GEOLOGY AND VERTEBRATE PALEONTOLOGY OF A LOWER PERMIAN DEPOSIT ON THE BRAZOS RIVER, BAYLOR COUNTY, TEXAS, WITH THE DESCRIPTION OF A NEW GENUS AND SPECIES OF ACANTHODIAN FISH

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I. ABSTRACT

A high concentration of vertebrate fossils is described from a Lower Permian Lueders Formation deposit. The study area is on the Salt Fork of the Brazos River, near the entrance to Miller's Creek, 22 km south of Seymour, Baylor County, Texas. Remains of an undescribed genus and species of acanthodian fish make up more than 90% of the fossils; sharks, coelacanth and paleoniscoid fishes constitute the remainder, with the exception of a few fragments of amphibians and reptiles. The dolostone matrix containing the fossils was deposited in shallow, near-shore marine water. All of the vertebrates, except tetrapods, are considered to be marine. The acanthodian is typified by large size, fin spines being symmetrical in cross-section and without surface sculpture, and scales consisting of a spongy bone core surrounded by concentric layers of orthodentine except externally, where it is covered with successive layers of an enameloid. Each scale bears an elongated posterior spine. Fauna from near Miller's Creek is less diverse in species content than the marine vertebrate fauna discovered in the Lueders Formation near Lake Kemp Dam, 30 km north-northeast of the Miller's Creek site, though both local faunas are nearly contemporary. At Miller's Creek, acanthodians dominate the fauna; at Lake Kemp Dam paleoniscoids constitute the bulk of the fauna.

II. INTRODUCTION

Lower Permian redbeds of north-central Texas yield remains of reptiles and amphibians that have attracted the attention of paleontologists and the public since their discovery more than a century ago. Basic stratigraphy of the region was established by Cummins (1890, 1891). The Wichita and Clear Fork formations of Cummins have since been elevated to groups and each group subdivided into several formations. The integrity of the formations has largely been preserved but there is controversy about the boundaries of the groups. The
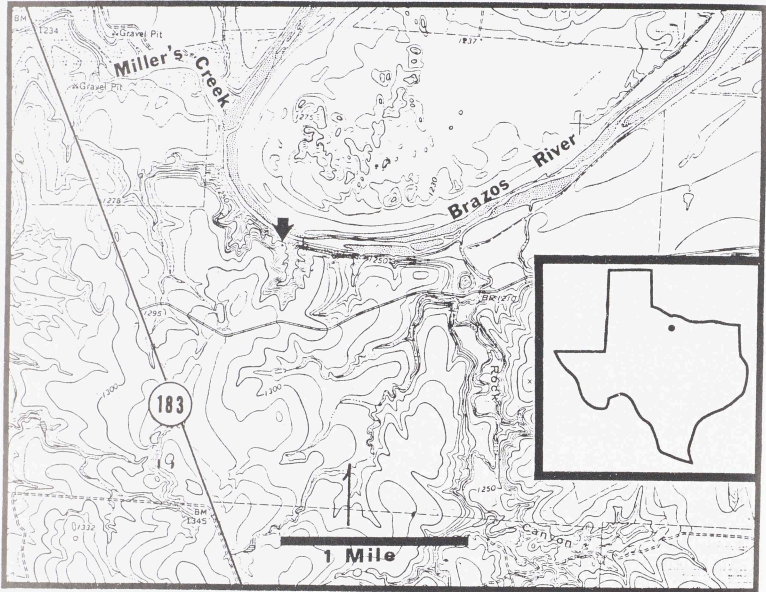
Fig. 1. Map showing the Miller's Creek locality (arrow) approximately 20 km south of Seymour, Texas, along the Salt Fork of the Brazos River. Dot on inset map indicates general location.

position of groups and formations in relation to the Pennsylvanian-Permian boundary is also controversial (Romer, 1935, 1938; Olson, 1958, 1975). We follow Berman (1970) in considering the Wichita-Clear Fork boundary to lie between the Lueders and Arroyo formations.

Regardless of the group boundaries, in north-central Texas the Lueders Formation is distinct. Formations above and beneath the Lueders consist largely of "redbeds," red and vari-colored clays, sandstones and shales of terrestrial or freshwater origin. Limestones or dolostones are few and thin. The Lueders is marked by numerous strata of dolostone and limestone, some of considerable thickness and of marine origin. The Lueders Formation was deposited along the eastern margin of the Early Permian mid-continental seaway

and records minor advances and retreats of the sea.

Johnson (1979) thought that Dalquest and Emsoff (1977) erred in placing the Miller's Creek collecting site in the Lueders Formation. He considered it to lie at the boundary of the Bell Plains and Clyde formations and, presuming a 2 degree dip to the northwest, calculated a difference of 85 meters elevation between our study area and the nearest mapped outcrop of the Aa2 "limestone" of the Maybelle Member, upper Lueders Formation. Our calculations dramatically disagree with those of Johnson. The nearest occurrence of the Aa2 "limestone" is beside U.S. Highway 183-283, 5 km north-northwest of our study area. U.S. Geological Survey Topographic Map, Wichita Falls, NI-14-8, shows the 1300 foot contour passing through the Aa2

site. Elevations of other nearby outcrops of the Aa2 "limestone" indicate that there is little or no dip in the immediate area. Garrett *et al.* (1937) show the top of the underlying Clyde Formation to lie 21 meters beneath the Aa2 "limestone." Using U.S.G.S. topographic maps, simple calculations indicate that the Aa2 "limestone" would lie, if present at our collecton site, 1265 feet in elevation. Our collection site is clearly in the lower part of the Lueders Formation.

More important is the limestone at the base of our measured section (Fig. 2). The Lake Kemp limestone marks the top of the Lueders Formation, the Talpa limestone the top of the Clyde Formatin, and the Bead Mt. limestone the top of the Bell Plains Formation. We found no limestones between the Aa2 outcrop of the Maybelle "limestone" beside Highway 183-283 and the limestone at the base of our measured section. We consider this basal limestone to be the Talpa, the top of the Clyde. Our fossil collection site is, therefore, near the bottom of the Lueders Formation.

The vertebrate fossils discovered in the late 1800s and early 1900s came from the strata above and below the Lueders. The Lueders was the orphan formation of early workers. Romer (1938) did not list the Lueders as a productive formation and remarked, "Few vertebrates are to be expected here; a *Trimerorhachis* skull is the only specimen definitely known to the writer to have been derived from this formation." Romer, who studied Texas Permian vertebrates and geology from 1926 until his death in 1973, restricted his investigations to the formations of the Wichita Group and older. The formations of the Clear Fork and younger groups were studied by E. C. Olson, then of the University of Chicago (Berman, 1970). The intermediate Lueders Formation was avoided by both.

Read (1943) first reported a vertebrate fauna, as well as its environmental significance, from the Lueders Formation near Lake Kemp in Baylor County. Other papers concerned with fossils from the Lueders Formation include Dalquest (1963, 1966, 1968), Berman (1968, 1970), Schaeffer and Dalquest (1978), and Dalquest and Kocurko (1986). Fossil plants were described by Mamay (1966). All of the above,
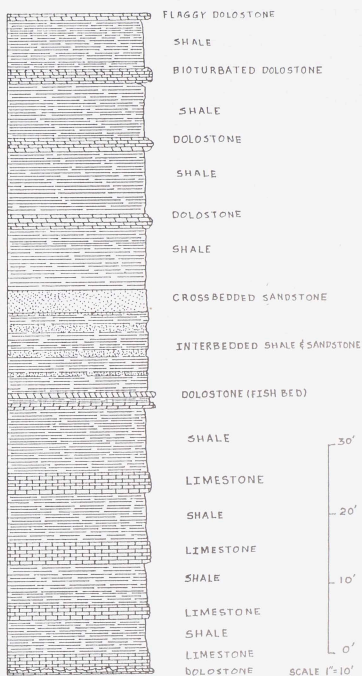

Fig. 2. Measured section at type locality of *Rodriguezichthyes luedersensis*.

and virtually all mention of vertebrate fossils from the Lueders Formation, are based on specimens collected in an area of a few square kilometers near the Lake Kemp Dam in Baylor County.

Dalquest and Emsoff (1977) reported abundant remains of acanthodian fishes, and a few associated vertebrates, from the Lueders Formation on the banks of the Salt Fork of the Brazos River. The location is on the Brazos River near the mouth of Miller's Creek, Baylor County, approximately 30 km SSW of the Lake Kemp Dam. The fauna listed by Dalquest and Emsoff is different from that discovered near Lake Kemp (Dalquest and Kocurko, 1986) and warrants description.

III. DEPOSITIONAL ENVIRONMENT

The Lueders Formation may never produce the quantity and quality of large vertebrates for which the other Lower Permian formations of the region are famous, but is important in other ways. As the boundary between Wichita and Clear Fork groups it is approximately the boundary between the equivalent Wolfcampian and Leonardian groups of marine sedimentary terminology. Climate and terrestial ecological conditions in the region during Wichita time were essentially humid, with little or no relief. Following the deposition of the Lueders Formation, the land was better drained and the climate more arid. In this region the Lueders Formation marks the end of swamp conditions.

The limestone and dolostone layers of the Lueders Formation shield softer sediments from erosion. Consequently, exposures are often steep, permitting study of the vertical extent of outcrops. As one moves laterally along an exposure, strata, especially sandstones, vary in thickness. Each change reflects events of the fluctuating sea margin during Lueders time. The marine strata of the Lueders Formation were probably deposited during a short interval of time.

The Permian-age sediments exposed at the Miller's Creek locality (Fig. 1) total 94 feet in thickness (Fig 2; we use feet rather than meters here, since most geologic sections described from Texas have been so measured). The section, represents a general regression of the Permian sea. The lower half consists of alternating dark shales and fossiliferous limestones. The limestones are rich in invertebrate fossils. Some of the shale layers yield a sparse vertebrate fauna of dermal scales, isolated teeth and other remains of fishes. The limestones of the lower part of the section are generally micritic and contain hematite pseudomorphs after framboidal pyrite.

Fig. 3. Part of a concentration of *Rodriguezichthyes luedersensis* fin spines. Note orientation, indicating gentle water curents or wave action. Scale is in 1 cm units.

Fossil remains consist of gastropods, pelecypods, ostracods, foraminifers and tabulate corals. Terrigenous clasts are occasionally incorporated into the limestone units. The limestone and shale sequence is interpreted to be marine in origin. The sediments probably accumulated in moderately shallow, quiet waters.

With continued regression of the Permian sea, marine sediments were covered by tidal or supratidal deposits. The first of these deposits is an orange dolostone unit, which we term the "fish layer." The unit consists of a sucrosic dolostone with minor internal bedding. The orange color, on freshly exposed surfaces, is probably due to hematitic and limonitic stain, whereas weathered surfaces are gray and similar in appearance to beds above and below. Fossil material in the fish layer consists of disarticulated bones, spines, teeth, scales of fish and rarely isolated bones of tetrapods. Lateral concentrations of these remains give rise to apparent bedding within the unit. Most of the elongate spines are oriented parallel to major bedding planes. Clustering and roughly parallel orientation of spine material (Fig. 3) indicates a possible reworking by marine current during high tides or storm tides. The presence of tetrapods in the unit indicates a nearshore tidal position.

Above the fish layer is an accumulation of pale gray dolostones, vari-colored shales and sandstones. This upper part of the section is interpreted as representing terrestrial conditions. The dolostones are probably tidal to supratidal deposits, whereas the sandstones and shales represent coastal, terrestrial deposits. The dolostones are virtually unfossiliferous other than trace fossils (bioturbation). The sandstones and shales likewise are barren of fossil remains. The terrestrial section terminates in a dense, flaggy dolostone. The only fossils in this unit are colonies of coral, measuring up to 25 by 37 cm in horizontal width and 4 cm thick.

IV. ACANTHODIAN FISHES

Emsoff (1975) discovered the "fish layer" at the top of the low bluff on the west side of the Brazos River. The richest concentration of fossils is approximately one kilometer south of the mouth of Miller's Creek in the orange dolostone matrix. The fossiliferous layer has been traced over several thousand square meters. All of the fossils on which the following accounts are based were obtained at the discovery site, where they are especially abundant. Elsewhere fossils are usually sparse, though some heavy concentrations of acanthodian spines were noted. The dominant and most prominent fossils in the "fish layer" are of acanthodians.
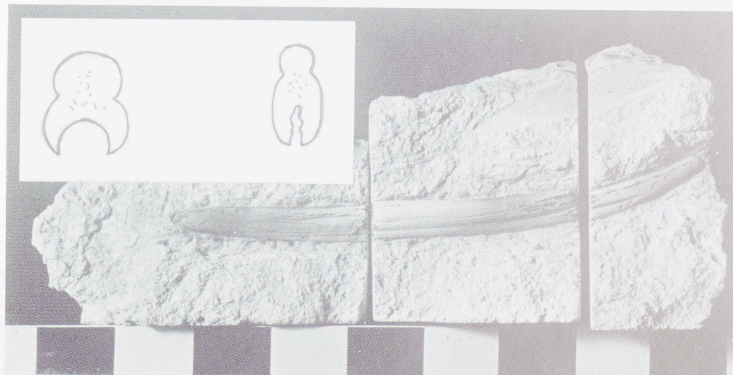

Fig. 4. *Rodriguezichthyes luedersensis* fin spines, sectioned to show cross-sectional shape. Inset: left, shape in upper portion; right, lower portion. Scale is in 1 cm units.

Acanthodians are best known from the Old World but were reported from the eastern United States and Canada almost a century ago (Zidek, 1976). The geological range of the Order Acanthodiformes extends from the Upper Silurian to the Lower Permian. Much of our recent understanding of American acanthodians comes from the studies of Zidek (1973, 1975a, 1975b, 1976, 1977, 1980), and a revision of the order Acanthodii by Denison (1979).

Acanthodians were not reported by early workers in the Texas Permian beds. Skulls and skeletons of amphibians and reptiles were found in unconsolidated Permian sediments and the hard, clay-pebble channel conglomerates that held disarticulated remains of acanthodians, as well as fragments of other vertebrates, were largely ignored. The first acanthodian reported from Texas was an almost complete but tiny, fingerling, individual (Dunkle and Mamay, 1956). This was collected 30 km SSE of Seymour, Baylor County, and only about 30 km from the present study area at

Miller's Creek. The specimen is from the Clyde Formation, and stratigraphically lower than the fossils from the Lueders Formation.

By the late 1960s it was common knowledge among students of the Texas Permian that acanthodian remains were present in the channel conglomerates of the Wichita Group (Admiral and Bell Plains formations), but the first published record of such occurrence was by Simpson (1974). The geologically youngest Texas specimens come from the Lueders Formation (Dalquest and Emsoff, 1977). However, Simpson (1973) reported acanthodians from a pond deposit in the lower part of the Hennessey Group near Frederick, Oklahoma. This occurrence is presumably equivalent to the Vale Formation, Clear Fork Group, of Texas. Olson (1958) worked extensively in the pond and channel deposits of the Vale Formation in Texas, and some of his localities (1958 map) are only about 80 km SSW of Simpson's site. Olson reported no acanthodian fossils in his systematic list of Vale fossils.

Fig. 5. Stout, curved spine (partly concealed by larger spine fragment) thought to be pelvic spine of *Rodriguezichthyes luedersensis*. Note scales in matrix.

Perhaps Simpson's site lies lower in the section than he believed.

Simpson's acanthodian fossils from Oklahoma and all Texas Permian occurrences known to us in the Wichita Group are from freshwater pond or channel deposits. The specimens are much smaller than those from the Lueders Formation. The acanthodian remains described here come from a marine dolostone stratum that contains fossil corals. Acanthodians occur throughout the fish layer and the underlying layer of black to gray shaley clay as well, and must have accumulated over a considerable period of time. The fossils can scarcely represent a catastrophic event that swept vast numbers of dead freshwater fishes into the sea. The sediments at the Miller's Creek site indicate shallow marine water, not remote from shore, but also not an estuary where dead freshwater fishes might be transported and accumulate. It is concluded, therefore, that the acanthodian remains at the Miller's Creek locality are of a marine species.

The acanthodians of the fish layer are completely disarticulated. We estimate that well over 30 square meters of fresh dolostone from the fish layer were exposed by splitting slabs, but no articulated bones or scales were discovered. Important generic characters of acanthodians include the positions and relative sizes of the fin spines, but this cannot be determined from the Miller's Creek material. Scales, however, are present in the dolostone by the countless millions, and we have made a detailed study of them. Scales of acanthodians are diagnostic at the generic level (Brotzen, 1934; Denison, 1979). In both morphology and histology the scales from Miller's Creek are unique among described acanthodians. The acanthodian represented by the fossils in the fish layer represents a heretofore unknown genus and species which is described below.

RODRIGUEZICHTHYES new genus

Type species: Rodriguezichthyes luedersensis new species.

Generic Diagnosis. Large, marine acanthodian having large, symmetrical fin spines measuring 100-135 mm in length. Scales unique in bearing an elongated posterior spine and in their construction of a core of spongy bone, base of concentric layers of orthodentine, and a crown of enameloid substance.

Etymology. Named for Dr. Louis J. Rodriguez, President of Midwestern State University, in recognition of his continued support of paleontological research.

RODRIGUEZICHTHYES LUEDERSENSIS new species

Holotype. Nearly complete fin spine (ichthyodorulite) No. 12303, Midwestern State University Collection of Fossil Vertebrates, preserved in dolostone matrix along with numerous isolated scales.

Type Locality. Top of low bluff on the west bank of the Salt Fork of the Brazos River, 22 km SSE Seymour, 1 km S of the mouth of a small tributary, Miller's Creek, Howard Farmer Ranch, Baylor County, Texas.

Horizon. Lueders Formation, top of the Wichita Group, Lower Permian Period.

Etymology. Name is derived from the Lueders Formation.

Diagnosis. Same as for genus.

Description of holotype. The holotype fin spine is nearly complete and partly embedded in orange dolostone that also contains numerous scales of *Rodriguezichthyes luedersensis.* The spine measures: greatest straight-line length, 116 mm; greatest anteroposterior diameter, 7.8

Fig. 6. Scapulacoracoid of *Rodriguezichthyes luedersensis.* Overall length is 22 mm. Bar scale is 10 mm.

mm. The spine lacks ornamentation other than the longitudinal grooves.

Discussion. A variety of different kinds of acanthodian scales have been described and figured (Brotzen, 1934; Denison, 1979). Most bear strong surface ornamentation; the scales of *Rodriguezichthyes* have smooth surfaces lacking ornamentation. Most described scales lack posterior spines, have short, blunt spines or have multiple spines. None have slender, elongated spines like the spines of *Rodriguezichthyes*. Most are rhomboidal in dorsal aspect, or somewhat triangular and broader than long. The scales of *Rodriguezichthyes* are almost oblong. The combination of elongated, rectangular scales with smooth surfaces and single slender, elongated posterior spines is not duplicated in any acanthodian genus that we have seen figured.

The histology of the scales of *Rodriguezichthyes* appears to be unique in that they have a core of spongy bone (Fig. 11 and 12) surrounded by a base of orthodentine and a crown of an enameloid substance. A bony core seems to be absent in scales of other described acanthodians, and the crown surface is composed of dentine or mesodentine (Denison, 1979). Brotzen (1934) figures Schmeltz [enamel] in the crowns of several genera and families but this is not cited by Denison.

Acanthodian remains make up almost all of the fossils in the fish layer; other fossils are rare. Remains are completely disarticulated. Stouter structures (scales, spines and scapulae) often suffer some minor damage and fracturing but are generally preserved intact. The moderately thick circumorbital plates are usually well-preserved. The thin endochondral bones, such as of the visceral skeleton, often poorly ossified to begin with, are almost all fragmented and shattered. Thin, flat fragments of bone are randomly dispersed through the matrix of the fish layer. What appear to be parts of neural or haemal arches, parts of the branchial skeleton, or cranial ossifications can sometimes be tentatively recognized but not with certainty.
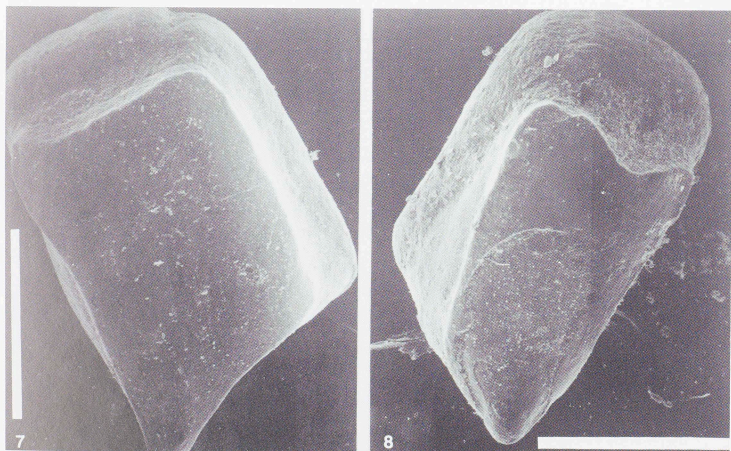
Complicating the problem are the re-

Fig. 7. Crown view of *Rodriguezichthyes luedersensis* scale showing hard, shiny enameloid and anterior expansion of scale base. Bar scale represents 1 mm. Fig. 8. Anteroblique view of another scale showing anterior expansion of base and parts of two outer layers of enameloid chipped away. Bar scale represents 1 mm.
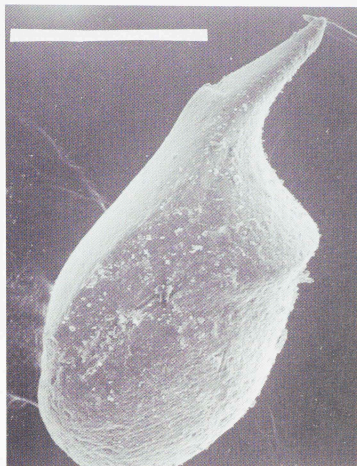
Fig. 9. Side view of typical scale showing posterior spine, posterior excavation for expanded scale base of next posterior scale, and rounded, almost ball-like ventral side of scale base. Bar scale represents 1 mm.

mains of osteicthian fishes. These are uncommon compared with remains of acanthodians but numerous phyllodont tooth plates were recognized. This indicates that other large fishes were present in some numbers, and their bones are mingled through the fish layer. The thin, cycloid scales of coelacanths are not preserved in the fish layer but fragments that might be dermal and endochondral bones of the head, and parts of vertebral arches of coelacanths, are fossilized. As a result, the only elements that we identify with confidence as acanthodian are fin-spines, scales, scapulae, and circumorbital plates.

The fin spines of *Rodriguezichthyes luerdersensis* are the largest reported from North America. Moy-Thomas and Miles (1971) note that most European acanthodians were less than 200 mm in length but Orvig (1967) mentions a fish two meters long. Zidek (1976) states that there is no allometry in the genus *Acanthodes* and implies that this is true of all acanthodians. In *Acanthodes bridgei* Zidek, from the Upper Pennsylvanian of Kansas, Zidek computed the length of the pectoral spines, the longest spine in the body of *Acanthodes*, to be 0.16-0.20 of the total length of a fish. The longest spine measured by Zidek was 76 mm in length and the articulated fish was 410 mm in total length. If this ratio holds true for *Rodriguezichthyes*, where the longer spines commonly measure 100 mm and the maximum observed was 135 mm, then the Miller's Creek acanthodians were 500 to 844 mm in total length.

Zidek (1975a) has recognized two types of freshwater acanthodian spines from Oklahoma: symmetrical in cross-section (dorsal and anal fins); and flattened, asymmetrical spines (pectoral and pelvic fins). We have studied hundreds of sections of *Rodriguezichthyes* spines and all resemble the median, symmetrical spines figured by Zidek (Fig. 4). Most of the spines from Miller's Creek are long but stout and gently curved, whereas some are shorter and more curved (Fig. 5). The shorter spines may be pelvics, and the very longest pectorals, but this is not certain. However, we found no flattened, asymmetrical spines like those of the freshwater acanthodians from Texas and Oklahoma.

Isolated circumorbital plates are common and many are intact. Unfortunately, the external surfaces of these dermal bones adhere tightly to the matrix, and invariably, when the dolostone is split the internal surfaces only are exposed. The
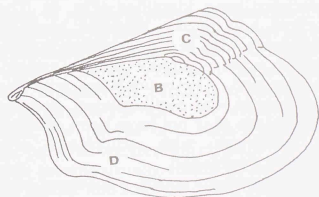

Fig. 10. Vertical section through scale of *Rodriguezichthyes luedersensis* showing enameloid crown (c), spongy bone core (b) and dentine base (d). Same scale shown in figure 20. Bar scale represents 1 mm.
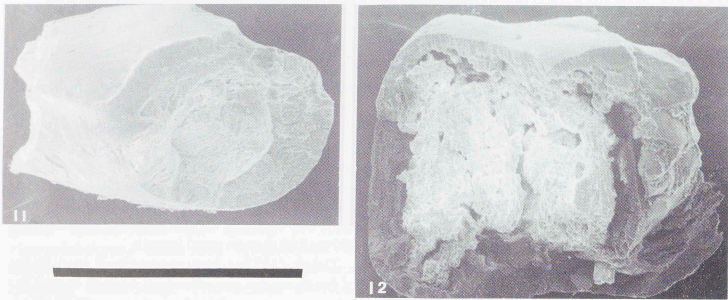
Fig. 11. *Rodriguezichthyes luedersensis* scale with part of orthodentine layer broken away to rounded outer surface of bone core. Fig. 12. *Rodriguezichthyes luedersensis* scale broken across base to show bone core and surrounding orthodentine. Bar scale represents 1 mm.

bones are oval in outline, slightly curved, and gently concave internally. Ornamentation of external surfaces consists of low, slightly divergent lines of small tubercles. Measurements of some large plates are: 36.4 x 22.0, 34.2 x 20.0 and 30.3 x 17.7 mm. The amount by which each plate overlapped its neighbor cannot be determined but, as *Rodriguezichthyes* presumably had five circumorbital plates as did other acanthodians, an eye diameter of more than 25 mm is suggested.

Pectoral girdle elements, represented only by perichondral bones are much rarer than fin spines. Perhaps 20 scapulacoracoids have been identified (Fig. 6). The proximal end of the scapular blade is slightly expanded in a thin ring but the termination is flat or slightly concave and appears ragged. The articulation with the suprascapula was cartilagenous, and the suprascapula may not have been ossified. No specimens with articulated procoracoids were found.

The scapulacoracoids recovered are mostly large but include one rather small and one moderate-sized specimen. It proved difficult to find points where comparable measurements could be taken. The greatest diameters of the proximal ends of the two largest scapular blades (suprascapulae missing) are 6.6 and 7.4 mm, whereas least diameters (constrictions) of blades between proximal and dis-

tal ends are 4.5 and 5.2 mm. The specimens all have narrow, shallow, longitudinal grooves on the distal portion that terminate in the hollow lateral to the procoracoid process and proximal to the subscapular fossa. The length of the scapulacoracoid from proximal end to the proximal margin of this hollow measures 19, 20 and 20 mm in three large specimens.

The scapulacoracoid of *Rodriguezichthyes* resembles that of *Acanthodes* more than that of any other acanthodian figured by Miles (1973). It closely resembles *A. wardi* Egerton and *A. lundi* (Zidek, 1980) in having the scapular blade constricted medially. *A. bronni* Agassiz (Miles, 1973) and *A. bridgei* (Zidek, 1976) have the scapular blade of more uniform diameter. The resemblance of the scapulacoracoid of *Rodriguezichthyes* to that of *Acanthodes* is close and perhaps the arrangement of fin spines was also similar.

One acanthodian braincase was found exposed in dorsal view with only the left side visible. It has been partly prepared but we are not able to describe it in detail at this time. Patches of the micromeric head scales form a single layer on the dorsal surface of the braincase. Patches of head scales were removed during preparation but some remain posterior to the occipital region, lateral and anterior to the left postorbital process, and lateral to the fontanelle depression. The scales are close
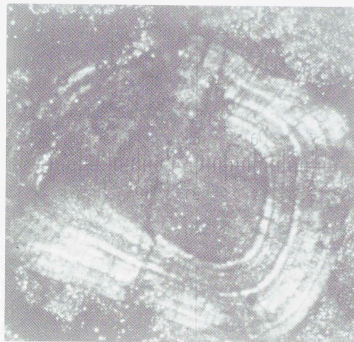
Fig. 13. Thin-section of *Rodriguez-ichthyes luedersensis* scale through upper part of scale base showing bone surrounded by successive layers of orthodentine. Bar scale represents 1mm.

together, but not in contact along their edges. They range from 0.2 to 0.6 mm in greatest diameter and vary widely in shape. Commonly they are flattened, irregular polygons with fluted margins but lacking ornamentation. Associated with the polygonal head scales are some of oval shape, while others have highly irregular outlines. We could not determine if the scales were originally in contact along their margins, or instead were separated to form a scale-studded expanse of skin.

The tesserae differ in detail from those described for other acanthodians. They most closely resemble those of *Acanthodes lundi* figured by Zidek (1980) but are larger, lack pit-like ornamentation, and have stronger fluting along the margins. Most acanthodian tesserae are thought to cover only the frontal region between and posterior to the orbits. Those of *Rodriguezichthyes* may have covered much of the head.

The squamation of *Rodriguezichthyes* appears to be unique among acanthodians. The scales are slightly elongated, rectangular in general outline at the crown, rather than square, and the posterodorsal margins are drawn out into sharp spines (Figs. 7, 8, 9). The outer layer is composed of laminae of a shiny enameloid. The scale

base is thick and rough on its lower surface. Zidek (1976) noted that the crowns of the scales of *Acanthodes bridgei* overlapped the scale bases posteriorly. This is true in *Rodriguezichthyes* also. SEM photos (Figs. 7, 8, 9) show that each scale base is excavated posterodorsally and posteroventrally, and expanded anterodorsally and anteroventrally to accomodate the overlap (Figs. 7, 8). The underside of each scale bulges out to form a rounded, almost ball-like protuberance, as in some other acanthodian scales.

The histology of several acanthodian genera and species has been described. Brotzen (1934) pointed out that acanthodian scale histology is distinctive in all genera and some species of acanthodians. Moy-Thomas and Miles (1971) recognized two major types of acanthodian scales: the *Nostolepis*-type and the *Acanthodes*-type. Denison (1979) did not follow the usage of Moy-Thomas and Miles (1971), but agreed that the *Nostolepis* scale was unique in that it grew by periodic deposition of substance at the sides of the scale only (Gross, 1971). Other kinds of acanthodian scales grew by deposition of concentric layers that enclosed the entire scale, beginning with the scale primordium.

Acanthodian scales consist of a base and a crown. The scale base may be of cellular bone, with prominent lacunae (Orvig, 1967), orthodentine or mesodentine. Orvig described as mesodentine, dentine "which in addition to vascular canals . . . ., contains spaces for enclosed sclerocytes and network of ramified, intercommunicating, canaliculi-like processes issuing in part from the sclerocyte spaces and in part from the vascular canals." The scale base may contain complicated canal systems, patterns of Sharpey's fibers, or even pulp cavities. For figures of a variety of histologic patterns see Denison (1979).

Scale crowns usually consist of material that is harder and smoother than the scale base. Brotzen's mention of enamel in the scale crown has not been accepted by later workers, but most are vague about the substance that composes the scale crown. In most figured sections of acanthodian scales the crown composes half or more of the scale as seen in cross-section. The crown is sometimes considered to be of orthodentine or mesodentine.

The scales of *Rodriguezichthyes* (Fig. 10) are unique in several ways. A core of spongy bone (Figs. 11 and 12) is present, occupying a considerable volume of the center of the scale, and only outside of the core is the scale arranged in concentric layers of orthodentine with typical dentinal canals. The hard material of the scale crown occupies only a comparatively small area with part of the orthodentine of the scale base exposed when the scale is seen in dorsal view. The thick scale base and thinner crown are formed independently and meet along their edges, clam-shell fashion. The layers of the scale base surround the bony core (Figs. 11, 12) and the layers of the crown are almost flat.

The spongy bone core of the *Rodriguezichthyes* scale somewhat resembles the trabecular dentine described and figured by Peyer (1968), but, as seen in Fig. 14, the structure of the material appears to be of bone alone.

A horizontal section of a scale, beneath the crown (Figs. 13, 14), shows sharply delineated layers of orthodentine and the bone core when examined in transmitted light. Collagenous fibers are prominent but dental canals show only faintly. A thinner, vertical section examined in polarized light (Fig. 15) shows the dentinal canals plainly arranged as slight sinuous, unbranched, parallel tubules.

The scale crown of *Rodriguezichthyes* is dense and shiny, superficially resembling the ganoin of paleoniscoid scales when seen under low magnification. The contact of the dense crown material with the rough orthodentine is sharp (Figs. 16, 17). We simply term this layer "enameloid." It is formed by successive layers that cover completely the layer beneath (Figs. 18, 19). The edges of the enameloid roll over the layer beneath, and occasionally a layer of enameloid appears to be continuous with a layer of orthodentine, but this is an artifact; most simply join. In cross-sections the dense enameloid layers stand out from
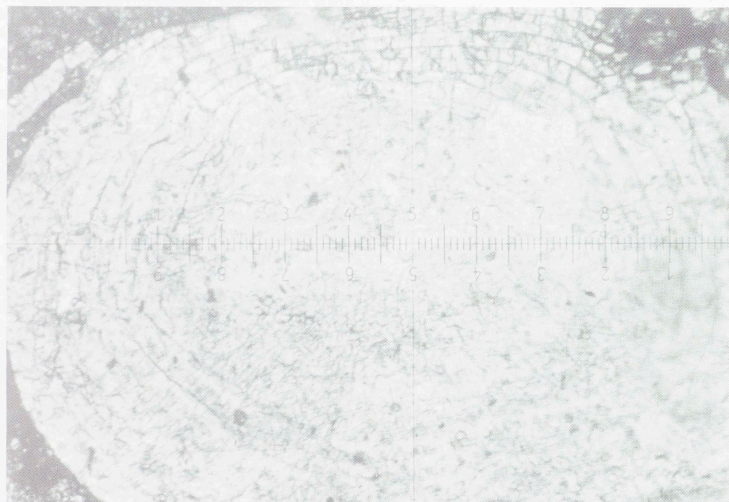

Fig. 14. Cross-section through *Rodriguezichthyes luedersensis* scale showing contacts of orthodentine layers and of bone core with orthodentine, lacunae, channels and collagenous fibers in bone core, collagenous fibers in orthodentine layers, and (upper right) enameloid layers separated in places "like bricks in a wall" by pore canals. Transmitted light. Scale represents 1 mm.

the less dense layers of orthodentine (Fig. 20).

Scanning electron micrographs (Figs. 21-24) show the nature of the enameloid substance. Highly magnified, the outer surface appears dimpled. In the center of each dimple is a pore leading directly downward as a pore canal. The pore canals terminate in cavities near the base of each enameloid layer. In thin-section pore-canals sometimes appear to separate the enameloid layers into short, vertical sections (Figs. 14), as bricks in a wall or cells in a cuboidal epithelium. The enameloid substance of the *Rodriguezichthyes* scale crown resembles, in some ways, Orvig's (1967) description of mesodentine, although no canaliculi-like structures were seen.

There is considerable variation in the size of the acanthodian scales in the fish layer. Larger scales are up to 1.4 mm in length, exclusive of the spine, whereas others are only 0.6 mm long. Most scales are slightly more than 1 mm long. Zidek (1975b) illustrates the difference in size between scales from the flank and ventral parts of a single acanthodian. We cannot say if the difference in sizes between the scales at Miller's Creek are due to difference in age of the fishes or parts of the body from which the scales were derived. A thin-section of a number of scales sectioned beneath their crowns shows roughly the same number of dentinal annuli on each.

V. SIGNIFICANCE OF *RODRIGUEZICHTHYES*

Acanthodians are the first fishes with true jaws to appear in the fossil record, appearing in the Lower Devonian and becoming extinct in the Lower Permian. Only the genus *Acanthodes* was previously thought to have survived into the Permian. All acanthodians from American Upper Pennsylvanian deposits that have been firmly identified to genus have been referred to *Acanthodes*.
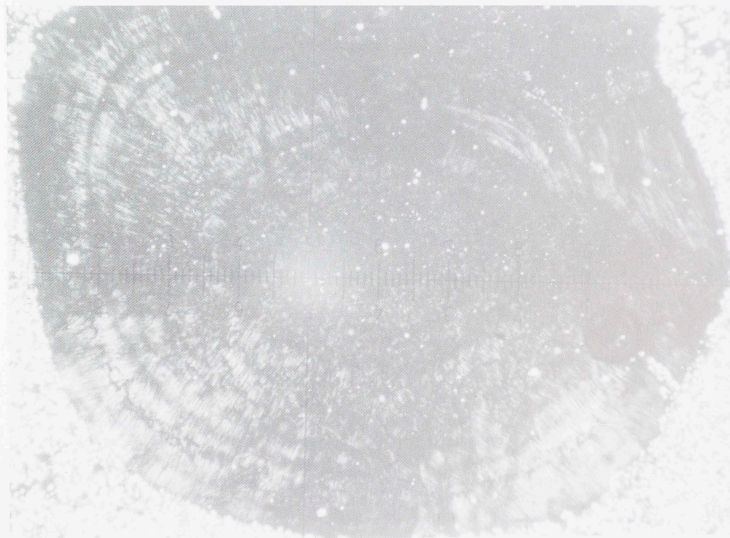

Fig. 15. Horizontal section through *Rodriguezichthyes luedersensis* scale in upper part of base, showing dentinal canals. Polarized light. Scale represents 1 mm.
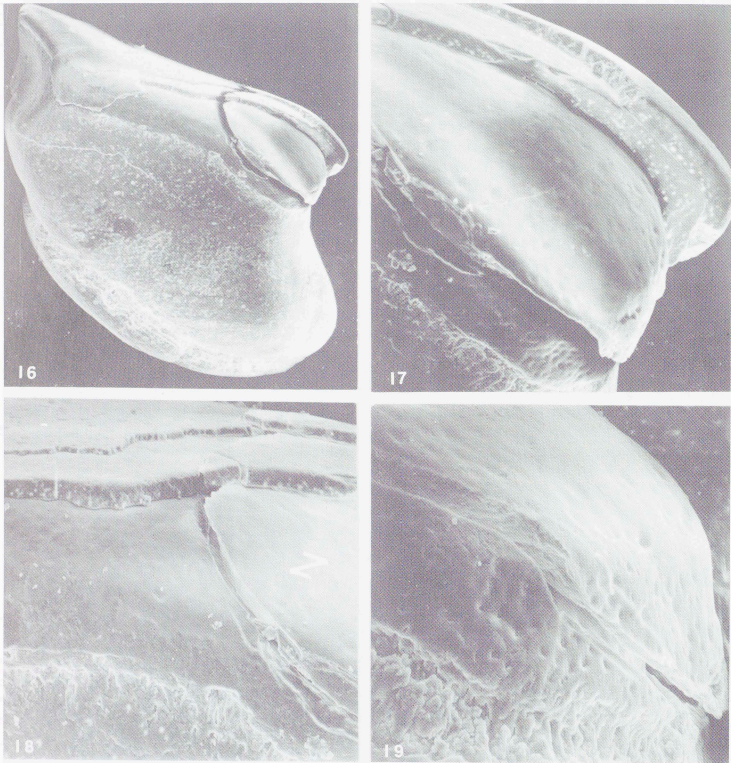
Fig. 16. *Rodriguezichthyes luedersensis* scale in lateral view. Outer layers of enameloid substance partly chipped away (fracture is accidental). At this magnification enameloid appears smooth and shiny (x 80).

Fig. 17. Enlargement of Fig. 16, showing how enameloid layers thin posteriorly, surface is dimpled, and pore cavities arranged at bases of enameloid layers. Note contact (lower right) of enameloid and rough orthodentine (x 250).

Fig. 18. Another view, showing dimpled surfaces of enameloid layers and contact with orthodentine of scale base (x 250).

Fig. 19. Enlarged view of enameloid surface of Figure 18, showing pore canal entrances at base of dimples in enameloid surface (x 570).

Fig. 20. Vertical section through *Rodriguezichthyes luedersensis* scale showing parallel enameloid (top) covering orthodentine scale base and bone core. Bar scale represents 1 mm.

Dunkle and Mamay (1956) termed a tiny, fingerling acanthodian from the Lower Permian of Texas *Acanthodes*. Zidek (1973) suggested the specimen might represent *Traquairichthyes* instead. Zidek later (1975a) referred freshwater acanthodian remains from Oklahoma to *Acanthodes*, and *Traquairichthyes* has not subsequently been mentioned. However, the discovery of *Rodriguezichthyes* shows that Permian acanthodians cannot automatically be referred to *Acanthodes*. *Rodriguezichthyes*, from the uppermost Wichita Group (uppermost Wolfcampian), is the youngest record of acanthodians other than the specimens of *Acanthodes* sp. from the Hennessey Group (Lower Leonardian) of Oklahoma. The presence of the enameloid layer on the scales may be a derived character.

VI. ASSOCIATED VERTEBRATES

Ctenacanthus cf. *C. amblyxiphias* Cope. – A ctenacanth shark spine measuring 240 mm was found. A shark with a spine of this length may have weighed more than 50 kg. Another smaller spine was found deeply imbedded in dolostone matrix. The length of this spine cannot be determined but also was of a large shark. Spines of similar large size were recovered from the Lueders Formation near Lake Kemp Dam (Dalquest and Kocurko, 1986).

"Orodus." – A single shark tooth of the *Orodus*-type was discovered by Dalquest and Emsoff (1977). The tooth is 6.5 mm wide and the sharply keeled crown rises gradually to the central cusp. The enamel is smooth. *Orodus* is a form genus for Paleozoic shark teeth with a low, elongated crown, a central cusp, and a deep groove or furrow separating the crown from the tooth base. Romer (1942) noted that such teeth might belong to any of several genera. *Orodus* is usually considered a hybodont shark. It is unusual that the only shark tooth discovered in the dolostone layers at either Lake Kemp Dam or Miller's Creek is of *Orodus*, while many fin spines, but no teeth, of *Ctenacanthus* were found.

"Acrolepis" scales. – The type of the genus *Acrolepis* Agassiz is *A. sedowicki*, known from complete specimens from European Permian deposits. The scales are thick and highly ornamented by elevated ridges of ganoin. The name *"Acrolepis"* has been used in Texas to describe palaeoniscoid scales ornamented by elevated ridges, but it is doubtful that these belong to *Acrolepis*. They may be derived from several different kinds of palaeoniscoids. Some may even be ridge scales of species with otherwise unornamented scales.

Progyrolepis tricessimilaris Dunkle, a palaeoniscoid rarely mentioned in the literature, was described from a freshwater deposit in the Admiral Formation of Archer County, Texas. The type locality is about 60 km east of and three formations lower than the Miller's Creek site. The scales of *Progyrolepis* were described and figured by Dunkle (1964) and are of the *Acrolepis*-type (Aldinger, 1937). We doubt that the *Acrolepis*-type scales from the marine deposit at the study area are *Progyrolepis*, though it is possible.

Acrolepis-type scales are widespread in the channel conglomerates of the Wichita Group in north-central Texas but are not especially common. At most sites where palaeoniscoid scales are abundant, less than one in ten scales is the highly ornamented type. Their glittery surfaces catch the eye and they may appear more common than they actually are. At the Miller's Creek site *Acrolepis*-type scales are almost as common as unornamented scales.

Unidentified palaeoniscoids. – Numerous unornamented palaeoniscoid scales are

scattered through the matrix at Miller's Creek, varying in size and shape. The scales appear to be of normal proportions. None of the dorsoventrally elongated scales, typical of platysomids, were found. Platysomids were quite common in the marine Lueders Formation deposits at Lake Kemp Dam.

Phyllodont tooth plates (unidentified coelacanth?). – Numerous phyllodont tooth plates are scattered among the acanthodian fossils at the study area. They are often difficult to recognize in the massed acanthodian scales unless the regularity of arrangement of the teeth is seen. Individual teeth on the tooth plates are almost the size of the acanthodian scales. The tooth-plate bearer was probaby the second most common vertebrate present in the fauna. Tooth plates are outnumbered by isolated paleoniscoid scales but each paleoniscoid had hundreds of scales. Individual tooth-plate bearers must have outnumbered paleoniscoids.

Johnson and Zidek (1981) have given a detailed description of phyllodont tooth plates from Lower Permian formations of Texas and Oklahoma, including the Lueders Formation. Our specimens resemble those figured and described by Johnson and Zidek (1981).

Johnson and Zidek (1981) conclude that the Lower Permian phyllodont tooth plates are of paleoniscoid fishes, more specifically platysomids. However, since the tooth-plate bearer was a fairly common fish at the Miller's Creek site, if it were a platysomid we would have expected other remains, especially its characteristic scales, to be common. If scales were preserved in proportion to tooth plates, thousands of scales should have been present. Instead, platysomid scales are absent. We cannot conceive conditions in which platysomid tooth plates, but not the scales, would be preserved in the Miller's Creek deposit, particularly given the ascribed ecological setting.
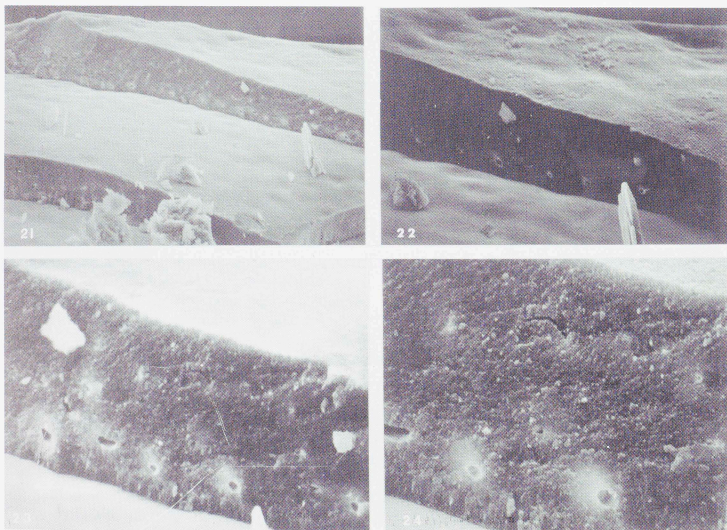
Figs. 21-24. Successive enlargements (use spire-like shard for location) of a slightly oblique section through a layer of enameloid of a scale of *Rodriguezichthyes luedersensis*. Note basal position of pore cavities, pore canals (broken across to show rounded sections only), and dense nature of enameloid. 21 = x 580, 22 = x 1160, 23 = x 2660, 24 = x 4060.

In addition, size argues against a platysomid origin of the tooth plates. Johnson and Zidek (1981) found phyllodont tooth plates to range from 3-50 mm in length. The only platysomid named from the Lueders Formation is *Schaefferichthyes luedersensis* Dalquest 1966, and Johnson and Zidek suggested that some of the isolated phyllodont tooth plates belonged to this species. The holotype of *Schaefferichthyes luedersensis* measured only about 90 mm (standard length) and numerous other specimens seen or collected at the Lake Kemp Dam site were little, if any, larger. The smallest tooth plate from Miller's Creek is 20 mm in length, and the largest more than 40. Such tooth plates are too large for fishes usually less than 100 mm in length. *Schaefferichthyes luedersensis* may have grown much larger, of course, or a different and much larger platysomid may have existed, but thus far their fossils have escaped detection.

The tooth plate bearer could not have been an acanthodian, since early acanthodians had spiral whorls of marginal teeth and later acanthodians *(Acanthodes)* had no teeth. The Permian lungfishes, *Sagenodus* and *Gnathorhiza*, are freshwater fishes *(Gnathorhiza* was reported from a freshwater stratum of the Lueders Formation at Lake Kemp Dam by Dalquest, 1968) and their distinctive tooth plates are quite different from the phyllodont plates. The giant paleoniscoid *Luederia kempae*, described from the Lueders Formation at Lake Kemp Dam, is large enough (ca. 800 mm) to have had tooth plates as large as those at Miller's Creek. However, as in the case of platysomids, had *Luederia kempae* been the tooth plate bearer, large scales and dermal bones of its skull should have been present. Rhipidistian fishes were presumably extinct by the time the Lueders Formation was deposited (we do know of one specimen of *Ectosterorachis* collected in the Clyde Formation, only one formation beneath the Lueders Formation). Again, the thick, shiny scales and dermal bones of *Ectosterorachis* would be expected to be present in numbers if it had been the tooth plate bearer.

Johnson and Zidek (1981) argue against the tooth plate bearer being *Spermatodus*

pustulosus Cope, the only coelacanth described from the Texas Permian. Earlier workers, notably the late A. S. Romer, considered tooth plates like those concerned here to belong to *Spermatodus*. According to Johnson and Zidek (1981: 532), *Spermatodus* has tooth-bearing parasphenoids and lacks tooth plates.

Our principal reason for rejecting paleoniscoids, platysomids, and rhipidistians as the bearer of tooth plates is the absence of the characteristic hard scales of these fish types in the Miller's Creek dolostone. Coelacanth fishes, however, had thin, cycloid scales that rarely preserve and would not be expected to be preserved in the Miller's Creek dolostone matrix.

Unidentified amphibians. – Several small pieces of highly sculptured bone were recovered that appear to be from amphibians. These bone fragments are not from fishes. Though they could be from small reptiles, their resemblance to amphibians is much closer. Amphibian remains would not be expected in a marine deposit but could have come from dead, bloated carcasses washed into the sea.

Dimetrodon? – A surprising discovery was the left maxillary of a large pelycosaur, probably *Dimetrodon*. The specimen is preserved as part and counterpart on slabs of orange dolostone. There is one long (60 mm) caniniform tooth, a space posterior to it for another, two small precanines and five postcanines. The specimen measures aproximately 165 x 120 mm.

Dimetrodon is the common, large carnivorous pelycosaur in Lower Permian deposits of Texas. The present specimen is not distinguishable from *Dimetrodon* (Romer and Price, 1940). *Dimetrodon* was a terrestrial reptile and if the maxillary belonged to that genus it probaby came from a bloated, floating carcass washed offshore, as suggested for the amphibians above. These specimens would also indicate deposition near shore.

Unidentified reptiles. – Three small, conical teeth were found that appear to be from reptiles. They are round in cross-section and lack the longitudinal grooves of labyrinthodont teeth. They are too small to belong to *Dimetrodon*.

VII. COMMENTS ON THE MILLER'S CREEK LOCAL FAUNA

The terrestrial and freshwater vertebrates of the Texas Permian have been studied and reported in great detail, but the marine vertebrates are less well known. Exposures of the Lueders Formation offer opportunity to study and compare the shallow water marine vertebrates from different places along the eastern margin of the Permian Mid-continental seaway. Two such faunas, the Lake Kemp Dam and Miller's Creek local faunas, are now available for comparison.

The Lake Kemp Dam site was a delta margin with marine mud intermittently covered with dark, freshwater sediments derived from shifting deltaic streams. The marine dolostones were intertidal deposits, often exposed to the air as indicated by mud cracks and footprints of large terrestrial amphibians and reptiles.

The fish-layer at the Miller's Creek site was probably a short distance offshore, and the dolostones formed in water less than a meter deep. The presence of a few remains of seemingly terrestrial amphibians and reptiles indicates a near-shore location. The presence of gentle currents is indicated by the orientation of acanthodian spines and scales. The vertebrate remains are probably largely of resident shallow-water fishes, and transient forms from deeper water.

In spite of their proximity (30 km), synchronology, and similarity in water depth, the Miller's Creek and Lake Kemp local faunas are strikingly different. At Lake Kemp Dam the fauna is dominated by paleoniscoids. Their disarticulated remains are ubiquitous, and scales and cranial elements are present in countless millions. Acanthodians are rare and represented by a single spine. At Miller's Creek the reverse is true; acanthodians are ubiquitous and paleoniscoids are relatively uncommon.

Even disregarding the tetrapods, freshwater paleoniscoids, and lungfish, the Lake Kemp Dam site has a much more diverse fauna. More kinds of paleoniscoids were identified at Lake Kemp Dam, because their remains are abundant and better preserved. Platysomids can be recognized even from isolated scales, but no platysomid scales were seen at Miller's Creek. Six bradyodont teeth were found at Lake Kemp Dam, but none were seen at Miller's Creek. The coelacanth from Lake Kemp Dam, questionably identified as *Spermatodus pustulosus*, may well be the same as the unidentified coelacanth (?) from Miller's Creek.

The cited differences between the two local fauna doubtless result from some important differences in ecological conditions. One would expect the shallow waters at the Miller's Creek site to have a more diverse fauna than the intertidal zone at Lake Kemp Dam, but this does not

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TABLE 1. COMPARISON OF THE FAUNAS OF THE LAKE KEMP DAM AND MILLER'S CREEK

Lake Kemp Dam	Miller's Creek
Ctenacanthus cf. *amblyxiphias*	*Ctenacanthus* cf. *C. amblyxiphias*
Janassa sp.	
Rodriguezichthyes luedersensis?	*Rodriguezichthyes luedersensis*
Luederia kempii	
near *Lawnia taylorensis*	
"*Acrolepis*"	"*Acrolepis*"
Schaefferichthyes luedersensis	
Platysomus palmaris?	
unidentified paleoniscoids	unidentified paleoniscoids
Spermatodus pustulosus?	unidentified coelacanth(?)
Gnathorhiza serrata	
Trimerorachis sp.	*Trimerorarchis?*
Eryops megacephalus	
Diplocaulus magnicornis	*Dimetrodon* sp.
Dimetrodon?	

seem to have been the case. The great number of acanthodians at Miller's Creek cannot be accounted for at this time.

VIII. ACKNOWLEDGMENTS

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REVIEWS

QUATERNARY GEOLOGY AND ENVIRONMENT OF CHINA, by Liu Tung-sheng. Publishedby China Ocean Press, Beijing, China, and distributed by Springer-Verlag, Berlin, Heidelberg, New York, and Tokyo, 1985, x + 301 pp., illus., $69.50

Preparatory to the 11th INQUA Congress in August 1982, a symposium was held at Beijing in February 1982, summarizing the result of Quaternary research in China in recent years. The forty-two papers and eighteen abstracts presented here are from that symposium. These papers can be divided into six parts, Quaternary Stratigraphy (8 whole texts, 5 abstracts); Lithology and Genesis of Quaternary Deposits (10, 2); Quaternary Flora and Fauna (6, 3); Quaternary Paleogeography (13, 5); Prehistoric Man and his Material Culture (1, 1); and, Natural Resources of Quaternary Deposits (4, 2).

Much useful information is included, though the volume suffers from the unevenness characteristic of symposium compilations. However, it does present an overview of Quaternary research in China which is a valuable reference.

SEDIMENTARY AND EVOLUTIONARY CYCLES, edited by Ulf Bayer and Adolf Seilacher. Published by Springer-Verlag, Berlin, Heidelberg, New York, Tokyo, 1985, vi + 465 pp., illus., paperbound, $29.50

This is the first volume in a new series, Lecture Notes in Earth Sciences, published by Springer-Verlag and edited by Gerald M. Friedman. This work is the synthesis of a symposium held at Tübingen September 15-17, 1983. It presents twenty-two papers by thirty authors arranged in six sections: Sea-level Changes: General Consequences; Sedimentary Trends in Marginal Epicontinental Basins; Evolutionary and Ecological Replacements in Marginal Epicontinental Seas; Gastropod Evolution in Lakes; The Lower Hierarchy of Cycles: Spatial and Temporal Substrate Gradients; and, Ecological and Morphological Gradients. It is a worthwhile volume.

––H.C.S.