It was mapped in 1929–1930 by L. W. Clark of the Amerada Petroleum Corporation.[13] This Company in a joint effort with the Rycade Oil Corporation then acquired a lease block of 20,000 acres on the favorable area and carried out a core-drilling program over the acreage in 1930. A seismograph survey followed in 1931, and as a result of this work the Company leased another 60,000 acres. A well to test the Edwards, Halff and Oppenheimer No. 1, was begun on August 28, 1932, and reached the total depth of 6,312 feet on January 1, 1933. The Edwards, encountered at 6,302 feet, carried a strong odor of oil, gas, and hydrogen sulfide, but the show did not justify an attempt to complete the well and it was abandoned. In 1937 the hole was worked over and completed as an oil well in the Austin. This first well had been located near the middle of the Pearsall structure. A second well, Amerada No. 1 Doering, located near the southwest end of the Pearsall anticline on a closure separated from the main structure by a saddle, was started on August 18, 1933, and was completed March 3, 1934, for a reported 1,500 M cubic feet of gas daily from the Edwards at 6,453 to 6,459 feet and the Georgetown at 6,351 to 6,363 feet. The well had to be abandoned in a short time. This area has since proved to be productive in the Olmos sand and is designated Doering field. After detailed seismic work in 1933, Amerada and Rycade drilled No. 2 Halff and Oppenheimer, located about 3 miles northeast of No. 1 Halff and Oppenheimer, to a depth of 10,050 feet. At 6,000 feet it entered the Edwards, which tested sulfur water. This hole, after being plugged back, made 16,000 M cubic feet of gas from the Olmos sand and thus became the discovery well of the Pearsall field.

The Pearsall field, although it has not produced commercially from the Edwards, is important in the history of Edwards production because the effort expended in exploring this area contributed information which has been very useful in later phases of Edwards exploration. Much credit is due the Amerada staff[14] who pioneered in this field.

The Imogene-Jourdanton-Charlotte fault system in central Atascosa County, which is a southwestward continuation of the Mexia-Milano-Tanglewood-Smithville fault trend,[15] was discovered by surface geology. Henry D. McCallum, working out of the San Antonio District Office of Humble Oil & Refining Company, mapped the Imogene structure in 1934. This Company assembled a block of 6,500 acres on the prospect early in 1935, but no tests were drilled until 1942. About a year after the Imogene area had been worked, surface faulting was found in the Charlotte area as McCallum's exploration continued westward to the Atascosa-Frio County line. Other operators, notably The Texas Company and Magnolia Petroleum Company, were active in the area by this time. Nevertheless Humble succeeded in leasing 7,000 acres on their new prospect, Magnolia somewhat less, and other operators picked up scattered leases in the play.

A gravity meter survey of the area by Humble followed the surface geology in 1937. Subsequently core drilling verified the displacement of both the Imogene and Charlotte faults. Reconnaissance seismic operations in 1940 confirmed the surface work, showing closure along the upthrown side of both the Imogene and Charlotte faults. In addition it pointed out the Jourdanton area, where surface faulting had

[13] A. Roger Denison, personal communication, July 1958.

[14] Sidney Powers, Chief Geologist, Tulsa, Oklahoma; A. Roger Denison, Division Geologist, Fort Worth, Texas; L. A. MacNaughton, District Geologist, San Antonio, Texas; O. C. Lester, Geophysical Supervision.

[15] Henry D. McCallum, personal communication, 1958.

been recognized but was not recommended because of its complexity. East Imogene also was a seismic prospect.[16] All of these faults are up-to-the-coast or with the downthrown block to the northwest.

George H. Clark of The Texas Company between 1935 and 1938 made a detailed study of Claiborne exposures from the Guadalupe River in Gonzales County to Pearsall in Frio County which led to his discovery of the Charlotte field anomaly in 1936. Upon Clark's recommendation The Texas Company acquired a block of about 3,000 acres in leases, much of which proved to be highly productive in the Olmos sands. Leroy Fish, well experienced in surface geology, also recognized the structural features of this area while working for The Texas Company. Seismic surveying in 1946 and 1947 closely tied down the surface indications of faulting in the Charlotte-Dobrowolski trend.[17]

Magnolia Petroleum Company and several independent operators obtained varying amounts of acreage in the play, but the bulk of the production is on Humble and Texas Company leases.

Imogene Field

The first test drilled along the Imogene-Charlotte trend was Humble Oil & Refining Company No. 1 M. L. Thompson wildcat, completed October 8, 1942, as an oil well from the Edwards at 7,563 to 7,576 feet. This became the discovery well of the Imogene field (named for a nearby townsite and railroad siding) and the first proven occurrence of Edwards oil or gas at a depth greater than 2,650 feet. The Thompson was a marginal well making only 38 barrels of oil per day and 71 barrels of salt water on pump. It was followed by dry holes on the A. C. Soechting and Duren and Richter leases, the latter terminating in the top of the Sligo at a depth of 9,390 feet. The first good production came from Humble's H. H. Coward No. 1 well in June 1944, which made 270 barrels of oil daily, but with a high gas ratio. Imogene field now has 25 oil wells and two gas wells. Peak oil production was reached in 1946 with a total of 248,000 barrels. This declined to 122,000 barrels in 1950 but increased to 138,537 barrels in 1951 after the treating plant south of Jourdanton began processing the gas from Imogene. A second peak of 140,000 barrels was reached in 1952, but the rate has declined since and amounted to 97,055 barrels for the year 1957. Cumulative production to January 1, 1958, is 2,110,000 barrels of oil. The productive area is approximately 1,050 acres.

Charlotte Field

Charlotte field Edwards production was discovered in Humble Oil & Refining Company No. 3 E. J. Pruitt in August 1944. Pruitt No. 1 proved to be outside the closure and was dry. Pruitt No. 2 was on the downthrown side of the fault on the Edwards and dry. Depth to the Edwards in the producing zone is near 6,900 feet, with the wells cutting an up-to-the-coast fault of 400 to 600 feet displacement. Production figures are not available because the Railroad Commission consolidates Edwards production with the Navarro, which is highly productive in the field. Of the 17,343,901 barrels total cumulative production to January 1, 1958, probably about one-fifth came from the Edwards. Total production for the year 1957 was 1,027,369 barrels, including oil from the Navarro. There are 14 Edwards producing wells in an area of 470 acres.

Jourdanton Field

The prospective area south of the town of Jourdanton, Atascosa County, which had been somewhat neglected by Humble in the urgency of activities at Imogene and Charlotte, soon attracted the attention of several other operators. Magnolia Petroleum Company started a seismic crew on what was known as the Christine surface prospect in November 1943; by October 1944 that crew had surveyed a wide strip across central Atascosa County. This enabled Magnolia, and several other operators who made localized surveys, to obtain favorable leases. However, Humble drilled

[16] Henry D. McCallum, personal communication, July 1928.
[17] George H. Clark, personal communication, August 1958.

the discovery well in their No. 1 Henry Schorsch, originally completed as a gas well on December 25, 1945. The first oil well was Humble Oil & Refining Company No. 1 Moursand, completed April 19, 1946. Development proceeded slowly because of war-time restrictions, and relatively few dry holes were drilled. Like all other south Texas Edwards fields discovered up to this time, the trap is formed by closure against an up-to-the-coast fault with 500 to 600 feet of vertical displacement. The average depth of the Edwards is 7,300 feet and closure is about 350 feet. In the early stages of development an attempt was made to establish zones of porosity separated by impervious beds. Experience in producing from the reservoir has indicated that there is intercommunication throughout the field and the gas-oil, water-oil contacts are uniform. Operators in the Edwards field are Humble, Magnolia, Pan American, Delta Gulf, Plymouth, and American Republics Corporation (now Sinclair Refining Company). On January 1, 1958, there were 37 flowing and 17 pumping wells in the Edwards reservoir. Oil produced in 1957 amounted to 256,837 barrels, and cumulative production to January 1, 1958, is 4,-059,709 barrels. Area of the field is approximately 4,600 acres.

Muil Field

The Muil field is situated down-dip from the Pleasanton field and the wells encountered the Edwards at an average depth of 8,950 feet. The trap is formed by an up-to-the-coast fault which bends southeastward across the regional strike and has a closure of about 100 feet. The structure was discovered by a seismic survey. Quintana Petroleum Corporation drilled the Muil lease, in which Magnolia Petroleum Company has a part interest, early in 1946 but abandoned the well as a dry hole because the top of the Edwards was tight and the drill stem test was negative. Later, in January 1947, it was deepened and completed as a gas well at 8,870 feet, in the Georgetown, but open to junked drill pipe and collars at the total depth of 9,012 in the Edwards. The gas probably comes from the Edwards. Quintana's Muil No. 2 and No. 3 were completed as oil wells in 1946. Wells Nos. 4 and 5, drilled in late 1946 and early 1947, were dry holes. The gas well made 263,000 M cubic feet of gas and 6,680 barrels of distillate during its productive life of two years. The two oil wells made 7,731 barrels of 42° gravity oil in 1957, and the cumulative production to January 1, 1958, is 134,418 barrels. The area covered is approximately 270 acres. Recently the Quintana interest has been acquired by Gulf Oil Corporation. An attempt to extend the producing area proved unsuccessful.

Imogene, East Field

East Imogene is a much later discovery along the northeastern extension of the Imogene-Charlotte fault system. The discovery well, drilled in October 1947, is Humble Oil & Refining Company No. 1 Gordon and Dinsmore. It was completed in the Edwards at 8,093 to 8,104 feet for 32 barrels a day of 33° gravity oil with a relatively high gas-oil ratio. Maximum oil production was obtained in 1948 at 48,800 barrels. Since 1952 the production has been gas-distillate, and the peak of this phase of production was reached in 1952 when the total gas amounted to 1,420,500 M cubic feet and the condensate totaled 41,560 barrels. This increase resulted from a connection having been built to the Lone Star plant at Pleasanton field. In 1957 the gas produced was 1,355,120 M cubic feet and the distillate 27,595 barrels of oil from four wells. Cumulative production to January 1, 1958, is 37,800 barrels of oil, 203,-782 barrels of condensate, and 8,541,800 M cubic feet of gas. The area assigned to production is approximately 1,250 acres.

Pleasanton Field

Pleasanton field is a Lone Star Producing Company's discovery on an up-to-the-coast fault of about 400 feet displacement. The average depth to the Edwards is 8,100 feet. The first well was Lone Star No. 1 Ferry, completed January 1, 1951, for 128 barrels of oil per day. Later wells had high gas-oil ratios, and the gas is cycled. Oil was produced until 1956 when the total cumulative production from five producing wells, with two injection wells, was 13,085,125 M cubic feet of gas and 3,131 barrels of condensate. The area of the field is approximately 885 acres. Closure amounts to 200 feet with 165 feet in the gas cap and 35 feet in the oil column. The field is unitized and pressure is maintained through a recycling plant. Reserves have been calculated at 9,000,000 barrels of oil and distillate and 31 billion cubic feet of gas. Recovery of 2,000,000 barrels of liquid hydrocarbons by recycling is estimated and 23 billion cubic feet of gas with 20 barrels of liquids per million after recycling operations cease (Knebel and Jones, 1957).

Pleasanton, South Field

Pleasanton, South, is a very recent (1957) discovery falling between the Imogene and East Imogene fields. The first well was Mosbacher et al. No. 1 Charles T. Troell, completed in March 1957 for 7,900 M cubic feet of gas open flow with a gas-oil ratio of 32,840:1. The Edwards pay is at a depth of 8,182 to 8,190 feet. There are only two wells in the field, both shut in because the gas is sour and scrubbing plant facilities are not yet available. Area under production in this field is estimated at 640 acres.

Tanglewood Field

The Tanglewood area near the northern corner of Lee County for many years has been recognized as a complex fault prospect. Most of the wells drilled to test the Edwards had shows of oil. Humble Oil & Refining Company made two small completions in 1948. Their No. 2 Vick had an initial production of about ten barrels of oil per day from open hole in the Edwards at 6,332 to 6,341 feet, and the No. 1 Johnson made 29.91 barrels of oil daily from open hole at 6,317 to 6,324 feet. Both wells were abandoned after producing a few thousand barrels.

Chriesman Field

The complicated faulting of the Tanglewood area in Lee County extends northeastward into the western part of Burleson County near the town of Chriesman. Several wells have been drilled to the Edwards, and one of these, Red Bank Oil Company No. 1 Coffield, was completed in May 1938 as a small producer. With pipe at 6,168 feet and the hole bottomed at 6,184 feet, initial production after acidizing is given as 40 barrels of oil a day and 100 barrels of salty sulfur water. The well did not prove to be commercial, and abandonment became necessary within a few months.

DEEP EDWARDS FIELDS

Exploration for production from the Edwards formation at depths below 10,000 feet has been based largely on seismic surveys. Available surface and subsurface geological control relates to Wilcox development and except for some faulting furnishes meager information on Edwards prospects. The first deep test was started in 1940 when the Quintana Petroleum Corporation drilled the South Texas Syndicate No. 3, in northeastern LaSalle County, to 11,042 feet. This well blew out on an attempted open-hole drill-stem test but was brought under control with weighted mud after two days. Completion efforts failed because the well had been drilled into water. Discouraged by this expensive attempt to obtain production, Quintana did not try again for deep Edwards until 1945, when they drilled No. 3-D South Texas Syndicate in the Green Branch area of McMullen County. This well reached a total depth of 15,301 feet with no shows recorded. The Gulf Oil Corporation drilled an unsuccessful Edwards test early in 1945 in the Weigand Carrizo-Wilcox field, which had been developed on the basis of a surface fault mapped in the vicinity of Fashing, Atascosa County (Pinkley, 1958). The possibility of Edwards production closer to the fault was recognized by George R. Pinkley and others, but several years elapsed before additional drilling resulted in the discovery of the Fashing field. Stanolind Oil and Gas Company attempted a deep test with their No. 1 Henry, located 6 miles northwest of Tilden, McMullen County. This well required nearly a full year to drill and was abandoned July 6, 1948, at a total depth of 14,046 feet in the Lower Cretaceous Hosston formation. It entered the Edwards at 10,310 feet with interfingering Kiamichi facies to 10,545 feet where reefing occurs. Shows of oil and gas were obtained from the upper part of the Edwards, but the porous zone was in the water and the well could not be completed as a commercial producer. The next deep hole, No. 1 Archbishop of San Antonio, drilled during 1949 in central LaSalle County by Plymouth Oil Company to 12,542 feet, had no Kiamichi and entered good Edwards reef limestone at 10,400 feet. Difficulty encountered in making drill-stem tests from the Edwards, although shows of oil were found in cores, necessitated abandonment of the well. In 1950 H. R. Smith drilled the No. 1 J. C. Dilworth, which went from Upper Cretaceous Taylor shales into clear rock salt at approximately 7,700 feet. This established the presence of salt domes along the deep Edwards trend (Kimmell, 1957). Phillips Petroleum Company No. 1-A Washburn Ranch in McMullen County which started December 1, 1951, was abandoned six months later in the Glen Rose at 16,410 feet. Another deep failure, Phillips No. 1 LaSalle Company in central LaSalle County, terminated July 11, 1952, at 12,000 feet in tight Edwards limestone. Neither of these Phillips wells furnished any evidence of salt dome or reefing but penetrated only normal marine sediments.

San Miguel Creek Field

The discovery of deep Edwards production is credited to the Humble Oil & Refining Company in their No. 1 Louis M. Gubbels well drilled during the summer of 1953. This well blew out when a drill-stem test was attempted at 10,178 feet, but it was brought under control and completed through open-hole perforations at 10,149 to 10,182 feet for 70,000 M cubic feet of gas per day on ⅛-inch choke. This production is from highly fractured Edwards on a deep salt dome, as indicated by seimic surveys. Since this discovery, one additional Edwards well has been drilled but the formation proved to be too tight for a completion. This one-well Edwards gas field has been shut in awaiting the installation of a large treating plant and the completion of new pipelines to furnish a market for the gas.

Stuart City Field

Southwestern LaSalle County was investigated by the Stanolined Oil and Gas Company (now Pan American Petroleum Corporation) in the early fifties. Martin L. Johnson and J. B. Souther prepared a geological report and, with the aid of a seismic survey, developed an exploratory program. The prospect did not receive urgent consideration, however, until cores from the Edwards in Plymouth's Archbishop well were examined. The definite reefing characteristics and oil staining found in these cores by J. B. Souther convinced Stanolind that their Stuart City prospect merited drilling.[18] Stanolind No. 1 Martin was begun September 15, 1953, and, true to expectations, encountered an Edwards reef at 10,030 feet. This proved to be a bioherm built up to the base of the Buda limestone of the Washita group near the top of the Comanche Cretaceous. This well was completed February 2, 1954, from perforations at 10,092 to 10,120 feet for an initial estimated 4,700 M cubic feet of gas daily. Five additional Edwards wells have been drilled on the prospect some of which have reefing up to the base of the Eagle Ford, but only three of these were completed. All four productive wells have been shut in awaiting plant facilities and pipeline connections.

Syndicate Field

H. R. Smith No. 1 South Texas Syndicate is the discovery well for this field in McMullen County. It was completed January 20, 1954, from perforations at 10,658 to 10,682 in an Edwards biohermal reef. The initial production has been estimated at 4,200 M cubic feet of gas a day on open flow with a small smount of 47.6° gravity distillate. This one-well field is shut in awaiting plant facilities and a market for the gas.

Washburn Field

Standard Oil Company of Texas opened this field with the drilling of South Texas Syndicate, Lease 2, No. 1, in east-central LaSalle County on February 14, 1955. Completed from open hole in the Edwards between 10,258 and 10,346 feet, the well made an estimated 10,500 M cubic feet of gas and 11 barrels of distillate per million per day. A second well completed by the same operators as the South Texas Syndicate, Lease No. 2, in April 1955 reported an initial production of 6,000 M cubic feet of gas per day from the upper Edwards perforated at 10,228 to 10,300 feet. The gas-oil ratio is given as 276,000:1. Both wells are producing.

Dilworth, Southeast Field

This field was brought in by Standard Oil Company of Texas with their No. 1 Mrs. Mary Jean Dilworth, which is located on a seismic prospect. The area is about 4½ miles southwest of Tilden, McMullen County. The well, completed on February 14, 1955, from perforations at 11,170 to 11,270 feet in Edwards reefing made an initial test of 11,300 M cubic feet of gas daily and 1.4 barrels of distillate per million cubic feet of gas. Two wells have been completed as producers to date. They are connected to the Transco pipelines.

Cooke Field

This is a one-well field discovered by Stanolind Oil and Gas Company No. 1 C. N. Cooke located near the geographical center of LaSalle County. Completed February 4, 1956, the initial production is reported to have been 4,600 M cubic feet of dry gas on open flow. It is from Edwards reefing at 10,286 to 10,326 feet. At present a one-well field, production is shut in awaiting development.

Henry Field

The early test drilled on the G. W. Henry ranch by Stanolind in 1947–1948 proved to be off structure, and it was not until August 1956 that Standard of Texas brought in the field with the drilling of their No. 1 J. B. Henry. This well is completed from Edwards porosity in open hole at 10,549 to 11,060 feet for 40,000 M cubic feet of gas and 18 barrels of distillate daily.

[18] J. B. Souther, personal communication, July 1958.

Presently a three-well field, it has been tied into the Transco pipeline.

Lowe Ranch Field

Newman Brothers of San Antonio found Wilcox production on the Lowe ranch, 11 miles southwest of Tilden, in 1951, but Amerada Petroleum Corporation No. 1 Ethel L. Craig, completed September 5, 1956, is a discovery well for the Edwards field. Drilled to a total depth of 14,479 feet, it topped the Edwards at 14,085 feet, Stratigraphers are not in full agreement as to the section drilled in the lower part of this hole, but the Amerada geologists and several others, including the writer, presently hold that the sediments are of deep-water origin with 2,100 feet of Georgetown and Kiamichi overlying the Edwards. The latter is hard and dense but highly fractured. Production is from the fractured zone with performations at 13,681 to 14,479 feet. The volume has been estimated at 97,500 M cubic feet of gas per day with a little distillate. A second test drilled in 1957 had to be abandoned because of mechanical difficulties, and the third hole, completed in March 1958, was dry. Gas from this field is sweet and has had a ready market.

White Kitchen Field

Coon and Dunwoody, drilling a Carrizo-Wilcox prospect 15 miles southeast of Cotulla, LaSalle County, discovered the White Kitchen (Wilcox) field in October 1954. Edwards production was found two years later when Lee Brothers Oil Company No. 2 Storey encountered gas at 10,400 feet. The well is completed through perforations at 10,407 to 10,430 feet for 1,800 M cubic feet of dry gas per day and is on a producing status. Pan American Petroleum Company, Texam Oil Corporation, and Luling Oil and Gas Company have interests in this well with Lee Brothers.

Mula Pasture Field

Phillips Petroleum Company drilled their No. 1 Mula in the Mula pasture of the Washburn ranch located 6 miles south of Fowlerton in McMullen County near the LaSalle County line. This well discovered Mula field Wilcox oil in September 1952. It was April 1957 before Jupiter Oil Company drilled a deep test to explore the Edwards in their South Texas Syndicate No. 2. This well is completed through perforations at 10,533 to 10,577 feet for an estimated open flow of 12,800 M cubic feet of dry gas per day. Like many other sour gas wells of this general area, production is shut in awaiting marketing facilities.

Dilworth Field

The Dilworth field is originally a lower Wilcox discovery brought in by H. R. Smith on the J. C. Dilworth lease located 7 miles west of Tilden, McMullen County, October 11, 1950. Humble Oil & Refining Company No. 2 J. C. Dilworth discovered the Edwards production in September 1957. This well is completed from perforations at 10,670 to 10,765 feet in the upper part of the Edwards for an estimated 36,500 M cubic feet of gas a day with 5.7 barrels of distillate per million. At present it is the only Edwards producer in the field. The original Smith well encountered salt at 7,710 feet, thus establishing the structure as a salt dome. Production is largely a result of fracturing in the Edwards.

Isaacks Field

Standard Oil Company of Texas in September 1957 completed the No. 1 J. V. Isaacks located on a seismic prospect 7 miles southwest of Three Rivers, Live Oak County. It is perforated in the Edwards at 12,456 to 12,736 feet and has an original potential of 1,122 M cubic feet of gas daily on $\frac{1}{4}$-inch choke. This is a one-well field shut in awaiting marketing facilities.

Fashing Field

The Fashing (Edwards) field has an interesting history because the discovery of commercial gas production did not occur until 12 years after it was first tested early in 1945 when Gulf Oil Corporation drilled the No. 1 Ada Tom to a depth of 10,528 feet. A drill-stem test from the top of the Edwards at 10,370 feet to the bottom of the hole showed a low working pressure over 3,000 feet of water cushion, and a recovery of 7,000 feet of black sulfur water with a strong hydrogen sulfide gas odor. Following the report of this discouraging test, no more deep exploration occurred until 1952. In March of that year H. R. Smith drilled the No. 1 H. A. Schumann to 10,666 feet, topping the Edwards at 10,533 feet. Abandonment followed unsatisfactory drill-stem tests. The area afterward received consideration for additional deep exploration by several operators, but the risk seemed too great to merit another well at the time.

Lone Star Producing Company, following their successful discovery of oil and gas in the Pleasanton field of Atascosa County, engaged in an active search for additional reserves from the Edwards formation. Knebel (1956, p. 117) said:

> In the course of this work it was noted that closure was present in the Fashing area on a known fault zone having a throw of approximately 300 feet at the 3,700-foot, or Carrizo-Wilcox level, such closure at this depth being proven by Carrizo oil production. The absence of Edwards production against the Edwards trace of this fault was conspicuous and inconsistent with other similar situations in the county. As you know, in general when an accumulation of oil and/or gas is found in one bed on the upthrown side of an up-to-the-coast fault in this area, and if that fault is the dominant sealing factor, drilling usually reveals additional producing zones on the same fault block. This concept is certainly not new, but it led to the Fashing (Edwards) discovery and will very probably be responsible for locating many similar fields in the future.

Following the subsurface study of the area, a lease block was assembled by Lone Star and surveyed with the seismograph to insure the location of a favorable drilling site. This proved to be the L. J. Urbanczyk No. 1-A at the high point of closure against the Edwards fault trace. The well, after thorough coring and open-hole testing, was completed January 9, 1957, through perforations at 10,790 to 10,816 and 10,824 to 10,850 feet for a potential of 36,000 M cubic feet of gas and 18½ barrels of distillate per million feet of gas. The top of the Edwards is at 10,216 (–9,807) feet, and the bottom of the hole is in the Glen Rose formation.

Other operators who have made successful completions in the field to date are Gulf Oil Corporation, Christi, Mitchell and Mitchell, and George Coates. There are now 15 producing wells with drilling operations still in progress, and the limits of the field not definitely defined. Extension of production both northeastward and to the southwest on other fault blocks is highly probable. Wildcat wells are drilling in both directions.

Lone Star Producing Company and Gulf Oil Corporation have completed treating plants which will sweeten the gas and may recover sulfur as a by-product. Reserves of gas in the Edwards are estimated at several trillion cubic feet and will keep the plants in operation for many years in the future. The treated gas now is entering the United Gas Company pipeline system.

Webb County

Recent exploration has extended the search for Edwards oil and gas southwestward to the Rio Grande in Webb County. The well-known surface feature designated Pescadito dome now proves to be a true salt dome as evidenced by the presence of rock salt in Ginther, Warren, and Ginther et al. No. 1 O. W. Killam. Originally intended to be an Edwards test, this well went from Upper Cretaceous, Taylor, into anhydrite at 14,350 feet and entered salt at 15,070 feet. The operators drilled salt to 15,107 feet and abandoned the hole August 19, 1957. Ginther, Warren, and Ginther, Gulf Oil Corporation, and M. T. Halbouty have drilled a second Edwards test as the No. 1-A Killam at a location 8,000 feet northwest of Killam No. 1. It reached a total depth of 19,503 feet but did not penetrate the Edwards. Production in the area from Wilcox sands has been found by Ginther, Warren, and Ginther, thus establishing the Pescadito field.

Northwest of Pescadito a distance of approximately 22 miles, Amerada Petroleum Corporation drilled the Rosa Benavides in 1949 to a depth of 11,679 feet, which was short of the Edwards. Hamman Oil and Refining Company re-entered this well in March 1958 deepening it to 13,856 feet where it was abandoned in August. In the writer's opinion this well still had not reached typical Edwards.

West-northwest of the Rosa Benavides, another 20 miles, the Copano Oil Company et al. have drilled the Desiderio Trevino No. 1 to 9,110 feet. Edwards reefing was encountered at 8,815 feet. The well has a potential test of 2,700 M cubic feet of gas a day. Galan (Edwards) has been proposed as the field name for this new discovery. It indicates a probable extension of the Stuart City reef trend toward the southwest and opens a large area for additional prospecting.

EDWARDS PRODUCTION IN EAST TEXAS

Exploration for Edwards production in east Texas has resulted in several discoveries in Fredericksburg limestones. Edwards as known in south Texas does not occur in the east Texas basin, and the producing zones there are facies of the Goodland and Walnut-Paluxy formations. In the upper part of the Gulf Coast region on the flank of the Sabine uplift, however, occurrences of reef limestone in the Fredericksburg correlate rather clearly with the Edwards of south Texas. No Edwards fields of major importance are present anywhere in east Texas, but they are included in this paper to make the record as nearly complete as possible.

South Bosque Field[19]

The oldest production of oil from rocks of Fredericksburg age in Texas was from the South Bosque field located 8 miles southwest of Waco. This discovery occurred about 1902 in the Goldstine-Migel No. 1 Grim well at approximately 500 feet. The producing zone consists of 1 to 3 feet of lenticular sand in the lower Walnut-Paluxy, or basal Fredericksburg. The field covers an area of approximately 2,000 acres and had a maximum of 60 wells in 1933. The number of producing wells declined to two in 1949, and the cumulative production to April 1950 amounted to 131,674 barrels (Price, 1951). In 1953 a water flood was started, and some additional oil has been recovered. The production in 1957 was 5,285 barrels, but definite figures on the cumulative are not available.[20]

Longwood Field

The Longwood field lies astride the Louisiana-Texas boundary, but most of the Washita-Fredericksburg (Edwards) production is on the Texas side in Harrison County. The discovery resulted from subsurface and seismic mapping. Triangle Drilling Company opened the Edwards production with the No. 1 F. M. Hearne et al. in August 1933 at approximately 2,400 feet. Trapping of the oil is due to unconformable relationships between the Fredericksburg and Washita beds (Buchanan, 1951, p. 207). The Texas Railroad Commission listed 180 wells in 1957, producing a total for the year of 338,486 barrels of oil. The cumulative production to January 1, 1958, is 625,481 barrels.

West Shelbyville Field

Shows of oil in old shallow wells 6 miles southwest of Center in Shelby County, on the south flank of the Sabine uplift, led to the discovery of oil in a Fredericksburg limestone in 1936. The Shelby County Oil Company drilled the No. 1 W. C. Windham into the Fredericksburg and completed the well as a small producer at 3,126 to 3,144 feet in localized limestone porosity (Cash, 1951). The oil is 36.4° gravity and has an intermediate paraffin base. Three wells were completed in this zone but only one is now producing. Peak production occurred in 1940 and declined to 298 barrels in 1957. The cumulative production to January 1, 1958, amounted to 17,356 barrels.

Glendale Field

Glendale field, in west-central Trinity County, is a Magnolia Petroleum Company prospect drilled in 1941–1942 for Wilcox production. In 1945 Magnolia drilled the Bolton No. 2 to test the Edwards. This well was completed in August of 1945 at 10,500 to 10,540 feet for 38,000 M cubic feet of sour gas daily on open flow. Since there is no market for this gas the well is shut in. Several other wells have been completed for oil in Woodbine sands.

Madisonville Field

The Madisonville field, located on the Madison-Grimes County line, is an original Wilcox subsurface and seismic prospect on

[19] South Bosque field in a strict sense is not geographically within east Texas, but its production is more closely related to that province than to production from south-central Texas fields.

[20] John Mulligan, Geologist, Magnolia Petroleum Company, Tyler, personal communication, 1958.

which Magnolia Petroleum Company acquired a lease block in the early 1940's. West Production Company also obtained leases in the area and drilled an Edwards test, in which the Magnolia has a half interest, on the Boring lease. This well, West Production Company No. 1 Boring, was completed October 7, 1947, at 9,236 to 9,271 feet in the Georgetown and Edwards for 2,000 M cubic feet of gas and 39 barrels of distillate per day. In April 1958, production amounted to 700,000 cubic feet of gas and 200 barrels of distillate. Cumulative production to January 1, 1958, was 1,325 M cubic feet of gas and 40,000 barrels of distillate. This is the only Edwards well in the field.

Harold Orr Field

A gravity anomaly and geological information just east of Bremond in Robertson County led Magnolia Petroleum Company to make a seismic survey of the area in 1943.[21] Core drilling which followed indicated additional favorable geology, and a lease block was assembled. In 1949 Magnolia drilled the No. 1 Kopercgak to test the Edwards; the well was dry.

K. L. McKenry took a farm-out on the acreage in 1953 and drilled two Edwards tests on an up-to-the-east fault. Both wells had shows of oil in the Edwards, but they were abandoned. B. B. Orr later took over the operation and in June 1957 drilled the No. 1 George Abraham between the two McKenry dry holes. This well discovered gas in the Edwards, and with perforations at 4,726 to 4,730 feet it had an initial production of 5,300 M cubic feet per day with 5.5 barrels of distillate per million. A second well drilled by Orr was dry. The field is shut in for lack of a market.

[21] John Mulligan, Geologist, Magnolia Petroleum Company, Tyler, Texas, personal communication, July 1958.

CONCLUSION

The evidence furnished by this historical outline leaves no doubt but that the Edwards formation has proved to be one of the most prolific producers of oil and gas in south Texas. Luling field with its cumulative production of not less than 110,000,000 barrels of oil, Darst Creek with 92,000,000 barrels, and Salt Flat recording more than 35,000,000 barrels, attest to this statement and the end is not yet, because it is estimated that ultimate recoveries from these fields will add an average of at least 10 percent to the 1958 cumulative figures. The later discoveries of gas in south Texas are just getting into production, but the reserves are substantial, and the Edwards definitely will furnish fuel to the gas transmission lines for many years in the future. Moreover, exploration has not exhausted the Edwards possibilities, and new fields probably of large potential likely will be discovered.

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Plates 4–38

PLATE 4

A. Locality 154-T-1, west end of Santa Fe Railroad cut near Valley Mills, Bosque County. Rudistid biohermal reef and onlapping inter-reef deposits. The bioherm is 11 feet thick. See Plate 3 for cross section of lithofacies and Plates 16, 17, and 18 for photographs of lithology.

B. Locality 154-T-2, 1 mile north of Crawford on State Highway 317, McLennan County. Rudistid biostromal reef overlain by granular limestones and fine shell debris of inter-reef facies. See Plates 12, 13, and 14 for photographs of lithology.

C. Locality 154-T-15, east bank of Hog Creek, McLennan County. Massive reef flank beds; the reef core is located to the left of the photograph.

D. Locality 154-T-12, old crossing of Bluff Creek, 3 miles west of Crawford. Massive reef flank deposit overlain by granular limestones and fine shell debris of inter-reef facies. Reef flank deposit shows incipient bedding.

E-G. Locality 154-T-16, Childress Creek, 4 miles north of China Springs, McLennan County. Upper surface of reef core. Dolomite (dark patches) fills the body chambers and has replaced the shell wall of some fossils. For photographs of lithology, see Plates 19 and 30. Dolomite also fills small cracks and pores in the matrix. All of these occurrences appear to be the result of void filling rather than direct recrystallization.

H. Locality 154-T-11, Bluff Creek, 2.5 miles northwest of Crawford, McLennan County. Massive reef flank deposit overlain by granular limestones and fine shell debris of inter-reef facies. For photographs of lithology, see Plates 12, 14, and 15.

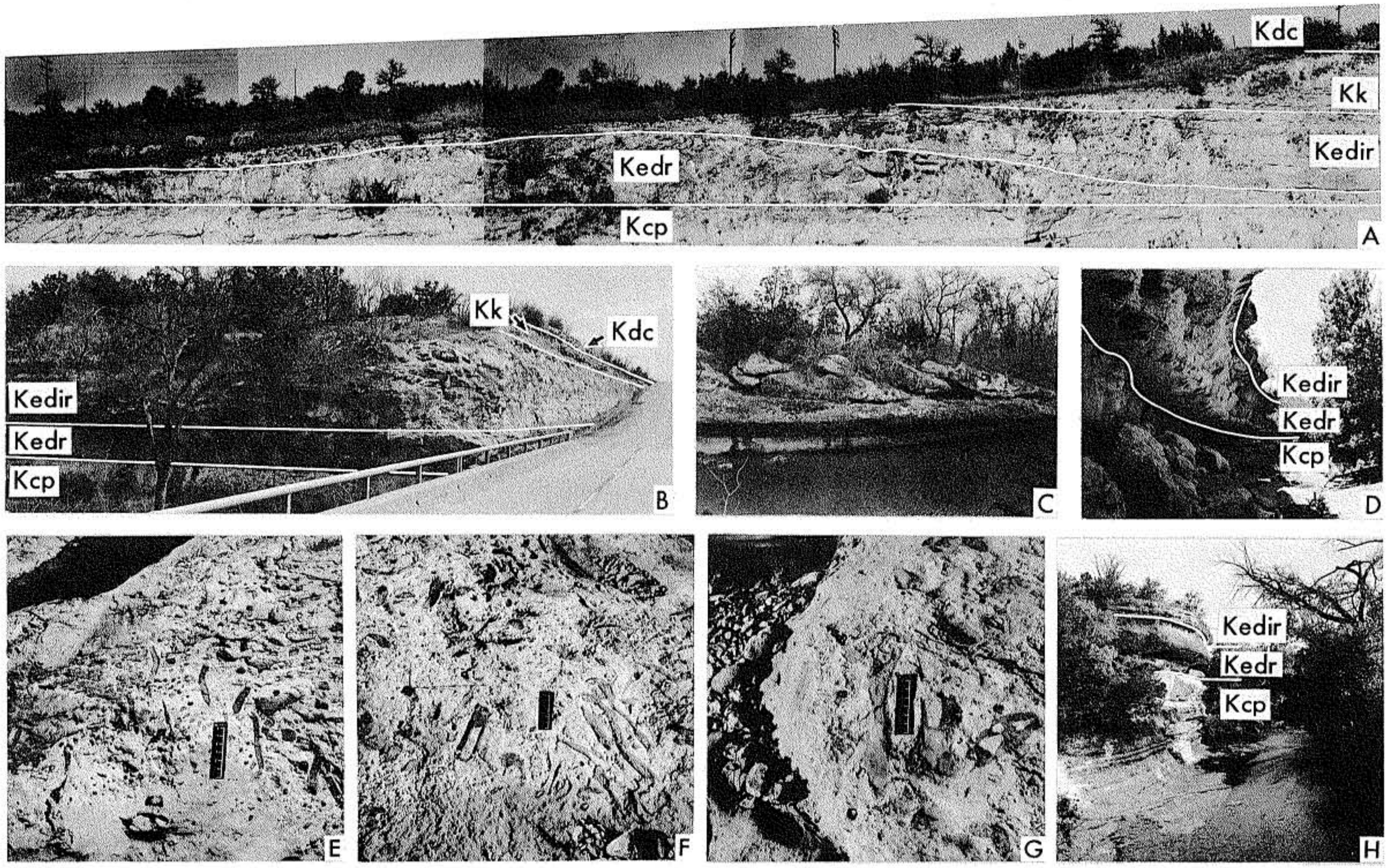
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Plate 4

PLATE 5

LOCALITY 154-T-14 AND 14A

A. Biohermal reef. Reef flank consists of tongues of reef core and beds of shell debris. Beds dip as much as 30°.

B. Massive reef flank deposit overlain by well-bedded granular limestones and fine shell debris of inter-reef facies. The reef flank shows incipient bedding and contains some thin lenses of detrital limestone. At this point, approximately 13 feet of the reef is exposed and the relief on its upper surface is 3 feet. When seen from a greater distance, it becomes apparent that the inter-reef facies is cross-bedded on a very large scale and each bed is successively a topset, foreset, and bottomset bed as it is traced to the north (to the right in the photograph).

C. Close-up view of reef core in the river bed.

D. Upper surface of the Edwards limestone. This pitted and oxidized surface is very characteristic of the top of the formation throughout the area. See Plates 13, 14, and 15 for photographs of the lithology.

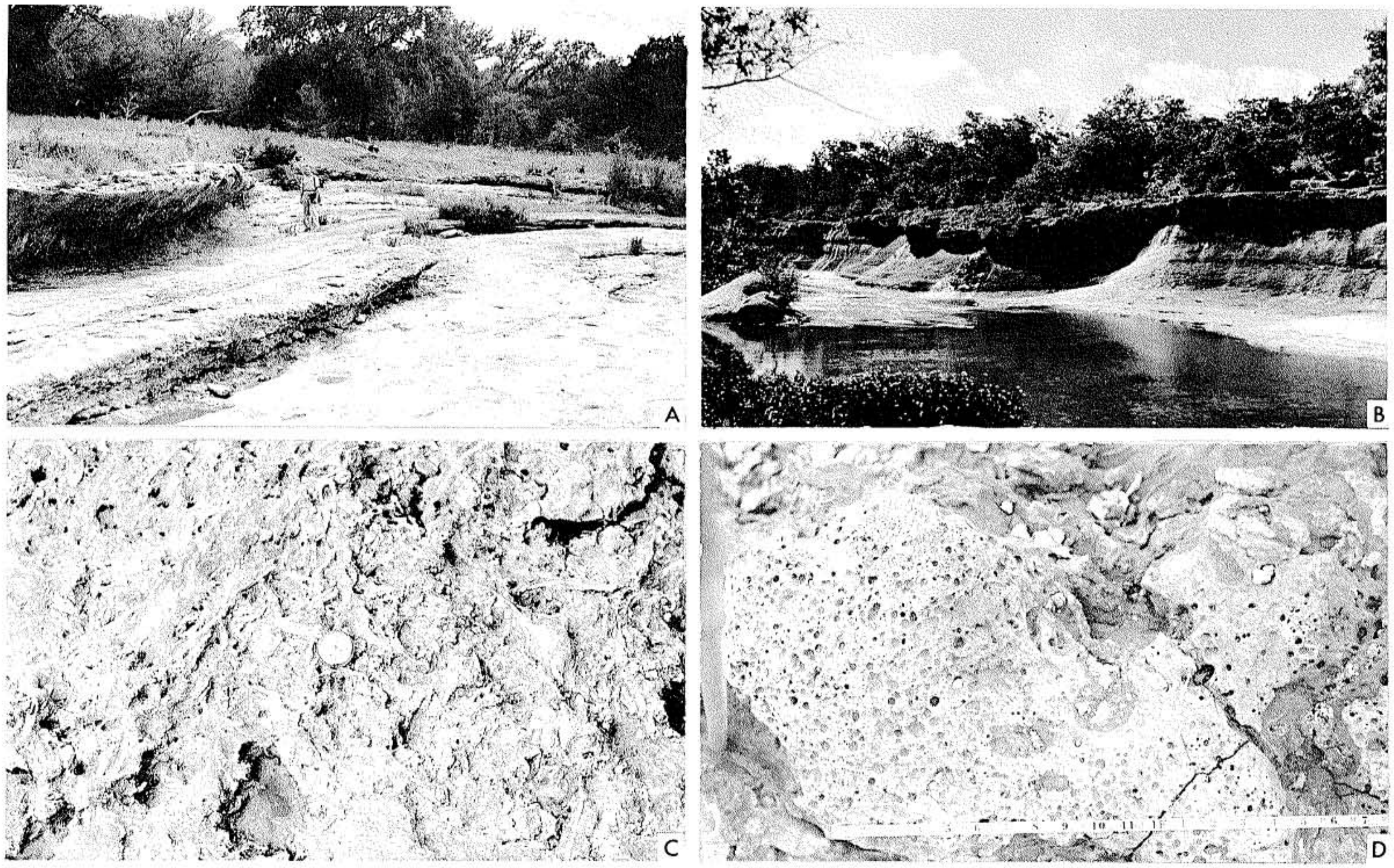


Plate 5

PLATE 6

A. Locality 50-T-4, Bluff Creek, north of Osage, Coryell County. Depressions in inter-reef limestones. Most of the chert which formerly occupied the depressions has been removed by stream erosion.

B. Locality 50-T-8, roadcut on U. S. Highway 84, approximately 6 miles east of Gatesville, Coryell County. Well-bedded cherty limestones of inter-reef facies. The massive bed at the base of the outcrop consists of coarse granular limestone and fine shell debris; it is laterally equivalent to the reef flank deposits shown on Plate 7, C.

C, D. Locality 50-T-6, abandoned quarry on U. S. Highway 84, 3.3 miles east of Gatesville, Coryell County. See Plate 3 for cross section of lithofacies and Plate 27 for photograph of lithology.

C. Reef core. Most of the fossils in the upper part of the quarry are preserved as molds.

D. Contact between the reef core and the reef flank sediments. The flank beds are composed of shell debris. Large fossils, whole or broken (but unabraded), are fairly common. These deposits grade laterally into the reef core (to the right as well as to the left) and they dip away from the core with an inclination of 30°.

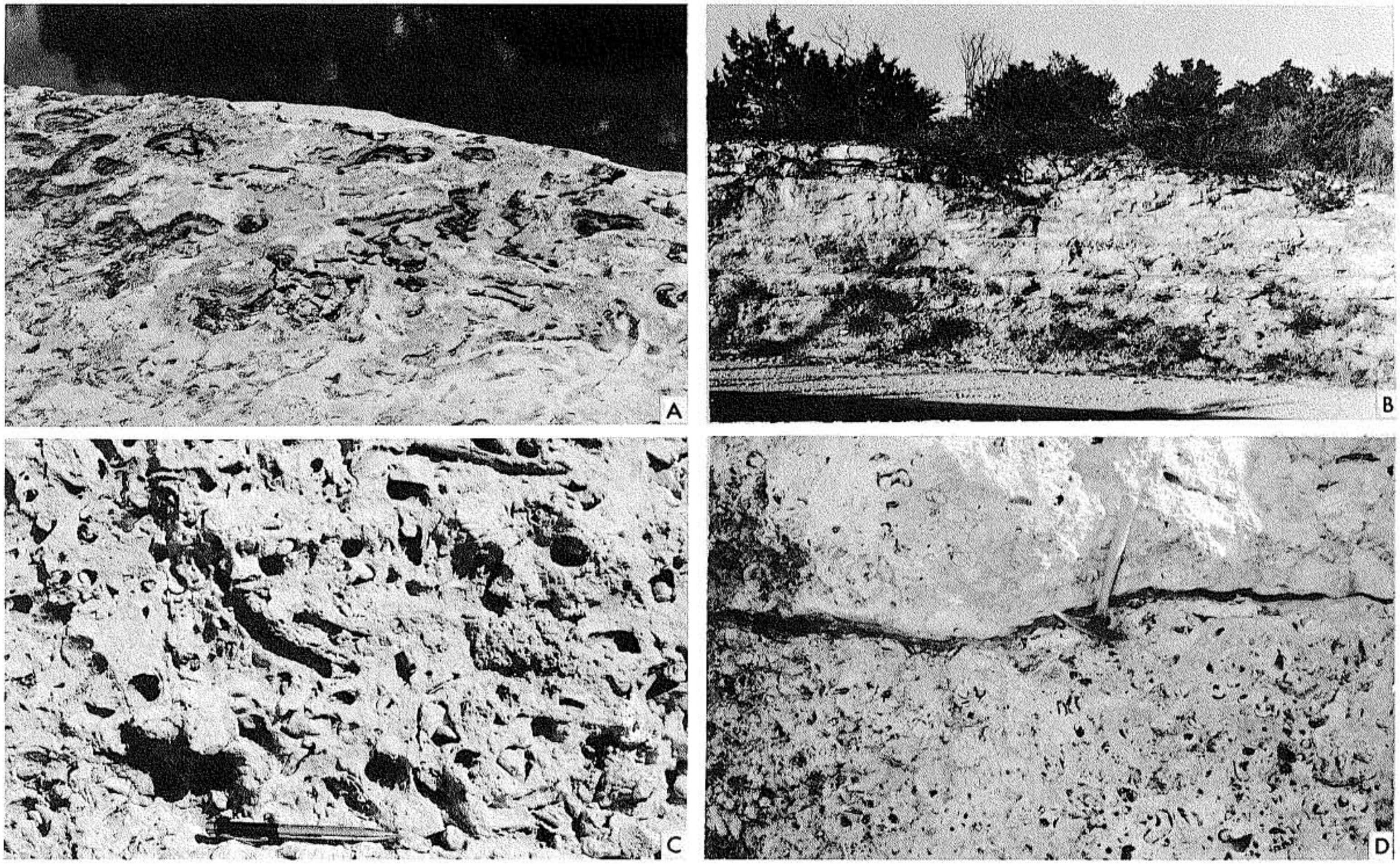


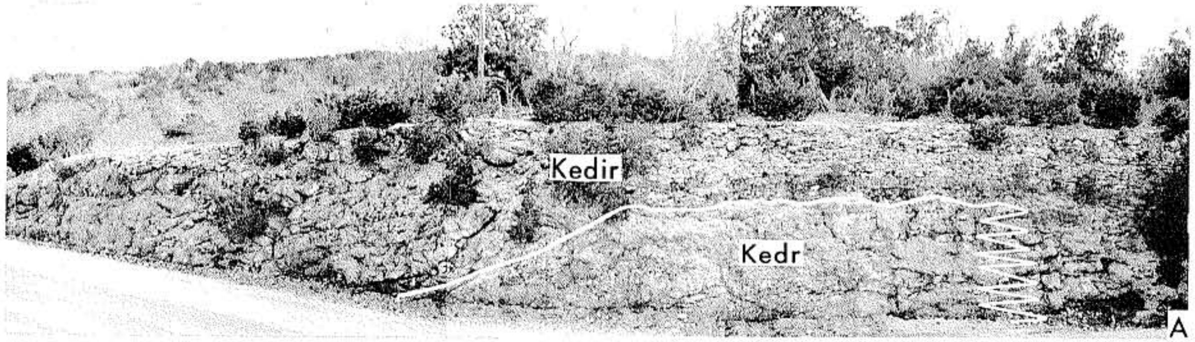
Plate 6

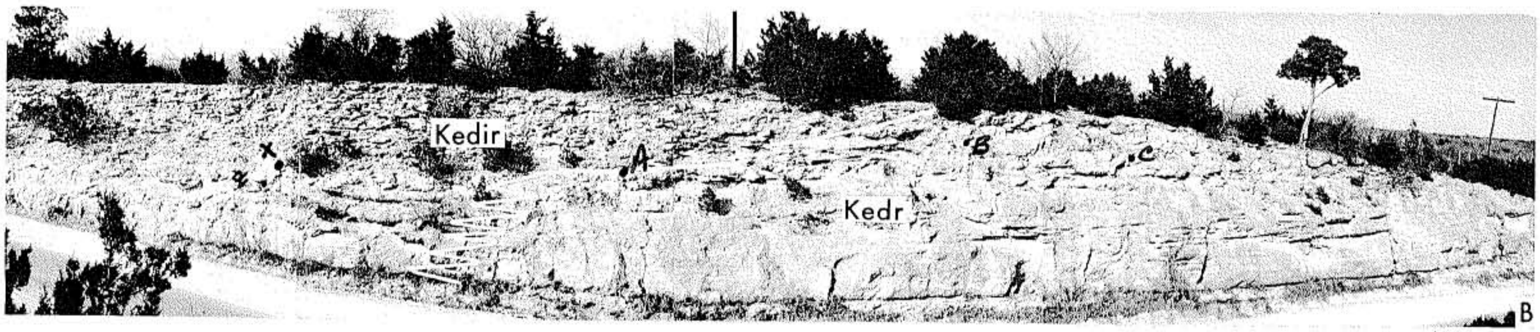
PLATE 7

A. Locality 50-T-7, south wall; roadcut on U. S. Highway 84, 4.5 miles east of Gatesville in Coryell County. The massive reef core is flanked by very coarse reef debris and is overlain by very fine-grained cherty limestone (calcilutite).

B. Locality 50-T-7, north wall. Massive reef flank deposit is overlain by very fine-grained cherty limestone of inter-reef facies. The reef flank deposit, though massive, shows incipient bedding upon weathering. For photographs of lithology at this locality see Plates 19–22; lithofacies are shown on Plate 3.

C. Locality 50-T-8, roadcut on U. S. Highway 84, approximately 6 miles east of Gatesville, Coryell County. Reef flank deposits consist of very coarse shell debris. These deposits are overlain to the west (left side of photograph) by very fine-grained cherty limestone (calcilutite). See Plates 20 and 22 for photographs of lithology and Plate 3 for description of lithofacies.





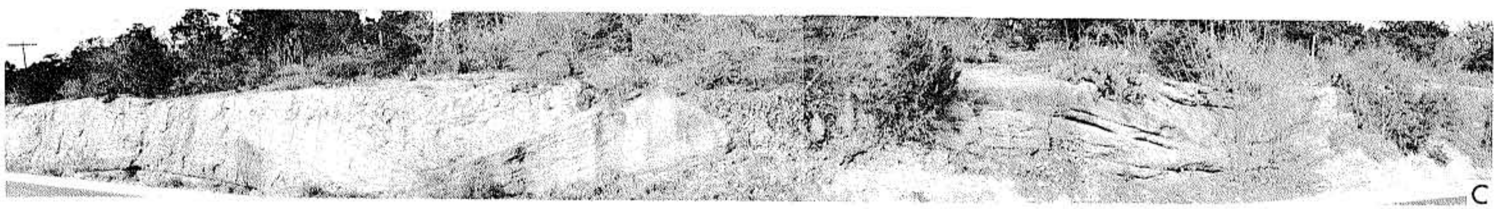


Plate 7

PLATE 8

LOCALITY 50-T-7

A. Reef core in south wall. See Plates 19 and 21 for photographs of lithology.

B. Interbedded chert and very fine-grained limestone (calcilutite) of inter-reef facies. See Plates 20 and 22 for photographs of lithology.

C. Chert nodules in north wall. Fine laminations in the limestones are bent around the chert nodules and indicate that the chert was in the position it now occupies prior to lithification.

D. Microfaults in the inter-reef facies, north wall. The displacement rarely exceeds one-fourth of an inch; no faults cross a bedding plane. These microfaults are believed to have originated as a result of compaction prior to complete lithification.

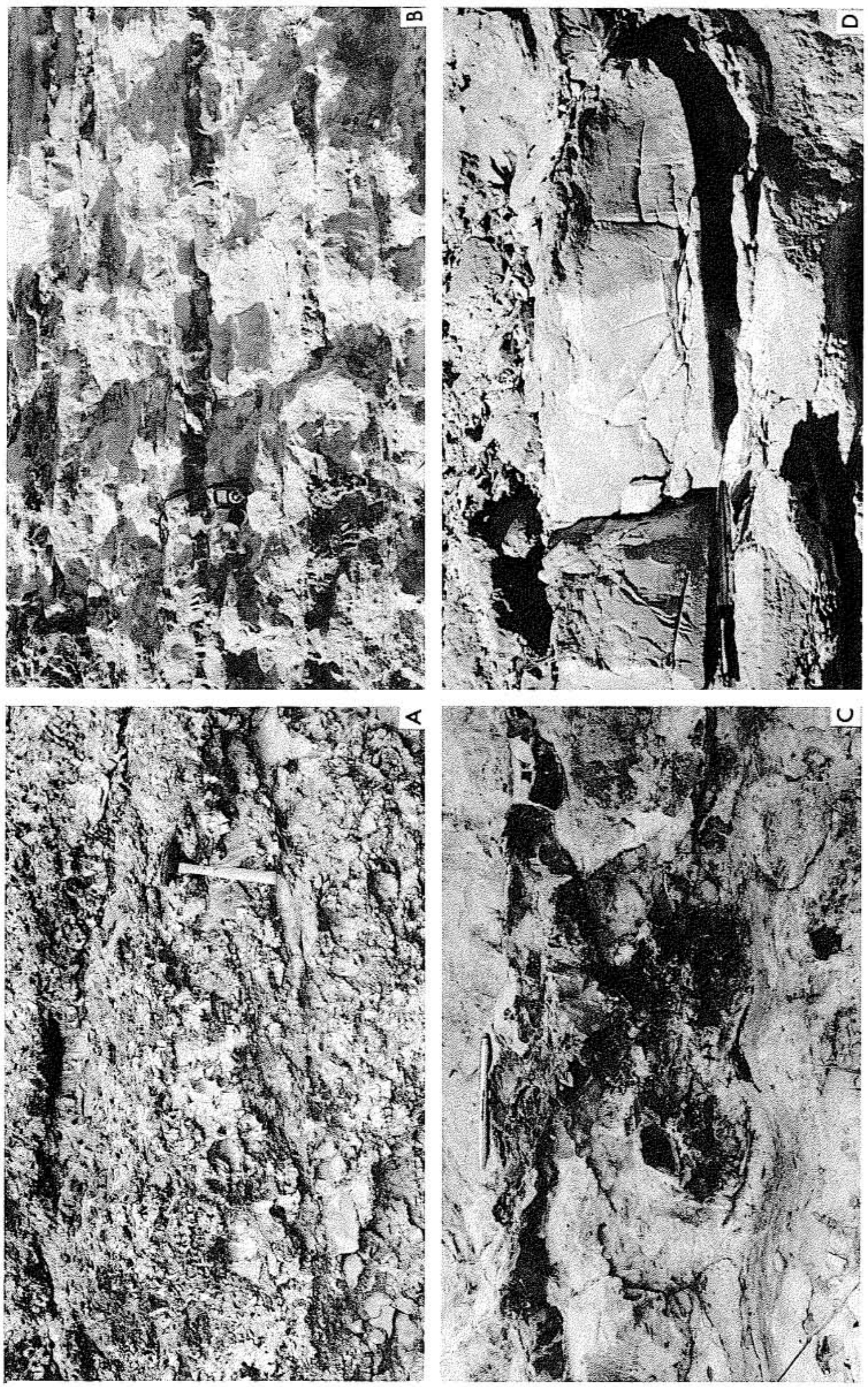

A
B
C
D

PLATE 9

LOCALITY 14-T-1

A. Interbedded dolomite (dark) and granular limestone (light), extreme east end of quarry. This dolomite is believed to be a primary deposit.

B. Bore hole zone in unit 1 near west end of quarry. This is laterally equivalent to the beds shown in photograph A. Dolomite is dark colored and fills the bore holes; the limestone is dolomitic.

C, D. Close-up views of interbedded dolomite (dark) and limestone shown in photograph A. Bore holes occur in each type of rock and are filled with the overlying rock. However, dolomite-filled bore holes in limestone are more common than limestone-filled bore holes in dolomite. See Plate 24 for photograph of lithology.

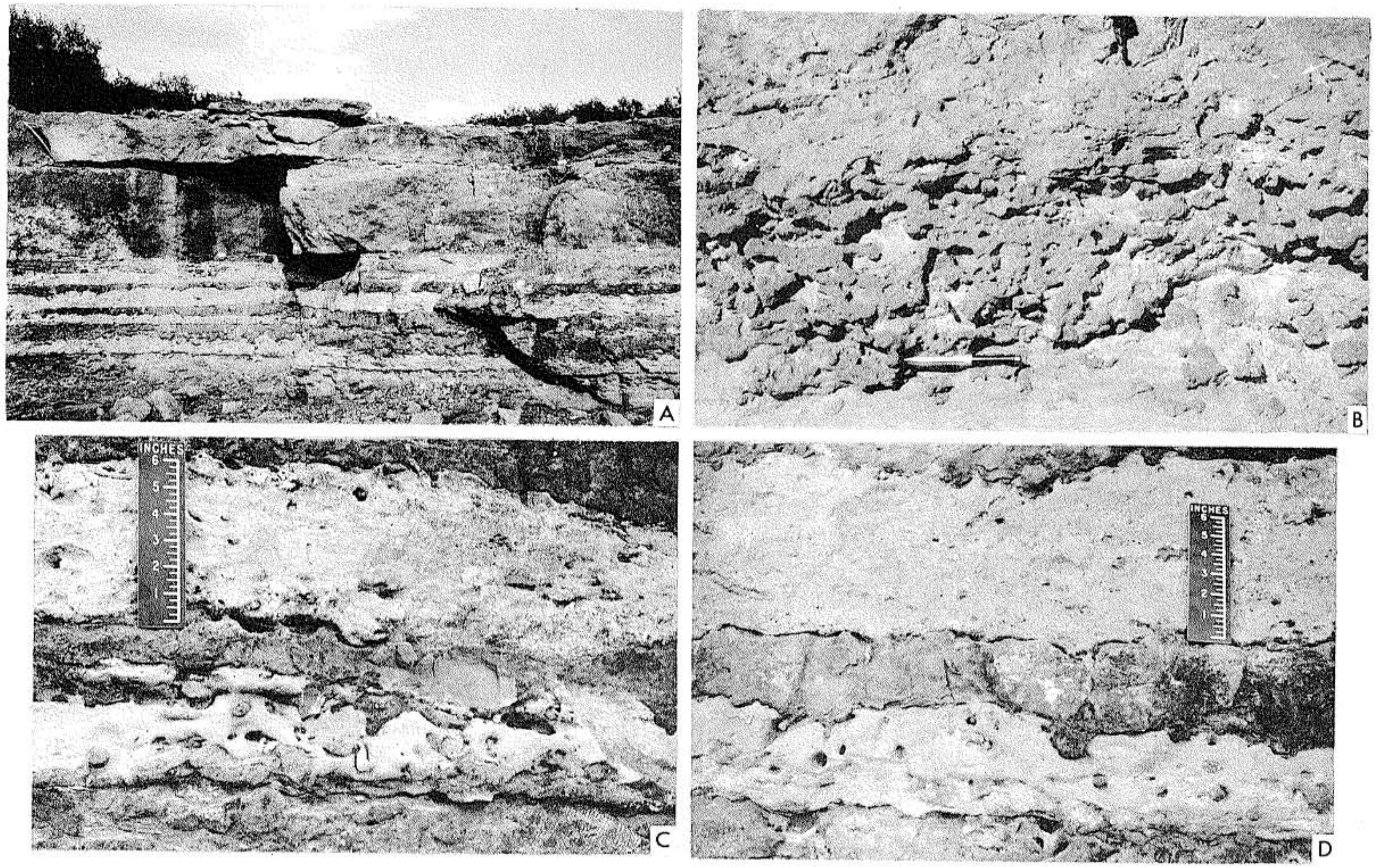


Plate 9

PLATE 10

LOCALITY 14-T-1

A. Center of quarry showing lithologic units. Note the cross-bedding in unit 5. See Plates 22–26 for photographs of lithology.

B. Rudistid horizon, unit 2.

C. Cross-laminated limestone of unit 4.

D. Silicified granular limestone and fine shell debris of unit 5.

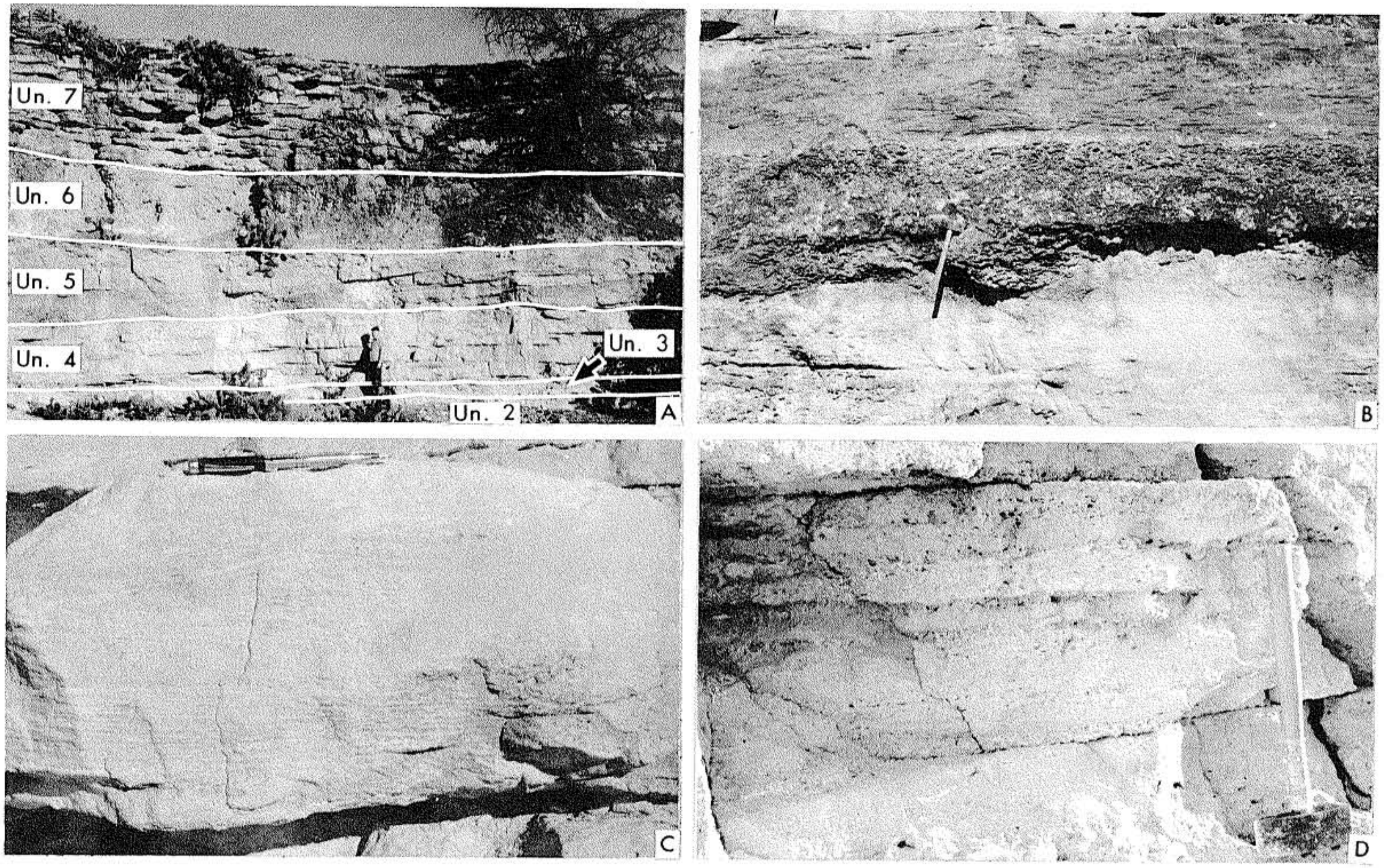


Plate 10

PLATE 11

A, B. Locality 14-T-8, roadcut on Belton-Youngsport road approximately 3 miles west of Belton, Bell County. See Plate 3 for cross section of lithofacies and Plates 27–29 for photographs of lithology.

A. Center of outcrops showing dolomitized reef core and post-lithification crystalline calcitic dolomite. Calcite was deposited in intercrystalline voids of post-lithification dolomite to form this rock.

B. Close-up view of post-lithification crystalline calcitic dolomite showing the characterstic mottling, color banding, and sharp but very irregular contact with the surrounding dolomite.

C, D. Flank beds of rudistid reef in Horse Creek east of Mother Neff State Park, Coryell County. The reef core is located between the flank beds shown in these pictures and is approximately 300 feet wide. The core is massive. The flank beds have a maximum dip of 25° and are composed of coarse shell fragments and whole fossils. They grade laterally into well-bedded fine-grained limestones (calcilutites and calcarenites). The height of the outcrop is approximately 15 feet.

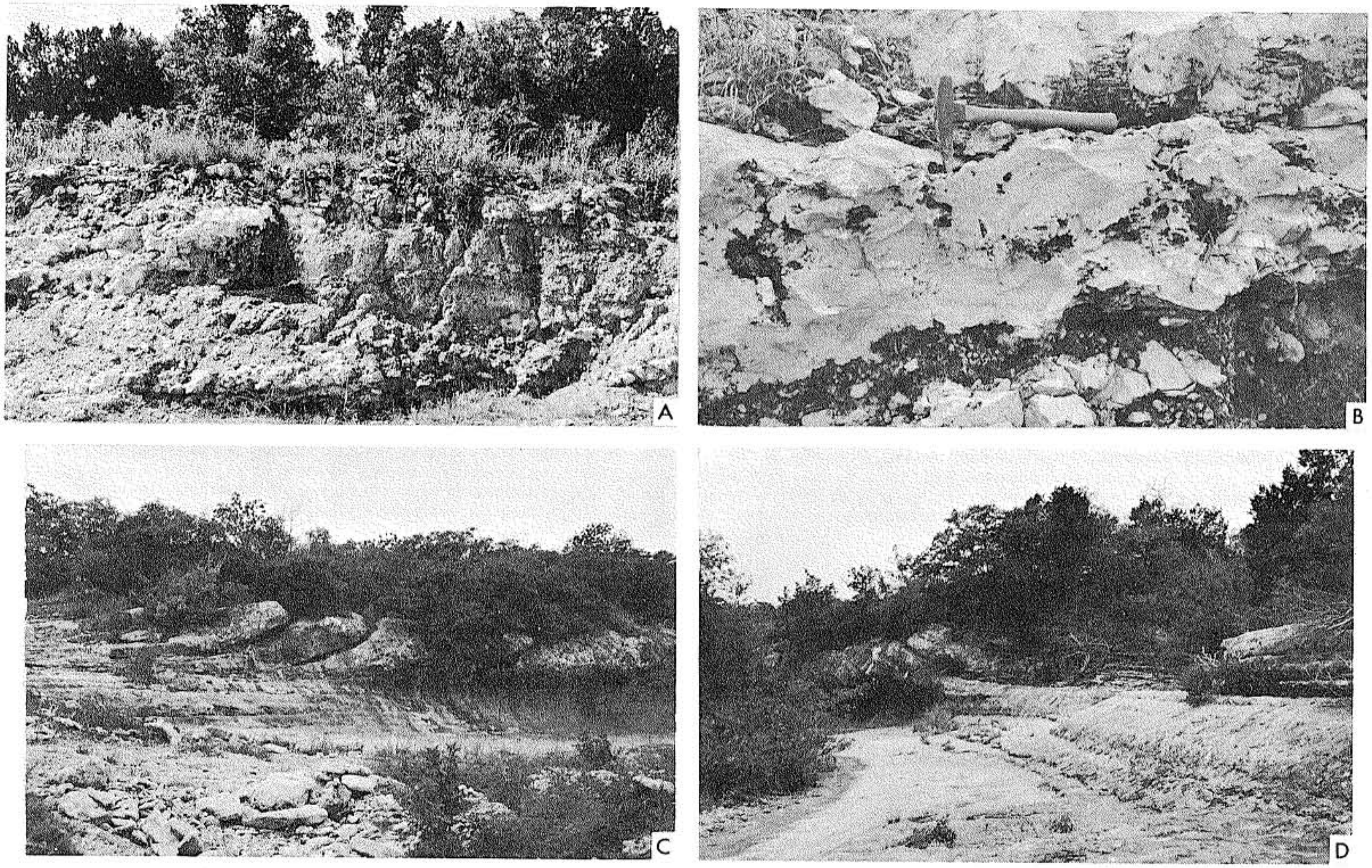


Plate 11

PLATE 12

REEF DEPOSITS

(All photographs are x1)

A-D. Very coarse shell debris; whole shells and large fragments of rudistids. There is no evidence of sorting or rounding of the fragments. The matrix is composed of extremely fine-grained (<0.006 mm) calcium carbonate. Dark shaded areas in photographs A, B, and D are dolomitic. Shells of *Eoradiolites* and *Caprinuloidea* are composed of an inner layer of clear coarse crystalline calcite and an outer layer of tan "original" shell material. In the outer wall of *Eoradiolites*, the intersection of the funnel plates and vertical radial plates form rhombic or rectangular areas that are filled with clear crystalline calcite as well as matrix material (original lime-mud). The vertical radial plates in *Caprinuloidea* form vertical canals that are usually filled with matrix material. The body chambers of *Eoradiolites* are filled with both matrix material and coarse crystalline calcite. All of these samples are considered to be essentially in situ reef deposits.

A, B. Locality 154-T-2.

C. Locality 154-T-9.

D. Locality 154-T-11.

Eoradiolites (EO)
Caprinuloidea (CA)
Cladophyllia (CL)

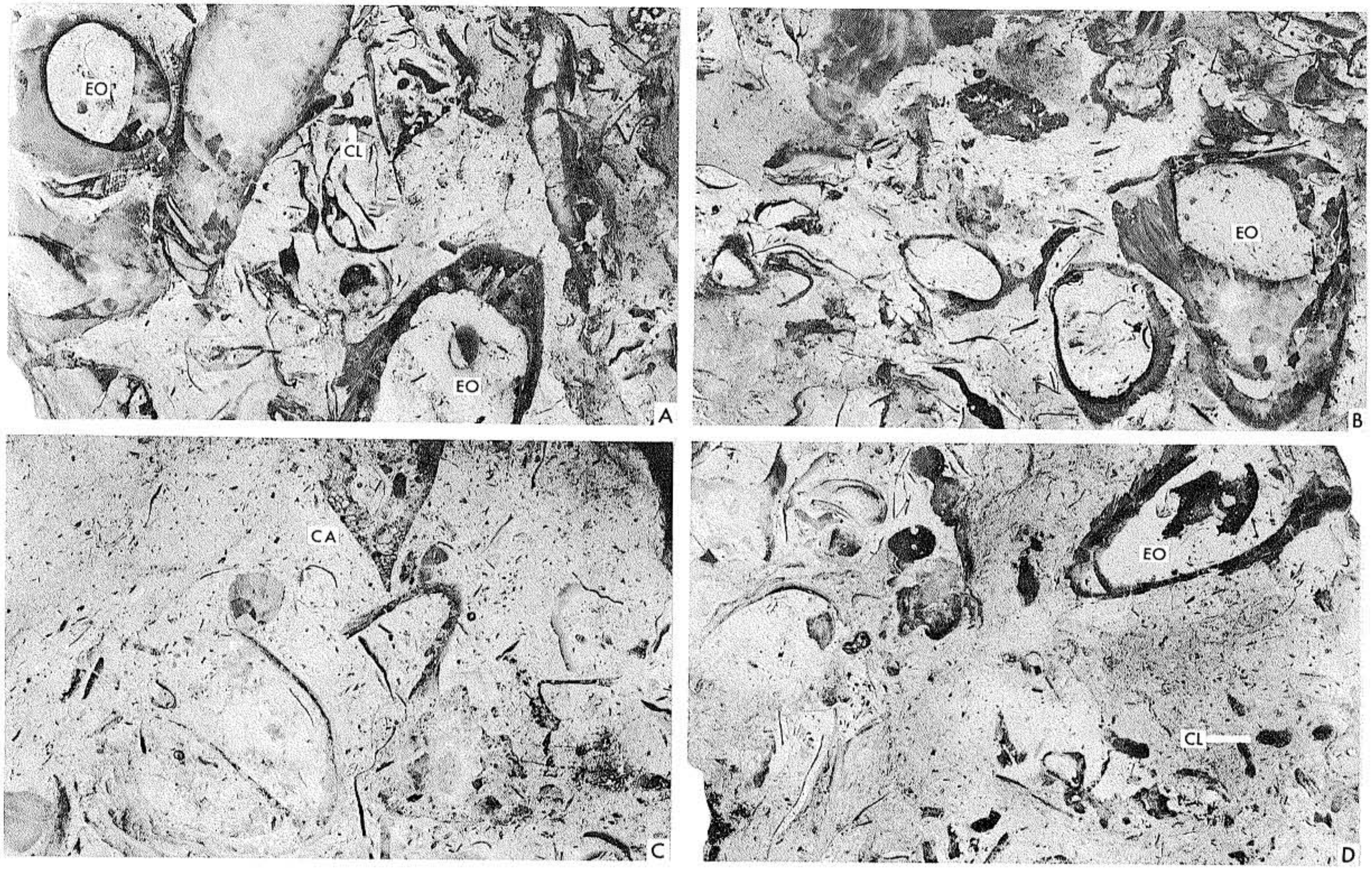

EO
CL
EO
A
EO
B
CA
C
EO
CL
D

PLATE 13

(All photographs are x1)

A. Reef flank deposit; fine shell debris. Most particles appear to be fragments of *Chondrodonta;* in general, they are oriented parallel to the bedding. Excellent inter-particle porosity. Interstices are partially filled with brown aphanitic calcium carbonate which appears to have been precipitated on the walls of the voids after which it grew inward to fill the remainder of the voids. Rhombohedral-shaped molds (dolomite?) are abundant in the brown calcium carbonate. Some are filled with an anisotropic mineral (calcite or dolomite) which may be either the original crystalline mineral or a secondary filling of the mold (Pl. 15, F). *Dictyoconus walnutensis* is abundant in this limestone. Locality 154-T-14a.

B. Reef core. Large fossils are *Chondrodonta.* Matrix is very fine-grained limestone (originally a lime-mud). Voids are partially filled in the same manner as those described in discussion of photograph A. Stylolites are common along the edges of the fossils. Locality 154-T-14a.

C. Inter-reef deposit; fine shell debris. Particles are poorly sorted but well rounded. They are composed of "original" shell material and recrystallized shell fragments surrounded by a rim of chalk ("dust" rim). The cement is clear crystalline calcite. Plate 14, F, is a photomicrograph of a texture somewhat finer grained but similar to this specimen. This rock has been honeycombed to a considerable extent by weathering. The voids are now partially filled with earthy calcium carbonate and tan crystalline calcite, both of which have the form of microstalagtites. Locality 154-T-6.

D. Inter-reef deposit; fine-grained limestone (calcilutite). Particles are very well sorted, angular, and composed of "original" shell fragments, recrystallized shell fragments, and opaque grains. Cement is crystalline calcite. Locality 154-T-2. Plate 14, C, is a photomicrograph of limestone similar to this specimen.

Chondrodonta (CH)

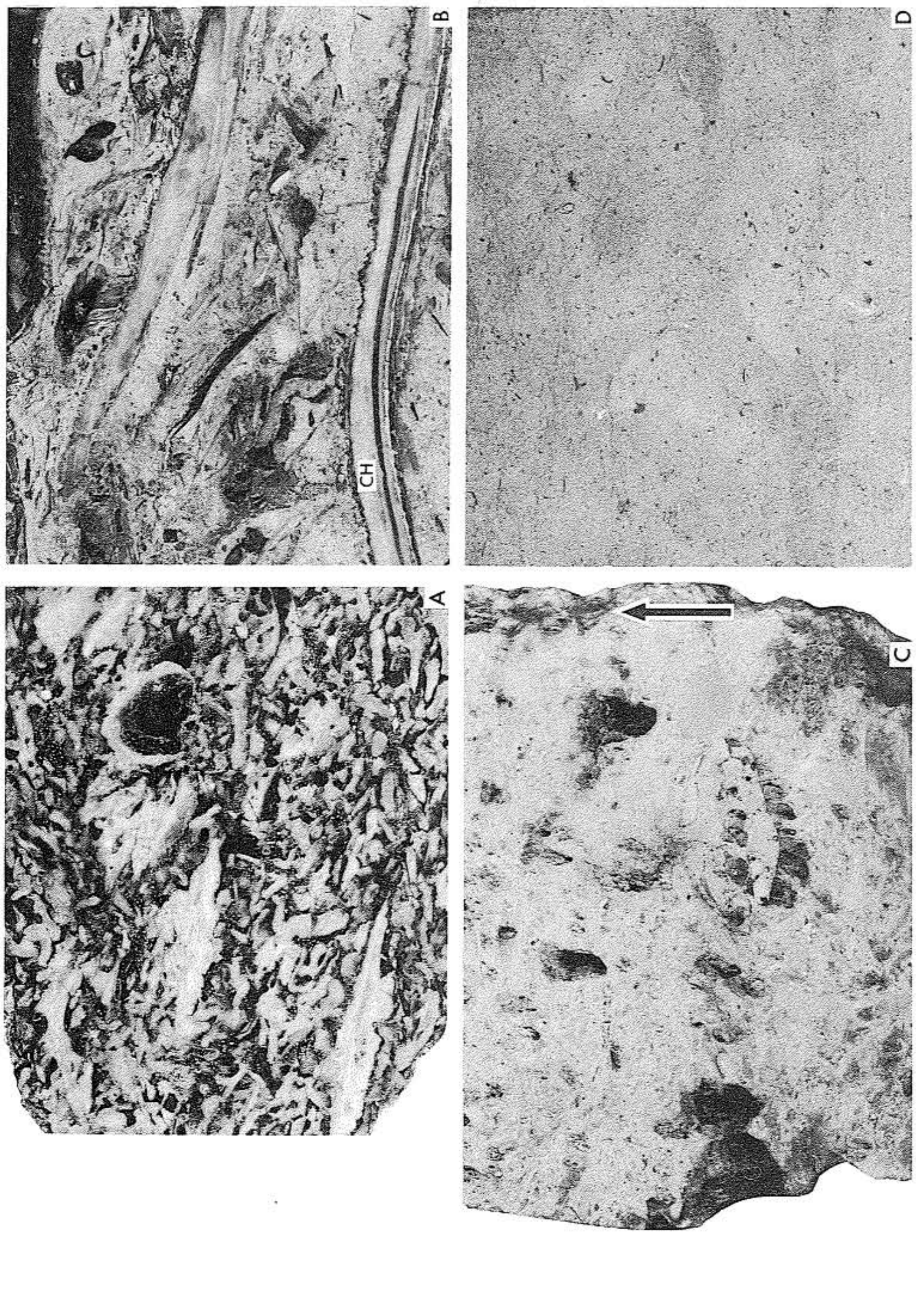

A
B
CH
C
D

PLATE 14

(All photographs are x15)

A. Biostromal reef deposit; coarse shell debris. Shell fragments are recrystallized calcite. Dark very fine-grained matrix has a detrital texture on polished rock surface (Pl. 12, A, B) and in the outcrop. This type of matrix is very characteristic of reef core and reef flank deposits. Locality 154-T-2.

B. Biohermal reef flank deposit; coarse shell debris. More fragmental than that in photograph A. Both "original" shell material (light gray and striated) and recrystallized shell material (clear mosaic) are present. Note the extreme angularity and poor sorting of the fragments. These features and the dark matrix are characteristic of the reef flank. See Plate 12, C, for photograph of hand specimen. Locality 154-T-9.

C. Inter-reef deposit; fine-grained limestone (calcilutite). Very well-sorted, generally angular "original" shell fragments, recrystallized shell fragments, and opaque grains make up the detrital particles. The cement is a mosaic of clear crystalline calcite. Locality 154-T-6.

D. Inter-reef deposit; granular limestone (calcarenite). Consists of poorly sorted rounded "original" shell fragments (gray), recrystallized shell fragments (clear mosaic), and opaque grains. The cement is clear crystalline calcite. In a hand specimen it appears to be as well sorted as photograph C. Locality 154-T-6.

E, F. Inter-reef deposits; very coarse-grained limestones (calcarenites). Well-rounded particles. In photograph E, particles are predominantly "original" shell fragments; in F, they are predominantly recrystallized shell fragments. The cement is clear crystalline calcite. Note the difference in texture between these specimens and the reef flank deposit shown in photograph B. All have approximately the same grain size in thin sections. The fragments shown in photographs E and F are well rounded, whereas those in photograph B are very angular. In addition, the recrystallized shell fragments have "dust" rims, whereas those in photograph B have none. The "dust" rims consist of microgranular calcite (chalk). The dark very fine detrital matrix of the reef flank contrasts sharply with the clear crystalline cement of the inter-reef deposits.

E. Locality 154-T-11.

F. Locality 154-T-14.

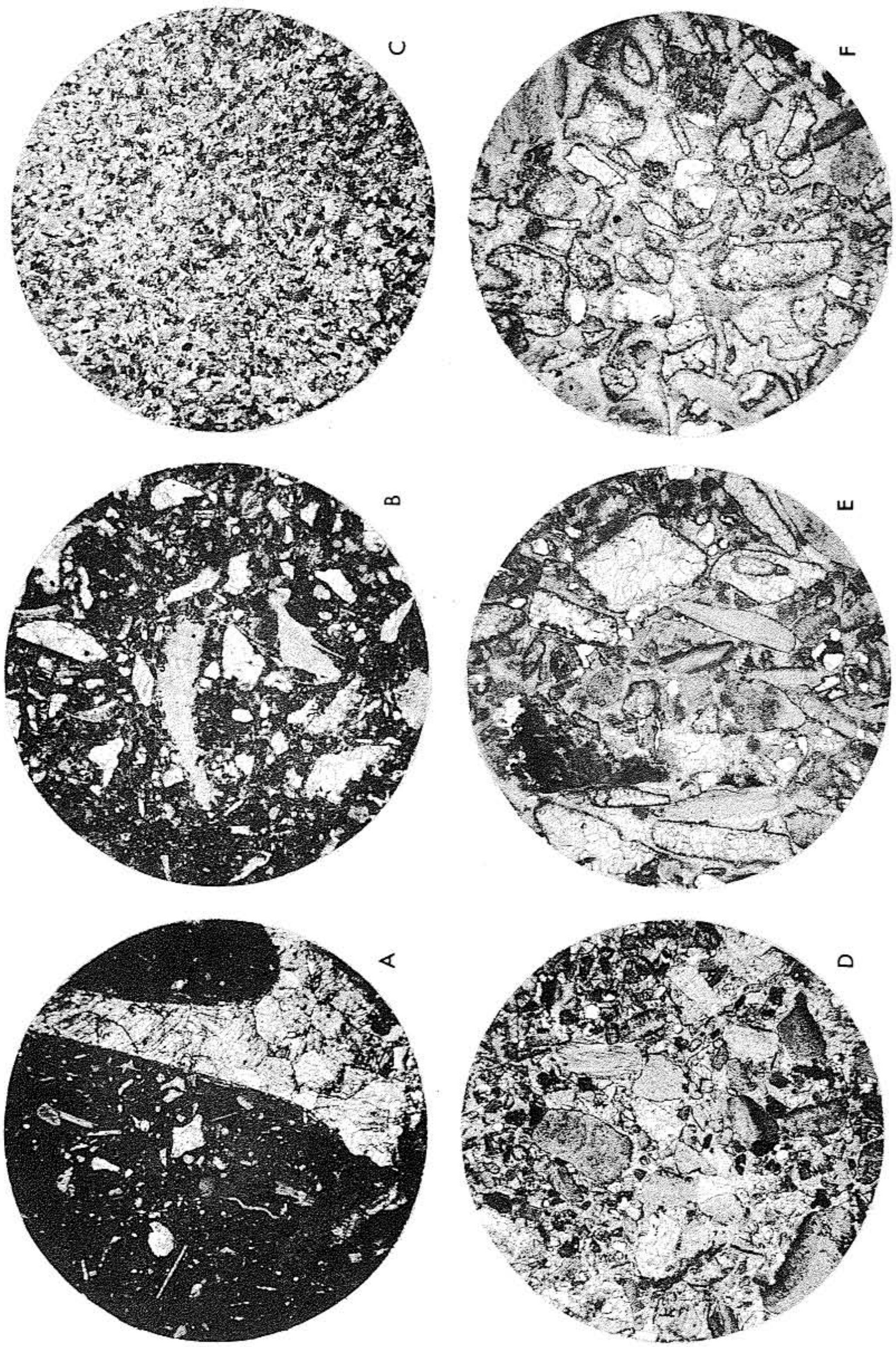

A
B
C
D
E
F

PLATE 15

A. Post-lithification alteration deposit; crystalline limestone. Small patch of recrystallized limestone at locality 154-T-6. Texture of this unit is shown on Plate 14, C. (x15)

B. Partially recrystallized shell. Mosaic of recrystallized calcite is superimposed upon the original structure of the shell. Locality 154-T-6. (x15)

C. Partially silicified shell fragment. Silicification almost invariably begins in the shell fragments rather than in the matrix. Locality 154-T-9. (x15)

D. Inter-reef deposit; fine-grained limestone (calcilutite). Enlarged view of Plate 14, C. Locality 154-T-6. (x60)

E. Development of dolomite along a stylolite. This is believed to be a post-lithification dolomite. Locality 154-T-11. (x60)

F. Development of post-depositional dolomite in the matrix of the reef core at locality 154-T-14a. This occurs at the top of the Edwards. Each large rhombohedron is surrounded by a rim of iron oxide. Normally rhombohedrons are preserved as molds; here they are filled with either dolomite or calcite. Dolomite also replaces the inner shell wall of many rudistids. (x60)

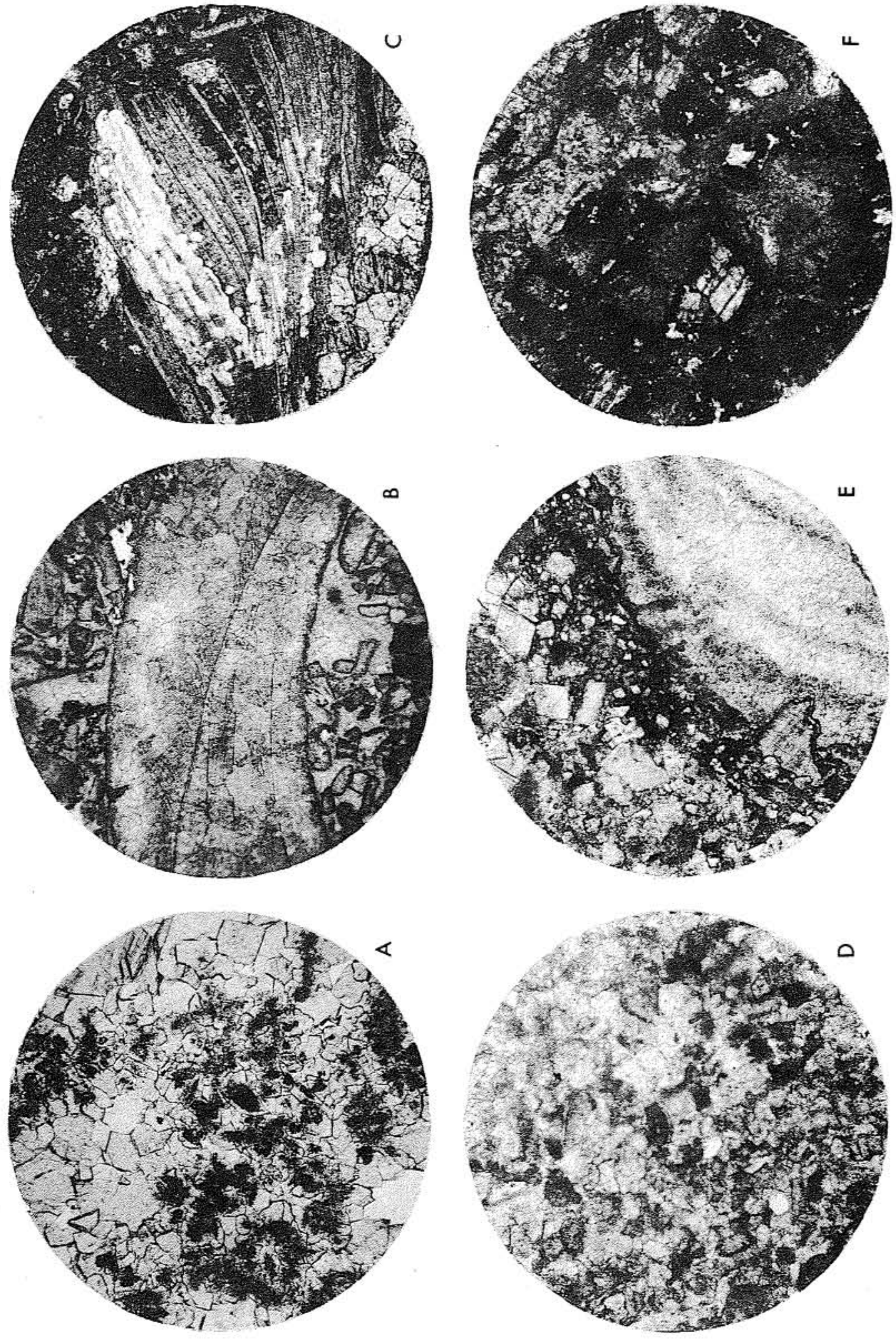

A
B
C
D
E
F

PLATE 16

(All photographs are x1)

A. Reef core. *Cladophyllia* is abundant. The matrix is a detritus of microgranular particles and tiny shell fragments. Locality 154-T-1, sample B (Pl. 3).

B. Reef flank deposit; coarse shell debris. Composed of whole shells and large fragments embedded in a matrix of very fine-grained limestone. Note that three specimens of *Eoradiolites* are intergrown, which suggests that they occur in their original growth position. The body chambers of the fossils are filled with coarse crystalline calcite as well as very fine-grained limestone. Locality 154-T-1, sample JJ (Pl. 3).

C. Top of reef; case-hardened shell debris. White patches at the top of the specimen are bore holes filled with the overlying inter-reef limestone. Laminations in the overlying limestone are depressed down into the bore holes. The dark coloration at the top of the specimen is due to oxidation of the limestone. The long bore hole near the center of the photograph and other bore holes on the right side of the specimen have clusters of tan dolomite rhombohedrons at the bottom of the holes. Coarse crystalline calcite partially surrounds the dolomite and fills the remainder of the bore holes. Locality 154-T-1, sample F (Pl. 3).

D. Rudistid biostrome; coarse shell debris. The biostrome is lithologically similar to the flank deposits in the bioherms. Locality 154-T-1, sample DD (Pl. 3).

Cladophyllia (CL)
Eoradiolites (EO)
Coarse crystalline calcite (CC)
Dolomite (D)
Bore hole (B)

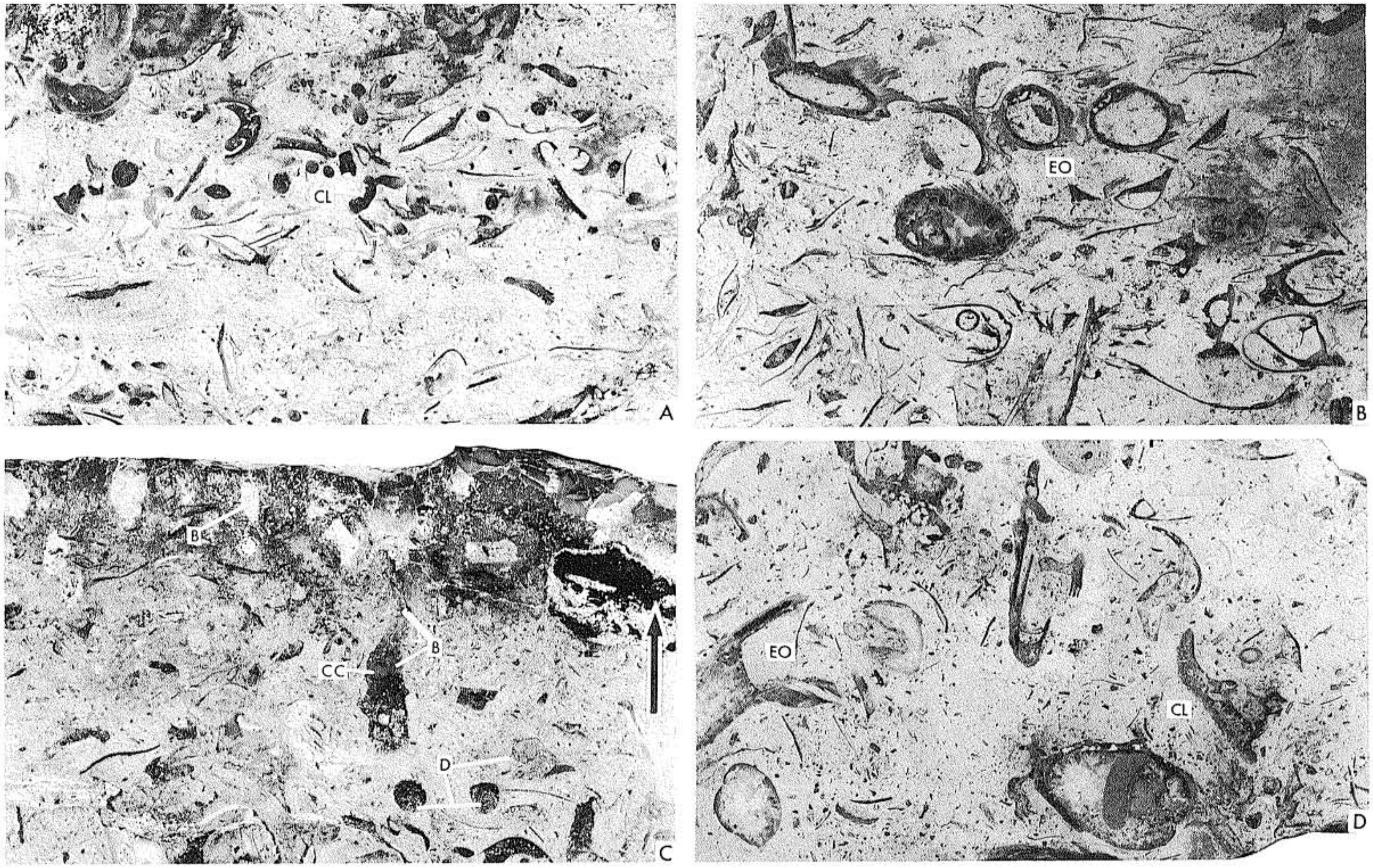

CL
A
EO
B
B
B
CC
D
C
EO
CL
D

PLATE 17

INTER-REEF DEPOSITS

(All photographs are x1)

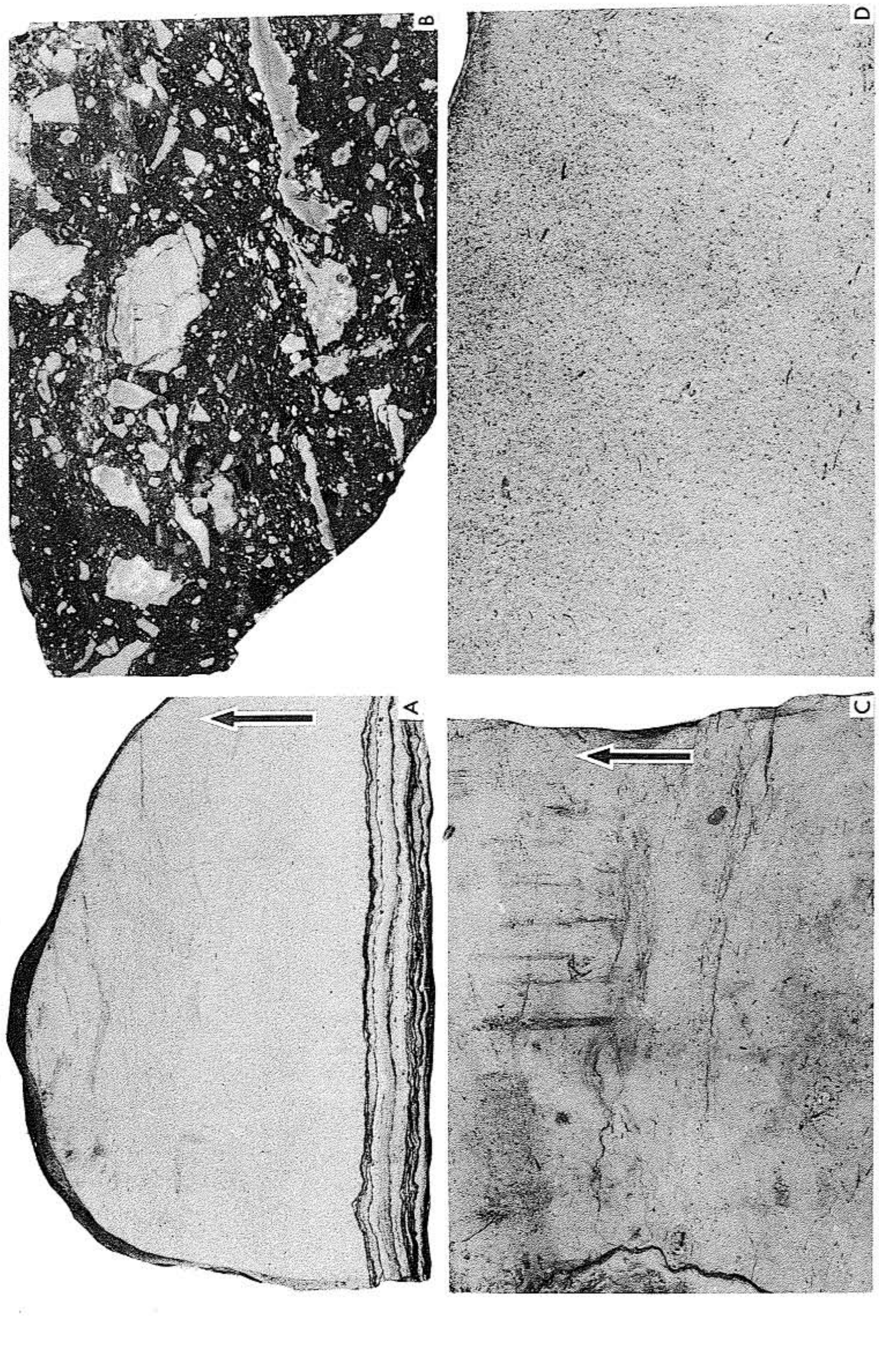
A, C. Extremely fine-grained limestones (calcilutites). Except for some tiny shell fragments and microfossils, individual particles are indiscernible.

A. Locality 154-T-1, lithologic unit 4, sample L (Pl. 3).

C. Locality 154-T-1, lithologic unit 6, sample R (Pl. 3).

B. Intraformational breccia. Fragments are similar to the limestone shown in photograph C. Matrix is extremely fine-grained argillaceous calcium carbonate. The fine hairlike cracks in the large fragment suggest fragmentation prior to complete lithification. Locality 154-T-1, lithologic unit 5, sample N (Pl. 3).

D. Miliolid limestone. The particles are composed almost exclusively of miliolids; the cement is clear crystalline calcite. Locality 154-T-1, lithologic unit 7, sample Q (Pl. 3).



A
B
C
D

PLATE 18

(All photographs are x15)

A. Recrystallized shell (*Eoradiolites*) in dark very fine-grained matrix of reef core. Locality 154-T-1, sample B (Pl. 3).

B. Alteration of reef core to chalk. Locality 154-T-1, sample C (Pl. 3).

C. Alteration of reef flank deposit to chalk followed by reprecipitation of calcium carbonate in voids to form very irregular patches of crystalline calcite. Note the fuzzy outline of the particles. This is characteristic of chalkification followed by reprecipitation of calcite. Locality 154-T-1, sample A (Pl. 3).

D. Rudistid biostrome; coarse poorly sorted shell debris. Both "original" (gray) and recrystallized (white) shell material are present. Matrix is composed of very fine-grained limestone. Lithology of this sample is similar to that shown on Plate 16, D. Locality 154-T-1, sample AA (Pl. 3).

E. Inter-reef deposit; very fine-grained well-sorted slightly argillaceous limestone (calcilutite). Dark laminations are composed of clay. Small shells and shell fragments are oriented parallel to the bedding. Hand specimen shown on Plate 17, A. Locality 154-T-1, lithologic unit 4, sample L (Pl. 3).

F. Inter-reef deposit; miliolid limestone. The miliolids have been altered to microgranular calcite (chalk). A few recrystallized shell fragments are present. The cement is composed of clear crystalline calcite. Calcite coats the walls and forms a mosaic of anhedral crystals in the center of the interstices. This feature indicates two stages of precipitation of calcite. Hand specimen shown on Plate 17, D. Locality 154-T-1, lithologic unit 7, sample Q (Pl. 3).

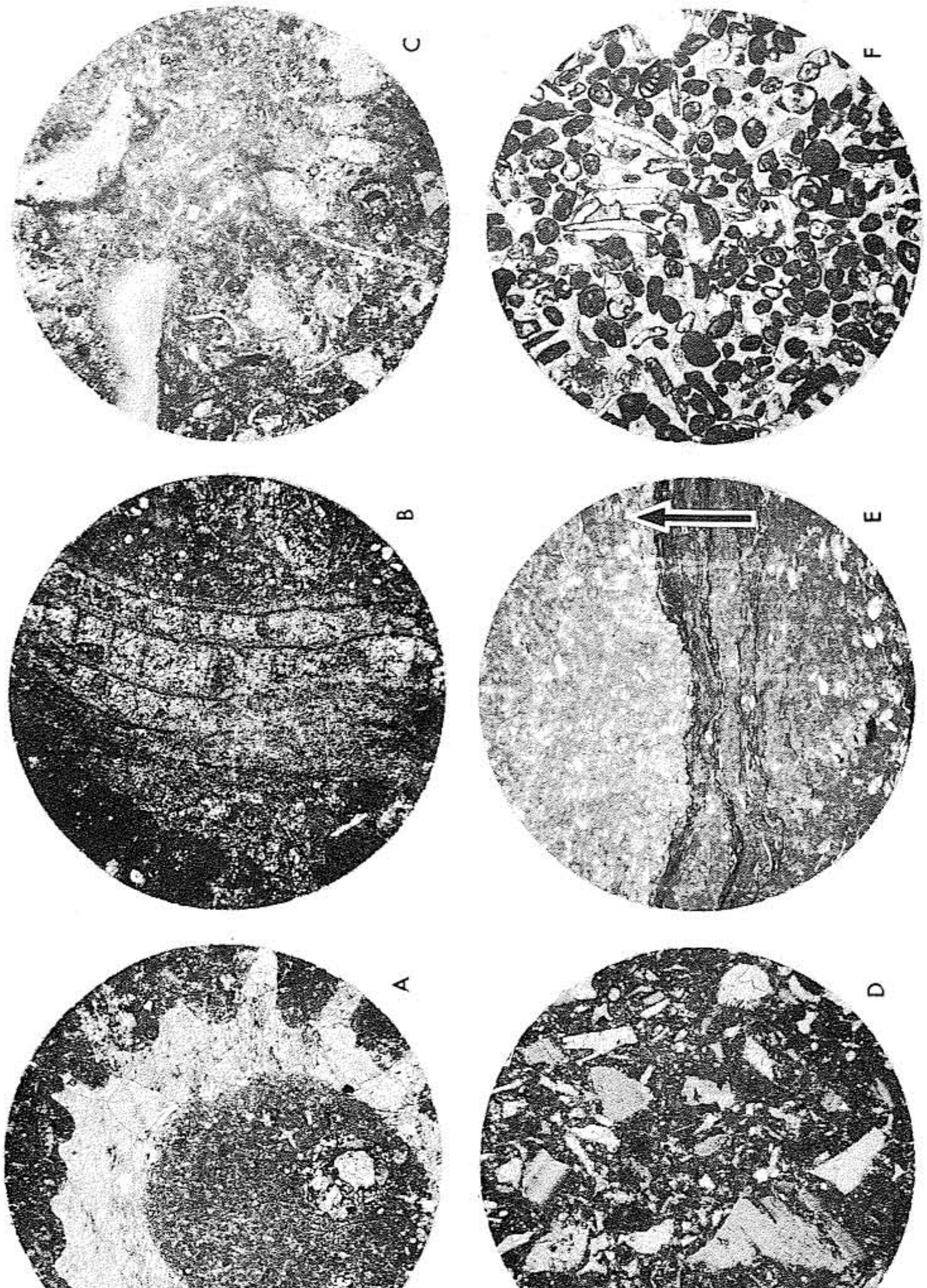

A
B
C
D
E
F

PLATE 19

A. Reef core. The matrix is a detritus of silt- and sand-sized particles of calcium carbonate and tiny shell fragments. The cement is clear coarse crystalline calcite. Dolomite fills the body chambers (upper right corner is the body chamber of *Caprinuloidea*), the inner shell wall of some fossils, and some interstices between the fossils. The lower part (dark strip) of the inner shell wall of the rudistid in the lower left corner is filled with coarse crystalline calcite that surrounds some of the dolomite, thereby indicating precipitation of the calcite contemporaneous with or after the dolomite. Attachment of several rudistids to each other indicates that they occur in their original growth position. Much of the matrix contains fine irregular hairlike cracks that suggest fracturing prior to complex lithification. Locality 154-T-16. (x2)

B. Reef core. Dolomite (D) fills the last body chamber of *Eoradiolites* and extends down the inner shell wall to the dolomite which has replaced the shell below. Note the graded bedding of the original lime-mud in one chamber of *Eoradiolites;* this indicates growth in a vertical position. Locality 154-T-16. (x2)

C. Reef core. The matrix consists of microgranular calcite. Photomicrograph of lithology similar to this is shown on Plate 21, A. Locality 50-T-7, sample C (Pl. 3). (x1)

D. Inter-reef deposit; poorly sorted coarse shell debris. The matrix is fine shell debris and carbonate sand. Locality 50-T-7, sample G (Pl. 3). (x1)

Chondrodonta (CH)
Cladophyllia (CL)
Eoradiolites (EO)
Dolomite (D)
Coarse crystalline calcite (CC)

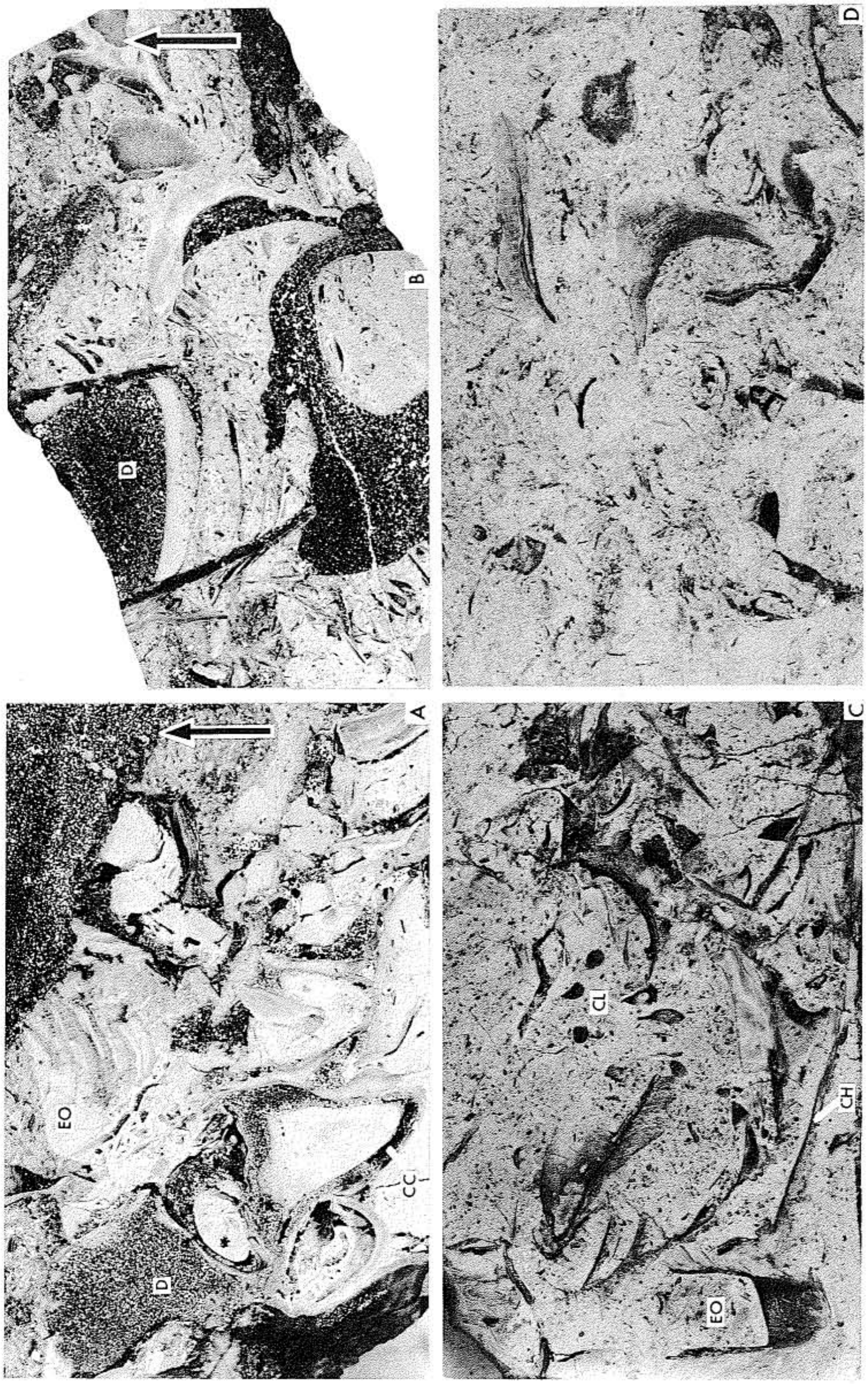

A
B
C
D
EO
D
CC
D
CL
EO
CH

PLATE 20

(All photographs are x1)

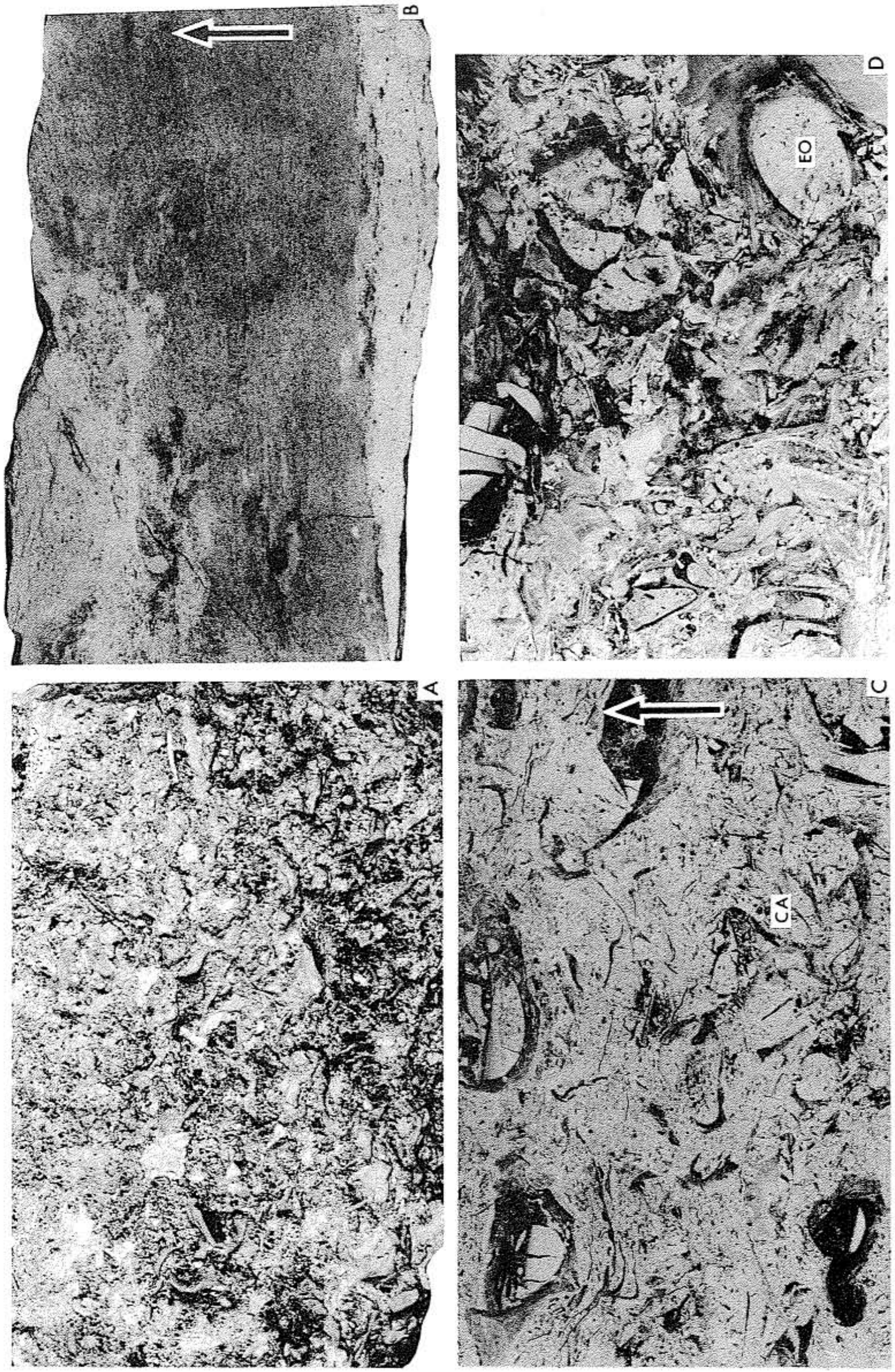
A. Inter-reef deposit; poorly sorted fine shell debris. Weathered surface. Individual fragments are slightly rounded. Photomicrograph is shown on Plate 21, E. Locality 50-T-7, sample HH (Pl. 3).

B. Inter-reef deposit; microgranular limestone (calcilutite). Mottled appearance is the result of weathering along bedding planes. Photomicrographs are shown on Plate 22, A, B. Locality 50-T-7, sample W (Pl. 3).

C. Reef flank deposit; poorly sorted coarse shell debris. Individual fragments are angular. Large, apparently whole, fossils are abundant. The matrix is composed of a poorly sorted detritus of lime-silt, lime-sand, and fine shell debris. Locality 50-T-8, sample D (Pl. 3).

D. Reef flank deposit; poorly sorted coarse shell debris. Very fine detritus is less abundant than normal. However, coarse crystalline calcite is considerably more abundant. Locality 50-T-8, sample R (Pl. 3).

Caprinuloidea (CA)
Eoradiolites (EO)



A
B
C
CA
D
EO

PLATE 21

(All photographs are x15)

A. Contact of *Eoradiolites* and surrounding dark microgranular matrix in the reef core. Voids between the funnel plates and vertical radial plates of the outer shell wall may be filled with original lime-mud, crystalline calcite, or both. Shell fragments are recrystallized. Locality 50-T-7, sample A (Pl. 3).

B. Chalkification of poorly sorted coarse shell debris. Fragments are composed for the most part of slightly rounded "original" shell material. The matrix is composed of fine shell debris, lime-silt, and lime-sand. Chalkification has reduced much of the detritus to microgranular crystalline calcite and has reprecipitated some of it as clear crystalline calcite which ramifies the entire sample. As a result, the boundaries between the original detritus and the reconstituted calcite are very indistinct. Locality 50-T-7, sample P (Pl. 3).

C. Pellets in the inter-reef deposits. Pelletal textures are rare in the Edwards limestone in this area. Small patches of pseudo-pellets are often formed by break-up of the lithified mud fillings in the vertical canals of the outer shell wall of *Caprinuloidea*. Locality 50-T-7, sample H (Pl. 3).

D. "Original" shell fragment showing bore holes. The dark color of the matrix of this and succeeding specimens on this plate is partially due to extensive chalkification. Locality 50-T-7, sample JJ (Pl. 3).

E. Inter-reef deposit; poorly sorted fine shell debris. Both "original" and recrystallized shell fragments are present. Most fragments are rounded. Locality 50-T-7, sample HH (Pl. 3).

F. Inter-reef deposit; poorly sorted fine shell debris similar to that shown in photograph E. *Dictyoconus walnutensis* occurs most frequently in the reef flank and coarse inter-reef deposits. It is rare or absent in the reef core. The matrix is being converted to crystalline calcite by chalkification and reprecipitation of the calcite. Locality 50-T-7, sample LL (Pl. 3).

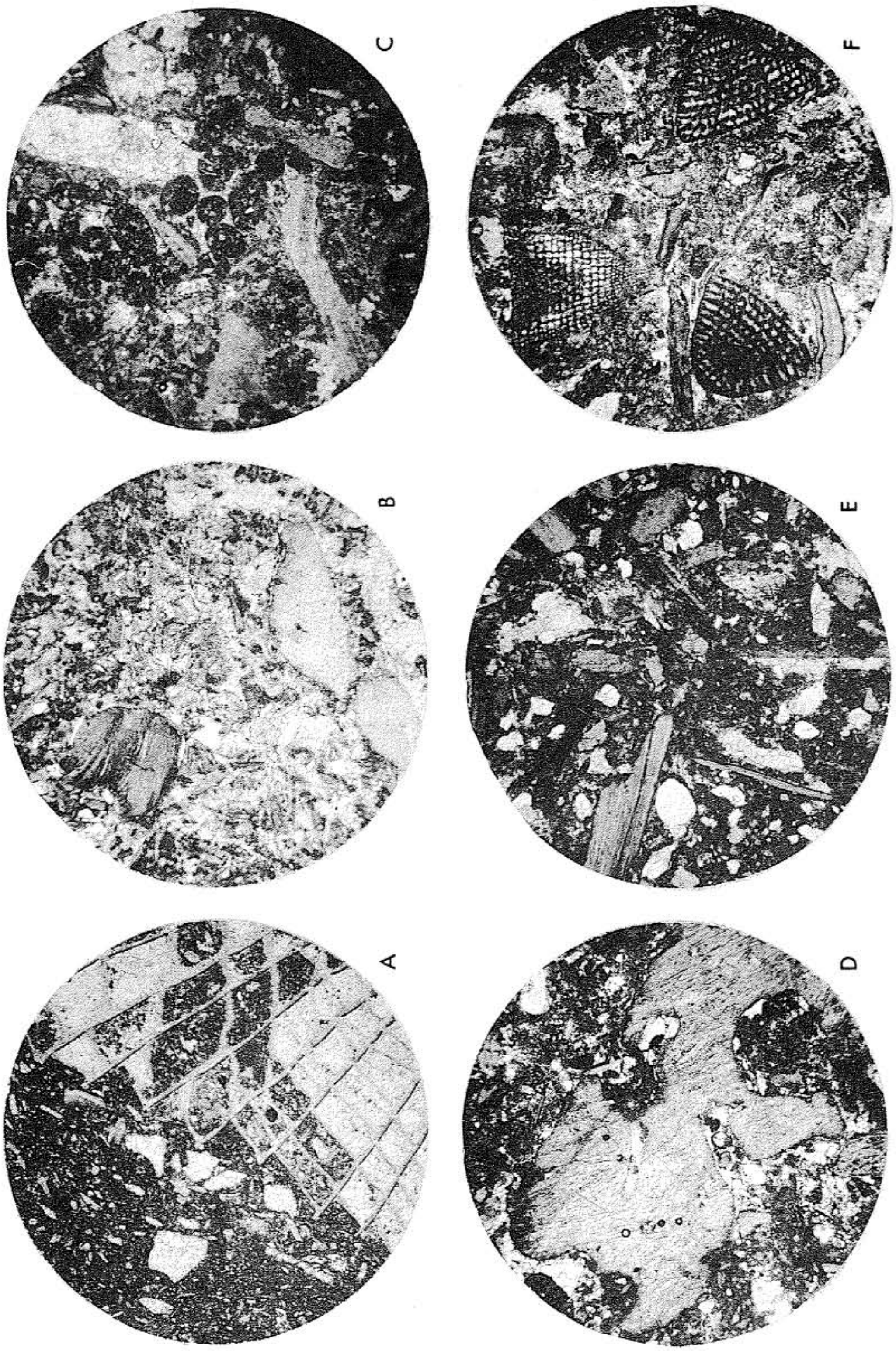

A
B
C
D
E
F

PLATE 22

A. Inter-reef deposit; microgranular limestone (calcilutite). Clastic particles are all recrystallized; some appear to be calcite casts of sponge spicules. The matrix is microgranular calcite. The extent to which chalkification may have reduced the original lime-mud to still finer calcite has not been determined. Locality 50-T-7, sample W (Pl. 3). (x15)

B. Enlarged view of photograph A. (x60)

C. Recrystallization of *Eoradiolites*. Recrystallization has encroached upon the shell from the body chamber which is filled with clear coarse cystalline calcite. Part of the original shell wall is still apparent in the coarse calcite. Locality 50-T-7, sample A (Pl. 3). (x15, crossed nicols)

D. Inter-reef deposit; fine shell debris. Shell fragments are poorly sorted, very angular, and largely recrystallized. The matrix is a detritus of fine silt and sand which has been chalkified to a considerable extent. Locality 50-T-8, sample C (Pl. 3). (x15)

E. Reef flank deposit; coarse shell debris. Similar to the limestone shown in photograph D, but coarse fragments and whole shells are more abundant. Reprecipitated calcite is evident at the top of the photograph. Locality 50-T-8, sample D (Pl. 3). (x15)

F. Dolomitic primary chert. Dark crystals are dolomite; many of them are slightly rounded. Sponge spicules oriented parallel with the lamination of dolomite crystals are abundant but can be seen only in polarized light. The bending of laminations in the limestone around the chert nodules indicates that the chert and hence the dolomite are of primary origin. Locality 14-T-1, sample RR (Pl. 3). (x15)

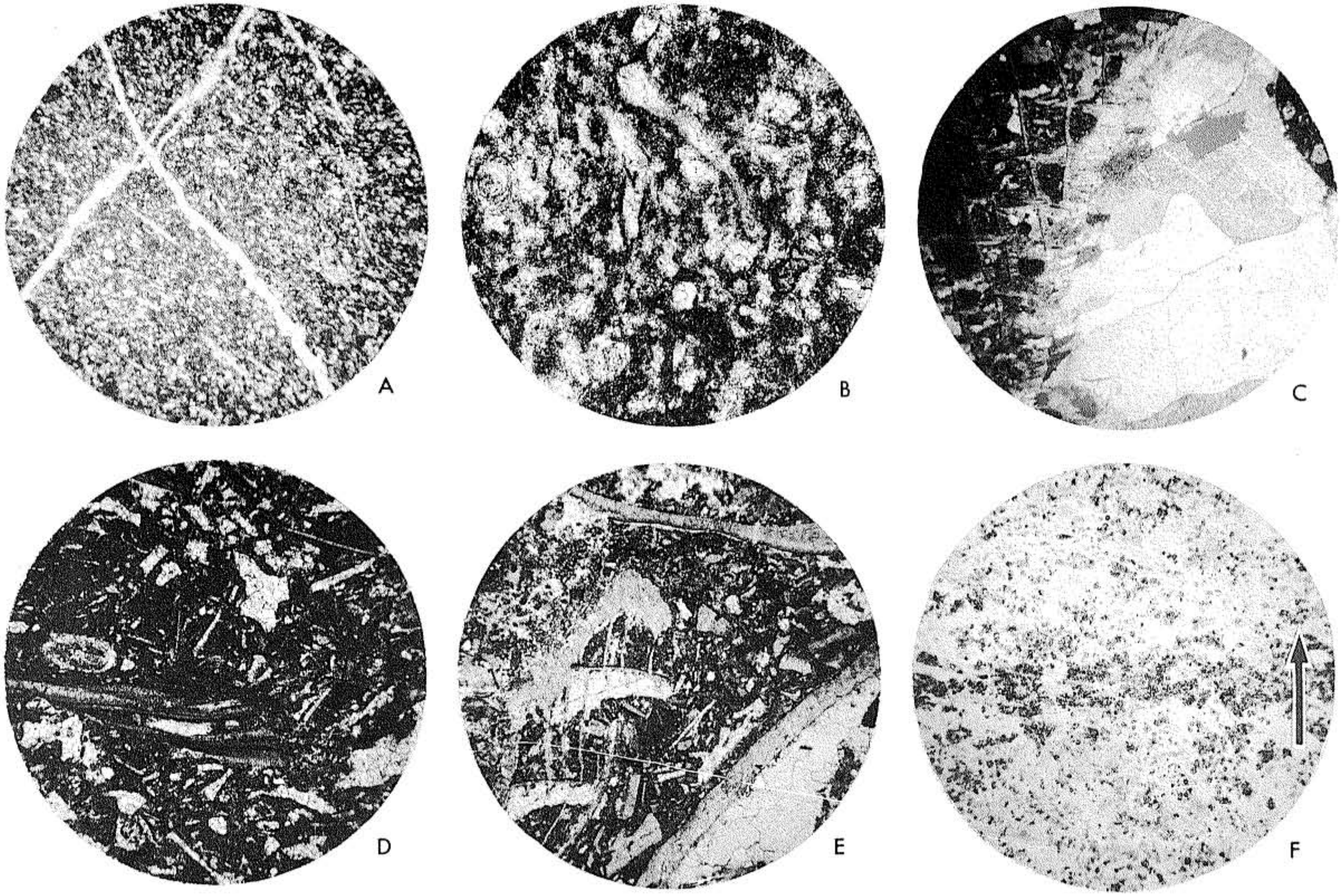

A
B
C
D
E
F

PLATE 23

LOCALITY 14-T-1

(All photographs are x1)

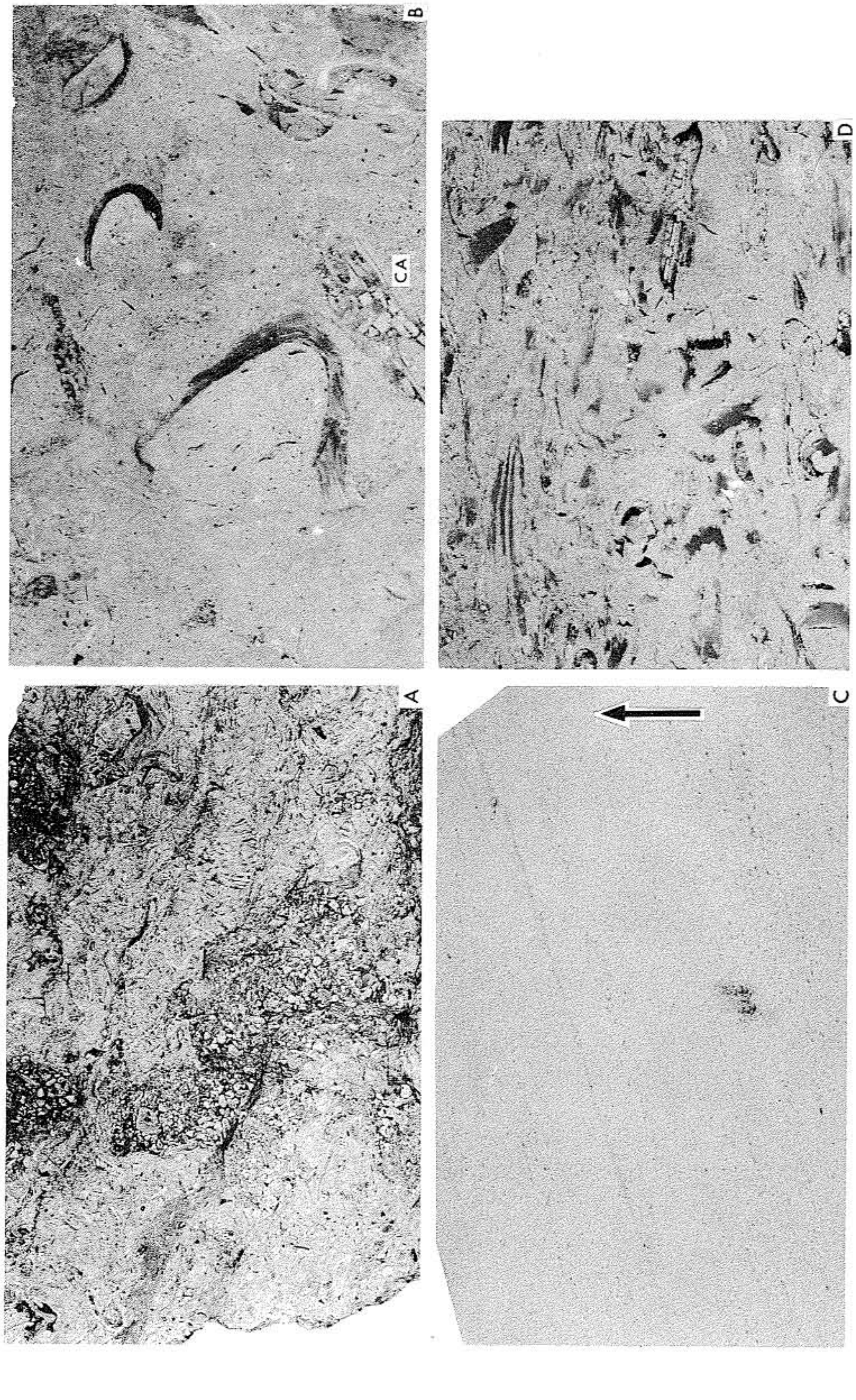
A. Inter-reef deposit; poorly sorted dolomitic (16 percent) fine shell debris. Individual particles are well-rounded recrystallized shell fragments having "dust" rims, "original" shell material (minor component), and microfossils (*Dictyoconus walnutensis* and miliolids). The cement is clear crystalline calcite and dolomite. Photomicrographs are shown on Plates 25, A, and 26, A, B. Lithologic unit 1, sample A (Pl. 3).

B. Inter-reef deposit; poorly sorted dolomitic (50 percent) coarse shell debris. Large shell fragments are angular. Matrix consists primarily of dolomitic lime-sand. Photomicrographs are shown on Plate 26, E, F. Lithologic unit 2, sample U (Pl. 3).

C. Inter-reef deposit; well-sorted granular limestone (calcarenite). Individual particles are predominantly small well-rounded recrystallized shell fragments having "dust" rims. Elongated particles are oriented parallel to the cross-laminations. The cement is crystalline calcite. Plate 25, D, is a photomicrograph of this type of lithology. Lithologic unit 4, sample M (Pl. 3).

D. Inter-reef deposit; poorly sorted coarse shell debris. Most fragments are well rounded and recrystallized. Matrix is lime-sand and fine shell debris. Lithologic unit 5, sample AA (Pl. 3).

Caprinuloidea (CA)



A
B
C
D
CA

PLATE 24

LOCALITY 14-T-1

(All photographs are x1)

A. Inter-reef deposit; silicified fine shell debris. The original texture of the rock is preserved even though the centers of the particles and the matrix have been replaced by crystalline quartz. A photomicrograph of this lithology is shown on Plate 30, E. Lithologic unit 5, sample GG (Pl. 3).

B. Post-lithification alteration deposit; very fine crystalline limestone. These rocks are very dense and are typically mottled shades of brown. The original texture may be completely or only partially destroyed. In this photograph, the light-colored patches still exhibit the original texture. The original texture may still be apparent in thin sections of the dark portion of the rock. A photomicrograph of this type of lithology is shown on Plate 25, F. Lithologic unit 5, sample F (Pl. 3).

C. Dolomitic and limy primary chert. Detrital particles in this chert nodule include dolomite crystals, lime-sand, unidentified shell fragments, and sponge spicules. Laminations in the surrounding limestone bend around the nodules, thus indicating that the chert nodule was in place before lithification. Lithologic unit 4, sample HHH (Pl. 3).

D. Dolomite cut by bore holes. Dark areas are very fine crystalline dolomite. Laminated areas consist of laminations of very fine crystalline dolomite alternating with slightly coarser crystalline dolomite. Bore holes are filled with relatively coarse crystalline dolomite in which angular to well-rounded "original" shell fragments and recrystallized shell fragments are embedded. Shell fragments are partially altered to dolomite. Extreme east end of quarry.

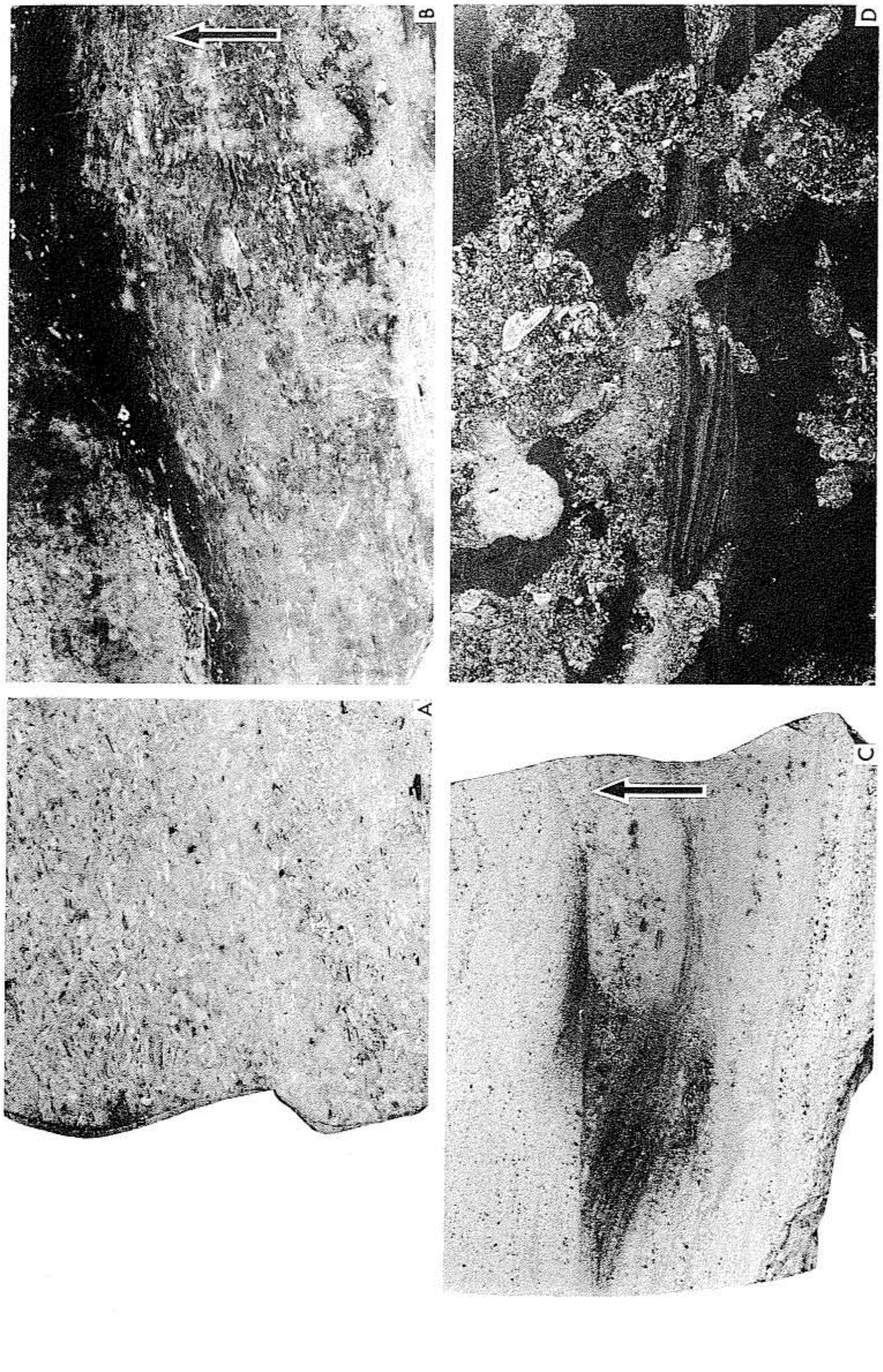

A
B
C
D

PLATE 25

LOCALITY 14-T-1

(All photographs are x15)

A. Inter-reef deposit; dolomitic fine shell debris. Poorly sorted, rounded particles are composed of "original" shell fragments, recrystallized shell fragments, and opaque grains. The cement consists of clear crystalline calcite in which dolomite crystals are irregularly distributed. This sample contains 16 percent dolomite. See Plate 26, A, B, for enlarged views. Lithologic unit 1, sample A (Pl. 3).

B. Inter-reef deposit; coarse-grained limestone (calcarenite). Particles consist of well-sorted and well-rounded "original" shell fragments, recrystallized shell fragments, opaque grains, oolites, and microfossils. Recrystallized shell fragments predominate. The cement is clear crystalline calcite. A trace of dolomite is present in this sample. For enlarged view see Plate 26, D. Lithologic unit 1, sample B (Pl. 3).

C. Inter-reef deposit; slightly dolomitic granular limestone (calcarenite). Particles consist of well-sorted angular "original" shell fragments and opaque grains. They occur in equal abundance. The cement is crystalline calcite. This sample contains 5 percent dolomite. Lithologic unit 3, sample E (Pl. 3).

D. Inter-reef deposit; granular limestone (calcarenite). Composed predominantly of very well-sorted and well-rounded recrystallized shell fragments embedded in a crystalline calcite cement. Elongated grains are oriented parallel to the bedding. Many grains are represented by molds. Lithologic unit 4, sample L (Pl. 3).

E. Inter-reef deposit; coarse-grained limestone (calcarenite). Similar to sample shown in photograph D except that it is more coarse grained. Lithologic unit 5, sample EE (Pl. 3).

F. Post-lithification alteration deposit. As seen in the field, this is a dense microcrystalline limestone that is mottled shades of brown. Much of the original texture is still apparent in a thin section and indicates that the original lithology was similar to that shown in photograph E. Both "original" shell fragments and recrystallized grains are present; the former are scarce, however. Many grains have almost disappeared. The large "original" shell fragment above the center of the photograph is partially silicified. Plate 24, B, shows the hand specimen of this type of lithology. Lithologic unit 5, sample OO (Pl. 3).

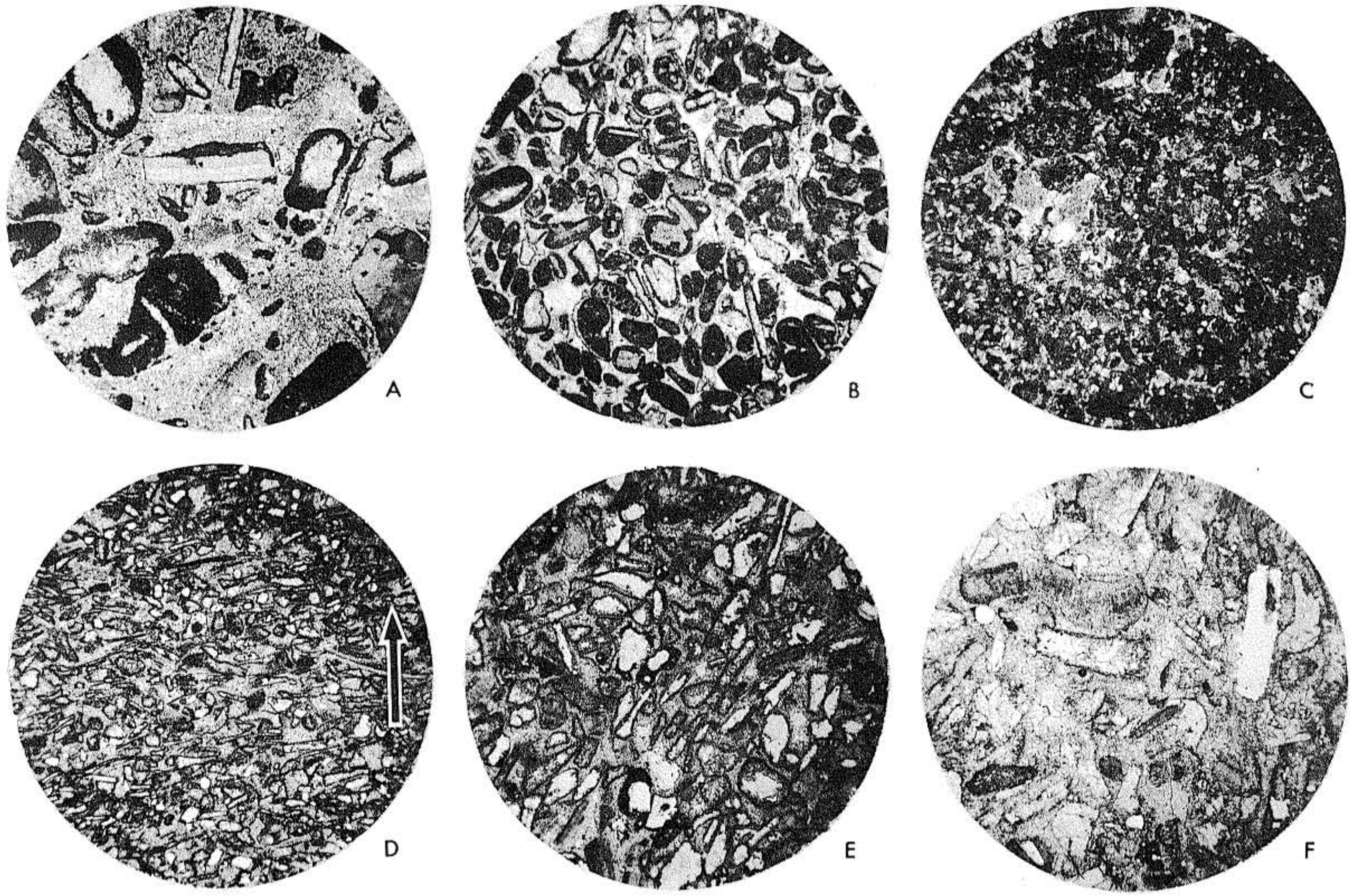


Plate 25

PLATE 26

LOCALITY 14-T-1

(All photographs are x60)

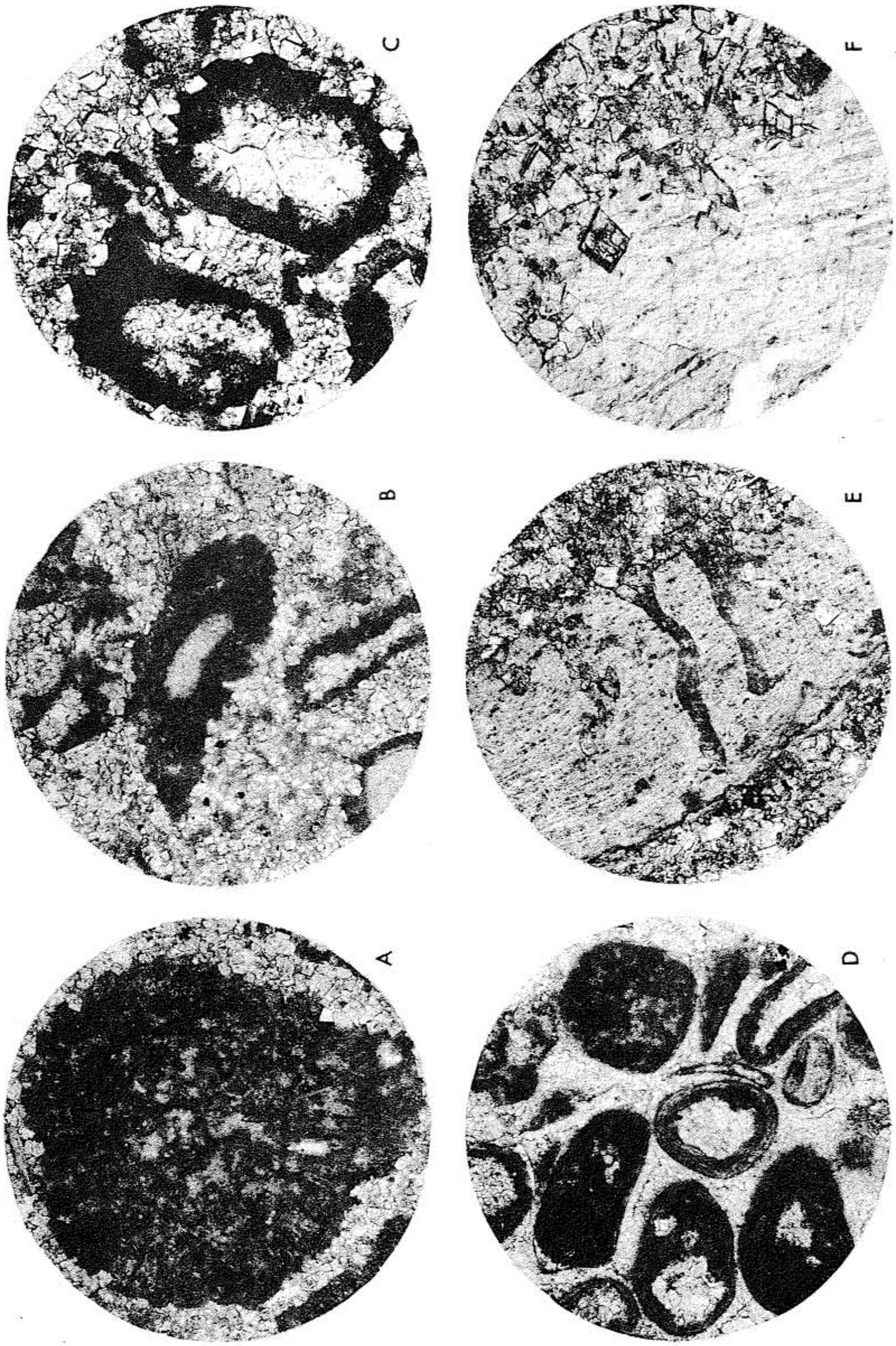
A. Encroachment of dolomite upon *Dictyoconus walnutensis*. Lithologic unit 1, sample A (Pl. 3).

B, C. Encroachment of dolomite on recrystallized shell fragments. Many fragments are represented only by "ghosts" in the matrix. Lithologic unit 1, samples A and R, respectively (Pl. 3).

D. Oolites in lithologic unit 1. The occurrence of the concentric laminations on the outside of the "dust" rims which surround most detrital recrystallized grains shows that recrystallization took place prior to cementation of the particles. Coatings of calcite crystals on the particles indicate that the interstices were filled during two stages of calcite precipitation. Lithologic unit 1, sample B (Pl. 3).

E. Bore holes in an "original" shell fragment. Borings like this are abundant in some places and indicate organic activity. Lithologic unit 2, sample U (Pl. 3).

F. Cementation of dolomite. The coarse crystalline calcite was precipitated in the intercrystalline voids of the dolomite. Ltihologic unit 2, sample U (Pl. 3).
sample U (Pl. 3).


A
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F

PLATE 27

(All photographs are x1)

A. Inter-reef deposit; poorly sorted fine shell debris. Shell fragments are angular and are usually recrystallized. Some "original" shell material is present. Matrix is composed of a detritus of fine lime-silt. Photomicrograph is shown on Plate 28, A. Locality 14-T-8, sample N (Pl. 3).

B. Post-lithification dolomite; microcrystalline dolomite with excellent intercrystalline porosity. Fossil fragments are preserved as molds. Photomicrograph of lithology similar to this is shown on Plate 28, D, E. Locality 14-T-8, sample L (Pl. 3).

C. Post-lithification calcitic dolomite. Very fine crystalline texture. Extremely hard, dense, and mottled shades of yellow, pink, and brown. It was formed by precipitation of calcite in the intercrystalline voids of the dolomite. Photomicrograph of lithology similar to this is shown on Plate 28, F. Locality 14-T-8, sample AA (Pl. 3).

D. Reef core; *Cladophyllia* zone. Clear coarse crystalline calcite fills the interior of the corals and in many places has replaced the original shell material. The matrix consists of extremely fine-grained limestone. Locality 50-T-6.

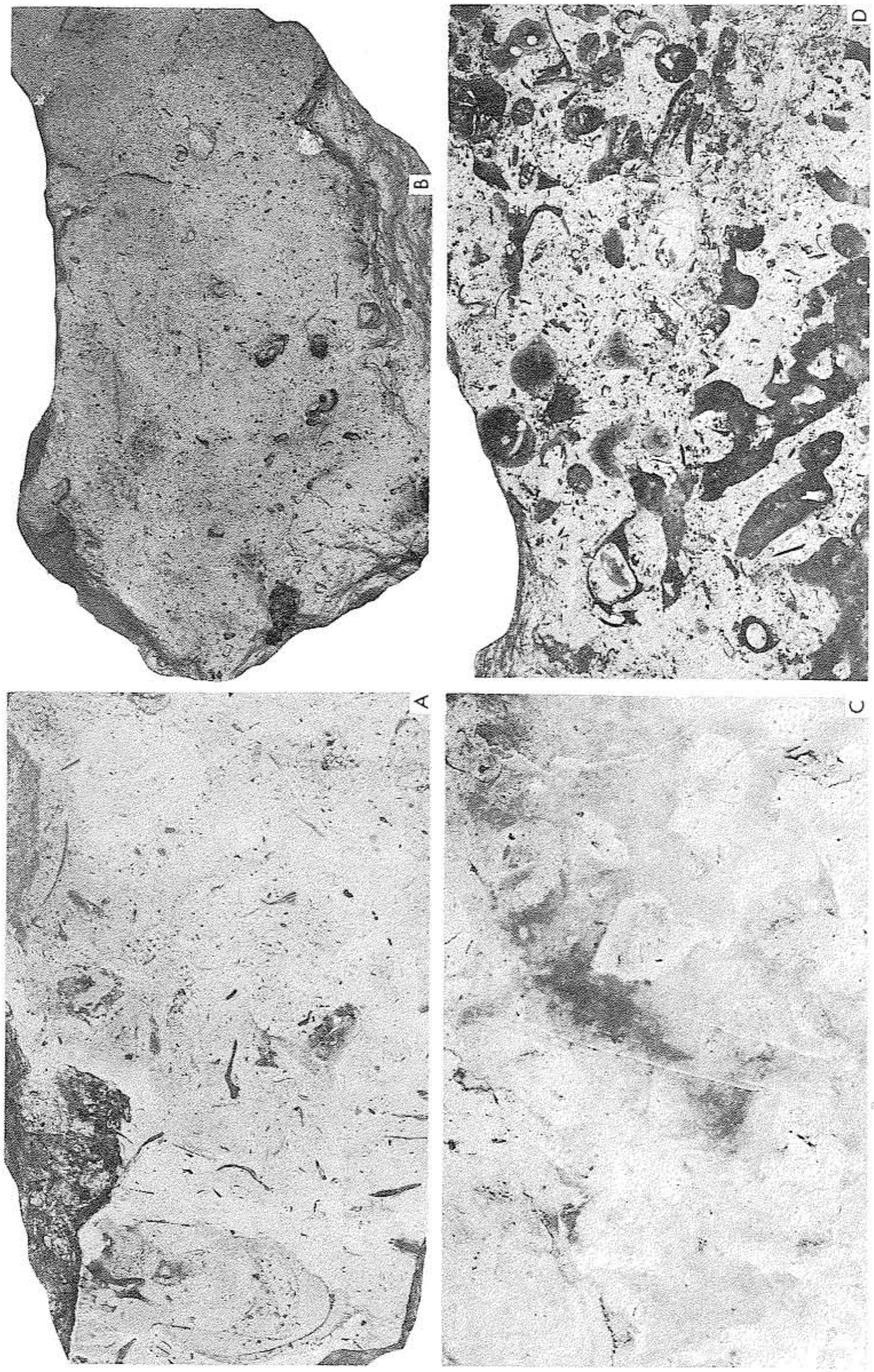
A
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PLATE 28

LOCALITY 14-T-8

A. Inter-reef deposit; fine shell debris. Poorly sorted shell fragments are angular and almost totally recrystallized. The matrix is a detritus of fine lime-silt. No dolomite is present. Sample N (Pl. 3). (x15)

B. Inter-reef deposit; dolomitic granular limestone. Consists of dolomite rhombohedrons embedded in well-sorted lime-sand and lime-silt. Seventeen percent dolomite. Sample T (Pl. 3). (x60)

C. Inter-reef deposit; dolomitic granular limestone. Dolomite has encroached upon an "original" shell fragment. Forty-five percent dolomite. Sample S (Pl. 3). (x60)

D. Post-lithification alteration deposit; very fine crystalline dolomite. Intercrystalline porosity is well developed. Crystals surrounding large pores tend to be larger than others. This results in a mottled appearance. Ninety-eight percent dolomite. Sample A (Pl. 3). (x60)

E. Post-lithification alteration deposit; very fine crystalline dolomite. Former shells and shell fragments are represented by molds. Sample H (Pl. 3). (x15).

F. Post-lithification alteration deposit; very fine crystalline calcitic dolomite. Intercrystalline arëas are filled with clear coarse crystalline calcite. In the field this rock is very hard, dense, and mottled shades of pink, brown, gray, and yellow. Sixty-four percent dolomite. Sample B (Pl. 3). (x60)

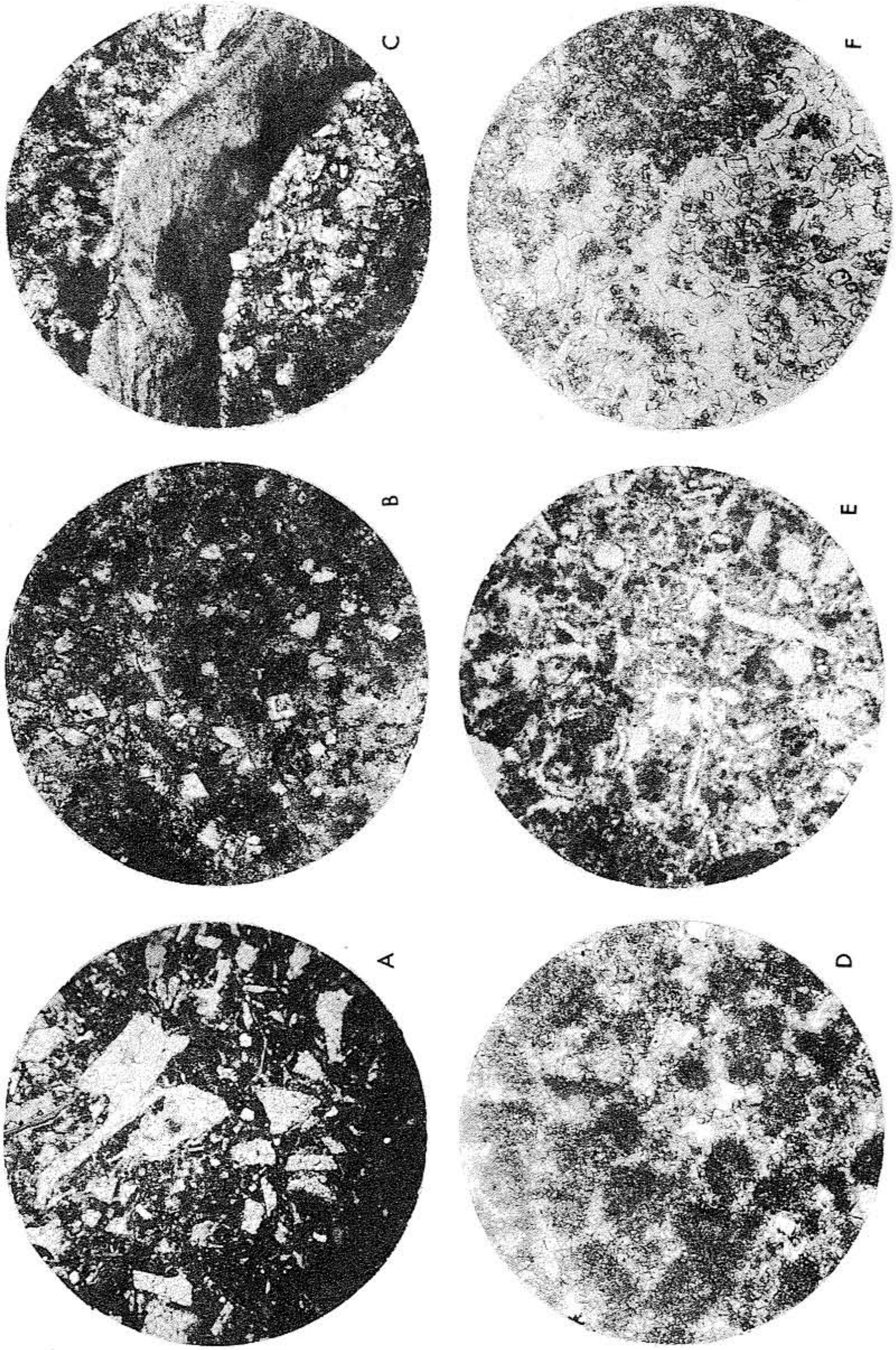
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PLATE 29

A-D. Dolomitization of the Comanche Peak formation, locality 14-T-8.

A. Very fine-grained limestone (calcilutite). No dolomite is present. Sample V (Pl. 3). (x60)

B. Slightly dolomitic fine-grained limestone. Eighteen percent dolomite. Sample D (Pl. 3). (x60)

C. Calcitic dolomite. Fifty-seven percent dolomite. The original clastic texture has been almost completely obliterated. Sample E (Pl. 3). (x60)

D. Post-lithification deposit; fine crystalline dolomite. One hundred percent dolomite. Intercrystalline porosity is well developed. Sample F (Pl. 3). (x60)

E. Post-lithification alteration deposit. The limestone is hard, brown, and very finely crystalline. It has a concretionary structure. The interconcretionary voids are the result of nondeposition. Roadcut near Frank's Landing on the south side of Belton reservoir west of Belton, Bell County.

F. Post-lithification alteration deposit. The limestone is hard, dark brown, and very finely crystalline. In contrast to the limestone shown in photograph E, the vugs in this limestone are the result of solution. Locality 14-T-3, near base of measured section.

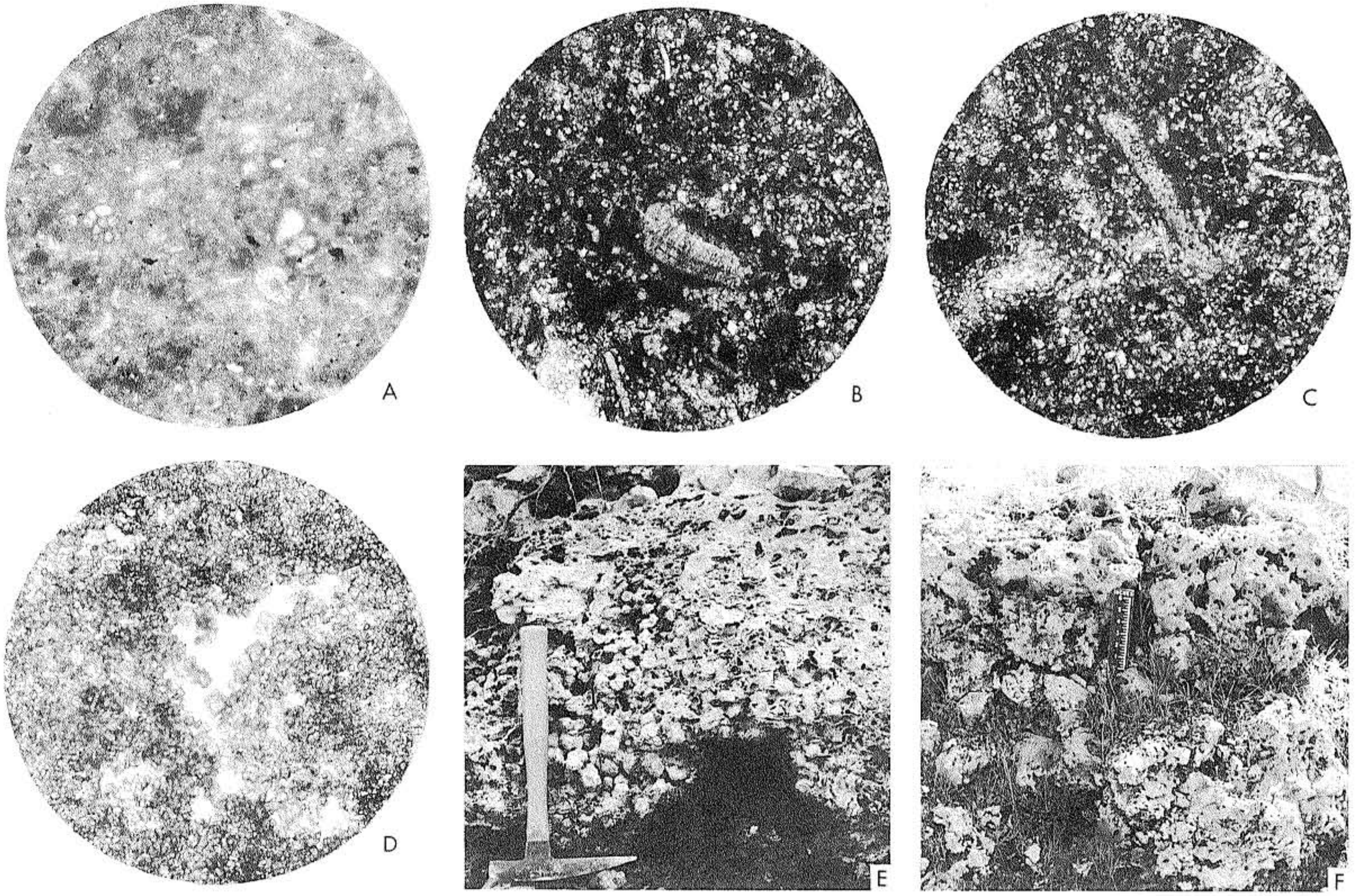


Plate 29

PLATE 30

MODES OF SHELL PRESERVATION

A. "Original" shell of *Eoradiolites* showing prismatic structure of outer shell wall filled with secondarily deposited clear crystalline calcite. The dark wall material of this wall exhibits fibrous and prismatic structures under high magnification. The inner shell wall is clear coarse crystalline calcite; it is believed to be of diagenetic origin. Locality 50-T-7, sample J (Pl. 3). (x1.3)

B. Partially recrystallized shell. A mosaic of clear anhedral calcite crystals is superimposed upon "original" shell structure (dark). Other fragments in various stages of recrystallization are also present. For enlarged view see Plate 15, B. Locality 154-T-6. (x2.5)

C. Partially replaced *Caprinuloidea*. The original shell was removed by solution and is now being replaced by secondarily deposited clear crystalline calcite. The lithified lime-mud filling of one chamber has fallen out following solution of the shell wall. Replacement takes place by deposition of a thin layer of crystals on the walls of the cavities and bridging of the remaining space by crystal growth. Locality 50-T-6. (x1.6)

D. Chert casts of dolomite molds of fossils. The original rock was rudistid limestone. It was converted to dolomite by post-lithification dolomitization and in the process many fossils were preserved as molds. In places, silica has been deposited in the voids. In ordinary light the dolomite molds are not readily differentiated from the chert casts in the dolomite. Locality 14-T-1, unit 6. Sample collected east of mapped portion of quarry. (x15)

E. Silicified shell. The original shell has been replaced by clear anhedral crystalline quartz. Quartz also fills some of the chambers in the fossils. Locality 14-T-1, sample BB (Pl. 3). (x15)

F. Dolomite cast of fossil. The dolomite is believed to have been deposited as a void filling. Dolomite also fills part of the body chamber of a fossil at the base of the photograph. See Plate 19 for other views of dolomite casts. Locality 154-T-16. (x1.3)

G. Chalkified *Dictyoconus*. The original form of the shell is still vaguely apparent but the shell material has been converted to microgranular calcite. Locality 14-T-1, sample DD (Pl. 3). (x15)

H. Partially recrystallized *Rangia cuneata*, a brackish-water pelecypod. This is a thin section of the specimen shown in photograph I. The specimen was collected in the Gulf of Mexico in approximately 75 feet of water. It is of late Pleistocene or early Recent age. Note the irregular manner in which the shell recrystallizes. Compare it with photograph B. The shell structure is still apparent in the crystalline calcite. This method of direct recrystallization is believed to be one manner of recrystallization of ancient shells. (x2).

I. *Rangia cuneata* shell agglomerate. Note that some of the shells are altering to chalk. Note also the scalenohedral calcite crystals coating several shells. This feature occurs in many places in the Edwards limestone. The cement is clear crystalline calcite. (x1)

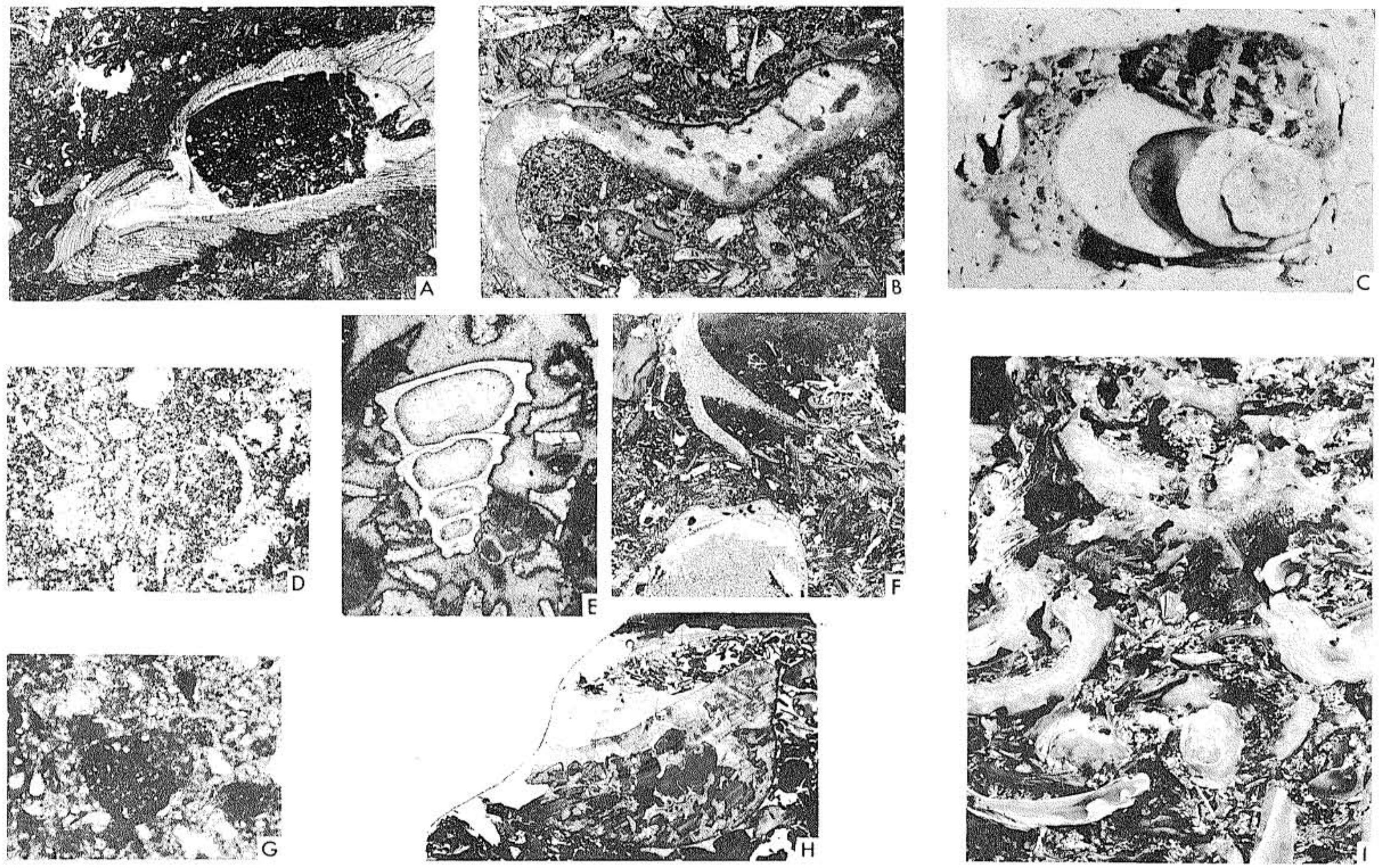
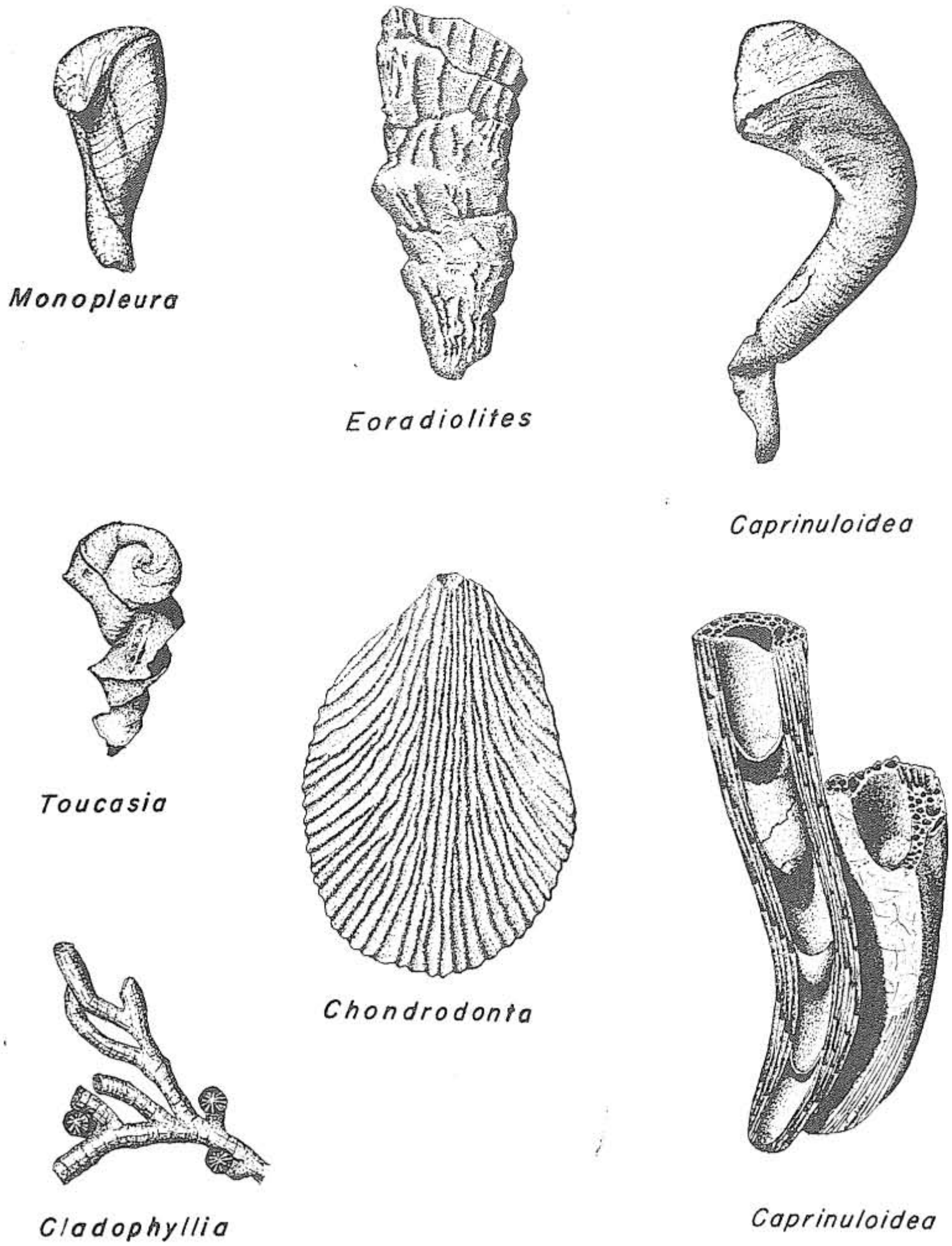


Plate 30



Typical genera of the Edwards limestone tabular reef. *Eoradiolites* is a Rudistaceae: *Toucasia*, *Monopleura*, and *Caprinuloidea* are Chamaceae; *Chondrodonta* belongs to the Pernidae, Mytilacea; and *Cladophyllia* to the Actinaria. Illustrations about 2/3 natural size.

PLATE 32

FOSSILS FROM EDWARDS LIMESTONE

(All from upper 50 feet of the Edwards limestone, Barton Creek, Barton Hills addition, Austin, Travis County, Texas, unless otherwise indicated)

FIGURES—

1. *Eoradiolites davidsoni* (Hill). From the Edwards limestone, Bee Mountain, Bosque County, Texas. x *c*. 57.
2. *Eoradiolites* sp. From the upper 50 feet of Edwards limestone, Red Bud Trail, Austin, Travis County, Texas. x *c*. 57.
3. *Monopleura*. x *c*. 57.
4. Miliolid. x *c*. 57.
5. Miliolid and unidentified foraminifers. x *c*. 170.
6. Diceratid, probably *Toucasia* sp. x *c*. 57.
7. Miliolids and ostracods. x *c*. 170.
8. *Durania austinense* (Böse). Austin chalk, Little Walnut Creek and U. S. Highway 290 (to Manor), Travis County, Texas. x *c*. 57.
9. *Monopleura* sp. x *c*. 170.
10. *Monopleura* sp. Same specimen as figure 9. x *c*. 57.
11. Ostracods. x *c*. 57.

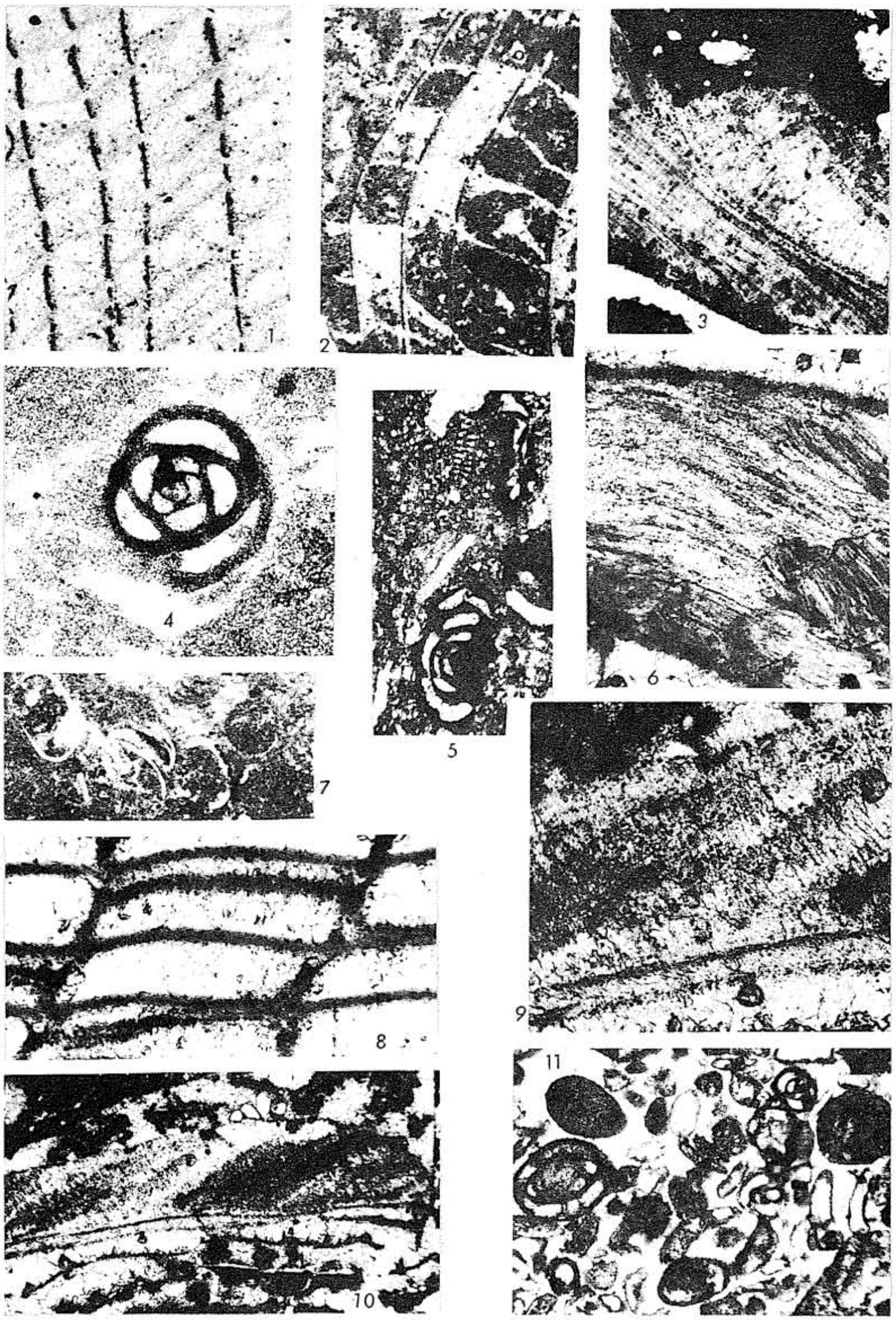

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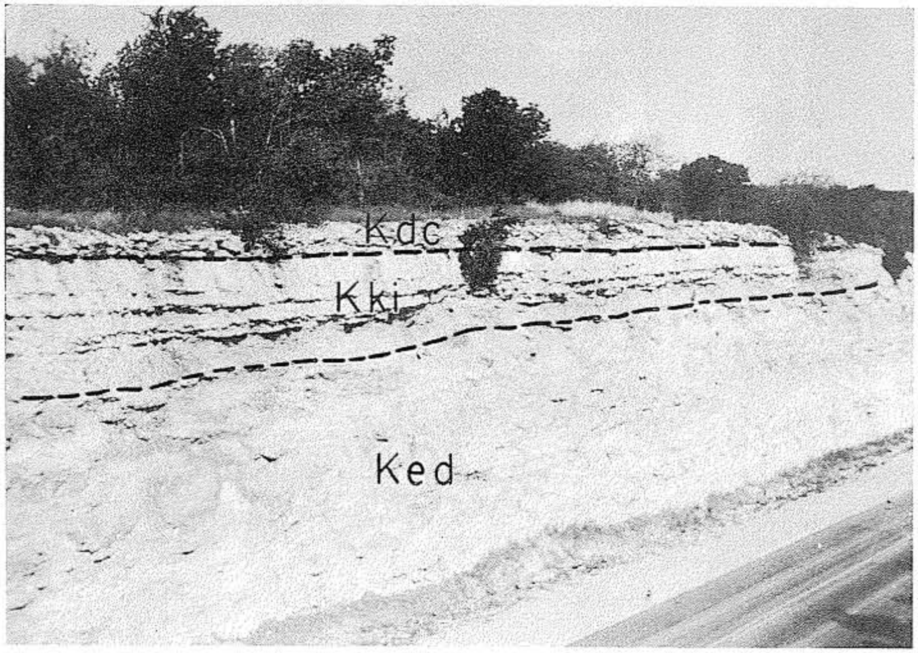
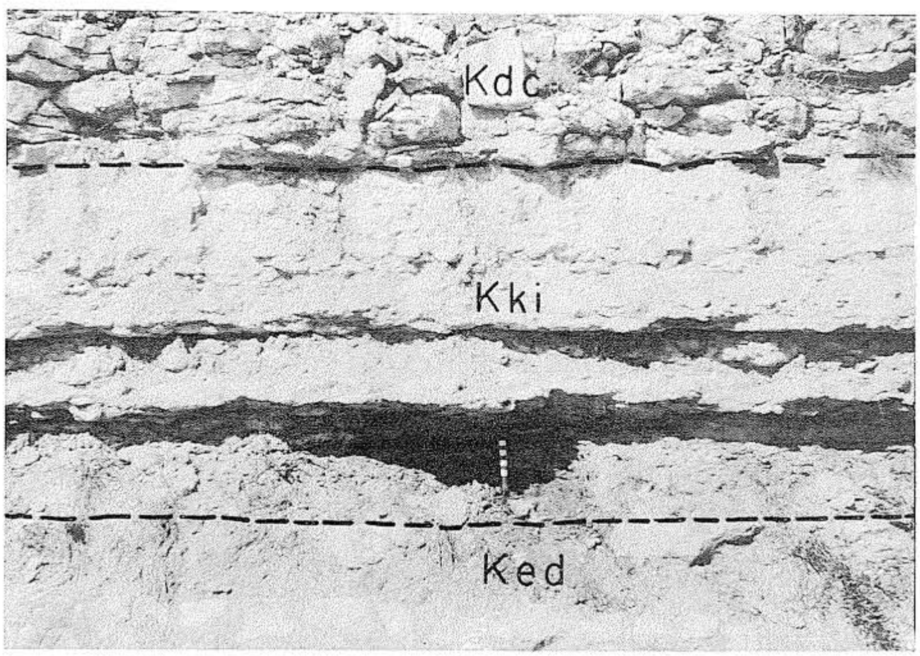
PLATE 33

A. Road cut on State Highway 317 north of Crawford, which exposes the reef facies of the Edwards formation, the Kiamichi formation, and the basal Duck Creek member of the Georgetown formation. The upper part of the Kiamichi is severely weathered.

B. Uppermost Edwards formation, Kiamichi formation, and basal Duck Creek member of the Georgetown formation in the road cut pictured above. Stratigraphic Section XII, showing the three lithologic divisions of silty shale, wavy-bedded limestone, and calcareous clay.



A

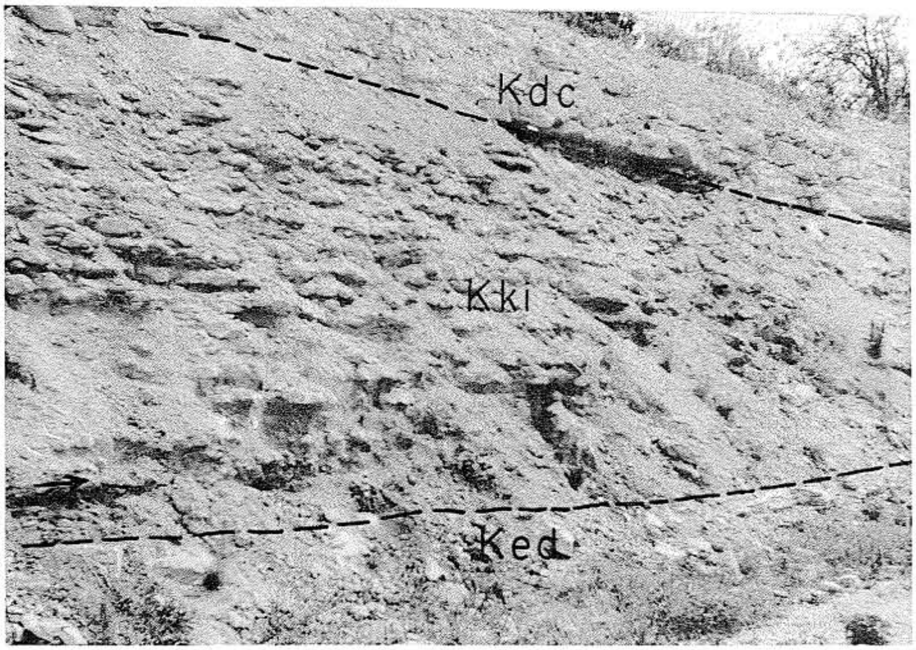


B

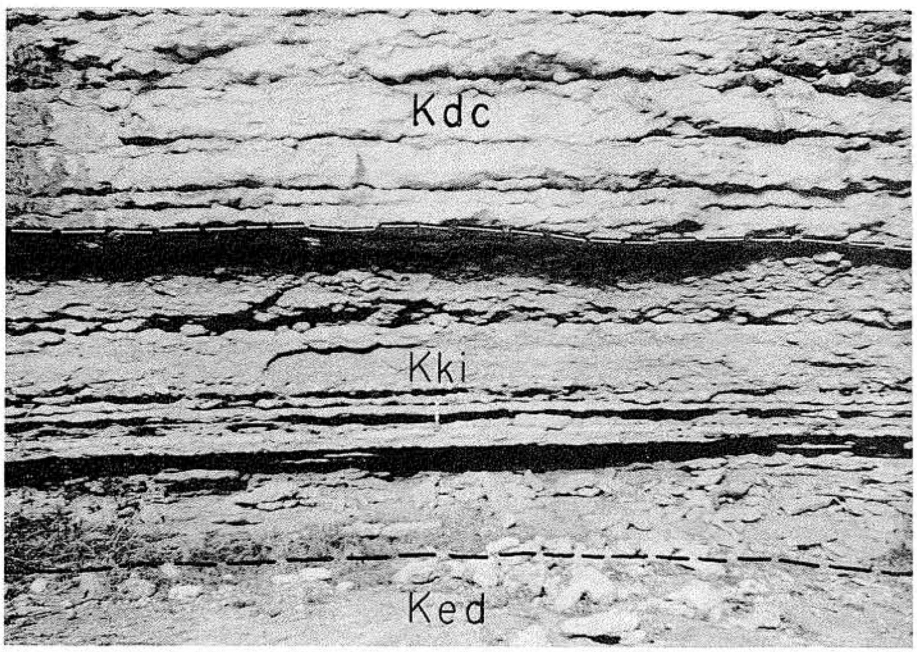
PLATE 34

A. Uppermost inter-reef limestones of the Edwards formation, Kiamichi formation, and basal Duck Creek member of Georgetown formation in a road cut on State Highway 22 west of Whitney Dam, Bosque County (Stratigraphic Section III-A). This exposure is relatively fresh and shows the lithology of unweathered shales and limestones of the Kiamichi. The position of a *Gryphaea* bed is indicated by the arrow.

B. Top of reef facies of the Edwards formation, Kiamichi formation, and basal Duck Creek member of the Georgetown formation in the banks of Childress Creek in northern McLennan County (Stratigraphic Section VI-A). This exposure illustrates the nodular and wavy bedding of limestones in the Kiamichi. The percentage of limestone is overemphasized due to rapid removal of shale by the waters of the creek.



A

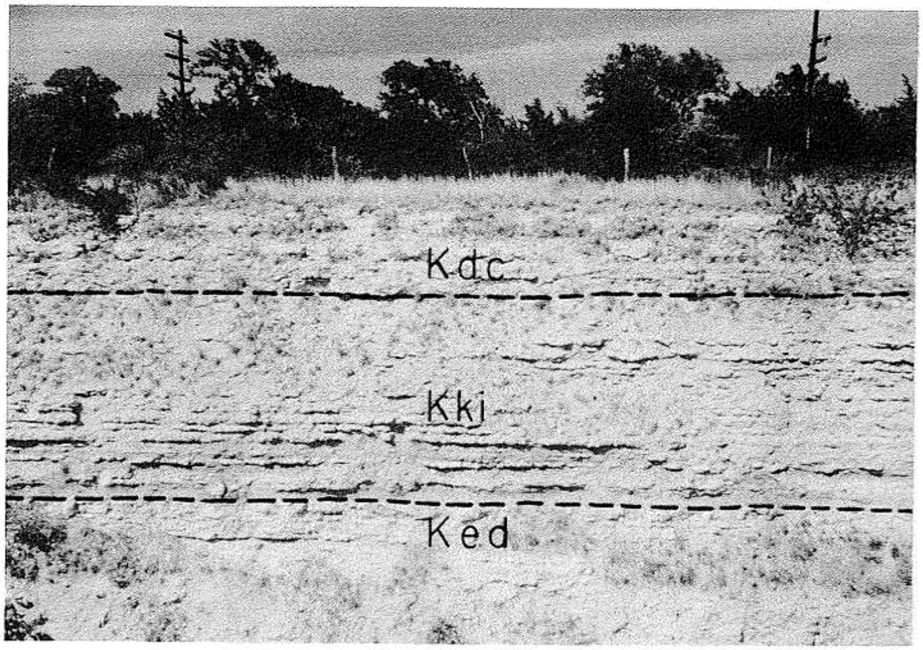


B

PLATE 35

A. Edwards formation, Kiamichi formation, and basal Duck Creek member of Georgetown formation in north face of railroad cut near Valley Mills. The Kiamichi in this exposure (Stratigraphic Section VIII) is abnormally thick and overlies inter-reef facies of the Edwards.

B. Pebbles of Edwards limestone associated with a *Gryphaea* bed in the lower Kiamichi as exposed in the railroad cut near Valley Mills. The base of the Kiamichi is shown at the lower right.



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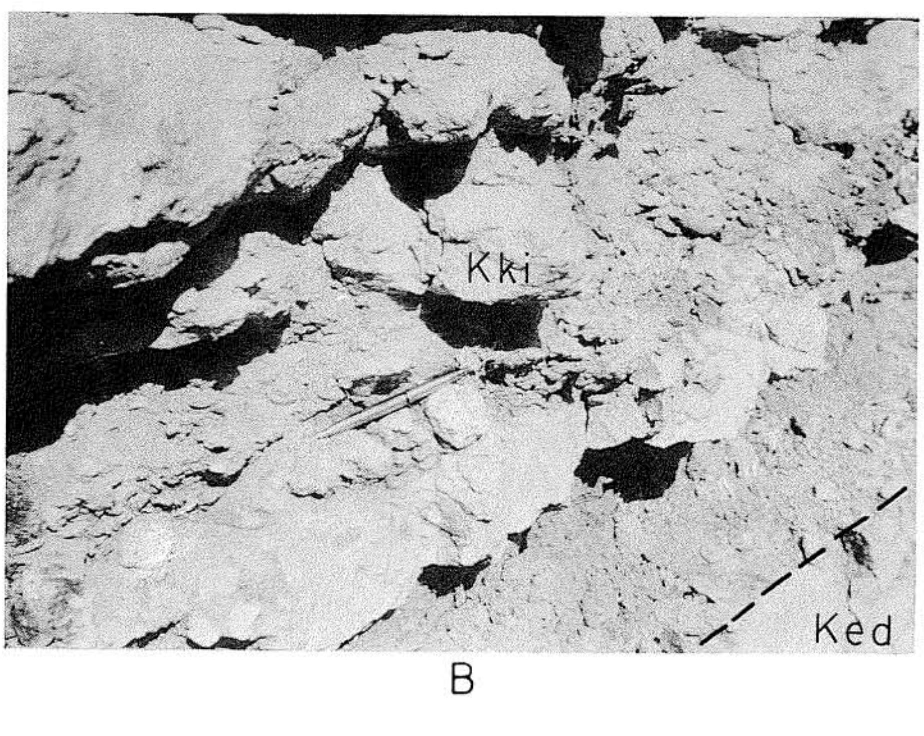
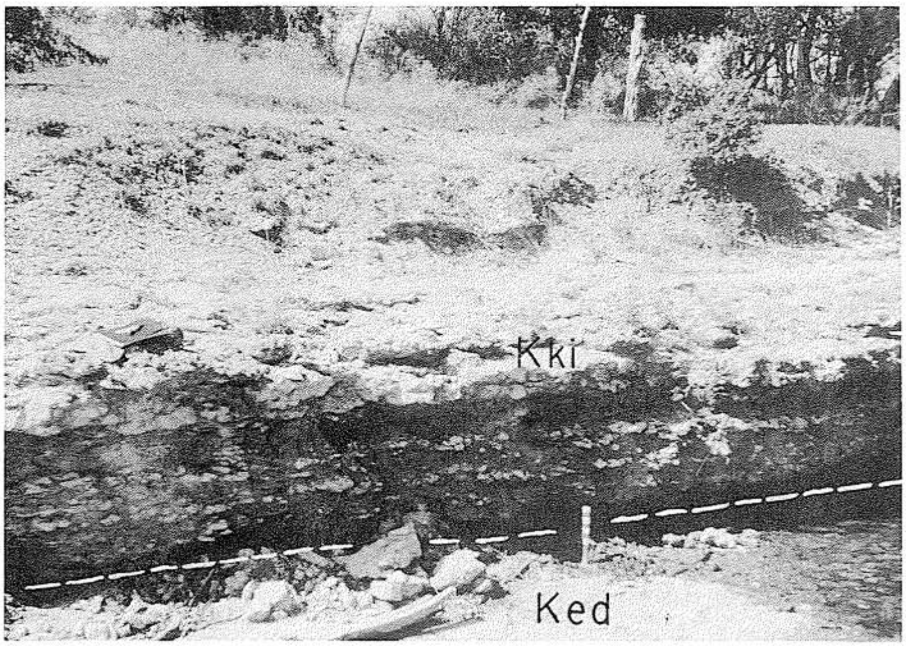


B

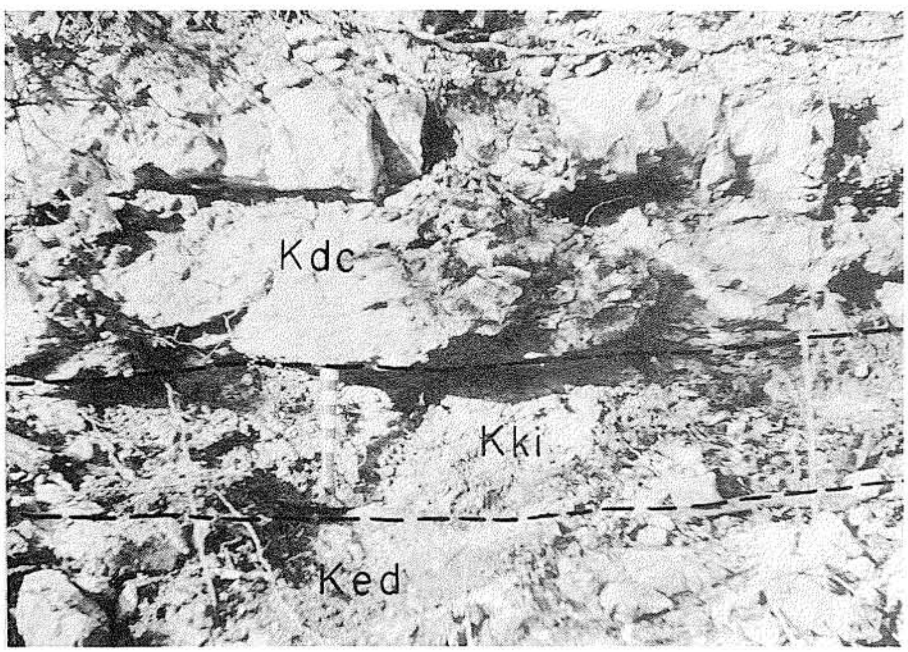
PLATE 36

A. Lower silty shale and nodular limestone of the Kiamichi formation as exposed in the banks of Hog Creek near Patton in McLennan County. The hammer is resting on the top of the Edwards formation which is exposed at the water level of the creek. This is the lower part of Stratigraphic Section IX.

B. Top of inter-reef limestone of the Edwards formation, Kiamichi formation, and the basal Duck Creek member of the Georgetown formation as exposed on Horse Creek near Whitson in Coryell County. This is the southernmost exposure of the Kiamichi formation in central Texas (Stratigraphic Section XVII).



A



B

PLATE 37

Gryphaeas of the Kiamichi formation (all x1)

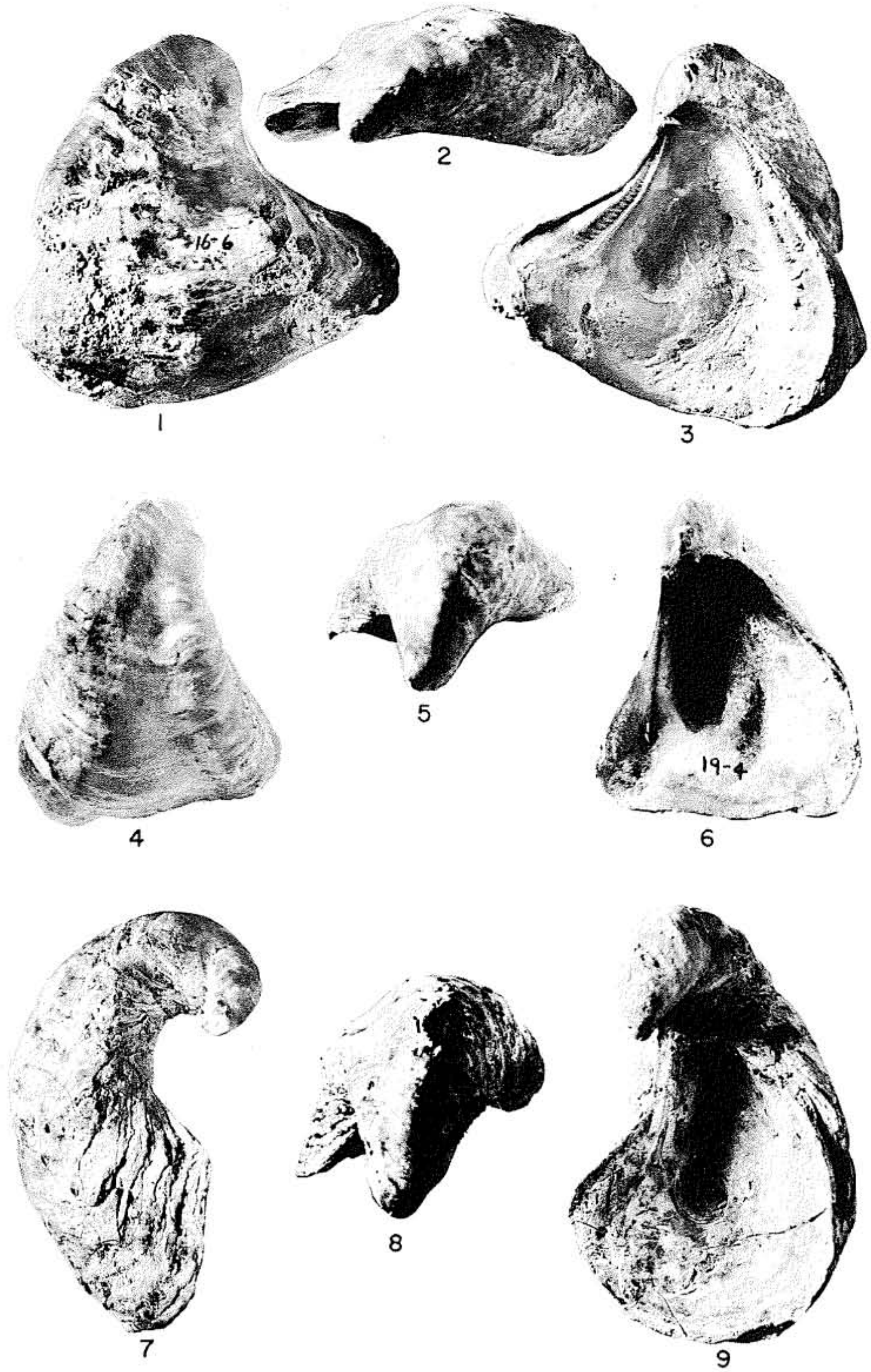


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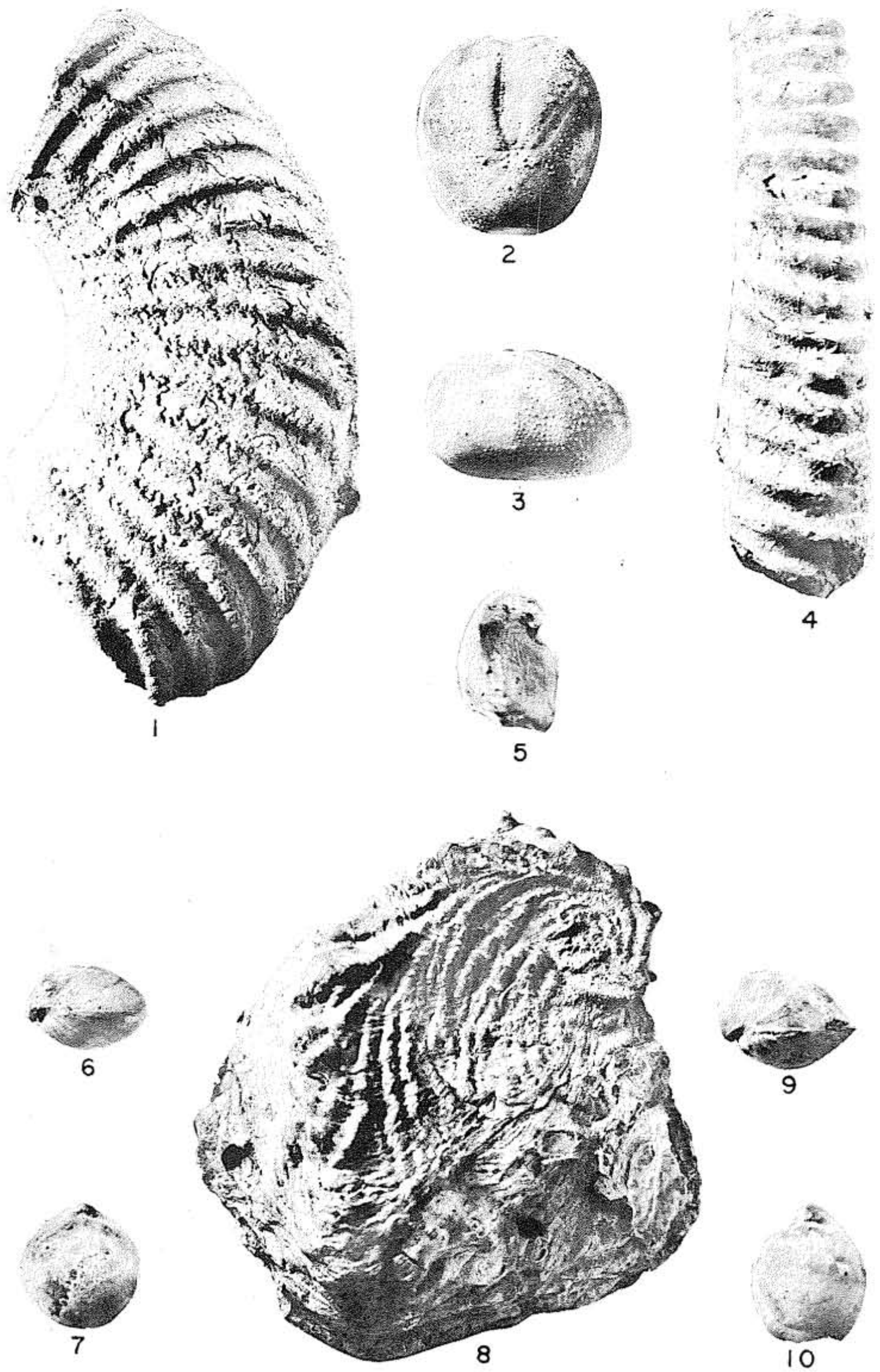
PLATE 38

Megafossils of the Kiamichi formation and basal Duck Creek member of the Georgetown formation (all x1 except fig. 1 which is x.6)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