72-29,878

ECHOLS, Betty Joan, 1932-
BIOSTRATIGRAPHY AND REPTILE FAUNAS OF THE UPPER AUSTIN AND TAYLOR GROUPS (UPPER CRETACEOUS) OF TEXAS, WITH SPECIAL REFERENCE TO HUNT, FANNIN, LAMAR AND DELTA COUNTIES, TEXAS.

The University of Oklahoma, Ph.D., 1972
Paleontology

University Microfilms, A XEROX Company, Ann Arbor, Michigan

THE UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

BIOSTRATIGRAPHY AND REPTILE FAUNAS OF THE UPPER AUSTIN AND TAYLOR GROUPS (UPPER CRETACEOUS) OF TEXAS, WITH SPECIAL REFERENCE TO HUNT, FANNIN, LAMAR AND DELTA COUNTIES, TEXAS

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

degree of

DOCTOR OF PHILOSOPHY

BY

JOAN ECHOLS

Norman, Oklahoma

1972

BIOSTRATIGRAPHY AND REPTILE FAUNAS OF THE UPPER AUSTIN AND TAYLOR GROUPS (UPPER CRETACEOUS) OF TEXAS, WITH SPECIAL REFERENCE TO HUNT, FANNIN, LAMAR AND DELTA COUNTIES, TEXAS

APPROVED BY

Jiri Zidek

David B. Kitts

Harvey Blatt

Glen [illegible]

Charles W. [illegible]

DISSERTATION COMMITTEE

BIOSTRATIGRAPHY AND REPTILE FAUNAS OF THE UPPER AUSTIN AND TAYLOR GROUPS (UPPER CRETACEOUS) OF TEXAS, WITH SPECIAL REFERENCE TO HUNT, FANNIN, LAMAR AND DELTA COUNTIES, TEXAS

BY

Joan Echols

Major Professor: Dr. David B. Kitts

Upper Cretaceous rocks in northeast Texas have furnished many vertebrate specimens, some of which occur as concentrations (eight animals at one locality) of fossils in particular lithologies. Explanations for the concentrations involve both biologic and sedimentologic factors.

The units studied are, in ascending order, the Roxton Limestone (Upper Austin Group), and the Ozan Formation, Wolfe City Formation, Pecan Gap Formation and Marlbrook Formation (Taylor Group). These rocks are of Campanian age. The Roxton Limestone is a cross-bedded, intensely bioturbated biomicrite containing many vertebrate and invertebrate fossils. The Ozan and Marlbrook marls are gray, calcareous mudrocks with some fossils. A condensed zone in the Ozan Formation is a glauconitic packed biomicrite containing many vertebrate and invertebrate fossils. The Wolfe City Formation is a massive, light brown orthoquartzite that contains few fossils. The Pecan Gap chalks are white to cream sparse biomicrites, the basal ten feet of which are another condensed zone. All carbonate and mud rocks are texturally immature and poorly sorted, and all show evidence of bioturbation.

Condensed zones occur in the Roxton Limestone, the Ozan Formation and at the base of the Pecan Gap Formation. All of these zones contain concentrations of fossils and phosphatic casts and nodules. Some vertebrate specimens from these zones are disarticulated by currents and burrowers, encrusted or bored by marine organisms, bitten and reworked. These specimens were exposed on the sea floor for long periods of time, in areas of by-passing where slow sedimentation caused condensed deposits to form. The occurrence of some of these zones around a synchronous

high, the Preston anticline, provides evidence of at least indirect tectonic control of biofacies as well as lithofacies. Concentrations of fossils in the Roxton calcarenitic biomicrites may also indicate tectonic control if currents flowing around the Preston anticline washed carcasses into the area and beached them on the shoal areas near the crest. One species of mosasaur, Clidastes propython, is restricted to occurrence in the Roxton Limestone, because members of this species may have preferred to live in shallow water around the Preston anticline.

The vertebrate fauna includes remains of many mosasaurs, a few plesiosaurs and turtles, and many fishes and sharks. The fossils may represent the Clidastes propython-Platecarpus ictericus-Tylosaurus proriger zone, which occurs in the Niobrara and Pierre Formations. Tylosaurus was the most abundant genus of mosasaurs, and Globidens was the rarest. Some specimens of Tylosaurus are estimated to have been more than 50 feet in length. The fossils occur scattered in all lithologies and in all stratigraphic units but they form concentrations in the condensed zones. Restrictions of mosasaur species other than Clidastes propython are the result of rarity of the specimens, rather than biological, temporal or sedimentological restrictions.

During the late Cretaceous, northeastern Texas may have been similar to the Rowley-Sahul Shelf area (northwestern Australia). Both areas had slow carbonate deposition around alternate highs and basins, with condensed zones forming on the highs where currents removed fine particles. Thus the occurrence of lithofacies and biofacies was influenced by tectonic features in the study area.

ACKNOWLEDGMENTS

This study is submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at the University of Oklahoma. The problem was suggested by Dr. Roy N. Jervis, Head of Earth Sciences Department, East Texas State University. The work was directed by Dr. David B. Kitts, whose assistance is gratefully acknowledged.

Gratitude is due Drs. Harvey Blatt, Charles Harper, Jiri Zidek for checking the manuscript and making helpful suggestions. I want to thank Dr. John T. Thurmond for his assistance in checking the identifications and systematic paleontology. Special thanks are due Dr. Gideon T. James, Earth Sciences Department, East Texas State University, for his assistance with field and laboratory techniques, photography, and helpful discussions.

The writer wishes to thank Drs. Charles Mankin, David Kitts, and Nolan McWhirter (Head of Earth Sciences Department, East Texas State University) for help in obtaining funds for the project. These funds included Geological Society of America grants number 1145-67 and 1244-69, and a grant from University of Oklahoma School of Geology funds. Dr. McWhirter's assistance in obtaining work space, tools, student assistants, and travel funds was especially appreciated. Special thanks are due the Southwest Pump Company, Bonham, Texas, for their loan of a portable gasoline jackhammer for work on ET Locality 43.

The helpfulness of many paleontologists during study trips was greatly appreciated; Professor Bob Slaughter, Shuler Museum of Paleontology, Southern Methodist University, Dr. Eugene Gaffney, American Museum of Natural History, Drs. Nicholas Hotton III and Robert Purdy, United States National Museum, Dr. Robert Scott, University of Texas at Arlington, Dr. Bryce C. Brown, Strecker Museum, Baylor University, and Dr. Wann Langston, University of Texas at Austin were very helpful.

Several students have assisted with special techniques, and I want to thank University of Oklahoma students Dah-Cheng Wu for X-ray analysis of one sample and Kenneth Sargeant for assistance with insoluble residue techniques. East Texas State University art student Gary Panter did the line drawings and Charles Griffith drafted the map and measured sections. Their help is greatly appreciated. My gratitude is expressed to the many students who assisted with laboratory and field work, especially Irene (Mrs. Retus) Beeler, Otha Boozer, Larry Brent, David Butts, Donald Galbraith, Tad Poutinen, Harold Sheppard, David Stroud, Jesse Todd, Jack Tucker and John Wright. Numerous other students have donated specimens and given locality information; their help is also acknowledged.

I want to express special thanks to my parents, Ben Russell Echols and the late Edna Bollinger Echols, for their assistance and encouragement in all phases of the work.

TABLE OF CONTENTS

Page

SYSTEMATIC PALEONTOLOGY -- (Continued)

LIST OF TABLES

LIST OF ILLUSTRATIONS

BIOSTRATIGRAPHY AND REPTILE FAUNAS OF THE UPPER AUSTIN AND TAYLOR GROUPS (UPPER CRETACEOUS) OF TEXAS, WITH SPECIAL REFERENCE TO HUNT, FANNIN, LAMAR AND DELTA COUNTIES, TEXAS

INTRODUCTION

The author became aware of the subject of this report during the autumn of 1964, shortly after appointment to the faculty of East Texas State University (Commerce, Texas). The study area has been known to amateur and student collectors for many years as a source of vertebrate fossils. Students Millard Brent, Donald Galbraith, Lee Johnson and Arthur Umberger brought specimens to me and to Miss Hazel Peterson and collection for the current project began in the fall of 1964.

Purpose

The purpose of the investigation is to describe the reptilian fauna and the distribution of vertebrate remains from Upper Austin and Taylor strata in northern Hunt, Delta, southern Fannin and southwestern Lamar Counties, Texas (fig. 1). Collecting made apparent vertebrate concentrations in strata that were petrologically different from the rest of the section, although vertebrate remains come from all lithologies and all units under study. Explanations of distribution must be

<u>Figure 1</u>

Index map showing location of study area (cross-hatched), and those counties from which additional vertebrate specimens have been collected (indicated by an X).

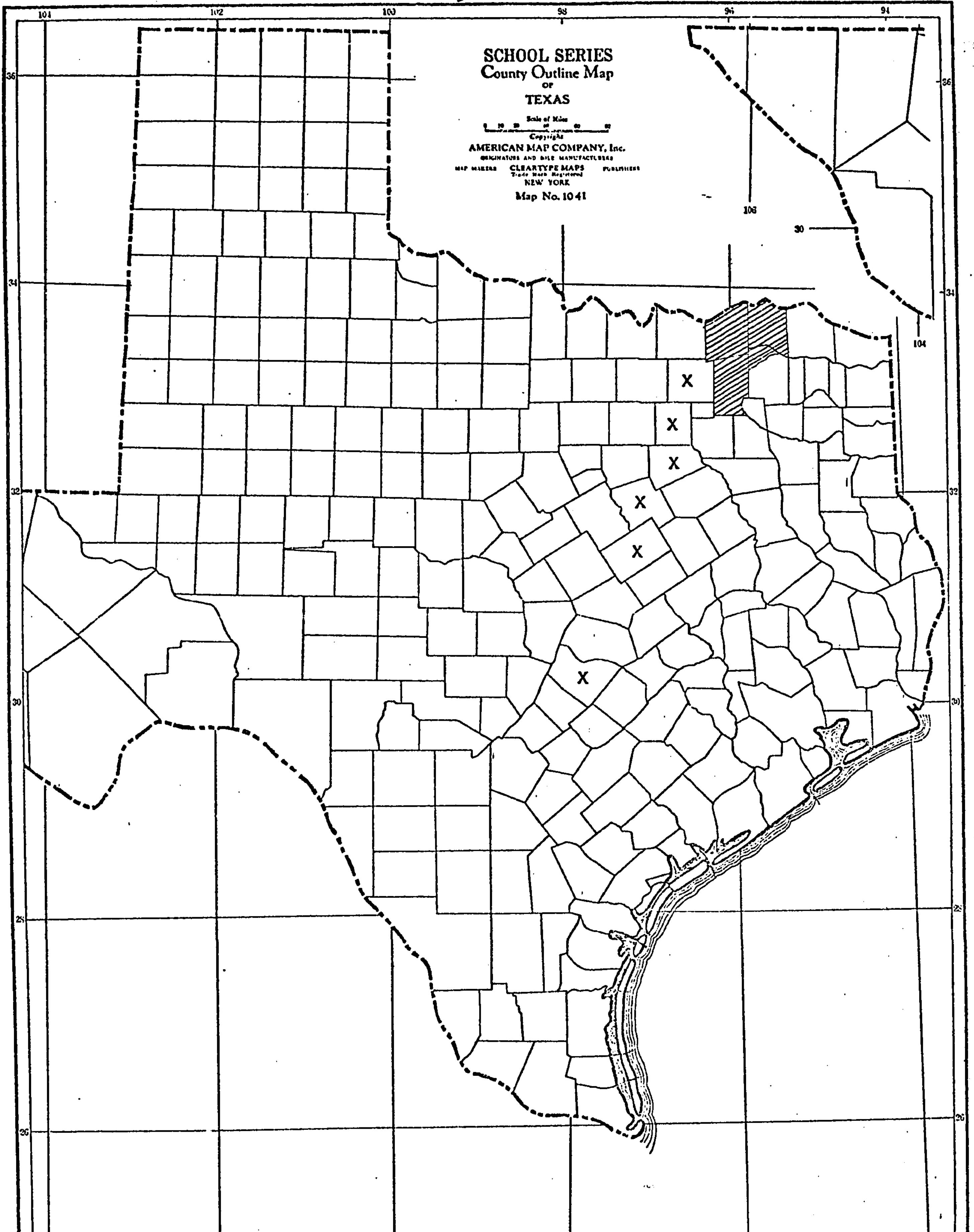

SCHOOL SERIES
County Outline Map
OF
TEXAS
Scale of Miles
Copyright
AMERICAN MAP COMPANY, Inc.
CLEARTYPE MAPS
NEW YORK
Map No. 1041
X
X
X
X
X
X

FIGURE 1

partially petrographic and partially zoologic (that is, involving the nature of the depositional environments, lithification and diagenetic history as well as where and how the animals lived). Thus the distribution throughout the area and geologic section had to be explained, as did local concentrations such as those at localities near Roxton, Gober and Bailey, and the concentrations in several units such as the Roxton Limestone, Ozan condensed zone and basal Pecan Gap Chalk. Abundance of the remains and differences in the condition and preservation of the bones also had to be explained. Extremely worn specimens had probably been washed into stream and river gravels during Pleistocene weathering cycles, and are now being washed again into river bottom gravels in the North Sulphur River and its tributaries. Some specimens are worn when collected from the Roxton Limestone, and Pecan Gap basal zone. These bones were worn subaqueously before final burial, while others were worn during more recent subaerial conditions.

Scope

Original plans for the work included only Taylor Group vertebrates but the Roxton Limestone, uppermost Austin unit, furnished many specimens and was included in the study. Preliminary stratigraphic work showed that the Roxton Limestone was not similar lithologically to the underlying Gober Chalk or the Pecan Gap Chalk. Literature search showed no petrographic work on Austin or Taylor rocks in this area; because proper classification of carbonate rocks is not possible without thin section study, preliminary petrographic investigation of the strata was included. The results of even this reconnaissance study showed that the strata with concentrations of vertebrate specimens were peculiar petrographically and that sedimentary conditions influenced the vertebrate concentrations. Preparation of specimens revealed that some were encrusted with invertebrate epifauna.

The current study included prospecting outcrops for specimens, collection of ten partial skeletons of mosasaurs, one of plesiosaur, several specimens of fishes, and numerous isolated specimens. Many students and faculty members have donated specimens, including mosasaur, fish and turtle material. Samples were collected for thin sections and for washing for small vertebrates. Other work included preparation of vertebrate specimens, and their description and illustration, plotting localities and stratigraphic and other information for interpretation.

The following abbreviations are used throughout the paper:

ET - East Texas State University

TMM - Texas Memorial Museum, University of Texas at Austin

USNM - National Museum of Natural History, Smithsonian Institution at Washington, D.C.

AMNH - American Museum of Natural History, New York

SMU - Shuler Museum of Paleontology, Southern Methodist University

SMB - Strecker Museum, Baylor University

UTA - University of Texas at Arlington

DMNH - Dallas Museum of Natural History.

PROCEDURES

Stratigraphic Procedures

Stratigraphic investigations included study of outcrops, measured sections, collection of vertebrate and invertebrate fossils and samples for petrographic study. Most of the samples were grab samples collected from each unit of a measured section or from selected outcrops at irregular intervals. Thin section study was required to apply proper rock names to each of the units under study. Samples for thin sections were representative of lithologic types, vertebrate locality matrix or other unusual occurrences. Care was taken to obtain unweathered (if possible) and uncontaminated samples.

Part of selected samples was crushed, weighed and acidized for insoluble residues. Standard techniques for obtaining the residues were used (see Table 5). One brickette was made from crushed phosphate casts and nodules from the Ozan condensed zone and X-ray analysis was done by Dah-Cheng Wu (see ms. p. 75).

Paleontologic Procedures

Field work. During the three summers of field work (1967, 1968, 1969) all units under study were prospected for vertebrate specimens by walking outcrops. All specimens located were collected. Later prospecting concentrated on the Roxton Limestone and the various condensed zones, which are most productive. Donations by students or local residents lacked exact locality information. Two such localities were visited; digging did not furnish more specimens, but did serve to locate the approximate stratigraphic horizon.

Small float specimens were brought into the laboratory for preparation. Partially articulated specimens with more than a few bones were carefully uncovered with hand tools, partially trenched, lifted out, and placed in cardboard cartons. Slightly larger blocks were hardened with Gelva dissolved in alcohol (ordinary ditto spirit fluid) or shellac when plastic preservatives were not available.

Large blocks requiring extensive digging were often covered overnight with newspapers or plastic sheets weighted with rocks or soil lumps. The coverings lessened digging time following rainstorms and prevented damage to and loss of bone fragments.

Articulated skulls or partial skeletons were removed by the standard method of blocking and jacketing with plaster. Care must be taken to trench specimens in marls to sufficient depth to prevent cracking of the block. Specimens in very weathered marl that is quite jointed and fissile may be hardened with plastic preservatives (shellac is not strong enough) and the whole hardened slab then loosened and slipped into a crate. Care must be taken with the massive bioturbated biomicrites for these crack in any direction, even with proper trenching.

Procedures for removing a large block (see Figs. 2 to 11) begin with exposing all bone with hand tools and outlining the skull or skeleton. At Locality 43 the following procedures were followed. Once the skull and partial vertebral column were outlined, a large trench was dug

Figure 2

ET Locality 36, digging in progress, with volunteers from Earth Science 432, spring, 1965. Plastic sheets covering partial skull in the background.

Figure 3

ET Locality 36, scattered partial vertebral column of Polycotylus latipinnis (*ET 4277).

FIGURE 2

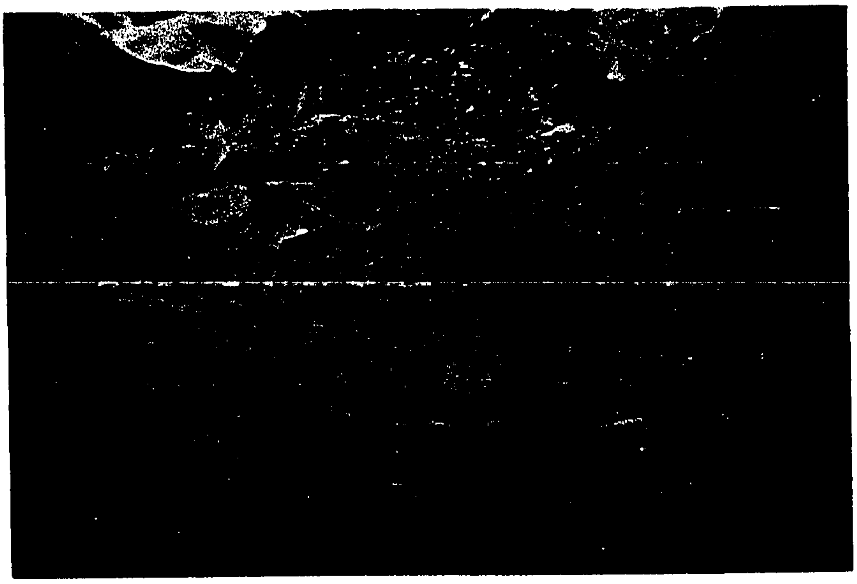


FIGURE 3

Figure 4

ET Locality 43, skull of Tylosaurus proriger (*ET 4351) uncovered and partially trenched. Piling is bridge support, skull is in streambed. Note several teeth showing in anterior half of block (to the right). Posterior portion of block broke off as trenching progressed, forming two smaller blocks.

Figure 5

Same locality and block, hand trimmed and ready for further trenching with jackhammer.

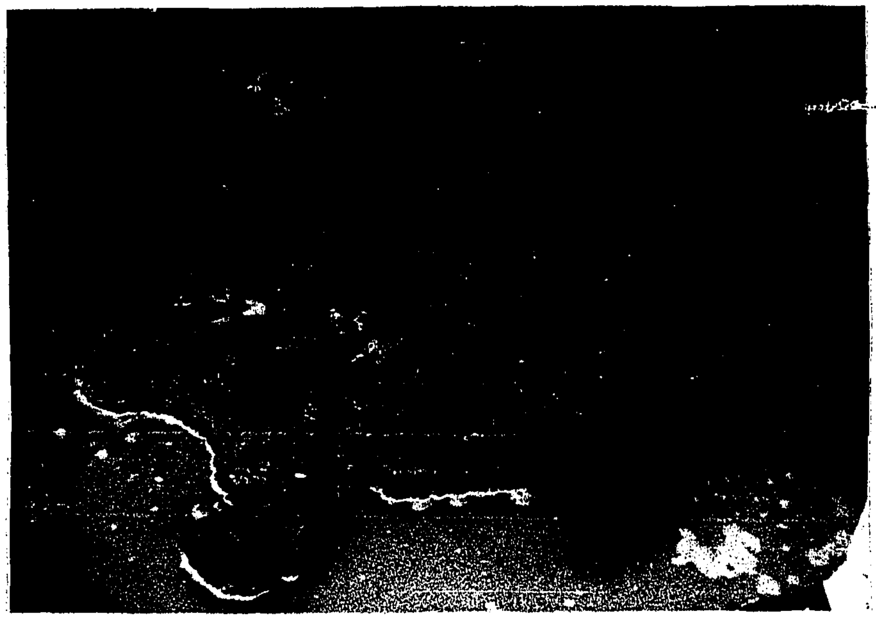


FIGURE 4

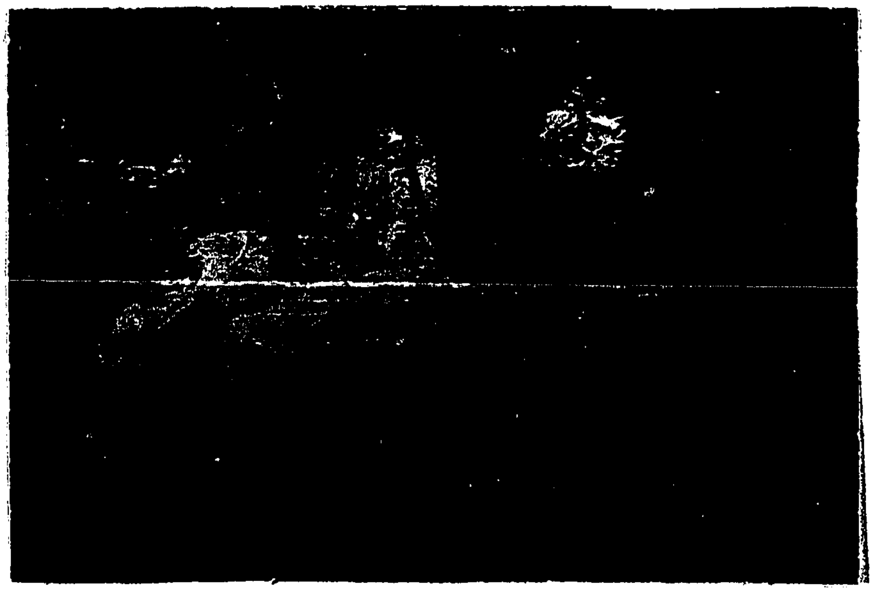


FIGURE 5

Figure 6

Same locality and block, trenching completed.

Figure 7

Same locality and block, with partial cast and reinforcing rods in place.

FIGURE 6

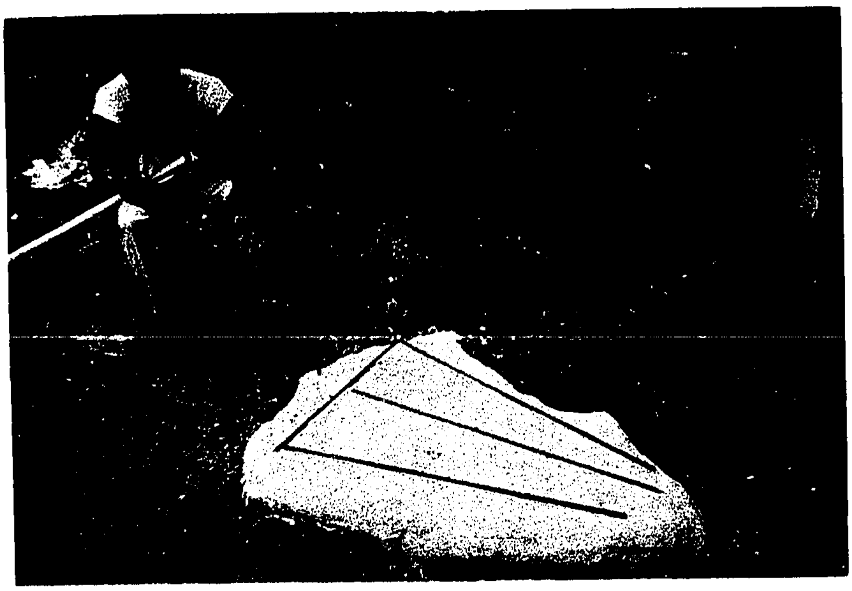


FIGURE 7

around the blocks with picks. The blocks were trimmed with a rock hammer to eliminate excess rock and further trenching to a depth of about three feet and width of several feet was done with a portable gasoline jackhammer (see Figs. 4 to 11). The blocks were undercut until wide pedestals remained under them. The blocks were then plastered using the usual method of bandaging with burlap strips soaked in water, wrung nearly dry and dipped in plaster of about the consistency of thick cream. Two layers of these bandages were added on top of three layers of bathroom tissue put on with wet whisk brooms. Reinforcement with steel construction rods preceded further bandaging. The pedestals were then partially reduced with picks and jackhammer. Steel chisels and railroad spikes were set at intervals around the pedestals, and struck alternately around to keep the blocks from cracking. When the blocks were loosened, they were turned, placed on sleds of two-by-four planks and then bandaged to the sleds with plaster-dipped burlap strips. Canvas straps were fixed to the sleds and the blocks were winched up the stream bank to a truck. Smaller blocks were handled in the same manner, and carried by hand to the truck. Isolated and scattered vertebrae, ribs and other fragments were taken out with hammer and chisels, wrapped in labeled newspapers or paper sacks, and placed in cartons. At most localities, overburden was removed with pick and shovel, but at Locality 36 a bulldozer removed the overburden.

<u>Laboratory methods</u>. Preparation of specimens involved the use of hand tools, a power hand tool, the Gravermeister, and chemicals to dissolve or soften matrix on the bones. Each lithology develops different

Figure 8

Same locality and block, plaster jacket completed.

Figure 9

Same locality and block, with chisels set to loosen block. Dr. G. T. James is striking each of the chisels in sequence.

FIGURE 8

FIGURE 9

mineral associations on the bones. The marls have specimens with pyrite blebs and patches that weather to iron-stained carbonate material that usually becomes covered with selenite crystals. Other specimens from the marls have hardened concretionary carbonate material as scattered patches or as complete coverings. Although the carbonate around the specimen may be depositional (syngenetic), it appears to harden during weathering for it is most completely developed in extremely weathered specimens. Clusters or rosettes of calcite or selenite form in fractures in the bone, or in patches on the surface; many specimens have been split or broken by growth of these crystals. Specimens from the biomicrites (both chalks and calcarenites) also develop patches of pyrite and calcite; the former oxidize to give the bone a reddish or pinkish color. These may dissolve and soften during weathering so that extremely weathered specimens may be wet with water or alcohol (if previously hardened with Gelva) and the matrix removed with a dissecting needle.

Chemicals useful in removing crystals and stains were glacial acetic acid (approximately 10:1), denatured alcohol, and RoVer Rust Remover (Hach Chemical Company), diluted as directed. Hard carbonate patches did not respond to xylol, alcohol or several detergents, including Quaternary "O". Specimens were hardened with Gelva dissolved in ditto spirit fluid or Glyptal dissolved in acetone. Very thin mixtures were used to soak bones but thicker mixtures of Glyptal or Duco were used to glue broken specimens. Denatured alcohol removed old shellac easily, and Gelva was removed by soaking bones in spirit fluid or by brushing it over selected areas.

Figure 10

Same locality and block, turned and placed on plank sled.

Figure 11

Same locality and block, block bandaged to sled, ready for winching.

FIGURE 10

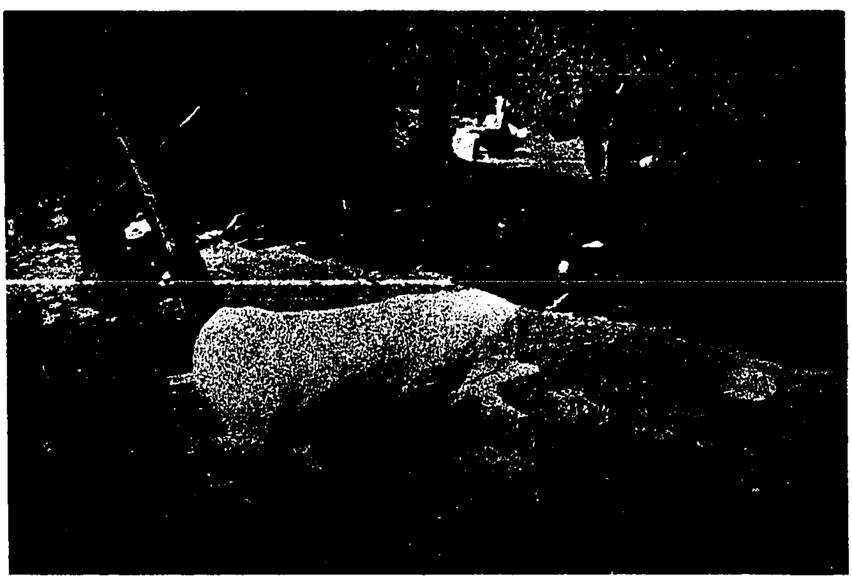


FIGURE 11

Several methods of removing natural minerals and coatings were used. Selenite may be removed by soaking in water or rust remover; the latter seems to loosen crystals best. Crystalline patches are easily removed if a needle is forced along the base of a seam of crystals, or down between crystals or cleavage planes. Oxidized layers, shales, iron-stained marls and carbonate patches are also more easily removed after soaking in rust remover solution. Many of the films and coverings have good planes of separation from the bones, and the rust remover seems to loosen these further. Ordinary marls or weathered Roxton Limestone (biomicrites) are softened by soaking in water or glacial acetic acid. The latter is also useful for softening calcite patches so that they may be removed with a needle or other hand tools. Very large patches or concretionary coatings of calcite or pyrite were removed with hand tools or the Gravermeister. If the outer portions of the coatings were softened by weathering, they were soaked and then worked off with needles or hand tools. Although care was taken not to damage bone surfaces, some of the pyrite and calcite coatings impregnating the bones sometimes stripped off the surface when removed. Much care was also taken to protect specimens with encrusting epifauna; these were carefully cleaned with needles under a binocular microscope.

Specimen measurements were made for all available appropriate skull elements (Table 6), and for selected undistorted vertebral centra (Table 7). Plesiosaur measurements are listed separately (Table 8). All measurements are maximum unless otherwise stated. A few isolated measurements of turtle and other material are listed under the taxon in the text. Skull measurements of mosasaurs are the same as Russell (1967, p. 208, 209) listed so that comparisons and future statistical work can be made more easily.

Line drawings were made by Gary Panter, East Texas State University art student, at natural size and were reduced one half during plate reproduction.

Photographs in the text were taken with a box camera on Kodacolor or Verichrome Pan film. Photographs on Plate 4 were taken at f/8, from eight to thirty seconds, using a #3 or #4 filter, or at f/ 5/6 at eight seconds, or f/8 at twelve to fifteen seconds, without filters. Photomicrographs were taken on Panatomic X at four to eight seconds, ASA 50 (DIN 18) with Nomarski interference with high intensity xenon arc light, or at eight to fifteen seconds with a K-2 yellow filter and low intensity light.

STRUCTURE

General Statement

Upper Cretaceous rocks of northeast Texas comprise carbonates and fine clastics deposited in shallow shelf seas at the northern rim of the Gulf of Mexico Geosyncline (Stephenson, 1918). The chalks, marls, and orthoquartzitic sandstones represent the orthoquartzite-carbonate facies common to miogeosynclines. In the area of study the Austin and Taylor rocks strike from northeast to east, and dip from one to three degrees southeastward (except near faults). At many localities these rocks contain microfossils, invertebrate, vertebrate and plant fossils. Stratigraphic units considered in this report include, in ascending order, the Gober Chalk and Roxton Limestone of the Austin Group and the Ozan Formation, Wolfe City Formation, Pecan Gap Chalk, and Marlbrook Marl of the Taylor Group.

Structural Setting

Any discussion of distribution of facies or fossil occurrence must also consider structural setting. Many of the structures in northeast Texas were influencing sedimentation and biotopes during late Cretaceous time. Hunt, Fannin and Delta Counties (see map, and Fig. 1) are approximately at the nose of the East Texas Embayment (also variously called the Tyler Basin, East Texas Basin, and East Texas

Syncline), at the change in strike of the Mexia-Talco fault zone, and southeast of the nose of the Preston anticline. These structures were in formative stages during the deposition of Austin and Taylor sediments and influenced both distribution of facies and fossil zones. Positions of many of these structures were determined by subsurface Precambrian or Paleozoic structural trends. Major references for structure were Murray, 1961, Hager and Burnett, 1960, Flawn, et al., 1961 and Sellards and Baker, 1934.

Faults. In prospecting for vertebrate fossils, many faults were noticed; the literature revealed that no faults had been reported in Fannin and Lamar Counties. The faults are about 20 miles north of the Mexia-Talco fault zone and may represent an extension of the Balcones fault zone. The former zone is currently considered to be the rim fault in the northeast Texas area. It stretches from south Texas through Kaufman and Hunt Counties, makes a 75° turn (Crosby, 1971, p. 2690) at Commerce, Hunt County, and extends eastward through Delta and Hopkins Counties. Several authors have suggested a northward extension of the Balcones system; it had been thought to end in the vicinity of Waco. Many small faults had been seen north of Waco, and at Italy, and McKinley, Collin County (Sellards and Baker, 1934, p. 49). Reaser (1961, p. 1759) described faults in northern Ellis and southern Dallas Counties which he believes to be an extension of the Balcones zone. Throw of these faults is 90 to 100 feet, and many are down to the west and northwest (not down to the Gulf), but some also show typical Gulf Coast fault type reverse drag. The Mexia-Talco fault system is also a series of graben with many of the faults down to the west, not east, forming the graben (Sellards and Baker, 1934, p. 63; Hager and Burnett, 1960, p. 338; Crosby, 1971, p. 2693). In the Mexia-Talco zone, Hager and Burnett (1960, p. 338) find that displacement increases with depth; "front" faults (south side of graben) are down to the southeast in some cases and "back" faults intersect them. The graben displacement dies out downward, as back faults die out on and intersect the front faults. It may be the same in the Balcones zone. The attitude of the beds in the Mexia-Talco zone graben is erratic and complex; faulting is not continuous (Hager and Burnett, 1960, p. 342). Crosby (1971, p. 2697) finds that strikes of individual faults change less than the whole zone, being an average of 36° around the great bend in the zone, instead of 75° for the zone in general; this too would indicate that faulting is not continuous but a series of small faults and graben making up the whole zone. Surface faults are evident where strata are disrupted, or slickensides or other features occur. Reaser (1961, p. 1759) remarks that, "Openings along the faults are usually filled with calcite, and impressions of slickensides on the fault surface are preserved on the calcite. Drainage is locally controlled by the faulting and streams are abruptly deflected by resistant fault scarps of Austin Chalk." Faulting in the study area seems to fit the patterns mentioned above.

High angle normal faulting in Fannin and Lamar Counties, and northern Delta County forms small graben and horsts. Slickensided surfaces are common; calcite casts of these are found at many localities. Deflection of streams in the area was noticed by Don Galbraith, then a graduate student, who brought this to my attention. At Locality 43 a slickensided scarp with displacement of about 10 feet brings Roxton Limestone into contact with lower Ozan marl. Slickensides are both vertical and dipping at high angles westward. Conjugate shear jointing is present at many localities. The major fault is a hinge or scissor fault, for it continues for about a quarter of a mile and dies out in Ozan marls. The stream is deflected at the point of the scarp, and runs along it for nearly its full length (see Figs. 12, 14). A small horst at Locality 36 has boundary fault displacements of three feet and possibly more on the northwest side. Roxton Limestone is faulted against lower Ozan marl. Conjugate shear patterns may be seen (see Fig. 13). The complementary set has slickensides straight down the fault plane, and displacements of about one foot. Some of the smaller faults are hinge faults and appear to be the result of contemporaneous faulting which may have occurred when the sediments were still plastic enough to slump (Dr. Kerby LaPrade, East Texas State University, 1968, personal communication). Numerous high angle normal faults are also seen in Ozan marl and limestone sequence in the North Sulphur River bed; the section is repeated many times between Gober and Ben Franklin, making estimates of thickness inaccurate. Small faults may be seen at Localities 39 and 41. On Merrill Creek, near Bugtussle, faults in the Ozan marl are difficult to see and are not shown on the new Texarkana sheet (Barnes _et al._, 1966). Their displacement is only a few feet, inches in some cases. A small graben at Locality 45 brings Marlbrook Marl into contact with Pecan Gap Chalk, with displacement of approximately five feet. Small normal faults are also seen in Gober Chalk in the bed of Cane Creek west

Figure 12

ET Locality 43. Large, slickensided fault scarp in Roxton Limestone. Creekbed is deflected and continues along base of scarp. Down is to the right (north), with Ozan marls on the down side. Displacement is estimated to be ten feet.

Figure 13

ET Locality 36. Conjugate shear pattern shown by faults on small horst. Horst itself has contemporaneous step faults. Roxton Limestone is faulted against Ozan marls.

FIGURE 12

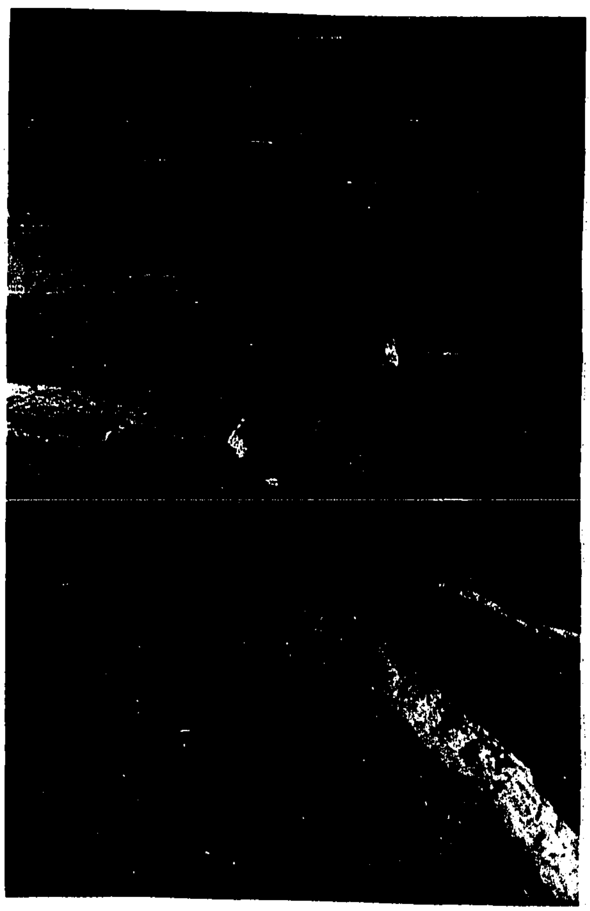


FIGURE 13

of Locality 46, (streambed of Cane Creek, at bridge on dirt road 2 mi. west of Highway 38, $1\frac{1}{4}$ mi. north of Roxton) and also in the floor of the quarry at Locality 38. Displacements of several inches are common, and some have slickensides or fault breccia. Upstream, east of Locality 43, a larger normal fault shows a movement of at least ten feet.

The only thrust fault seen is located about one-fourth mile west of the west Ladonia bridge, west of Locality 44. Displacement is about two feet, and the fault dies out into a shallow fold on the south bank of the North Sulphur River. Several more shallow folds occur upstream, west of the fault. Downstream the usual normal faulting resumes.

Faults in the Gober-Roxton area strike east-west and northwest-southeast, with about equal numbers in each trend. Dips of the fault planes vary from 30 to 70° and displacements from one to 30 feet. Around Gober, at the nose of the Preston anticline, is a "boxwork" of faults, with many downthrown to the west. These form a series of small offset grabens (Charles Griffith and Ray Pashuck, students, East Texas State University, 1970, personal communication).

Fault patterns in the area are part of the general Gulf Coast pattern of graben and normal faults that indicate tensile stress in the rocks. Cloos (1968, p. 443) nearly duplicated this pattern experimentally and stated that it results from gravity creep, which provides tension for a "tear-off rift" or marginal fault system. The rate of deformation may determine whether local or regional patterns dominate. Bornhauser (1958) thinks that Gulf Coast structures are related to gravity flow of either salt or igneous material at depth, producing folding, faulting and salt piercement folds. An interesting comparison between the Gulf Coast and the African and other rift systems is made by Walthall and Walper (1967). The features common to both may be caused by tension but the cause of the tension in the Gulf Coast system is still largely unknown. Crosby's (1971, p. 2699) data indicate that the Louann Salt (Jurassic) wedges out just at the Mexia-Talco fault zone; salt flowage may increase this unit's thickness in the East Texas Embayment. This would indicate long duration creep of the salt bed, with sediments riding passively on top of it.

Many features suggest that the faults have been discontinuously active for long periods. Sellards and Baker (1934, p. 60) thought that the faulting began in Cretaceous times with the tilt and submergence of the pre-Cretaceous land surfaces. Eaton (1956, p. 84) suggests that faulting began during Glen Rose time (Early Cretaceous) and continued to the present. Motion may have begun in Jurassic times and continued to the present (Crosby, 1971, p. 2691). These faults are contemporaneous in the sense of Hardin and Hardin (1961, p. 240, fig. 1); their report shows additive thickness changes, with "down" sides receiving more sediments so that the section is progressively thicker as faulting continues. Strong movements on some faults and on the Sabine uplift during Austin and Taylor time were reported by Eaton (1956, p. 82). In central Texas, Beall (1964, p. 16, 20) found contemporaneous faulting on Luling and Mexia fault zones throughout Taylor time. The strata, especially the lower marl, are thicker by 200 feet on the western, downthrown blocks. Displacement is less at the top of the Pecan Gap than at the base of the Austin chalks. The Wolfe City sand thins eastward over one of the Mexia faults (Beall, 1964, p. 20, 25). Drilling records show that the Mexia-Talco fault system was contemporaneous during late Taylor and Navarro time, for the rocks thicken westward on both sides of the fault zone; main motion was in Pecan Gap time, as the strata are about 20 feet thicker on down sides (Hager and Burnett, 1960, p. 328). Many authors cite motion on the faults in historic time. Bryan (1933, p. 439-442) suggests that recent motion is also occurring in the Balcones system, for plumbing and pipes continue to break just north of Waco. Sellards and Baker (1934, p. 61) recorded an earthquake in a line from Hunt County to Choctaw County, Oklahoma, on April 11, 1934. Faulting perhaps associated with the Sabine uplift boundary faults occurred in 1964 (Murray, 1961; Fowler, 1964). Caddo Lake formed in the 1800's from earthquakes and the bottom of the lake was stirred and waves were formed on March 27, 1964, during the Alaska earthquake (Fowler, 1964, p. 189). This data suggests that the fault system rimming the Gulf Coast has been active for a long time geologically, and also influenced sedimentation of Austin and Taylor ages.

Associated with the fault zones is a series of igneous rocks, both extrusive and intrusive. The only indication of volcanism in northeast Texas area was a chunk of pumice about six inches in diameter found at Locality 43; it was glassy, vesicular, yellowish to greenish brown in color and light enough to float on water. The specimen was embedded in the Roxton-Ozan transition zone. Igneous rock complexes occur for many miles on either side of the Balcones and Mexia systems (Sellards and Baker, 1934, p. 50). Beall (1964, p. 22) found bentonite seams in the

Figure 14

ET Locality 43. West end of fault scarp shown in Figure 13. Student is standing on top of Roxton Limestone, so that displacement on this scissor fault is about six feet here. Basal Ozan marls are exposed on the down (north) side.

Figure 15

ET Locality 38. Nearly complete section of Roxton Limestone showing massive bedding in lower part. Note thinner bedding in tan upper part (transition zone), with gray basal Ozan marls above.

FIGURE 14

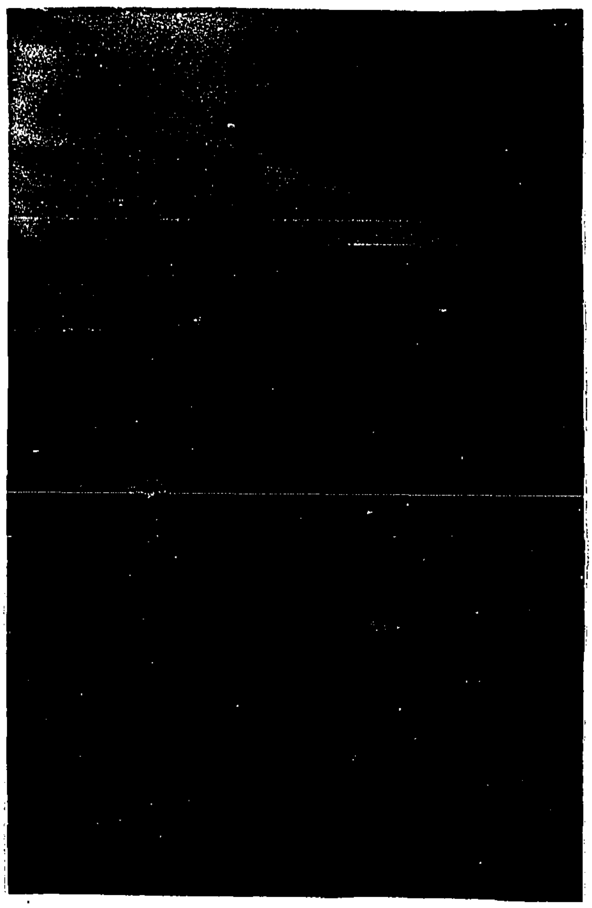


FIGURE 15

Figure 14

ET Locality 43. West end of fault scarp shown in Figure 13. Student is standing on top of Roxton Limestone, so that displacement on this scissor fault is about six feet here. Basal Ozan marls are exposed on the down (north) side.

Figure 15

ET Locality 38. Nearly complete section of Roxton Limestone showing massive bedding in lower part. Note thinner bedding in tan upper part (transition zone), with gray basal Ozan marls above.

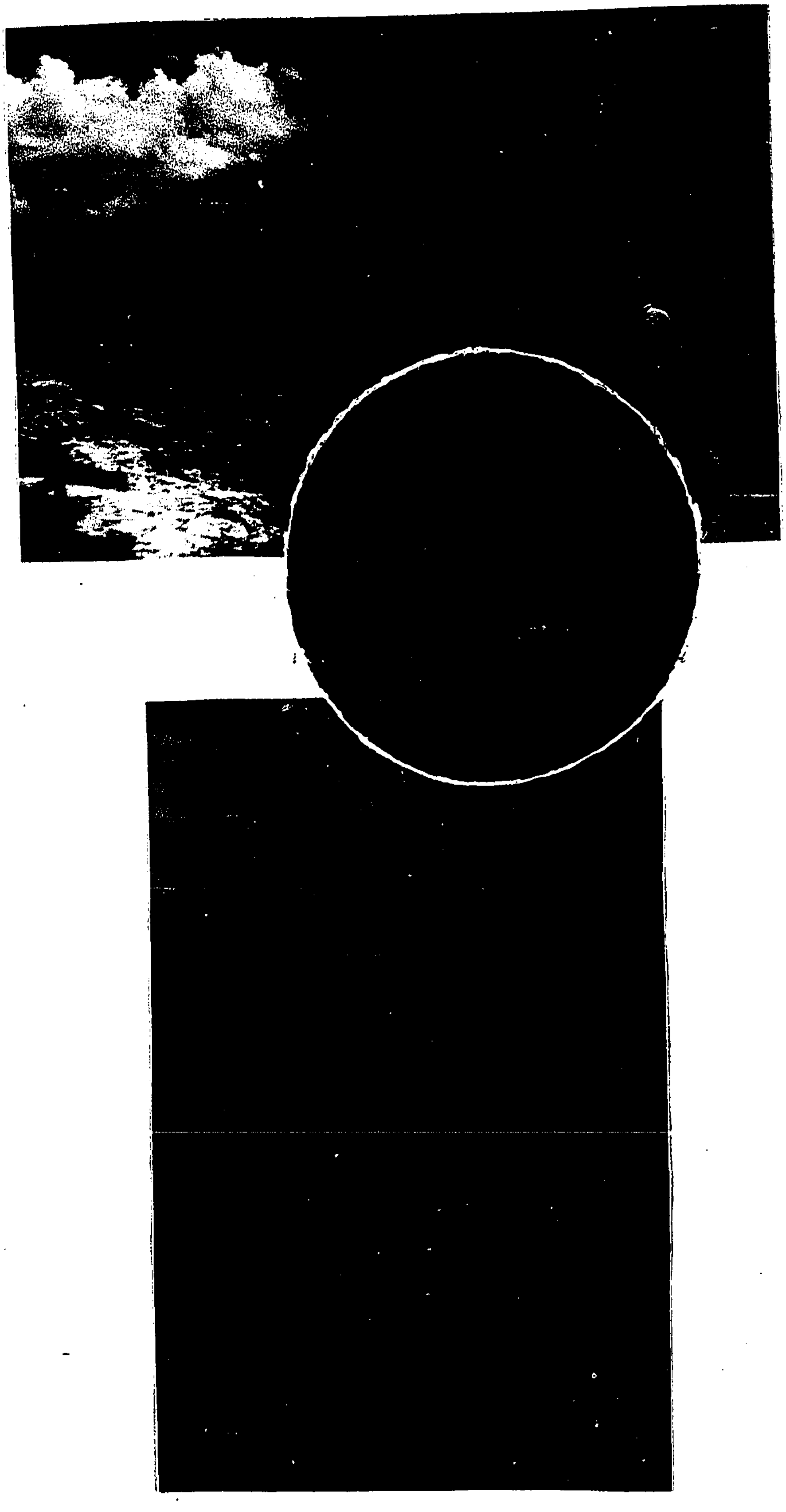


FIGURE 15

upper part of the lower Taylor marl, and near the top of the upper marl at several localities in central Texas. Outside of the immediate area, Murray (1961, p. 358) records the presence of waterlaid volcanic material in the Taylor of western Mississippi and adjacent Arkansas and Louisiana.

Folds. A number of shallow folds, anticlines and synclines, as well as broad uplifts like the Sabine uplift, occur in northeast Texas. From east to west, they are the Sabine uplift, on the Texas-Louisiana border, the East Texas Embayment, Preston syncline, Preston anticline, with the Leonard-Celeste monoclinal nose, Sherman syncline, and Sherman anticline. Farther southwest, a number of alternating arches and synclines, among them the Belton high, Roundrock syncline, and San Marcos arch, form noses or basins on the edge of the Ouachita system.

The Sabine uplift behaves more as a broad uplift than a local one, with greater percentages and greater thicknesses of clastic sediments on the flanks rather than on the arch itself (Granata, 1963, p. 66-67). Austin and Taylor sediments thin over the uplift; they are 20 percent thicker in northwest Louisiana (Granata, 1963, p. 119). Austin and Taylor rocks also thin over the San Marcos arch (Sellards and Baker, 1934, p. 45; Seewald, 1959, p. 5) indicating that these arches were growing during deposition. These arches would be "synchronous highs" in Scholten's (1959, p. 1794) sense. He referred to ". . . any local area which was topographically expressed, however gently and for whatever cause, as a high on the sea or lake bottom during the general span of time when sediments were being deposited in the region." The rising of the arch changed the northwest-southeast trend of the East Texas

Embayment to a more north-south trend (Sellards and Baker, 1934, p. 48).

The East Texas Embayment is a broad shallow basin that probably dates from Jurassic and certainly from Cretaceous time (Coon, 1956, p. 86); most of the downwarp occurred in Eagle Ford and Taylor times (Coon, 1956, p. 87). Strong movements in the basin during Austin-Taylor time were only moderate on the Sabine uplift (Eaton, 1956, p. 82). The basin may have been closed during the late Cretaceous; a rim stretching from Smith to Madison Counties was a narrow shelf with sediments typical of shelves (Coon, 1956, p. 90).

The Preston anticline trends northwest-southeast from Marshall and Bryan Counties, Oklahoma, to Gober, Fannin County, Texas (Fohs and Robinson, 1923, p. 713; Stephenson, 1918, p. 159). Displacements of about 800 feet were measured (Stephenson, 1918, p. 159). Stephenson (1918, p. 160) noted that the axis of the anticline paralleled that of major Arbuckle Mountain trends, and that faults and folds might be related to this uplift and might be basement-controlled features. He supposed that the Cretaceous folding was incidental to the upbowing of basement rocks. Bullard, Mason and Redfield (1930, p. 514-516) further suggested that the anticline might parallel the Criner Hills trends for its 30 to 50 mile length. Hopkins, Powers and Robinson (1923, p. 6-8) noted the disruption of normal south and southeast dips of 30 to 80 feet per mile. On the north side of the anticline dips are 60 to 140 feet per mile, while the steeper southwest side has dips of up to 400 feet per mile, the highest dip at a locality two miles northeast of Pottsboro.

Their (p. 8) mention of the Leonard-Celeste monoclinal nose is one of the few references to the fold in print; they measured 200 feet of displacement on this feature.

A similar arch far south of the area is the San Marcos arch, which has influenced structural and sedimentation development of the San Marcos-San Antonio area since the late Triassic or early Jurassic. Most Cretaceous units thin over this arch (Halbouty, 1966, p. 18). This arch may be similar to those in northeast Texas.

The Sherman syncline is a shallow fold southwest of the Preston anticline, recognized by Hopkins, Powers and Robinson (1923, p. 6), Flawn, et al. (1961, p. 132), and Fohs and Robinson (1923, p. 713), who noted thickening of the beds in the syncline. Flawn, et al. (1961) refer to this fold as the Marietta-Sherman basin or syncline, saying that it lies between the Muenster and Amarillo-Wichita-Criner element, all of which have northwest trends. Stephenson (1918, p. 160) also notes a shallow syncline paralleling the Preston anticline to the north, with a steepened south limb. Dips of 300 feet per mile on the south side resulted in outcrops narrow enough to cause Taff (1893, p. 297) to name this feature the "Cooke's Spring fault."

The Preston syncline is a shallow fold at the northwest end of the East Texas Embayment (Hager and Burnett, 1960, p. 352); this fold sank in late Taylor and Navarro times as evidenced by thickening of these beds (Hager and Burnett, 1960, p. 350). The Pecan Gap Chalk is eroded from part of this syncline in Delta County along the Mexia-Talco fault zone (Hager and Burnett, 1960, p. 348), so perhaps the faulting influenced this minor fold.

Structural control of lithofacies. General patterns in sedimentation are apparent; both Austin and Taylor rocks are more clastic in northeast Texas than in the areas of outcrop to the southwest. Austin rocks include clastics in the northeastern part of Texas (Waters, McFarland and Lea, 1955, p. 1831); Paulson (1960, p. 28) notes that the Preston anticline separates a carbonate sequence to the southwest from clastic sequences to the east. The Austin becomes more carbonate over this high, and the Gober Chalk merges into this carbonate mass in that vicinity (Paulson, 1960, p. 9). The high also acted as a barrier to the deposition of the calcarenite lentil of Roxton facies (Paulson, 1960, p. 28). Austin facies are also affected; downdip equivalents in Hopkins County are sandy shales and shales (Hager and Burnett, 1960, p. 346).

Taylor rocks show similar influence. Murray (1961, p. 3508) finds more clastics in Texas, Arkansas and Louisiana, than in central Texas especially in the Ozan shale which is increasingly sandy toward east Texas. (See p. 35 for influence of structure in Preston syncline.)

More general information concerning areas other than the study area indicates more general structural patterns. Eaton (1956, p. 82) states that the Upper Cretaceous regional thinning to the south is "depositional rather than structural." Granata (1963, p. 66-67) remarks that the Sabine uplift acted as a broad arch and that with contemporaneous structural growth and sedimentation that sands settled out on the flanks of the uplift. Calcareous sands might be expected to accumulate on the flanks of such uplifts including perhaps the Preston anticline. Halbouty (1966, figs. 7, 11, 12) notes arenaceous beds around the "toes" of the San Marcos, Tamaulipas, and Coahuila arches. His fig. 7 shows a small patch of arenite at the crest of the East Texas Embayment. Bishop (1968, p. 94) found a blanket calcarenite in the Smackover which thins southward toward the shelf slope on the Louisiana-Arkansas border. The shelf slope had deeper water, ". . . with active structural growth which promoted calcarenite deposition in positive areas." The south edge of the shelf for the Smackover Formation was from East Texas to Mississippi, and was a tectonic hinge line ". . . where deposition kept pace with subsidence." Further influence of sedimentation, in this case reef limestone, occurs on the Jackson and Monroe uplifts (Murray, 1961, p. 358). Henson (1950, fig. 11) saw the development of reefs and condensed zones across highs in the Middle East, and Said (1961, p. 212) the same for Egypt.

It seems reasonable that such influence of sedimentation and resulting lithofacies should be reflected in biofacies (Stehli and Creath, 1964). Said (1961, p. 198) suggests that paleontology can contribute to understanding of tectonic framework of an area, although he knew of no attempt to characterize biological associations of structural facies such as has been done in the case of sedimentary associations. This type of tectonic-biologic association is shown by vertebrate distribution in northeast Texas during late Austin and Taylor times. Other fossil groups might furnish additional evidence when studied in detail. The following sections of this report will attempt to present the evidence given by vertebrate distribution.

<u>Summary</u>. The following conclusions have been taken from the above discussion:

1. A system of faults and synchronous folds influenced the distribution of litho- and biofacies of Austin and Taylor.

2. A system of high angle normal faults in Fannin and Lamar Counties may be an extension of the Balcones fault zone.

3. A brief period of volcanism may have occurred during late Austin (Roxton) time.

4. Vertebrate distribution was affected by the structural setting of the area, producing both biological and sedimentological concentrations of the fossils.

STRATIGRAPHY

General Statement

The fossiliferous sequences of Upper Cretaceous chalks and marls in northeast Texas have not been studied in detail. In spite of much work in the area the stratigraphic relationships remain poorly understood and no adequate depositional model has been proposed. Early correlations by various authors were confused by alternations of similar lithologies and lack of systematic paleontologic studies. These are now beginning and papers by Beall (1960, 1964), Pessagno (1969), Seewald (1959, 1967) and Young (1963) are helpful. Recent work on modern carbonate deposition by Cloud et al. (1962), Bathurst (1967), Bromley (1967) and others and practical classifications such as those of Folk (1959, 1962) and Dunham (1962) have facilitated study of carbonate rocks. Helpful reviews of literature can be found in Adkins (1933), Beall (1964), Ellisor and Teagle (1934) and Murray (1961).

Raynor (1958, p. 137) urged paleontologists to take exact data on stratigraphic information, fossil occurrence, abundance etc. for the study of vertebrate fossils, and later (p. 153) remarked, ". . . the paleontologist who studies systematics or evolution knows that he must base his researches on comparative anatomy; if he also wants to pursue problems of environment he will ignore sedimentary petrology at his peril." This study will make use of sedimentary petrology in an attempt to explain vertebrate distribution.

The following descriptions are based on field data, washed and acidized samples, spot samples for insoluble residue checks, and x-ray analysis of nodule samples. Short, local measured sections are also included (see Appendix III); full thicknesses could not be measured because of poor exposures and difficulty in determining stratigraphic levels at many localities. In the report "Locality" will refer to places from which vertebrate specimens were obtained, whether used in this report or not, and "Station" will refer to places used for stratigraphic information only. For carbonate rocks, Folk's (1959, 1962) classification will be used, with reference to that of Dunham (1962). Non-carbonate rocks are referred to Pettijohn's (1957) classification.

Austin Group

Gober Chalk

Definition. Stephenson (1927, p. 8) named the chalks around Gober for the town of that name; Adkins (1933, p. 439) included the Gober Chalk in the Taylor Group. Young (1963, p. 30) shows the Gober as a tongue of the upper Austin Group, and correlated it with part of the Lower Taylor.

Lithology. Several outcrops of upper Gober Chalk were examined for comparison with other carbonates in the section and to determine the nature of the base of the Roxton Limestone member. Outcrops are gray to light gray or bluish gray, white- or light gray-weathering bioturbites.

These chalks have been intensely burrowed. Large and small burrows cross and recut each other. Bedding is massive, but as the chalk weathers, fissility becomes more pronounced, and the chalks may split into small chips or large conchoidal slabs. Spots of limonite appear, probably alteration products of pyrite or glauconite. The chalks develop poor jointing and many joint and fault surfaces are stained with limonite.

Thin sections show that these are fossiliferous micrites or sparse biomicrites (Folk, 1959, 1962), or mudstones and wackestones (Dunham, 1962). Fossils are foraminifers, a few ostracods, shell fragments, many of which are *Inoceramus* prisms, and rare echinoid remains (one slide, OU 1180, showed one cross-section of a spine). Several slides show small (0.03 mm.) spheres of sparry calcite. These have been recognized in slides (Seewalk, 1959; Steinhoff, 1964) and identified as small foraminifers of the family Gavelinellidae (Kolodny and Sass, 1965). Slide OU 1177 has small curved "nodular" strings that may be algal. Fossils form from five to 35 percent of the rock, and range in size from a few hundredths of a mm. to 1.2 mm. The fossil fragments are randomly oriented and have an uneven distribution that may be the result of the intense burrowing. This gives the rock a poorly sorted, immature texture (Folk, 1962). Three of the six slides studied have traces of green, detrital glauconite (OU 1179, 1184, 1181). Two slides (OU 1179,1181) have traces of angular, silt-sized, white quartz grains. One slide (OU 1180) had one angular phosphate fragment 0.5 mm. across, which is perhaps a bone fragment. Most of the slides show blebs, fillings of foraminifer chambers, and stains of hematite and limonite, which may be alterations of pyrite. Pyrite occurred in two slides (OU 1180, 1181).

Similar rocks are shown in thin section by Folk (1959, pl. 2, fig. 17, a foraminiferal biomicrite and pl. 3, fig. 24, a fossiliferous micrite). Seewald (1967, p. 151) found that the Austin of central Texas is a soft, white sparse to packed, pelecypod and foraminifer biomicrite; these may be quite similar to the Gober of northeast Texas.

No washed samples were examined. Hand specimens show the very fine nature of the matrix, for the carbonate particles are not visible. These rocks would be termed calcilutites.

Interpretations of similar rocks give further information. Seewald (1967, p. 151) interprets biomicrites and the absence of any biosparites to indicate deposition below wave base on a broad carbonate shelf. Fisher and Garrison (1967, p. 488) found calcium carbonate occurring on the sea floor, apparently precipitated chemically. Others assume that most micrite particles are of biologic origin, and have been ground up to small size either by waves or biologic agents such as burrowers. Pre-compactional concretions and lithified Globigerina ooze occur on the sea floor, but some of these lithified masses are Cretaceous and some are Tertiary (Fisher and Garrison, 1967, p. 488). The exact nature of the Gober micrite particles would be difficult to determine. The shales and limestones of the Jurassic of England contain the remains of burrowing clams in living positions, many trace fossils (burrows, trackways, etc.), and shells which show poor sorting and random orientation; Hallam (1960, p. 34) interprets these as being off-shore deposits with life assemblages and ammonites that floated in. All other factors being equal, carbonates are of shallower water origin than shales (Hallam, 1960, p. 130). Nagle (1968, p. 8) finds that in similar carbonates of the central Texas Glen Rose Formation that bioturbation is of greater intensity than physical processes and shells are unsorted and of all shapes, the larger shells having broken edges. Larger shells may be wave-oriented but smaller ones are oriented by bioturbation. Nagle (P. 8) and Folk (1962, p. 74-75) find that subtidal carbonate rocks are immature in texture because of the biologically broken shells. Beall (1960, p. 119) interpreted microcrystalline pyrite, abundant calcium carbonate and microfossils to indicate deposition of Taylor marls of central Texas in warm, shallow seas of a shelf environment. The pyrite indicated reducing bottom conditions. The fine clastic clay and areal uniformity of Taylor marls suggested to him that the shoreline was quite distant. Clark and Bird (1966, p. 322) studied foraminiferal faunas of the Taylor and Austin contact; they concluded that: "The lithologic similarities of the Austin and Taylor seem to imply similar environments of deposition, and also judging from the apparent similarity in their foraminiferal compositions, we may reasonably treat them together as representing a single depositional environment." Seewald (1959, p. 23) also concluded that clay and carbonate depositional environments were similar and that the rocks would also be similar in composition and texture. Stevenson (1961, p. 238-239) had a different interpretation of similar foraminiferal biomicrites of the Niobrara Chalk of South Dakota. These rocks are 80 percent pelagic foraminifers, the remainder being carbonate, with a few fish scales. The only large fossils are <u>Inoceramus</u> with small <u>Ostrea</u> attached to the shells. The cold water foraminiferal fauna suggest to Stevenson that the chalk was deposited in deep water as a constant rain of pelagic shells, and where only large, thick-shelled pelecypods could survive (Stevenson, 1961, p. 240). It would appear that the Gober Chalk is much like the bioturbated, shallow-water shelf carbonate deposits mentioned above.

Facies of the Gober Chalk include the Roxton Limestone, and parts of the Lower Taylor, Ozan (Arkansas) and Annona (Young, 1963, p. 30). It is a tongue of chalk that extends eastward from the main body of Austin chalks (Adkins, 1933, p. 459), and feathers out in Lamar County (Barnes et al., 1966, Texarkana sheet legend). Stephenson thought that the top of the Austin rose in the section, but may have had the chalks confused (1918, p. 148; 1937, p. 139-140). The chalk is part of a large lithosome that occurs over the Preston anticline (Seewald, 1967, p. 151) and is separated from equivalent clastics in northeast Texas (Seewald, 1967, also Paulson, 1960, p. 28; Murray, 1961, p. 350, fig. 6.35a). Seewald (1967, p. 151) also notes that the Austin thins and becomes more fragmental and glauconitic over the Belton high and the Preston anticline. Waters et al. (1955, p. 1831) noted that the Austin becomes less calcareous in the southwest. Hallam (1964, p. 164) observed that Jurassic sections of Germany were thinner than standard section but that this was not true of the English Jurassic carbonate sections. There also synchronous highs like the Sabine uplift and Preston anticline influenced the depositional environments. The area across the high would probably be brought to or above wave base with resultant winnowing of chalks to calcarenites.

Paleontology. Fossils in the Gober Chalk include numerous microfossils, and various invertebrates, Inoceramus being the most common.

Small oysters and other pelecypods, and the worm Hamulus, as well as trace fossils are seen. Stephenson (1918, p. 149) lists a rudist (Radiolites) from the Ector tongue (lower Austin chalk). Most outcrops also contain vertebrate remains as isolated scales and bones, and mosasaur bones. One partial mosasaur of about a dozen vertebrae and ribs, was collected from upper Gober at Locality 46 (Cane Creek, northwest of Roxton). This chalk is sparsely fossiliferous. Trenchard (1968, p. 206) suggests that the rate of sedimentation may dilute or mask the fauna. Rapid rates may inhibit or repress the development of fossil communities so that the biotope of the Gober may have been collecting carbonate particles too rapidly to support large faunas. Another reason may be that burrowing has broken the fossils until few complete specimens are seen. Depth of water was estimated from microfossils, including both pelagic and benthonic forms, at about 200 to 1,700 feet for these biotopes (Clark and Bird, 1966, p. 323).

Preservation of invertebrates is good to poor. Poorly preserved external molds, probably with the shells dissolved, occur at many outcrops associated with preserved shells. Inoceramus in these chalks is quite thin-shelled and perhaps the shells dissolved or broke up, or were fragmented by bioturbation. Fish scales and isolated bones are well preserved. The mosasaur from Locality 46 was well preserved but worn in the Recent weathering cycle.

Roxton Limestone

Definition. The "Roxton beds" were first noted by Hill (1901, p. 340-341) as being a "glauconitic calcareous stone," which he saw at

Roxton, Honey Grove and Ladonia (Lamar and Fannin Counties). He was uncertain of the correlation. Adkins (1933, p. 459), following Stephenson (1927, p. 8), called it a "soft, tough limestone" from one to ten feet thick and remarked that it was a good building stone. Stephenson (1937, p. 140) realized that this was part of the upper Gober tongue. Paulson (1960, p. 8) first called it a calcarenite, and noted the phosphate cast bed near the top. Barnes et al. (1966, 1967) refer to it as a sandy, red, glauconitic limestone. A type locality has not been designated, but a complete section is shown in a quarry north of Roxton (Locality 38).

Lithology. Outcrops of the Roxton Limestone are gray, tan- to red-weathering, sandy, soft bioturbite containing many burrows. Fossils and glauconite can be seen and many "nests" and streaks (many in burrows) of hematite give a blotched appearance to the rock. Sedimentary structures include graded bedding (Localities 38 and 43) and cross-bedding (Localities 38 and 43) (see Fig. 16). Graded bedding is not pronounced and does not occur at all outcrops, perhaps because of disturbance by burrowing. Similar cross-bedding is illustrated by Boutte (1969, p. 53, fig. 8b) in the Edwards Limestone. It is interpreted as large scale accretion bedding of a submarine spit. Klein (1965, p. 180, fig. 5) also shows channel cross-bedding much like this. Individual beds here are couplets of a basal shelly zone and an upper oölitic zone (Klein, 1965, p. 179-180). Channels from meandering distributaries on a carbonate tidal flat would produce such structures. These deposits he interprets as those of the seaward edge of a tidal flat (Klein, 1965, p. 186).

Figure 16

ET Locality 38. Cross-bedding, and some partial graded bedding can be seen. Hammer handle is one foot long. Roxton Limestone.

Figure 17

ET Locality 38. Hematite burrow fillings make these burrows in the Roxton Limestone easily seen. Also cross-bedded and some burrows end on cross-bed surfaces. Hammer gives scale.

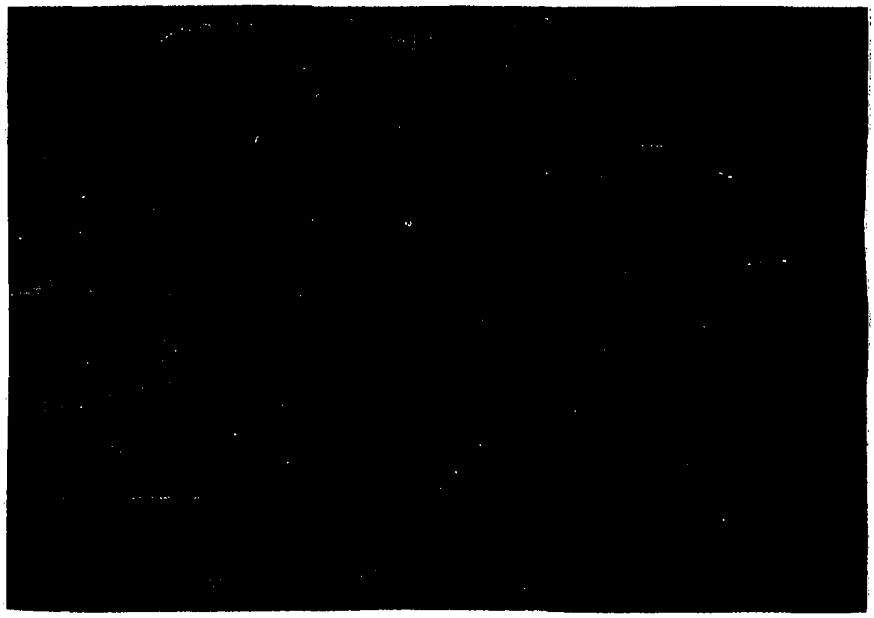


FIGURE 16

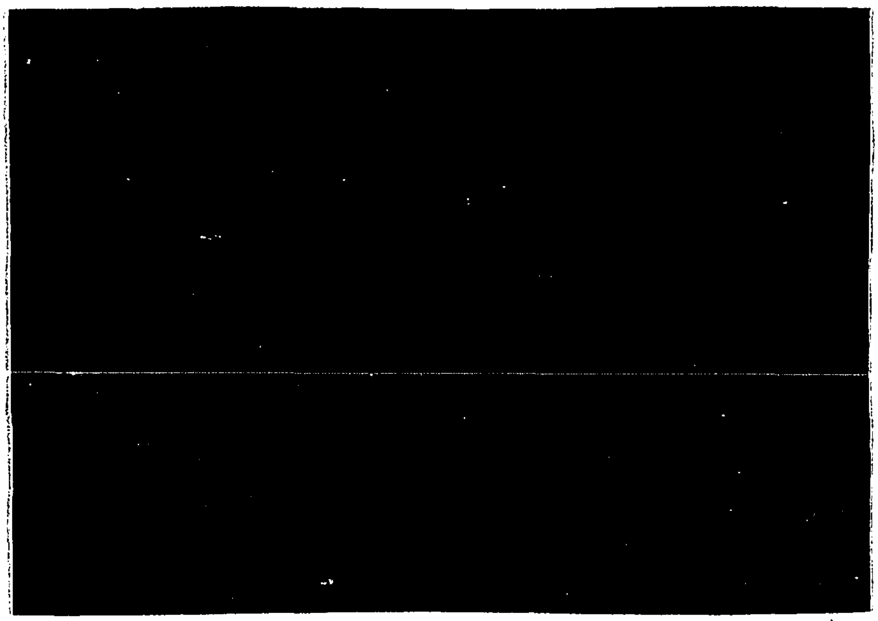


FIGURE 17

Hand specimens and washed samples show fossil fragments, mostly _Inoceramus_ prisms, other shell fragments, glauconite, rounded to ellipsoidal fecal pellets, and bone fragments, scales, fish teeth and many microfossils (foraminifers, ostracods and others). Rarer are gray, rod-shaped fecal pellets and echinoid parts.

Thin sections show the Roxton to be sparse to packed fragmental biomicrite, or wackestone and packstone. Fossils comprise from 25 to 60 percent of the rock, but most slides show about 50 percent fossil content. One exception is OU 1192, a sparse biomicrite with 25 to 30 percent fossils. Fragments range in size from a few hundredths of a mm. to 2.5 mm. in size. Detrital quartz (probably terrigenous in origin) which ranges from traces to 3 percent, is angular to round, and from 0.1 to 0.3 in maximum size. Most of the quartz is clear, but some grains appear to be composite and some have inclusions and undulose extinction. A few on slides OU 1186 and 1189 have carbonate overgrowths. Glauconite percentages vary from 0.5 to 3 percent. The grains are angular to rounded, and appear to be detrital. These may have been brought in by currents along with the terrigenous quartz. It is unlikely that these grains, most of which have clear boundaries and some of which are angular, are authigenic. Neither the quartz or the glauconite grains show any overgrowths. Intraclasts are not common, but some slides have a few grains that appear to be composite. Slide OU 1191 has one oölite. Phosphate fragments, probably bone and scale fragments so obvious in hand specimens, range from traces to 5 percent in OU 1188. Fragments and rounded bits are brown to pale brown or yellowish, angular to rounded, and range from tiny to 0.7 mm. The matrix is carbonate. One sample from which slide OU 1185 was made was also used for insoluble residue check. The sample was 53.8 percent carbonate. Perhaps some of the matrix is actually fine clay, although it appears to be carbonate in thin section. When viewed in strong light many slides have a poorly defined looped or banded appearance, probably due to burrowing. Patchy distribution and random orientation of fossils may also be the results of burrowing. All of the slides show poor sorting and are texturally immature sediments. Heavy minerals occur in some of the slides but only in traces. Chert, plagioclase, microcline, muscovite, biotite, zircon and questionable quartzite grains were seen. The greatest number of these were on slide OU 1185. Hematite and limonite appear as blebs, fillings of foraminifer chambers and cracks and also occur as stains and in some instances are associated with pyrite blebs as alteration products. The hematite and limonite staining causes the tan color of the weathered rock and the blotchy appearance. Most references, including Barnes et al., refer to this unit as tan or red which indicates that they must have seen only the weathered or altered rock.

The Roxton Limestone is a peculiar rock, according to Folk (1962, p. 74) and Dunham (1962, p. 118) who reviewed all limestone types. They referred to other limestones containing large particles in a micritic matrix. The paradox of large fragments in a matrix whose tiny particles indicated a low energy depositional environment must be explained. Dunham (1962, p.118) suggests that these packstones are compacted wackestones. He supposes they are produced by: 1) prolific grain production in calm water, 2) mixing by burrowers, 3) incomplete winnowing by currents, 4) late infilling of mud. Folk (1959, p. 12) also suggested the first and third steps above, and supposed that currents might be too weak or not persistent enough to winnow out fine particles. Later he stated (1962, p. 74-75) that burrowing could also produce such a rock. Biologic breakage of specimens produces the patchy distribution and random orientation of fragments noted in the Roxton Limestone. He cites the fact that many present-day calm environments of 100 feet in depth have finely broken shells. Micrite may be trapped in high energy environment by algal mats, but this would be a rare event (Dunham, 1962, p. 75). Some of the fossils in the Roxton slides are oriented in poorly defined bands which may result from momentary episodes of increased wave or current energy in normally calm environments, which will sort out millimeter-thick bands with high percentages of allochems (including fossils) (Folk, 1959, p. 12). Probably the latter mechanism, plus burrowing, accounts for the distribution of grains and allochems in the Roxton Limestone.

Other information bearing on this problem comes from Cloud et al., (1962, p. 47), who remarked that bimodal sediments, pellets or shell fragments in fine muds could indicate "large and persistent annelid populations" or sites of slow or intermittent deposition. Most of the pellet-makers live in shoal waters but high currents may remove some of the worm population. Evans et al. (1964, p. 129) studied modern carbonates on the Qatar Peninsula and concluded that shallow water carbonates were mainly skeletal, and pass laterally into marls and calcilutites in deeper water. Spits developed in the shallow water, and interspit-areas were subtidal and characterized by the presence of snails, crabs, many trails and burrows and fecal pellets in the sediments (Evans, et al., 1964, p. 134). Illing's (1954, p. 17) classic study of modern carbonate sands shows that fragments form from 10 to 40 percent of bank and bank edge sediments. Silt and mud fractions decrease in the dominant current direction, so that carbonate grains may behave as any other grains in currents (Illing, 1954, p. 53). The particles will be carried to other areas; for example Illing (1954, p. 65) found that shallow banks had much silt and mud at the down current edge where the water was quieter and slightly deeper. It may be that the Roxton is a "lime sand" carried to the depositional site by currents, as Illing suggests, around the edge of the Preston anticline. Coleman and Gagliano (1965, p. 143) suggested that in basins receiving little clastic material, organic precipitation and reworking would be important and shell fragments, foraminifers, large well-defined burrows, and shell hashes would be common. The presence of micrite and much burrow-mottling in Devonian limestones of New York indicated to Laporte (1969, p. 114) that deposition took place below wave base, but no current structures were present in the Devonian rocks of New York that he studied. Currents of some kind are indicated by cross-bedding and graded bedding in the Roxton. It may be that the Roxton represents a channel where all of the fragments were washed in including the bones and mosasaur bodies.

In spite of the evidences of current action, micritic matrix is present in significant percentages. Perhaps this is one exception in which the algal mat explanation would be valid. Bathurst (1967, p. 736) found a colorless, transparent, elastic gel at subtidal levels on lime sands. It made a coherent sheet about one-fourth cm. thick, which when strong enough broke into flakes. It is not algal but is full of small invertebrates, micrinvertebrates and plants. It might therefore have been a food source for fishes, echinoderms, holothurians, gastropods, polychaetes and crustaceans. He found that it was absent on burrow surface mounds, on mobile oölite shoals, and some tidal channels. This "carpet" can make miles of calcarenites hydrodynamically stable. When removed the sands beneath developed ripple marks in a few hours. Areas of oölites become stuck in the mat, which may slow or curtail sorting, even causing poor sorting in a high energy environment (Bathurst, 1967, p. 464). These algal films may develop on calcarenites in as much as six feet of water, below low tide level (Ginsburg et al., 1958, p. 311). Dr. Erle Kauffman (U.S. National Museum, 1969, personal communication) suggested that some of these carbonate-depositing areas had been a soft, slurry-like bottom. This might be true for quiet bottoms, but might not give the particle sorting and current bedding such as the Roxton shows.

Fecal pellets are a small percentage in thin sections and are difficult to recognize in the sections. In washed samples several kinds include small (several mm.) rounded or ellipsoidal, shiny brown objects. The same type but with faint spiral markings may be the markings of the spiral intesine of primitive teleosts or small sharks (Willcox, 1953, p. 126). A different kind is the gray, rod-like, dull surfaced pellets which may be from crustaceans such as Callianassa (Shinn, 1968, p. 885). Dapples (1942, p. 123) and Evans et al. (1964, p. 134) both state that fecal pellets concentrate in shallow water. In areas of slow sedimentation these pellets may become glauconitized or may be centers for phosphatization in deep water (Dapples, 1942, p. 123-125); this kind of induration may be necessary for preservation of the pellets (Ginnsburg, 1957, p. 83). Glauconite in fecal pellets, foraminifer chambers or other organic fillings may have formed in a reducing microenvironment, as decaying organic matter may counteract the general oxidizing environment of the sea (Burst, 1958, p. 320). Any pellet-containing rock must not only have had them present in the sediment, but must have had some kind of preserving circumstances. Many of the non-pelletal rocks in the section in the study area are strongly bioturbated, but perhaps the burrowers' pellets simply were not preserved.

Pyrite may also form in environments similar to that of glauconite (Ginsburg, 1957, p. 91; Carozzi, 1958, p. 142; Raynor, 1958, p. 143). Raynor (1958, p. 143) further comments that calcium carbonate may also concentrate, along with pyrite, when organic matter decomposes. Several mosasaur specimens from this unit had both pyrite and calcite concentrations around the bones. The small percentages of glauconite in the Roxton probably did not form in the area but were carried in and so give little indication of depositional environment. However the pyrite and its alteration products hematite and limonite may give the information with further study.

Another feature of the Roxton Limestone is a thin (one foot or so) zone, not lithologically different, at the base of the transition between the Roxton and Ozan units, which has numerous casts of Baculites, Inoceramus, Hamites and other ammonites, as well as shark teeth, fish parts and concentrations of partial skeletons of mosasaurs and plesiosaurs. No nodules have been seen but the zone shows evidence of winnowing or reduced sedimentation. Emery and Dietz (1950, p. 11-12) list many references to the association of phosphatic nodules with unconformities and Stephenson (1929, 1937) and Dane and Stephenson (1928) took these nodules to indicate unconformities in the Austin and Taylor sections. Steinhoff (1964, p. 33) suggested that casts and nodules may form during a sedimentation stand-still and be incorporated in the overlying sediments when deposition resumes. Frizzell and Anderson (1950) also have this opinion. This may explain why the zone has not been differentiated lithologically. Stephenson (1937, p. 140) found that the Roxton, as the upper part of the Gober Chalk, thinned and pinched out about four miles northeast of Pattonville (Blossom, Lamar County, according to Paulson, 1960, p. 9), but that the phosphatic zone continued eastward. It is a zone of glauconitic marl overlain by several feet of sandy marl. It would seem that these phosphatic zones are independent of lithology and must be associated with some other conditions.

Additional information is given by evidence of bioturbation, which is intense in the Roxton. Networks of burrows an inch or more in diameter are common on weathered surfaces and are easily seen when filled with hematite-stained matrix (see Fig. 17). Several authors have illustrated burrows much like these, particularly Shinn (1968): pl. 109, fig 1 of the recent shrimp Alpheus floridanus, pl. 110, figs. 1, 2 of Callianassa, pl. 111, fig. 2 crustaceans, Stone City beds, Eocene, and fig. 3 shows a shrimp in a burrow from the Eagle Ford formation; text fig. 15a shows the surface of the Denton marl, Cretaceous which is a network of burrows. Bromley (1967, pl. 7, a, b) also shows burrows similar to these. Kennedy (1967) in a study of English trace fossils, shows other burrows that resemble the Roxton forms; these are shown in pl. 2, figs. 1, 2, 4 and pl. 5, showing Spongeliomorpha, filled with matrix (Chondrites) and pls. 3, 4 and 8, fig. 5, showing Thalassinoides. All of these burrows have many tubes and some pocketing in the ends of the tunnels. Some curve, some are vertical and some seem to parallel bedding more closely. Bromley (1967, p. 165) shows burrows filled with superjacent rock, and reburrowed, especially by the small Chondrites; they may contain fossils from rock missing in a diastem. The English Cretaceous chalks are also bioturbites, except for channel fills, although the shell lag concentrations in them may have their bases blurred by bioturbation (McKerrow et al., 1969, p. 57). Burrowing may also mix coarse grains with fine and completely obliterate bedding (McKerrow et al., 1969, p. 60). This may explain why the bedding is massive and the graded bedding is somewhat obscured in some parts of the Roxton. Recent studies by Rhoads (1967, p. 475) of harbor sediments in Massachusetts bays shows that biogenic reworking may indicate but not prove high densities of benthic organisms. He also cites irregular layering and mottling of beds in biogenically reworked sediments. Vertical burrows, down to 30 cm., were common in intertidal zones, where animals burrow to escape tides, and are more horizontal in subtidal environments in the upper two or three centimeters. Laporte (1969, p. 110) finds burrows abundant in some of the Helderberg rocks but not in cross-bedded rocks; most of the other Helderberg rocks are bioturbites. Perhaps the Roxton is peculiar also in being a cross-bedded bioturbite, unless stabilization by an algal mat made the sands firm enough for the burrowers. Most modern burrowers live in the upper foot of sediments and may rework many tons of sediment per year, reducing grain size in the process (Dapples, 1942, p. 120). In addition they may also oxygenate the sediments (Ginsburg, 1957, p. 84). The commonest burrowers are worms, pelecypods, crustaceans, and a few others. Arenicola (lug worm) can eat 3,147 tons per acre per year, producing mounds and shell layers (Ginsburg, 1957, p. 84). Most of these burrowers occur in shallow water carbonate-depositing areas, in depths of about 200 feet (Ginsburg, 1957, p. 85). Included with burrowers are rock crushers such as parrot fish, Cliona, echinoderms (such as the coral-eating starfish) and molluscs. These may bore into and riddle a rock surface down to several inches (Newell and Rigby, 1957, p. 48). Callianassa now inhabits water five to 50 fathoms deep and prefers sandy or muddy bottoms near shore (Krinsley and Schneck, 1964, p. 272). Shinn (1968, p. 884) also finds Callianassa common in intertidal waters and down to 35 feet in depth. If the Roxton burrowers were Callianassa-like burrowers (and some decapod crustaceans have been collected from the unit), then the Roxton must be a shallow water deposit. The burrowers themselves are seldom preserved. Bromley (1967, p. 171) remarks that most of them die and shed outside of the burrow. Chances of preservation are better in carbonate-depositing areas because of more rapid sedimentation. Others say (Bromley, 1967, p. 171) that burrowing crustaceans prefer areas of low sedimentation rates, and so are not preserved. It seems improbable that burrows would be preserved anyway. Most burrows, however, become filled with sediment and this must happen very soon after they are formed because many are then reburrowed with Chondrites and other small burrows (Shinn, 1968, p. 890). Most burrowing animals prefer stiff mud bottoms and in those may not line the burrow but Kennedy (1967, p. 131) found some burrows pyritized, with the outer surface coated and altered to limonite, perhaps an alteration of the old mucus lining.

Another effect of bioturbation is "biological winnowing" or modification of grain size by burrowing (Shinn, 1968, p. 893). Burrowers bring sediment to the surface and pump it out of burrows so that the fine material is removed by currents. Mounds surrounding the burrow opening consist of coarse grains and pellets. Recycling this sediment may make the burrow coarser in size than surrounding sediments, causing distinct burrow fillings. Thus grain size is not always dependent upon current speed. In the case of the Roxton the above discussion of bioturbation may furnish explanations for the abundance of fragmental fossil remains, apparent compaction of the calcarenite to a packed biomicrite (or wackestone to packstone), and massive bedding with partially obscured graded bedding. The fact that the fossil fragments are unworn suggests to Silver (1963, p. 16) that they were macerated by shell-crushing animals rather than currents; the latter would have worn and rounded the fragments. Dapples (1942, p. 124) thinks that in addition to currents sweeping fine particles away, they may also be re-eaten and dissolved by the burrowers. He further suggests that if bedding exists in such bioturbated rocks, sedimentation must have exceeded the bioturbation. Swinchatt (1965, p. 86) also says that bioturbation may be more effective than currents and is much more important than previously thought. This may well have been true of the Roxton; perhaps particles brought in by currents were sorted by biological winnowing.

Several properties of the Roxton suggest that sedimentation was rather slow, at least for the phosphate cast zone near the top. Presence of the casts, along with noticeable glauconite percentages, indicated to many authors that either slow sedimentation or by-passing may concentrate these. Bromley (1967, p. 171) points out that burrowing crustaceans prefer areas of slow sedimentation. Middlemiss (1962, p. 33-40) further suggests that the more glauconite and the greater the bioturbation, the slower the deposition. Currents may be quite strong down to 2,000 m. (Twenhofel, 1936, p. 687) so that currents would be available for winnowing processes. It would be more reasonable to assume that currents would be active as Irwin (1965, p. 542) suggested for his zone Y of high energy on sea bottom where wave base touched the bottom and stirred and sorted particles. Either situation might be one of by-passing. Phosphate and manganese nodules sometimes indicate submarine unconformities or condensed zones. Because they are authigenic they may form in areas of slow sedimentation or by-passing (Twenhofel, 1936, p. 696). Lowered wave base may rework bottom sediments, concentrating shells as a lag gravel, along with rolled shells, chert and detrital quartz. Fossils may be sorted and oölites may form (Dott, 1958, p. 11). Glauconite is common in environments of non-deposition or "weak agitation" and may not be present when the water depth increases (Carozzi, 1958, p. 137). Burst's (1958, p. 320) study of glauconites in the Texas Tertiary section suggested that glauconite at unconformities may be different from that in conformable strata, and that perhaps marsh and neritic glauconites might also be different.

General evidence of stratigraphic condensation has been cited by many authors. Kennedy (1967, p. 128-129) found that some English Cretaceous chalks were condensed, with many erosional breaks and hard "winnowed" chalk. Current evidence included the presence of glauconite, phosphate pebbles and fossil casts, rolled chalk, and ammonite body chambers filled with small fossils carried in. This is also the case in the Roxton. The basal few feet of the "Glauconitic Marl" in Kennedy's area is rich in glauconite, phosphate, which "clearly indicates slow deposition." Henson's (1950, p. 224) study of Middle East reef areas also showed these minor breaks of diastems. He says, "Such breaks are marked by concentration of foraminiferal tests, fish fragments, phosphatic nodules, and glauconite (fig. 10), indicative of stratigraphic condensation (fig. 11)." Hallam (1960, p. 34) found that this happened in the Jurassic of England, at the tops of beds in a cyclic sequence. Some of the tops showed increased turbulence and non-deposition and are crowded with shells and ammonites, concentrations of glauconite and phosphate nodules, which is "an association characteristic of condensed deposits." This association may be seen at the phosphatic zone near the top of the Roxton, especially at Locality 38 where the casts are of hematite or limonite. At other localities, phosphate casts occur. Ammonites are filled with small fossils and matrix. Leriche (1934, p. 134-136) reports a zone in France between the Campanian and Maestrichtian with a basal bored zone, phosphate nodules, abundant and varied invertebrate faunas and shark, enchodontid and mosasaur teeth.

When first seen under the microscope, the Roxton appeared to be similar to the bone beds in the Devonian of Ohio. It would seem that there is much lithologic resemblance. Applying the concept of by-passing to vertebrate concentrations, Raynor (1958, p. 139) finds that most bone beds usually result from water concentrations of the vertebrate remains, from the rocks themselves or at erosional surfaces. Wells (1944, p. 291) found four alternatives for creating bone beds, including 1) catastrophic destruction of a fauna, 2) enrichment of organic matter by washing out inorganic matter (winnowing), 3) enrichment by cessation of sedimentation, 4) washing together of scattered material by water movements. Raynor favored number 4, but Wells suggests 2 and 3 for the Ohio bone beds. For the Roxton "bone bed" processes 2, 3, and 4 may have been operating. Bioturbation could also enter into this. If burrowers concentrate heavy coarse particles like glauconite bone fragments too could be concentrated in burrowers' mounds (like fusulinids around ant hills). In the Ohio case, Wells (p. 295) assumes a local arching of the sea bottom with fine particles being swept out of the area. The base of some of the bone beds is gradational, so that these are "weakly developed lag deposits" (Wells, 1944, p. 296). Dr. Erle Kauffman (1969, personal communication) spoke of calcarenites that sound much like the Roxton as being concentrations from by-passing, usually the deposits of the shallow edges of carbonate basins.

It can be shown that many of the fossils are either rolled by waves or left as lag deposits, sometimes being encrusted as they lie on the bottom (Frizzell and Anderson, 1950, p. 56). Nagle (1968, p. 8) studied the Glen Rose formation of central Texas and concluded that some shells tend to concentrate because of their shape; for instance, cones and round or smooth fusiform shells roll easily and may be current-sorted. Plate-shaped shells are left as lag concentrates in high energy areas, but "rollers" often go long distances to quieter areas and concentrate either on-shore in supratidal environments or off-shore, past wave base. It may be that Baculites is so common in the cast beds because it has rolled to quieter areas of slightly slower currents. Other objects that might be concentrated in this manner would be logs, or bloated bodies of vertebrates. Dunbar and Rodgers (1957, p. 63) mentioned an articulated skeleton of the dinosaur Claosaurus agilis Marsh in the Niobrara Formation that probably drifted in as a bloated body floating on currents. Langston (1960, p. 319, 320) reported a similar occurrence of dinosaurs in the Selma Group. Perhaps this might be true of mosasaurs and plesiosaurs such as the Roxton specimens.

The creation of a biotope in which vertebrates might concentrate would certainly be related to the topography of the sea floor and tectonic environment. The various authors above have pointed out the occurrence of lithofacies changes with carbonates, reefs, diastems and condensed zones associated with positive areas. The fragmental, bioturbated, glauconitic and partially condensed Roxton Limestone may well be what Wells (1944) termed a weakly-developed lag deposit associated with the Preston anticline.

Both contacts of the Roxton are gradational, with the above-mentioned phosphate bed in the transition zone between the Roxton and the overlying Ozan marls. The gradual upward increase in fragmental and skeletal material and the massiveness in bedding can be seen at Localities

38 and 43. Paleontologically the two units cannot be separated, although further study of the faunas should prove helpful. The contact with the overlying Ozan Formation appears to be sharp (see Fig. 15). Stephenson (1929, p. 1130) recognized the phosphate conglomerate at the base of the Taylor as being indicative of unconformable relations. The unconformity extends from McClennan to Dallas Counties, but from there northward the contact appears to be gradational. He estimated by using fossil zones that 200 feet of section was missing. Later he (1937, p. 139-140) discovered that in Fannin County, about five miles south of Leonard, the contact was sharp but also had phosphatic casts and nodules. It appeared to him that the Austin-Taylor contact rose stratigraphically in the section, some 400 feet from south of Waco to the Leonard area. North of Dallas and in Collin County the contact is transitional through about ten feet of interbedded clay and marl (Clark and Bird, 1966, p. 316). At section number 1 and Localities 36 and 43 the contact is transitional through a zone about two feet thick in which bedding and fissility become more pronounced because of increased clay content. The phosphatic cast layer, sometimes with concentrations of partial skeletons, is at the base of this transition layer. The basal Ozan marls are gray and respond to weathering as normal marls, but contain many Inoceramus prisms. Perhaps as the current speed decreased and clay was introduced and not winnowed out, the beds became less of a lag deposit. This must have happened gradually. The cast bed may be independent of lithology, for Stephenson (1937, p. 140) found that when the Roxton pinched out east of the study area, the cast bed continued in a bed of glauconitic marl. If so then the conditions for condensation may have had nothing to do with

the Roxton condensed zone, but is perhaps a diastem of wide areal extent. The gradational contacts here are interpreted as being conformable, cast bed not withstanding. The Roxton Limestone represents a partially condensed zone, with an enriched fauna from this condensation, including vertebrate faunas.

Paleontology. Fossils of all divisions, microfossils, invertebrates, and vertebrates are numerous. Intense bioturbation has left many trace fossils (as yet not identified) at most outcrops. Invertebrates (excluding the phosphate zone) are *Inoceramus*, small and many ammonites, with *Baculites* and *Scaphites* the commonest. Crustaceans have been collected from this unit. A rudist fragment, rolled and worn, was collected from Locality 43 by students Charles Griffith and Ray Pashuck. This fragment was 6.5 cm. in length. Other students collected a number of specimens of the brachiopod *Terebratulina*, probably from the Roxton. This genus is diagnostic of the Austin strata in the area (Paulson, 1960, p. 9). Moore (1967, p. 31) states that it is a ". . . widely distributed shelf sea brachiopod" and a shallow water form. A phosphatized internal cast of the arm of a starfish, 10 cm. long, was collected from Locality 51 by Griffith and Pashuck. Washed samples show many foraminifers, ostracods, *Inoceramus* prisms, pellets and some echinoid parts. Other echinoids were collected, and small sea urchins occur in the cast bed. The broken shells are not worn or rolled (except the rudist), so that biologic action is suspected. None of the forms in this thanatocoenosis were types normally found in living position. Some of the *Inoceramus* and *Baculites* are bored by clionids or have small oysters attached. Most of the shells are small, Inoceramus less than five inches in length, but at Locality 38 some specimens about one foot long were collected. The phosphatic zone has a number of other forms in addition, including shark and enchodontid teeth, other fish parts, Hamites, nautiloids and apparently a greater abundance of attached and bored forms. The presence of both casts and shells indicates that some of the fossils (cast fauna) were "exotics," were selectively leached (Behrens, 1965, p. 93), or that some of the organisms lived on the bottom around the casts lying there. At Locality 43 large streamlined, flattened ammonites occur. The cast fauna is preserved either as small brown or black phosphatic casts (Locality 36) or as ironstone or hematite concretionary material that is altered matrix filling. Kauffman and Kesling (1960, p. 236) suggest that the large streamlined ammonites lived on mud bottoms, especially baculitids, scaphitid, placenticerid, and abberrant coiled forms such as Hamites. Tourtelot and Cobban (1968, p. 4) report similar cast faunas from the Niobrara chalk nodule beds in the Black Hills region. The Roxton fauna may be a mixed life and indigenous death assemblage (Hallam, 1960, p. 34), with bottom-dwelling epi- and infauna, and ammonites and other planktonic and nektonic forms (foraminifers, fishes, mosasaurs) brought in after death. The fauna occurs scattered throughout the unit, but concentrates in the cast beds, the result of winnowing or bioturbation.

The vertebrate fauna is also scattered throughout the unit, but has concentrations, many of which are in the upper cast bed. Small fish bones, scale fragments, teeth, vertebrae and shark teeth are common in most samples of the rock. Isolated mosasaur teeth and vertebrae occur, but again most of the material concentrates in the cast bed. One isolated vertebra (*ET 4304, collected by Griffith and Pashuck) was encrusted with barnacles, oysters, and worm tubes. This specimen strengthens the case for winnowing, as it apparently lay on the bottom long enough to be encrusted. The vertebrate fauna includes mosasaurs, all partial skulls and skeletons, one partial plesiosaur, many fishes (University of Texas) as well as isolated parts of these. Some of the above specimens have oysters or barnacles attached. Dunbar and Rodgers (1957, p. 128) and Miller (1956, p. 727) suggest that partial skeletons are preserved when sedimentation is too slow to cover and protect the whole skeleton. Dr. Wann Langston (University of Texas, 1969, personal communication) assured me that Recent bones exposed on the sea floor are soon covered with encrusting organisms, and John Thurmond (Southern Methodist University, 1968, personal communication) has Cretaceous specimens with attached oysters.

Preservation of the invertebrates is good, with many preserved as whole shells. The cast fauna is poorly to well preserved. Some ammonites have suture marks preserved and sometimes the inner nacreous layer, which is still irridescent. Preservation of the bones is good and internal structure is visible. Specimens from Locality 36 appear to be worn but this may also be due to the current weathering cycle, although some of the parts of these skeletons are encrusted. Other bones are in good condition and brown in color. As the bones weather, pyrite around them is altered to hematite and limonite, giving the surface of weathered bones a pinkish brown color. "Float" specimens can sometimes be identified as to stratigraphic level by their color. Specimen ET 4317, for example, was an isolated float specimen but is presumed to come from the Roxton because of its pinkish color. In preparing specimens it was discovered that pyrite is usually nearest to the bone, with a layer of calcite-cemented hematite about an inch thick, then an outer discoloration of the matrix an inch or so wide. The pink "patina" around the bone is then surrounded by firm calcite matrix, and may form what others term nodules or concretions. These are especially noticeable on the Roxton fish specimens, and may be several inches thick. These "nodules" are not syn- or post-depositional, but appear to develop as weathering proceeds, and the bones are exposed to ground water. The discolored zone around *ET 4351 from Locality 43 is in the beginning stages of development while UT 30962-25 has it well developed. Specimens from Locality 36 did not show this, but these had been exposed at ground level in a stream bed; perhaps extreme weathering removed the "patina" and left the matrix soft and undiscolored. Pyrite and hardened calcite are usually concentrated around the teeth, but these specimens showed no sign of having been pyritized.

Depositional environment. From the discussion above, the depositional environment for both the Gober and Roxton units may be summarized. Both fine grain size and carbonate composition suggest a quiet depositional environment for the Gober Chalk, while the fauna suggests mud bottom conditions. Laporte (1969, p. 115) postulated an offshore area of ". . . quiet marine waters with good circulation, and with the depositional interface lying below wave base." for burrowed carbonate muds with abundant and diverse biota. Land detritus from a distant source (perhaps like the traces of terrigenous quartz in the Gober and Roxton) furnished limy, argillaceous muds for other stratigraphic units associated with the above. Kummel (1961, p. 237) suggested deeper water neritic environments for marls, shales or sandy carbonates with abundant and varied fauna which included a variety of ammonites. The occurrence of a rudist fragment in the Roxton would indicate that shallow water environments were not very distant (Kummel, 1961, p. 237). Rudists are shallow-water shelf- or platform-edge reef-builders which in early Cretaceous times formed reef trends in the Edwards Limestone (Fisher and Rodda, 1969, p. 60). Perhaps this fragment (and many others found as float specimens) came from a similar reef trend on a nearby positive, shoaling area (Preston anticline?). Russell (1967, p. 191) stated that mosasaurs inhabited shallow epicontinental seas, either near the shore or even in brackish water. He also postulated temperatures comparable to modern subtropical areas, for such large reptiles could not have survived cold temperatures. Sedimentary structures, except burrows, have gone unnoticed in the Gober chalks. Perhaps its massive bedding results from destruction of any bedding or lamination in bottom sediments by bioturbation. Kennedy (1967, p. 129) supposed that Inoceramus lived on stiff mud bottoms and may have had byssal attachment. Both the Gober and Roxton environments then were probably shallow, but perhaps deeper than inner neritic, warm water, with much plankton and nekton to serve as food sources for the many fishes and reptiles that must have been present. The Gober sea bottom must have been firm, intensely bioturbated carbonate mud, with microfaunal shells and biologically broken shells on the bottom and subinterface.

In addition to the above generalizations, the Roxton shows the following evidence of currents: larger grain size, cross-bedding, graded bedding, presence of fossil concentrations in lag deposits. Winnowing by these currents is shown by: encrusting fauna on large specimens, fossil concentrations, presence of higher percentages of glauconite and bone fragments, presence of heavy mineral grains, presence of phosphatic casts in the upper part. Evidence of bioturbation includes: many trace fossils, massive bedding, fecal pellets, broken but nonabraded fossil fragments, and some of the glauconite and fossil concentrations in burrows, concentrations by biological winnowing. The presence of micrite indicates that some mechanism, perhaps an algal mat, prevented its complete removal by winnowing. The mat might also provide the firm bottom for Inoceramus and other attached forms in this unit.

Waters above the stabilized carbonate sand bottom must also have had much plankton or nekton as food for fishes and reptiles. Currents may have been weak or not persistent, but the Preston anticline must have been influencing their flow (Stehli and Creath, 1964, p. 1824). This would move the carbonate sands through shallow waters, perhaps shoaling across the top of the anticline to the flanks and quieter depositional environments. Perhaps much of the winnowing evidenced in the Roxton is biological and not current-induced.

The Roxton biotope then would have been a stabilized, intensely bioturbated carbonate sand with large invertebrates either "floating" on or attached to the bottom. Dead shells would be crushed and fragmented by crustaceans and further reduced in grain size by other burrowers. Burrowers would also be in the process of orienting the fragments and destroying bedding, bringing fine material to the surface from beneath the algal mat so that it would be winnowed out, leaving the concentrated fossil remains. This process must have been much more active in the Roxton biotope than in that of the Gober. Currents would be of high enough velocity to produce some of the current and graded bedding, perhaps in shallow channels or at the end of a submarine spit where such winnowing could take place. Currents would assist biological processes in winnowing out fine particles and concentrating larger or heavier particles such as heavy mineral grains, glauconite grains and phosphatic fragments or casts. Vertebrate skeletons that were washed in, perhaps already somewhat concentrated by currents, would fall into this environment. In lying on the bottom these bones would form attachment sites for encrusting epifauna, and would be dissociated by storm waves or perhaps burrowing beneath the skeleton. Predation is not indicated for few of the bones appear to have tooth marks. Unless the formation of post-depositional concentration of pyrite or calcite around the bones began early, fish skeletons would be easily dismembered and fragmented by burrowers or other scavengers.

Tectonic control can be demonstrated in this case and therefore it provided a biotope in which vertebrate remains would concentrate and be preserved. This control is expressed by thinning and carbonate deposition, usually of fragmental and glauconitic composition, over the positive areas, with currents sweeping around these features with resultant winnowing, and perhaps positioning of facies. Control on sedimentation demonstrates that a synchronous high, the Preston anticline, controlled litho-and biofacies. If Irwin's (1965, p. 451) model of epeiric seas is correct, then this feature could have had great influence on conditions on a broad, gently sloping sea floor. The final condition of depositional environment for the Roxton would be an area of slightly higher currents, on the flank of a synchronous high.

Taylor Group

Ozan Formation

Definition. Dane (1926) named a section of sandy marls and sands Ozan for Ozan Creek and the town of Ozan, Hempstead County, Arkansas. He (1929, p. 58) revised and restricted this definition to remove this formation from Veatch's Brownstown formation. The lower marl of the Taylor Group had been unnamed, but Barnes *et al*. (1966, 1967) have applied Arkansas names to Taylor units in the northeast part of Texas and correlated the lower Taylor marl with the Ozan Formation. Adkins (1933, p. 459) considered the lower Taylor between the Gober Chalk and the Wolfe City sand to be ". . . considerable thickness of Taylor clay, continuous with the main body of type Taylor. . . ." The name Taylor was taken from Hill's 1889 papers as the Blue Bluffs division and later (1891) renamed the Taylor marls. Beall (1964) retains the names Upper and Lower Taylor Marls for strata in the Waco area. Barnes *et al*. repress the Taylor as a group name. The age of the Ozan is early Campanian (Young, 1963, p. 24). If Paulson (1960, p. 22, 25) is correct in correlating the unconformity within the Ozan with that at the base of the Taylor near Austin and at the base of the Annona Chalk, the Ozan may be the equivalent of at least part of the Annona and the lower part may be the equivalent of at least the upper part of the Austin Chalk.

Lithology. Hill (1901, p. 122) refers to the Taylor in the Trinity River section as "bluish joint clays" and estimated their thickness at 500 feet. Stephenson (1918, p. 154) suggested that the Ozan was equivalent to the Brownstown formation, and described it as 600 feet of blue and gray calcareous clay, containing *Exogyra ponderosa* Roemer. Drilling records show thicknesses for the lower marl of 519 and 545 feet on up sides and 565 and 588 on down sides of faults in the Mexia-Talco fault zone (Hager and Burnett, 1960, p. 348). In the Sulphur Bluff zone the lower marl is slightly more sandy and about 475 feet thick (Hager and Burnett, 1960, p. 325). To the east, in northwest Louisiana, Ozan sands are oil-producers near their apparent source in south Arkansas. Sand and total clastics decrease to the southeast, but many stratigraphic units have coarse clastics south of the Sabine uplift (Cullom *et al.*, 1962, p. 111). Beall (1964, p. 16) finds that lower Taylor marls of central Texas are dark gray to brown montmorillonite clay, with varying amounts of silt-sized quartz, calcite fragments, glauconite, pyrite, hematite and phosphate and pyrite nodules. They weather to light gray or white, and have poor fissility, showing blocky conchoidal fracture.

In northeast Texas the Ozan Formation consists of marls that are dark gray to black when fresh, but weather to bluish gray or lighter gray (see Figs. 18-20). Very weathered fragments are almost white and take on a silvery patina. These are finely laminated in hand specimen, but outcrops show very little bedding in fresh exposures. Fissility develops as the strata weather, probably because of alteration of clay minerals. Bedding and jointing become more apparent as weathering continues. Large slabs torn loose in the Sulphur River bottom split into finer and finer

Figure 18

ET Locality 39. Ozan condensed zone, showing red weathering color. Normal gray marls surround this zone. Condensed zone is approximately one foot thick here.

Figure 19

Same locality, showing detail of weathered surface. Note concretionary appearance, rubble of casts, fossils and nodules.

FIGURE 18

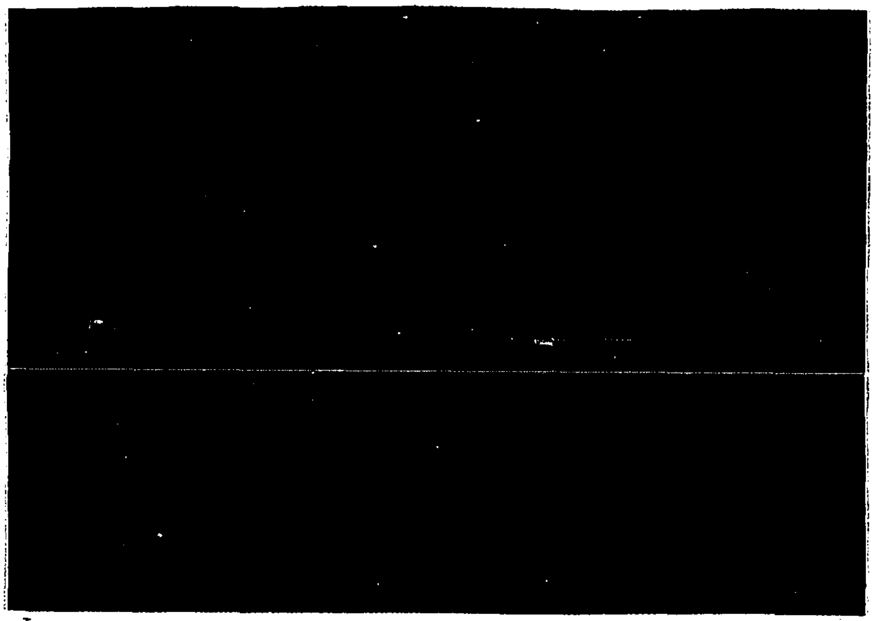


FIGURE 19

pieces as they weather and finally form small chips. Fractures become limonite-stained for an inch or more around the crack and may also become covered with minute selenite crystals. Some localities have large selenite crystals or rosettes.

Several key beds crop out in the western part of the area. The most extensive of these is a condensed zone with concentrations of fossils and glauconite. Several feet above this bed is a series of alternating marls and thin, nodular, discontinuous limestone beds. The limestones thin eastward and disappear near Ladonia, Fannin County. The condensed zone is not exposed east of Pecan Gap, Delta County but it has been correlated with unconformities to the east and south, partly by ammonites and electric log data (Paulson, 1960, p. 22).

The condensed zone is a peculiar, partly carbonate-cemented bed about 8 inches thick. It has concentrations of fossils, glauconite and nodules. It is approximately 150 feet above the top of the Gober Chalk (Paulson, 1960, p. 22). Outcrops are rusty red due to weathering of glauconite, but the fresh rock is greenish gray. Weathered surfaces appear knobby and concretionary because of the nodules and "concretions" which may be burrow fillings. Phosphatic nodules and iron-manganese casts occur in great numbers and cover weathered surfaces of this zone (see Fig. 19). Some of these nodules and casts are bored and appear rounded and shiny as if they had been rolled. Irregular black masses of iron-manganese concretions occur along with black fossil casts. X-ray analysis of one of the nodules (Dah-Cheng Wu, University of Oklahoma, 1968, personal communication) showed calcium carbonate-phosphate with minor trace elements of strontium, vanadium and other elements. Another opinion (Dr. Gideon T. James, East Texas State University, 1970, personal communication) was that the black color was due to iron and manganese, which also showed high peaks in x-ray analysis. Fossils also occur as ironstone concretionary casts that are larger than the small (few inches) black cast fossils. Some of the ironstone casts have nodules with glauconite and microfossils filling the chambers of ammonites along with the matrix in other types of fossils. Some of the ironstone cast fossils retain the shell and seem well-preserved. Other fossils, Inoceramus, small oysters and a few gastropods, are preserved as whole shells. The cast faunas are also molluscan, with Baculites the commonest ammonite in both black and ironstone cast faunas. Ammonites of several other types are dominant fossils in the ironstone cast fauna and are much like those reported for the Roxton Limestone at Locality 38. Slabs of pale gray, micritic limestone are common and occur as oblong or irregular shaped nodules up to eight inches long. These large fragments must have been lithified elsewhere and washed in. Evidence of transport is seen in borings on both sides (or all around cylindrical pieces). Small networks of borings may be made by any lithophagous organisms but a number of the slabs and pieces had fillings of burrows of sipunculoid worms. This would indicate that lithified slabs lay on the bottom and were bored, perhaps rolled or turned over and bored on all sides. Some of these pieces also have blackened surfaces and may also be impregnated with iron-manganese. Burrowing animals were also present. The base of the condensed zone is burrowed down into normal marl, (Locality 40), and is irregular perhaps because of submarine scour at Station 27. Pellets in acidized samples are further evidence of burrowing organisms. Residues also contained much glauconite, limonite flakes, traces of muscovite or selenite, biotite, many Inoceramus prisms, shell fragments, foraminifers and both brown and black bone fragments, as well as the pellets, which are gray, ellipsoidal and several millimeters long. This zone has evidence of reworked fossils and nodules and some large intraclasts that have been reworked and bored.

The overlying limestone-marl sequence resembles the Jurassic of England in having typical marls between limestone beds a few inches or a foot or more in thickness. The four to six limestone beds thin and become discontinuous, fading out into the adjacent marls and reappearing at the same stratigraphic level a few inches or feet away. Some of the English sequences show beds burrowed into each other but this is not the case here. Sugden and McKerrow (1962, p. 367) suggest that the marls weather differently because of their greater clay content. In limestones crystals of calcium carbonate form interlocking cohesive masses and are firmer than marls. The clay in the marls keeps carbonate crystals separate. The clay minerals absorb water, making the wet marls quite plastic. Taylor marls of northeast Texas are extremely slick when wet and both marls and carbonate beds weather to fine mud. Limestone-marl alternations in the Jurassic of Germany have differences of about 13 percent in carbonate content of "limestone" and "marl." This is partly primary but also depends upon depth of weathering. This was interpreted as variation in amount of carbonate against a background of clay deposition, all deposited in quiet water but the clays at a slower rate (Duff et al., 1967, p. 167). The opposite conclusion was reached by Seewald

(1959, p. 24), in his study of the Austin of central Texas. The marls are a mixture of carbonate and clay, ". . . and appear to be the result of dilution by clay of the calcium carbonate normally deposited." If carbonate deposition proceeded at a constant rate, then the marls signify more rapid deposition. He further found (p. 12) that in fresh quarry faces the alternating chalks and marls were all dark bluish gray when exposed, but on weathering the marls stay dark and develop fissility because of the higher clay content, while the chalks turned buff or white as the iron minerals were oxidized. The irregular occurrence of the limestone beds may have been related to minor carbonate-accumulating areas on the sea floor. A possible mechanism for deposition of patchy carbonates might be the "whitings" observed by Wells and Illing (1964, p. 429) in the Persian Gulf and by Cloud (1962, p. 19-22) near the Bahamas. These are irregular patches of turbid, carbonate-producing water that result from almost instantaneous precipitation of aragonite. They range from one to ten kilometers in size and may grow in a few minutes and remain for several hours. Wells and Illing (1964, p. 429) found that one gram of precipitate for each 100 liters of water was an average. The microcrystalline aragonite flocculates in one millimeter aggregates and the process seems to be independent of water depth, but whitings are smaller but more frequent in depths of less than 10 meters (Wells and Illing, 1964, p. 432). They suggest that in already-saturated sea water, these whitings may produce much carbonate and be a ". . . dominant source of lime mud over a broad shallow marine shelf." (Wells and Illings, 1964, p. 434). The northeast Texas alternating sequence seems related to differential deposition of carbonate and perhaps weathering phenomena. The European Jurassic cycles tend to be thick and conformable and shaly in basins, but thinner and more limy sequences with more condensation and erosion over the high areas. The "large intermediate areas" had limestone-marl alternations (Hallam, 1961, p. 128). The Taylor alternating sequence may be related to the carbonate-depositing area around the Preston anticline.

A total of 18 thin sections from the Ozan Formation show that the marls are much like the Gober Chalk in texture, with some particles being clay instead of carbonate. Insoluble residue checks show percentages of carbonates of 29.0 from the condensed zone (OU 1197), 37.8 for one of the carbonate beds (sample from OU 1200), 37.8 and 38.8 for two normal marl samples (OU 1199, 1204). By Pettijohn's (1957, p. 410) classification, rocks with 35 to 65 percent calcium carbonate can be termed marl. Therefore most Taylor marls are borderline marls, and even the carbonate beds are more marly than formerly supposed.

The normal gray marls have dense, fine-grained matrix with fossil fragments amounting to 3 to 10 percent of the volume of the rock, with many slides consisting of about 5 percent fossil fragments. Fossils include many foraminifers and shell fragments ranging in size from barely identifiable to 0.6 mm. Most of the ten slides show minor banding of the fossils, perhaps due to very short episodes of current activity. Most sections have from traces to 2 percent (by volume) of fine, angular to rounded , and averages about 0.1 mm. with larger grains up to 0.2 mm. in diameter. Some of the slides show traces of hematite and limonite stain, and some have small (up to 0.2 mm. in diameter) pyrite blebs. OU 1199 has clasts that appear to be rounded clay lumps about 0.2 mm. in size.

Three slides taken from the condensed zone give definite evidence of stratigraphic condensation. Percentages of fossils and glauconite are much higher than those of the surrounding marls. The matrix is clayey marl (Pettijohn, 1957, p. 410) and the carbonate seems to be cementing material for the samples are easily acidized. Therefore this unit will be considered a carbonate rock and Folk terms will be applied. The rocks are sparse biomicrites, oölite-bearing sparse biomicrite and intramicrite. They are peculiar in that large fragments occur in micritic matrix; the characterization of the Roxton Limestone would also apply to these samples (ms. p. 67). Fossil content varies from 5 to 25 percent (by volume), and consists of foraminifers, shell fragments, most of which are angular and fresh, Inoceramus prisms and echinoid parts (latter on OU 1197). Sizes range up to 3.3 mm., but most are under 1.0 mm. in diameter. Orientation is random, but some slides show vague parallel banding presumably from bioturbation. The rocks are poorly sorted and immature as were those of the Roxton Limestone, so that the same interpretation may be applied here. Quartz is present and forms about one percent of the rock shown on two slides, and increases to 7 percent of OU 1197. Grain size has a maximum of 0.2 mm. and most grains are angular to subround. OU 1197 has some grains with carbonate coatings and a few with inclusions and undulose extinction. Glauconite is quite evident, and varies from 7 to 10 percent on most slides but OU 1205 has 25 percent glauconite. These grains are green, detrital, and from 0.5 to 1.0 mm.

in diameter. The shape is angular to subround. Some of these grains on OU 1205 and 1223 are coated with carbonate, apparently microspar, and a few grains are cracked and recemented with this spar. Phosphate is also evident, ranging from 0.5 to 3 percent by volume; some of the rounded grains may be phosphatized fecal pellets. On OU 1123 some of these grains are also spar-coated. Slide OU 1205 contains grains of up to 1.3 mm. but most are much smaller (0.3 to 0.6 mm.). Intraclasts occur in OU 1223, and are either glauconite, phosphate and composite grains coated, as superficial oölites. Some foraminifer shells are also surrounded by microspar. Slide 1197 has about 0.5 percent of these superficial oölites, as well as coated grains and one apparently worm-bored carbonate pebble. Hematite and limonite occur as stains. All slides show traces of other minerals, including muscovite, biotite, chert, plagioclase and one questionable metamorphic rock fragment. Pyrite occurs as blebs and fillings of foraminifer chambers; many such filled shells occur on OU 1223. This slide is an unusual one, being a section of one of the ironstone concretions. It shows radiation cracks with secondary carbonate recementing the fractures. It also has a larger number of coated grains and superficial oölites. Perhaps the coatings are of organic origin and concentrated from mucus coatings of pellets and egested particles, or sparry calcite which tends to concentrate in these concretions. The oölites are symmetrical and coated all round the grain indicating that all of the grain surface was exposed to whatever process coated them. Similar (texturally) rocks are illustrated by Folk (1959, pl. 1, fig. 8, an intramicrite) and Dunham (1962, pl. 6b, much like both the Roxton Limestone and the condensed zone, although it appears to be a sparite, not micrite). Aggregate intraclasts such as the composite carbonate particles are typical of shallow subtidal units of the Devonian Helderberg rocks (Laporte, 1969, p. 105).

Four slides of the carbonate beds appear to have much higher carbonate content than the residues indicate; OU 1200, with 37.8 percent carbonate could be classed as a marl. Its weathering characteristics are those of a limestone. Fossils are foraminifers, including the tiny spar-filled spheres, and shell fragments up to 0.6 mm. in diameter. Orientation is random but some slides show poorly defined parallel banding (bedding or burrowing) and OU 1200 is visibly patchy when viewed in strong light. These are poorly sorted, immature carbonates, with one exception. OU 1208 appears to be well-sorted because nearly all fossils are the tiny spheres. Fossil content ranges from 5 to 25 percent (by volume) so that these are fossiliferous micrites or sparse biomicrites. Silt-sized quartz is present, with maximum size about 0.1 mm. Most is angular, but some subrounded and rounded grains occur. Traces of green detrital glauconite up to 0.2 mm. in diameter occur in all slides; it is angular to subround. Phosphate is fragmentary, brown to reddish brown, angular (fish scale fragments) to rounded (cross-sections of fish teeth), and ranges from tiny to 0.3 mm. in size. All four slides show traces of pyrite, as tiny blebs or foraminifer chamber fillings and two show traces of very small flakes of muscovite.

Contacts of the Roxton-Ozan can be referred to on ms., p. 63. The condensed zone unconformably overlies typical Ozan marls as shown by irregular base and burrowing into the underlying marls. The abundance of

Figure 20

ET Locality 44. Ozan Formation, limestone and marl sequence overlying condensed zone of Figures 18 and 19. Note discontinuous nature of the carbonate beds. Note also the small thrust fault in the beds.

Figure 21

Station 18. Pecan Gap chalks, across highway from type locality. Lower chalk is seen as typical white-weathering, slabby to conchoidally weathering chalk. Several concentrations of small oysters occur at this locality.

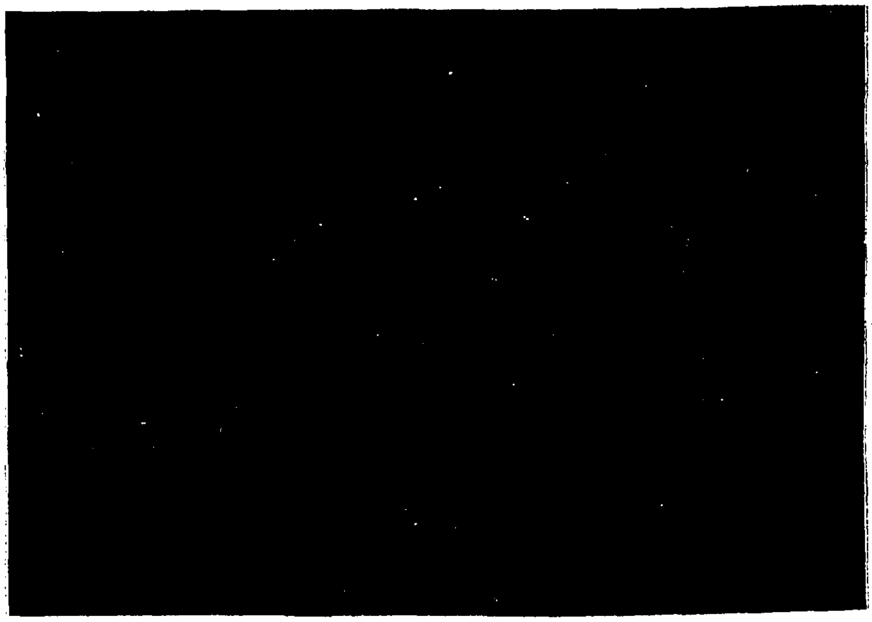


FIGURE 20

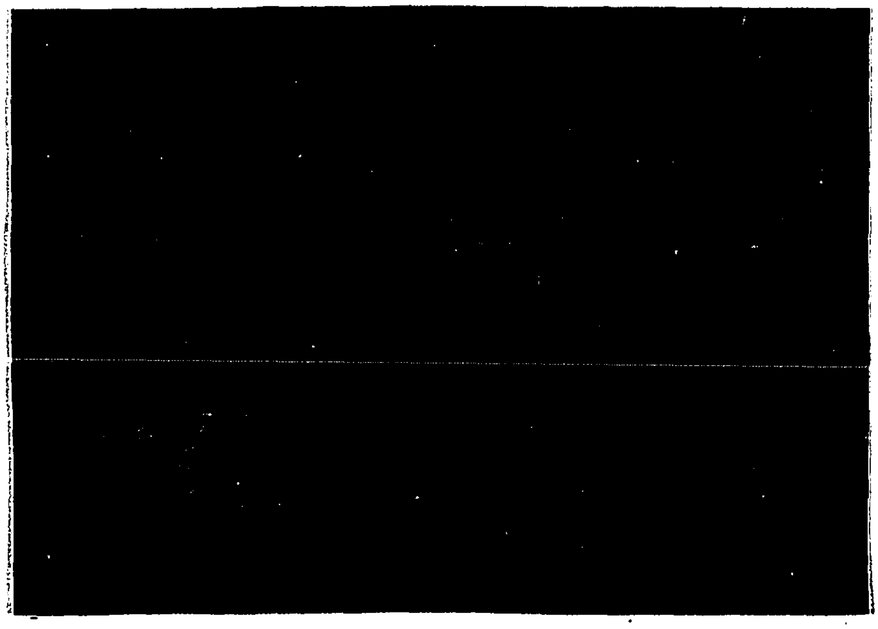


FIGURE 21

fossil fragments, glauconite, phosphate, nodules, bored intraclasts is interpreted as evidence of stratigraphic condensation. The upper contact is gradational, indicating that the conditions producing the diastem at the base and the overlying condensed zone gradually returned to normal, marl-depositing conditions. The discontinuous white carbonate beds represent indistinct gradations between marl and carbonate deposition, or additional carbonate deposition against a background of marl or clay deposition. Their contacts appear distinct but are probably all transitional. The upper contact of the Ozan Formation is discussed on ms. page 94.

Paleontology. Fossils of all divisions are common in all units of this formation. The gray marls have fossils at all levels but *Inoceramus* and *Exogyra ponderosa* concentrations occur at many levels. *Baculites* and *Hamites* are the commonest ammonites but others occur. Most of the thin-shelled forms are flattened and difficult to collect. A similar molluscan fauna occurs in the carbonate beds, along with rare echinoids and a few large ammonites. Fossils of the condensed zone are also mainly molluscan, and further identification will be necessary to determine exotic or reworked forms. Presence of burrowers is indicated by the burrowed base, fecal pellets and the boring sipunculoids in the intraclasts. Some of the shells and casts show boring by *Cliona* and one ironstone cast had oysters attached to it. The only coral seen in this formation came from the condensed zone and is a small, black phosphatic fragment. One poorly preserved fragment of a rudist was collected from one of the carbonate beds. Beall (1964, p. 19) reports a rudist from the lower Taylor marl of central Texas. Such a fauna indicates to Kummel (1961, p. 237) normal marine, neritic conditions, usually represented by shales, marls or sandy carbonates with thick-shelled pelecypods, gastropods, many foraminifers, echinoids and ammonites. The presence of Cliona indicates clear, silt-free water of normal salinity, and a depth of 60 to 600 feet (Krinsley and Schneck, 1964, p. 273).

Vertebrate faunas consist mostly of fishes and mosasaurs; one turtle plate was collected from near Ben Franklin, Delta County. Several partial mosasaurs have come from lower Ozan strata in Fannin County, two with skull parts. Others consist of vertebrae and ribs only, one of these from the carbonate beds. Several fish specimens are also from the carbonate beds, all collected as float specimens, but the lithology is distinctive enough to allow recognition of general stratigraphic level. Several others are from the lower Ozan marls. Isolated fish teeth and other specimens occur, and concentrations of these may be collected from the condensed zone. Most of the specimens are well preserved, and the bones and teeth are dark brown. Some of these weather to lighter shades of brown and some develop concretionary patinas but their characteristics are distinctive enough to distinguish float specimens from those of the Roxton Limestone. Specimens from the carbonate beds may be well preserved and may occur in thickened parts of the bed. Specimens from the marl may have lighter gray, partly carbonate material around the bones. On weathering some of this develops a brownish patina on the bones under the gray, hardened concretionary material. This cannot be acidized and so is not completely carbonate. Several specimens, including a partial mosasaur skull, had pyrite near the bones in addition to the hard gray material, and also developed iron-stained patinas. An outer "frosting" of selenite, both crystalline and granular, covered both specimens. Very weathered specimens that have lost the selenite and much of the concretionary material still retain the light brown or grayish brown stain on the bone surface. Some of the specimens from the condensed zone may be reworked; some of them are black like the cast fauna. One black mosasaur vertebra, float specimen probably from this unit, was collected by a student (Don Galbraith, 1965, personal communication). Another specimen, a mosasaur vertebra, had some of the bored micrite in the neural canal. Perhaps these have been reworked from other areas into the condensed zone. The Ozan marls have produced more fish specimens than any other unit. Raynor (1958, p. 139-140) suggests that fish fossils are more common on mud bottoms because they are covered rapidly. If Seewald is correct, then marls do represent higher rates of sedimentation, and fish fossils could be expected to occur more frequently in marls. Others report the occurrence of Taylor vertebrates, but Young (University of Texas, 1969, personal communication) reported seeing very few vertebrates in the Taylor group anywhere. Beall (1964, p. 16) reported a large tooth, probably plesiosaur, with other teeth and bones in the lower marl near Waco. Shark teeth occur in the basal Ozan phosphatic zone in a sandy bed that is 50 percent glauconite (Dane, 1929, p. 58).

Depositional environment. The above discussion would indicate deposition on a shallow, marine shelf, normal salinity being indicated by the abundant and varied marine fauna, including clionids, marine fishes, turtles and mosasaurs. Similar shelf shales were described by Fisher and McGowen (1969, p. 47) in a study of Wilcox deltaic systems; they found that shelf mudstones tend to be light to medium gray, olive or buff, with marine fossils and glauconite pellets common, with many of them containing pyrite or carbonaceous matter. Most are laminated to extensively burrowed. Kauffman and Kesling's (1960, p. 235) study of Pierre shale faunas indicates that sequences of uniform, fine-grained shales with local iron-manganese layers and concretions, and with thin-shelled pelecypods and many reptile bones may be deposited slowly in quiet water well below wave base. This information shows that the Ozan marls must have been deposited in deeper neritic shelf areas. Fish faunas of the Ozan may indicate fairly rapid sedimentation rates, if Raynor and Seewald are correct.

Different conditions are probable for the condensed zone. Iron and manganese are common in the sea, and Tikhomirova (1964, p. 144) states that manganese is commoner in marls than siltstones and that manganese content increases in sediments in the center of basins. Recent concretions and nodules on the sea floor may be intensely bored and show light coatings of iron and manganese, or may form nodules and pancakes (Fisher and Garrison, 1967, p. 489). Red Sea nodules are smooth to scoriaceous on the upper surface, black or brown with oxide coatings, and are encrusted with pelecypods and other invertebrates. The sediments have burrows that extend into the substrate (Fisher and Garrison, 1967, p. 490). These nodules have formed in rather deep water, but would appear to be similar to the nodules of the condensed zone. Bored limestone pebbles indicated to Hallam (1964, p. 167) that they were lithified in a fairly short time, and are related to "minor nonsequences." Perhaps such nodules form during sedimentary stand-still and become incorporated when deposition resumes (Steinhoff, 1964, p.32-33). Emery and Dietz (1950, p. 11-12) found many references to associate phosphatic nodules with unconformities; usual associated particles are glauconite and shell fragments. Phosphorite and phosphatic nodules indicate shoaling and non-deposition or erosion by waves or currents, rather than emergence (Hallam, 1961, p. 129). Many others have noted their association with condensed deposits; but Frizzell and Anderson (1950, p. 57) remarked that boring and encrusting may be only the last events in the nodules' history, and that they concentrate, but perhaps do not form, in non-depositional environments. If Nagle is correct, casts and nodules that roll easily should concentrate on either side of Irwin's (1965) high-energy, wave-washed zone Y. Thus rather slower deposition with enough current energy nearby to concentrate, break up and roll nodules and intraclasts to the area would be a reasonable assumption about the condensed zone depositional environment.

More general statements can be made about environments for the Ozan strata. Mollan et al. (1970, p. 595) found that on a shallow shelf such as the Tertiary Rowley Shelf off the west coast of Australia, with low supply of terrigenous muds, carbonate facies distribution was related to tectonic and eustatic sea level changes. The seabed topography at any instant in time was an influence on facies distribution, and depressions were sites of carbonate muds and marls and the ". . . rises and shoals were sites of deposition of biogenic limestone and calcarenite." (Mollan et al., 1970, p. 598). Such a depositional model would be reasonable for the northeast Texas area, with marls forming in the depression of the East Texas Embayment and the carbonate beds in the intermediate area off the rise of the Preston anticline to the west. The discontinuous nature of the eastern extension of the carbonate beds might indicate that carbonate was added to the background of clay (or vice versa) perhaps by the instantaneous precipitation of whitings. Whatever sedimentary processes were operating, they slowed long enough to permit the burrowed base and condensation of the nodule-fossil zone, then gradually returned to normal. Preserved in the sediments is a mixed life and indigenous death assemblage as observed in stratigraphic units described above.

Wolfe City Formation

Definition. This sandy part of the Taylor was named for exposures in a railroad cut northeast of Wolfe City, Hunt County, by Stephenson (1918, p. 155). He found 75 to 100 feet of fine calcareous gray sand, with some calcareous concretions and calcareous clay lenses in the upper part. This sandstone facies of the Taylor has been called "Corsicana sand" by various authors except Hill (Adkins, 1933, p. 460). Adkins (1933) reviews the literature on this unit, and cites several references to the nature of the sand in the Rockwall (Rockwall County) sandstone dikes, assuming that it is Wolfe City sand. This would be hard to prove, for there are several sands at various levels to the south of the type area. Barnes et al. (1966, 1967) refer to it as a formation. Young (1963, p. 24, 30) assigns the unit a lower Campanian position and correlates it with the Annona Chalk and upper Ozan marl.

Lithology. This sandstone is usually poorly exposed, and outcrops are usually overgrown with vegetation, so that little is known of its sedimentary structures or geometry. The grayish brown, greenish brown or light brown weathered sandstone was sampled and studied at several localities. Only invertebrates have been reported from this sand lens; most of these occur in a fossiliferous layer mentioned by Stephenson (1918, p. 155). This layer is about 12 to 18 inches thick, a resistant, dark brown weathering sandstone seen at Stations 6 and 2, the latter being the type locality. This zone has a dominantly molluscan fauna. The numerous facies have not been completely mapped. Barnes et al. (1966, 1967) find the lower part to be dark gray mudstone with abundant marine fossils; eastward the resistant molluscan zone appears. Thickness ranges from 75 feet in the western part of the area to a maximum of 120 feet, then it decreases and feathers out eastward (Barnes, et al., 1966, 1967, legends). Stephenson, (1918, p. 155) states that it feathers out to the west, near Farmersville, Collin County. There it is a glauconitic marly sand with phosphate casts and nodules and is about 75 feet thick (Dane and Stephenson, 1928, p. 44-45). Eaton (1956, p. 82) mentioned the ". . . erratic sands of the Wolfe City section." Downdip, in Hopkins County, the Wolfe City sands are better developed than in the eastern half of the county (Hager and Burnett, 1960, p. 348). Rouse (1944, p. 524) remarks that most of the sand is near the type locality and has a thickness of 200 to 300 feet. In central Texas, the sand called Wolfe City shows grain size decreases upward in the unit, possibly indicating a beginning transgression or at least reduction of height in the source area (Beall, 1960, p. 121). Later studies showed that average grain size increased northward

(Beall, 1964, p. 19). It is reworked and less well sorted to the north, and contains lenses of volcanic fragments. The sands are also cross-bedded and burrowed. A few "steeply" (2°) dipping ledges, may be cross-bedding of a set of massive large foreset delta beds (Beall, 1964, p. 20). Such information is not available for the Wolfe City Formation in north-east Texas but probably some of these features occur. Beall (1964, p. 25) interprets the sands in the Waco area as having been neritic or deltaic. Sisk (1958, p. 81) suggested a deltaic environment with distribution by small turbidity currents. Adkins (1933, p. 457) had postulated a marginal or near shore origin for these strata. Kent (1968, p. 2113, and fig. 10) suggested that fine sediment might be drifted by long-shore currents, with a source "delta influence," as in the Mancos Shale of the western Great Plains. No cross-bedding or other features that would indicate deltaic environment have been seen in the study area but rapid facies changes indicate that further study is needed to determine if they do exist.

Four thin sections from random samples contained from 40 to 50 percent quartz grains. These are angular to round (OU 1209 has a few round grains), but most grains are angular. They range in size from recognizable to 0.1 mm. Some of the grains have inclusions, a few have undulose extinction, and some have carbonate overgrowths. OU 1212 shows a few grains that appear to be slivers of "shards." The grains have random orientation. Among the quartz grains are traces of green detrital glauconite that is subangular to subround. The grains range from a few hundredths to 0.1 mm., with a few up to 0.2 mm. in diameter. Also present in traces are brown and yellowish brown phosphate fragments of

0.1 to 0.3 mm. maximum size. OU 1210 has a few questionable clay chips, and about 0.5 percent of non-quartz grains, including dolomite rhombs (OU 1209 shows some of these grains). The other slides also show traces of dolomite rhombs, some of which are euhedral and a few of which are zoned, and up to 0.1 mm. in diameter. These are scattered over the slide, and are referred to as "floating fabric." Sabins (1962, p. 1186) finds these single euhedral grains confined to calcite cemented sandstones, and concludes that they are replacement features, not vug or pore space filling. They are post-calcite cement in the sequence of diagenesis. He (p. 1193) supposed that the "floating fabric" was enough to demonstrate the replacement nature of the dolomite. These fabrics are found rarely in lenticular marine sandstones. Other non-quartz grains include zircon, muscovite, biotite, orthoclase, microcline, plagioclase, pyrite and questionable quartzite and metamorphic rock fragments. Adkins (1933, p. 460) reviewed the work of others and listed additional occurrences of garnet, staurolite, sphene (titanite) and rutile in the sandstone dikes at Rockwall. Provenance can only be guessed but presumably is either igneous or metamorphic, or first or second cycle sedimentary rocks. Goldstein (1959) reports the above heavy minerals, plus tourmaline in the Paleozoic sandstones of the Ouachita Mountains of Oklahoma and Arkansas. If these areas stood as islands, they might furnish heavy minerals to the East Texas Embayment. The cementing material of this sandstone is apparently calcareous, although a residue showed only 0.8 percent carbonate; perhaps there is more clay than originally supposed. The micritic matrix seems to enclose many grains in one optically continuous patch, a texture Friedman (1965, p. 651) referred to as poikilotopic.

Sabins (1962, p. 1186) also mentions this texture in his samples. One slide, OU 1211, was collected from the mollusc zone; fossils form 20 percent of the rock and are large fragments up to 15 mm. in length but most of the fragments are smaller. Some of the fragments appear to interlock, and are randomly oriented and evenly distributed. One shell section of an Exogyra is bored, probably by clionids. Inoceramus prisms can be seen, along with echinoids and bryozoan fragments and a few foraminifers. This information shows that these fine-grained sandstones are orthoquartzites.

The base of the Wolfe City Formation was not observed but is reported to be gradational.

Paleontology. Adkins (1933, p. 461) and Stephenson (1918, p. 155) list fossils for this unit. The only fossils seen are those of the mollusc zone and Exogyra at Locality 50, at the top of the unit. Rouse (1944, p. 529) states that Exogyra ponderosa occurs in the Wolfe City but not in the Pecan Gap. At Locality 50 both units contain that species.

Depositional environment. Little can be inferred concerning the depositional environment of this fine-grained sandstone. Further study is needed to determine grain size distribution, sedimentary structures and paleoecology of the mollusc zone before much can be concluded. Further mapping of lithofacies to determine geometry and stratigraphic relationships is also needed. The energy of the environment must have been fairly low, for the grain size is small; either currents were active enough to sort the sands or these grains were the only ones available from the source area. The broken nature of the shells in the mollusc zone might be more indicative of bioturbation than of currents. Provenance of the grains cannot be determined at present. Perhaps these are prodeltaic fine sands distributed by long-shore currents or turbidity currents acting across a broad shallow shelf environment.

Pecan Gap Chalk

Definition. Stephenson (1918, p. 157) named chalk outcrops in a railroad cut 0.5 mile east of Pecan Gap, Delta County, for the town of that name. The outcrops show the basal condensed zone, about ten feet thick here (Stephenson, 1918, p. 156). He found about 50 feet of bluish gray sandy or argillaceous chalk in the area. Previous work had confused several of the chalks, since most are lithologically similar. Gordon (1911) gives the impression that some of the confusion about age and "transgression" of the chalks upward in the section resulted from having the chalks miscorrelated ("Austin," "Annona," "White Cliffs" and others). In fact Stephenson (1918, p. 151-152) correlated the Pecan Gap and Annona correctly but then miscorrelated it with the Roxton Limestone of the Lamar County area. He did not recognize the unconformity at the base of the unit. Adkins (1933, p. 461) repeated some earlier observations and noted that the contact was not irregular in the area west of Rockwall. Ellisor and Teagle (1934) reviewed the literature and resolved the early name conflicts (p. 1507-1509). Their microfaunal study corroborated the physical evidence of disconformity at the base. Rouse (1944) reviewed again the correlations and his account was repeated in a guidebook for field study (East Texas Geological Society, 1945). Recent correlations by Young (1963, p. 24) assign this unit a late Campanian age and suggest equivalency with the Pecan Gap of central and south-central Texas and the Annona of east Texas and south Arkansas. Paulson (1960, p. 26) considers it an eastward-projecting tongue of the Annona, as does Barnes _et al_. (1966, 1967).

Lithology. This chalk is much like the Gober Chalk and many remarks for that unit and some for the Roxton Limestone apply equally well to this unit. Most outcrops consist of white-weathering, blue or bluish gray bioturbites. At Station 18 and Loc. 55 (road cut, dirt road 0.4 mi. east of Highway 128, about 3.7 miles east of Ben Franklin, Delta County) burrow fillings form a network on the weathered surface. Bedding is massive and the chalks develop fissility and slabby or conchoidal fracture as they weather. The basal zone is a tan, cream or white weathering, sandy chalk with many brown or black phosphatic nodules and fossil casts. It varies from about three to ten feet in thickness and represents another weakly-developed lag deposit like the Roxton Limestone. Particular horizons are difficult to trace and the most effective zonal markers are microfossils. The upper part of the chalk at Localities 45 and 58 is darker gray and weathers light gray. Its sandy appearance is caused by numerous glauconite grains and shell fragments. This zone is about 8 inches thick, and about one foot below an apparent transition zone to the Marlbrook Marl. This zone has produced a number of terebelloid worm burrows lined with vertebrate (mostly fish) remains. The burrows are filled with darker, more glauconitic chalk containing fossil fragments and small shells. Fossils in this zone include _Inoceramus_ with thicker shells than those of the other strata of the Taylor Group, and small oysters preserved as whole shells. The large fragmented shells may be evidence of bioturbation, or perhaps a short episode of higher energy. The waters depositing the material in this zone may have been shallower than usual, for the zone also contains abundant, small (up to 3 or 4 inches) pinkish tan, irregular algal nodules. Isolated vertebrate remains also occur in this zone. An acidized sample had much glauconite, and pyrite, brown bone chips, foraminifers and ostracods. Inoceramus prisms were abundant. Fecal pellets were not seen, although they might be expected to be present; perhaps they simply were not preserved. Rouse (1944, p. 526) mentions "fucoids," mottled chalk and "nests of glauconite" that might be evidence of bioturbation. Ellisor and Teagle (1934, p. 1524-1526) call the chalk near Ladonia, Fannin County (probably near Locality 54) a soft, medium-bedded, white to cream, conchoidally fracturing chalk. In Delta County, they found it to be a massive, fairly hard, blue-white, conchoidally fracturing chalk. These exposures belong to their Bolivina incrassata zone, the upper microfossil zone. They found (p. 1528) that the basal zone was missing in Hunt and Delta Counties, because of the basal unconformity. Farther east, near Clarksville, Red River County, upper Taylor strata rest on the middle zone, with borings, phosphatic and glauconitic beds. Part of the thinning in the study area may be due to these unconformities. Barnes et al. (1966) give a thickness of about 450 feet for the full body of the Annona Chalk but say it thins eastward. They (1967) also give a thickness of about 120 feet for the Pecan Gap Chalk but remark that it thins to 50 or 75 feet to the west. Drilling records show thicknesses of 95 and 116 feet on up and down sides, respectively, in the Sulphur Bluff fault zone (Hager and Burnett, 1960, p. 326) and 120 and 133 feet on up and down sides of the Hatchetville fault zone in Delta and Hopkins Counties (Hager and Burnett, 1960, p. 328). The differences were interpreted as indicating motion on these fault zones during the deposition of the chalks. Local erosion occurred in Delta County, due to uplift in the Preston syncline; thicknesses here are 93 on up and 123 on down sides of a fault, showing considerable motion (Hager and Burnett, 1960, p. 348). Elsewhere the Pecan Gap is chalk or various other marly or sandy facies. Beall (1964, p. 20) stated that this unit thickens basinward to 215 feet in the central Texas area and becomes more clastic to the north. The clays are montmorillonites and glauconite and rounded quartz grains occur. The upper contact is gradational; it also grades laterally into the Wolfe City facies in the north (Beall, 1964, p. 25). A shallow, neritic near shelf-edge environment is interpreted for this chalk. Taylor carbonates to the east, in south Arkansas and north Louisiana, in the Sabine uplift area, ". . . appear to be biochemical deposits of shallow water origin," (Cullom et al., 1962, p. 106). West of the study area, in Collin County, other evidence of shallow water carbonates was found by Barnes et al. (1967). The upper 45 feet of Pecan Gap is interbedded hard, granular, dark bluish gray limestone and soft, light to medium olive-gray, glauconitic lime sand which is "minutely" cross-bedded and burrowed. Perhaps this too was influenced by the presence of the Preston anticline.

In thin sections, these chalks are similar to those of the Gober Chalk; all seven sections are sparse biomicrites, or wackestones. Most of the sections are from the upper part of the unit, but the chalks are quite similar in all outcrops observed. No insoluble residue samples were checked but they should be quite high in carbonate content. Fossils include many foraminifers, shell fragments, Inoceramus prisms which make up 20 to 30 percent of the rock, with most slides having about 30 percent. Most of the fragments are 1.0 to 2.0 mm. in maximum size, but long thin shell fragments of 8.0 (OU 1218) and 11.0 mm. (OU 1219) occur in slides from the algal bed. OU 1217 contains a long filament of possible algal origin. Most of the thin sections show random orientation and rather patchy distribution of the fossils, but OU 1214 has a poorly defined parallel orientation, with streaks and patches of up to 50 percent of the fossil material, either from currents or bioturbation. Only one slide (OU 1214) had more than a trace of quartz where it amounts to one percent. OU 1219 contains some large angular grains about 0.5 mm. but most grains are angular to subround and about 0.1 mm., with a few others up to 0.3 mm. Glauconite is also present in varying amounts, from traces up to 10 percent (OU 1218, the algal bed, OU 1215 had 7 percent). These are the usual green, detrital grains, subangular to round in shape. They range from tiny to 0.5 mm. on OU 1216, 1217. Some are fillings in foraminifer shells and irregular masses, a few of which are replaced with calcite, others with pyrite or hematite (the latter may be an alteration of pyrite). Most slides have traces of brown phosphate fragments, angular to round, from tiny to 0.6 mm. Hematite and limonite occur as weathering stains and as blebs, fillings and stains around pyrite and glauconite grains. Intraclasts were found on two slides, one large one per slide; these were rounded, carbonate-coated and one and six millimeters in size. Pyrite

Figure 22

Photomicrograph of OU 1216, X 104. Pecan Gap normal biomicrite. Note immature texture. Foraminifer shells and a large oblong *Inoceramus* prism are shown. The texture and grain size are also common to the normal marls.

Figure 23

Photomicrograph of OU 1205, X 82. Ozan condensed zone, a very glauconitic biomicrite. Foraminifer shells, quartz grains (very white grains), and glauconite grains (medium gray), with blebs of hematite (black patches).

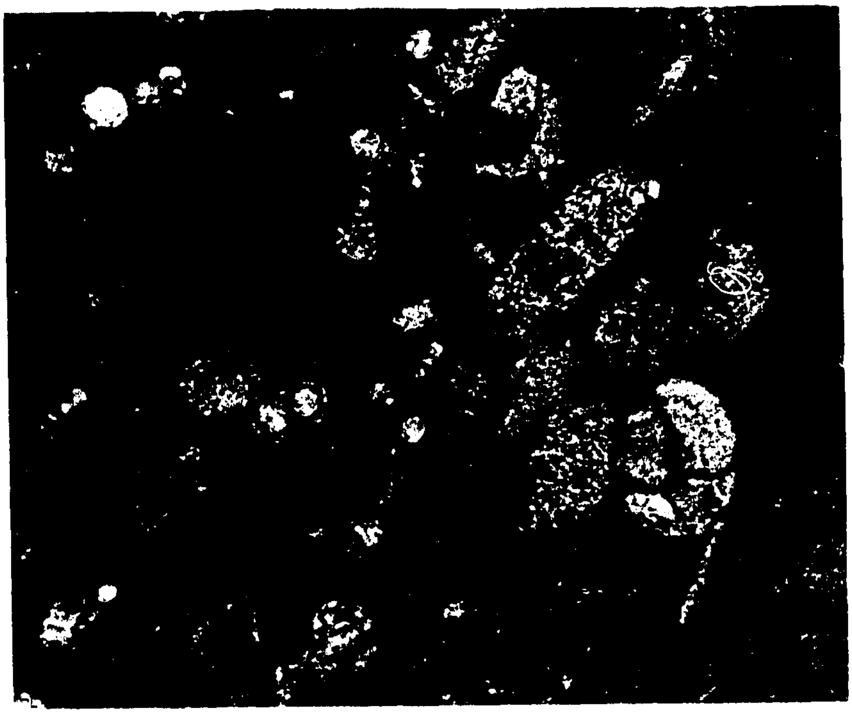


FIGURE 22

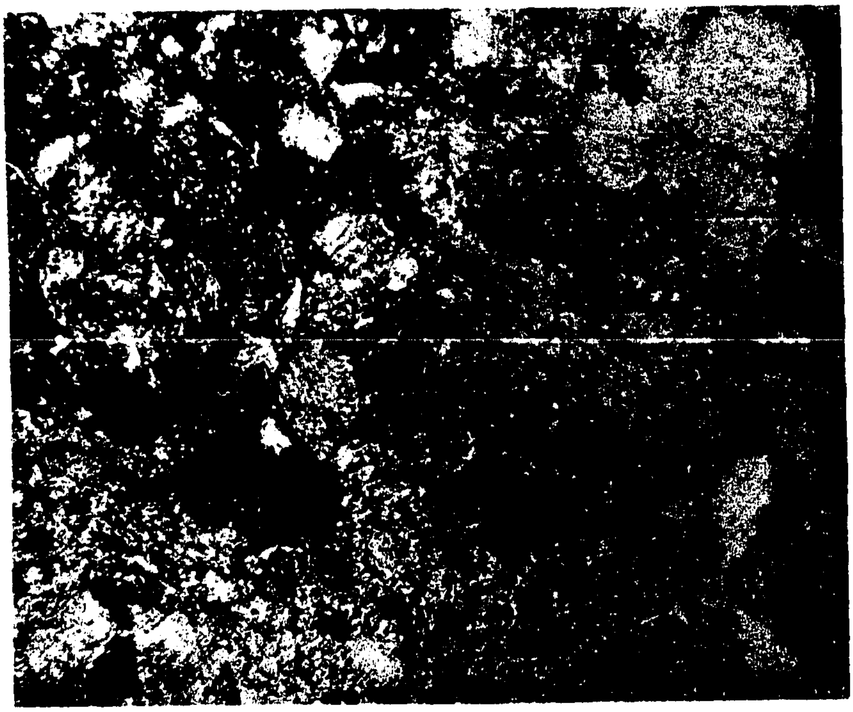


FIGURE 23

occurs as blebs, fillings and irregular small crystalline masses. Non-quartz grains include orthoclase, plagioclase, and questionable chert and dolomite (latter two not seen when re-examining the slides). Steinhoff (1964, p. 33) noted grains of zircon in the Pecan Gap in Collin County. All of the slides show poorly sorted and immature texture, similar to the other carbonates under study.

The base of the Pecan Gap Chalk has long been recognized as a disconformity. Most outcrops of the base in northeast Texas show burrowing into the underlying Wolfe City sands with nodules and casts, some of which have been drawn down into the burrows along with the chalk filling (Locality 50; Stations 16, 17). Most of the casts are small (few inches) and brownish but are black at Station 16. Some of the casts are encrusted with oysters, worms and other epifauna, and one isolated mosasaur vertebra was encrusted with foraminifers, and worms. The disconformity or diastem, with the overlying 3 to 10 foot thick condensed zone, is much like the Ozan condensed zone, and much of the discussion of that zone applies here (ms., p. 88). Dane and Stephenson (1928, p. 42) observed the unconformity at the type locality, but farther west (near Rockwall) the two formations seem to interfinger. "Elsewhere" they observed the beds to have conformable contacts. Rouse (1944, p. 525) found the base unconformable from northern Rockwall to western Red River Counties, and observed the usual chalk-filled burrows into the underlying strata. The upper contact will be discussed later.

Paleontology. Inoceramus and Exogyra ponderosa are the most common fossils from this unit, the latter species having many shells bored by clionids. Smaller oysters and small gastropods are common, and ammonites occur sparingly. At Locality 55 echinoid fragments and solitary corals about 1.5 inches long are common; the surrounding chalk also has many worm tubes and burrows. Most of the larger shells are either chalk-filled casts or broken shells, the former possibly from leaching, the latter from bioturbation. Terebelloid worm burrows (Davies, 1879) with fish remains occur in the upper part of the unit. The basal zone has most of the above (except the corals), and fossils that occur as small brown or black casts. The cast fauna includes Inoceramus, other small pelecypods, both low and high spired gastropods, belemnites, nautiloids and several types of ammonites. Some of the casts are encrusted with epifauna. The fauna as a whole is much like the cast fauna of the upper Roxton cast bed and the Ozan condensed zone. Other faunal lists are given by Adkins (1933, p. 462), who included a rudist, "Radiolites" and other fossils (p. 476-478). Ellisor and Teagle (1934, p. 1508) separated the Pecan Gap into three microfossil zones and list fossils for each zone. One of their index fossils, Diploschiza certacea, occurs throughout the Pecan Gap Formation in central Texas (Beall, 1964, p. 20). The unit in central Texas contains the usual molluscan fauna, plus the rudist Durania (Beall, 1964, p. 20). Stephenson and Monroe (1940, p. 243) found Diploschiza cretacea and Terebratulina filosa in the Pecan Gap in Mississippi and Alabama and remark that both are indigenous to limy bottoms. Clionid borings are much like those shown by Lawrence (1969, p. 542 and fig. 1b), called Cliona cf. C. vastifica Hancock.

Vertebrates are represented by isolated worn mosasaur vertebrae from the base at Locality 50 and from the algal bed at Locality 45. Rouse

Figure 24

Photomicrograph of OU 1200, X 75. Ozan carbonate bed (from Measured section 4, unit 4), a sparse biomicrite. Note good sorting due to occurrence of foraminifer shells of nearly the same size. Small dark blebs are pyrite and hematite.

Figure 25

Photomicrograph of OU 1211, X 108. Wolfe City Formation, an orthoquartzite. Note rhombs of dolomite (high relief grains), and large shell fragment (*Inoceramus* prism), and angular to subangular quartz grains. Dark blebs are hematite.

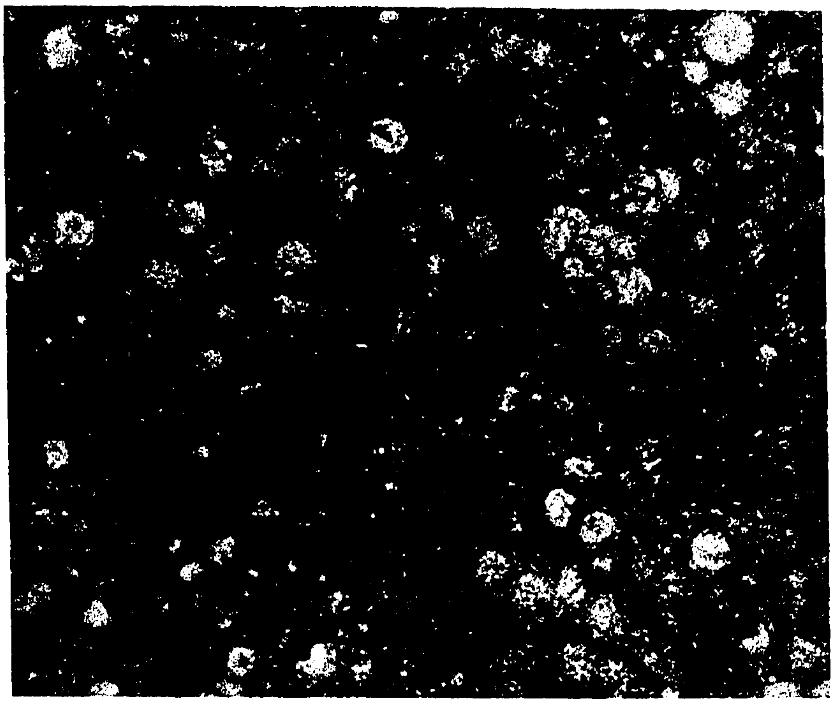


FIGURE 24

FIGURE 25

reports bones from the basal zone (1944; repeated in East Texas Geological Society guidebook, 1945). Fish remains occur as scattered isolated scales and bones in the chalk or on terebelloid burrows at several levels.

Depositional environment. Conditions must have been similar to those for deposition of the Gober Chalk, with stiff mud bottoms for the *Inoceramus* and the corals. Bioturbation must have been intense. Presence of clionids again indicates clear water. Algal nodules in the bed near the top must indicate very shallow water, and the bioturbation and terebelloid burrows in that bed suggest shallow subtidal or even perhaps intertidal environments. By-passing and condensation is indicated for the basal zone by the phosphatic casts and nodules and the encrusted bones and casts.

Marlbrook Marl

Definition. This unit was named by Hill (1888, p. 72, 84-86) from outcrops in Arkansas and redescribed and renamed Marlbrook by Veatch (1906, p. 26), who estimated their thickness at 50 to 750 feet. The rocks are white chalky glauconitic marls. Stephenson and Dane (1927, 1929) restricted the definition to include the strata between the Annona and Saratoga Chalks. Dane and Stephenson (1928, p. 45) suggest conformable relations with Annona and Pecan Gap Chalks. Rouse (1944, p. 522) thought that the upper Taylor marl in northeast Texas might be equivalent to the Marlbrook of Arkansas. Recent stratigraphic revisions (Beall, 1964, p. 10, 11; Barnes *et al*., 1966, 1967) include the Neylandville Formation in the Taylor or the suppression of the group names. The upper contact is gradational in many places and lithologies of the Marlbrook and Neylandville are similar (Plummer, 1935, p. 281; Beall, 1964, p. 11).

Lithology. Poor exposures make study difficult but outcrops observed show a dark gray, lighter gray to brownish gray weathering, slightly glauconitic marl. Barnes *et al.* describe it as medium bluish gray to yellowish gray, gray to white weathering, slightly glauconitic marl. Marine fossils are scarce. The fresh marls are much like the Ozan marls, and are dark bluish gray marls with poor fissility. They develop blocky or chunky pieces on weathering. The browner weathering color may be due to more pyrite and siderite as in central Texas (Beall, 1960, p. 122). Barnes *et al.* (1966) show outcrops of Marlbrook south of Station 14 but outcrops of the blue gray marl may be seen in the North Sulphur River channel about 13 miles southeast of Paris, Lamar County.
A similar brown, sandy concretionary layer occurs near the top of the unit at Station 29, just west of Cooper, Delta County; this has many large oysters in addition to the usual molluscs. These layers are much like a Recent concretion described by Pantin (1958, p. 371); the carbonate matrix was both organic and detrital and formed in about 7,500 years. He interprets it as being of diagenetic origin. Preservation of some of the molluscs was good. Some in the lower layer of the Marlbrook concretionary layer had shells preserved. The upper layer has more casts. The marls surrounding the lower layer had large numbers of large and very well preserved *Exogyra ponderosa*; digging revealed other smaller invertebrates of a fauna similar to that of the Ozan. Little study of facies of the Marlbrook has been made. Hager and Burnett (1960, p. 326)

state that the Marlbrook is ". . . several hundred feet of dark gray to black sticky shales with some sandy phases." in the Sulphur Bluff fault zone. Adkins (1933, p. 462-463) reports 300 feet of marl south of Hunt County and 500 feet east of Hunt County. Barnes et al. has been quoted as saying it thins eastward, but perhaps he and Adkins measured some Neylandville also, by mistake. The only clay study was done by Beall (1964, p. 22), who finds montmorillonite clays with varying amounts of calcite fragments, silt-sized quartz, glauconite, pyrite and local concentrations of phosphatic nodules. A bentonite seam occurs in the upper part, which grades into the overlying Neylandville marls. He interprets the depositional environment as near-shore marine, with areas of slow deposition (phosphate and glauconite).

Study of three thin sections shows both carbonate and clay in the matrix, and presumably the carbonate content is similar to that of the Ozan marls. Samples for thin sections were taken from the lower part of the formation. Fossils form 10 to 25 percent of the rock, and include foraminifers, shell fragments and Inoceramus prisms, ranging in size up to 2.5 mm., but most are about 0.5 mm. or less. Distribution is patchy and orientation is random, as in other units. These are texturally immature sediments. Traces of angular to subangular quartz grains occur in all slides, with maximum size up to 0.1 mm. Traces of green detrital glauconite, up to 0.3 mm. occur. These grains are angular to rounded. Angular to round fragments of brown phosphate are present in traces, and range up to 0.5 mm. in size. Two slides have irregular clay patches up to 5.0 mm. across. Pyrite occurs in one slide, and limonite stain was observed on all slides. Most of the remarks for the Ozan marls apply to this unit.

Contacts of the Marlbrook in this area are difficult to determine; they were not observed in the southwestern part of the study area. At Locality 58, the contact appears conformable but several phosphatic beds occur in a transitional sequence. Exposures are few and scattered, and lithologic similarity to the overlying Neylandville marls increase the difficulty. In Delta County the basal contact seems to be unconformable, with limestone pebbles and phosphate casts overlying a hard, massive white chalk (Pecan Gap) (Rouse, 1944, p. 526, 528). At Locality 45 basal Marlbrook Marl is burrowed into Pecan Gap Chalk, but no pebbles or casts were present. Rouse's (1944) measured section is repeated by East Texas Geological Society Guidebook (1945). Pebbles at the base are reported at stops 10 through 12 in eastern Lamar County. At Stop 14 it is reported that the base is ". . . rich in Inoceramus prisms and in glauconite, the glauconite occurring as disseminated grains and in 'pockets' up to one inch in diameter." This may be much like the basal Ozan; perhaps the glauconite "pockets" are burrow fillings. To the east, at stop 15, Inoceramus prisms, limestone and phosphate pebbles were seen above a soft chalk. South of Hunt County, the contact appears conformable (Adkins, 1933, p. 462). Between Farmersville, Collin County, and Greenville, Hunt County, the contact is not sharp (East Texas Geological Society, 1945). East of the study area the base also has worm burrows and phosphatic nodules (Presley, 1965, p. 7). Microfossils indicate that the duration of the hiatus was not as long as that at the base of the Pecan Gap Chalk (Presley, 1965, p. 16). Near Clarksville, according to

Stephenson (1937, p. 143) this contact is marked by a phosphatic zone with a few waterworn novaculite pebbles. This is important for determining provenance, and is here interpreted to mean that the Ouachita Mountains were being eroded and furnished clastics for the East Texas Embayment. Heavy mineral studies might also furnish information on provenance.

The contact with the overlying Neylandville Formation has not received so much attention. Dane and Stephenson (1928, p. 46) report a two-foot thick layer of strongly glauconitic marl, with poorly preserved fossil casts and prints, and angular pieces and nodules of phosphate, underlying a sandy marl, which they designate as the base of the Navarro Group. Plummer's (1935, p. 281) review of the contact problem, shows that an actual contact was not seen but that a zone of Crenella senica Conrad in the lower part of the Navarro might be near the contact (Plummer, 1935, p. 283). Young (1965, p. 5), in a revision of Taylor nomenclature for central Texas, reported a burrowed, phosphate pebble zone in a calcareous siltstone; he interpreted the burrowed surface as indicating a possible disconformity.

Paleontology. The paucity of faunas has resulted from lack of collecting and study. Most outcrops produce fossils, sometimes by digging. The two mollusc zones should prove productive as well as the normal marls. Several creekbeds in Delta County furnished ammonites and concretions or burrow fillings with isolated fish remains in them. Exogyra ponderosa and Inoceramus are the commonest megafossils and many small molluscs are present.

Vertebrate specimens are not common in the study area; other than questionably assignable float vertebrae and fish parts, no other specimens were seen. Dane (1929, p. 96, pl. 6) reports that reptilian vertebrae are common and are used as "doorstops" around Columbus, Arkansas. Plate 6 shows a partial mosasaur vertebral column of about 30 vertebrae. Shark teeth are also reported from the phosphatic and black chert pebble layers in a sandy zone 50 percent glauconite (Buckrange sand) (Dane, 1929, p. 58). Teeth and bones are reported in the Farmersville area in a Rouse measured section repeated by East Texas Geological Society (1945). Teeth and vertebrae also occur in the upper Taylor marl in central Texas phosphate beds (Beall, 1964, p. 22).

Depositional environment. The Marlbrook marls must have been deposited in conditions similar to those of the Ozan marls, so that those conclusions apply here. Beall (1964, p. 27) suggests that the upper Taylor there was a regressive phase with slow deposition, so that it contains much glauconite, phosphate and nodules. This would indicate, along with the fauna, that it was a near-shore marine environment.

Conclusions

From the above discussion, the following conclusions have been taken:

1. Nearly all carbonates are immature and poorly sorted, probably the result of bioturbation; the texture of the marls is the same.

2. Nearly all the rocks contain glauconite, phosphate and quartz, at least in traces.

3. Nearly all rocks show direct or indirect evidence of bioturbation.

4. Almost all rocks contain grains of minerals or bone that are most abundant in condensed zones; however some of the fossils in these zones are reworked or "exotic."

5. Sandstones are orthoquartzites, carbonates are biomicrites and fossiliferous micrites and mudstones are borderline marls; all rocks have at least some calcium carbonate.

6. At least two diastems (base Ozan condensed zone, base Pecan Gap Chalk) and three condensed zones (zones above the diastems plus the Roxton Limestone) occur; the condensed zones all have concentrations of glauconite, phosphate, as bone, casts or nodules, and fossils. Some of the fossils are reworked, and encrusted specimens give evidence of at least some winnowing.

7. Fossils occur in all units, and are a mixed life and indigenous death assemblage.

8. Vertebrates occur scattered in all units but concentrate in the condensed zones.

9. All skeletons of vertebrates collected are partial, probably because sedimentation was slow enough to allow them to become disarticulated. Some of the material was also affected by washing together of material and winnowing.

10. These are deposits of a shallow shelf, but deeper neritic area, with slow deposition in the condensed zones.

11. Tectonic control is demonstrated for carbonate accumulation, occurrence of diastems, distribution of lithofacies and biofacies.

BIOSTRATIGRAPHY

Faunal Analysis

The Upper Austin and Taylor rocks studied are of Campanian age (Russell, 1967, charts, p. 231-237; Young, 1963); therefore they are correlatives of the Selma Group (Mooreville, lower Demopolis), upper Niobrara Formation, lower Pierre Formation, and rocks of similar age in Europe, England, New Jersey and the eastern coast of North America.

The fauna of this stratigraphic interval consists mostly of predaceous marine reptiles. Elements that are missing from the vertebrate fauna of the study area that might be expected to be present in shallow-water marine deposits include pterosaurs, birds, dinosaurs (all present but rare in the Niobrara fauna, and the latter is rare in the Selma fauna), crocodiles, tortoises, and many groups of fishes including gars, coelacanths, lungfishes, and otoliths of other groups of fishes. Ptychodontids and pristids are very rare in the study area, Otoliths might be expected in condensed deposits but do not seem to be present in any of the Austin or Taylor condensed zones. Invertebrates that are missing or rare include Gryphaea, collected only occasionally, and ammonites in the Wolfe City Formation. With these exceptions, the invertebrate faunas appear to be normal for late Cretaceous time.

Comparison of the mosasaur faunas (see Table 3) using Simpson's index of faunal resemblance indicates that Austin and Taylor faunas show

Table 1

Stratigraphic Occurrence of Taxa

Taxon	Stratigraphic Unit					
	Roxton	Ozan	Ozan c.a.	Wolfe City	Pecan Gap	Marlbrook
Chelonia:						
Protostega dixie		X				
Toxochelys sp.		?				
Mosasauridae:						
Clidastes propython	X					
Clidastes sp.	X	X	X			
Mosasaurus conodon		X			X	?
M. missouriensis				X		
Globidens alabamaensis		X	X			
Platecarpus coryphaeus		X				
P. somenensis			X			
Platycarpus sp.	X	X	X			
Halisaurus sp.		X	X			
Tylosaurus proriger	X	X	X			
Tylosaurus sp.	X	X	X		?	?
Plesiosauria:						
Polycotylus latipinnis	X					

100 percent resemblance to the Pierre fauna, and 80 percent resemblance to the Niobrara and Selma faunas, based on Russell's (1970, p. 378) faunal lists. Many genera of mosasaurs occur in all formations, with Clidastes, Mosasaurus, Platecarpus and Tylosaurus being found in nearly all of the above formations. Globidens occurs in the Selma Group and the lower Pierre Formation, and was reported from the Taylor of Texas (on the basis of a poorly labeled specimen from New Jersey). The latter record is now supported for this genus does occur in the Taylor (Ozan Marl) Group. Russell (1967, p. 191) discusses the foreign occurrences of Globidens and similar forms, and notes that they occur in the "Mediterranean belt" of corals and rudistid reefs. Both corals and rudistids are present in the Upper Austin and Taylor rocks in northeastern Texas. This, as well as the large size of some of the specimens, indicates that the late Cretaceous seas were warm.

Russell's (1967, 1970) excellent reviews of the occurrences of mosasaurs suggest that a tentative zonation can be established for the Niobrara Formation, with a lower Clidastes liodontus-Platecarpus coryphaeus-Tylosaurus nepaeolicus zone and an upper Clidastes propython-Platecarpus ictericus-Tylosaurus proriger zone. Identified material from this study would fall within the Clidastes propython-Platecarpus ictericus-Tylosaurus proriger zone. However C. propython is restricted to the Roxton Limestone and P. ictericus has not been found in this area. If the specimen UTA 2206 is from the Taylor then it is the only identified specimen of the latter species. Following Russell's (1967, p. 187) method of analysis, the percentages of skulls from the fauna under study show that Tylosaurus is the commonest genus. Of 13 identifiable skulls, eight (61.5 percent) were Tylosaurus, four were Clidastes (30.8 percent), and one (7 percent) was Platecarpus. In considering numbers of isolated specimens, again Tylosaurus is the commonest genus. Globidens is the rarest genus, followed by Halisaurus, the next rarest. This fauna is more closely related to the European and eastern American faunas than to those of California and the Pacific area (Russell, 1967, p. 191).

Stratigraphic ranges of the taxa studied are generally those given by Russell (1967) and Thurmond (1969). Platecarpus coryphaeus has been listed as an index for Coniacian strata (Thurmond, 1969, p. 69), but this species occurs in the Campanian age Ozan Marl. His other two index fossils for the Campanian, Globidens alabamaensis and Platecarpus somenensis, occur in Campanian rocks in the study area. Mosasaurus conodon appears to range from mid-Campanian to Maestrichtian, so that occurrence in the Ozan Marl may be slightly early for this species. Other restrictions in occurrence (see Table 1) among mosasaurs include Clidastes propython to the Roxton Limestone, Mosasaurus missouriensis to the Wolfe City Formation, Platecarpus coryphaeus to the Ozan Marl and P. somenensis to the Ozan condensed zone. Other elements of the fauna are represented by only one specimen and are of course restricted in occurrence. The mosasaur restrictions may also be accidents of collecting. Other reptile groups represented in Upper Austin and Taylor faunas also occur within their normal ranges; Polycotylus latipinnis is present in the Niobrara Formation, and the turtles Toxochelys and Protostega dixie both occur in the Selma Group, with related species in the Niobrara Formation. Therefore Upper Austin and Taylor reptile faunas appear to be normal with

Figure 26

Composite section (not to scale) showing location of vertebrate localities in the study area. The Roxton is shown as a tongue or channel of the Gober Chalk. Location of number on the section shows approximate stratigraphic horizon. Localities are listed in Appendices I and II.

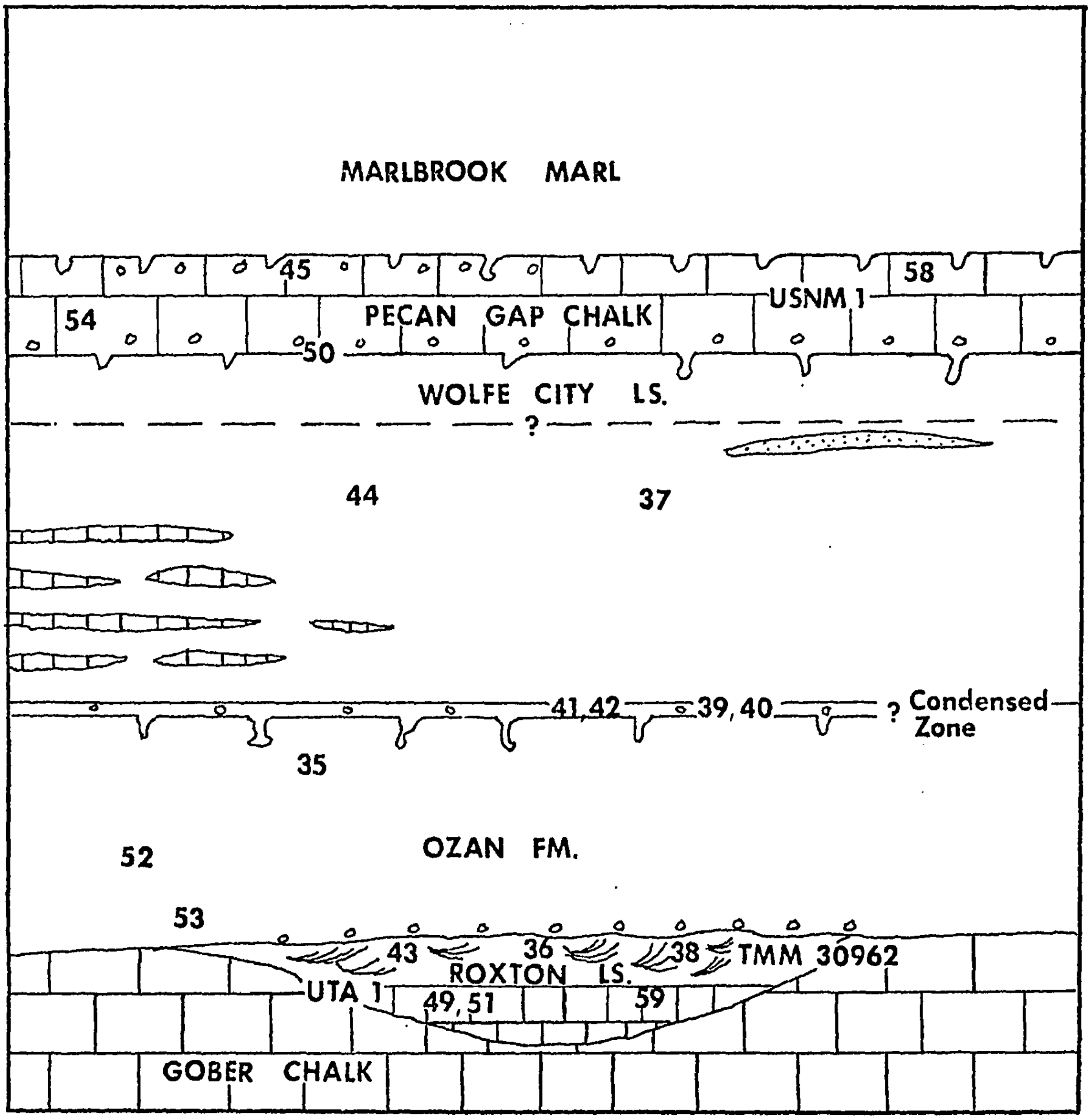

MARLBROOK MARL
45
58
54
PECAN GAP CHALK
USNM 1
50
WOLFE CITY LS.
?
44
37
41,42
39, 40
? Condensed Zone
35
52
OZAN FM.
53
43
36
38
TMM 30962
ROXTON LS.
UTA 1
49, 51
59
GOBER CHALK

FIGURE 26

regard to stratigraphic ranges, without any significant extensions of range.

Concentrations of Fossils

Concentrations of vertebrate remains have been noticed in the Roxton Limestone (this report), the Ozan condensed zone (this report; Thurmond, 1969, p. 70; Slaughter and Thurmond, 1965a, p. 4, 1965b, p. 4, 5), and the Pecan Gap basal zone (East Texas Geological Society, 1945). All of the above are described here as condensed or partially condensed deposits. Most of the specimens from the Ozan normal gray marls occur singly, but concentrations in the Roxton Limestone have the remains of two or more animals. The Ozan condensed zone usually produces single specimens but from many different localities. Two specimens of *Tylosaurus proriger* and another partial skull (unprepared), probably of the same species, were collected from the Roxton Limestone at ET Locality 43. ET Locality 36 furnished the remains of at least eight animals, which can be referred to as the Woodson Farm Local Fauna. It includes at least two specimens of *Tylosaurus proriger*, one each of *Clidastes propython*, *Clidastes* sp., *Platecarpus* sp., *Polycotylus latipinnis*, one undetermined chelonian vertebra and one unidentified vertebra of a large fish. TMM Locality 30962 furnished several specimens and will be referred to as the Maness Farm Local Fauna, which includes one specimen each of *Tylosaurus* sp., *Clidastes propython*, and about two dozen associated fishes and a number of decapod crustaceans. Several localities have furnished numerous float specimens, and can be considered as producing "faunas." One of these is ET Locality 53, from which *Tylosaurus proriger*, *Tylosaurus* sp. and one of the undetermined pliosaur vertebra were taken. ET Locality 41

Table 2

Stratigraphic Distribution of Taxa Collected *in Situ*

Taxon (Number of Specimens)	Stratigraphic Unit					
	Roxton	Ozan	Ozan c.z.	Wolfe City	Pecan Gap	Marlbrook
Chelonia:						
Protostega dixie		1				
Chelonia indet.	1					
Mosasauridae:						
Clidastes propython	5					
Clidastes sp.	2		1			1?
Mosasaurus conodon					1	
M. missouriensis				1		
Globidens alabamaensis			1			
Platecarpus somenensis			1			
Platecarpus sp.	1					
Tylosaurus proriger	4	2	2			
Tylosaurus sp.	2	3	4			
Plesiosauria:						
Polycotylus latipinnis	1					
Totals	15	5	9	1	1	1

furnished specimens of Tylosaurus sp. and Platecarpus sp. ET Locality 44, near the Ozan condensed zone, furnished specimens of Tylosaurus sp., Clidastes sp. and Halisaurus sp.; a specimen of Globidens alabamaensis was obtained near this locality. The richest float fauna is from the area of ET Locality 39, and specimens of Tylosaurus sp., Platecarpus sp., Mosasaurus conodon, Clidastes sp., Halisaurus sp., Platecarpus coryphaeus, and one undetermined pliosaur vertebra were all collected as float material near outcrops of the condensed zone and normal Ozan marls. This indicates that both the Roxton Limestone and the Ozan Marl, including the condensed zone, are the most prolific producers of vertebrate specimens in this area. Thurmond (1969, p. 70 and Slaughter and Thurmond, 1965a and b) has remarked that condensed zones, especially the ones under discussion, bear many specimens and should be prospected diligently. Such concentrations of vertebrate remains indicate that either currents or slow deposition or possibly other factors, contributed to the process of concentrating remains. Little is published about similar concentrations, but Persson (1959, 1963) describes a similar occurrence in Sweden.

Because a number of factors contribute to concentrations of vertebrate remains, some of these will be briefly reviewed.

Living concentrations. Concentrations of living organisms would be represented by schools of fishes, coral reefs, and herds of land animals, and might be expected at feeding or breeding grounds (Avnimelech, 1949, p. 489); such groupings are supposed to explain concentrations of fishes and reptiles in the Campanian and Maestrichtian phosphate deposits of Israel. Death of a few animals over extended periods of time, or death

Table 3

Stratigraphic Distribution of Mosasaur Genera
in Central United States

Genus	Formation			
	Selma	Niobrara	Pierre	Austin-Taylor
Clidastes	X	X	X	X
Ectenosaurus		X		
Globidens	X		X	X
Halisaurus	X	X		X
Mosasaurus		X	X	X
Platecarpus	X	X	X	X
Prognathodon	X			
Tylosaurus	X	X	X	X

of many or most animals in such groups in a short period of time would result in preservation of many of these organisms. Natural disasters such as rapid temperature changes or "red tides" for fishes or drought, disease and storms for land animals would kill many organisms quickly. Conditions for preservation in the area of death would govern how many would be preserved as fossils.

Biological concentrations. Some little-studied possibilities include concentrations by invertebrate action. Crabs or other crustaceans break up, clean and discard shell and bone fragments; some take the material into their burrows and then discard the fragments at the mouth of the burrow. Some invertebrates sort and use shell material or vertebrate fragments to line their burrows; terebelloid worm burrows lined with fish remains are common at several horizons in the Gober Chalk and Pecan Gap Chalk. Other invertebrates may act as parasites or as scavengers. Bowman (1971, p. 540) found an isopod crustacean (Palaega) with the skeleton of a large shark. Perhaps such invertebrates are partially responsible for the disarticulated condition of many of the partial skeletons found in the area. The association of so many decapod crustaceans at TMM Locality 30962, with one found in the matrix of one of the mosasaur specimens, would indicate that this may not be a unique occurrence. Bitten or chewed bones (such as ET 4300) are not common in the Austin-Taylor fauna, but Williston (1914, p. 9) notes their common occurrence in the Niobrara fauna. Many bones are bitten or have teeth embedded in them. Bowman (1971, p. 540) quoted Slaughter as saying that the association of shark teeth with large skeletons is common in the

Texas area. Remains of sharks and predaceous fishes are common in this area. These large fishes might have been living in the area because of the rich food supply of invertebrates and smaller fishes. This in turn must have attracted the predaceous reptiles, which fed on the larger fishes or each other, or invertebrates (Globidens).

Sedimentological concentrations. Paleoecological interpretations are difficult for nektonic organisms because bottom conditions should have had little or no control over their distribution during life. Indeed, Russell (1967, p. 192) remarks that mosasaurs are found in all types of lithologies. It may be quite different for dead organisms, all of which, once coming to rest on the bottom, are "sediment" just as sand grains and pebbles are. Then sedimentary conditions will exert an influence on the organic remains as on inorganic sediment. The phosphatic content of bones make them dense enough to be concentrated into lag deposits by currents that cause sedimentary by-passing or winnowing. It is reasonable to assume that these concentrations will occur in association with diastems or unconformities, in basal gravels, or in condensed zones, and are therefore associated with tectonic features in some areas. Most of the concentrations of Austin-Taylor vertebrates can be explained by their association in this type of situation. The zones in which these concentrations occur have features resulting from slow deposition in shallow water, and have associations of heavy "lag" minerals as well as bones, and mixed fossil assemblages.

Evidence of the shallow water origin of Upper Austin and Taylor rocks may be seen in invertebrates such as Inoceramus with fairly thick shells (Pecan Gap, upper zones, ET Locality 45), rudistids (common as float specimens but not seen in situ), oyster-like forms such as Exogyra, Ostrea, and Diploschiza, all of which Moore (1967, p. 31) says are shallow water forms. Fisher and Rodda (1969, p. 60) find rudistids on the shelf edge of Edwards Limestone depositional platforms. Among the vertebrates, Russell (1967, p. 191) suggests that mosasaurs inhabited shallow, epicontinental seas, or even brackish waters near the margin of the seas. Williston (1893, p. 110) remarks that the upper Niobrara Formation evidently formed in shallower water than the lower Niobrara, and says that birds, pterodactyls and turtles are commoner in the upper part. He used this information to interpret the restriction of Clidastes to the upper part as meaning that this genus was a shallow water mosasaur. In the study area, Clidastes propython is confined to the Roxton Limestone, and Clidastes sp. is commoner in this unit; perhaps members of this genus frequented shoaling waters near the Preston anticline. Possible contrary evidence is seen in the thin-shelled invertebrates, in high planktonic foraminifer ratios, and in lack of stratification in the chalks and marls. The former two may be explained by solution of some of the shell matter, and the latter by intense bioturbation common in shallow waters.

Sedimentary features characteristic of shallow water deposits include large grain size, current bedding (cross-bedding), high ratios of planktonic foraminifers and the presence of fecal pellets. Skeletal carbonates (calcarenites) are frequently deposited in shallow waters (Evans et al., 1964, p. 129); Seewald (1959, p. 5) noted this for Austin rocks on the San Marcos arch, where the strata thin and become fragmental and glauconitic. Kauffman (personal communication, 1969) mentioned a skeletal carbonate deposit much like the Roxton Limestone which he interpreted as having formed by by-passing on the edge of a carbonate basin. These might result from shoaling conditions on highs such as the San Marcos and Preston arches. The occurrence of micrites, burrow mottling and absence of current bedding suggested to Laporte (1969, p. 114) that the Helderberg deposits in New York formed below wave base. Current bedding such as that present in the Roxton Limestone suggested to Boutte (1969, p. 53) that large scale accretion cross-bedding might form in an offshore spit. Dapples (1942, p. 123) found high concentrations of fecal pellets in shallow water deposits. Reference to the stratigraphic information will show that most of these features occur in upper Austin and Taylor rocks in the study area.

Numerous workers have noted that phosphate nodules and casts, and glauconite form in areas of slow deposition (Seewald, 1959, p. 27; Beall, 1964, p. 27; Twenhofel, 1936, p. 696; Steinhoff, 1964, p. 33). Both Coleman dnd Gagliano (1965, p. 143) and Huelsenbeck and Beerbower (1964, p. 178) state that shell beds do indicate slow deposition. Crustaceans prefer to live in areas of slow sedimentation (Bromley, 1967, p. 171). Kauffman and Kesling (1960, p. 235) suggest that local iron-manganese layers with abundant reptile bones and thin shelled pelecypods in the Pierre Formation indicate deposition in quiet waters well below wave base.

In areas of slow sedimentation, the above associations also contain many bones (Slaughter, 1964, p. 11; Henson, 1950, p. 224;

Kennedy, 1967, p. 128; Hallam, 1960, p. 34). Henson (1950, p. 224, fig. 11) believes that this indicates stratigraphic condensation and occurs along diastems. Beall (1964, p. 27) assumes that these associations also indicate near-shore marine conditions. Such zones in and near the study area include those reported by Dane (1929, p. 58, basal Ozan containing these plus shark teeth), Beall (1964, p. 525, 526), basal Pecan Gap), and Steinhoff (1964, p. 31), who found some of the nodules encrusted by epifauna. Tourtelot and Cobban (1968, p. 14-16) found bored and encrusted phosphatized nodules in the Niobrara Formation. It would seem that references to bored and encrusted fossil bones would be common, but only a few reports of this have been noted by the author. Zangerl (1948, p. 14) mentions that some of the bones from the Selma Group are encrusted, and other reports come from Owen (1864, English Greensand fossils), Persson (1959, 1963, encrusted, disarticulated reptile bones from Sweden), and Boreske et al. (1972, a bored cetacean skull reworked into Miocene deposits). Some of the bones from the study area have been bored, encrusted, and a few have been phosphatized (see Special material, ms., p. 195). At least one was reworked. These must have been exposed on the sea floor for a length of time sufficient to allow them to be encrusted, bored into, chewed and disarticulated by predators or scavengers, or scattered by currents or burrowers. Presumably such conditions would be found in areas of by-passing or where diastems or disconformities were forming.

The condition of the partial skeletons collected in the study area, and those seen from other areas, is also indicative of slow sedimentation. No complete skeletons, or skulls, were found; those that were partially articulated had bones missing or displaced and most were crushed. Distorted bones are commoner in the marls. Most skulls have the skull roof missing, no frontals have been collected and only two partial premaxillae have been seen. Prefrontals are also rare, as are neurocranial parts. Most articulated partial skeletons consist of skull elements, crushed, displaced or lost (one member of a pair of bones), and vertebrae from all parts of the vertebral column. Rib fragments may be common in some skeletons, missing from others. Pectoral and pelvic girdle elements are rare, as are other limb bones. Perhaps the skull, with its tight covering of skin, was the last part of the skeleton to become disarticulated and was therefore most easily preserved. Among isolated specimens, the vertebrae are commonest, with jaw fragments or pterygoid sections next commonest. Russell suggests that quadrates are heavy bones and are usually preserved, but this does not seem to be the case in this area. Isolated quadrate bones occur, but rarely. Mosasaur bones are most numerous, followed by plesiosaur and turtle material.

Further evidence that some of the specimens lay partly exposed on the sea floor, perhaps partially covered is their encasement in concretion-like masses of carbonate material. Most of these specimens come from the marls, but specimens from the Roxton Limestone also develop iron-stained concretionary coverings, also partly of carbonate material. Many of the latter also contain pyrite. Raynor (1958, p. 143) suggests that iron sulfide and calcium carbonate concentrate as organic matter decomposes, and this would explain the occurrence of pyrite and other minerals around some specimens which are not enclosed in the "concretions."

Burt (1932, p. 42) found that ammonia and carbon dioxide which are products of the decay of animal tissue, may precipitate also as calcium carbonate and help to precipitate aluminum oxides as the hydroxide. His study of crabs in the Texas Eocene showed traces of copper sulfides in the concretions, presumably from the copper pigment in the crab's blood, precipitated as the animal decayed. Iron minerals might be commoner around decomposing vertebrates. If these mineralized bones lie partially covered then the decomposition products would be retained. Weathering would certainly tend to concentrate them, as some of the surrounding matrix (clays or calcite) was leached away. The minerals might then weather into the hematite or selenite which occur frequently around or on the bones. This is confirmed by the occurrence of well-developed concretionary masses around very weathered specimens.

Concretions of partial skeletons, scattered remains and invertebrate shells being condensed into shell beds such as the Ozan condensed zone, require current sorting. Wells (1944, p. 291) reviews some of the methods of sorting, several of which may have operated during the late Cretaceous in this area. His number 2, enrichment of organic matter by washing out inorganic matter (winnowing during slow deposition), number 3, enrichment by cessation of sedimentation (slow deposition or total by-passing), and number 4, washing together of scattered material by currents (reworking from other zones or concentrating floating carcasses prior to deposition) might have worked together. Raynor (1958, p. 139) remarks that most "bone beds" usually result from water concentrations from the sediments themselves or at erosional surfaces. Perhaps the mosasaur and other carcasses were "beached" in shoal areas, as Persson

(1959, 1963) suggested for the Swedish fauna. The carcasses would be exposed to burrowing and reshuffling by this process (Frizzell and Dante, 1965, p. 688) when brought to shallow areas. Concentrations of bones so that only vertebrae and jaw fragments are found may be explained by sorting also. Nagle (1968, p. 8) finds that rounded, fusiform and cone-shaped shells (or bones) might roll easily and are often swept long distances to areas of quiet deposition. Such "rollers" concentrate either in supratidal areas or off-shore, past wave base. Flat bones or shells may be left as "lag" in high energy areas. Ribs and limb bones may act as "rollers" and tend to be removed from current-swept deposits.

Evidence for reworking exists in some of the deposits. One reworked bone was found in the Ozan condensed zone. Many casts in the area are also encrusted, and Frizzell and Anderson (1950) suppose that encrusting of bones or other objects on the sea floor may be simply the last stage in their development, and that they may have been "reworked" soon after initial burial. They (p. 57) give a sequence of events for the explanation of encrusted casts that is probably valid for the Austin and Taylor encrusted casts as well as for those from the Pecan Gap Chalk that they studied (near Austin, Travis County). The sequence includes: 1) burial and filling of the shells, 2) deposition of some overburden of sediments, 3) cementation of mud fillings, 4) erosion and redeposition of shells (perhaps by deflationary currents), 5) attachment of encrusting epizoans (foraminifers in their case), 6) renewal of sedimentation and reburial of casts with epifauna. One vertebra studied, TMM 41166-1, from their locality did have encrusting foraminifers on it.

They (p. 56) also found mosasaur bones, shark teeth, amphibian and crocodile plates, along with Baculites and other casts, and remark that these layers differ only in the concentrations. This is also the case in the basal Pecan Gap at ET Locality 50.

Diastems and condensed zones. The preceding discussions have indicated that concentrations of bored, bitten, encrusted and disarticulated bones associated with phosphate casts and nodules, glauconite, and mixed fossil assemblages probably gathered along diastems. A review of the term shows that it was erected for minor stratigraphic breaks usually too minor to be detectable by paleontologic methods (Barrell, 1917, p. 748). Following this suggestion, Eaton (1929, p. 716) applied the term to surfaces of subaqueous by-passing where erosion but non-emergence were indicated. He (p. 726) suggested that a profile of equilibrium was important and that no grain coming to rest above it would stay, but would be picked up again by currents. He (p. 721) thought that a diastem might result from total by-passing. Twenhofel (1936, p. 696) also used the term "condensed zone" for a marine disconformity, and Frizzell and Anderson (1950, p. 55, 56) used the term to indicate the entire zone of condensed deposits. The concept of condensed zone has been clarified by Adkins (1949, p. 95), who discussed such a zone in the Eagle Ford Formation near Austin which contained five ammonite zones in two or three feet of sediments. He correlated this thin zone with 300 feet of strata containing the same five ammonite zones near Dallas.

In this report the use of the term diastem will follow Barrel and Eaton, limiting it to surfaces of by-passing and submarine erosion, as Newell (1967, p. 350) does. The overlying zones of slowly accumulated deposits with the features discussed above, will be considered to be condensed zones. Those noted in the northeast Texas area are, in ascending order, the Roxton Limestone, especially the upper cast bed, the base of the Ozan at some localities, the Ozan condensed zone, the basal Pecan Gap chalks, one major and several (?) minor cast beds near the top of the Pecan Gap Formation, and the base of the Marlbrook Marl. The upper cast beds do not crop out over the entire study area and have not been fully described or prospected closely for vertebrate specimens.

Similar faunas. Several similar faunas have been described. Zangerl (1948, p. 13, 14) described the Selma fauna as including turtles, fishes, mosasaurs, dinosaurs and plesiosaurs, in order of decreasing abundance. Most of the turtles are protostegids and toxochelyids but some are fresh-water pelomedusids. Mosasaurs include Clidastes and other small mosasaurs. The fishes are sharks and large teleosts, much as the Taylor faunas. One dissimilarity is the lack of any fresh-water forms in the Austin-Taylor fauna, Some of the Selma bones are encrusted with barnacles and bryozoans, and the skeletons are partial and disarticulated. Zangerl (p. 14) comments that the bones have been scattered by predators but that they lay on the bottom for ". . . a considerable length of time . . ." thus permitting encrusting.

Persson (1959, 1963) described a Senonian fauna from southern Sweden consisting of teeth, bones and fragments in a coarse shelly limestone. In this fauna, plesiosaurs are commonest, then mosasaurs, fishes with rarer turtle, crocodile and dinosaur remains (1959, p. 458). Fishes include chimaerids, sharks, pycnodontids and other actinopterygians; many teeth and vertebrae occur (1963, p. 3). Invertebrates included cephalopods, especially belemnites, which must have been a source of food for the other animals. The bones are rolled and worn by currents, and encrusted with oysters, serpulids and bryozoans, indicating that they lay on the bottom for a while, perhaps as stranded carcasses (1959, p. 433). Some of the bones are bitten, and Persson (1959, p. 434) suggests that the heads of most the skeletons are missing because they were bitten off by sharks and (p. 458) other reptiles or even shore-based carrion feeders when the gas-distended carcasses drifted ashore. Not only are condition of the bones, type of animals and sediments similar, but so is the tectonic setting. The shelly limestone overlies a thick kaolin deposit, the scuthern end of which abuts against a hill of Archean bedrock that was an island in the Senonian sea (1959, p. 433). These hillocks were a series of emerging horsts, that made a favorable environment for the invertebrates and furnished a food supply for the reptiles, which may be bound to near-shore areas (1963, p. 3).

Depositional Model

The above discussions indicate that tectonic setting of the sedimentation area can have direct bearing on the concentration of both vertebrate and invertebrate (coral and rudistid reefs on highs) animals. A depositional model is important to our concept of how the animals lived, died and were preserved.

Similarities in chalks and marls are apparent in grain sizes and faunas, so that these probably were deposited in very similar depositional environments (Clark and Bird, 1966, p. 322). Lower Taylor marls were interpreted by Beall (1964, p. 22, 23) as being deposited in clastic neritic to inner neritic marine areas, with sub- or prodeltaic sand stringers (Wolfe City Formation). The alternating marl and sand indicated to him that either storms or migrating delta distributaries were the cause of sand stringers and lenses such as those near Station 28. The dipping ledges of large cross-bedding indicated (p. 19) that these might be massive foreset delta beds (Wolfe City Formation). Beall (1960, p. 119) interpreted the abundant calcium carbonate, and microfossils as indicating warm, shallow seas, of a shelf environment, with reducing muds. The great thickness and areal uniformity also indicated shelf environment. Sisk (1958, p. 80) also suggested that the shelf was subsiding and that sedimentation approximately equaled subsidence. Beall's idea of the deltaic nature of the Wolfe City Formation was also confirmed (p. 81), and the further suggestion was made that some of the material was distributed by small turbidity currents. Earlier Adkins (1933, p. 457) had suggested that the Wolfe City, Durango and other unnamed sands in that stratigraphic interval were probably marginal, and near-shore in origin. The fine-grained nature of the sands here and their lack of evident cross-bedding means that perhaps in this area the Wolfe City sands are prodeltaic in origin, with the strandline far away. Perhaps Sisk is correct and these are turbidity current deposits from shelf slopes on the basin edges.

Both Bryant _et al_. (1969, p. 2528 and fig. 29) and Cullom _et al_. (1962, p. 106) suggest that the carbonates of the northern Louisiana and southern Arkansas area, especially across the Sabine uplift, are shallow water "bank carbonates." Other evidence for shelf origin would be the abundance of shallow water organisms; mosasaurs, phesiosaurs, large fishes, many sharks, as well as oysters, rudistids and other invertebrates would corroborate this. It remains then to find a shelf model that is not simply a broad, uniformly sloping feature.

Several shelf models are available; Irwin (1965, p. 452) describes an idealized shelf with several zones, including a zone Y of high energy near shore. This would deposit pellet or bioclastic limestones or sandstones, which might grade shoreward into algal carbonates or lithographic carbonates. This zone Y would occur wherever wave base is touching bottom. Zone X, with little deposition, would be just seaward of zone Y and would be shallow enough (p. 451) that any tectonic or other topographic feature on the sea floor (such as the Preston anticline) would again touch the base of the Y zone and the higher energy environment would sort grain sizes or fossils, perhaps as Nagle suggested. Assuming that the Preston anticline was a synchronous high, and influencing accumulation of sediments and vertebrates, then a shelf model with some tectonic activity would be more nearly correct. Two such shelves have been studied.

Fairbridge (1953), Rodgers (1957) and Mollan et al. (1970) published descriptions of the Sahul and Rowley Shelves on the northwest coast of Australia that seem similar to the supposed conditions on the Cretaceous Gulf Coast shelf area. Mollan et al. (1970,p. 595) described the Rowley Shelf as having a shallow epicontinental sea with a low supply of terrigenous muds. Distribution of carbonate facies was related to transgressions and regressions, so that seabed topography influenced depositional environments. Depressions were sites of calcilutite and marl deposition, while rises and shoals were sites of calcarenite deposition (p. 598). Tectonic and eustatic changes also influence deposition. North of there, the Sahul Shelf has some reefs, and also has a very low supply of terrigenous muds. The deposits of the Rowley Shelf consist mainly of calcareous glauconitic muds or sands, or in some areas, no deposits at all (Rodgers, 1957, p. 9). Fairbridge (1953, p. 13, map, p. 3) describes the Sahul Shelf as an epicontinental platform with neritic sedimentation, with reduced amounts of terrigenous muds. He contrasts it with the nearby Sunda Shelf and the northern Gulf of Mexico, which are paralic platforms with neritic sedimentation. He assumed that eustatic changes were very important; he remarked that sedimentation was very slow in places, and that glauconite was common in such areas. His map (p. 3) shows that the shelf has alternate rises and basins (much as the alternate anticlines and synclines of the northeastern part of Texas must have been). The sediments (p. 11) are green muds, about 30 percent calcium carbonate, 25 to 50 percent quartz and glauconite and 25 to 40 percent "fine washings" (clays, probably). Many foraminifer and other shell fragments occur, and this type of sediment might readily be consolidated into a Roxton-type limestone, or into biomicrites of the Ozan condensed zone type. Fairbridge (p. 12) suggests that this might be common off arid coasts with little terrigenous mud to mask the amount of glauconite forming. He also remarks that such slow sedimentation could lead to the formation of unconformities.

Another area that may have had a similar shelf during the Cretaceous was the Egyptian shelf area, described by Said (1961). He too (p. 202) realized that simple transgressions and regressions were not the only factors limiting lithofacies and biofacies distribution, but on mobile shelves changes in bottom configuration in a continuously flooded area would have great influence. Mobile shelves are divided into alternate basins and swells, indicated by facies and thickness variations (p. 210). The Egyptian shelf was mainly calcareous, with terrigenous clastics rare. He suggests that clastics are common on stable shelves, but that unstable ones have carbonates with reefs on highs and deeper water faunas in the basins (p. 216) (<u>Clidastes</u> rare in marls, commoner in calcarenites in this area). He (p.213) concludes that the units are quite time-transgressive within short distances, depending upon 1) amount of uplift, 2) position relative to the high area, 3) time of motion of the related high. His (p. 214) example cites a unit on that shelf that changes in 40 kilometers from Maestrichtian to Danian. He did not mention diastems, but perhaps they occur over the highs, or at least perhaps some of the units are condensed.

It would seem that the Texas Gulf Coast during the Cretaceous might have been similar to both of these areas, and probably was more tectonically active than the Sahul Shelf is now. The sediments and sea-floor configuration were certainly probably similar. Certainly the Texas Gulf Coast was similar to the Egyptian shelf in its carbonate deposition and time-transgressive units. During the Cretaceous northeast Texas must have somewhere near the shelf edge, with several hundred feet of warm water covering the sea floor topography. Perhaps water depth was less, and certainly so over the tops of the various anticlines. Currents were strong enough (at least some of the time) to sort sediments and fossils. The waters must have been teeming with organisms suitable for food for large predaceous fishes and reptiles. When these animals died, their carcasses were sorted by currents, perhaps beached on the high areas, and left to be sorted and disarticulated by currents, burrowers, and predators. The disarticulated remains lay on the bottom long enough to become worn, and encrusted, and to accumulate slowly along with invertebrates of many kinds, phosphatic casts and nodules and other lag deposits.

Conclusions

The following conclusions have been taken from the preceding discussions:

1. The Austin-Taylor fauna of reptiles is normal for the Campanian, and may represent the *Clidastes propython*-*Platecarpus ictericus*-*Tylosaurus proriger* zone.

2. No significant range extensions were discovered; *Mosasaurus conodon* occurs slightly early, and *Platecarpus coryphaeus* cannot be considered as an index to the Coniacian.

3. The mosasaur fauna is closely similar to that of the Pierre Formation, and more like the European faunas than the west coast faunas.

4. Most of the stratigraphic restrictions appear to be accidents of collecting; however *Clidastes propython* may be restricted to the Roxton Limestone because its members may have frequented shoal water areas where calcarenites were being deposited.

5. Vertebrate fossils concentrate in condensed zones because carcasses are swept by currents to areas of by-passing, where diluting sediments were swept away and the stable bottom accumulated remains for a long time.

6. Evidence for no. 5 is found in the bored, bitten, encrusted, disarticulated condition of the partial skeletons.

7. Similar faunas occur in Alabama (Selma Group) and Sweden.

8. The area must have been similar to the Sahul-Rowley Shelf complex of Australia and the Egyptian shelf during the Cretaceous period. Slow carbonate sedimentation, with much glauconite is characteristic of all three.

9. Tectonic control of vertebrate occurrences is shown by pre-depositional washing of carcasses to shoal areas, and to areas of by-passing where diastems and condensed zones form. Most of the vertebrate concentrations (with eight individuals in one local fauna) are sedimentological, rather than biological.

SUMMARY

Twenty species representing fourteen genera of reptiles were collected from the Roxton Limestone (Upper Austin Group) and the Ozan, Wolfe City, Pecan Gap and Marlbrook Formations (Taylor Group), all of Upper Cretaceous, Campanian age, in Hunt, Fannin, Lamar, and Delta Counties, Texas. Additional specimens from other counties were also studied. The purpose of the investigation was to find explanations for the distribution of the vertebrate specimens, their concentration at some localities and in certain units, and the disarticulated, worn, or encrusted condition of some of the specimens. The distribution might be due to biological, living or sedimentological concentrations of the organisms. As work progressed, tectonic control on sedimentation of inorganic grains and vertebrate remains was noticed. Therefore several topics of study were: 1.) lithology and distribution of each unit, 2.) structures in the area and their influence on deposition of sediments or fossils, 3.) taxonomic study of identifiable specimens, and 4.) stratigraphic and geographic distribution of the vertebrate remains.

Rocks in the study area are limestones (chalks or calcarenites), marls, or sandstones. Study of 50 thin sections indicated that the carbonate rocks are texturally immature, poorly sorted biomicrites. Most of these carbonates were sparse biomicrites, with fewer than 50 percent

(by volume) fossils, but some slides made from condensed zones were packed biomicrites, with more than 50 percent fossil material. The marls (Ozan, Marlbrook) have the same texture and grain size, and are more than 35 percent (by weight) calcium carbonate. The Wolfe City Formation is a fine-grained orthoquartzite, with very few vertebrate fossils.

Structures in the study area include a number of normal faults of the Balcones and Mexia-Talco fault systems, one small thrust fault, and one synchronous high, the Preston anticline, which extends from Grayson to Fannin counties. Both the normal faults, some of which are growth faults with thicker rocks on the downthrown side, and the Preston anticline influenced the distribution of sediments. The latter caused by-passing of sediments in areas where the currents were stronger, resulting in the formation of diastems and condensed zones. Two known diastems occur at the base of the Ozan condensed zone and at the base of the Pecan Gap Formation. The rocks immediately overlying these zones are condensed, as well as the strata of the Roxton Limestone and several fossil cast beds near the top of the Pecan Gap Formation.

Sedimentary structures also indicate that currents were stronger during deposition of the Roxton Limestone and other condensed zones. The Roxton Limestone has cross-bedding and graded bedding at three localities. Other sedimentary structures include many burrows preserved in all of the rocks, indicating intense bioturbation. The massive bedding of the rocks may result from this process. Currents may also have influenced the distribution of fossils by washing carcasses to shoal areas. One such area was the Preston anticline, which caused deposition of the Roxton

Limestone. Stronger currents winnowed fine-grained sediments from other areas as well, at several different times, and allowed bones to lie exposed on the sea floor, as the condensed zone formed. Carcasses in these areas were exposed long enough to become disarticulated by currents and burrowing organisms, to be chewed by predators and bored or encrusted by oysters, barnacles, worms, or foraminifers, and to concentrate (undiluted by sediments) by accumulation on the same surface for long periods of time. Further evidence of slow deposition in these zones is found in concentrations of glauconite, phosphate nodules, and phosphatic fossil casts, some of which are also encrusted. One fossil and numerous slabs of bored limestone collected from the Ozan condensed zone were reworked into that unit. Thus tectonic control of lithotope and biotope are demonstrated.

During the late Cretaceous period, northeast Texas may have been similar to the Sahul-Rowley Shelf area (northern Australia) or to the Cretaceous Egyptian Shelf. All three areas were characterized by slow carbonate sedimentation, and concentrations of glauconite. Some of the Australian deposits are also condensed.

Vertebrate distribution shows very well the concentrations in the Roxton Limestone and the Ozan condensed zone (see Table 2 and Fig. 26), but specimens occur scattered in all lithologies and in all units under study. Concentrations of many specimens at one locality (eight at one locality) and many isolated individual specimens from small areas occur only in the condensed zones. The vertebrate and invertebrate faunas represent a mixed life and indigenous death assemblage.

Faunal studies indicate the dominance of mosasaurs, with rarer plesiosaurs and turtles. Other vertebrates in the study area include many sharks and predaceous marine fishes. The absence of birds, dinosaurs, crocodiles, and non-marine fishes indicates deposition far from shorelines. *Tylosaurus* is the most abundant of mosasaur genera, and *Globidens* is the rarest. This fauna may represent the *Clidastes propython*-*Platecarpus ictericus*-*Tylosaurus proriger* zones of the Upper Niobrara Formation of Kansas. These three species also occur in the Lower Pierre Formation, and perhaps the zone should be extended to include that formation (Russell, 1967, p. 187). Simpson's index of faunal resemblance indicates 100 percent resemblance to the mosasaur faunas of the Pierre Formation (Wyoming), and 80 percent resemblance to the mosasaur faunas of the Niobrara Formation (Kansas, Nebraska) and the Selma Group (Alabama) (see Table 3). Some of the species appear to be restricted in occurrence because of the rarity of the species, but *Clidastes propython* may be restricted to the Roxton Limestone because members of this species lived in shallower waters than those of other species and were restricted to the shallow shoal area where the Roxton calcarenites were being deposited. *Platecarpus coryphaeus* cannot be considered an index fossil for the Coniacian, for it occurs in the Campanian age Ozan Formation.

All of the members of the fauna are predaceous except *Globidens* and perhaps the turtles. It is assumed that the mosasaurs and plesiosaurs fed upon some of the fishes that were abundant in the waters above the Cretaceous shelf. Some very large specimens (mosasaurs 50 feet or more in length) indicate that favorable conditions for their growth existed.

Tectonic influence on the distribution of vertebrate specimens is indicated by the restriction of Clidastes propython to the Roxton Limestone and by the concentrations of vertebrate remains in the tectonically controlled condensed zones. Reptile faunas were controlled in part by currents which swept carcasses to, and winnowed sediments from, the tectonically formed shoal areas to form the concentrations found in the condensed zones. Thus the concentrations of vertebrates in the study area were mainly sedimentological rather than biological in nature.

SYSTEMATIC PALEONTOLOGY

Introduction

In the following discussion, the general systematic outline is that of Romer (1970). The classification of turtles follows that of Zangerl (1953, 1960), of mosasaurs, that of Russell (1967) and of plesiosaurs, that of Persson (1963).

Measurements given in Tables 6-8 are all of maximum dimensions, unless otherwise stated. "Partial skeletons" are specimens with more than three articulated or associated bones. When referring to particular bones of one specimen, field numbers or accession numbers may be used to distinguish them when necessary. Specimens listed with an asterisk (*) before the number were collected *in situ* and have accurate stratigraphic data.

Plates and figures are supplemental to published illustrations and are not complete for any particular taxon.

Class Reptilia

Subclass Anapsida

Order Chelonia

Suborder Cryptodira

Superfamily Chelonioidea

Family Toxochelyidae (Baur, 1896) Zangerl, 1953

Subfamily Toxochelyinae (Baur, 1896) Wieland, 1902

Genus Toxochelys Cope, 1873

Toxochelys sp.

Plate 1, figs. 1-5

Toxochelys sp. Zangerl, 1953, Chicago Nat. Hist. Mus. Fieldiana: Geol. Mem. 3, no. 4, p. 198-199, fig. 81.

Distribution. Marlbrook Marl?, Taylor Group.

Referred specimens. USNM 11797.

Description. Poor locality data prevent an exact determination of stratigraphic horizon. According to Barnes et al. (Sherman Geologic Atlas, 1967) the locality is near Farmersville; the town itself is located on outcrops of Pecan Gap Chalk and Wolfe City Formation. East of the town the Marlbrook Marl crops out, and west of the town the Ozan Marl crops out. Judging from the appearance of the specimen, it is from one of the marls.

This fragmentary skeleton was assigned to the genus by Zangerl (1953, p. 198). His discussion compares the specimen to Toxochelys barberi (Marlbrook, Arkansas), T. latiremis (Niobrara, Kansas) and T. moorevillensis (Selma, Alabama). Comparison with T. weeksi as figured by

Collins (1951, pl. 1, figs. 3, 4) shows some similarity of one fragment to the lateral bridge of the hypoplastron of that species.

Zangerl did not discuss or figure the two complete costals. The first and fourth costals were repaired and are figured here. These two bones have lengths of 12.8 and 18.2 cm., respectively, and have maximum widths of 5.5 and 4.7 cm. Lateral projections on both articulated loosely to the marginal plates and are finely ridged. The projections are similar to those shown for _T_. _moorevillensis_ (Zangerl, 1953, fig. 75). Anterior and posterior articular margins are serrate. Though essentially smooth, these elements appear to have a punctate surface due to the numerous tiny nutritive foramina; this is generally true for all of the other elements of this specimen.

A fragment of the restored left hypoplastron is interpreted as the lateral bridge between the lateral fontanelle and the inguinal sinus. This fragment is much like the bone figured by Collins (1951, pl. 1, figs. 3, 4) as _T_. _weeksi_. The lateral articular edge is serrate and finely lined. The maximum width is 6.8 cm. and the maximum width is 5.0 mm. Collins (1951, p. 268) notes that the plastron may be almost paper-thin in places. Perhaps this accounts for the fragmentary state of the plastron. A few other plastral fragments could not be identified.

One partial right pubis was identified by comparison with Zangerl's (1953, fig. 65) figures of the pubis of _T_. _moorevillensis_.

The proximal part of the left femur described and figured by Zangerl (1953, p. 198, fig. 81) is much like that of _T_. _moorevillensis_ as shown in his fig. 70.

Other bones present include four partial costals, three neurals, the nuchal, several peripherals, a shell centrum, and several unidentified fragments.

Discussion. Similarities between skeletal elements of this specimen and *T. moorevillensis* perhaps indicate some affinities between the two taxa. It would be reasonable to assume that the southern taxa might be more closely related to each other than to some of the northern (Kansas) species.

Family Protostegidae (Cope, 1873) Zangerl, 1953

Subfamily Protosteginae Wieland, 1902

Genus *Protostega* Cope, 1873

Protostega dixie Zangerl 1953

Protostega dixie Zangerl, 1953, Chicago Nat. Hist. Mus. Fieldiana: Geol. Mem. 3, no. 3, p. 94-118, pl. 7, figs. 30-55.

Type. Chicago Natural History Museum P27314, partial skeleton, Harrell Station area, southeast of Marion Junction, Dallas County, Alabama (Zangerl, 1953, p. 94).

Distribution. Ozan Marl; other specimens are from the Mooreville Chalk, Selma Group.

Referred specimens. *ET 4296, ET 4320.

Description. Most of a left hypoplastron and a few undetermined fragments were collected from the upper part of the Ozan Marl at ET Locality 37. The surface of the bone is smooth, but finely lined with many minute nutritive foramina. The digitations of the plate are broken, but the body of the plate is nearly complete and closely resembles Zangerl's (1953, fig. 44B) illustration. The medial portion is missing because of weathering and erosion but the hyoplastral sutural digitations are present, as is one xiphiplastral projection. The plate is 59 cm. long, and 2.0 cm. in maximum thickness near the slight crest on the external surface. One other fragment, from near ET Locality 39, probably weathered from the Ozan Marl. Both specimens are well preserved.

Chelonia indet.

Plate 1, figs. 6-9, Plate 4, figs. 1, 2

Distribution. Roxton Limestone, ?Ozan Marl, Ozan condensed zone.

Referred specimens. *ET 4280, ET 4386, ET 4393.

Description. The former specimen was collected from the Roxton Limestone at ET Locality 36; ET 4386 was donated without information about locality or stratigraphic horizon. Its appearance suggests the weathering characteristics of the Ozan Marl.

These two isolated centra may be chelonian (Thurmond, personal communication, 1971), for they resemble Zangerl's (1960, pl. 32) figures of cervical vertebrae of the modern turtle Caretta caretta. Both centra are procoelous, with the neurapophyses broken off. The neural arches and the neurocentral sutures are not present. The articular faces are nearly triangular, and this shape is accentuated by a broad ventral hypophyseal keel which extends the length of the centrum. Both specimens are worn and the spongy bone beneath the surface is evident. The surfaces may have consisted of the very thin film of bone covering a layer of postules and pores overlying the spongy mass of the centrum, as Zangerl (1960, p. 292) observed on Corsochelys halinches. Indeed, some minute channels are observed on the worn surface of ET 4386. In ventral view both centra most resemble Zangerl's (1960, pl. 32B 8) illustration except that the hypophyseal keel is much broader in the Texas specimens.

One plate resembling Zangerl's (1960, fig. 132D) figure of the eighth neural of Corsochelys halinches Zangerl was collected as float material near ET Locality 44. The specimen, approximately 4.0 cm. square, has broken margins on which the sutures are not preserved. The dorsal surface of the plate has a slight central crest, and a single large nutritive foramen at what appears to be left side of the crest; several smaller foramina occur and fine lines radiate from the largest foramen. Both surfaces are smooth except for the tiny foramina.

Discussion. *ET 4280 is encrusted with worm tubes on the right surface below the broken neurapophysis. This specimen from the Roxton Limestone may also be predepositionally worn, for the posterior articular surface has matrix-filled depressions. ET 4393 is preserved as a blackened phosphatized fragment. The ventral surface is broken and bored by some marine organism.

Subclass Lepidosauria

Order Sauria

Infraorder Platynota

Family Mosasauridae Gervais 1853

Subfamily Mosasaurinae (Gervais 1853) Williston 1897

Tribe Mosasaurini (Gervais 1853) Russell 1967

Genus Clidastes Cope 1868

Clidastes propython Cope 1869

Clidastes propython Cope, 1869, Boston Soc. Nat. Hist. Proc., vol. 12, p. 258.

Clidastes propython, Cope, 1869, Proc. Amer. Phil. Soc., vol. 11, p. 117.

Clidastes propython?, Cope, 1869-1870, Trans. Amer. Phil. Soc. n. s., pt. 2, p. 221, figs. 49 (5), 50, 51, pl. 12, figs. 1-21.

Clidastes cineriarum, Cope, 1871, Proc. Amer. Phil. Soc., vol. 11, p. 572.

Clidastes cineriarum, Cope, 1871, Proc. Amer. Phil. Soc., vol. 11, p. 582.

Clidastes cineriorum, Cope, 1871, Proc. Acad. Nat. Sci. Philadelphia, vol. 22, p. 132.

Clidastes propython, Cope, 1871, Amer. Assoc. Adv. Sci. Proc. 19th meeting, Troy, 1870, p. 217, 220, figs. 15, 19.

Clidastes cineriarum, Cope, 1871, U.S. Geol. Survey of Wyoming and portions of contiguous territories, 2nd (4th) ann. rept. R. V. Hayden, U. S. Geologist, Washington, p. 413.

Edestosaurus dispar, Marsh, 1871, Amer. Jour. Sci., ser. 3, vol. 1, no. 6, p. 447.

Edestosaurus velox, Marsh, 1871, Amer. Jour. Sci., ser. 3, vol. 1, no. 6, p. 450.

Clidastes wymani, Marsh, 1871, Amer. Jour. Sci., ser. 3, vol. 1, no. 6, p. 451.

Clidastes pumilus, Marsh, 1871, Amer. Jour. Sci., ser. 3, vol. 1, no. 6, p. 452.

Clidastes pumilus, Marsh, 1871, Proc. Acad. Nat. Sci. Philadelphia, vol. 23, p. 104 (also mentions C. wymani).

Edestosaurus tortor, Cope, 1872, Proc. Acad. Nat. Sci. Philadelphia, vol. 23, p. 298.

Clidastes vymanii, Cope, 1872, Proc. Amer. Phil. Soc. vol. 12, p. 170.

Edestosaurus stenops, Cope, 1872, Proc. Amer. Phil. Soc., vol. 12, p. 268.

Clidastes propython, Cope, 1872, Proc. Acad. Nat. Sci. Philadelphia, vol. 24, p. 141.

Clidastes cineriarum, Cope, 1872, U.S. Geol. Survey of Montana and portions of adjacent territories, 5th ann. rept. F. V. Hayden, U. S. Geologist, Washington, p. 330 (also lists C. pumilus, C. vymanii).

Edestosaurus rex, Marsh, 1872, Amer. Jour. Sci., ser. 3, vol. 3, art. 18, p. 463.

Edestosaurus rex, Marsh, 1872, Amer. Nat., vol. 6, no. 8, p. 497.

"mosasauroid," Leidy, 1873, U.S. Geol. Survey Terr. Rept. 1, pl. 35, fig. 14.

Clidastes cineriarum, Cope, 1874, U.S. Geol. Survey Terr. Rept. 1, no. 2, p. 33, 34 (also lists *C. tortor*, *C. stenops*, *C. velox* and other synonyms).

Clidastes cineriarum, Cope, 1875, U.S. Geol. Survey Terr. Rept. 2, p. 137, 266, pl. 21, figs. ?14-17.

Clidastes stenops, Cope, 1875, U.S. Geol. Survey Terr. Rept. 2, p. 133, 266, pl. 14, fig. 2, pl. 17, figs. 7-8, pl. 18, figs. 1-5, pl. 35, fig. 4, pl. 37, fig. 3, pl. 38, fig. 3.

Clidastes tortor, Cope, 1875, U.S. Geol. Survey Terr. Rept. 2, p. 131, 265, pl. 14, fig. 1, pl. 16, figs. 1, 6, pl. 17, fig. 1, pl. 18, figs. 1-6, pl. 36, fig. 3, pl. 37, fig. 2, pl. 38, fig. 2.

Clidastes propython, Cope, 1875, U.S. Geol. Survey Terr. Rept. 1, p. 265, pl. 37, fig. 1.

Clidastes tortor, Cope, 1877, U.S. Geol. Geog. Survey Bull. 3, no. 3, p. 583.

Clidastes propython, Owen, 1877, Quart. Jour. Geol. Soc. London, vol. 33, no. 4, p. 709, fig. 23.

Clidastes propython, Cope, 1878, U.S. Geol. Geog. Survey Bull. 4, p. 303.

Clidastes propython, Cope, 1891, Syllabus of lectures on geology and paleontology, Philadelphia, fig. 26.

Clidastes velox, Williston, 1891, Science, vol. 18, p. 345.

Clidastes westii, Williston and Case, 1892, Kansas Univ. Quart., vol. 1, p. 29.

Clidastes westii, Williston, 1893, Trans. Kansas Acad. Sci., vol. 13, p. 111.

<u>Clidastes</u> <u>medius</u>, Merriam, 1894, Palaeontographica, vol. 41, p. 34.

<u>Edestosaurus</u> <u>rex</u>, Marsh, 1897, U.S. Geol. Survey Monog. 27, p. 527.

<u>Clidastes</u> <u>velox</u>, Williston, 1897, Kansas Univ. Quart., vol. 6, no. 3, p. 110.

<u>Clidastes</u> <u>propython</u>, Cope, 1898, Syllabus of lectures on geology and paleontology, Philadelphia, fig. 27.

<u>Clidastes</u> <u>cineriarum</u>, Williston, 1898, Univ. Geol. Survey Kansas, vol. 4, p. 29.

<u>Clidastes</u> <u>tortor</u>, Williston, 1898, Univ. Geol. Survey Kansas, vol. 4, p. 100-234, 197-205, pl. 23, pl. 60, fig. 5, pl. 61, fig. 4, pl. 64, fig. 1, pl. 37, pl. 38.

<u>Clidastes</u> <u>velox</u>, Williston, 1898, Univ. Geol. Survey Kansas, p. 100-234, 197-205, pl. 24, fig. 7.

<u>Clidastes</u> <u>westii</u>, Williston, 1898, Univ. Geol. Survey Kansas, vol. 4, p. 100-234, 197-205, pl. 23, pl. 27, fig. 1, pl. 35, pl. 36, pl. 53, pl. 60, fig. 4.

<u>Clidastes</u>, Williston, 1898, Univ. Geol. Survey Kansas, vol. 4, pl. 28, figs. 1-4, pl. 39, upper fig.

<u>Clidastes</u> <u>tortor</u>, Holland, 1908, Ann. Carnegie Mus., vol. 4, p. 162-163, 167, fig. 5.

<u>Clidastes</u> <u>westi</u>, Sternberg, 1909, Life of a Fossil Hunter, New York, p. 135.

<u>Clidastes</u> <u>tortor</u>, Sternberg, 1909, Life of a Fossil Hunter, New York, fig. 6.

Clidastes, Williston, 1914, Water reptiles of the past and present, Chicago, fig. 71.

Clidastes, Sternberg, 1917, Hunting dinosaurs in the badlands of the Red Deer River, Alberta, Canada, Lawrence, Kansas, p. 21.

Clidastes westii, Camp, 1923, Bull. Amer. Mus. Nat. Hist., vol. 48, fig. 22.

Clidastes, Williston, 1925, The osteology of the reptiles, Cambridge, figs. 58, 158b.

Clidastes propython, Chaffee, 1939, Acad. Nat. Sci. Philadelphia Notulae Nat., no. 37, fig. 1.

Clidastes velox, Lane, 1947, Trans. Kansas Acad. Sci., vol. 49, pt. 3, p. 318, 319, fig. 7.

Clidastes propython, Zangerl, 1948, Chicago Nat. Hist. Mus. Fieldiana: Geol. Mem. 3, pt. 1, pl. 15.

Clidastes tortor, Gregory, 1951, Evolution, vol. 5, no. 4, fig. 4b.

Clidastes tortor, Gregory, 1952, Condor, vol. 54, no. 2, fig. 6.

Clidastes tortor, McDowell and Bogert, 1954, Bull. Amer. Mus. Nat. Hist., vol. 105, no. 1, fig. 32.

Clidastes, Romer, 1956, Osteology of the reptiles, Chicago, figs. 108c, 145b.

Clidastes tortor, Sevon, 1958, Proc. South Dakota Acad. Sci., vol. 36, p. 145-146, fig. 1.

Clidastes tortor, Edmund, 1960, Roy. Ontario Mus. Life Sci. Div. Contrib. 52, p. 89, fig. 25f.

Clidastes propython, Russell, 1967, Yale Peabody Mus. Nat. Hist. Bull. 23, p. 128-131, text-figs. 2B, 4B, 12-14, 22B, 39, 46B, 74, 75A, 76A.

?Clidastes velox, Callison, 1967, Kansas Univ. Paleont. Contrib., Paper 26, figs. 1, 9, 10.

Clidastes propython, Russell, 1970, Field Mus. Nat. Hist. Fieldiana: Geol. Mem. 3, pt. 7, p. 371-373, fig. 166B.

Type. Academy of Natural Science of Philadelphia 10193, Rotten Limestone, near Uniontown, Alabama (Russell, 1967, p. 128).

Referred specimens. *ET 4295, *ET 4278, *ET 4298, *ET 4292, *ET 4285, *ET 4289, *ET 4293, *ET 4281, *ET 4286, *ET 4290, *ET 4287, all from ET Locality 36; the latter three specimens may be from the same individual. *TMM 30962-8, *SMU 62504, the latter from "the upper Austin."

Distribution. Roxton Limestone; other specimens from Selma Group, Alabama, Smoky Hill Marl Member, Niobrara Formation, and Lower Pierre Formation, Kansas and South Dakota.

Description. Specimens apparently representing three individuals were collected from the Roxton Limestone at ET Locality 36, from the phosphatic cast bed in the upper part of the unit. *SMU 62504 may also have been collected from this locality (Mr. Gerard Case, personal communication, 1971), and may be part of the specimen with field label L-85. *TMM 30962-8 was taken from Locality TMM 30962.

All specimens consist of various skull and vertebral elements. *ET 4295, *TMM 30962-8 and *SMU 62504 consist of partial skulls, and along with *ET 4295, have nearly complete quadrates on which the specific identification is based. *ET 4295 has much of the mandible, partial pterygoid, coronoids, and a number of cervical, dorsal and caudal vertebrae. The vertebrae numbered *ET 4278 may belong to the same individual as *ET 4298 and the other ET numbers listed above.

Skull elements show several characters of the genus as listed by Russell (1967, p. 124-126): 1.) premaxilla (*ET 4295) with small pointed rostrum anterior to the teeth; 2.) no ventroposterior process on jugal; 3.) medial wing on squamosal (?); 4.) quadrate with thick tympanic ala, moderately large suprastapedial process and elliptical stapedial pit; 5.) coronoid with large posterior process at a high angle to the anterior portion; 6.) mandibular teeth compressed, bicarinate, smooth; 7.) heavy dorsal crest on retroarticular process; 8.) vertebrae with circular articular surfaces and well developed zygosphenes and zygantra.

Specific characters observed on the specimens were: 1.) premaxilla V-shaped in horizontal cross-section; 2.) premaxilla with posterior teeth exposed on the maxillary sutural face; 3.) infrastapedial process on quadrate (Russell, 1967, fig. 76A); 4.) 18 teeth present on dentary (Russell, 1967, p. 130). These characters become important when it is noted that a specimen from the Selma Group shows characters that are transitional between C. propython and C. liodontus (Thurmond, personal communication, 1971).

The atlas--neural arch complex is as shown by Russell (1967, p. 125, fig. 39). Caudal vertebrae show the attached hemal arches mentioned by Russell (1967, p. 81), and several subtriangular pygal vertebrae were observed among the specimens.

Discussion. Preservation of the specimens is good, but some of the bones were predepositionally eroded and have matrix-filled depressions and cavities. Some of the weathering may have resulted from the current weathering cycle. Several of the bones from ET Locality 36 were encrusted with oysters, marine worms and other organisms.

Clidastes sp.

Distribution. Roxton Limestone, Ozan Marl; specimens from other institutions include those marked "Upper Austin," Ozan condensed zone, and uppermost Taylor Formation.

Referred specimens. ET 1803, ET 1796, ET 4349, ET 4354, ET 4355, ET 4328, *ET 4394, *SMU 62098, *TMM 40890, *USNM 22964.

Description. *ET 4394 was collected from the cast bed in the upper part of the Roxton Limestone at ET Locality 36; ET 1796 and ET 4355 weathered from the Ozan condensed zone, and all other ET specimens appear to be from the normal gray Ozan Marl. *SMU 62098 and *USNM 22964 were discussed by Thurmond (1969, p. 70) who noted that the former was collected from the "Upper Austin." The matrix is quite similar to the Roxton Limestone. The latter specimen is stored unprepared, and is probably from the Ozan condensed zone.

Only *SMU 62098 includes skull material, with partial maxilla, dentary and frontal. One dorsal vertebra, as well as several others, was assigned to this genus by comparison with other specimens or with illustrations in Cope (1875). The vertebrae are dorsals with prominent zygosphenes and zygantra, or caudals with fused hemal arches.

Genus Mosasaurus Conybeare 1822

Mosasaurus conodon (Cope 1881) Russell 1967

Plate 1, fig. 10

Clidastes conodon Cope, 1881, Amer. Nat., vol. 15, p. 588.

?Mosasaurus lemonnieri, Dollo, 1889, Soc. Belge Geol. Mem. 3, p. 278, pl. 9, fig. 2, pl. 10, figs. 4, 5.

Mosasaurus poultneyi, Martin 1953, A South Dakota mosasaur, unpub. thesis, South Dakota School of Mines and Technology, 65 pp., p. 1-62, numerous figs.

Clidastes conodon, Miller, 1955, Jour. Paleont., vol. 29, no. 5, p. 909.

Mosasaurus conodon, Russell, 1967, Yale Peabody Mus. Nat. Hist. Bull. 23, p. 132-135, text-figs, 46A, 47B, 49A, 51, 61, 77, 78.

Type. AMNH 1380, from Freehold, Monmouth County, New Jersey (Russell, 1967, p. 132).

Distribution. Ozan Marl, Pecan Gap Chalk or Marlbrook Marl; other specimens are from the Marlbrook Marl, Arkansas, Pierre Formation, South Dakota, Navesink and younger Cretaceous, New Jersey, and ?Craie brune phosphatée de Ciply, Belgium

Referred specimens. ET 4314, ET 4353, ET 4307, ET 4308, *USNM 11904.

Description. Of the above specimens, *USNM 11904 and ET 4308 may be from either Pecan Gap Chalk or Marlbrook Marl; the remainder are weathered from the Ozan Marl.

The most complete specimen is the group of vertebrae and limb bones, *USNM 11904. Martin's specimen shows the characteristic fused hemal arches and a pear-shaped outline of the articular surfaces of the pygal and anterior caudal vertebrae (Martin, 1953, p. 21, 22). The four isolated caudal vertebrae listed above also show these characters, and were therefore assigned to this species.

Mosasaurus missouriensis (Harlan 1834) Leidy 1865

Ichthyosaurus missouriensis Harlan, 1834, Brit. Assoc. Adv. Sci. Rept. 3rd mtg. Cambridge, 1833, p. 440.

Ichthyosaurus missouriensis, Harlan, 1834, Trans. Geol. Soc. Pennsylvania, vol. 1, no. 1, p, 80.

Ichthyosaurus missouriensis, Harlan, 1834, Trans. Amer. Phil. Soc., n. s., vol. 4, p. 408.

Ictiosaurus missuriensis, Harlan, 1834, Bull. Soc. Géol. France, premier ser., vol. 4, p. 124.

Ichthyosaurus missouriensis, Harlan, 1835, in: Harlan, Richard, Medical and physical researches, Philadelphia, p. 284, p. 348, pl., figs. 1-6.

Batrachiosaurus missouriensis, Harlan 1839, Proc. Geol. Soc. London, vol. 3, p. 24.

Batrachotherium missouriensis, Harlan, 1839, Bull. Soc. Géol. France, ser. 1, vol. 10, p. 89.

Batrachiosaurus missouriensis, Harlan, 1842, Amer. Jour. Sci., vol. 43, no. 1, p. 142.

Mosasaurus maximilliani, Goldfuss, 1845, Nova Acta Caes. Leopoldino-Carolinae Germanicae Nat. Curiosorum, vol. 21, p. 179, pls. 6-8.

Mosasaurus neovidii, Meyer, 1845, Neues Jahrb. Min. Geognosie Geol., 1845, p. 312.

Mosasaurus maximiliani, (?) Goldfuss, 1847, Neues Jahrb. (Min.) Geognosie Geol., 1847, p. 123.

Mosasaurus Maximiliani, Owen, 1849, Quart. Jour. Geol. Soc. London, vol. 5, p. 382.

Mosasaurus maximiliani, Gibbes, 1850, Amer. Assoc. Adv. Sci. Proc. second mtg., Cambridge, p. 77.

Mosasaurus maximilliani, Gibbes, 1851, Smithsonian Inst. Contrib. Knowl., vol. 2, no. 5, p. 8.

Mosasaurus maximiliani, Pictet, 1853, Traité de paléontologie, 2nd ed., Paris, p. 505.

Mosasaurus missouriensis, Hayden, 1857, Proc. Acad. Nat. Sci. Philadelphia, vol. 9, p. 113.

Mosasaurus missouriensis, Meek and Hayden, 1857, Proc. Acad. Nat. Sci. Philadelphia, vol. 9, p. 117-119.

Mososaurus missouriensis, Leidy, 1858, Proc. Acad. Nat. Sci. Philadelphia, vol. 9, p. 90.

Drepanodon impar, Leidy, 1858, North Carolina Geol. Surv. Rept., Raleigh, p. 11 (bibliography shows p. 224, figs. 45, 46).

Mossosaurus maximilliani, Emmons, 1858, North Carolina Geol. Surv. Rept., Raleigh, p. 218.

Mosasaurus maximiliani, Leidy, 1860, Proc. Acad. Nat. Sci. Philadelphia, vol. 11, p. 92.

Mosasaurus missouriensis, Leidy, 1865, Smithsonian Inst. Contrib. Knowl., vol. 14, no. 6, p. 30, 33, 117.

Mosasaurus, Leidy, 1865, Smithsonian Inst. Ann. Rept. Board Regents for 1864, p. 69.

Mosasaurus missuriensis, Cope, 1869, Proc. Boston Soc. Nat. Hist., vol. 12, p. 263.

Mosasaurus missuriensis, Cope, 1869, Amer. Nat., vol. 3, p. 86.

Mosasaurus maximus, Cope, 1869-1870, Trans. Amer. Phil. Soc., n. x., pt. 2, (1870), p. 189.

Mosasaurus missuriensis, Cope 1869-1870, as above, p. 195.

Mosasaurus missuriensis Cope, 1871, Proc. Amer. Phil. Soc., vol. 11, p. 571.

Mosasaurus missuriensis, Cope, 1871, U.S. Geol. Survey of Wyoming and portions of contiguous territories, 2nd (4th) ann. rept. F. V. Hayden, U. S. Geologist, Washington, p. 386, 401.

Mosasaurus missuriensis, Cope, 1875, U.S. Geol. Survey Terr. Rept. 2, p. 269.

Mosasaurus, Cope, 1877, U.S. Geol. Geog. Survey, Bull. 3, no. 3, p. 567.

Mosasaurus maximilliani, Owen, 1877, Quart. Jour. Geol. Soc. London, vol. 33, no. 4, p. 683, 696, 701, figs. 5, 6, 16, 18.

<u>Mosasaurus</u>, Cope, 1879, U.S. Geol. Geog. Survey Bull. 5, p. 36.

<u>Pterycollosaurus</u> <u>maximiliani</u>, Dollo, 1882, Bull. Mus. Hist. Nat. Belgique, vol. 1, p. 61.

<u>Mosasaurus</u> <u>maximiliani</u>, Baur, 1892, Jour. Morph., vol. 7, no. 1, p. 9.

<u>Mosasaurus</u> <u>maximiliani</u>, Merriam, 1894, Palaeontographica, vol. 41, p. 5.

<u>Mosasaurus</u> <u>horridus</u>, Williston, 1895, Kansas Univ. Quart., vol. 3, p. 166, pls. 14-16.

<u>Mosasaurus</u> <u>horridus</u>, Williston, 1897, Kansas Univ. Quart., vol. 6, p. 95.

<u>Mosasaurus</u> <u>horridus</u>, Williston, 1898, Univ. Geol. Survey Kansas, vol. 4, p. 103-154, pls. 19-21, 32.

<u>Mosasaurus</u> <u>horridus</u>, Osburn, 1906, Ann. New York Acad. Sci., vol. 16, no. 3, pl. 8, fig. 27.

<u>Mosasaurus</u> <u>maximilliani</u>, Williston, 1914, Water reptiles of the past and present, Chicago, p. 151.

<u>Mosasaurus</u>, Williston, 1925, The osteology of reptiles, Cambridge, p. 273.

<u>Mosasaurus</u> <u>missouriensis</u>, Camp, 1942, Univ. Calif. Mem. 13, p. 45, 46.

<u>Mosasaurus</u> <u>missouriensis</u>, Simpson, 1942, Proc. Amer. Phil. Soc., vol. 86, p. 162, 172.

<u>Mosasaurus</u> <u>horridus</u>, Kauffman and Kesling, 1960, Mus. Paleont. Univ. Michigan Contrib., vol. 15, no. 3, p. 230, 231, figs. 1, 6a, tables 4-6.

Mosasaurus horridus, Schmidt, 1961, Natur und Volk, vol. 91, no. 8, fig. 7.

Mosasaurus missouriensis, Russell, 1967, Yale Univ. Peabody Mus. Nat. Hist. Bull. 23, p. 126-138.

Mosasaurus ?missouriensis, Thurmond, 1969, Texas Jour. Sci., vol. 21, no. 1, p. 70, 71.

Type. Number Goldfuss 1327, at Geol.-Paläont. Institut der Rhein. Friedrich-Wilhelm-Universität, "Big Bend region" of the Missouri River, between Fort Lookout and Fort Pierre (Russell, 1967, p. 137).

Distribution. Wolfe City Formation; other specimens from the Pierre Formation, South Dakota, and Bearpaw Formation, Montana.

Referred specimens. UTA uncatalogued specimen.

Description. A partial skull, mandible fragments, and a few vertebrae were described by Thurmond (1969, p. 71) and provisionally assigned to this species; little can be added to his description because of the fragmentary nature of the specimen.

Tribe Glibidensini (Dollo 1924) Russell 1967

Genus Globidens Gilmore 1912

Globidens alabamaensis Gilmore, 1912

Globidens alabamaensis Gilmore, 1912, Proc. U. S. Nat. Mus., vol. 42, p. 479, pls. 39-40, figs. 1-3.

Globidens alabamaensis, Williston, 1914, Water reptiles of the past and present, Chicago, p. 167, fig. 80.

Globidens alabamaensis, Gilmore,1921, Sci. Amer., vol. 124, p. 273, 280, fig.

Globidens alabamaensis, Abel, 1922, Lebensbilder aus der Tierwelt der Vorzeit, fig. 266.

Globidens, Camp, 1923, Amer. Mus. Nat. Hist. Bull. 48, p. 323.

Globidens alabamaensis, Abel, 1924, Die Eroberungszüge der Wirbeltiere in die Meere der Vorzeit, fig. 37.

Globidens alabamaensis, Dollo, 1924, Arch. Biol., vol. 34, p. 170, figs. 1, 5.

Globidens alabamaensis, Gilmore, 1927, Science, n. s., vol. 66, p. 452.

Globidens alabamaensis, Nopcsa, 1928, Palaeobiologica, vol. 1, p. 177.

Globidens alabamaensis, Zangerl, 1948, Chicago Nat. Hist. Mus. Fieldiana: Geol. Mem. 3, pt. 1, p. 15.

Globidens, McDowell and Bogert, 1954, Bull. Amer. Mus. Nat. Hist., vol. 105, no. 1, p. 106, 107, 129, 132.

Globidens, Romer, 1956, Osteology of the reptiles, p. 562.

Globidens alabamaensis, Edmund, 1960, Roy. Ontario Mus. Life Sci. Div. Contrib. 52, p. 90, fig. 25c.

Globidens, Kauffman and Kesling, 1960, Mus. Paleont. Univ. Michigan Contrib. 15, No. 9, p. 224, table 3.

Globidens alabamaensis, Russell, 1967, Yale Univ. Peabody Mus. Nat. Hist. Bull. 23, p. 144-145, table 1, charts 1-5.

Globidens alabamaensis, Thurmond, 1969, Texas Jour. Sci., vol. 21, no. 1, p. 71-72.

Globidens alabamaensis, Russell, 1970, Chicago Mus. Nat. Hist. Fieldiana: Geol. Mem. 3, pt. 7, p. 373.

Type. USNM 6527, from the Selma Chalk of Bogue Chitto Prairies west of Hamburg. . . Perry and Dallas County, Alabama (Gilmore, 1912, p. 479).

Distribution. Ozan Marl, and Ozan condensed zone; other specimens from Selma Group, Alabama and Mississippi, Pierre Formation, South Dakota.

Referred specimens. *ET 4304, cast of uncatalogued specimen, SMU 62102, SMU 62103, SMU 62105.

Description. Only two specimens were available for study, *ET 4304, a partial right maxilla with two teeth and two partial alveoli, and a portion of a right dentary with seven teeth and alveoli. The latter specimen is owned by Dr. Paul Evan Roberts, East Texas State University Biology Department, who allowed a cast to be made. One other specimen, a partial maxilla with several teeth was collected from the Ozan Marl near Ben Franklin, Delta County, and was shown to the author by the collector. Isolated teeth (the SMU specimens) were collected from float material and appear to have weathered from the Ozan Marl. The USNM specimen listed by Russell (1967, p. 144) is from the Marshalltown Formation, in Delaware, not Texas (Dr. John C. Kraft, University of Delaware, letter of September 20, 1971).

Both available specimens show the characteristic almost circular teeth. *ET 4303 has teeth that are somewhat "shouldered" and slightly squared, resembling in outline those of Globidens fraasi as illustrated by Price (1957, pl. 1, figs, 7, 9, pl. 2, figs. 1, 3). This may be due to the youth of the specimen. Cross-section views are typically rounded, nearly circular in shape, with unworn crowns. The portion of the preserved right maxilla has two teeth, both of which show pits for successional teeth. The adjoining alveoli are both broken. Thurmond (1969, p. 72) gives measurements for the SMU specimens, and suggests that the differences in the teeth (compressed shape, prominent carinae) indicate a juvenile animal. Pterygoid teeth of Globidens are not known, and one complete skull at the Chicago Natural History Museum has fragmented teeth unsuitable for study (Dr. Rainer Zangerl, letter of June 10, 1971).

Discussion. *ET 4303 from the Ozan condensed zone shows the same pinkish weathering patina as the uncatalogued Roberts specimen. The latter was collected from float material in the North Sulphur River channel about two miles north of Cooper, Delta County. The maxilla mentioned above and the SMU specimens appear to have weathered from normal Ozan Marl.

Subfamily Plioplatecarpinae (Dollo 1884) Williston 1897

Tribe Plioplatecarpini (Dollo 1884) Russell 1967

Genus Platecarpus Cope 1869

Platecarpus coryphaeus (Cope 1872) Cope 1874

Plate 1, fig. 11

Holcodus coryphaeus Cope, 1872, Proc. Amer. Phil. Soc., vol. 12, p. 269.

Lestosaurus gracilis, Marsh, 1872, Amer. Jour. Sci., ser. 3, vol. 3, no. 18, p. 460.

Lestosaurus coryphaeus, Leidy, 1873, U. S. Geol. Survey Terr. Rept. 1, p. 276, 344.

Platecarpus coryphaeus, Cope, 1874, U. S. Geol. Survey Terr. Bull. 1, pt. 2, p. 35.

Platecarpus coryphaeus, Cope, 1875, U. S. Geol. Survey Terr. Rept. 2, p. 142, 267, pl. 15, fig. 1, pl. 16, fig. 3, pl. 17, fig. 6, pl. 20, figs. 4-7, pl. 21, figs. 1-2, pl. 36, fig. 6, pl. 37, fig. 9, pl. 55, fig. 3.

Platecarpus gracilis Cope, 1875, U. S. Geol. Survey Terr. Rept. 2, p. 268.

Platecarpus coryphaeus Cope, 1877, U. S. Geol. Geog. Survey Bull. 3, no. 3, p. 584.

Holosaurus abruptus Marsh, 1880, Amer. Jour. Sci., ser. 3, vol. 19, no. 109, p. 87.

????? Owen, 1880, Ann. Mag. Nat. Hist., ser. 5, vol. 5, p. 180.

????? Hoffman, 1890, in: Bronn, H. G., Klassen und Ordnungen des Thierreichs, vol. 6, no. 3, p. 1322.

Platecarpus coryphaeus Merriam, 1894, Palaeontographica, vol. 41, p. 29-30, pl. 1, figs. 1-2.

Holosaurus abruptus Marsh, 1897, U. S. Geol. Survey Mon. 27, p. 527.

Platecarpus coryphaeus Williston, 1898, Univ. Geol. Survey Kansas, vol. 4, p. 186.

Lestosaurus coryphaeus Merrill, 1907, Bull. U. S. Nat. Mus., vol. 53, no. 2, p. 73.

Platecarpus coryphaeus Sternberg, 1909, The life of a fossil hunter, New York, fig. 10.

Platecarpus coryphaeus Drevermann, 1914, Ber. Senckenbergische Naturf. Gesell., vol. 45, fig. 8.

Platecarpus coryphaeus Abel, 1922, Lebensbilder aus der Tierwelt der Vorzeit, fig. 265.

Platecarpus, Gilmore, 1928, Natl. Acad. Sci. Mem. 22, 3rd mem., p. 87.

Platecarpus coryphaeus, Lane, 1947, Trans. Kansas Acad. Sci., vol. 49, pt. 3, p. 316-317, fig. 6.

Platecarpus, McDowell and Bogert, 1954, Bull. Amer. Mus. Nat. Hist., vol. 105, no. 1, p. 132.

Platecarpus coryphaeus, Edmund, 1960, Roy. Ontario Mus. Life Sci. Div. Contrib. 52, p. 89.

Platecarpus coryphaeus, Russell, 1967, Yale Univ. Peabody Mus. Nat. Hist. Bull. 23, p. 153-155, text-fig. 85A.

Platecarpus coryphaeus, Thurmond, 1969, Texas Jour. Sci., vol. 21, no. 1, p. 72-73.

Type. American Museum of Natural History 1566, from Fossil Spring Canyon, from the "yellow chalk."

Distribution. Ozan Marl; other specimens from the Niobrara Formation, and lower Austin Group.

Referred specimens. ET 4344, perhaps also ET 4312, ET 4309, ET 4310.

Description. Only the anterior end of a right dentary (ET 4344) bearing two teeth and one partial alveolus was collected from float material near ET Locality 39. Matrix on the specimen appears to be Ozan Marl. Collected nearby a few minutes later, the other specimens listed may also be part of the same individual. The specimens include partial mandible, with partial surangular-articular and partial pterygoid.

Russell (1967, p. 153, 155) found that *P. coryphaeus* was quite similar to *P. ictericus* and could be separated from the latter by the character of the maxillary-premaxillary suture, and the exits for the mandibular ramus of the fifth nerve, which in *P. coryphaeus* separate into two diverging lines at the anterior end of the dentary. (The two rows are parallel in *P. ictericus*). This character is shown on the anterior dentary from the Ozan Marl.

Platecarpus cf. *P. somenensis* Thevenin 1896

Platecarpus somenensis Thevenin, 1896, Bull. Soc. Géol. France, ser. 3, vol. 24, p. 907-910, pl. xxx.

Platecarpus cf. *P. somenensis*, Persson, 1959, Arkiv för Mineral. Geol., Bd. 2, no. 35, p. 463-464, pl. 15, figs. 3a-c.

Platecarpus somenensis, Persson, 1963, Publ. Inst. Min. Pal. Quat. Geol., Univ. Lund, no. 118, p. 6.

Platecarpus cf. *P. somenensis*, Russell, 1967, Yale Univ. Peabody Mus. Nat. Hist. Bull. 23, p. 155-156.

Platecarpus cf. *P.* *somenensis*, Thurmond, 1969, Texas Jour. Sci., vol. 21, no. 1, p. 75-76.

Type. Incomplete skull in National Museum of Natural History in Paris (Persson, 1959, p. 463).

Distribution. Ozan condensed zone; other American specimens from Pierre Formation, South Dakota.

Referred specimens. *SMU 61617.

Description. The specimen described by Thurmond was collected from the Ozan condensed zone at SMU Bardwell 2 locality.

Both Russell (1967, p. 155) and Thurmond (1969, p. 75) recognize the difficulty in separating this species from other *Platecarpus* species, partly because of the nature of the specimens (Russell). Thurmond (1969, p. 76) indicates that the smallest described dentary of *P.* *somenensis* is about 20 percent larger than the largest of *P.* *ictericus* for which Russell gives measurements. The SMU specimen consists of partial mandible and skull fragments. Thurmond refers to the large size of the dentaries as characteristic, and Russell's other characters of heavy, bicarinate teeth and parallel rows for exists of the fifth nerve seem to be the only other observable ones, for the specimen does not include jugals or endocranial parts.

Platecarpus sp.

Distribution. Roxton Limestone, Ozan Marl, Ozan condensed zone.

Referred specimens. *ET 4288, ET 4306, ET 4311, ET 4334, ET 4343.

Description. The specimens include partial pterygoids and vertebrae that can be assigned to the genus because of general shape and size. *ET 4288 is a partial pterygoid with the general shape of those illustrated by Cope (1875, pl. 36). This was collected from ET Locality 36, from the bast bed in the upper part of the Roxton Limestone. Only two teeth with the crowns broken off are present. Other pterygoid fragments are ET 4306, from float material near ET Locality 41, from the Ozan condensed zone, and showing usual pinkish weathering patina, and ET 4343 from the normal Ozan Marl. Both specimens are placed here because of their general shape.

The other specimens are vertebrae with rather rounded outlines but attached hemal arches, which Thurmond (personal communication, 1971) suggests may be present in this genus because of pathological or gerontological fusion.

?Subfamily Plioplatecarpinae incertae sedis

Genus Halisaurus Marsh 1869

Halisaurus sp.

Plate 1, figs. 12, 13

Distribution. Ozan Marl, Ozan condensed zone.

Referred specimens. ET 4339, ET 4369, ET 4370, ET 4371, ET 4372.

Description. None of the above specimens was collected in place but weathering characteristics indicate that most of them are from the Ozan Marl. ET 4372 shows reddish weathering marks that indicate that it possibly came from the Ozan condensed zone. ET 4371 was donated without reference to locality or horizon.

The specimens include one posterior cervical, two anterior cervical and two dorsal centra. All have the very wide, nearly rectangular articular faces and centrally located synapophyses mentioned by Russell (1967, p. 168). The anteroventral extensions of the synapophyses are broken on both cervicals, but may have extended below the centrum. The anterior zygapophysis is worn on ET 4370 but was stout, as described by Russell. Russell (1967, p. 168) quotes Williston and Dollo as stating that the hypapophyses were fused to the cervical centra. The posterior cervicals bear worn peduncles, but ET 4371 has a large oval (laterally compressed) facet for articulation on a short and slightly posteriorly inclined peduncle. The outline of the latter specimen in anterior view resembles a drawing of a posterior cervical centrum of H. sternbergi, from the Selma Group (Russell, 1970, fig. 164B). He (1970, p. 371) remarks that the zygosphenes and zygantra are as well developed as those of Platecarpus but none were seen on ET 4370 (an anterior dorsal).

Subfamily Tylosaurinae (Williston 1895) Williston 1897

Genus Tylosaurus Marsh 1872

Tylosaurus proriger (Cope 1869) Marsh 1872

Plate 1, fig. 14

<u>Macrosaurus</u> <u>proriger</u> Cope, 1869, Proc. Acad. Nat. Sci. Philadelphia, vol. 21, p. 123.

<u>Macrosaurus</u> <u>piriger</u>, Cope, 1869, Nature, vol. 1, p. 122.

<u>Liodon</u> <u>proriger</u>, Cope 1869-1870, Trans. Amer. Phil. Soc., n. s., pt. 2, p. 201.

<u>Liodon</u> <u>proriger</u>, Cope, 1871,U. S. Geol. Survey of Wyoming and portions of contiguous territories, 2nd (4th) ann. rept. F. V. Hayden, U. S.Geologist, Washington, p. 401.

<u>Liodon</u> <u>proriger</u>, Cope, 1872, Proc. Acad. Nat. Sci. Philadelphia, vol. 23, p. 297.

<u>Liodon</u> <u>proriger</u>, Cope, 1872,. Proc. Amer. Phil. Soc., vol. 12, p. 279-280.

<u>Liodon</u> <u>proriger</u>, Cope, 1872, Proc. Acad. Nat. Sci. Philadelphia, vol. 24, p. 143.

<u>Liodon</u> <u>proriger</u>, Cope, 1872, U. S. Geol. Survey of Montana and portions of adjacent territories, 5th ann. rept. F. V. Hayden, U. S. Geologist, Washington, p. 333.

<u>Rhinosaurus</u> <u>proriger</u>, Marsh 1872, Amer. Jour. Sci., ser. 3, vol. 3, no. 18, p. 19.

<u>Rhinosaurus</u> <u>micromus</u>, Marsh, 1872, Amer. Jour. Sco., ser. 3, vol. 3, no. 18, p. 461, pl. 13, figs. 1a-c.

<u>Tylosaurus</u> <u>proriger</u>, Marsh, 1872, Amer. Jour. Sci., ser. 3, vol. 4, no. 20, p. 147.

<u>Rhinosaurus</u> <u>micromus</u>, Marsh, 1872, Amer. Nat., vol. 6, no. 8, p. 497.

<u>Tylosaurus proriger</u>, Leidy, 1873, U. S. Geol. Survey Terr. Rept. 1, p. 274, 343-344, pl. 35, figs. 12-13, pl. 36, fig. 3.

<u>Rhamphosaurus nepaeolicus</u>, Cope, 1874, U. S. Geol. Survey Terr. Bull. 1, no. 2, p. 37-38 (non Cope, 1872, p. 141).

<u>Liodon proriger</u>, Cope, 1875, U. S. Geol. Survey Terr. Rept. 2, p. 161, 271, fig. 7, pl. 28, figs. 8, 9, pl. 29, pl. 30, figs. 10-14, pl. 36, fig. 2, pl. 37, fig. 6.

<u>Liodon dyspelor</u>, Cope, 1875, U. S. Geol. Survey Terr. Rept. 2, p. 167, 271, fig. 7, pl. 28, figs. 1-7, pl. 29, pl. 30, figs. 1-9, pls. 31-33, pl. 36, fig. 1, pl. 37, fig. 5.

<u>Liodon dyspelor</u>, Snow, 1878, Trans. Kansas Acad. Sci., vol. 6, p. 54, 57, figs.

<u>Liodon dyspelor</u>, Cope, 1879, Amer. Nat., vol. 13, p. 132.

<u>Tylosaurus micromus</u>, Marsh, 1880, Amer. Jour. Sci., ser. 3, vol. 19, no. 109, p. 85, fig. 1.

<u>Tylosaurus proriger</u>, Merriam, 1894, Palaeontographica, vol. 41, p. 23, 24, pl. 1, fig. 3, pl. 2, pl. 3, figs. 1-2, pl. 4, fig. 7.

<u>Tylosaurus proriger</u>, Williston, 1895, Kansas Univ. Quart., vol. 3, no. 3, pl. 17, fig. 2.

<u>Tylosaurus proriger</u>, Williston, 1897, Kansas Univ. Quart., vol. 6, p. 102, pls. 9-12.

<u>Tylosaurus proriger</u>, Williston, 1897, Kansas Univ. Quart., vol. 6, no. 3, p. 110, pl. 13, fig. 3.

<u>Tylosaurus proriger</u>, Williston, 1897, Kansas Univ.Quart., vol. 6, no. 4, pl. 20, fig. 1.

Tylosaurus proriger, Williston, 1898, Univ. Geol. Survey Kansas, vol. 4, p. 28.

Tylosaurus proriger, Williston, 1898, Univ. Geol. Survey Kansas, vol. 4, p. 102-134, 173, pls. 16-18, pl. 29, fig. 4, pl. 31, figs. 1-3, pl. 60, figs. 1-2, pl. 72, fig. 3.

Tylosaurus micromus, Williston, 1898, Univ. Geol. Survey Kansas, vol. 4, p. 175.

Tylosaurus dyspelor, Williston, 1898, Univ. Geol. Survey Kansas, vol. 4, pl. 61, figs. 1-2.

Tylosaurus dyspelor, Osborn, 1899, Amer. Mus. Nat. Hist. Mem. 1, no. 4, p. 169, pls. 21-23, figs. 1, 7, 8, 9, 11-14.

Tylosaurus dyspelor, Osborn, 1899, Science, ser. 2, vol. 9, p. 912.

Tylosaurus, Fürbringer, 1900, Jenaischen Zeitschr. Naturwiss., vol. 34, p. 616.

Rhinosaurus micromus, Williston, 1902, Kansas Univ. Sci. Bull., vol. 1, p. 253.

Tylosaurus proriger, Merrill, 1907, Bull. U. S. Natl. Mus., vol. 53, no. 2, p. 80.

Tylosaurus dyspelor, Sternberg, 1909, The life of a fossil hunter, New York, fig. 8.

Tylosaurus proriger, Pompeckj, 1910, Jahresber. Niederächsischen Geol. Ver., vol. 3, p. 137.

Tylosaurus dyspelor, Pompeckj, 1910, Jahresber. Niederächsischen Geol. Ver., vol. 3, p. 137.

Tylosaurus dyspelor, Stromer, 1910, Fortschr. Naturwiss. Forsch. Berlin, vol. 2, pl. 2.

Tylosaurus micromus, Dreverman, 1914, Ber. Senckenbergische Naturf. Gesell., vol. 45, p. 43, fig. 7.

Tylosaurus dyspelor, Lambe, 1914, Geol. Surv. Canada for 1912, Summary Rept., p. 402.

Tylosaurus, Williston, 1914, Water reptiles of the past and present, Chicago, fig. 72c.

Tylosaurus, Sternberg, 1917, Hunting dinosaurs in the bad lands of the Red Deer River, Alberta, Canada, p. 13, fig. 5.

Tylosaurus dyspelor, Féjérváry, 1918, Ann. Natl. Hungarici, vol. 16, fig. 25.

Tylosaurus proriger, Gilmore, 1921, Sci. Amer., vol. 124, p. 273.

Tylosaurus, Williston, 1925, The osteology of the reptiles, Cambridge, p. 273, fig. 5.

Tylosaurus proriger?, Lane, 1947, Trans. Kansas Acad. Sci., vol. 49, pt. 3, p. 313-314, fig. 5.

Tylosaurus, Romer, 1956, Osteology of the reptiles, Chicago, fig. 220.

Tylosaurus proriger, Kauffman and Kesling, 1960, Mus. Paleont. Univ. Michigan Contrib., vol. 15, no. 9, p. 225, 226, 229, fig. 6d.

Tylosaurus proriger, Russell, 1967, Yale Univ. Peabody Mus. Nat. Hist. Bull. 23, p. 173-175, frontispiece, pl. 1, fig. 3, pl. 2, fig. 1, text-figs. 2C, 5A, 24C, 27, 48A, 55, 63, 92, 93B, 94A.

Tylosaurus cf. T. proriger, Thurmond, 1969, Texas Jour. Sci., vol. 21, no. 1, p. 76-78.

Type. Formerly at Harvard University Museum of Comparative Zoology, now lost, but collected from Niobrara Formation in the vicinity of Monument Rocks, Kansas (Russell, 1967, p. 173).

Distribution. Roxton Limestone, Ozan Marl, Ozan condensed zone, Taylor-Navarro contact; other specimens from the Niobrara Formation, Kansas and Colorado, Pierre Formation, Kansas and South Dakota, and Telegraph Creek Formation, Montana.

Referred specimens. *ET 4274, *ET 4276, *ET 4351, *ET 4294, *ET 4282, *ET 4283, *ET 4279, ET 4346, ET 4347, ET 4348, SMB 3225, *DMNH uncatalogued specimen, *TMM 40601, SMU 61635 (=SMB 3225).

Description. Several well-preserved partial skulls include diagnostic elements (quadrate, parietal, pterygoid, coronoid) that allowed assignment to this species. Two specimens, *ET 4274 and *ET 4276, also had partial neurocrania, the latter nearly complete, and a DMNH uncatalogued specimen includes a nearly complete but unprepared neurocranium.

Each of two Ozan Marl localities (ET Locality 52 and 35) produced one partial skull (*ET 4274 and *ET 4276, respectively). Two partial skulls (*ET 4351 and an unprepared specimen) were collected from the upper Roxton Limestone cast bed at ET Locality 43. The other ET specimens collected in situ were taken from the Roxton Limestone upper cast bed at ET Locality 36; at least two individuals were represented, a large specimen over 30 feet in length and a much smaller individual. Both specimens include skull elements, one quadrate and a partial pterygoid. SMB 3225 is a partial skull of a very large individual (over 50 feet in length) collected from a dumpheap at SMU Bardwell Number 1 Locality; SMU 61635 is also part of this individual, and was taken from the same dumpheap (Slaughter, personal communication, 1971). The matrix indicates that these specimens were collected from the Ozan condensed zone, as was *DMNH uncatalogued specimen. The latter is a very large individual (over 60 feet in length), taken from SMU Locality 4. Only two of the ET specimens include associated vertebrae (*ET 4278 and *ET 4351). Other ET specimens were partial pterygoids and quadrates collected from float material.

Russell's (1967, p. 29-40) description of the occipital unit in mosasaurs does not include a detailed account of the dorsal view of the basioccipital-basisphenoid block. *ET 4274 is a partial neurocranium showing this view (see pl. 1, fig. 14). The basioccipital has basal tubera of moderate size, which are posteriorly directed. No large basilar artery foramen is visible and the dorsal surface (floor of the medullary cavity) is deeply grooved. The groove becomes very narrow and sharply V-shaped anteriorly. The posterior half of the cavity is more rounded and has a very narrow crest of bone in the central part. A large (nearly 7 mm. in diameter) rectangular foramen is present at the anterior margin of the bone, at the suture with the basisphenoid. A thin tongue of bone extends forward from the suture to this foramen. The large foramen which may have been the normal exists for the basilar artery (Russell, 1967, fig. 10) were not observed on either specimen (*ET 4274, *ET 4276). The normal exits for the internal carotid artery are present in the floor of the sella turcica, and are separated by a very narrow crest of bone, as shown in the figure. This condition more nearly resembles that of Prognathodon than Platecarpus (Russell, 1967, p. 30). Several small foramina occur in the smooth bone of the medullary cavity.

In ventral view the basioccipital appears slightly triangular with the apex anterior, and the posterior part bearing the occipital condyle and posterolaterally directed basal tubera. The tubera are partially covered by an underlying projection of bone from the basisphenoid. The distal ends of the tubera are roughened and cartilage-capped in life (Russell, 1967, p. 30). The tubera are connected by a rounded ridge of bone, in the center of which is a cluster of six foramina, three on each side of midline, two larger ones centrally located and a third smaller one anterolateral to them (on *ET 4274). Merriam (1894, pl. 4, fig. 1) shows a basioccipital with two such foramina; Russell (1967, p. 171) assigns Merriam's specimen to "Tylosaurus sp.". Anterior to these and in a deep depression, is the large rectangular foramen at the basioccipital-basisphenoid suture.

The basisphenoid is similar to those Russell (1967, p. 30, 31, fig. 10) described; the basipterygoid processes are smaller than those of Platecarpus. The alar processes which cover the vidian canal are broken off of both specimens. The dorsum sellae is rounded and not laterally curved as shown for Platecarpus. Above the dorsum sellae the foramen for the sixth nerve is present (4 mm. long on *ET 4274). The dorsal surface of the bone is deeply V-shaped, a continuation of the deep groove in the basioccipital. The dorsum sellae rises from the anterior end of the groove to a smoothly rounded crest, then curves abruptly ventrally to the sella turcica. In the latter, the central crest of bone separates two small foramina, probably those for the internal carotid branch shown in Russell's figure. The two basilar artery exists on the same figure are not visible on either specimen. The base of the parasphenoid rostrum is halved by the continuation of the crest, which fades out soon on the surface of the parasphenoid.

The parasphenoid of *ET 4276 is broken anteriorly but is apparently short and straight (Russell, 1967, p. 33 suggests that the parasphenoid of Tylosaurus is shorter and narrower than those of other genera). The crest of bone from the sella turcica continues for only a few mm. and then disappears. The parasphenoid is oval in cross-section, and dorsoventrally flattened, being flattest on the ventral side and very slightly convex dorsally.

The prootics are present on *ET 4276 but are somewhat crushed and pyritized, thus obscuring some internal structures.
Both suspensorial rami are missing. Where the sutures can be distinguished they resemble those of Clidastes (Russell, 1967, fig. 13). The foramen for the seventh nerve is visible, as is a portion of the fenestra ovalis (Russell, 1967, fig. 14, 15). The mesial surface is pyritized and the foramina are not visible. Russell (1967, p. 36) refers to a great enlargement of the otosphenoidal ala, but this does not appear much larger on *ET 4276 than on Clidastes.

The opisthotics and exoccipitals are fused as is normal and again are much as described by Russell (1967, p. 37, 38). The paroccipital processes are broken off. The fenestra rotunda is more anteroposteriorly oriented than normal (Russell, 1967, p. 38, fig. 12) and is not parallel the otosphenoidal crest of the prootic. The foramina on the lateral surface are as described by Russell (1967, p. 39, 40). The medial surface is also obscured by pyritization but the three small foramina for the twelfth nerve are visible, and above them the larger opening for the tenth and eleventh nerves. The foramina are much as shown but in this specimen they are not restricted to the anterodorsal quarter of the bone but to the anterior half (Russell, 1967, p. 40).

In *ET 4276 the surface of the supraoccipital is damaged by weathering and pyritization, and the dorsal surface is broken off. None of the foramina are visible but a 35 mm. long sinus may be part of the labyrinth. It is centrally located under the crest of the bone. It begins anteriorly with no visible foramen and expands posteriorly to enter the brain cavity in the medial part of the bone.

*ET 4276 is the most complete skull, having the almost complete neurocranium described above, and pairs of complete or nearly complete pterygoids, ectopterygoids, postorbitofrontals, supratemporals, squamosals, coronoids, quadrates, maxillae and mandibular elements. Only one palatine-vomer and one prefrontal are present. The parietal is nearly complete but only the posterior tip of the premaxilla is present. The frontal, lacrimals and jugals are missing. The same may be true of *ET 4351, still in preparation, which also has associated vertebrae and ribs.

Dentigerous bones were present only with *ET 4276 and *ET 4351. The structure of the mandible is much as shown by Cope (1875, p. 28, fig. 2). The dentary and maxilla each bear 13 teeth. The edges of the teeth are serrate, a feature which may be characteristic of Tylosaurus (John Thurmond, personal communication, 1971). The teeth of *ET 4276 are striated, usually bicarinate (posterior carina sometimes less well developed), and facetted. Serrations occur on both carinae on most teeth, and on some isolated teeth (ET 1717, *ET 4373, *ET 4374). Serrations extend from the base to near the tip of the tooth. Most of the teeth show the flattened labial and U-shaped lingual surfaces present on the teeth of Mosasaurus (Russell, 1967, p. 54, fig. 30). However some of the teeth are nearly circular in cross-section, and are more symmetrical about the carinae. The tips are recurved posterolinguad, or on some, just posteriorly. Three broken and isolated pterygoid teeth are more sharply recurved and more strongly striated than the marginal teeth, and have less sharply defined, non-serrate carinae. The few visible teeth of *ET 4351 agree with this description. Several successional teeth in various stages of development occur in both specimens and appear to follow the sequence described by Russell (1967, p. 55).

Discussion. Only two bones of *ET 4276 have encrusting epifauna: the right pterygoid has a small oyster attached to the dorsal surface, and the left surangular has two small rudistid "spat" fragments attached. These are the only two known encrusted bones from the normal gray Ozan Marl; all other encrusted bones are from the Ozan condensed zone or the Roxton Limestone.

Tylosaurus sp.

Distribution. Roxton Limestone to Marlbrook Marl (?).

Referred specimens. *ET 4350, ET 4325, ET 4329, ET 4324, ET 4367, ET 4341, ET 4395, ET 4345, ET 4352, ET 1717, ET 4315, *ET 4373, *ET 4374, *ET 4275, ET 4357, ET 4358, ET 4359, ET 4360, ET 4361, ET 4362, ET 4363, ET 4364, ET 4365, ET 4368, ET 4356, ET 4389, ET 4390, ET 4391, ET 4392; the following sequence may belong to one individual: ET 4336, ET 4337, ET 4338, ET 4340, ET 4342, ET 4375, ET 4376, ET 4377, ET 4378, ET 4380, ET 4381, ET 4382, ET 4383, ET 4384, ET 4385, ET 4387; ET 4388, SMU 62496, SMU 62505, *TMM 30962-25, *USNM 18496, UTA uncatalogued, several specimens.

Description. Material assigned to this genus includes several partial skulls with diagnostic bones missing, some skull elements larger than those of other species, some limb bones associated with a partial skull and several series of vertebrae which show the characteristic peduncles for the articulation of hemal arches to the caudal centra and lack zygosphenes and zygantra on the dorsal and cervical centra. Many isolated vertebrae and a few pelvic elements are also included here, most of which are from the Ozan Marl. Several jaw fragments and teeth were also assigned to this genus on the basis of serrate teeth (John Thurmond, personal communication, 1971).

*TMM 30962-25 (from TMM Locality 30962) was collected from the Roxton Limestone, and consists of a partial skull with portions of the mandibles and various unidentified and worn fragments. The anterior tips of the dentaries of this specimen have the characteristic rectangular rostrum anterior to the first tooth. Portions of both ischia are present and agree with Russell's (1967, fig. 58) drawing. A few dorsal and caudal vertebrae are present, the latter with typical peduncles for hemal arch attachment.

Two series of vertebrae, *ET 4350 from Ozan Marl at ET Locality 53 and SMU 62505, locality unknown, represent normal sized adult animals (about 30 feet in length); *ET 4275 is a series from a very large mosasaur (estimated at 50 ft. in length), collected from the Ozan Marl at ET Locality 39. The SMU specimen includes cervical, dorsal and caudal vertebrae, and the others dorsal and caudal vertebrae. Associated with *ET 4350 were pelvic elements (ET 4324, ET 4325, ET 4329) which may have belonged to the same animal.

SMU 62496 is a portion of a very large dentary from the Ozan condensed zone near Ladonia, Fannin County, with two serrate teeth and two partial alveoli. *USNM 18496 from the Ozan condensed zone at USNM Locality 3 was not seen but is stored unprepared. UTA uncatalogued specimens include a set of jaw fragments with serrate teeth, from the Roxton Limestone at Bailey, Fannin County; a very large caudal centrum from the Wolfe City Formation at UTA Locality 3; and three very large dorsal centra from the "Lower Taylor" at UTA Locality 2.

Other specimens include several isolated teeth, pelvic and limb fragments and numerous isolated vertebrae, most of which were collected from float material from the Ozan Marl, and for the most part from near ET Localities 39 and 44.

Discussion. Several fragments or partial skeletons of very large individuals of the genus Tylosaurus have been observed, and were noted by Thurmond (1969, p. 77). He saw only three specimens but nearly a dozen have been observed or collected by others. The dimensions of vertebrae shown in Table 7 (ms., p. 242) indicate that a Tylosaurus 30 feet in length might have vertebrae with centrum heights ranging from 50 to 60 mm. Specimens of Tylosaurus more than 40 feet in length may have centrum height measurements varying from 70 to more than 100 mm. If Russell's (1967, p. 210) estimates based on mandible length as one tenth of body length are correct, then further estimates of body length may be taken from specimens with complete mandibles. If the specimens have associated vertebrae, these bones may be used for comparison with isolated centra in order to estimate the size of the animal from which the isolated centra came. Comparison of ET specimens with *ET 4351 which included both skull material and vertebrae indicates that the former may have been approximately 30 feet in length, and that *ET 2475, ET 4279, ET 4336 and the UTA uncatalogued specimens must have exceeded 50 feet in length. Jaw sections bearing teeth can also be used for approximate size estimates. *ET 4276 or *ET 4351, both of which were probably about 30 feet in length, have teeth approximately 50 mm. in length. *ET 4295 has smaller jaws and teeth about 30 mm. long, indicating a size range of from 12 to 15 feet for the animal. SMU 62496, SMB 3225 and DMNH uncatalogued specimens have jaws and teeth approximately twice that size, indicating a size range of 50 to 65 feet for these animals. ET 4388 is a very large dorsal centrum from near ET Station 7; weathering characteristics suggest that it is from the Roxton Limestone. Of the specimens described above, *ET 4275, the series of vertebrae and jaw fragments listed in referred specimens (ET 4336 to ET 4387), SMU 62496, and the UTA specimens from Localities 2 and 3, are very large and probably represent animals up to 50 feet in length. *TMM 30962-25 was probably about 40 feet long, and two very large _Tylosaurus_ _proriger_ individuals are the SMB 3225-SMU 61635 and DMNH uncataloged specimens, over 50 and over 60 feet in length, respectively. This is a total of nine animals of more than 40 feet in length; the only other very large mosasaur is "Bunker's mosasaur," University of Kansas 5033, from the Pierre Formation, which is also more than 50 feet in length. The presence of such large animals indicates that not only were the seas warm but that food was abundant. Poikilothermic animals cannot live in cold water because they become too sluggish to catch prey. Such large individuals might have fed upon very large fishes (partial skeletons of very large fishes have been collected in the study area), smaller mosasaurs, plesiosaurs or very large ammonites.

Subclass Euryapsida (Synaptosauria)

Order Sauropterygia

Suborder Plesiosauria

Superfamily Pliosauroidea Welles 1943

Family Polycotylidae Williston 1908

Genus _Polycotylus_ Cope 1869

Polycotylus latipinnis Cope 1869

Plate 2, figs. 1-7; Plate 3, figs. 1-3

Polycotylus latipinnis Cope, 1869, Proc. Amer. Phil. Soc., vol. 11, p. 117.

Polycotylus latipinnis, Cope, 1869-1870, Trans. Amer. Phil. Soc., n. s., pt. 1, p. 36, pl. 1, figs. 1-3.

Polycotylus latipinnis, Cope, 1871, U. S. Geol. Survey of Wyoming and portions of contiguous territories, 2nd (4th) ann. rept. F. V. Hayden, U. S. Geologist, Washington, p. 388.

Polycotylus latipinnis, Leidy, 1873, U.S. Geol. Survey Terr. Rept. 1, p. 279.

Polycotylus latipinnis, Cope, 1874, U.S. Geol. Survey Terr. Bull. 1 (2), p. 27.

Polycotylus latipinnis, Cope, 1875, U.S. Geol. Survey Terr. Rept. 2, p. 45, 72, 255, pl. 7, figs. 7, 7a.

Polycotylus latipinnis, Williston, 1903, Field Mus. Publ. 73, p. 67, pl. 21.

Polycotylus latipinnis, Williston, 1906, Amer. Jour. Sci., ser. 2, vol. 21, p. 234, pl. 3, fig. 1.

Polycotylus latipinnis, Williston, 1908, Jour. Geol., vol. 16, p. 735-736, figs. 6, 13, 14.

Polycotylus, Williston, 1914, Water reptiles of the past and present, Chicago, fig. 34.

Polycotylus latipennis, Lane, 1947, Trans. Kansas Acad. Sci., vol. 47, no. 2, p. 306.

Polycotylus, Romer, 1956, Osteology of the reptiles, Chicago, figs. 122P, 123G, 131F.

Polycotylus latipinnis, Welles, 1962, Univ. California Publ. Geol. Sci., vol. 44, p. 66 (as a nomen vanum).

Polycotylus latipinnis, Persson, 1963, Lunds Univ. Arsskrift, vol. 59, no. 1, p. 36.

Type. University of Kansas 5916, upper Niobrara Formation, near Fort Wallace, Kansas (Lane, 1947, p. 306).

Distribution. Roxton Limestone.

Referred specimens. *ET 4277.

Description. Only one specimen was collected from the Roxton Limestone. It occurred in a cast bed at the base of a zone transitional to the Ozan Marl, at ET Locality 36. The specimen comprises 22 vertebrae, three pectoral (cervical-dorsal transitional), 15 dorsal and four anterior caudal vertebrae, one cervical(?) rib, two other partial ribs, and numerous other fragments of centra and ribs. The distal end of the right ilium is also present.

The pectoral vertebrae have moderately concave, articular surfaces. The surfaces of the vertebrae are smooth except for nutritive foramina. A central mammilla is preserved on anterior and posterior articular surfaces of most of the vertebral centra. This feature is similar to those shown by Williston (1908, fig. 13; 1914, fig. 34). Ventral surfaces have two (rarely one) nutritive foramina, which are not separated by a ventral keel. The margins are not grooved or beveled

(Tarlo, 1959, p. 42-43). The short vertebral centra and single-headed cervical rib are characteristic of polycotylid pliosaurs. The pectoral centra have synapophyses for rib attachment on the lateral central surface, connected to the neural arch by a ridge of bone, giving a "figure eight" shape to broken synapophyses. Neural arches are incomplete on all of the centra; bean-shaped anterior zygapophyses occur on one centrum. Continuous series indicate that pliosaur cervical vertebrae have synapophyses that become more dorsal posteriorly, and finally join with and are incorporated into the neural arch (Tarlo, 1959, p. 44). Because none of the cervical vertebrae of this specimen have rib facets, or connected synapophyses, they are interpreted as representing posterior cervical or "pectoral" centra (Tarlo, 1959, p. 44). Tarlo (1960) suggests that cervical centra are distinctive and can be used as taxonomic characters.

The dorsal vertebrae are similar to those shown by Williston (1908, fig. 13). Dorsal vertebrae are not distinctive (Tarlo, 1959, p. 44) but no other illustrations seen show the prominent central mammila present in this specimen. The synapophyses are on pedicles which extend dorso-laterally from the neural arches, and have the expanded distal ends shown by Williston. The neural canal is smooth and subtriangular in cross-section and has a shallow floor with one or two small centrally located foramina. The neural spines are incomplete on all but two centra, and the dorsal tip is swollen and expanded. Zygapophyses are present on some of the vertebrae, and both anterior and posterior zygapophyses have smooth, bean-shaped articular surfaces.

Four anterior caudal vertebrae with dorsolateral rib facets and processes also have various facets or processes for the articulation of hemal arches. These may not all be present on one centrum, and may consist of either "thumb-print" depressions on the ventrolateral margins or short processes, or one of each on a margin. Centrum L-85-4 has three depressions, one of which is anterior. L-85-20 has only one edge of the right posterior margin produced into a short process. L-85-29 has two depressions, on the anterior right and the posterior left margins, a short process (broken) on the anterior left margin which is completely separate from the margin, and a very slight swelling of the posterior right margin forming a very short process. L-85-29a has two very slight depressions on the anterior margin and two larger (17 mm.) depressions on the posterior margins.

The single cervical(?) rib (L-85-3) is broken distally but the head is present; it is nearly circular and slightly oval dorsoventrally. The rib is short, nearly straight and T-shaped, with the "cross-bar" of the T oriented dorsally, anteroposteriorly. The remaining ribs are also single-headed and curved dorsoventrally. The proximal sections are rectangular and both anterior and posterior surfaces are slightly grooved. Distally the ribs become narrow rectangles or ovals, flattened anteroposteriorly. None of the ribs is complete.

Only the distal half of the right ilium represents the pelvis. The articular surface is badly weathered but was deeply pitted and evidently finished in cartilage to form part of the acetabulum. The medial surface is smoothly oval, but the lateral surface of the shaft is subrectangular. The posterior edge of the shaft bears a sinuous ridge so the distal surface appears comma-shaped, with the projecting ridge forming the "tail." At the anterolateral corner of the bone the acetabular surface is extended up onto the shaft as Romer (1956, fig. 158F) has indicated in Muraenosaurus. This pitted surface may have functioned as a muscle attachment, or may be the result of weathering. The proximal end is broken off but may have been much like that of Trinacromerum (Romer, 1956, fig. 159B). The ilium most nearly resembles that of "Plesiosaurus latispinus" (Owen, 1864, pl. 9, fig. 1).

Pliosauroidea indet.

Plate 3, figs. 4-7

Distribution. Lower Ozan Marl, Pecan Gap Chalk.

Referred specimens. ET 4301, ET 4313, ET 4316.

Description. All of these are isolated specimens collected from float material in stream valleys; preservation suggests that ET 4316 may be from the Pecan Gap Chalk, and the other specimens from the Ozan Marl. None of the centra have the raised central mammilla characteristic of Polycotylus but all are short pliosaurid centra.

The largest centrum (ET 4301) resembles the posterior cervical or "pectoral" vertebrae of Polycotylus in general shape, concavity, and smoothness of the surface, but no central mammilla was observed. The neural arch and zygapophyses were broken off, but portions of the connected synapophyses are present on both sides. The type of preservation indicates that this centrum weathered from Ozan marls near ET Locality 39.

ET 4316 is a smaller anterior caudal centrum collected as a float specimen near ET Locality 45; the light brown color indicates that the specimen weathered from the Pecan Gap Chalk nearby. The general shape of the centrum is similar to that shown for Cimoliasaurus (Leidy, 1865, pl. 5), and also resembles that of Polyptychodon (Welles and Slaughter, 1963, pl. 18A-D) except that the outline is more oval. The centrum body is moderately concave with no central mammilla. The surface and margins are smooth. The neural arch is missing but two oval articular facets are smooth and are oriented anteroposteriorly. The neural canal is narrow, and the floor has been weathered away. Broken synapophyses occur dorsomedially, and are subtriangular in shape, with the apex ventroanteriorly directed. The surface anterior to these facets is rugose. The ventrolateral border of the posterior margin bears two oval dorsoventrally oriented facets for the hemal arch articulation and the surface just anterior to these two facets is also rugose. The ventral surface is flattened, without a ventral keel and bears one large and one small foramen.

A smaller cervical(?) vertebra (ET 4313), also a float specimen, shows the dark gray to black color and iron-stained weathering characteristic of other Ozan Marl specimens. Collected near ET Locality 53, it could have come only from the lower Ozan Marl. This small centrum has an extremely weathered dorsal portion, and the neural arch, canal and facets are not preserved. The surface is smooth. The body is rather distorted but appears to be slightly heart-shaped, with maximum width dorsal to midline. The margins are regular, and finely lined parallel to the circumference. The articular surfaces are moderately concave and a central mammilla is absent. Two oval synapophyses are present on the ventrolateral border, their surfaces extending anteroposteriorly from margin to margin. The articular surfaces are broken. The ventral surface is distorted but has two large foramina deeply set in depressions and separated by a prominent ventral keel. The ventral surface is similar to that of Macroplata longirostris (Blake) (White, 1940, fig. 5, the twenty-seventh cervical vertebra).

Superfamily Plesiosauroidea Welles 1943

Family Elasmosauridae Cope 1869

Elasmosauridae indet.

Plate 3, figs. 8, 9

Distribution. Roxton Limestone.

Referred specimens. ET 4317.

Description. This weathered and broken centrum was donated to the University without locality information. The specimen probably came from the channel of the North Sulphur River in the vicinity of Gober, Fannin County. Matrix clinging to the specimen is similar to the Roxton Limestone, with bits of shells, a partial shark tooth and questionably attached oyster. The worn condition of the specimen indicates that it may have weathered from Roxton outcrops far upstream, or that it is a reworked Pleistocene gravel "clast."

The centrum has the greater length and flat articular surfaces characteristic of elasmosaurids (Welles, 1952, p. 51-52; Persson, 1963,

p. 7). The centrum is oval, flattened dorsoventrally, and only very slightly concave. The articular surfaces are not smooth but are irregular and rugose, perhaps from weathering. None of the processes is preserved; two broken sections near the ventrolateral margins may have born rib facets. The neural arch is completely missing and its base consists of two narrow ridges of broken bone. The neural canal is a concave trough with a very narrow central "keel" of bone separating two tiny nutritive foramina. The ventral surface of the centrum is flattened but has a prominent central rounded keel between two large nutritive foramina. The vertebra may be a posterior dorsal or posterior cervical centrum.

Special Material

Several specimens show special features such as tooth marks or encrustation by marine organisms.

Pathologic specimens:

1. ET 4300, unidentified mosasaur dentary fragment with tooth mark, which became infected and developed into a fistula and partially healed before the death of the animal (Dr. Glenn Anderson, Commerce, personal communication, 1970) (see Pl. 4, fig. 7).

2. ET 4327, unidentified partial mosasaur frontal, with rugose patch of healed bone on dorsal surface, probably from the Ozan Marl, from ET Locality 41.

Specimens with post-mortem, pre-depositional damage:

3. ET 4319, unidentified partial mosasaur pubis with tooth marks resembling those made by sharks (Dr. Thurmond, personal communication, 1971), Ozan Marl, near ET Locality 44 (Pl. 4, fig. 6).

4. ET 4393, neural plate of unidentified turtle with borings in ventral surface, Ozan condensed zone, near ET Locality 44 (Pl. 4, figs. 1, 2).

5. *ET 4277, Polycotylus latipinnis, rib with shark tooth embedded, Roxton Limestone, ET Locality 36 (Pl. 4, fig. 8).

Encrusted specimens:

6. *ET 4302, unidentified mosasaur vertebra encrusted with worm tubes and foraminifers, basal Pecan Gap Chalk condensed zone, ET Locality 50.

7. *ET 4304, unidentified mosasaur vertebra, with oysters, barnacles and worm tubes, Roxton Limestone, ET Locality 51 (Pl. 4, fig. 5).

8. *ET 4276, Tylosaurus proriger, oyster attached to right pterygoid and rudistid "spat" on surangular, Ozan Marl, ET Locality 35.

9. *ET 4277, Polycotylus latipinnis, dorsal vertebra with barnacle set on articular process, Roxton Limestone, ET Locality 36.

10. *ET 4280, unidentified chelonian cervical vertebra with worm tubes on lateral surface, Roxton Limestone, ET Locality 38.

11. *ET 4295, Clidastes propython, oyster on medial surface of maxilla, and on broken portion of dorsal vertebra, Roxton Limestone, ET Locality 36 (Pl. 4, fig. 4).

12. *ET 4299, unidentified mosasaur dorsal (?) vertebra with oyster in neural canal, Roxton Limestone, ET Locality 59 (Pl. 4, fig. 3).

13. SMB 3225, Tylosaurus proriger, oyster spat on premaxilla, on outer surface and on maxillary suture, Ozan condensed zone, SMU Locality 1.

14. TMM 41166-1, unidentified mosasaur caudal (?) vertebra with barnacle on lateral surface, lower Pecan Gap Chalk condensed zone, TMM Locality 41166.

Reworked specimens:

15. *ET 4305, unidentified mosasaur vertebral fragment with bored white carbonate material filling neural canal, Ozan condensed zone, ET Locality 39.

The above list indicates that bitten or pathologic specimens are commoner in the Ozan normal gray marls, while all but one encrusted specimen (*ET 4276) comes from condensed zones in the Ozan or Pecan Gap Formations, or from the Roxton Limestone. This provides convincing evidence that some of these bones lay exposed on the surface for some time before being covered in zones of slow sedimentation. Evidence of reworking can be seen in *ET 4305 with the carbonate filling of the neural canal; this carbonate material is not common to the Ozan condensed zone. This specimen and ET 4393 are both blackened and partially replaced with calcium phosphate. Perhaps both specimens are reworked.

Additional Material

Specimens for which no data is available, or which are unidentifiable are listed here for completeness of the record.

1. ET 1120, mosasaur scraps, Broun collection. Matrix indicates Roxton Limestone, listed from "Radton," probably Roxton.

2. UTA uncatalogued material. Scraps from various localities.

3. UTA 2206, <u>Platecarpus</u> <u>ictericus</u> (<u>Platecarpus</u> cf. <u>P.</u> <u>curtirostris</u> of Thurmond, 1969, p. 74), a partial skull roof, with

quadrate, prootic and other fragments. Horizon and locality unknown. Thurmond remarks that the specimen may be from either Austin, Taylor or Niobrara because it resembles specimens from all of these formations.

4. ET 4322, ET 4323, partial plesiosaur limb bones, probably from Ozan Marl near ET Locality 44.

5. ET 4334, partial fish or turtle fragment, probably from the Ozan Marl near ET Station 31.

6. ET 4318, turtle marginal plate(?), probably Ozan Marl, near ET Locality 44.

7. ET accession number L-5-4, pitted bone of uncertain origin, probably Ozan Marl, near ET Locality 44.

8. Many fish specimens, from in situ and float, including shark and teleost from all stratigraphic levels and many localities.

REFERENCES

Adkins, W. S., 1933, The Mesozoic Systems in Texas; in: The Geology of Texas, v. 1, Stratigraphy, Sellards, E. H., S. W. Adkins, F. B. Plummer, 1932, Texas Univ. Bull. 3232, pt. 2, p. 239-517.

_______, 1949, Eagle Ford condensed zone in Travis County, Texas; in: Shreveport Geol. Soc. Guidebook, 17th ann. field trip, Sept. 1949.

Avnimelech, M., 1949, On vertebrate remains in Senonian phosphate beds in Transjordan; Ecl. geol. Helv., v. 42, no. 2, p. 486-490, 2 figs.

Barnes, V. E., 1966, Geologic atlas of Texas: Texarkana sheet; map, explanation.

_______, 1967, Geologic atlas of Texas: Sherman sheet; map, explanation.

Barrell, Joseph, 1917, Rhythms and the measurements of geologic time; Bull. Geol. Soc. Amer., v. 28, p. 745-904, pls. 43-46.

Bathurst, R. G. C., 1967, Depth indicators in sedimentary carbonates; Marine Geol., v. 5, no. 5/6, p. 447-471, not illus.

Beall, Arthur O., Jr., 1960, The Taylor Formation; in: Baylor Geol. Soc. Field Conf., April, 1960, p. 118-123.

_______, 1964, Stratigraphy of the Taylor formation (Upper Cretaceous), east-central Texas; Baylor Geol. Studies, Bull. 6, 34 p., illus.

Behrens, E. William, 1965, Environment reconstruction for a part of the Glen Rose limestone, central Texas; Sedimentology, v. 4, no. 1/2, p. 65-111, 10 pls., 11 figs.

Bishop, William F., 1968, Petrology of upper Smackover limestone in North Haynesville field, Claiborne Parish, Louisiana; Bull. Amer. Assoc. Petrol. Geol., v. 52, no. 1, p. 92-128, figs. 1-32.

Boreske, J. R., Leonard Goldberg and Barry Cameron, 1972, A reworked cetacean with clam borings: Miocene of North Carolina; Jour. Paleont., v. 46, no. 1, p. 130-139, pl. 1, 6 figs.

Bornhauser, Max, 1958, Gulf Coast tectonics; Bull. Amer. Assoc. Petrol. Geol., v. 42, no. 2, p. 339-370, figs. 1-12.

Boutte, Andre L., 1969, Callahan carbonate-sand complex, west-central Texas; in: Depositional Environments, Lower Cretaceous, Guidebook, Dallas Geol. Soc., p. 40-74, figs. 1-21.

Bowman, T. E., 1971, Palaega lamnae, new species (Crustacea: Isopoda) from the Upper Cretaceous of Texas; Jour. Paleont., v. 45, no. 3, p. 540-541, 1 fig.

Bromley, Richard Granville, 1967, Some observations on burrows of thalassinidean Crustacea in chalk hardgrounds; Quart. Jour. Geol. Soc. London, v. 123, pt. 2, no. 490, p. 157-182, pls. 7-11, figs. 1-5.

Bryan, Frank, 1933, Recent movement on a fault of Balcones system, McLennan County, Texas; Bull. Amer. Assoc. Petrol. Geol., v. 17, no. 4, p. 439-442, 1 fig.

Bryant, W. R., A. A. Meyerhoff, N. K. Brown, Jr., M. A. Furrer, T. E. Pyle, and J. W. Antoine, 1969, Escarpments, reef trends, and diapiric structures, eastern Gulf of Mexico; Bull. Amer. Assoc. Petrol. Geol., v. 53, no. 12, p. 2506-2542, 29 figs.

Bullard, Fred M. and John S. Redfield, 1930, Love and Marshall Counties; Oklahoma Geol. Surv., Bull. 40, v. 3, p. 505-530, 5 figs., map.

Burst, John F., 1958, "Glauconite" pellets: their mineral nature and applications to stratigraphic interpretations; Bull. Amer. Assoc. Petrol. Geol., v. 42, no. 2, p. 310-327, figs. 1-11.

Burt, F. A., 1932, Formative processes in concretions formed about fossils as nuclei; Jour. Sed. Petrol., v. 2, no. 1, p. 38-45.

Carozzi, A. V., 1958, Micro-mechanisms of sedimentation in the epicontinental environment; Jour. Sed. Petrol., v. 28, no. 2, p. 133-150, figs. 1-13.

Clark, David and K. J. Bird, 1966, Foraminifera and paleoecology of the upper Austin and lower Taylor (Cretaceous) strata in north Texas; Jour. Pal., v. 40, no. 2, p. 315-327, illus.

Cloos, Ernst, 1968, Experimental analysis of Gulf Coast fracture patterns; Bull. Amer. Assoc. Petrol. Geol., v. 52, no. 3, p. 420-444, 38 figs.

Cloud, P. E., Jr. (and others), 1962, Environments of calcium carbonate deposition west of Andros Island, Bahamas; U. S. Geol. Surv. Prof. Paper 350, 138p., 10 pls., 46 figs.

Coleman, James M. and Sherwood M. Gagliano, 1965, Sedimentary structures: Mississippi River deltaic plain; in: Soc. Econ. Pal. Min., Spec. Publ. 12, p. 133-148, 8 figs.

Collins, R. E. L., 1951, A new turtle, Toxochelys weeksi, from the Upper Cretaceous of West Tennessee; Jour. Tennessee Acad. Sci., v. 26, p. 262-269, 2 pls.

Coon, Lester A., 1956, Tertiary-Cretaceous growth of the East Texas basin; Trans. Gulf Coast Assoc. Geol. Soc., v. 6, p. 85-90, pls. 1-5.

Cope, E. D., 1869-1870, Synopsis of the extinct Batrachia, Reptilia and Aves of North America; Amer. Phil. Soc., n. s., v. 14. pt. 1, viii and 252 pp., 12 pls., 55 figs.

Crosby, G. W., 1971, Gravity and mechanical study of the great bend in the Mexia-Talco fault zone, Texas; Jour. Geophys. Res., v. 76, no. 11, p. 2690-2705, 6 figs.

Cullom, M., W. Granata, S. Gayer, R. Heffner, S. Pike, L. Herrman, C. Meyertons, and G. Sigler, 1962, The basin frontiers and limits for exploration in the Cretaceous system of central Louisiana; Trans. Gulf Coast Assoc. Geol. Soc., v. 12, p. 97-115, figs. 1-12.

Dane, Carl H., 1926, Oil-bearing formations of southwestern Arkansas; U.S. Dept. Interior Memo. for the Press, no. 8823 (Not seen).

_______, 1929, Upper Cretaceous Formations of southwestern Arkansas; Arkansas Geol. Surv., Bull. 1, 215 p., 29 pls., 4 figs., map.

_______, and L. W. Stephenson, 1928, Notes on Taylor and Navarro formations; Bull. Amer. Assoc. Petrol. Geol., v. 12, no. 1, p. 41-58, pl. 2, fig. 1.

Dapples, E. C., 1942, The effect of macroorganisms upon near-shore marine sediments; Jour. Sed. Petrol., v. 12, no. 3, p. 118-126, not illus.

Davies, William, 1879, On some fish exuviae from the Chalk, generally referred to Dercetis elongatus Ag.; and on a new species of fossil annelide, Terebella Lewesiensis; Geol. Mag., Dec. 2, v. 6, no. 4, p. 145-148, not illus.

Dott, R. H., Jr., 1958, Cyclic patterns in mechanically deposited Pennsylvanian limestones of northeastern Nevada; Jour. Sed. Petrol., v. 28, no. 1, p. 3-14, figs. 1-3.

Duff, P. McL. D., A. Hallam and E. K. Walton, 1967, Cyclic Sedimentation; Developments in Sedimentology, v. 10, Elsevier Publ. Co., New York, 280 p., illus.

Dunbar, Carl O. and John Rodgers, 1957, Principles of Stratigraphy; John Wiley and Sons, New York, 356 p., illus.

Dunham, Robert J., 1962, Classification of carbonate rocks according to depositional texture; Amer. Assoc. Petrol. Geol., Mem. 1, p. 108-121, pls. 1-7.

East Texas Geological Society, 1945, Field trip guidebook and road log (Greenville and Paris-Clarksville area of northeast Texas, Pecan Gap, Wolfe City and Annona formations, Upper Cretaceous): Dec. 2, 1945, 11p., map.

Eaton, J. E., 1929, The by-passing and discontinuous deposition of sedimentary materials; Bull. Amer. Assoc. Petrol. Geol., v. 13, no. 7, p. 713-761, figs. 1-12.

Eaton, R. W., 1956, Resumé of subsurface geology of northeast Texas with emphasis on salt structures; Trans. Gulf Coast Geol. Soc., v. 6, p. 79-84, not illus.

Ellisor, Alva C., and John Teagle, 1934, Correlation of Pecan Gap Chalk in Texas; Bull. Amer. Assoc. Petrol. Geol., v. 18, no. 11, p. 1506-1536, illus.

Emery, K. O., and R. S. Dietz, 1950, Submarine phosphorite deposits off California and Mexico; Cal. Jour. Mines Geol., v. 46, no. 1, p. 7-15, pls. 1-5.

Evans, G., D. J. J. Kinsman and D. J. Shearman, 1964, A reconnaissance survey of the environment of recent carbonate sedimentation along the Trucial Coast, Persian Gulf; in: Developments in Sedimentology, v. 1, p. 129-135, 3 figs.

Fairbridge, R. W., 1953, The Sahul Shelf, northern Australia; its structure and geological relationships; Roy. Soc. Western Australia Jour., v. 38, p. 1-33.

Fisher, A. G., and R. E. Garrison, 1967, Carbonate lithification on the sea floor; Jour. Geol., v. 75, no. 4, p. 488-496.

Fisher, W. L., and J. H. McGowen, 1969, Depositional systems in Wilcox Group (Eocene) of Texas and their relation to occurrence of oil and gas; Bull. Amer. Assoc. Petrol. Geol., v. 53, no. 1, p. 30-54, figs. 1-12.

Fisher, W. L., and Peter U. Rodda, 1969, Edwards Formation (Lower Cretaceous), Texas: dolomitization in a carbonate platform system; Bull. Amer. Assoc. Petrol. Geol., v. 53, no. 1, p. 55-72, figs. 1-14.

Flawn, Peter T., A. Goldstein, Jr., P. B. King, and C. E. Weaver, 1961, The Ouachita System; Texas Univ. Publ. 6120, 401p., pls. 1-15, figs. 1-13.

Fohs, F. J., and H. M. Robinson, 1923, Structural and stratigraphic data of northeast Texas petroleum area; Econ. Geol., v. 18, no. 8, p. 709-731.

Folk, Robert L., 1959, Practical petrographic classification of limestones; Bull. Amer. Assoc. Petrol. Geol., v. 43, v. 1, p. 1-38, figs. 1-41, pls. 1-5.

______, 1962, Spectral subdivision of limestone types; Amer. Assoc. Petrol. Geol., Mem. 1, p. 62-84, pl. 1, figs. 1-7.

Fowler, Phillip T., 1964, Basement faults and Smackover structure; Trans. Gulf Coast Assoc. Geol. Soc., v. 14, p. 179-191, 8 figs.

Friedman, Gerald M., 1965, Terminology of crystallization textures and fabrics in sedimentary rocks; Jour. Sed. Petrol., v. 35, no. 3, p. 643-655, figs. 1-11.

Frizzell, Donald L., and I. J. Anderson, 1950, Diastems in the Pecan Gap chalk of Travis County, Texas; Jour. Sed. Petrol., v. 20, no. 1, p. 55-59, figs. 1-6.

Frizzell, D. L., and J. H. Dante, 1965, Otoliths of some early Cenozoic fishes of the Gulf Coast; Jour. Paleont., v. 39, no. 4, p. 687-718, illus.

Ginsburg, R. N., 1957, Early diagenesis and lithification of shallow-water carbonate sediments in south Florida; Soc. Econ. Pal. Min., Spec. Publ. 5, p. 80-100.

______, and H. A. Lowenstam, 1958, The influence of marine bottom communities on the depositional environment of sediments; Jour. Geol., v. 66, no. 3, p. 310-318, pls. 1, 2, figs. 1-4.

Goldstein, August, Jr., 1959, Petrography of Paleozoic sandstones from the Ouachita Mountains of Oklahoma and Arkansas; in: Geology of the Ouachita Mountains, symposium, Dallas and Ardmore Geol. Soc., p. 97-116.

Gordon, C. H., 1911, Geology and underground waters of northeastern Texas; U. S. Geol. Surv. Water Supply Paper 276, pls. 1, 2, figs. 1-6.

Granata, Walter H., Jr., 1963, Cretaceous stratigraphy and structural development of the Sabine uplift area, Texas and Louisiana; in: Herrmann, Leo A. Report on Selected North Louisiana and south Arkansas Oil and Gas Fields, Shreveport Geol. Soc., 1963, reference v. 5, p. 50-95.

Hager, D. S., and C. M. Burnett, 1960, Mexia-Talco fault line in Hopkins and Delta Counties, Texas; Bull. Amer. Assoc. Petrol. Geol., v. 44, no. 3, p. 316-356.

Halbouty, Michael T., 1966, Stratigraphic trap possibilities in upper Jurassic rocks, San Marcos Arch, Texas; Bull. Amer. Assoc. Petrol. Geol., v. 50, no. 1, p. 3-24, 13 figs.

Hallam, Anthony, 1960, A sedimentary and faunal study of the Blue Lias of Dorset and Glamorgan; Roy. Soc. London, Phil. Trans., ser. B, v. 243, no. 698, p. 1-44, illus.

_______, 1961, Cyclothems, transgressions and faunal change in the Lias of north-west Europe; Edinburgh Geol. Soc., Trans., v. 18, pt. 2, p. 124-174, figs. 1-7.

_______, 1964, Origin of limestone-shale rhythm in the Blue Lias of England; a composite theory; Jour. Geol., v. 72, no. 2, p. 157-169, figs. 1-6.

Hardin, Frank R., and George C. Hardin, Jr., 1961, Contemporaneous normal faults of Gulf Coast and their relation to flexures; Bull. Amer. Assoc. Petrol. Geol., v. 45, no. 2, p. 238-248, 6 figs.

Henson, F. R. S., 1950, Cretaceous and Tertiary reef formation and associated sediments in Middle East; Bull. Amer. Assoc. Petrol. Geol., v. 34, no. 2, p. 215-238, 14 figs.

Huelsenbeck, Peter and J. R. Beerbower, 1963, Paleoecology of Upper Cretaceous (Navesink) beds at Poricy Brook, Monmouth County, New Jersey; Proc. Pennsylvania Acad. Sci., v. 37, p. 175-178, 2 tables.

Hill, R. T., 1888, Neozoic geology of southwestern Arkansas; Arkansas Geol. Surv. ann. rept. 1888, pt. 2, p. 1-260, illus.

_______, 1894, Geology of parts of Texas, Indian Territory and Arkansas adjacent to Red River; Bull. Geol. Soc. Amer., vol. 5, p. 297-338, pls. 12, 13.

_______, 1901, Geography and Geology of the Black and Grand prairies, Texas; U. S. Geol. Surv. ann. rept. 21, pt. 7, 666p., illus.

Hopkins, O. B., Sidney Powers and H. M. Robinson, 1923, The structure of the Madill-Denison area, Oklahoma and Texas, with notes on oil and gas development; U. S. Geol. Surv. Bull. 736, pt. 2, p. 1-33, pls. 1-6.

Illing, L. V., 1954, Bahaman calcareous sands; Bull. Amer. Assoc. Petrol. Geol., v. 38, no. 1, p. 1-95.

Irwin, M. L., 1965, General theory of epeiric clear water sedimentation; Bull. Amer. Assoc. Petrol. Geol., v. 49, no. 4, p. 445-459, 12 figs.

Kauffman, Erle G., and R. V. Kesling, 1960, An Upper Cretaceous ammonite bitten by a mosasaur; Univ. Mich., Contrib. Mus. Paleont., v. 15, no. 9, p. 193-248, pls. 1-9, figs. 1-7.

Kennedy, William James, 1967, Burrows and surface traces from the Lower Chalk of southern England; Bull. Br. Mus. nat. Hist. (Geol.), v. 15, no. 3, p. 125-167, pls. 1-9, figs. 1-7.

Kent, Harry C., 1968, Biostratigraphy of Niobrara-equivalent part of Mancos Shale (Cretaceous) in northwestern Colorado; Bull. Amer. Assoc. Petrol. Geol., v. 52, no. 11, p. 2098-2115, figs. 1-10.

Klein, George DeVries, 1965, Dynamic significance of primary structures in the Middle Jurassic Great Oölite series, southern England; Soc. Econ. Pal. Min. Spec. Publ. 12, p. 173-191, figs. 1-19.

Kolodny, Y., Y. Nathan and E. Sass, 1965, Porcellanite in the Mishash Formation, Negev, southern Israel; Jour. Sed. Petrol., v. 35, no. 2, p. 454-463, figs. 1-10.

Kinsley, David H., and M. Schneck, 1964, The paleoecology of a transition zone across an Upper Cretaceous boundary in New Jersey; Paleontology, v. 7, pt. 2, p. 266-280, 4 figs.

Kummel, Bernhard, 1961, History of the Earth: An Introduction to Historical Geology; W. H. Freeman and Co., San Francisco, 610p., illus.

Langston, Wann, Jr., 1960, The vertebrate fauna of the Selma Formation of Alabama, pt. 6, The dinosaurs; Chicago Nat. Hist. Mus., Fieldiana: Geol. Mem. 3, no. 6, p. 317-360, pl. 34, figs. 146-163.

Laporte, Leo F., 1969, Recognition of a transgressive carbonate sequence within an epeiric sea: Helderberg Group (Lower Devonian) of New York State; in: Depositional Environments in Carbonate Rocks, Soc. Econ. Pal. Min. Spec. Publ. 14, p. 98-119, 15 figs.

Lawrence, David R., 1969, The use of clionid sponges in paleoenvironment analyses; Jour. Pal., v. 43, no. 2, p. 539-543, 1 fig.

Leidy, Joseph, 1865, Cretaceous Reptiles of the United States; Smithsonian Contrib. Knowl. 192, vol. 14, art. 26, 125 pp., 20 pls., 35 figs.

Leriche, M., 1934, Sur le Crétacè supèrieur du Hainaut et du Brabant; Ann. Soc. Geol. Belgique, v. 58, B, no. 3-4, p. B118-B141, 3 figs., map.

McKerrow, W. S., R. T. Johnson, and M. E. Jakobson, 1969, Palaeoecological studies in the Great Oölite at Kirtlington, Oxfordshire; Palaeontology, v. 12, pt. 1, p. 56-83, pls. 8-12, figs. 1-5.

Middlemiss, F. A., 1962, Vermiform burrows and rate of sedimentation in the Lower Greensand; Geol. Mag., v. 99, no. 1, p. 33-40.

Miller, H. W., Jr., 1956, Correlation of Paleocene and Eocene formations and Cretaceous-Paleocene boundary in New Jersey; Bull. Amer. Assoc. Petrol. Geol., v. 40, no. 4, p. 722-736, 3 figs.

Mollan, R. G., R. W. Craig and M. J. W. Lofting, 1970, Geologic framework of continental shelf off northwest Australia; Bull. Amer. Assoc. Petrol. Geol., v. 54, no. 4, p. 583-600, 9 figs.

Moore, R. C., 1967, Unique stalked crinoids from Upper Cretaceous of Mississippi; Kansas Univ. Paleo. Contrib., Paper 17, 35p., 8 pls., 8 figs.

Murray, Grover F., 1961, Geology of the Atlantic and Gulf Coastal Province of North America; Harper and Bros., New York, 692p., illus.

Nagle, J. Stewart, 1968, Glen Rose cycles and facies, Paluxy River valley, Somervell County, Texas; Texas Bur. Econ. Geol., Geol. Circ. 68-1, 25p., 7 figs.

Newell, Norman D., and J. Keith Rigby, 1957, Geological studies on the Great Bahama Bank; in: Soc. Econ. Pal. Min. Spec. Publ. 5, p. 15-79, pls. 1-22, figs. 1-22.

Owen, Richard, 1864, A monograph of the fossil reptilia of the Cretaceous Formations; Palaeontographical Soc., Supplement 4, Order Sauropterygia, Owen.

Pantin, H. M., 1958, Rate of formation of a diagenetic calcareous concretion; Jour. Sed. Petrol., v. 28, no. 3, p. 366-371, 2 figs.

Paulson, Oscar, 1960, Ostracoda and stratigraphy of the Austin and Taylor equivalents of northeast Texas; Louisiana State Univ., Ph.D. dissert., 114 p.

Persson, Per Ove, 1959, Reptiles from the Senonian (Upper Cretaceous) of Scania (southern Sweden); Arkiv. Miner. och Geol. (K. Svenska Vetenskapsakad.), bd. 2, h. 5, no. 35, p. 431-478, 20 pls., 14 figs.

______, 1963, A revision of the classification of the Plesiosauria with a synopsis of the stratigraphical distribution of the group; Lunds Univ. Arsskrift, v. 59, no. 1, p. 1-60, 9 figs.

Pessagno, Emile A., Jr., 1969, Upper Cretaceous Stratigraphy of Western Gulf Coast Area of Mexico, Texas and Arkansas; Geol. Soc. Amer., Mem. 111, 139p,, 60 pls.

Pettijohn, F. J., 1957, Sedimentary Rocks; second ed., Harper and Row, New York, 718p., illus.

Plummer, Helen Jeanne, 1935, Microscopical evidence of the Navarro-Taylor contact in subsurface sections in central Texas; Texas Univ. Bull. 3501, p. 281-292, illus. (Feb., 1936).

Preseley, O. D., 1965, Ostracoda of the Pecan Gap (Cretaceous) formation of northeastern Texas; Univ. Oklahoma, unpubl. thesis, 65p., 8 pls., 5 figs.

Price, L. I., 1957, A presenca de <u>Globidens</u> no Cretacio superior do Brasil; Serv. Geol. Min. Brasil, Bol. 169, 24p., 3pls. (English summary).

Rayner, Dorothy H., 1958, The geological environment of fossil fishes; in: Westoll, ed., Studies on Fossil Vertebrates, p. 129-156, not illus.

Reaser, Donald F., 1961, Balcones fault system: its northeast extent; Bull. Amer. Assoc. Petrol. Geol., v. 45, no. 10, p. 1759-1962, 3 figs.

Rhoads, Donald C., 1967, Biogenic reworking of intertidal and subtidal sediments in Barnstable Harbor and Buzzards Bay, Massachusetts; Jour. Geol., v. 75, no. 4, p. 461-476, illus.

Rodgers, John, 1957, The distribution of marine carbonate sediments; a review; in: Soc. Econ. Pal. Min. Spec. Publ. 5, p. 2-14, figs. 1, 2.

Romer, A. S., 1956, Osteology of the reptiles; Univ. Chicago Press, Chicago, 772p., 248 figs.

______, 1970, Vertebrate Paleontology, 4th ed. Chicago, 468p., 443 figs.

Rouse, John Thomas, 1944, Correlation of the Pecan Gap, Wolfe City, and Annona formations in east Texas; Bull. Amer. Assoc. Petrol. Geol., v. 28, no. 4, p. 522-530, illus., map.

Russell, Dale A., 1967, Systematics and morphology of American mosasaurs; Peabody Mus. Nat. Hist., Bull. 23, p. vii and 240, frontispiece, figs. 1-99, charts 1-7.

______, 1970, The vertebrate fauna of the Selma Formation of Alabama, pt. 7, The mosasaurs; Chicago Mus. Nat. Hist. Fieldiana: Geol. Mem. 3, no. 7, p. 365-380, figs. 164-173.

Sabins, Floyd F., Jr., 1962, Grains of detrital, secondary, and primary dolomite from Cretaceous strata of the western Interior; Bull. Geol. Soc. Amer., v. 73, no. 10, p. 1183-1196, 1 pl., 5 figs.

Said, Rushdi, 1961, Tectonic framework of Egypt and its influence on distribution of Foraminifera; Bull. Amer. Assoc. Petrol. Geol., v. 45, no. 2, p. 198-218, 7 figs.

Scholten, Robert, 1959, Synchronous highs: preferential habitat of oil; Bull. Amer. Assoc. Petrol. Geol., v. 43, no. 8, p. 1793-1834, figs. 1-30.

Seewald, K. O., 1959, Stratigraphy of the Austin Chalk; Baylor Univ., unpubl. thesis.

______, 1967, Stratigraphy of the Upper Cretaceous Austin Group, central Texas; (abs.) Trans. Gulf Coast Assoc. Geol. Soc., v. 17, p. 151.

Sellards, E. H., and C. L. Baker, 1934, The Geology of Texas, v. 2, Structural and Economic Geology; Univ. Texas Publ. 3401, 884p., pls. 1-8, figs. 1-40.

Shinn, Eugene A., 1968, Burrowing in recent lime sediments of Florida and the Bahamas; Jour. Pal., v. 42, no. 4, p. 879-894, pls. 109-112, figs. 1-17.

Silver, Burr A., 1963, The Bluebonnet Member, Lake Waco Formation (Upper Cretaceous), central Texas - lagoonal deposit; Baylor Geol. Studies, Bull. 4, 46p., illus.

Sisk, Connie Calvin, Jr., 1958, The Taylor marl; in: Baylor Geol. Soc. Guide to the mid-Cretaceous geology of central Texas, 1958, p. 79-83, not illus.

Slaughter, Bob H., 1964, Geological survey and appraisal of the paleontological resources of the Cooper Reservoir, Delta and Hopkins Counties, Texas; Southern Methodist Univ., Fondren Sci. Ser. no. 6, 12p., map.

_______, and Thurmond, 1965a, Geological and paleontological survey of the Forney Reservoir basin, Kaufman and Rockwall Counties, Texas; Southern Methodist Univ. Fondren Sci. Ser. no. 7, 12p., map.

_______, and J. T. Thurmond, 1965b, Geological and paleontological survey of the Bardwell Reservoir basin, Ellis County, Texas; Southern Methodist Univ. Fondren Sci. Ser. no. 8, 12p., map.

Stehli, F. G. and W. B. Creath, 1964, Foraminiferal ratios and regional environments; Bull. Amer. Assoc. Petrol. Geol., vol. 48, no. 11, p. 1810-1827, 9 figs.

Steinhoff, R. O., 1964, Geology of the Lavon area, Collin County, Texas; Tulane Studies Geol., v. 2, no. 2, p. 29-38, illus.

Stephenson, L. W., 1918, A contribution to the geology of northeastern Texas and southern Oklahoma; U.S. Geol. Surv. Prof. Paper 120-H, p. 129-163, pls. 18-30.

_______, 1927, On the origin of the "rock wall" at Rockwall, Texas; Jour. Wash. Acad. Sci., v. 17, no. 1, p. 1-5, 2 figs.

_______, 1929, Unconformities in the Upper Cretaceous of Texas; Bull. Amer. Assoc. Petrol. Geol., v. 13, no. 10, p. 1323-1334.

_______, 1937, Stratigraphic relations of the Austin, Taylor, and equivalent formations in Texas; U.S. Geol. Surv. Prof. Paper 186-G, p. 133-146, pl. 44, fig. 7.

_______, and W. H. Monroe, 1940, The Upper Cretaceous deposits; Mississippi Geol. Surv. Bull. 40, 296p., 15 pls., 48 figs.

Stevenson, Robert E., 1961, "Preliminary paleoecological data for the Niobrara Chalk' in south central South Dakota; Proc. South Dakota Acad. Sci., v. 40, p. 239-240. (abs).

Sugden, W., and W. S. McKerrow, 1962, The composition of marls and limestones in the Great Oölite series of Oxfordshire; Geol. Mag., v. 99, no. 4, p. 363-368, 1 fig.

Swinchatt, Jonathan P., 1965, Significance of constituent composition, texture, and skeletal breakdown in some Recent carbonate sediments; Jour. Sed. Petrol., v. 35, no. 1, p. 71-90, pls. 1-3, figs. 1-9.

Taff, J. A., 1893, Report on the Cretaceous area north of the Colorado River; in: Dumble, E. T., Geol. Surv. Texas, 4th ann. rept., 1892, vol. 4, pt. 1, p. 239-254, map.

Tarlo, L. B., 1959, Stretosaurus gen. nov., a giant pliosaur from the Kimeridge Clay; Palaeont., v. 2, p. 39-55, pls. 7-9, 6 figs.

_______, 1960, A review of Upper Jurassic pliosaurs; Bull. Brit. Mus (Nat. Hist.), Geol., v. 4, no. 5, p. 145-189, pls. 20-28, 9 figs.

Thurmond, J. T., 1969, Notes on mosasaurs from Texas; Texas Jour. Sci., v. 21, no. 1, p. 69-80, 2 figs.

Tikhomirova, E. S., 1964, Distribution of iron, manganese and phosphorus in the Lower Oligocene deposits of Mangyshlak; Dolk. Akad. Nauk. S.S.S.R., v. 143, p. 143-145.

Tourtelot, Harry A., and W. A. Cobban, 1968, Stratigraphic significance and petrology of phosphate nodules at base of Niobrara Formation, east flank of Black Hills, South Dakota; U. S. Geol. Surv., Prof. Paper 594-L, 22p., 2 pls., 9 figs.

Trenchard, Walter H., 1968, Sedimentation and the distribution of marine biofacies; Trans. Gulf Coast Assoc. Geol. Soc., v. 18, p. 205-207, not illus.

Twenhofel, W. H., 1936, Marine unconformities, marine conglomerates and thickness of strata; Bull. Amer. Assoc. Petrol. Geol., v. 20, no. 6, p. 677-703.

Veatch, A. C., 1906, Geology and underground water resources of northern Louisiana and southern Arkansas; U. S. Geol. Surv. Prof. Paper 46, 422p., map.

Walthall, B. H., and J. L. Walper, 1967, Peripheral Gulf riftings in northeast Texas; Bull. Amer. Assoc. Petrol. Geol., v. 51, no. 1, p. 102-110.

Waters, J. A., P. W. McFarland and J. W. Lea, 1955, Geologic framework of Gulf Coastal Plain of Texas; Bull. Amer. Assoc. Petrol. Geol., v. 39, no. 9, p. 1821-1850, 23 figs.

Welles, S. P., 1952, A review of North American Cretaceous elasmosaurs; Univ. California Publ. Geol. Sci., v. 29, no. 3, p. 47-144, 25 figs.

Welles, S. P., and B. H. Slaughter, 1963, The first record of the plesiosaurian genus Polyptychodon (Pliosauridae) from the New World; Jour. Paleont., v. 37, no. 1, p. 131-133, 1 pl.

Wells, A. J., and L. V. Illing, 1964, Present-day precipitation of calcium carbonate in the Persian Gulf; in: Developments in sedimentology, v. 1, p. 429-435, 3 figs.

Wells, J. W., 1944, Middle Devonian bone beds of Ohio; Bull. Geol. Soc. Amer., v. 55, no. 3, p. 273-302, 1 pl., 14 figs.

White, T. E., 1940, Holotype of Plesiosaurus longirostris Blake and classification of the plesiosaurs; Jour. Paleont., v. 14, p. 451-467, 13 figs.

Williston, S. W., 1893, The Niobrara Cretaceous of western Kansas; Trans. Kansas Acad. Sci., v. 13, p. 107-111.

______, 1914, Water reptiles of the past and present; Univ. Chicago Press, Chicago, 251p., illus.

Young, Keith P., 1963, Upper Cretaceous ammonites from the Gulf Coast of the United States; Texas Univ. Publ. 6304, 373p., 82 pls., 34 figs.

______, 1965, A revision of Taylor nomenclature, Upper Cretaceous, central Texas; Texas Univ. Bur. Econ. Geol. Circ. 65-3, 11p., 3 figs.

Zangerl, Rainer, 1948, The vertebrate fauna of the Selma Formation of Alabama, pt. 1, Introduction, pt. 2, The pleurodiran turtles; Chicago Mus. Nat. Hist. Fieldiana: Geol. Mem. 3, nos. 1, 2, p. 1-58, 3 pls., 16 figs.

______, 1953, same, pt. 3, The turtles of the family Protostegidae; pt. 4, The turtles of the family Toxochelyidae; ibid., nos. 3-4, p. 59-277, figs. 17-123, pls. 5-29.

______, 1960, same, pt. 5, An advanced cheloniid sea turtle; ibid., nos. 5-6, p. 281-312, pls. 30-33, figs. 125-144.

______, and E. S. Richardson, Jr., 1963, The palaeoecological history of two Pennsylvanian black shales; Chicago Mus. Nat. Hist. Fieldiana: Geol. Mem. 4, xii and 352p., 56 pls., 51 figs.

UPPER AUSTIN AND TAYLOR REPTILES

PLATES 1-4

The species presented in the following plates are arranged in taxonomic order. Drawings on Plates 1 through 3 are at one-half natural size; lines to the lower left of each specimen on Plate 4 indicate one centimeter. The photographs on Plate 4 are unretouched. These illustrations are supplementary to other published illustrations and do not include each species in the fauna.

Plate 1

Chelonian and Mosasaur Material

1. Toxochelys sp. Specimen USNM 11797; horizon unknown, USNM Locality 2. Internal view of first costal.

2. Toxochelys sp. Same specimen. External view of fourth costal.

3. Toxochelys sp. Same specimen. Articular view of right pubis.

4. Toxochelys sp. Same specimen. Dorsal view of right pubis.

5. Toxochelys sp. Same specimen. Hypoplastral fragment.

6. Chelonia indet. Specimen *ET 4280; Roxton Limestone, ET Locality 36. Anterior view of cervical (?) vertebra.

7. Chelonia indet. Same specimen. Ventral view of same bertebra.

8. Chelonia indet. Same specimen. Posterior view of same vertebra.

9. Chelonia indet. Same specimen. Dorsal view of same vertebra.

10. Mosasaurus conodon (Cope). Specimen ET 4314; Ozan Marl, west of Station 32. Anterior view of caudal vertebra, slightly reconstructed after ET 4353, Ozan Marl, near ET Locality 39.

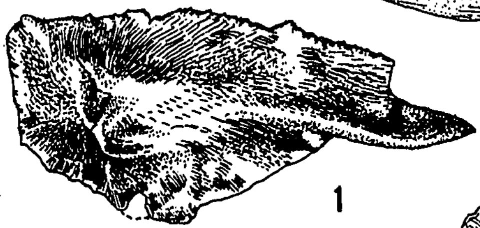
11. Platecarpus coryphaeus (Cope). Specimen ET 4344; Ozan Marl, ET Locality 39. Lateral view of anterior tip of right dentary.

12. Halisaurus sp. Specimen ET 4369; Ozan Marl, east of ET Locality 37. Lateral view of dorsal vertebra.

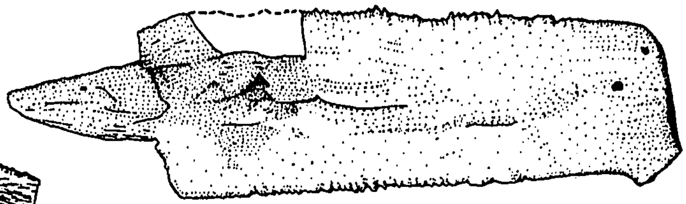
13. Halisaurus sp. Same specimen. Anterior view of same vertebra.

14. Tylosaurus proriger (Cope). Specimen *ET 4274; Ozan Marl, ET Locality 52. Dorsal view of basioccipital-basisphenoid, anterior to the left.

PLATE 1



1

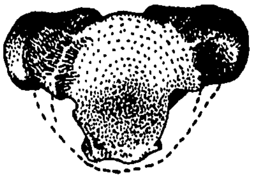


2

3

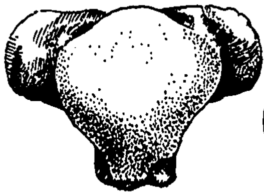
4

5



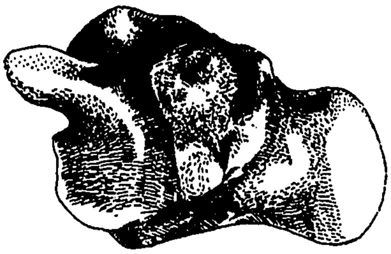
6

7

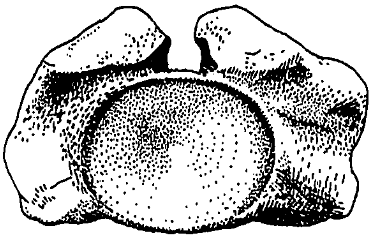


8

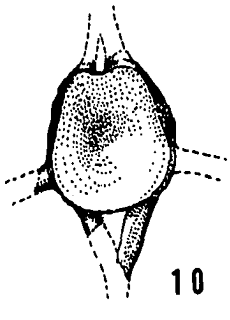
9



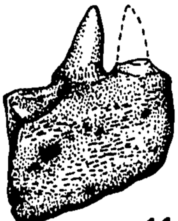
12



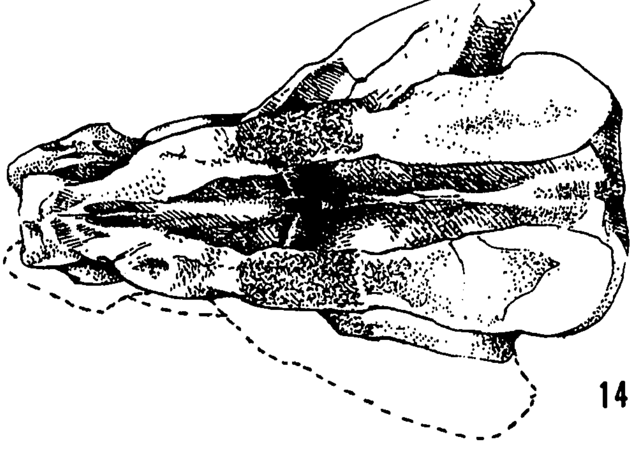
13



10



11



14

Plate 2

Plesiosaur Material

1. Polycotylus latipinnis Cope. Specimen *ET 4277; Roxton Limestone, ET Locality 36. Ventral view of pectoral vertebra.

2. Polycotylus latipinnis Cope. Same specimen. Lateral view of the same vertebra, anterior to the right.

3. Polycotylus latipinnis Cope. Same specimen. Anterior view of same vertebra.

4. Polycotylus latipinnis Cope. Same specimen. Anterior view of dorsal vertebra.

5. Polycotylus latipinnis Cope. Same specimen. Anterior view of caudal vertebra.

6. Polycotylus latipinnis Cope. Same specimen. Lateral view of same vertebra, anterior to the left.

7. Polycotylus latipinnis Cope. Same specimen. Posterior view of same vertebra.

PLATE 2

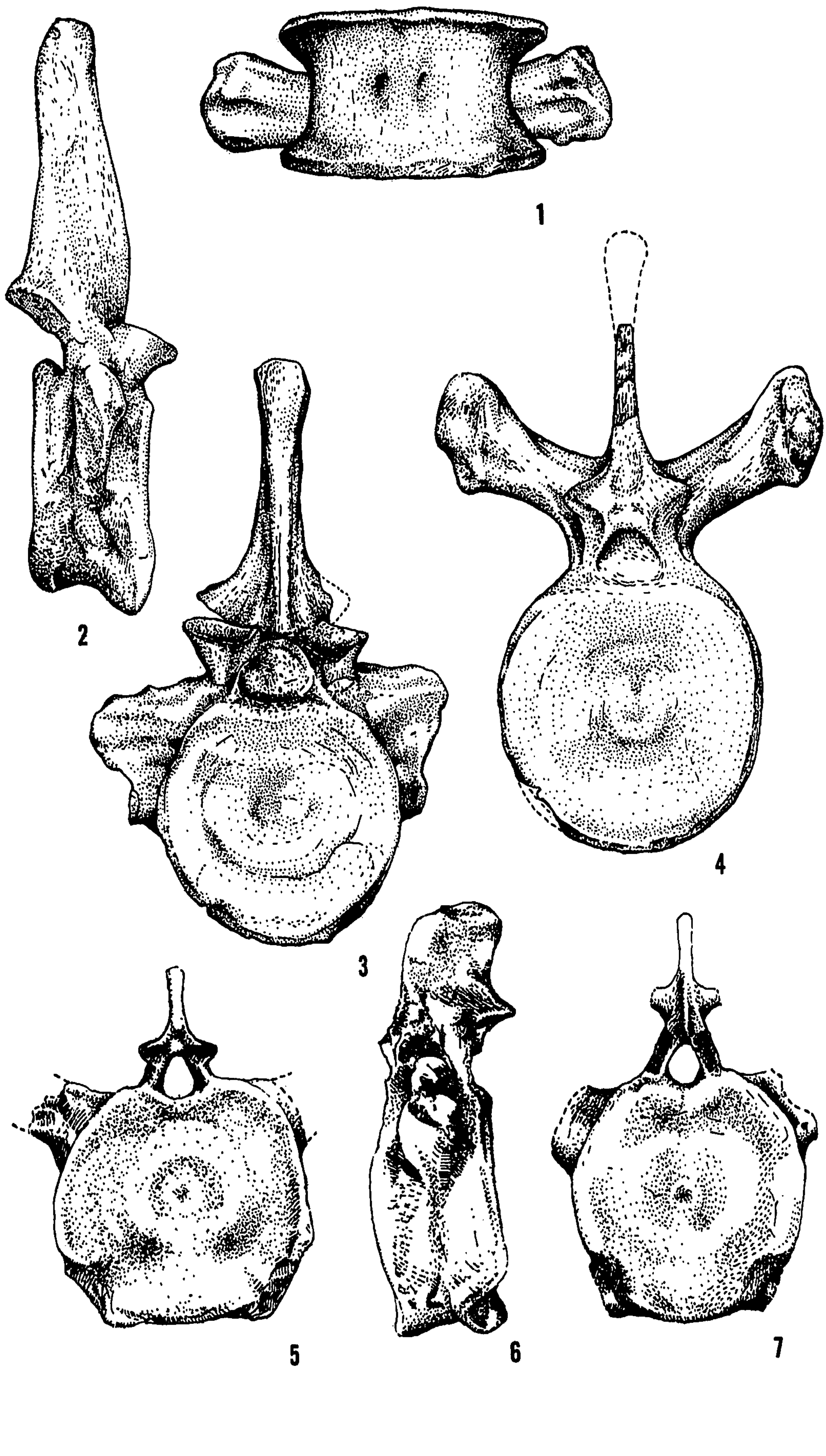


Plate 3

Plesiosaur Material

1. _Polycotylus latipinnis_ Cope. Specimen *ET 4277; Roxton Limestone, ET Locality 36. Medial view of medial surface of distal end of right ilium; distal (articular) end is up.

2. _Polycotylus latipinnis_ Cope. Same specimen. Ventral view of articular surface, posterior at the top.

3. _Polycotylus latipinnis_ Cope. Same specimen. Lateral view of same bone.

4. Pliosauridae indet. Specimen ET 4313; Ozan Marl, near ET Locality 53. Anterior view of cervical (?) vertebra, slightly reconstructed.

5. Pliosauridae indet. Same specimen. Ventral view of same vertebra.

6. Pliosauridae indet. Specimen ET 4316; Pecan Gap Chalk(?), near ET Locality 45. Anterior view of caudal vertebra.

7. Pliosauridae indet. Same specimen. Lateral view of same vertebra, anterior to the left.

8. Elasmosauridae indet. Specimen ET 4317; Roxton Limestone (?), locality unknown. Anterior view of dorsal (?) vertebra.

9. Elasmosauridae indet. Same specimen. Ventral view of same vertebra.

PLATE 3

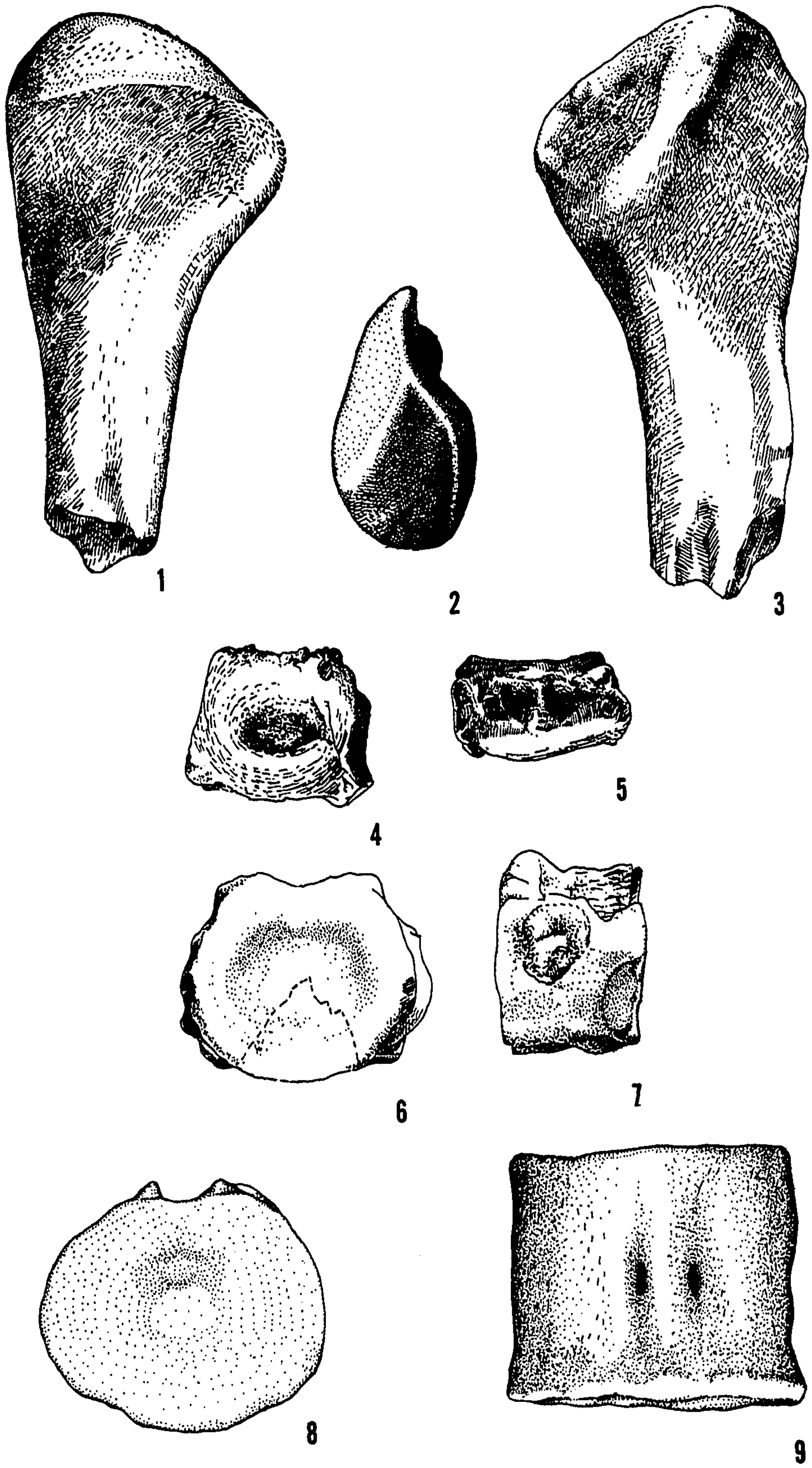


Plate 4

Special Material

1. Chelonia indet. Specimen ET 4393; Ozan condensed zone, near ET Locality 44. Dorsal view of eighth neural plate.

2. Chelonia indet. Same specimen. Ventral view showing bored surface.

3. Unidentified specimen *ET 4299; Roxton Limestone, near ET Locality 59. View of dorsal surface of dorsal (?) vertebra of mosasaur, showing oyster attached to neural arch and neural canal.

4. Clidastes propython Cope. Specimen *ET 4295; Roxton Limestone, ET Locality 36. Medial surface of maxilla with attached oyster.

5. Unidentified specimen *ET 4303; Roxton Limestone, ET Locality 51. View of worn mosasaur vertebra with oyster and worm tubes attached to surface; other surfaces of the specimen had attached barnacles.

6. Unidentified specimen ET 4319; Ozan Marl, near ET Locality 44. Partial mosasaur pubis showing scratches from shark gnawing.

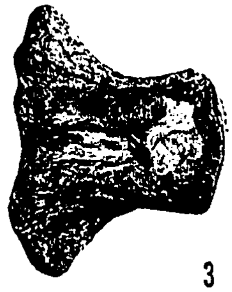
7. Unidentified specimen ET 4300; Ozan Marl (?), locality unknown. Dentary fragment showing partially healed tooth mark.

8. Polycotylus latipinnis Cope. Specimen *ET 4277; Roxton Limestone, ET Locality 36. Cross-section of broken rib, showing embedded shark tooth.

PLATE 4

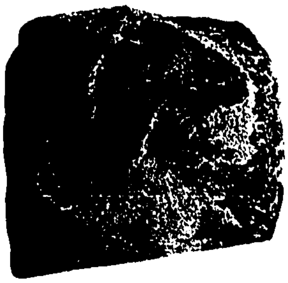
1

2



3

4



5

6

7

8

APPENDIX I

ET LOCALITIES

The following list shows East Texas State University collecting Localities (from which fossil vertebrates were taken) and Stations (from which stratigraphic information was taken). An asterisk (*) indicates those at which sections were measured.

Locality 35: streambed and bank about 100 yards south of unnamed county road 3.3 road miles northwest of Ladonia, Fannin County, on unnamed tributary of Davis Creek; upper third of Ozan Marls probably just below condensed zone; vertebrate and invertebrate specimens collected, grab samples taken.

Locality 36: streambed about 100 yards upstream from bridge on unnamed county road, 3/4 mile due east of Gober, Fannin County, on unnamed tributary of North Sulphur River; upper Roxton Limestone, in phosphate cast bed just below transition zone at the base of the Ozan marl; vertebrate and invertebrate specimens collected, grab samples taken.

Locality 37: side of channel, North Sulphur River, about 0.5 to 1.0 mile west of Ben Franklin, Delta County; near top of Ozan marl; vertebrate specimen collected.

*Locality 38: quarry just east of Texas Highway 38, 1.3 miles north of bridge on Cane Creek, north side of Roxton, Lamar County; upper Gober Chalk, Roxton Limestone, lower Ozan Formation; vertebrate and invertebrate specimens collected, grab samples and slabs taken.

Locality 39: "island" of large blocks, streambed of North Sulphur River channel, about 1.3 miles west of bridge on unnumbered county road just northwest of Ladonia, Fannin County; Ozan marls, condensed zone, carbonate sequence; vertebrate and invertebrate specimens collected, grab samples taken.

Locality 40: river bank, North Sulphur River channel, beside Locality 39; same strata and type of specimens collected.

Locality 41: "island" of large blocks in North Sulphur River channel about $\frac{1}{4}$ mile east of bridge on unnumbered county road 1.8 miles northwest of Ladonia, Fannin County; Ozan marls; vertebrate and invertebrate specimens collected.

*Locality 42: river bank, North Sulphur River channel, beside Locality 41; same strata and types of specimens collected.

Locality 43: streambed at bridge on dirt road 1.0 mile east of County Road 1552, and 3.1 miles east of intersection of Highway 78 and 1552 in Bailey, Fannin County; cast bed of Roxton Limestone, lower Ozan marls; vertebrate and invertebrate specimens collected, grab samples taken.

Locality 44: Streambed of North Sulphur River channel, just west of bridge on unnumbered county road 1.8 miles northwest of Ladonia, Fannin County; upper 1/3 of Ozan marls; vertebrate and invertebrate specimens collected.

*Locality 45: Streambed of Journigan Creek just east of bridge on Farm Road 904, 0.35 mile north of junction with Farm Road 2456, on Fannin-Delta County line, about 1.25 miles south of Pecan Gap; uppermost Pecan Gap Chalk, lower Marlbrock Marl; vertebrate and invertebrate specimens collected, grab samples taken.

Locality 48: river bed, North Sulphur River channel, 1-3/4 miles west of Ladonia, west of Locality 44; Ozan marls, condensed zone, vertebrate and invertebrate specimens collected.

Locality 49: Creekbed of Spring Creek, just south of Highway 1281, 5.5 miles northwest of intersection of 1281 and Texas Highway 34 in Wolfe City, Fannin County; Roxton Limestone; vertebrate specimen collected, grab sample taken.

Locality 50: roadcut on Farm Road 1563; 4.0 miles east of Wolfe City, in Hunt County; uppermost Wolfe City Formation, base and condensed zone of Pecan Gap Chalk; vertebrate and invertebrate specimens collected, grab samples taken.

Locality 51: streambed, Spring Creek, about $\frac{1}{4}$ mile south of ford on dirt road north of Farm Road 1281, just north of Locality 49; uppermost Gober Chalk, Roxton Limestone; vertebrate and invertebrate specimens collected, grab sample taken

Locality 52: small streambed, unnamed tributary of Bralley Pool Creek, behind deserted farm house, about 0.4 mile north west of Farm Road 1550, just west of Highway 34, junction of those two roads

Locality 52: (Continued)--in Bug Tussle, Fannin County; lower half of Ozan marls; vertebrate specimen donated.

Locality 53: river bank, North Sulphur River channel, north bank just west of bridge on Texas Highway 68, 2.1 miles southeast of Gober, Fannin County; lower 1/3 of Ozan marls; vertebrate and invertebrate specimens collected.

*Locality 54: roadcut south side of Farm Road 2456, 3.1 miles east of junction with Highway 11, just south of Ladonia, Fannin County; lower 1/3? of Pecan Gap Chalk; vertebrate and invertebrate specimens collected.

Locality 58: streambed of North Sulphur River channel, about 1 mile west of ford crossings at Slabtown, on dirt road south of Farm Road 1498, approximately 3.0 miles east of bridge on Highway 24 over North Sulphur River channel, south of Paris, Lamar County, Texas; upper Pecan Gap Chalk, lower Marlbrook Marl; vertebrate and invertebrate specimens collected.

Locality 59: streambed of unnamed tributary of Brushy Creek, approximately 2.6 (2.2 airline) miles east-northeast of Gober, Fannin County, Texas; Roxton Limestone; vertebrate specimens collected.

Station 2: Railroad cut 1.5 miles northeast of Wolfe City, in Hunt County (type locality); middle? Wolfe City Formation, including mollusc zone; invertebrate specimens collected, grab samples taken.

Station 3: streambed of small tributary of unnamed creek flowing into North Sulphur River, west of farm house near junction of Highways 34 and 68, north of Wolfe City, in Fannin County; upper 1/3 of Ozan marls; vertebrate specimen collected.

Station 4: streambed north of county road 1.5 miles northwest of junction with Texas Highway 64, 1.9 miles west of junction of 64 and Farm Road 904, Fannin County; upper Ozan marls just above carbonate sequence; invertebrate specimens collected.

Station 5: roadcut, county road, 0.5 mile north of Highway 64, 1.3 miles east of Ladonia, Fannin County; lower Wolfe City Formation; petrology samples taken.

Station 6: roadcuts on either side of Texas Highway 904 and Highway 64, west of Pecan Gap, in Fannin County; middle? Wolfe City Formation; invertebrate specimens collected, petrology samples taken.

Station 7: streambed of Merrill Creek, upstream from bridge on Texas Highway 34, 0.6 mile north of junction of 34 and Farm Road 1550 at Bug Tussle, Fannin County; lower Ozan marls; vertebrate and invertebrate specimens collected.

Station 8: streambed at point where small tributary enters Merrill Creek, northwest of bridge on Farm Road 1550, 0.9 mile east of junction of 1550 and Highway 34, at Bug Tussle, Fannin County; middle Ozan marls; vertebrate and invertebrate specimens collected.

Station 9: streambed of Merrill Creek, about 1.25 miles southeast (downstream) from bridge at Station 8; upper Ozan marls, condensed zone; invertebrate fossils collected.

Station 10: quarry on west side of Texas Highway 38, 0.5 mile north of bridge over Cane Creek, just north of Roxton, Lamar County; Roxton Limestone; vertebrate and invertebrate specimens collected, grab sample taken.

Station 11: streambed at, and north of, bridge on Texas Highway 38 at Roxton, Lamar County; upper Gober Chalk, Roxton Limestone; invertebrate specimens collected.

Station 12: streambed, as in Station 11, but downstream (south) to first bridge on east side of Roxton, Lamar County; Roxton Limestone, lower Ozan marls; invertebrate specimens collected.

Station 13: streambed, south of bridge on dirt road 0.8 mile west of Farm Road 2675, on Cane Creek, about 2.3 miles southeast of Roxton, Lamar County; upper? Ozan marls; invertebrate specimens collected.

Station 14: riverbed, North Sulphur River channel at bridge on Texas Highway 24, about 12 miles south of Paris, Lamar County; lower Marlbrook marls; vertebrate and invertebrate specimens collected.

Station 15: roadcut at farm house, 0.1 mile east of Locality 54, on Farm Road 2456; lower 1/3 Pecan Gap Chalk; invertebrate specimens collected.

Station 16: roadcut on Texas Highway 128, opposite dirt road, 1.2 miles east of junction of 128 and Farm Road 1533, east of Ben Franklin, Delta County; uppermost Wolfe City Formation, lower Pecan Gap Chalk; invertebrate specimens collected, grab sample taken.

Station 17: railroad cut, 0.5 mile east of Pecan Gap, Delta County (type locality); uppermost Wolfe City Formation, lower Pecan Gap Chalk; invertebrate specimens collected.

Station 18: abandoned quarry near farm house across Highway 128 from Station 17; lower Pecan Gap Chalk; invertebrate specimens collected, grab sample taken.

Station 19: streambed just east of bridge on dirt road, about 3/4 mile south of junction of the road and Highway 128, junction is 1.5 miles east of Pecan Gap, Delta County; vertebrate and invertebrate specimens collected.

Station 20: streambed just east of bridge on dirt road, 0.6 mile south of Station 19, about 1.25 miles south of junction with Highway 128, east-southeast of Pecan Gap, Delta County; upper Pecan Gap Chalk; invertebrate specimens collected.

Station 21: streambed east of bridge on dirt road, 3/4 mile north of junction with Farm Road 64, about 0.5 mile south of Station 20; lower Marlbrook Marl; vertebrate and invertebrate specimens collected, grab sample taken.

Station 22: streambed at bridge over dirt road, just east of Texas Highway 64, 0.8 mile south of Pecan Gap, Delta County; vertebrate and invertebrate specimens collected.

Station 23: roadcut at farm house, Texas Highway 128, 2.6 miles northeast of Pecan Gap, Delta County; lower (basal?) Pecan Gap Chalk; vertebrate and invertebrate specimens collected.

Station 24: streambed on dirt road just off Texas Highway 128, 2.7 miles southeast of Wolfe City limit, Hunt County; upper Pecan Gap Chalk; invertebrate specimens collected.

Station 25: streambed at bridge on dirt road, 1.4 miles south of Station 24 on unnamed tributary of south Sulphur River, Hunt County; invertebrate specimens collected.

Station 26: streambed of Honey Creek, at bridge on Texas Highway 34, 10.0 miles north of junction of 34 and Texas Highway 24 in Greenville, Hunt County; lower Marlbrook Marl; vertebrate and invertebrate specimens collected, grab sample taken.

Station 27: riverbed and bank, North Sulphur River channel, 1-$\frac{1}{4}$ miles west of new Ladonia bridge on Highway 34, 5 miles north of Ladonia, Fannin County, Texas; Ozan marl, condensed zone; vertebrate and invertebrate specimens collected.

Station 28: streambed of North Sulphur River channel, about $\frac{1}{4}$ mile west (upstream) from ET Locality 57, about 1-$\frac{1}{4}$ miles west (upstream) from bridge on Highway 24, over the North Sulphur

Station 28: (Continued)--River channel, about 10 miles south of Paris, Lamar County, Texas; Wolfe City? or upper Ozan Marl; invertebrate specimens collected.

Station 29: roadcuts on either side of Highway 24 at railroad underpass about 1 mile west of Cooper, Delta County, Texas; top? Marlbrook Marl; invertebrate specimens collected.

Station 30: streambed and banks on either side (east and west) of bridge on Highway 38 crossing North Sulphur River channel just north of Ben Franklin, Delta County, Texas; upper Ozan Marl; vertebrate and invertebrate specimens collected.

Station 31: streambed and banks on either side (east and west) of bridge on Highway 904 crossing the North Sulphur River channel 2.8 (1.9 airline) miles northwest of Pecan Gap, in Fannin County, Texas; upper Ozan Marl; vertebrate and invertebrate specimens collected.

Station 32: streambed and banks on either side (east and west) of bridge on Highway 34, 1.6 miles north of Ladonia, Fannin County, Texas; middle Ozan Marl; vertebrate and invertebrate specimens collected.

APPENDIX II

ADDITIONAL LOCALITIES

SMU Locality 1 - dumpheap for spillway, Bardwell Dam, Bardwell Reservoir 4.3 miles south of Ennis, Ellis County, Texas; Ozan condensed zone; vertebrate specimens collected by Ronnie Finch and Bob Slaughter, John Thurmond.

SMU Locality 2 - about 1 mile northeast of Bardwell reservoir, Ennis West 7.5' Quadrangle, 32° 16' 12" N, 96° 40' 58" W, Ellis County, Texas; Ozan condensed zone; vertebrate specimens collected.

SMU Locality 3 - outlet of Bardwell Dam, Bardwell Reservoir, Cryer Creek 7.5' Quadrangle, 32° 14' 55" N, 96° 35' 44" W, Ellis County, Texas; Ozan condensed zone; vertebrate specimens collected.

SMU Locality 4 - Hanna Johnson farm, 2 miles west-northwest of Farmersville, Collin County, Texas; Ozan condensed zone; vertebrate specimen collected by Bob Slaughter.

SMU Locality 5 - quarry on east side of Loop 12, at Ferguson Road, east side of Dallas, Dallas County, Texas; "Upper Austin"; vertebrate specimens collected.

TMM Locality 30962 - quarry (now abandoned and filled in) on Maurice Maness farm, 1.5 miles north of Roxton (approximately 2.0 miles north of town) west side of Highway 38, Roxton, Lamar County, Texas; Roxton Limestone; vertebrate and invertebrate specimens collected.

TMM Locality 40601 - creekbed just east of bridge, Texas Highway 308, 2.6 miles north of Malone, Hill County, Texas; Taylor Marl; vertebrate specimens collected.

TMM Locality 40890 - about 150 yards north of Locality 40606, on Little Walnut Creek, 2.2 miles east of intersection of U. S. 290 and U. S. 81, just north of LaSalle Drive, Austin, Travis County, Texas; Austin-Taylor contact?, perhaps uppermost Austin; vertebrate specimen collected.

TMM Locality 41166 - roadcut, New Maynor [sic] Road, 7.5 miles east of Austin, Travis County, Texas; lower? Pecan Gap Chalk; vertebrate specimens collected.

UTA Locality 1 - "Bailey, Texas" (Fannin County); Roxton Limestone; vertebrate specimens collected.

UTA Locality 2 - "North Waco", McLennan County, Texas; "Lower Taylor"; vertebrate specimen collected.

UTA Locality 3 - creekbed near Riesel, 10 miles southeast of Waco, McLennan County, Texas; Wolfe City Formation; vertebrate specimen collected.

UTA Locality 4 - 1.5 miles northeast of Riesel, McLennan County, Texas; Wolfe City Formation; vertebrate specimen collected.

USNM Locality 1 - gully on north-facing slope of North Sulphur Creek, about 1.1 mile west of Paris-Greenville highway, Delta County, Texas; lower Pecan Gap Chalk?; vertebrate specimen collected.

USNM Locality 2 - "near Farmersville" (Collin County, Texas); horizon unknown; vertebrate specimen collected.

USNM Locality 3 - one mile east of Culeoka, Lavon Reservoir area, Collin County, Texas; "Taylor Formation," probably Ozan condensed zone; vertebrate specimen collected.

APPENDIX III

STRATIGRAPHIC DATA

Descriptions of measured sections plotted on the chart (in pocket) are included here. Strata at these localities are horizontal, with 1-3° dips to the south or southeast. Strikes are approximately northeast-southwest.

Table 4 shows data obtained from study of thin sections (on repository at University of Oklahoma), which are listed for future comparison. The following abbreviations are used: biomic, biomicrite, foss, fossiliferous, immat, immature (texture), mat, mature (texture, or carbonate in matrix, in %CO_3 column), mic, micrite, glauc, glauconite, orthoqtzt, orthoquartzite, pa, packed, qtz, quartz, sort, sorting, sp, sparse, tr, trace.

Table 5 summarizes results of insoluble residue study of seven selected samples.

Thin sections from samples not shown on measured sections (in pocket) are listed for reference.

Measured Section 1, Locality 38

Base is floor of quarry, top is hilltop; strike and dip undetermined, but strata essentially horizontal.

Unit	Description	Feet	Inches
6	Covered interval to hilltop	?	?
5	Ozan Marl; gray, blocky, weathers dark gray, white carbonate nodules on surface . . .	8-10	0
4	Roxton-Ozan transition zone; biomicrite, gray-tan, weathers tan, base gradational thin irregular bedding, ironstone fossil casts, oysters, clionids, Inoceramus, Baculites, Scaphites, other ammonites, nautiloids, teeth (one enchodontid) . . .	2	1
3	Roxton Limestone; biomicrite, tan, weathers tan to light gray-tan, with streaks and blotches of red, maroon and yellow iron oxide stains, base gradational, lower part massive, upper part thin bedded, rest is cross-bedded, with planes 1 to ½ feet, bioturbated, invertebrates, Inoceramus, Baculites, oysters, mosasaur, shark teeth	6	1
2	Gober-Roxton transition zone; biomicrite, like unit 1 but gradually sandier texture upward	2	0
1	Gober Chalk; biomicrite, grayish blue, weathers brownish, white or tan, massive, bioturbated, invertebrates, shark tooth . .	1	0
	Total Thickness	19-21	2

Measured Section 2, Locality 54

Base is ditch by roadcut, lowest exposure seen, top is hilltop; strike and dip undetermined.

Unit	Description	Feet	Inches
4	Covered interval to hilltop	20	8
3	Pecan Gap Chalk; biomicrite, gray, weathers lighter gray, nodular, invertebrates, coral, *Inoceramus*, *Turrilites*	6	0
2	Pecan Gap Chalk; biomicrite, gray tan, light gray, weathers pale gray, bedding irregular, weathers platy, scattered fish scales and invertebrates top and 3 feet above base has many burrows lined with fish remains	5	2
1	Pecan Gap Chalk; biomicrite, gray, weathers light gray to white, irregular patches of limonite stain, irregular bedding, nodular, echinoids.	1	6
	Total Thickness	33	4

Measured Section 3, Station 1

Base of section ditch by roadside, top is eroded surface of pit; strike and dip undetermined.

Unit	Description	Feet	Inches
6	Roxton Limestone: biomicrite, tan, weathers gray to dirty gray, sandy, contact with unit 5 irregular, gradational, few fish scales, invertebrates, burrows	2	0
5	Roxton Limestone?: biomicrite, tan to creamy, weathers cream to white, massive irregular beds	2	6
4	Covered interval	5	0
3	Gober Chalk: biomicrite, same as top of unit 1, but weathers creamy	1	0
2	Covered interval	4	2
1	Gober Chalk: biomicrite, gray, tan, weathers gray, weathers to small chips, flakes, upper part slabbier, limonite streaks, fish scales, invertebrates, oysters, *Inoceramus* . . .	20	8
	Total Thickness	34	4

Measured Section 4, Locality 42

Base of section is streambed, top is covered interval to hilltop; strike and dip undetermined but strata essentially horizontal.

Unit	Description	Feet	Inches
9	Ozan marl: same as unit 3	0	8
8	Ozan marl: biomicrite, same as unit 4 but thicker and blockier	0	2-3
7	Ozan marl: same as unit 3	1	6
6	Ozan marl: biomicrite, same as unit 4 but blockier	0	6
5	Ozan marl: marl, same as unit 3 but with patchy biomicrite bed near middle . . .	1	6
4	Ozan marl: biomicrite, thin, shaly, light gray, weathers lighter gray . . .	0	2-3
3	Ozan marl: marl, dark gray, weathers black to gray, platy to lumpy, weathers to flakes.	3	2
2	Ozan condensed zone: biomicrite, marly, dark greenish gray, weathers brownish red, glauconitic, surface weathers to uneven lumpy appearance due to ironstone concretions and fossil casts, many black casts and concretions, microfossils, invertebrates, <u>Inoceramus</u>, <u>Baculites</u>, <u>Hamites</u>, other ammonites, bone chips, teeth	1	0
1	Ozan marl: dark greenish gray, weathers black to gray, platy and flaky, invertebrates	1	6
	Total Thickness	9	2-4

Measured Section 5, Locality 45

Base is streambed, top is covered interval to hilltop; strike and dip undetermined, essentially horizontal.

Unit	Description	Feet	Inches
4	Marlbrook Marl: brownish gray, weathers light gray, blocky, chalky, invertebrates, oysters, base is burrowed into unit below	1	0
3	Pecan Gap Chalk: biomicrite, light gray, weathers lighter gray, bedding irregular, weathers to slabs, slightly glauconitic, pyrite nodules, invertebrates	1	2
2	Pecan Gap Chalk: biomicrite, light gray, weathers lighter gray, thin bedding, glauconitic, algal nodules, invertebrates, *Inoceramus*, oysters, burrows lined with fish remains, bone fragments .	2	0
1	Pecan Gap Chalk: biomicrite, bluish gray, weathers light gray, massive, bioturbated, few invertebrates	2	0
	Total Thickness	5	3

Table 4

Thin Section Information

Slide	% foss.	% qtz.	% glauc.	% PO_4	% CO_3	% clasts	Texture	Sort.	Name
Gober:									
1177	20-25	--	--	--	mat	--	immat.	poor	sp.biomic.
1178	20	--	--	--	mat	--	immat.	poor	sp.biomic.
1179	15-20	tr	tr	--	mat	--	immat.	poor	sp.biomic.
1180	25	--	--	tr	mat	--	immat.	poor	sp.biomic.
1181	30-35	tr	tr	--	mat	--	immat.	poor	sp.biomic.
1184	5	--	tr	tr	mat	--	immat.	poor	fos. mic.
Roxton:									
1182	50	1	1	tr	mat	(1)	immat.	poor	pa.biomic.
1183	50-60	3	3	tr	mat	--	immat.	poor	pa.biomic.
1184	50	3	1-3	tr	53.8	tr	immat.	poor	pa.biomic.
1186	50	3	2	tr	mat	tr	immat.	poor	pa.biomic.
1187	60	1	3	tr	mat	--	immat.	poor	pa.biomic.
1188	50	tr	1	5	mat	tr	immat.	poor	pa.biomic.
1189	50	½	½	½-1	mat	few	immat.	poor	pa.biomic.
1190	50	tr	1	1	mat	tr?	immat.	poor	pa.biomic.
1191	50	1	1	1	mat	tr	immat.	poor	pa.biomic.
1192	25-30	1	½	1	mat	few	immat.	poor	sp.biomic.

Table 4--(Continued)

Slide	% foss.	% qtz.	% glauc.	% PO_4	% CO_3	% clasts	Texture	Sort.	Name
Ozan:									
1193	7	½	--	--	mat.	--	--	--	marl
1194	7-10	1	tr	tr	mat	--	--	--	marl
1195	5	1	tr	--	mat	--	--	--	marl
1196	3-5	--	--	tr	mat	--	--	--	marl
1198	--	--	--	--	---	--	--	--	marl
1199	3	2	tr	tr	38.8	--	--	--	marl
1202	5	2	tr	tr	mat	--	--	--	marl
1203	3	tr	tr	--	mat	--	--	--	marl
1204	5	tr	tr	--	37.8	--	--	--	marl
1206	5	1	tr	tr	mat	tr	--	--	marl
Ozan, carbonate beds:									
1200	25	½	tr	--	37.8	--	immat.	poor	sp.biomic.
1201	10	1	tr	tr	mat	--	immat.	poor	sp.biomic.
1207	5	tr	tr	tr	mat	--	immat.	poor	fos. mic.
1208	5	tr	tr	tr	mat	--	(mat)	good	fos. mic.
Ozan, condensed zone:									
1197	20	7	10	3	29.0	tr	immat.	poor	sp.biomic.
1205	5	1	25	5	mat	few	immat.	poor	sp.biomic.
1223	10	1	7	½	mat	½	immat.	poor	sp.biomic.

Table 4--(Continued)

Slide	% foss.	% qtz.	% glauc.	% PO_4	% CO_3	% clasts	Texture	Sort.	Name
Wolfe City:									
1209	tr	50	tr	tr	mat	--	---	good	orthoqtzt.
1210	tr	40	tr	tr	mat	few	---	good	orthoqtzt.
1211	20	40	tr	tr	mat	--	---	good	orthoqtzt.
1212	--	40	tr	tr	mat	--	---	good	orthoqtzt.
Pecan Gap:									
1213	30	tr	tr	--	mat	--	immat.	poor	sp.biomic.
1214	30	1	tr	tr	mat	--	immat.	poor	sp.biomic.
1215	20	tr	7	--	mat	--	immat.	poor	sp.biomic.
1216	30	tr	3	tr	mat	1	immat.	poor	sp.biomic.
1217	30	tr	tr	tr	mat	--	immat.	poor	sp.biomic.
1218	30	tr	10	$\frac{1}{2}$	mat	1	immat.	poor	sp.biomic.
1219	25	tr	$\frac{1}{2}$	tr	mat	--	immat.	poor	sp.biomic.
Marlbrook:									
1220	25	--	tr	tr	mat	--	---	—	marl
1221	10	tr	--	tr	mat	1	---	—	marl
1222	15	tr	tr	tr	mat	few	---	—	marl

Table 5

Insoluble Residues of Selected Samples

Unit Name	Sample Number	Initial Weight	Residue Weight	% Carbonate
Roxton	1185	50g.	23.1g.	53.8
Ozan	1189	50g.	30.6g.	38.8
Ozan: condensed zone	1197	50g.	35.5g.	29.0
Ozan: carbonate bed	1200	50g.	31.1g.	37.8
Ozan	1204	50g.	31.1g.	37.8
Wolfe City	1212	50g.	49.1g.	0.8
Marlbrook	1221	50g.	31.2g.	37.6

List of Grab Samples for Thin Sections

OU 1184: Gober Chalk, quarry at Leonard, Fannin County.

OU 1185: Roxton Limestone, from Locality 36.

OU 1205: Ozan condensed zone, from Locality 39.

OU 1206: Ozan Marl above 1205, from Locality 39.

OU 1207: Ozan Marl, carbonate bed #2, near Locality 41.

OU 1208: Ozan Marl, carbonate bed #6, near Locality 41.

OU 1209: Wolfe City Formation, Station 2.

OU 1210: Wolfe City Formation, Station 6.

OU 1211: Wolfe City Formation, "*Exogyra* reef," mollusc zone, Station 6.

OU 1212: Wolfe City Formation, above mollusc zone, Station 6.

OU 1213: Pecan Gap Chalk, lower nodular zone, Station 15.

OU 1214: Pecan Gap Chalk, upper zone, Station 15.

OU 1215: Pecan Gap Chalk, creekbed approximately 1 mile west of Locality 54.

OU 1216: Pecan Gap Chalk, upstream, same locality as 1215.

OU 1217: Pecan Gap Chalk, uppermost exposed chalk, same locality as 1215.

OU 1222: Marlbrook Marl, 3 feet below top, Station 26.

OU 1223: Ozan Marl, concretion from condensed zone, Locality 39.

APPENDIX IV

SPECIMEN MEASUREMENTS, TABLES 6-8

In the following tables, all measurements are maximum and are given in millimeters. The following abbreviations are used: ant., anterior, caud., caudal, cerv., cervical, dor., dorsal, pec., pectoral, post., posterior, pyg., pygal, sac., sacral. The letter "a" following a measurement indicates that the anterior articular surface was measured, and a letter "p", the posterior one. Measurements in parentheses are approximate.

Skull measurements follow those of Russell (1967, Appendix A, Table 1, p. 208, 209): A, length of skull along midline; B, length of premaxillary rostrum; C, width of frontal between orbits; D, length between first and sixth maxillary tooth; E, height of quadrate; F, length of lower jaw, G; length of dentary; H, length between first and sixth dentary tooth

Table 6

Mosasaur Skull Measurements

Name	Specimen Number	A	B	C	D	E	F	G	H
<u>Clidastes propython</u>	ET 4295	--	--	--	(105)	--	--	(420)	(97)
	ET 4298	--	--	--	--	67	--	--	--
	TMM 30962-8	--	--	--	--	74	--	--	--
<u>Platecarpus somenensis</u>	SMU 61617	--	--	--	140	--	--	--	140
<u>Tylosaurus proriger</u>	ET 4276	--	--	--	235	127	--	--	--
<u>Tylosaurus</u> sp.	SMU 62504	--	--	--	--	(66)	--	--	--
	DMNH uncat	--	770	--	--	--	--	--	390

Table 7

Mosasaur Vertebral Measurements

Specimen Name	Number	Position	Height	Width	Length
<u>Clidastes</u> <u>propython</u>	ET 4278	sacral	39a	39	38
	ET 4295				
	L-91-2	pygal	38p	38	41
	L-81	ant. dor.	29a	41	57
	L-81	post. pyg.	26p	31	26
<u>Clidastes</u> sp.	ET 4349	dorsal	36	--	61
	SMU 62098	dorsal	25	39a	61
<u>Mosasaurus</u> <u>conodon</u>	ET 4314	caudal	38	34	39
	ET 4353	caudal	39	40a	42
<u>Platecarpus</u> sp.	ET 4311	caudal	50a	48	49
<u>Halisaurus</u> sp.	ET 4339	cervical	48a	62	--
	ET 4371	cervical	--	38	41
	ET 4367	dorsal	32a	46	48
<u>Tylosaurus</u> sp.	ET 4350:				
	L-80-1	post. cerv.	54p	59	75
	L-80-7	dorsal	53p	74	81

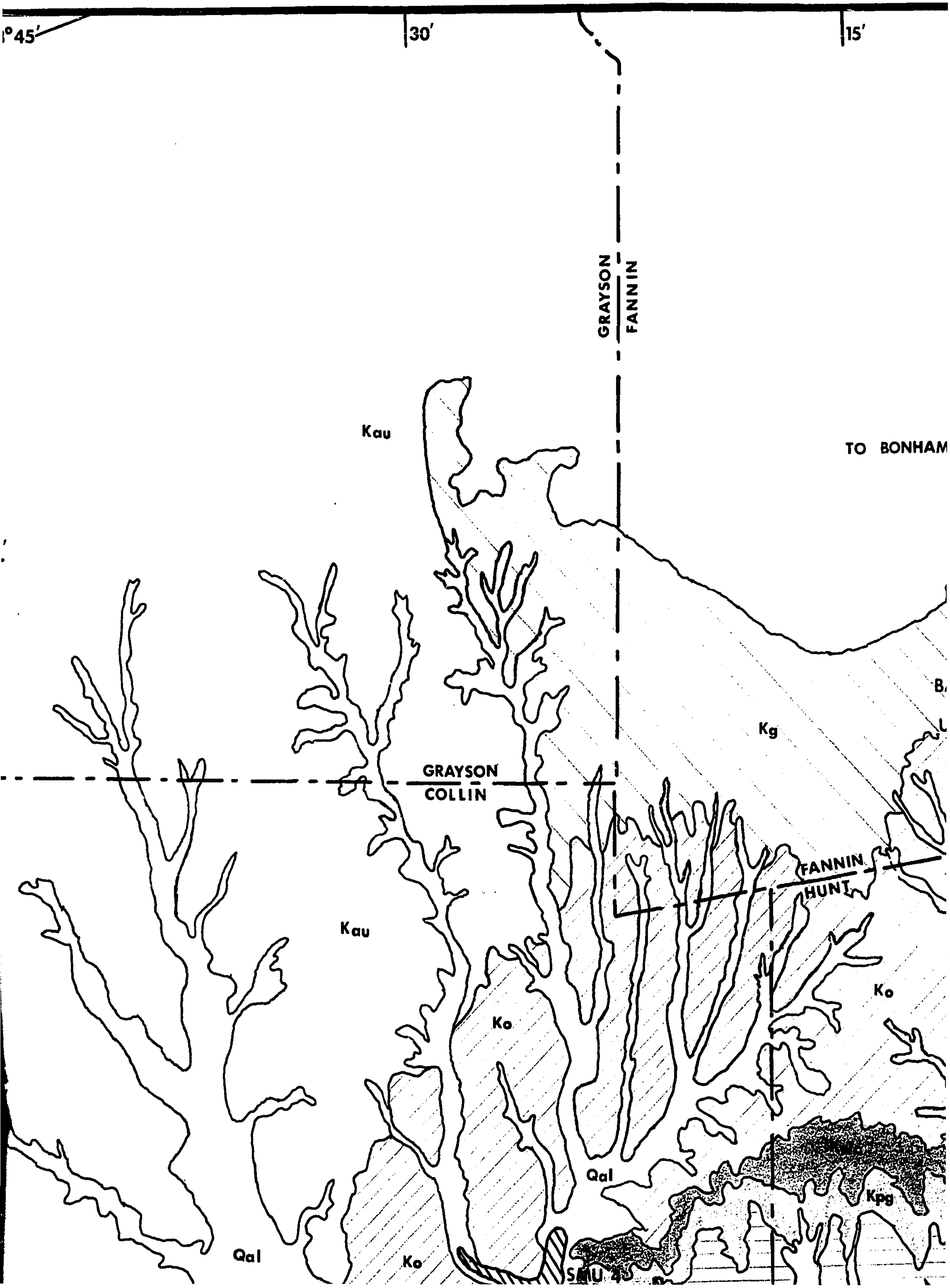
Table 7--(Continued)

Specimen Name	Number	Position	Height	Width	Length
Tylosaurus sp.	(Continued)				
	ET 4350:				
	L-80-11	post. dor.	63p	70	77
	L-80-13	"sac."	64p	68	66
	L-80-19	pygal	62p	63	55
	ET 4275:				
	L-94-25	ant. pyg.	92p	105	81
	L-94-19	pygal	74p	--	61
	L-94-18	post. pyg.	70p	71	39
Tylosaurus sp.	SMU 62505:	ant. cerv.	33p	40	56
		ant. dor.	39p	44	64
		post. dor.	48p	53	69
		"sacral"	55p	57	62
		pygal	59p	54	55
	ET 4379	cervical	84	91	97
	ET 4384	dorsal	--	--	100
	ET 4279	ant. dor.	44p	58	(73)
	UTA uncat.	post. dor.	73	103	94
	UTA uncat.	pygal	99a	101	87
	ET 4357	post. dor.	--	45	47
	ET 4336	caudal	84	94	67

Table 8

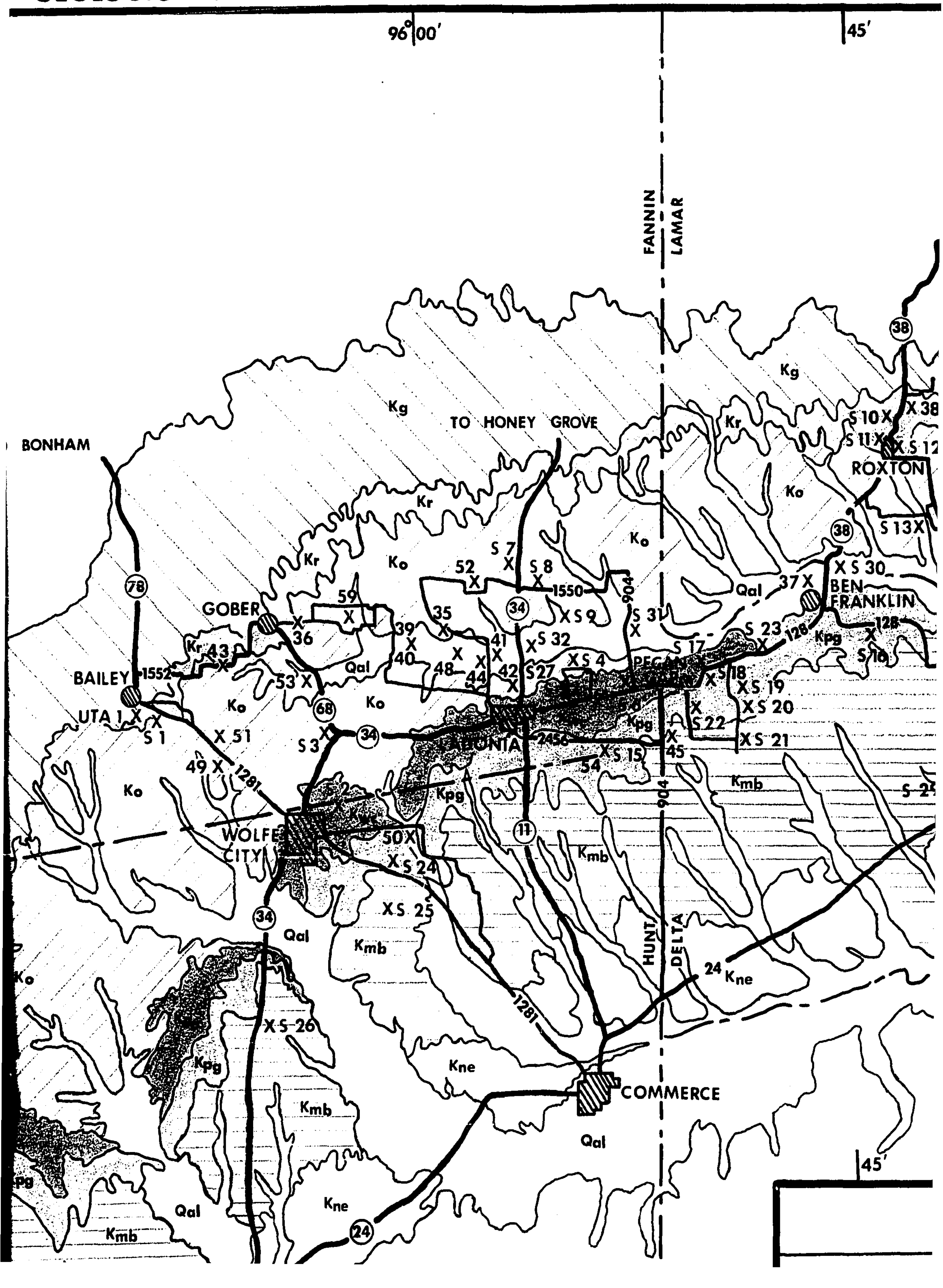
Plesiosaur Vertebral Measurements

Specimen Number	Specimen Name	Height	Width	Length
ET 4277	<u>Polycotylus latipinnis</u>			
	L-85-22 pec.	69a	80	36
	L-85 ant. dor.	71a	81	46
	L-85-17 dor.	85p	85	54
	L-85 dor.	80a	84	54
	L-85-20 ant. caud.	78a	89	45
	L-85-29a caud.	68p	74	--
ET 4313	Pliosaurid indet.	--	45	--
ET 4316	Pliosaurid indet.	53	63	38
ET 4317	Elasmosaurid indet.	70	--	68

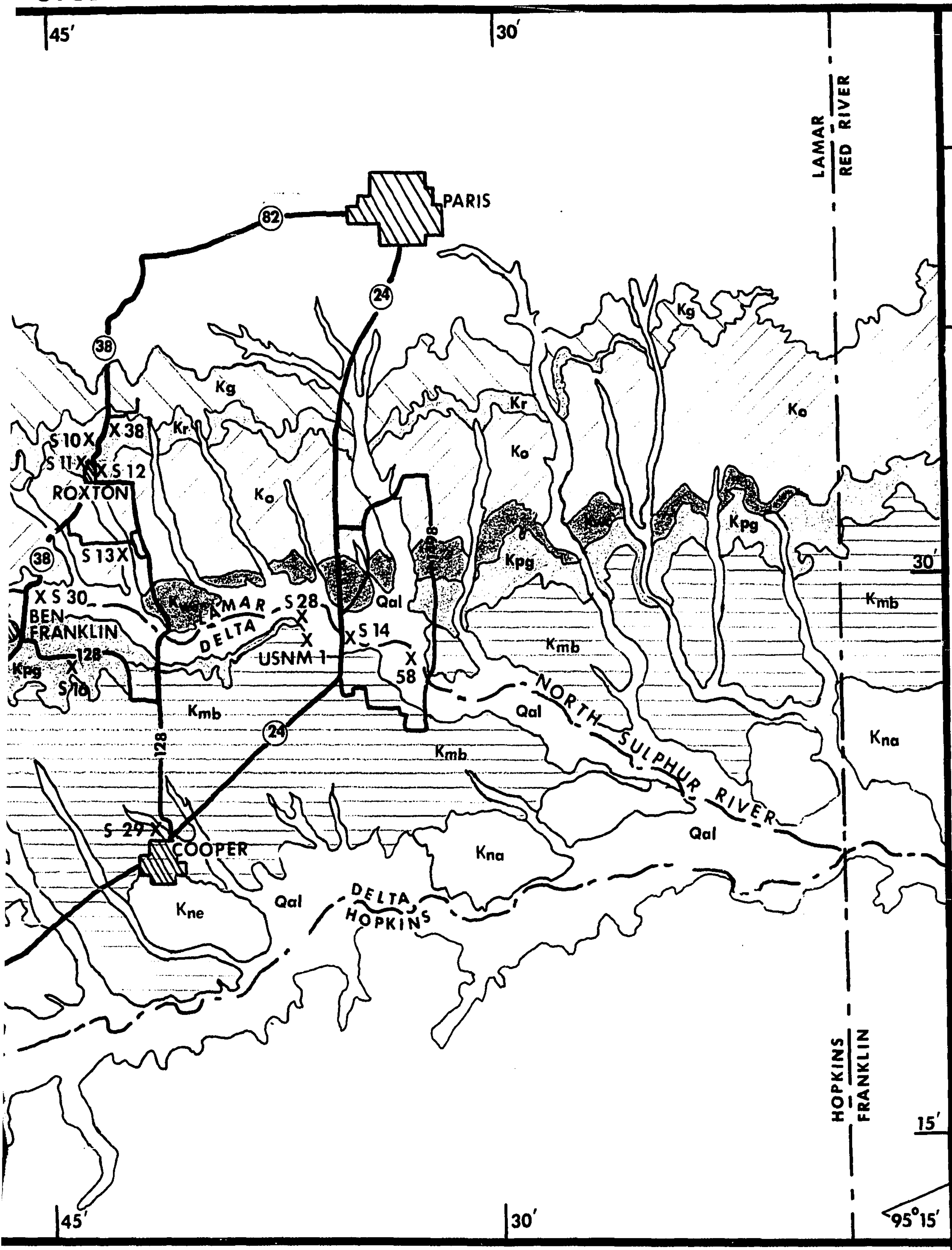


°45′
30′
15′
GRAYSON
FANNIN
Kau
TO BONHAM
Kg
GRAYSON
COLLIN
FANNIN
HUNT
Kau
Ko
Ko
Qal
Kpg
Qal
Ko
SMU 2

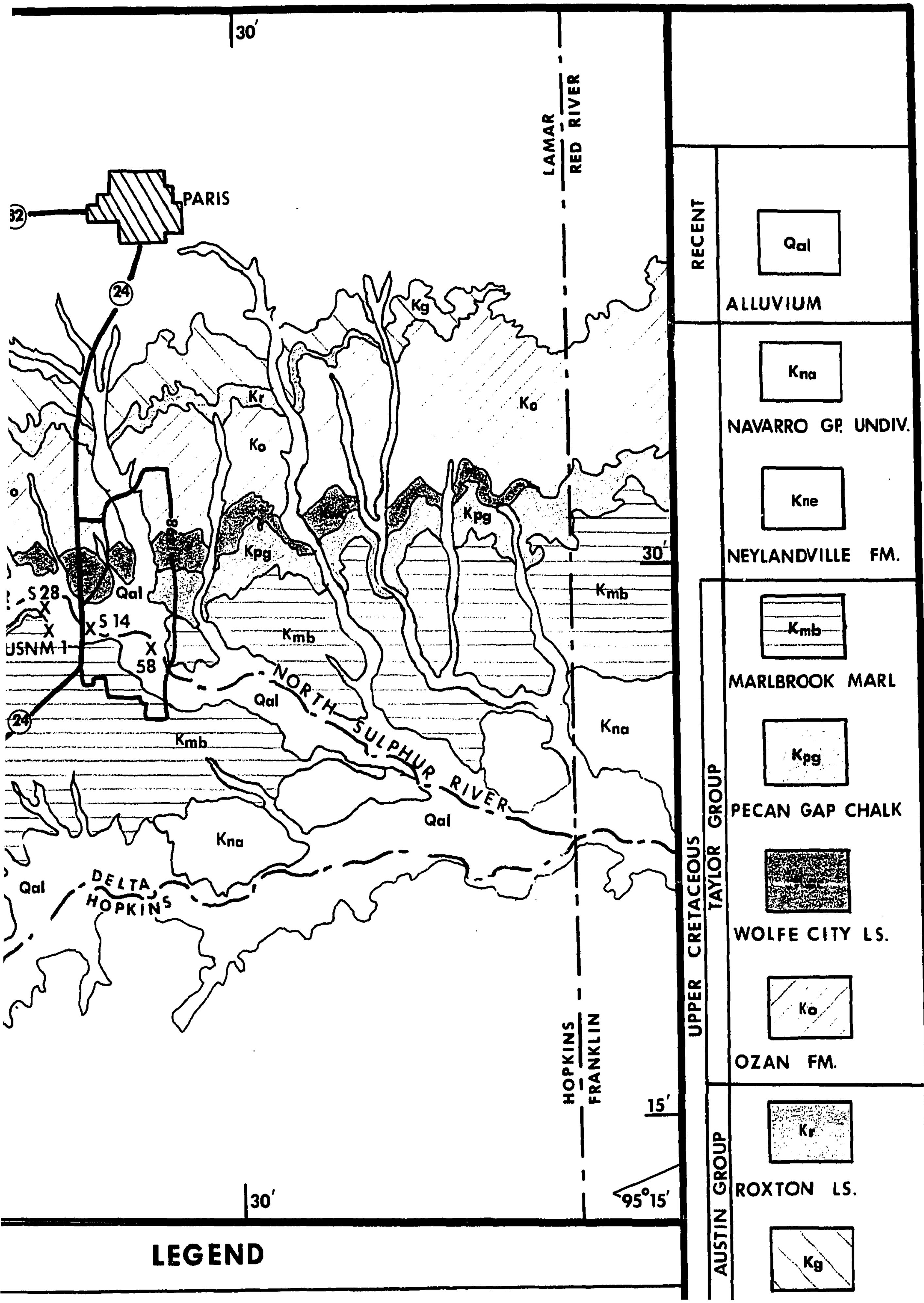
GEOLOGIC MAP SHOWING VERTEBRATE LOCALITIES IN STUDY



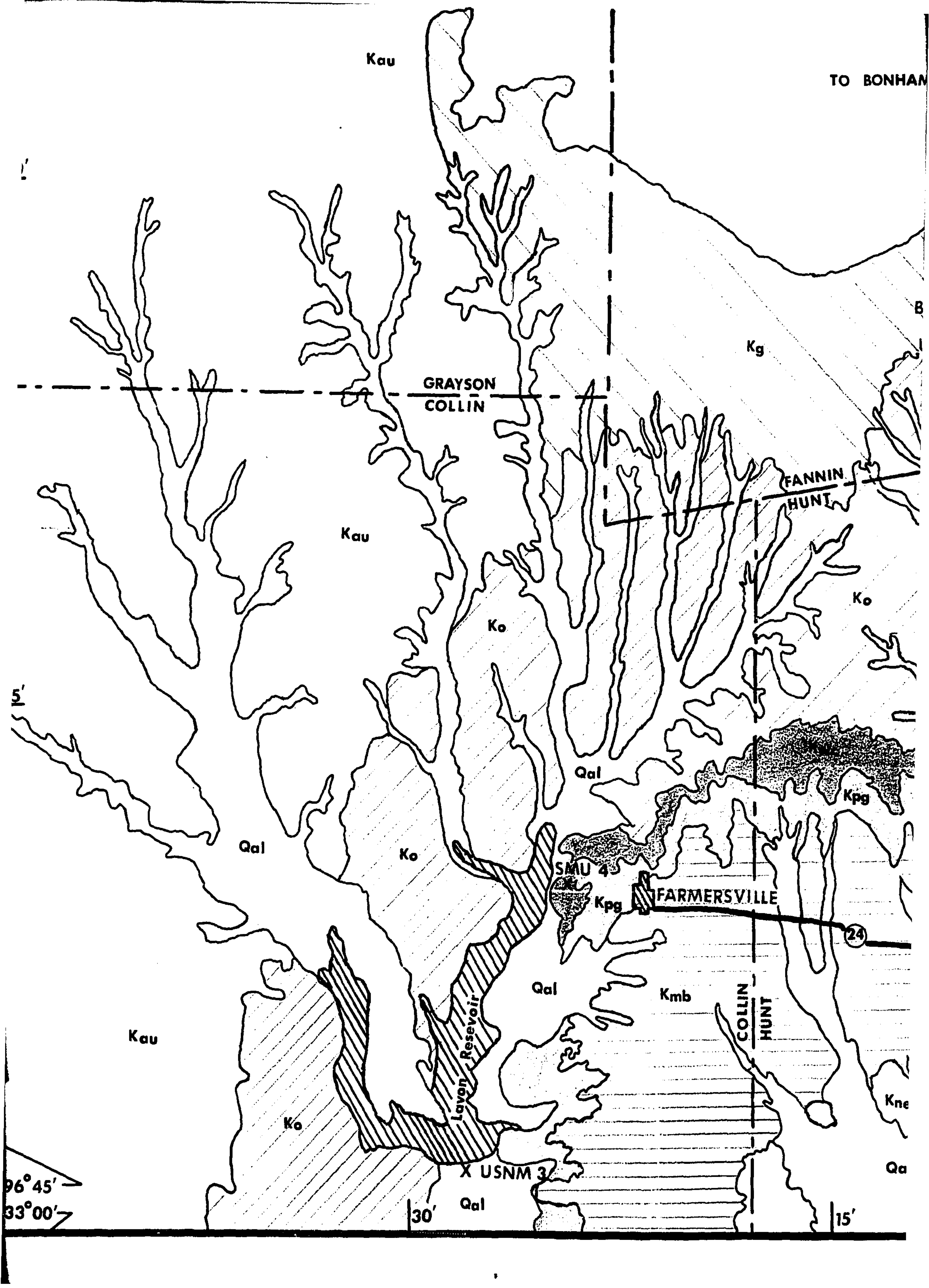
STUDY AREA

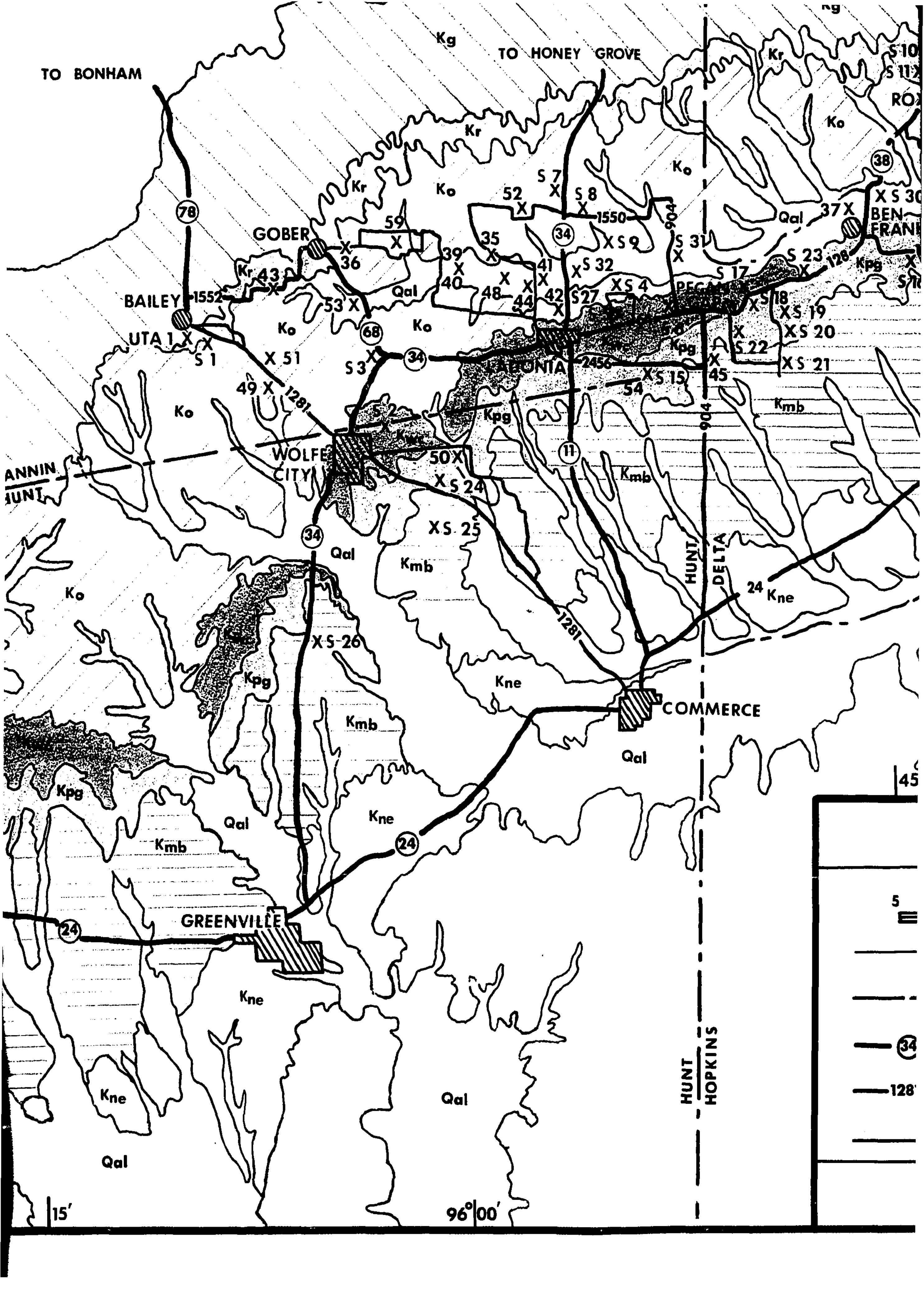


LEGEND

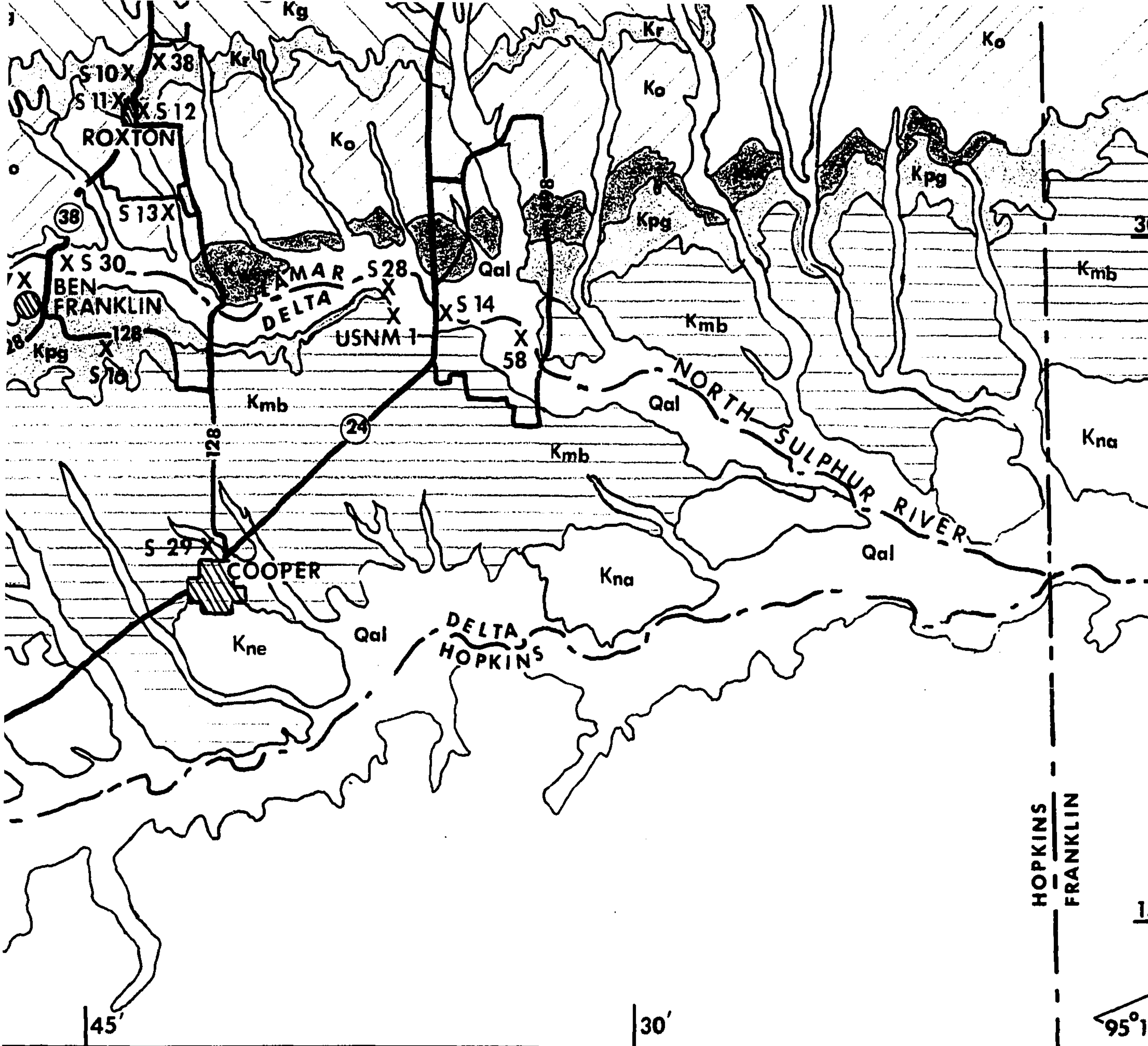


30′
LAMAR
RED RIVER
PARIS
32
24
Kg
Kr
Ko
Kpg
Qal
S 28
S 14
USNM-1
58
Kmb
NORTH SULPHUR RIVER
Kna
DELTA
HOPKINS
HOPKINS
FRANKLIN
15′
95°15′
LEGEND
RECENT
Qal
ALLUVIUM
Kna
NAVARRO GP. UNDIV.
Kne
NEYLANDVILLE FM.
UPPER CRETACEOUS
TAYLOR GROUP
Kmb
MARLBROOK MARL
Kpg
PECAN GAP CHALK
WOLFE CITY LS.
Ko
OZAN FM.
AUSTIN GROUP
Kr
ROXTON LS.
Kg


Kau
TO BONHAM
Kg
GRAYSON
COLLIN
FANNIN
HUNT
Kau
Ko
Ko
Qal
Kpg
Qal
Ko
SMU 4
Kpg
FARMERSVILLE
24
Qal
Kmb
COLLIN
HUNT
Lavon Resevoir
Kau
Ko
Kne
Qa
X USNM 3
96°45′
33°00′
30′
Qal
15′



TO BONHAM
Kg
TO HONEY GROVE
Kr
Ko
Kpg
Kmb
Kne
Qal
78
GOBER
BAILEY
1552
UTA 1
S 1
X 51
49
1281
43
36
53
59
68
S 3
34
35
39
40
48
44
41
42
S 7
S 8
52
1550
904
S 31
S 9
S 32
S 27
S 4
S 17
S 23
37
38
BEN
FRANK
128
S 18
S 19
S 20
S 21
S 22
45
2456
S 15
54
LADONIA
PECAN
S 2
WOLFE CITY
50
S 24
S 25
S 26
11
FANNIN
HUNT
DELTA
HOPKINS
24
COMMERCE
GREENVILLE
S 10
S 11
15′
96°00′



LEGEND

Scale 1: 250,000

5 0 5 10 15 20 Miles

FORMATION CONTACT

COUNTY BOUNDARY

34 STATE HIGHWAY

1281 FARM TO MARKET ROAD

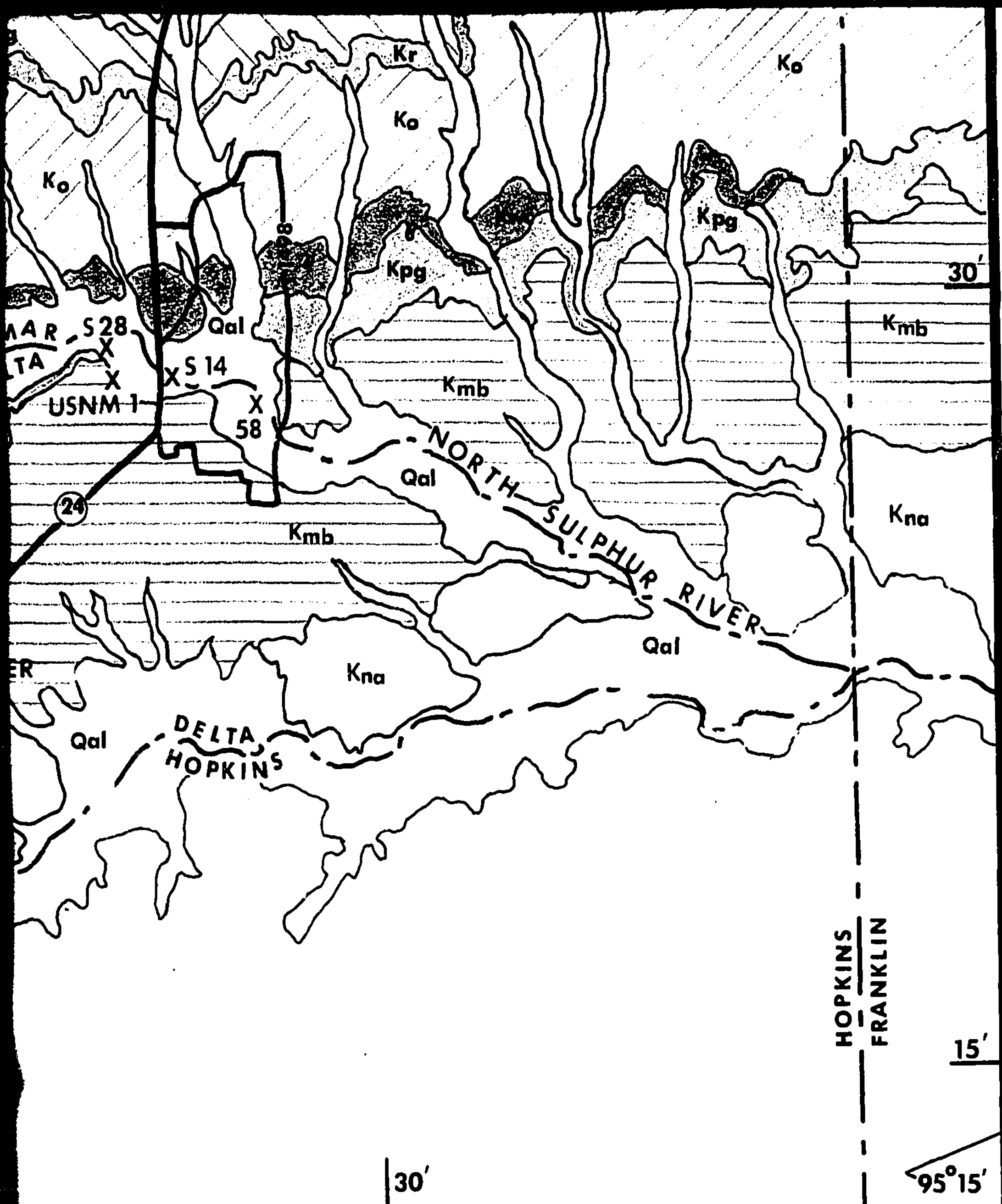
BLADED EARTH ROAD

XS 38 STATION

X 50 LOCALITY

FOR OTHER SYMBOL DESIGNATIONS SEE APPENDIX

BASE MAPS: GEOLOGIC ATLAS OF TEXAS, TEXARKANA SHEET, 1966
GEOLOGIC ATLAS OF TEXAS, SHERMAN SHEET, 1967



Kna
NAVARRO GP. UNDIV.

Kne
NEYLANDVILLE FM.

UPPER CRETACEOUS

TAYLOR GROUP

Kmb
MARLBROOK MARL

Kpg
PECAN GAP CHALK

WOLFE CITY LS.

Ko
OZAN FM.

AUSTIN GROUP

Kr
ROXTON LS.

Kg
GOBER CHALK

Kau
AUSTIN GP. UNDIV.

LEGEND

Scale 1: 250,000

5 10 15 20 Miles

ON CONTACT

BOUNDARY — XS 38 STATION

GHWAY — X 50 LOCALITY

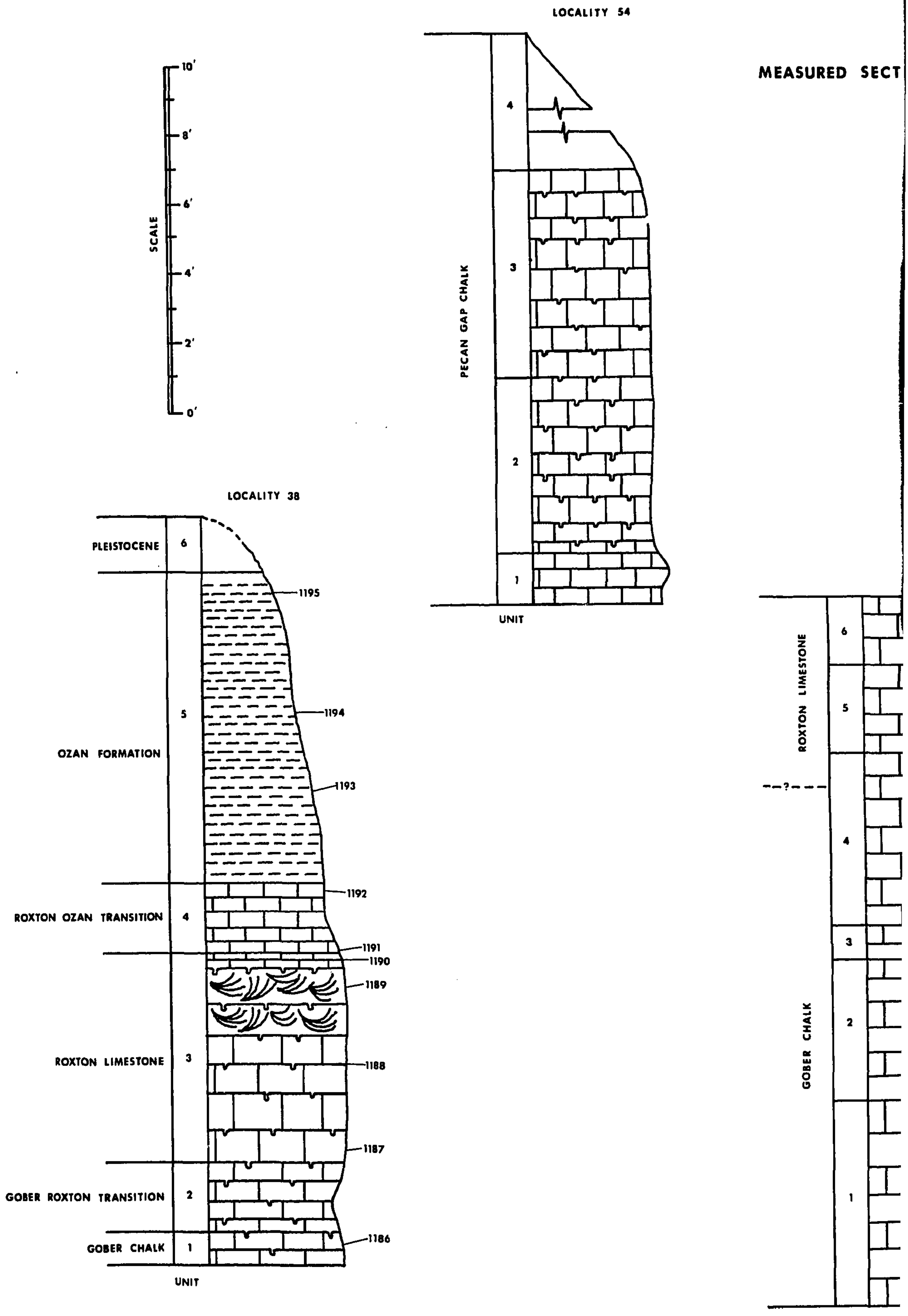
MARKET ROAD

EARTH ROAD

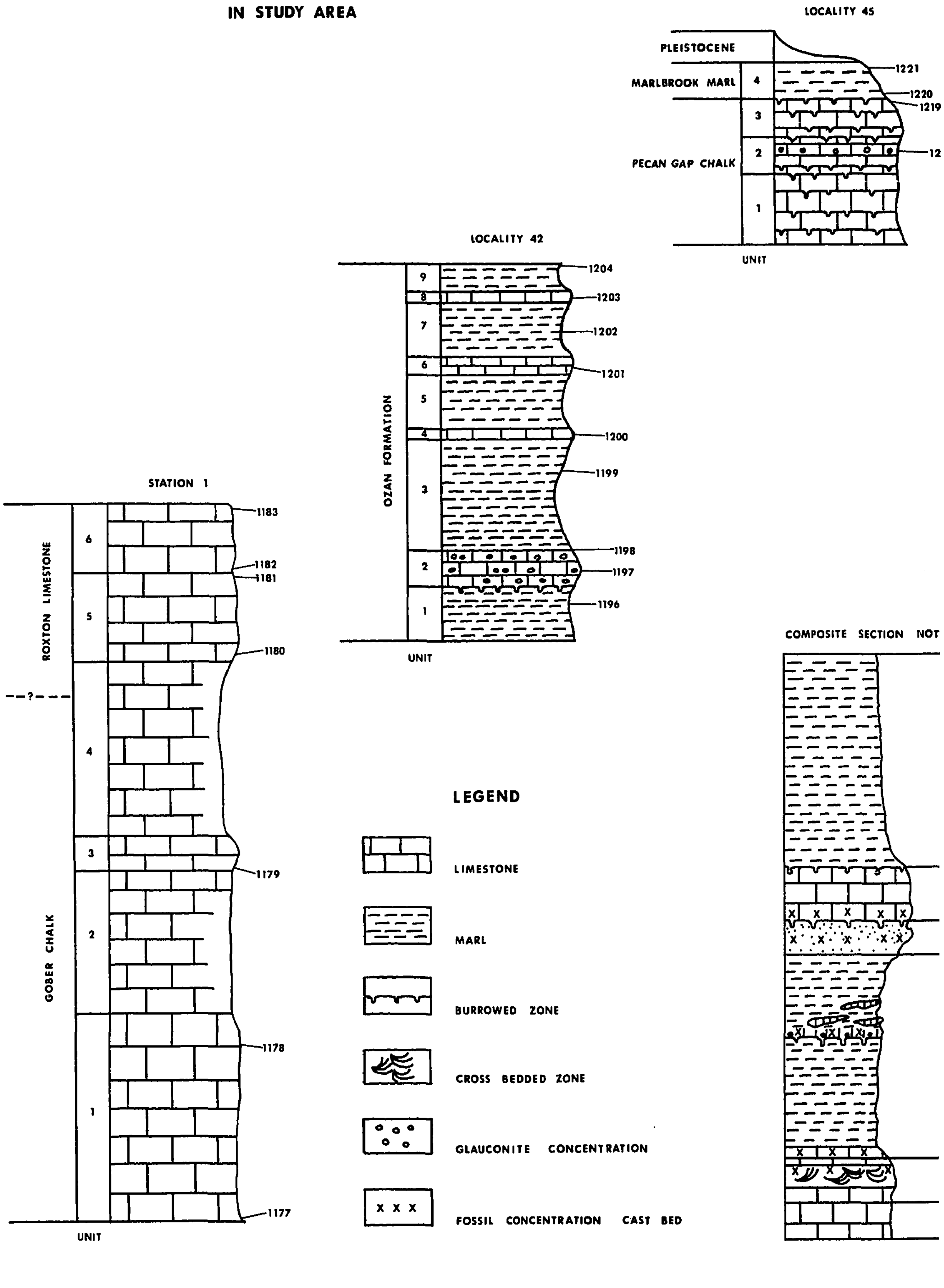
FOR OTHER SYMBOL DESIGNATIONS SEE APPENDIX

GEOLOGIC ATLAS OF TEXAS, TEXARKANA SHEET, 1966

GEOLOGIC ATLAS OF TEXAS, SHERMAN SHEET, 1967


MEASURED SECT
SCALE
10'
8'
6'
4'
2'
0'
LOCALITY 54
PECAN GAP CHALK
4
3
2
1
UNIT
LOCALITY 38
PLEISTOCENE
6
OZAN FORMATION
5
ROXTON OZAN TRANSITION
4
ROXTON LIMESTONE
3
GOBER ROXTON TRANSITION
2
GOBER CHALK
1
UNIT
1195
1194
1193
1192
1191
1190
1189
1188
1187
1186
ROXTON LIMESTONE
6
5
--?--
4
3
GOBER CHALK
2
1
UNIT

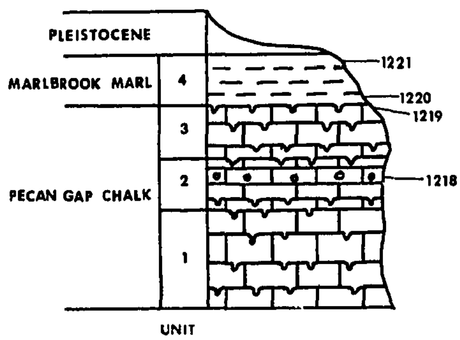
MEASURED SECTIONS OF UPPER AUSTIN AND TAYLOR GROUPS IN STUDY AREA



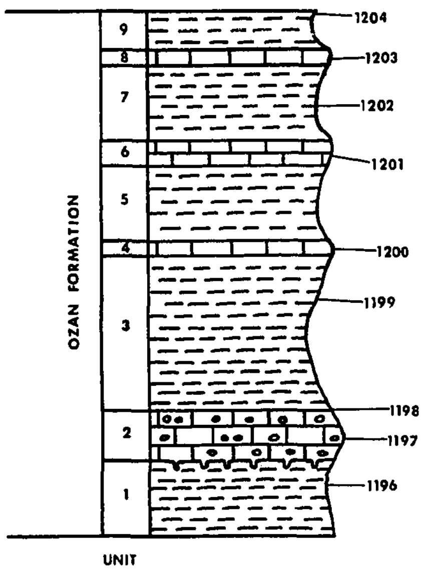
'ER AUSTIN AND TAYLOR GROUPS

TUDY AREA

LOCALITY 45



LOCALITY 42

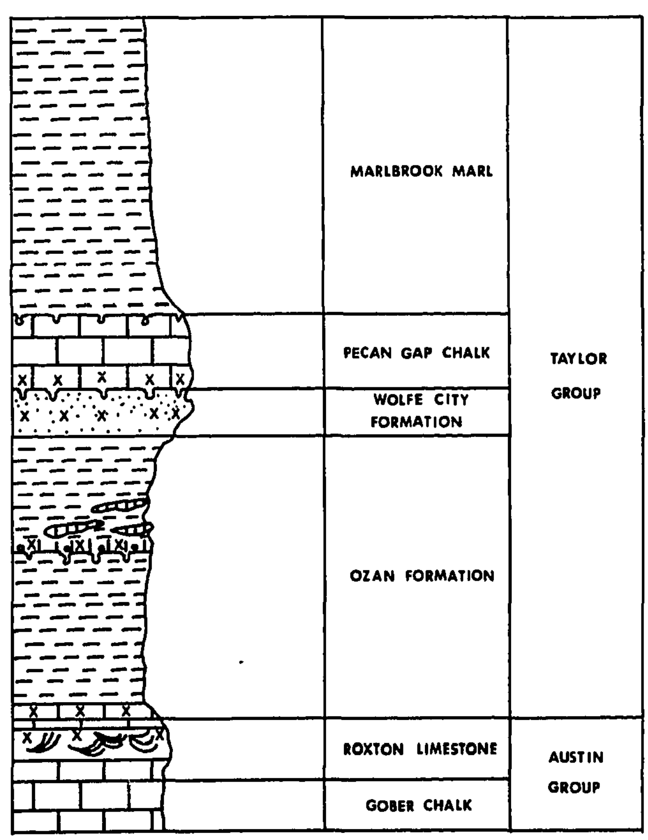


183

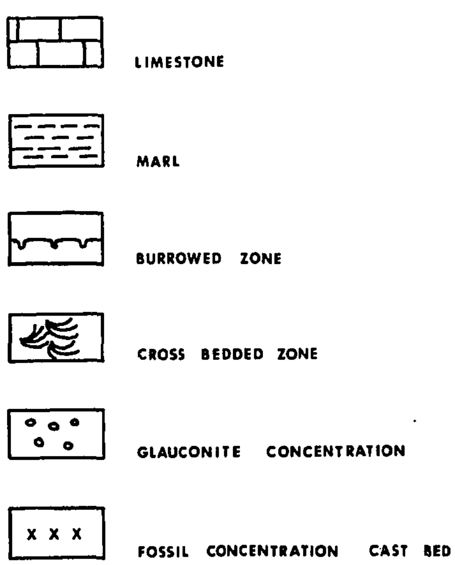
182
181

-1180

COMPOSITE SECTION NOT TO SCALE OF UPPER AUSTIN AND TAYLOR STRATA



LEGEND



179

1178

-1177