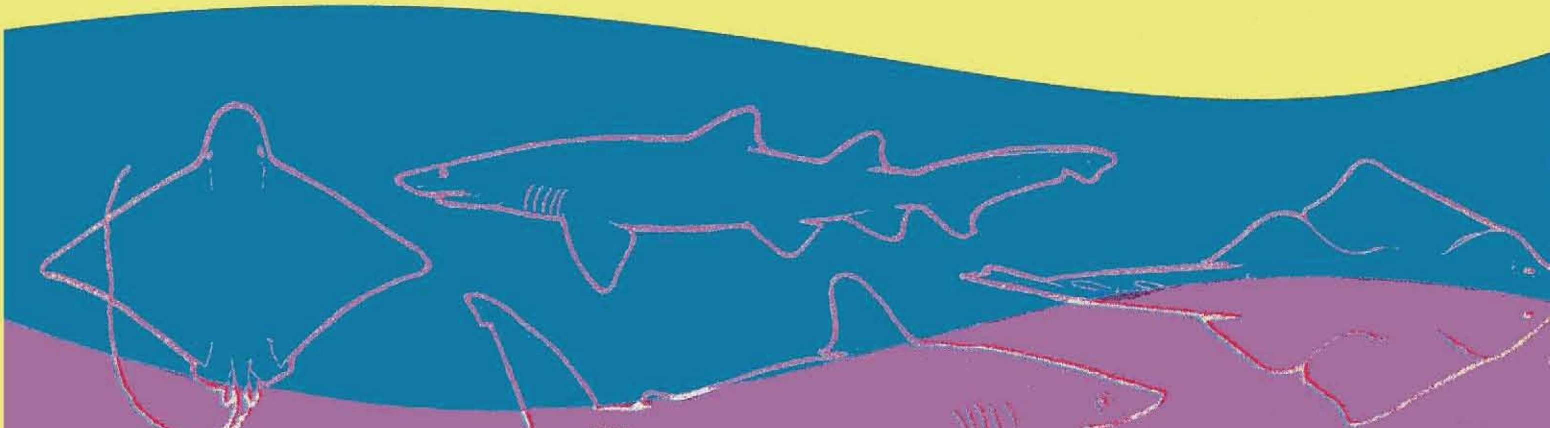
The Collector's Guide to

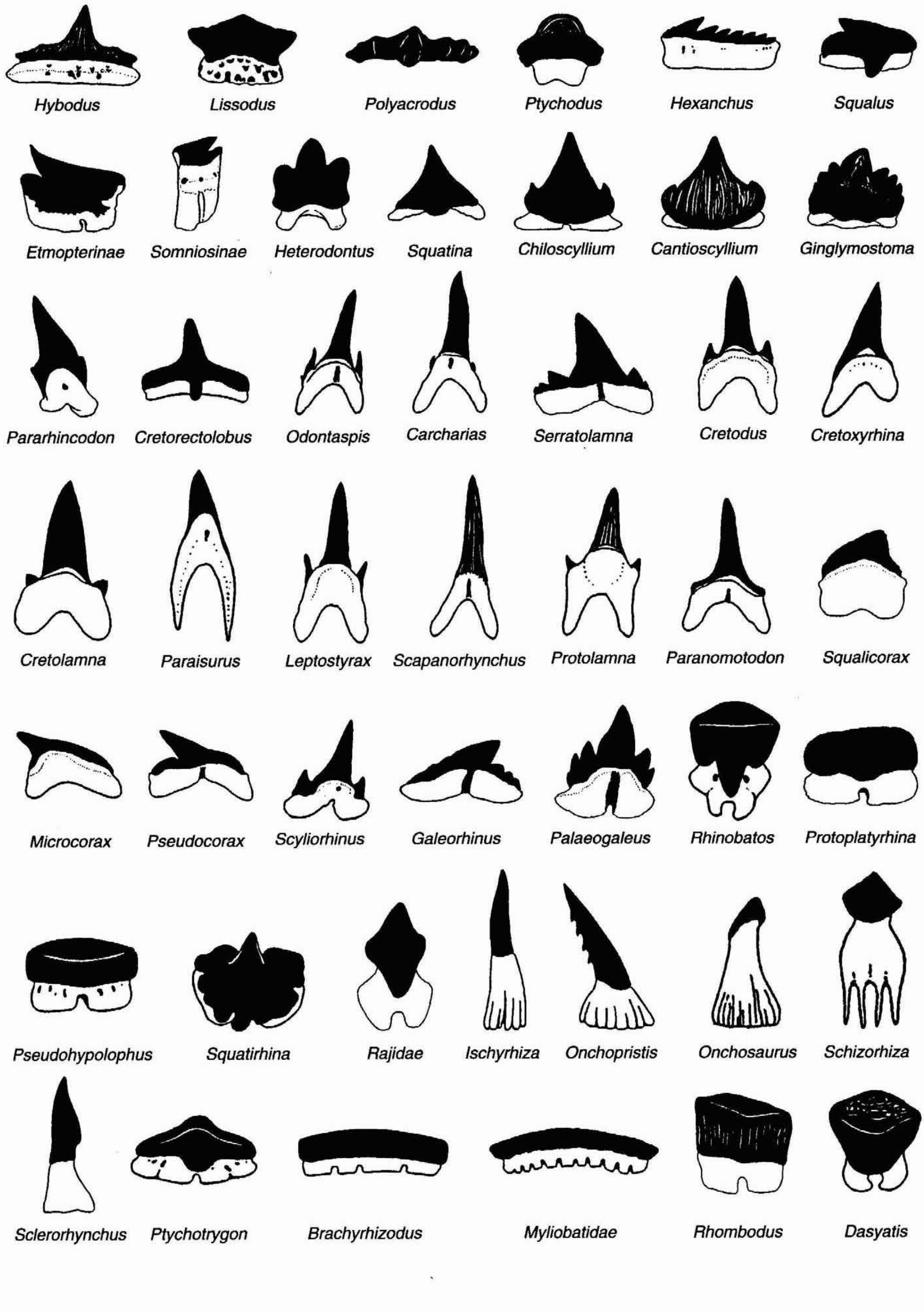
Fossil Sharks and Rays

From the Cretaceous of Texas



Bruce J. Welton, Ph.D.
Roger F. Farish

A must for Collectors and Professional paleontologists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Heterodontus
Squatina
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Cantioscyllium
Ginglymostoma
Pararhincodon
Cretorectolobus
Odontaspis
Carcharias
Serratolamna
Cretodus
Cretoxyrhina
Cretolamna
Paraisurus
Leptostyrax
Scapanorhynchus
Protolamna
Paranomotodon
Squalicorax
Microcorax
Pseudocorax
Scyliorhinus
Galeorhinus
Palaeogaleus
Rhinobatos
Protoplatyrhina
Pseudohypolophus
Squatirhina
Rajidae
Ischyrhiza
Onchopristis
Onchosaurus
Schizorhiza
Sclerorhynchus
Ptychotrygon
Brachyrhizodus
Myliobatidae
Rhombodus
Dasyatis

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About the Authors

Roger F. Farish is currently a Financial Advisor/Investment Broker with A.G. Edwards & Sons. Previously, he was a Senior Staff Geophysicist with Mobil Oil Corporation in Dallas, Texas and Saudi Arabia. His quest to understand the earth's prehistory through paleontology has led him through two terms as president of the Dallas Paleontological Society and has resulted in a specialization in the study of fossil sharks.

Bruce J. Welton has specialized in the study of modern and fossil sharks and rays for more than 20 years and has authored numerous scientific papers on this subject. In 1978 he received a Ph.D. in Vertebrate Paleontology from the University of California at Berkeley for his studies of Cretaceous and Tertiary deep water sharks from the west coast of North America. Dr. Welton has held research and curatorial positions in Vertebrate Paleontology at the Natural History Museum of Los Angeles County, California and is currently a petroleum geologist with Mobil Exploration and Producing Technical Center in Dallas, Texas.

Acknowledgments

Since the time this book was first conceived, over four years ago, we have been compiling and documenting copious volumes on the occurrence and distribution of Texas Cretaceous sharks and rays. A substantial part of this invaluable data base comes from the first hand knowledge of numerous Texas collectors and it is to these individuals we owe our sincere gratitude. Over the course of writing this book, we photographed literally thousands of shark and ray teeth based on specimens in numerous private collections. Many teeth were personally carried to our residence for examination and photography while other collectors invited us, along with all of our equipment, into their homes to examine and photograph their shark and ray teeth. We also must thank the seemingly endless procession of enthusiastic collectors who at every opportunity have shown us teeth or provided valuable collecting locality and stratigraphic information. To the many people who provided encouragement, support and advice throughout the writing of this book, we are very grateful.

We are especially indebted to the following individuals for allowing us to examine and photograph their Texas Cretaceous shark and ray collections: Ron Basserman, Chuck Blair, Mark Cohen, Dick and Diane Collier, Peter Cornell, Frank and Joan Crane, Billy Davidson, Ed and Nancy Emborsky, Linda Farish, Jimmy Green, John Hodge, Becky Liberato, John Maurice, John Meyer, Jack McLellan, John Moody Jr., John Moody Sr., Gina Natho, Walter and Dianna Pepper, Mike and Sandy Polcyn, Rob Reed, Karen Samfield, Marty Selznick, Larry Shindel, Ken Smith, David Swann, Van Turner, Phillip Virgil, Jim and Alice Williams, Mark and Paul Walters and Richard and Shawn Zack.

For access to fossil sharks and rays in the Dallas Museum of Natural History collections, we sincerely thank Charles Finsley and Lloyd Hill. We would like to thank Dr. Louis Jacobs and Dr. Dale Winkler of Southern Methodist University, Schuler Museum of Paleontology, for allowing us to use museum facilities and permission to borrow and photograph museum specimens. We thank Dr. Melissa Winans, Dr. Gordon Bell and David and Laura Froelich of the University of Texas, Balcones Research Laboratory for permission to examine and borrow specimens in their paleontological collection.

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Lastly, we would especially like to thank Mr. Jack McLellan for his friendship and generosity in sharing with us his knowledge of Texas Cretaceous sharks and rays. Through years of careful stratigraphic bulk sampling, acidizing and microscopic sorting of Cretaceous sediments, Jack amassed comprehensive elasmobranch assemblages with a unique knowledge of their taxonomy and distribution throughout Texas. In addition to providing the support necessary for this project, he has been a insightful technical reviewer and an energetic cheerleader.

Foreword

For over 140 years, amateur and professional paleontologists have been scouring the hills and stream valleys of Texas discovering the fossil evidence of this state's fascinating prehistory. Among those objects that have stimulated some of the greatest curiosity are the beautifully formed, diverse and easily found teeth and other remains of long extinct sharks and rays.

These fishes are among the most adaptable and hardiest forms of life on this planet and have been here about 100 times longer than man. Among these are some of the most aggressive and ferocious predators of either ancient or modern oceans. Today, as in the past, sharks and rays are found worldwide from polar to equatorial seas; at shallow to abyssal water depths; and in salt, brackish and fresh waters.

Modern-day paleontologists strive to understand these ancient sharks and rays by comparing their teeth and other fossilized remains with skeletons of closely related living species. For example, the seemingly overwhelming task of separating a day's collection of fossil teeth into discrete species groups becomes a much simpler task once the principles of tooth variation (heterodonty) are understood. Within just one species of shark or ray, teeth can differ drastically in size and shape depending on their position in the mouth, the age of the individual and even its sex!

Shark and ray teeth are extremely durable objects that resist deterioration and, because of their weight, may accumulate in large numbers within sedimentary lag deposits. Shark and ray teeth are also abundant because every individual naturally sheds thousands of them throughout life.

Excellent exposures of highly fossiliferous Cretaceous (131 to 66.5 million years ago) age rocks in Texas have made it possible for thousands of amateur and professional paleontologists to amass outstanding shark and ray tooth collections. From this successful collecting effort has risen an obvious need for assistance in the identification of the 80 or so shark and ray species known to date from the Cretaceous in Texas.

After numerous requests by our friends, fellow collectors and colleagues, we decided to write *The Collector's Guide to Fossil Sharks and Rays from the Cretaceous of Texas*. This book brings together in an easily understood way, the diverse elements of modern and ancient shark hard-part biology and paleontology. Amateur and professional paleontologists alike will find this book to be a useful guide to the identification and understanding of Texas Cretaceous shark and ray teeth.

Preface

The compilation of a guide book for the identification of Texas Cretaceous shark and ray teeth is a difficult task. It must be comprehensive enough for the professional or serious collector and yet basic enough for the beginner in paleontology. Unfortunately, no single format can please everyone. So, we selected a format to make the voluminous collection of data most accessible for the serious collector.

Included in this book are all the species of Texas Cretaceous sharks and rays that have been published to date in the scientific literature. They are arranged, described and illustrated in the following pages according to their systematic classification — from the most primitive to the most advanced. This is a practical book with numerous firsthand observations and background research that was necessary to properly cover the topic.

We have attempted to present a comprehensive overview of shark and ray hard-part biology and paleontology. A number of fundamental paleontological principles are introduced and the reader is provided with some general introductory information on the Cretaceous stratigraphy of Texas. For completeness, the student of fossil sharks will find chapters on **Tooth Collecting**, **Fossil Preparation**, **Taking Care of Your Collection**, **Displaying Your Collection** and **Collecting Localities** especially useful.

During preparation of this book, we observed a number of shark and ray teeth that are new to science, found numerous teeth that were previously only poorly described in the literature and established new stratigraphic and geographic ranges for several species. These findings will be published in detail at a later date in the appropriate technical literature.

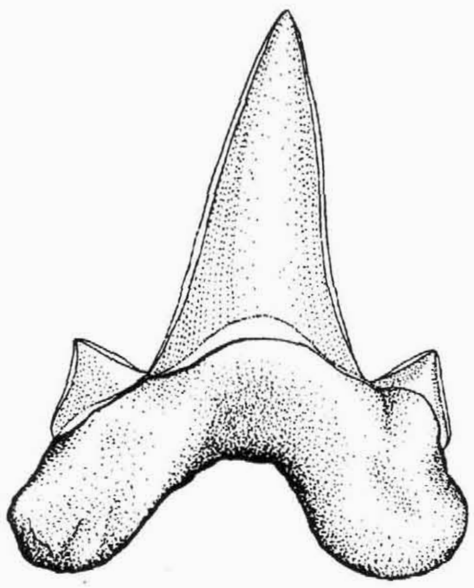
There are numerous departures here from the purely technical taxonomic descriptions of species, documentation of localities, and lengthy comparisons with other known or closely related taxa. We have omitted most synonymies (chronologic listing of invalid names) and have limited reference citations to principal authors. The systematics and taxonomy used here are current and the identifications conform to those most widely in use among paleontologists today. This is not to say, however, that some identifications are not controversial and subject to change after further study. A list of selected references for additional information on each species is provided for the serious collector. A glossary of technical terms is included at the end of this book.

Emphasis has been placed on understanding the patterns and types of tooth variation among sharks and rays. This information is essential for identifying and distinguishing morphological variations that differentiate one species from other closely related forms.

The photographs and illustrations in this book are all of Texas specimens and are largely taken from numerous private collections around the central and north central Texas area. An attempt has been made in most cases to select specimens that show the full range of variation within each species.

Since this is a practical work, the writers will greatly appreciate additional observations by readers on the stratigraphic occurrence, maximum tooth size, unusual specimens, or new additions to the Cretaceous shark and ray fauna of Texas.

Bruce J. Welton
Roger F. Farish



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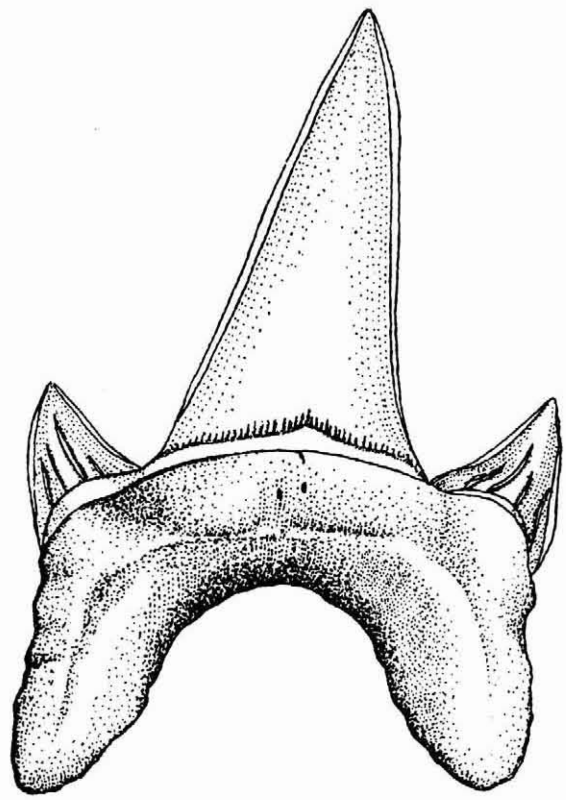
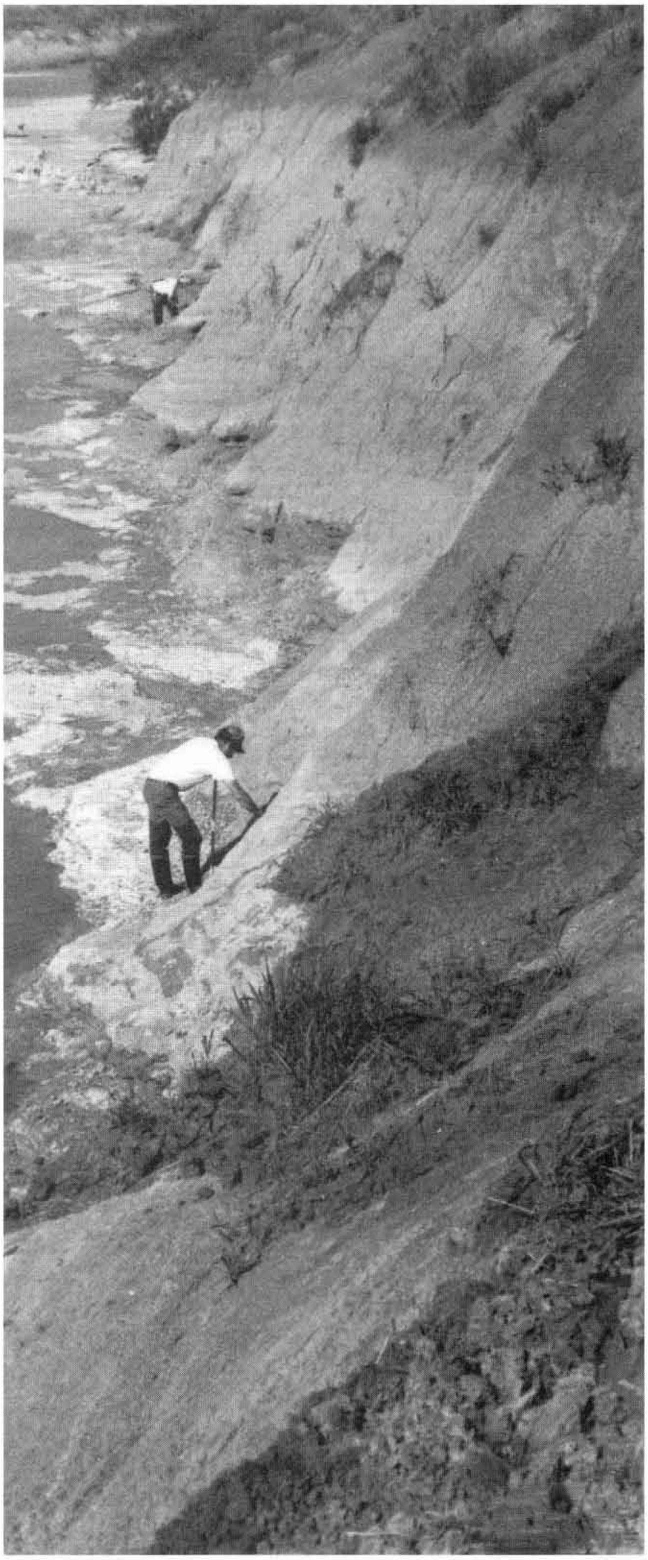
The Collector's Guide to Fossil Sharks and Rays from the Cretaceous of Texas



Introduction

Among Texas fossil collectors, there is a no more dedicated nor enthusiastic group than the one specializing in the collection of fossilized shark and ray teeth. Annually, thousands of amateur paleontologists of all ages indulge in this activity for many reasons and at all levels of interest. For the persistent collector, teeth are found in abundance at numerous sites where Cretaceous rocks have been exposed through weathering and erosion. Popular collecting localities occur in road cuts, quarries, creek and river beds and at temporary exposures associated with construction for housing, highways and industry.



Building a tooth collection can be a great hobby or the beginning of a rewarding scientific endeavor, stimulating your natural curiosity about these fascinating fishes. However, **CAUTION** is advised. Collecting fossil shark teeth may become an obsession with you like it has for some of us!

Although the scope of this book is the Cretaceous of Texas, many of the figured species have cosmopolitan (worldwide) distributions. Aside from an introductory section on Texas stratigraphy, all other chapters in this book address subjects of widespread interest to fossil shark and ray tooth collectors, regardless of the fossil's geologic age or geographic origin.

All previously described sharks and rays found in the Cretaceous outcrops of Texas, from Sherman to San Antonio, then west to Big Bend, are included in this book. Most species the Texas collector encounters are figured and easily identified. A number of sharks and rays having very small teeth, which are only found by using special collecting methods, have also been included, as have teeth representing new genera and species that have yet to be formally named in the scientific literature. Finally, teeth of a few species are extremely rare, known only by one or two records in Texas.

Except for the absence of earliest Cretaceous (Neocomian) rocks in Texas, and hence any fossil record of this time period, the remaining Cretaceous

(Aptian to Maestrichtian) strata record a nearly unbroken sequence of warm tropical marine sedimentation. Within this heterogeneous succession of sands, shales, chalks and limestones is found a remarkably rich and diverse shark and ray fauna in excess of eighty species.

The oldest Texas Cretaceous sharks and rays are found in fresh, brackish and shallow marine environments of the Trinity and Fredericksburg groups. Deposits such as the Paluxy and Glen Rose formations yield a characteristically sparse shark and ray fauna. Teeth are rarely found in the overlying Walnut, Comanche Peak and Goodland formations, nor are they common in basal Washita Group rocks. Then, in the latest Albian, shark and ray teeth appear in abundance beginning with the Weno and Pawpaw formations and continue upward into the Upper Cretaceous (Cenomanian) Grayson, Pepper and Woodbine formations. The teeth are especially abundant throughout the Eagle Ford Group (Cenomanian-Turonian) and in the overlying Coniacian age basal Atco Formation of the Austin Group (but not formations above the Atco), and most formations comprising the overlying Taylor (Campanian) and Navarro (Maestrichtian) groups.

Numerous paleontological studies describing the Cretaceous sharks and rays of Texas have been published since the mid 1800s and, unfortunately, the only comprehensive work is an unpublished 1975 doctoral dissertation by Robert Meyer. In the eighteen years since Meyer completed his outstanding research, many new specimens have been found and a substantial number of changes have taken place in shark and ray systematics and taxonomy which either invalidate or significantly alter many of his original conclusions and interpretations.

This book is not a revision of Meyer (1975) but a completely new interpretation of Texas Cretaceous sharks and rays based on reexamination of pertinent museum collections and numerous private collections. Supplementing the above data is an extensive chronostratigraphic collection of teeth based on our own resampling efforts. New collecting methods, largely involving the bulk sampling, acid concentration and microsieving of fossiliferous rocks, led to the discovery of many new genera and species, new stratigraphic and chronologic ranges and the addition of several species representing orders and families of sharks that were not previously reported from the Texas Cretaceous.

Identifying your Cretaceous shark and ray teeth is our primary concern in writing this book. To this end, we provide a well illustrated and easy-to-use identification guide, plus substantial supporting information covering a wide range of topics that collectively define the hobby or avocation of shark and ray paleontology.

Chapter 1

Geology

The most successful Texas fossil shark tooth collectors are, without doubt, individuals who have keen eyesight, persistence, and most importantly, a good working knowledge of Texas Cretaceous geology. Shark teeth are not found everywhere. Some geologic formations are more fossiliferous than others; successful collectors know this and concentrate their efforts on the most productive beds. The presence or absence of teeth, their abundance, size range and diversity (number of species) at any locality are attributes controlled by the environment at the time of deposition. These are factors such as depth, salinity and temperature of the water, abundance of food, rate of sediment accumulation, **taphonomy** (the postmortem history of the shark) and changes that take place to organic matter after burial.

Clearly, an understanding of Texas Cretaceous geology is essential background for appreciating the teeth you have found. Knowing where you are collecting geologically enables you to communicate this information to others and will be of assistance to you in collecting the same formation at other localities. It is valuable scientific data that should always be recorded and kept with the teeth you find and is essential for any paleontological study. The following section provides the geologic framework and terminology you will need to fully utilize this book.

EUROPEAN STAGE AGES

The Cretaceous rocks in Texas contain abundant invertebrate fossils somewhat similar to the modern chambered nautilus (cephalopods) but belonging to an extinct group of animals called **ammonites**. Paleontologists use ammonites, among other groups, to determine the age of the rocks they are found in. A series of ammonite stages, representing distinct periods in geologic time, was originally established in Europe and subsequently recognized and refined in North America (Figure 1). Thus, ammonites, as well as other marine invertebrates with restricted life spans, have proven useful as markers for the various stages of the Cretaceous.

If ammonites are not found within the stratigraphic section you would like to date, then an approximate

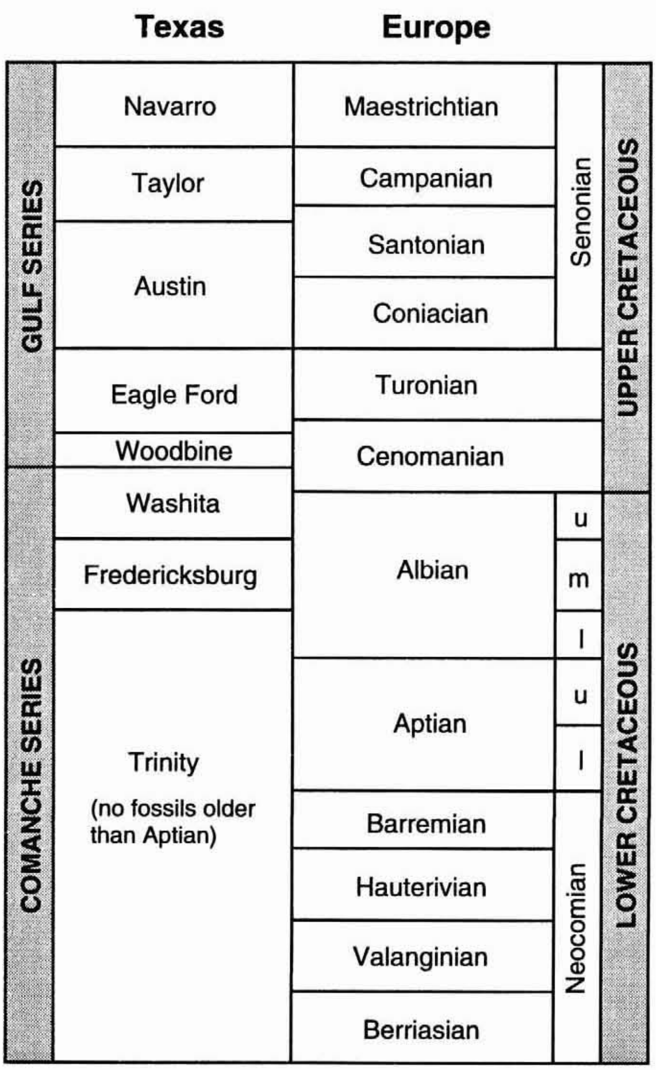


Figure 1. Subdivisions of the Texas Cretaceous and their relation to European stages. Modified from Amsbury (1974: Figure 1).

age can be inferred by bracketing the sequence with dated rocks occurring above and below that section. Absolute dates, in terms of millions of years, have been assigned to these European ammonite stages by radiometrically dating the rocks using the potassium-argon method.

Figure 1 shows the European ammonite stages as applied to the Texas Cretaceous and we strongly recommend that you become familiar with these names. Using these stage ages facilitates communication. If someone tells you they found a certain species of shark in formation X and you are unfamiliar with formation X, then little information is shared. However, if you are told that formation X is Campanian in age, then it is possible to relate these fossils to all other Campanian age species worldwide.

THE TEXAS CRETACEOUS

The Cretaceous Period spans a time range from 131 to 66.5 million years ago (**mya**). A geologic map of Texas (Figure 2) shows a wide Cretaceous outcrop

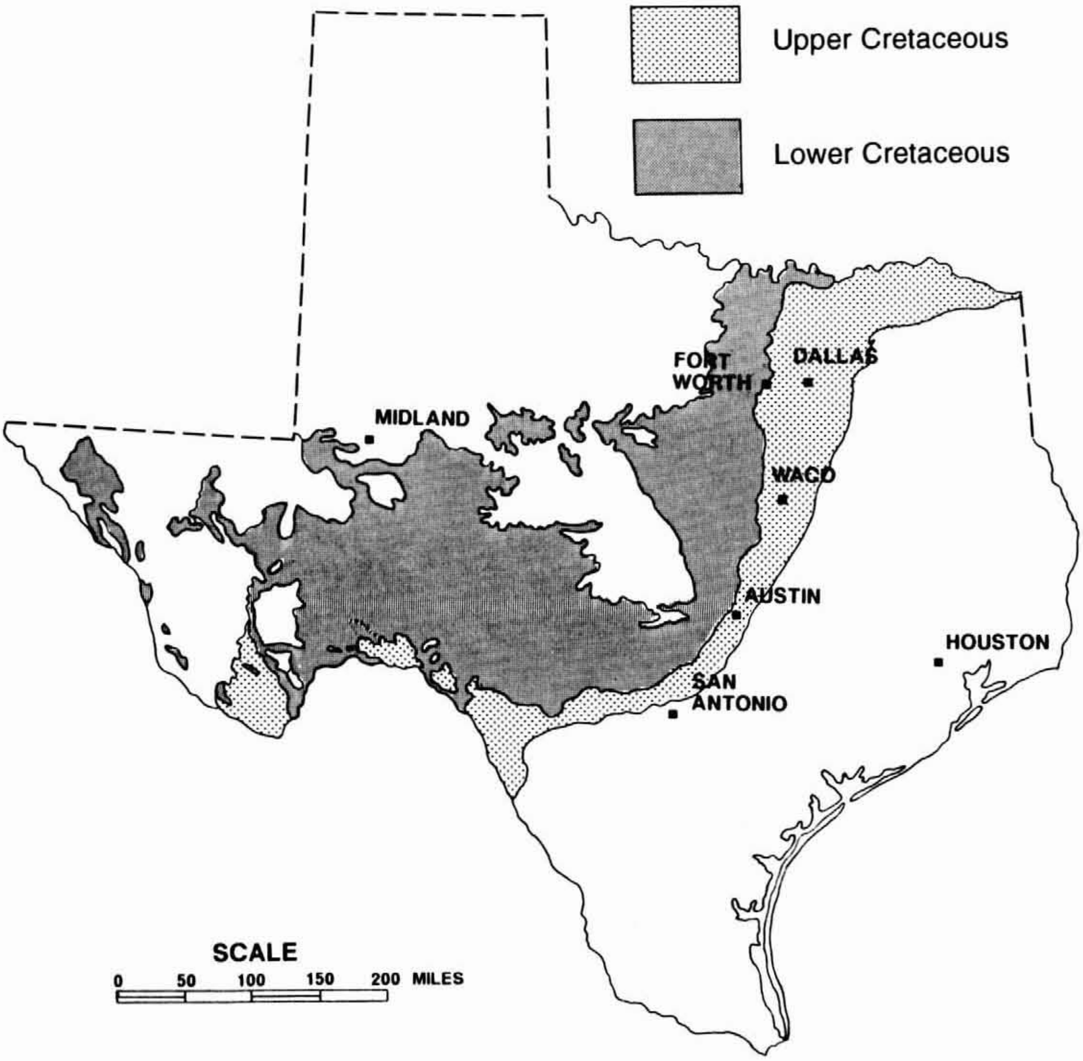


Figure 2. Geologic map of Texas showing the distribution of Lower and Upper Cretaceous rocks. Modified from Stose (1946) and Perkins (1960).

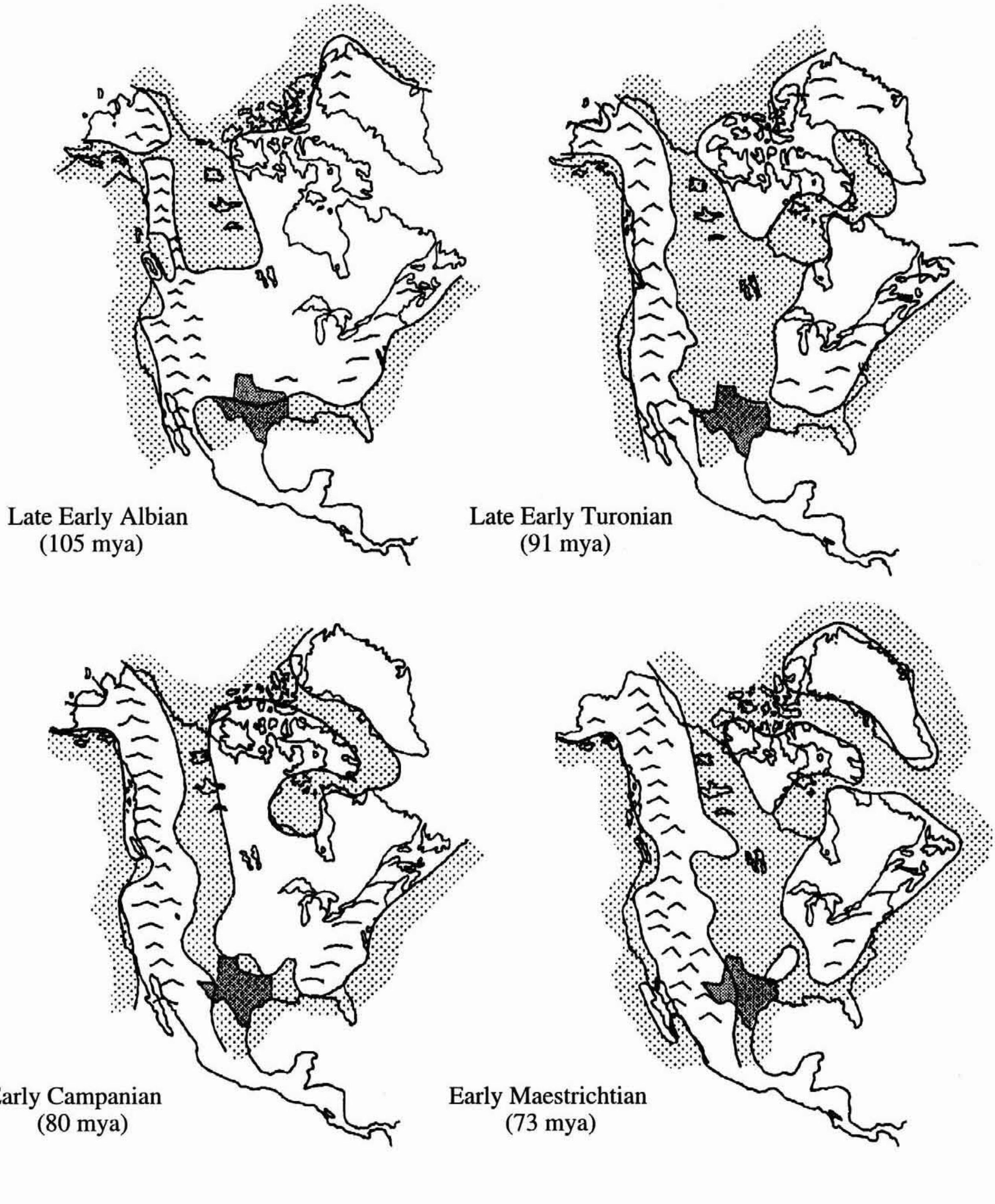


Figure 3. Generalized maps of North America showing the extent of the Western Interior Cretaceous Seaway during the late early Albian, late early Turonian, early Campanian, and the early Maestrichtian. Stippled pattern indicates water. Maps adapted from Williams and Stelck (1975).

belt extending roughly northeast-southwest from the Texas-Oklahoma border to Mexico. Sometimes over 100 miles wide, this belt passes through Dallas-Fort Worth, Waco, Austin then westward from San Antonio to Big Bend and beyond.

Throughout most of the Cretaceous period, a great seaway extended across Texas and divided North America into two widely separated land masses (Figure 3). At its maximum extent, this interior or epicontinental sea extended from Arctic Canada and Alaska south to the Gulf of Mexico, approximately 4800 kilometers (3000 miles).

Shoreline deposits suggest that this seaway had a maximum width of about 1620 kilometers (1000 miles). The seaway's size and shape changed many times during the Cretaceous due to fluctuations in sea level, tectonics (mountain building) and rates of sedimentation as deltaic deposits built out from the shoreline.

The seaway was initially flooded from the north during the Aptian Stage (Lower Cretaceous). By middle Albian, a continuous marine seaway extended from the Gulf of Mexico to the Arctic Sea. After a brief marine regression in the late Albian, the two arms of the seaway again joined in the latest Albian-earliest Cenomanian time and remained as a continuous marine system for nearly 30 million years.

These seas moved back and forth across Texas numerous times during the Cretaceous, leaving behind over 15,000 feet of highly fossiliferous sediments. Except for some Trinity and Woodbine sands, which are at least partly nonmarine, the vast majority of Texas Cretaceous sediments were laid down under subtropical marine conditions.

STRATIGRAPHY

The Cretaceous rocks of Texas are subdivided into two well defined series: **Gulf** (approximately Upper Cretaceous) and **Comanche** (approximately Lower Cretaceous). The Gulf Series includes, from oldest to youngest, the **Woodbine**, **Eagle Ford**, **Austin**, **Taylor** and **Navarro** groups (Figure 4). The older Comanche series is subdivided into, from oldest to youngest, the **Trinity**, **Fredericksburg** and **Washita** groups (Figure 5).

Each group consists of one or more geologic formations — bodies of rock large enough to be mapped. Formations have well defined stratigraphic tops and bases and are composed of characteristic rock types (e.g., sandstone, limestone, chalk, etc.). Formations are the essential units in the classification of local stratigraphic sequences and are the product of a particular set of depositional events. Formations may have very broad or only limited geographic extent and they may vary greatly in thickness throughout their range.

The correlation charts shown in Figures 4 and 5 illustrate generalized stratigraphic sections for the Dallas, Austin, Waco, Marathon/Big Bend and Fannin County areas of Texas. As you can see, the formational names for time-equivalent intervals are not necessarily the same between geographic areas. An example is the Cenomanian Woodbine Formation of the Dallas area and the correlative (time-equivalent) Pepper Formation of the Austin and Waco areas. The sandy Woodbine Formation was deposited in a variety of near-shore marine and terrestrial environments. The clay-rich Pepper Formation was also deposited during Woodbine time but further from shore in deeper and quieter water.

The stratigraphic range and occurrence of each species of fossil shark and ray from the Cretaceous of Texas is given in the Species Identification section of this book. Refer back to Figures 4 and 5 for details on the age and correlation of sharktooth-bearing formations.

Knowing which formation you are collecting in and where you are stratigraphically within the geologic section is useful information. Often, an experienced collector can supply you with these facts or you may want to obtain the opinion of a professional geologist or paleontologist. Also, a number of excellent publications and geologic maps describing the Cretaceous stratigraphy of Texas are available from the Bureau of Economic Geology at the University of Texas in Austin.

			BIG BEND	AUSTIN	WACO	DALLAS	FANNIN CO.
UPPER CRETACEOUS	NAVARRO GP	MAASTRICHTIAN	JAVELINA FM	ESCONDIDO: KEMP CLAY	KEMP CLAY	KEMP CLAY	KEMP CLAY
				ESCONDIDO: CORSICANA MARL	CORSICANA CLAY	NACATOCH SAND	NACATOCH SAND
				(shaded)	NACATOCH SAND		
				BERGSTROM CLAY	NEYLANDVILLE MARLS	MARLBROOK	MARLBROOK
				PECAN GAP CHALK	UPPER TAYLOR		
	TAYLOR GP.	CAMPANIAN	AGUJA FM.	(shaded)	PECAN GAP CHALK	PECAN GAP CHALK	PECAN GAP CHALK
					WOLFE CITY	WOLFE CITY	WOLFE CITY
			SAN CARLOS FM.	SPRINKLE	OZAN - LOWER TAYLOR	OZAN - LOWER TAYLOR	BROWNSTOWN
	AUSTIN GROUP			BIG HOUSE	UPPER CHALK	UPPER CHALK	
			PEN FM.	PFLUGERVILLE			
				BURDITT			GOBER CHALK
		SANTONIAN	BOQUILLAS FM.	DESSAU			BROWNSTOWN
				JONA			
				VINSON	MIDDLE MARL	MIDDLE MARL	MIDDLE MARL
		CONIACIAN		ATCO	LOWER CHALK (= ATCO)	LOWER CHALK (= ATCO)	LOWER CHALK (= ATCO)
	EAGLE FORD GROUP	TURONIAN		SOUTH BOSQUE SHALE	SOUTH BOSQUE SHALE	ARCADIA PARK	MARIBEL SHALE
						KAMP RANCH	" Fish Bed Conglomerate"
		CENOMANIAN		BOULDIN FLAGS	LAKE WACO	BRITTON	BELLS SANDSTONE
				CLOICE	BLUE BONNET	TARRANT - SIX FLAGS	Undifferentiated EAGLE FORD SHALE
	WOODBINE GP.		(shaded)	PEPPER	PEPPER	WOODBINE: Arlington Mbr.	WOODBINE
						WOODBINE: Lewisville Mbr.	
						WOODBINE: Dexter Mbr.	
						WOODBINE: Rush Creek Mbr.	

Figure 4. Age and generalized stratigraphic correlation of Upper Cretaceous rocks in the Big Bend, Austin, Waco, Dallas and Fannin county areas of Texas after Burket (1965), Pessagno (1969), Young (1977, 1983), Eby and Clarke (1983), Young and Woodruff (1985), Kennedy (1988), Jiang (1989), Thompson (1991) and Rowe *et al.* (1992).

			BIG BEND	AUSTIN	WACO	DALLAS	FANNIN CO.
U. CRETACEOUS	WASHITA	CENOMANIAN	BUDA	BUDA	BUDA	GRAYSON	GRAYSON
			DEL RIO	DEL RIO	DEL RIO	MAINSTREET	MAINSTREET
LOWER CRETACEOUS		ALBIAN		GEORGETOWN	GEORGETOWN	PAWPAW	PAWPAW
						WENO	WENO
						DENTON	DENTON
						FORT WORTH	FORT WORTH
						DUCK CREEK	DUCK CREEK
						KIAMICHI	KIAMICHI
	FREDERICKSBURG			EDWARDS	EDWARDS	GOODLAND	GOODLAND
					COMANCHE PEAK		
				WALNUT	WALNUT	WALNUT	WALNUT
					PALUXY		
	TRINITY			GLENROSE	GLENROSE	BLUFF DALE	BLUFF DALE
		APTIAN		HENSEL	HENSEL		
				COW CREEK	COW CREEK		
				HAMMET	HAMMET		
		NEO.		SYCAMORE	SILAGO		

Figure 5. Age and generalized stratigraphic correlation of Lower Cretaceous rocks in Big Bend, Austin, Waco, Dallas and Fannin county areas of Texas after Perkins (1960), Burket (1965), Young (1967, 1977) and Brown (1971).

Chapter 2

Sharks and Rays

All sharks and rays plus their relatives the chimaera and ratfishes are members of the Class **Chondrichthyes** (cartilage + fishes). Chondrichthians differ from almost all other fish in having no bone at all in their skeleton. They are also distinctive for having a solid braincase (**chondrocranium**), tooth-like placoid scales, teeth anchored to a membrane and restricted to the jaw margins, a series of external gill openings, lack of a gas bladder plus many other distinguishing attributes.

The Class Chondrichthyes is divided into two subclasses: the **Elasmobranchii** (plate + gills) including all modern and fossil sharks and rays, and the **Holocephali** containing chimaeroids and ratfishes (Figure 6). The holocephalians are not discussed further in this book. Modern sharks and rays are primarily marine fishes but some also inhabit brackish water estuaries and fresh water rivers and lakes. They reach their greatest diversity in tropical and warm temperate waters and are found worldwide at all latitudes and at depths ranging from abyssal to intertidal.

Compagno (1982) compiled data on the total lengths attained by 296 modern shark species and found that their average maximum adult size is about 1.5 meters or 4.9 feet. The smallest living adult shark, *Euprotomicrus*, is barely 20 centimeters or less than 8 inches in total length. At the other end of the scale is the whale shark, *Rhincodon,* known to be over 15 meters or 49 feet long! Interestingly, the world's two largest sharks, *Rhincodon* and *Cetorhinus* (basking shark), are pelagic fishes that feed almost entirely on microscopic marine plankton.

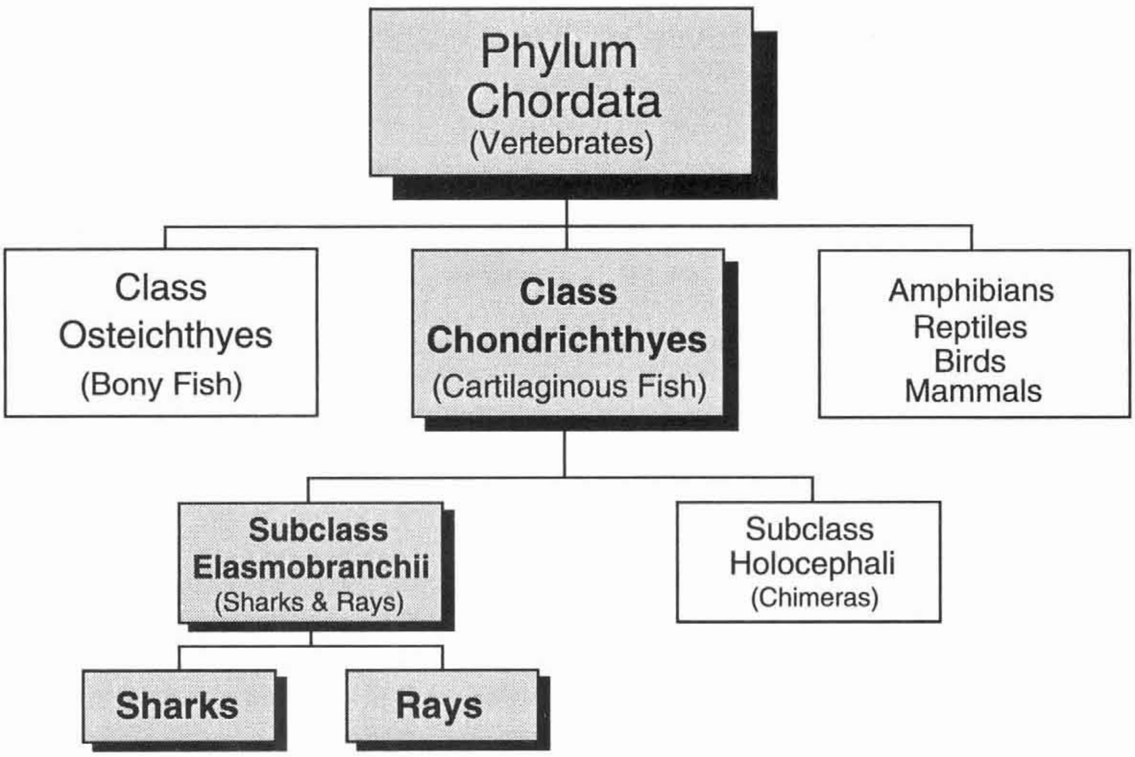


Figure 6. Phylogenetic relationships of the class Chondrichthyes.

Sharks and rays differ markedly from one another in ways that relate to divergent habits. Many sharks are predacious fishes with streamlined bodies and large, strong tails. Their paired fins have narrow bases and their gill slits are lateral in position. Most rays, in contrast, spend much of their time resting on the bottom or swimming sluggishly along in search of shellfishes or other relatively inactive food. Their bodies differ from sharks in being flattened (pancake-like), their pectoral fins are fused to the head, the gill openings are ventral and the pectoral girdle is attached or articulates with a series of fused cervical vertebrae called a **synarcual**.

THE FOSSIL RECORD

The origin of the chondrichthyes is essentially unknown, with possible but unidentified ancestors among Paleozoic **placoderms** and/or **acanthodians**. The oldest demonstrable sharks are found in the Devonian Period, over 350 million years ago.

The problems of deciphering chondrichthian origins arise from inadequate preservation of the cartilaginous endoskeleton and because the exoskeleton, with rare exceptions, consists only of dermal scales or denticles and spines. Cartilage seldom preserves well unless it has been calcified (mineralized). Calcification, in general, and particularly as it applies to vertebrae, is a rather advanced feature that is lacking in most Paleozoic sharks, but is present in many later Mesozoic, Cenozoic and living sharks and rays. Occasionally, however, cartilaginous skeletons are preserved and, in rare instances, the full body form, including impressions of soft tissue, is found.

The fossil record of sharks and rays consists mainly of unassociated or isolated teeth, spines and scales. Although sharks first appear in the Devonian Period, rays are not found until much later, in the Lower Jurassic. These early rays are **guitarfishes**, similar to living forms but more primitive in several characteristics including the presence of fin spines and a very short synarcual. All other rays may ultimately be derived from guitarfishes, but this evolutionary relationship is poorly understood.

TEXAS CRETACEOUS SHARKS AND RAYS

The Cretaceous Period was an exciting time in the history of elasmobranch evolution. During this 64.5 million year period, many modern shark and ray families, and even genera, make their first appearance. It was a time in which the number of species literally exploded relative to what is known about earlier Mesozoic fishes. Then, ending the Cretaceous was an extinction event that saw the demise of many animal and plant groups, including the dinosaurs, and also had an impact on shark and ray diversity. In spite of this late Mesozoic extinction, 17 of the 24 shark families (70%) and 4 of the 9 ray families (44%) found in the Cretaceous are still present today.

Texas has an excellent fossil record of Cretaceous sharks and rays. Cappetta (1987) lists approximately 96 genera of elasmobranchs that he considers to be valid taxa from the Cretaceous worldwide. One-fourth of these genera occur in Texas and numerous undescribed forms are awaiting study. Sharks and rays from Texas Aptian through Maestrichtian strata are well represented across a broad spectrum of environmental settings including nonmarine fluvial, brackish estuarine, coastal deltaic and inner to outer marine shelf settings. Water temperatures were primarily tropical to warm temperate.

Among the best represented sharks and rays, in terms of their abundance, species diversity and distribution throughout the Cretaceous, are hybodonts belonging to the genus *Ptychodus*; carpet sharks or orectolobids; small to very large predacious sharks belonging to the Order Lamniformes; and diverse bottom-dwelling sawfishes (rays).

Chapter 3

Shark and Ray Hard Parts

Almost everything we know about fossil elasmobranch fishes, including their anatomy, evolutionary relationships, geographic and geologic distribution and paleoecology, is based on studies of their mineralized skeletal structures, their sedimentologic context and the fossilized animals and plants found in association with them.

Although living sharks and rays are separated from their earliest ancestors by over 350 million years, a substantial amount of information can be gained by studying the biology of modern sharks and rays and using this information to interpret the fossil record. This is especially true for Cretaceous sharks and rays, many of which are closely related to living genera in taxonomy and in form and function.

The convention of using comparative anatomy as the basis for unraveling the fossil record constitutes the foundation for modern shark paleontology. This chapter describes the basics of elasmobranch hard-part biology as it applies to the study of Texas Cretaceous sharks and rays.

Elasmobranch hard parts are components of either the **endoskeleton** or the **exoskeleton**. Endoskeletal elements include cartilages of the skull (chondrocranium), jaws and gill supports, vertebrae and the vertebral column (**axial skeleton**), fin radials and supports, pectoral and pelvic girdles and clasper cartilages (**appendicular skeleton**). Preservation of these cartilages usually requires that they be at least mineralized (calcified) during life. Aside from unusual environments of preservation, calcified vertebrae and cartilage fragments are the only common endoskeletal elements found in the Texas Cretaceous.

The exoskeleton (**dermal skeleton**) is made up of exposed, hard, mineralized (phosphatic/apatitic) structures including **placoid scales** that cover the body surface, mouth cavity and gill bars; enlarged placoid scales (**dermal denticles**); fin and head (cephalic) spines; rostral teeth (sawfishes and sawsharks) and oral teeth. Modern, and presumably ancient, sharks and rays also have fossilizable calcareous granules or **statoliths** within their otic (ear) capsules.

The mineralized and very durable nature of these exoskeletal elements accounts for their abundance in the fossil record. As pointed out previously, teeth are the most common exoskeletal elements in the Texas Cretaceous. Placoid scales and dermal denticles are also common but usually overlooked because of their small size (often < 1 millimeter) and the necessity of using special techniques to collect them. Rostral (snout) teeth of bottom-dwelling (sclerorhynchid) rays are especially common in the Upper Cretaceous, and both Trinity and Woodbine sands yield fragmentary hybodont shark dorsal fin and cephalic spines. The following discussion of hard parts, appropriately emphasizing the elasmobranch dentition, defines a terminology for the description of teeth and presents the fundamentals of heterodonty (tooth variation) in sharks and rays. All other endoskeletal and exoskeletal elements are reviewed under the second part of the chapter, **Other Hard Parts**.

THE DENTITION

Teeth of the elasmobranchs range between sharp or **prehensile** and **crushing** types. Between these extremes, multitudes of complex patterns occur. The following section addresses in detail these dental variations, relying largely on observations made on the teeth in modern sharks and rays.

Tooth Replacement

Sharks and rays have a **polyphyodont** dentition; that is, they shed old teeth and replace them with new ones throughout their lives. Figure 7 illustrates this process. Teeth develop along the inner surface of the jaw cartilage in association with infolding of epidermal tissue. They are attached to the dental membrane and advance anteriorly in a conveyor-belt fashion, erupt and become functional for a time.

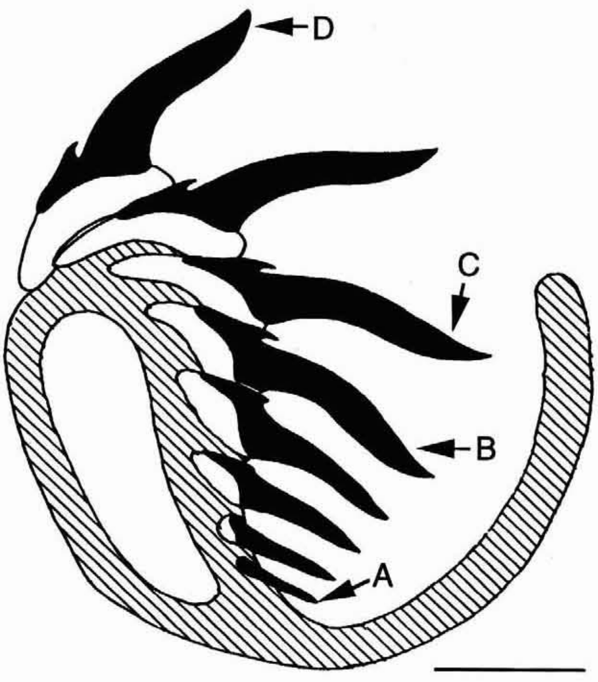


Figure 7. Cross section through the lower jaw (Meckel's cartilage) of the sand tiger shark *Carcharias taurus* Rafinesque 1810 showing the ontogeny of an anterior tooth row A-D. A) new tooth, B) incomplete replacement tooth, C) fully formed nonfunctional replacement tooth, D) functional tooth. Scale line = 1 cm.

An enamel-like crown cap forms first. The root develops later, filling in the crown, and becomes fully formed by the time the tooth reaches a functional position.

Many teeth are lost in the feeding process but many others are simply shed due to this conveyor-belt process. This is one reason shark teeth are so common in the fossil record. Teeth that have been shed during life may have broken or worn crowns, but the roots will always be fully developed. In contrast, the teeth lost as a result of the death of an individual will contain all tooth growth stages from simple enameloid caps through intermediate and mature stages of root and crown formation. An example of one such developmental sequence is evident in the associated dentition of the late Albian shark *Paraisurus compressus* (Figure 8). Often, collectors assume that a tooth with a poorly formed root is broken when in fact it may be an incompletely developed, nonfunctional, replacement tooth.

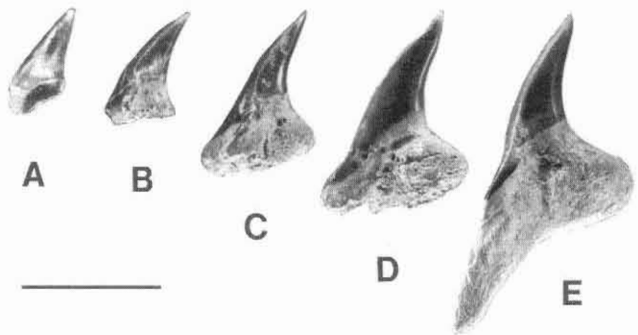


Figure 8. Ontogenetic growth series of teeth from an associated dentition of *Paraisurus compressus* (Albian, Weno Formation, Tarrant County) illustrating the progression of root and crown development (A-E). Immature tooth (A) has only a thin enameloid cap and no crown-filling dentine. Mature tooth (E) has a fully formed crown and root. Scale line = 1 cm.

Tooth Orientation

Describing teeth requires a terminology that clearly conveys tooth orientation. The following terms pertain, in part, to a single tooth (Figure 9) or the entire dentition (Figure 10).

Upper and **lower teeth** refer to the teeth from the upper jaw (**palatoquadrate cartilage**) and the lower jaw (**Meckel's cartilage**).

Symphysis is the midline of each jaw where the left and right jaw cartilages meet.

Labial and **lingual** refer to the faces of the tooth. The lingual side is toward the tongue (inner face) and the labial side is toward the lips (outer face).

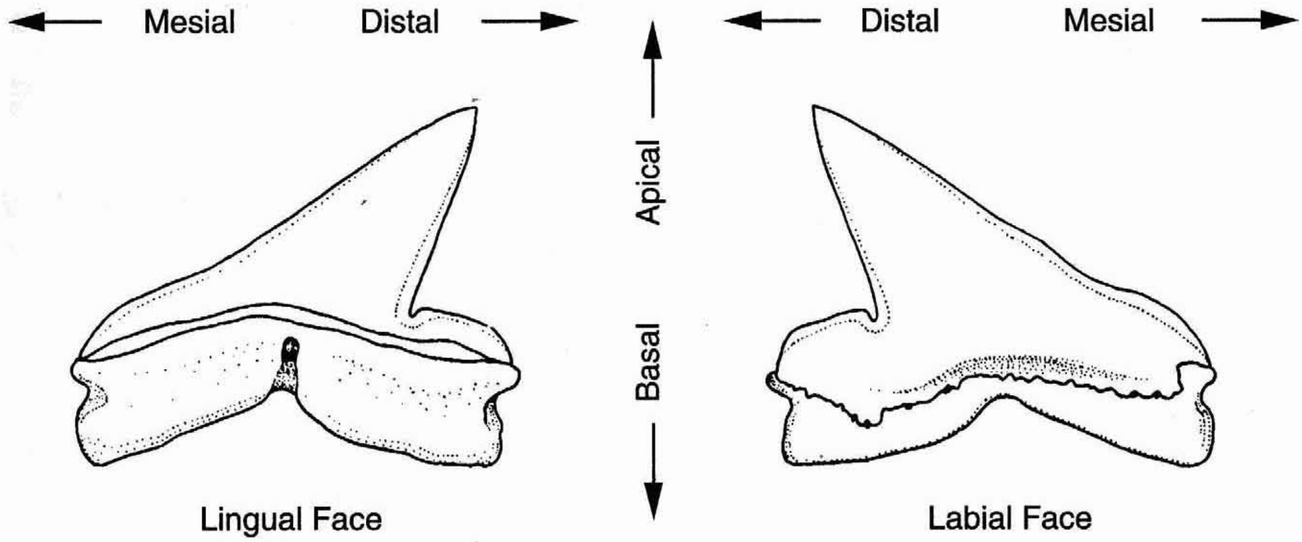


Figure 9. Tooth orientation terminology.

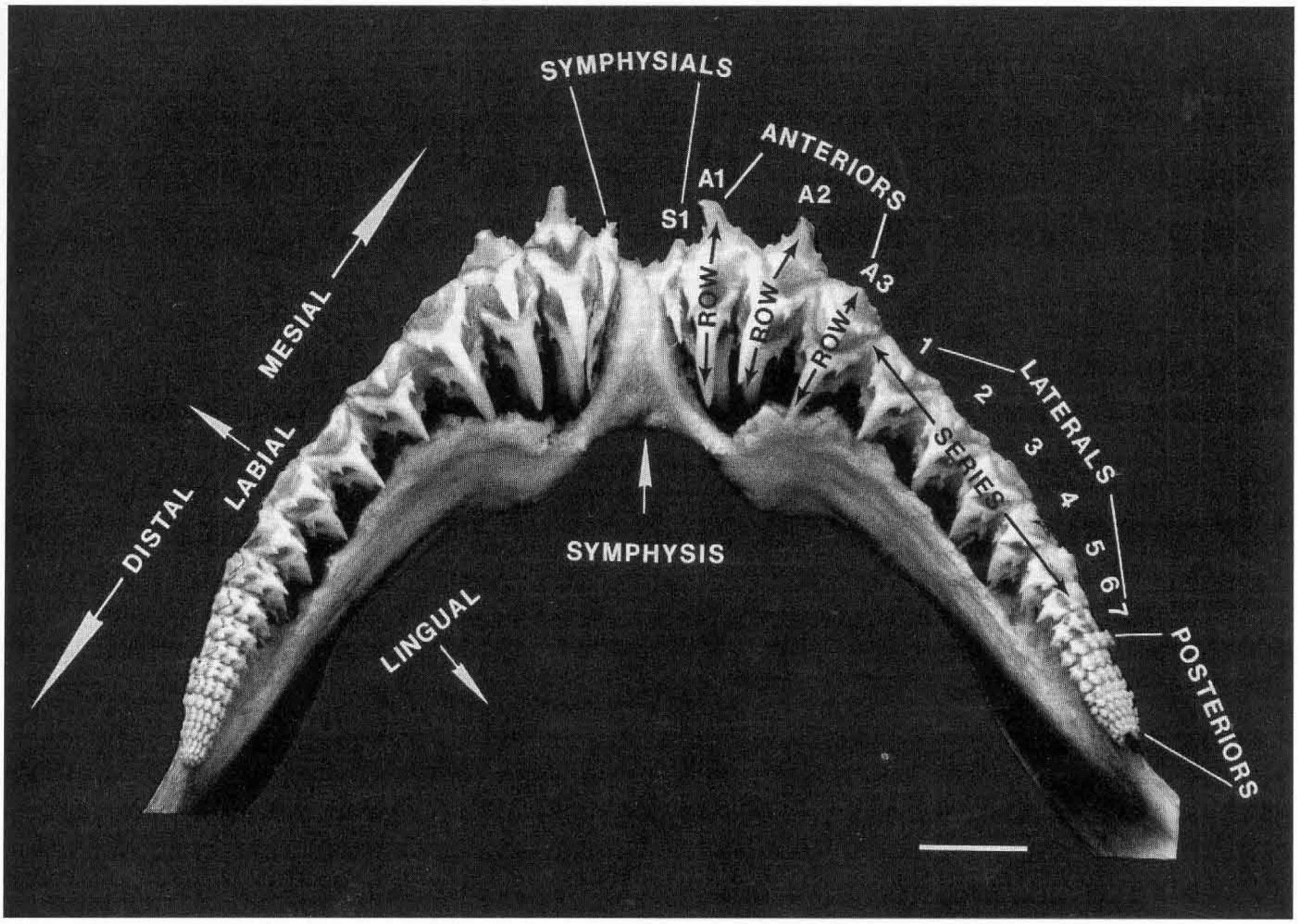


Figure 10. Tooth orientation and series-row terminology applied to the lower jaw of the modern sand tiger shark *Carcharias taurus* Rafinesque 1810. Scale line = 1 cm.

Mesial and **distal** refer to the sides of teeth. Mesial is toward the jaw symphysis (midline) and distal is toward the hinge of the jaw (corners).

Apical and **basal** refer to the top or bottom of a tooth. The tip of the crown or cusp is apical and the root or base is basal.

Series and Row Configurations

Tooth series and row relationships are best studied in modern wet-preserved or cleaned and dried shark and ray jaws. The mesodistal alignment of teeth along the jaw edge is termed a **series** (Figure 10). The labiolingual sequence of teeth leading from the inner surface of the jaw to the functional tooth position and comprising a continuous ontogenetic progression is termed a **row** (Figure 10).

At least six different series-row configurations are found among the Elasmobranchii and these are illustrated in Figure 11. Each pattern can be described in terms of the relationship of a single tooth with other teeth in the same row and according to their spatial relationship to teeth in adjacent rows.

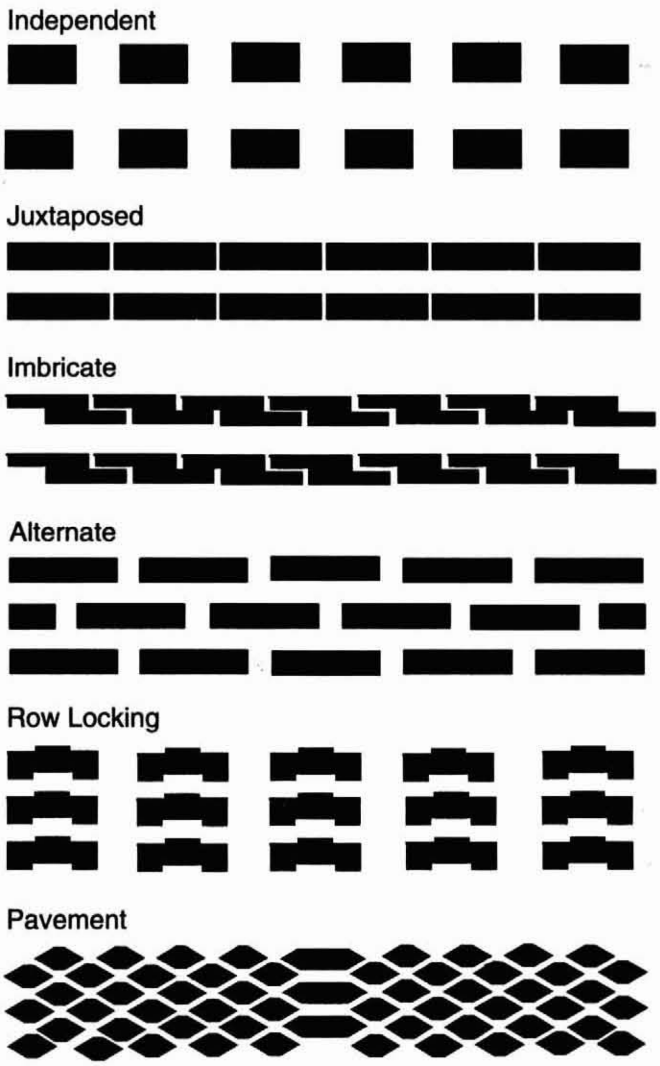


Figure 11. Occlusal view of generalized series-row tooth patterns found in sharks and rays.

An **independent** configuration is one in which the tooth is not in contact with any other tooth; e.g., the modern basking shark *Cetorhinus*. A **juxtaposed** arrangement is one where all teeth in the row abut with the mesial or distal ends of teeth in adjacent rows and the rows are aligned in parallel columns (i.e., they do not alternate or interlock labially and lingually with adjacent teeth in the same row; e.g., *Hexanchus* and *Squalicorax*. An **imbricate** arrangement develops by the shingle-like overlap of adjacent teeth in all rows, thus forming a continuous interlocking knife-like series; e.g., most squaloid sharks. The term **alternate** pattern applies when every other tooth in each row is offset mesially or distally by about half a tooth width; e.g., many carcharhinid sharks. **Row locking** occurs when the protruding (convex) labial root or crown face of one row tooth articulates or interlocks with an embayed lingual crown or root face of the next labial tooth in the row; e.g., *Ptychodus*. Interlocking row teeth can also articulate with adjacent row teeth. The last pattern generalizes what is actually a complex of many different styles of articulation and interlocking morphologies. The **pavement** dentition is a tight pattern of all the teeth and is used for crushing prey. This configuration is most highly developed among the rays.

Homodonty

Homodonty means that all the teeth in the mouth have the same shape and are approximately the same size. It is doubtful that there are any truly homodont sharks or rays, although some approach this condition.

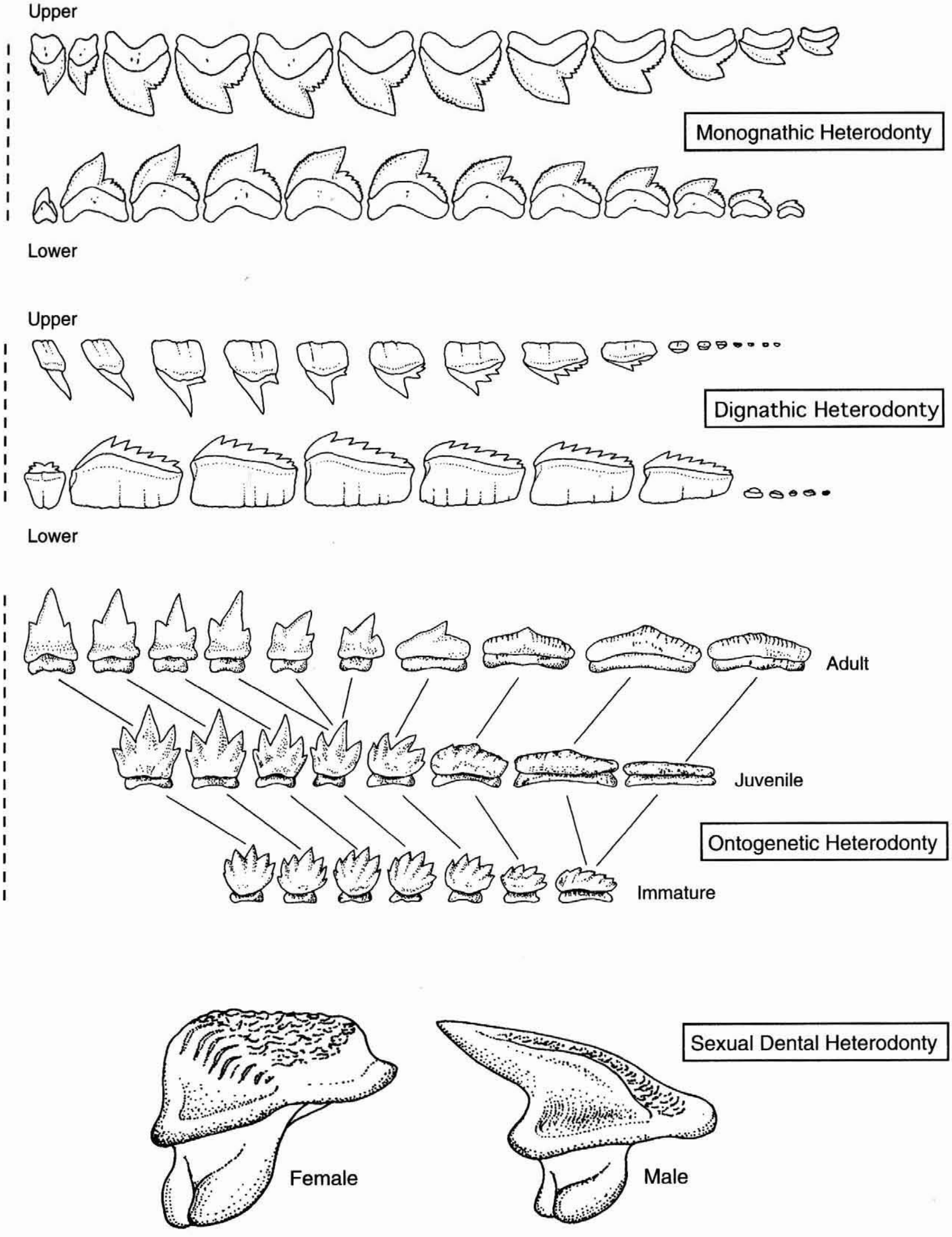


Figure 12. Examples of monognathic, dignathic, ontogenetic and sexual dental heterodonty. Strong dignathic heterodonty is illustrated in the upper and lower right dentition of the modern sixgill shark *Hexanchus griseus*. Gradient monognathic heterodonty is shown in the right dentition of the modern tiger shark *Galeocerdo cuvier*. The lower left dental series of the modern horn shark *Heterodontus franciscanus,* shows well developed ontogenetic heterodonty between immature, juvenile and adult dentitions. Dental sexual heterodonty is well illustrated by the obvious differences between male and female teeth in the stingray *Dasyatis*. The dashed vertical line indicates the position of the jaw symphysis.

Heterodonty

The opposite of homodonty is **heterodonty**, which simply means tooth variation. Teeth can vary in size and shape along the jaw, between the upper and lower jaws, between sexes, with age or between two or more individuals of the same sex and age.

Changes in tooth shape along a dental series can be **gradational** (slowly changing crown size and inclination in a mesial to distal direction) or **disjunct** (abrupt). Four major patterns of heterodonty in sharks and rays were defined by Compagno (1970). Although the extremes of each heterodonty type are distinct, most patterns grade into one another. These four types of heterodonty are defined next and illustrated in Figure 12.

Monognathic heterodonty: changes in tooth shape from mesial to distal along the dental series in either the upper or lower jaw.

Dignathic heterodonty: differences between teeth opposing each other in upper and lower jaws.

Ontogenetic heterodonty: changes in tooth shape throughout life as the shark or ray grows.

Sexual dental heterodonty: different tooth shapes in similar rowgroup positions in males and females of the same species and life stage.

Rowgroups and Dental Formulas

It is possible to subdivide the dental series into clusters or groups of adjacent rows (**rowgroups**) based on tooth size, shape and position relative to the mandibular (jaw) symphysis. Clearly, a dentition with pronounced disjunct monognathic heterodonty will have more rowgroups than one with weak gradient heterodonty.

A rowgroup terminology was originally proposed by Leriche in 1905 to describe the strong disjunct monognathic and dignathic heterodonty in the sand tiger shark *Odontaspis ferox*. Leriche assigned the terms **symphysials**, **anteriors**, **intermediates** and **laterals** to different tooth types in much the same way that a biologist groups mammalian teeth into incisors, canines, premolars and molars. Applegate (1965) and others have added the terms **posteriors**, **medials**, **alternates** and **parasymphysials** to describe rowgroups found in other elasmobranchs.

Figure 13 is an example of the application of this rowgroup terminology to the upper and lower right dentition of the modern sand tiger shark *Carcharias taurus*. The strong disjunct monognathic heterodonty in both jaws makes it relatively easy to subdivide the dental series into distinct rowgroups. In sharks or rays with poorly developed heterodonty, few rowgroup distinctions can be made and tooth types grade into one another. The latter example employs terms such as **anterolaterals** to express this gradational dental character.

Dental formulas provide a convenient method for recording the sequence of tooth types and number of rows within each rowgroup in the upper and lower dental series. Because the right and left jaw halves are usually symmetrical, it is the convention to write the dental formula for only the right upper and lower jaws. As Figure 13 illustrates, the tooth rowgroup terms are abbreviated: A = anterior, I = intermediate, L = lateral, P = posterior and S = symphysial. The rows comprising each rowgroup are numbered 1, 2, 3, etc. in a mesial to distal direction along the dental series.

The dental formula progresses from left to right, beginning at the jaw symphysis, using the abbreviated rowgroup name followed by the number of rows in the group. A horizontal line separates the teeth of the upper and lower jaws. The dental formula for the series of teeth illustrated in Figure 13 is written as follows:

$$\frac{\mathbf{A3\quad I1\quad L8\quad P5}}{\mathbf{S1\quad A3\qquad\quad L7\quad P6}}$$

Tooth Sets

Comparative studies of living and fossil (Cretaceous and younger) elasmobranch dentitions have revealed a surprising degree of stability in the dental formulas of some shark groups. The recognition of this fact

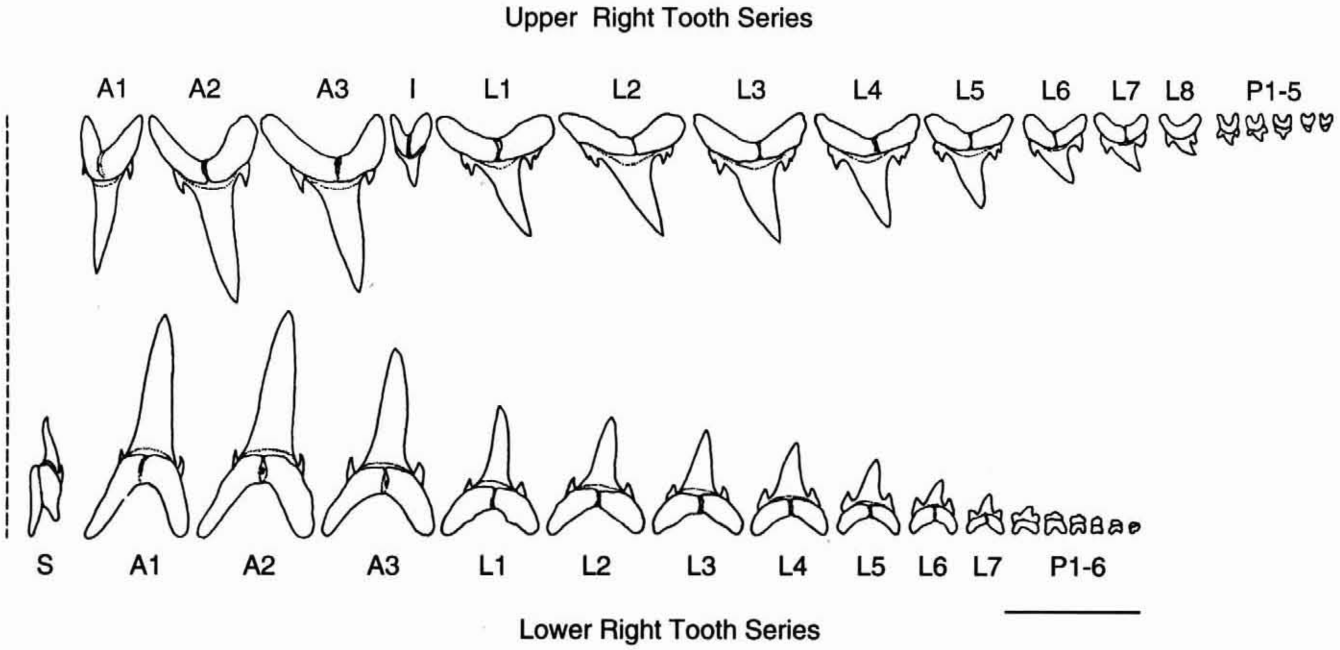


Figure 13. Application of tooth rowgroup terminology and dental formulas to the upper and lower right tooth series of *Carcharias taurus* Rafinesque 1810. Abbreviations: A = Anterior, I = Intermediate, L = Lateral, P = Posterior, S = Symphysial. Scale line = 1 cm.

adds validity to the use of modern elasmobranch dental formulas as a guide or model for the reconstruction of fossil shark and ray dentitions.

A complete upper and lower dental sequence including all tooth types and rows from the mandibular symphysis to the distal end of the dental series is termed a **tooth set**. The exact rowgroup configuration in any fossil shark or ray can be proven only under exceptional conditions of preservation where the teeth are still in place in the jaws. This is termed a **natural tooth set**. An example is the dentition of *Ptychodus rugosus*, which is illustrated in the identification section of this book. An **associated tooth set** is one based on the teeth of an individual shark or ray where the teeth were found displaced from their natural positions. Here, a certain amount of interpretation is necessary to reassemble the dental series. The identification section of this book illustrates tooth sets of *Ptychodus whipplei*, *P. mortoni*, *Paraisurus compressus* and *Cretoxyrhina mantelli*, which are all based on associated dentitions. Finally, an **artificial tooth set** can be constructed from a number of tooth types from one locality that are believed to belong to one species. In doing this, comparisons are made with known related natural or associated tooth sets. More commonly, the artificial tooth set is developed using a modern shark or ray dentition as a model. Individual tooth positions are selected based on the range of tooth morphologies present in the fossil sample.

Compare the natural tooth set of the modern porbeagle shark *Lamna nasus* (Bonnaterre 1788) with the artificial tooth set of the Cretaceous lamnoid *Cretolamna appendiculata* (Agassiz 1843) in Figure 14. The dental formulae are almost identical and note the close resemblance in crown and root shape for all tooth rowgroups. This artificial tooth set is based on a sample of 160 teeth from one locality in the Albian of Texas.

One should never hesitate to construct a tooth set of any kind as long as it is based on an adequate sample size and a reasonable modern analog. Once developed, the merits of the tooth set can be debated; otherwise, there is nothing to discuss!

It is obvious from the preceding discussion of heterodonty that comparative studies of the teeth in modern sharks and rays are absolutely essential for the accurate interpretation of fossil species. When

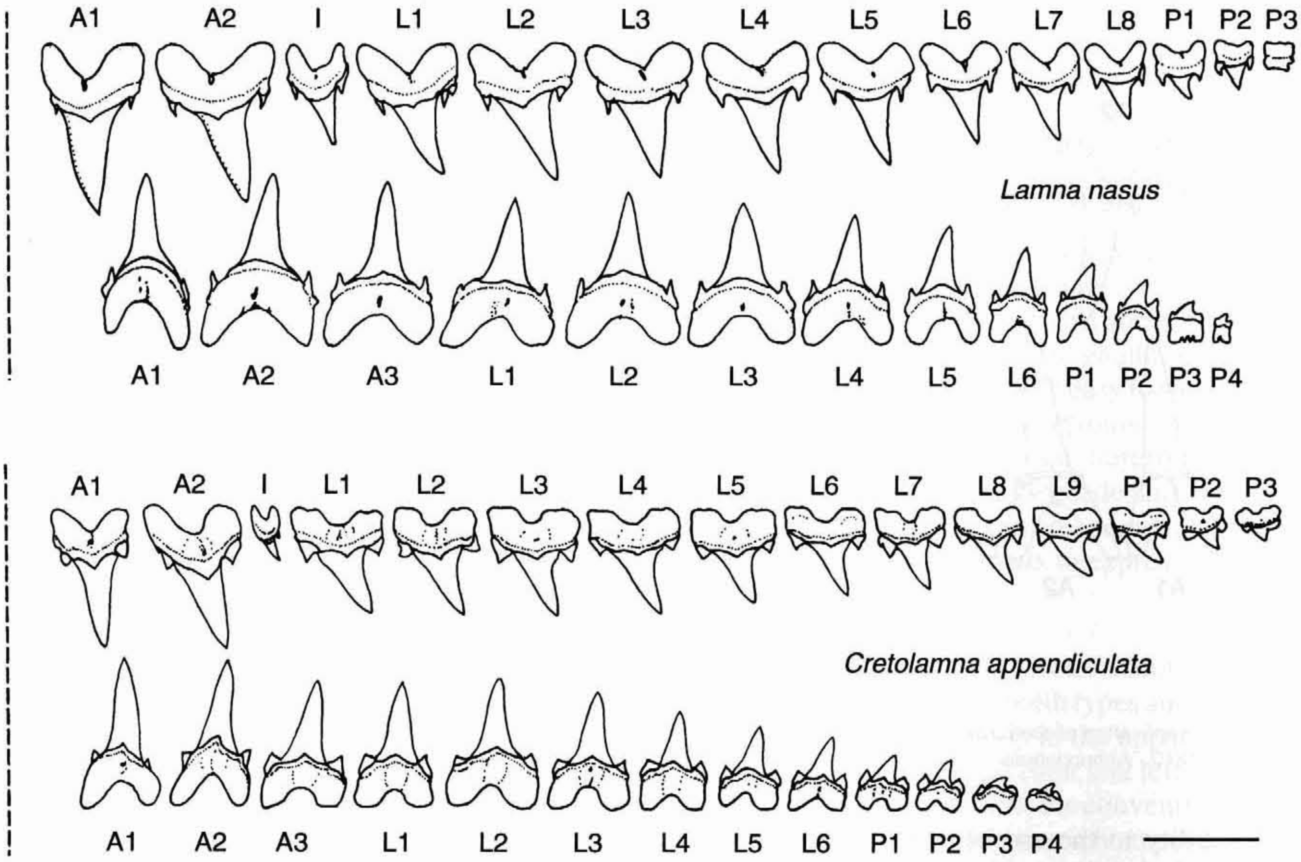


Figure 14. Comparison of a natural tooth set of the modern porbeagle shark *Lamna nasus* (Bonnaterre 1788) (2476 mm total length, sex unknown; from the Mediterranean) with an artificial tooth set of the Cretaceous lamniform *Cretolamna appendiculata* (Agassiz 1843) (Weno Formation, late Albian, Tarrant County). Scale line = 1 cm.

attempting to identify shark or ray teeth, keep these patterns of heterodonty foremost in your mind. Strive to explain tooth differences in terms of tooth placement in the jaw before assuming you have found different species.

When comparing two teeth of similar shape but greatly different size, consider the possibility of ontogenetic heterodonty or sexual dental heterodonty. This is especially true in rays having radically different tooth shape or with modern counterparts that exhibit this attribute.

Heterodonty and Species Diversity

Anyone who has seriously, or even casually, researched the literature on fossil sharks must be overwhelmed and confused by the number of described species (**nominal species**), synonyms and conflicting identifications. Many historical factors contributed to this situation but the principal cause has been a failure of paleontologists to understand how much variation does exist in tooth shape.

The number of named species for some genera has been inflated because different tooth rowgroup positions, variations, ontogenetic stages and even pathologies were ascribed to new species and even new genera in some cases. There are at least sixty-five nominal species defined on this basis for the Miocene great white shark *Carcharocles megalodon* (Agassiz) and over fifty species of the bat sting ray *Myliobatis* based on a highly variable dentition lacking few diagnostic characteristics.

Today, we know that many modern and fossil sharks have worldwide distributions but to some early shark paleontologists and neoichthyologists, geographic separation, in the absence of tooth or other morphological differences, was sufficient basis for establishing a new species.

In recent years, most shark paleontologists have become acutely aware of the implications of heterodonty and revisionary studies are significantly reducing the number of fossil species in selected groups.

Splitters and Lumpers

As you have read from the preceding discussion of heterodonty and species diversity, the number of named fossil species for some groups has been greatly exaggerated (for example, species of the genus *Ptychodus*). In the past, paleontologists referred to as **splitters** ascribed great significance to every minor tooth detail and thus erected new species for every tooth shape encountered. This has been especially true for shark and ray groups having strong disjunct monognathic or dignathic heterodonty. Splitting almost always occurs when the range of tooth variation (heterodonty) within a species is poorly understood. The consequence of this taxonomic practice is that some elasmobranch groups appear as if they were more diverse in the past than they actually were.

At the other end of the spectrum from splitters are the **lumpers** who ignore minor differences in the recognition or definition of species and genera. Lumpers take a very conservative approach to taxonomy and, in the case of elasmobranch teeth, have a much broader concept of the morphological species than splitters. Thus, two or more closely related species are likely to be combined into one species if they have strong gradient monognathic and weak dignathic heterodonty. Because of lumping, the number of fossil species described for selected shark and ray groups is much smaller than it should be.

Tooth Terminology

The tooth terminology used throughout this book is defined and illustrated on the following pages. As with any other branch of zoology, a specialized series of terms describes the diverse morphological characters found in the dentitions of elasmobranch fishes.

The terms defined here and keyed to illustrations in Figure 15 are commonly used by many paleontologists. They are applied extensively in the species identification section of this book and the reader is encouraged to become familiar with them.

Shark and ray teeth consist of two basic parts, **crown** and **root**. These structures can be simple or complex depending on the species under consideration. No single tooth possesses all the features defined by the following terms.

Crown Terms

Barb: Hook-like, enameloid-covered crown prominence situated on the posterior border of rostral teeth of some fossil and recent sawfishes and sawsharks.

Basal Ledge: Ledge formed by expansion of the crown foot above the root.

Blade: Modification of the crown always mesial or distal to a cusp or cusplet(s) bearing a cutting ridge along its apical surface.

Crown: Pointed or rounded, enameloid-covered portion of an oral or rostral tooth, scale or denticle, supporting blades, cusplets, cusps and shoulders.

Crown Foot: Base of the crown where it joins the root.

Cusp: Principal crown prominence. May be blade-like (labiolingually compressed) or knob-like (massive and rounded).

Cusplet: One or more, often paired, small miniature cusps usually situated at the mesial and/or distal base of the cusp.

Cutting Ridge: Sharp, longitudinal, straight to sinuous ridge formed by the junction of labial and lingual crown faces along mesial and distal cusp and cusplet edges and on top of blades.

Depression: Concave area for the imbrication and articulation of adjacent teeth.

Enameloid: Enamel-like, mineralized tissue coating shark and ray teeth and other dermal denticle derivatives. Probably not the same as mammalian tooth enamel.

Labial Flange: A basally directed projection of the labial face of the crown foot either free or attached to the root.

Lingual Peg: Lingual, knob-like prominence developed above the notch.

Longitudinal Ridges: Parallel to subparallel or anastomosing, raised, enameloid ridges found on labial, lingual and occlusal crown faces.

Marginal Area: Flattened and ornamented shelf-like surface surrounding the cusp on teeth of *Ptychodus*. Often exhibits a branching, radiating, concentric or granular enameloid pattern.

Protuberance: Labial or lingual expansions of the crown face.

Serrations: Small projections, like the teeth of a saw, that occur exclusively along the cutting ridge of a cusp, cusplet or blade. Cusplets can grade into serrations.

Transverse Ridges: Ridges developed in the enameloid on the apical surface of the crown and oriented transversely.

Root Terms

Attachment Surface: Portion of the root that seats in the dental membrane against the jaw surface.

Central Foramen: A large foramen (or cluster of small foramina) centrally positioned on the lingual or basal face of the root and often within the nutrient groove.

Dental Band: A narrow, smooth, enameloid-free band at the crown-root junction on the labial or lingual surfaces or completely encircling the tooth.

Foramen: Any hole in the root.

Lingual Protuberance: Lingual expansion of the root just below the crown foot and above the separation of the root lobes, involving part of the attachment surface.

Notch: A rectangular indentation situated between root lobes, in labial or lingual view, formed by the termination of the nutrient groove.

Nutrient Groove: Shallow to deep, continuous to discontinuous groove often containing a central foramen or foramina and separating the mesial and distal root lobes on the basal or lingual root face.

Root: Osteodentine structure that supports the crown and anchors the tooth to the dental membrane.

Root Lobe: Usually, one of two branches, the mesial and distal lobes, which may be symmetrical or asymmetrical.

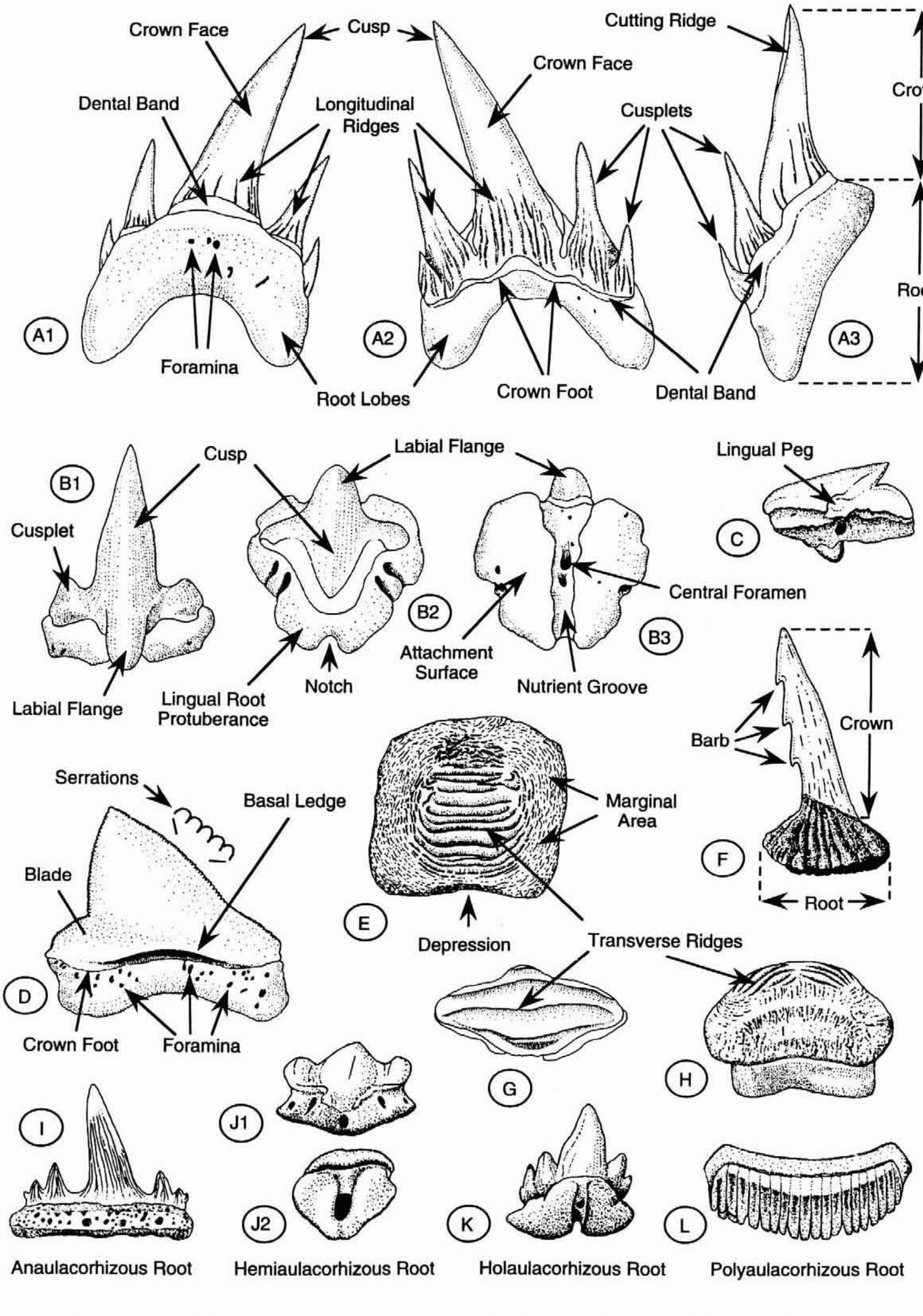


Figure 15. Shark and ray tooth terminology. A) *Protolamna* aff. *sokolovi*, (A1) lingual, (A2) labial, (A3) mesial views; B) *Onchopristis dunklei*, (B1) labial, (B2) apical, (B3) basal views; C) *Squalus* sp., lingual view; D) *Squalicorax falcatus*, labial view; E) *Ptychodus latissimus*, occlusal view; F) *Onchopristis dunklei*, rostral tooth, dorsal view; G) *Ptychotrygon triangularis*, occlusal view; H) *Ptychodus latissimus*, lingual view. Root types. I) *Hybodus* sp.; J) *Cantioscyllium decipiens*, lingual (J1) basal (J2) views; K) *Palaeogaleus* sp., lingual view; L) *Myliobatis* sp., basal view.

Root Types

The root structure and vascularization patterns found in shark and ray teeth were extensively studied by the Belgian paleontologist Edgar Casier. After surveying modern and fossil selachians, Casier (1947a-c) proposed four basic structural tooth types or stages that he defined mainly on the placement of foramina and attributes of the nutrient groove.

Primitive Paleozoic and many Mesozoic selachians, including hybodonts and hexanchoids, have **anaulacorhizous** roots that are flattened or tabular, lack a nutrient groove and are very porous (Figure I).

Teeth having **hemiaulacorhizous** roots first appear in the Jurassic and are found in heterodontids (horn sharks), some orectolobids (carpet sharks) and the squatinoids (angel sharks). These roots are broadly triangular in basal view and have a large central foramen set in a shallow to deep depression. A foramen situated on the lingual root protuberance connects with the basal central foramen via a canal within the root. If this canal is not covered, it is termed a nutrient groove (Figures J1, J2).

Holaulacorhizous roots have a continuous, well developed nutrient groove lying between mesial and distal root lobes. Many Texas Cretaceous teeth have this root structure, including most notably the lamnoids, carcharhinoids and almost all the batoids except for certain myliobatoid rays (Figure K).

The mesodistally expanded teeth of some myliobatoid rays (Myliobatidae including *Brachyrhizodus*) have many labiolingually-oriented nutrient grooves, giving the root a comb-like appearance. Many foramina pierce each groove and the labial and lingual root faces. Roots having this structure are termed **polyaulacorhizous** (Figure L).

Tooth Histology

Shark tooth **histology** is the study of the highly mineralized microscopic tissues that comprise the crown and root. Histological details are best revealed through the examination of thin sections under a transmitted light microscope using a series of specialized techniques. Thin sections are made by slicing and carefully grinding a tooth down to a thickness of 30 to 80 microns (a micron is 1/1000 millimeter), using saws, abrasive powders and diamond polishing agents.

Shark teeth are composed of the mineral **fluorapatite**, $Ca_5(PO_4)_3F$, which occurs in two calcified tissue types. **Dentine** surrounds a pulp cavity and **enameloid** (analogous to mammalian enamel) coats the outer surface of the crown. Three generalized types of dentine are recognized; **pallial dentine**, **osteodentine** and **orthodentine** (Orvig 1951; Radinsky 1961; Patterson 1964; Applegate 1967). The root consists entirely of osteodentine.

Elasmobranch teeth can be broadly grouped into two distinct histologic tooth types, **osteodont** and **orthodont** (Figure 16). Osteodont teeth have osteodentine filling the core of the crown (no large pulp cavity), surrounded by pallial dentine and covered by a thin enameloid layer. Orthodont teeth have a crown with an enlarged pulp cavity surrounded by a thick orthodentine layer and an intermediate thin, pallial dentine layer and an outer superficial enameloid sheath.

The nonmineralized portion of the tooth consists of cavities, canals and dental tubules. The nutrient canal leads from the lingual or basal root face inward into vascular canals or the pulp cavity in orthodont teeth. Vascular canals in the roots, however, open directly to the outside without passing through or near the nutrient canal.

The distinction between osteodont and orthodont tooth types can generally be made without having to undergo the complex intermediate step of making a thin section. Examination of a broken tooth crown under a hand lens or binocular microscope will almost always reveal the presence or absence of a central pulp cavity. If present, the tooth is orthodont, but if the crown is filled by a spongy tissue, then it is osteodont.

Tooth histology can be an important taxonomic criterion for determining elasmobranch interrela-

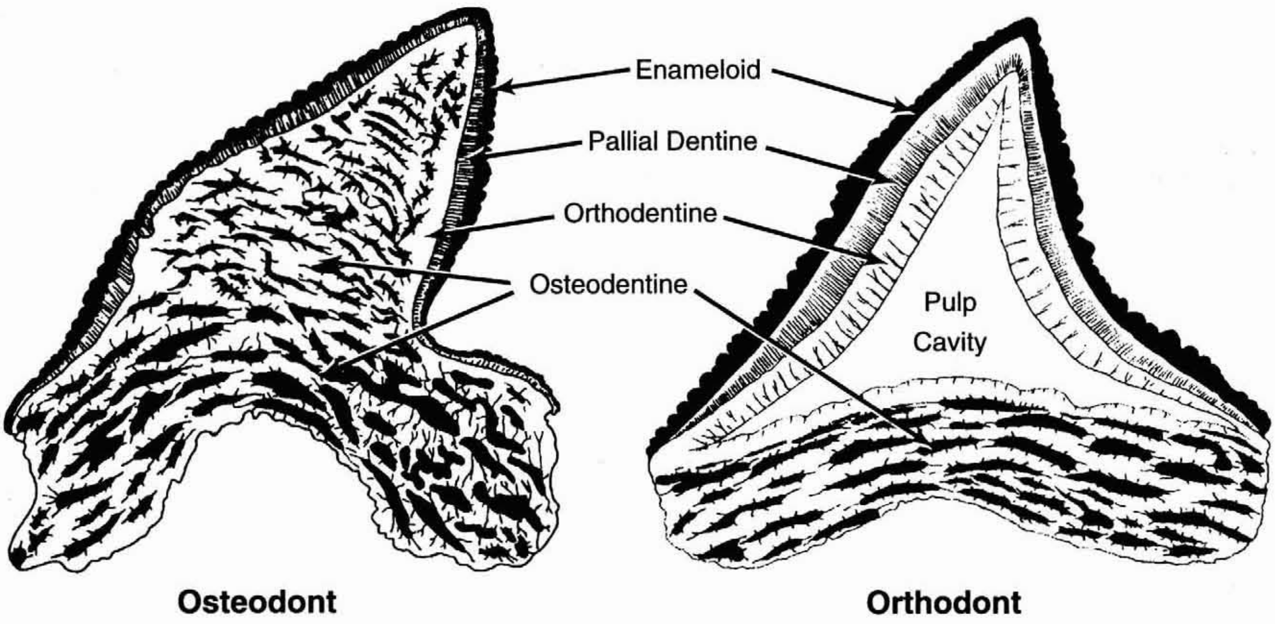


Figure 16. Tooth histology.

tionships. For this reason, the histologic type, either osteodont or orthodont, is noted for each species in the identification section of this book.

Broken, Worn and Pathologic Teeth

If a functional tooth is broken, chipped, cracked or otherwise damaged, presumably during feeding or for any other reason, it cannot be healed or repaired. In fact, broken and damaged teeth are commonly seen in the dentitions of living sharks and rays. It is, therefore, reasonable to assume that some, if not many, of the broken teeth we collect were damaged during life rather than due to some breakage after death.

Occasionally, teeth are found that display aberrant looking flat, polished or angular crown faces (Figures 17A-D). These features are called **wear facets** and are caused by abrasion or rubbing of one tooth against another. Apical crown facets are the product of occlusion between opposing upper and lower teeth. Wear facets found on the sides of the crown are caused by constant rubbing or articulation of the tooth with teeth in the same or adjacent rows. The enameloid layer wears away as the facet develops, exposing tooth dentine, and producing the characteristic porous or punctate surface texture.

Wear facets are ubiquitous features in sharks and rays having crushing dentitions. They are found on many Texas Cretaceous teeth and are especially common in some hybodont sharks (*Lissodus*, *Polyacrodus*, *Ptychodus*) and almost all rays.

Pathologic teeth are developmental abnormalities caused by a genetic mutation or possibly damage to an immature tooth. These teeth develop with distorted or disfigured crowns and collectors usually have very little trouble recognizing them (Figures 17E-L). Not all pathologic teeth are immediately obvious, even to the expert. More than one fossil species has been described based on an abnormal tooth!

OTHER HARD PARTS

Sharks and rays have a number of highly mineralized endoskeletal and exoskeletal structures, in addition to teeth, which are preserved in the Texas Cretaceous. These include microscopic **placoid scales** and some of their dermal derivatives includ-

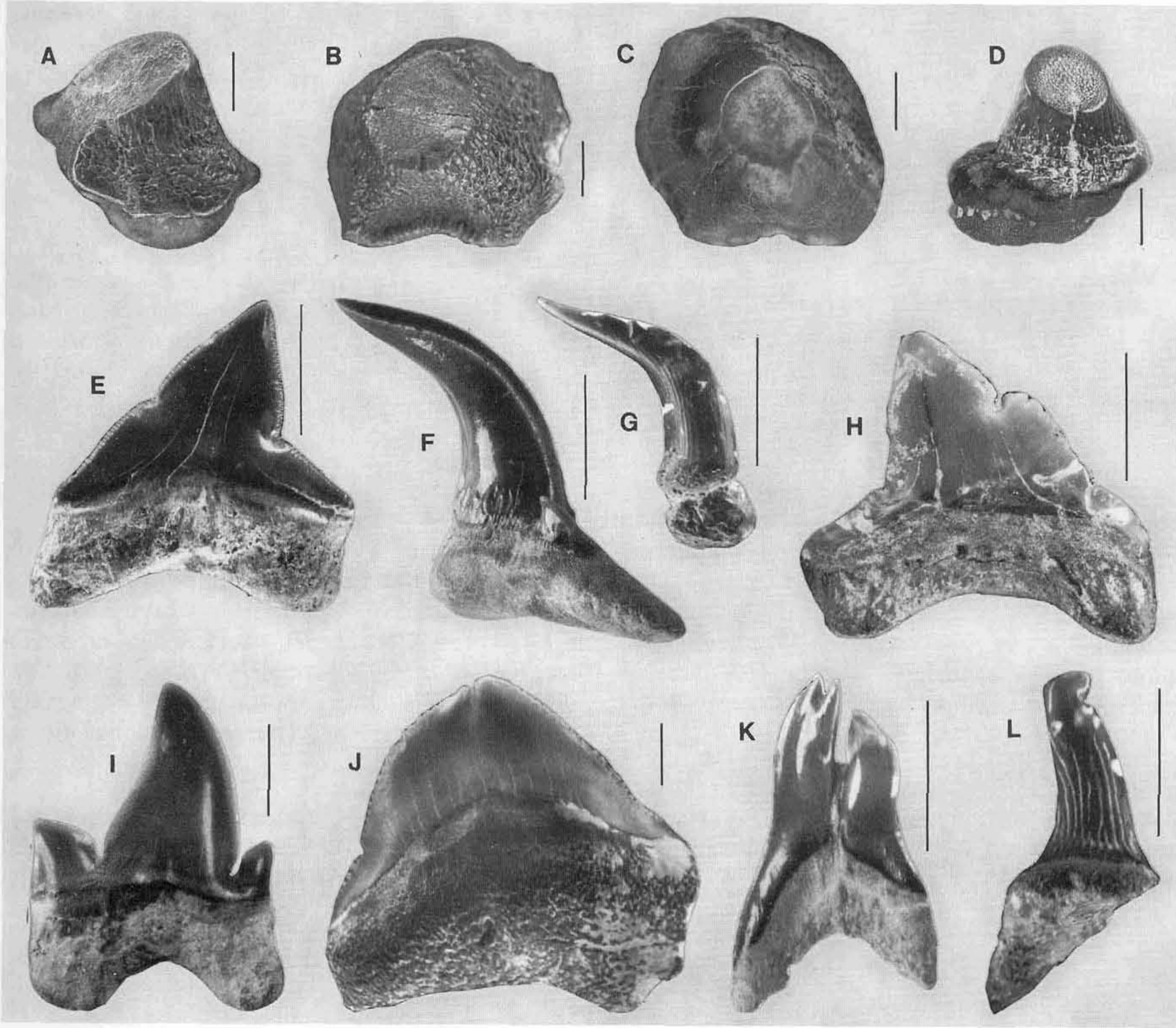


Figure 17. Wear facets and pathologic teeth. (A-D) *Ptychodus whipplei* teeth with well developed wear facets on the apical crown face. (E-L) Pathologic teeth. E) *Squalicorax falcatus*, F) *Cretodus crassidens*, G) *Scapanorhynchus raphiodon*, H) *Squalicorax falcatus*, I) *Cretolamna appendiculata*, J) *Squalicorax falcatus*?, K) *Paraisurus compressus*, L) *Scapanorhynchus raphiodon*. Teeth E-J and L from the Atco Formation of the Austin Group (Coniacian), Grayson County. Specimen K from the Weno Formation (Albian), Tarrant County. Scale line = 5 mm.

ing enlarged **dermal denticles**, **fin spines**, **cephalic spines**, **rostral teeth**, **vertebrae** and **prismatic calcified cartilage**.

Placoid Scales

Placoid scales are found only in sharks and rays and have a histology similar to teeth. Like oral teeth, they are nongrowing structures that are periodically shed and replaced by larger scales as the animal grows. The placoid-covered skin of living sharks has a texture like sand paper and, when dried, is known as **shagreen**. A single scale consists of a small cusp or blade, attached to a broad base by a short neck. In life, the base is fixed to the skin by connective tissue and is perforated by a central canal through which nerves and blood vessels enter.

A large central pulp cavity is surrounded by dentine and the scale surface is covered with enameloid (Figure 18).

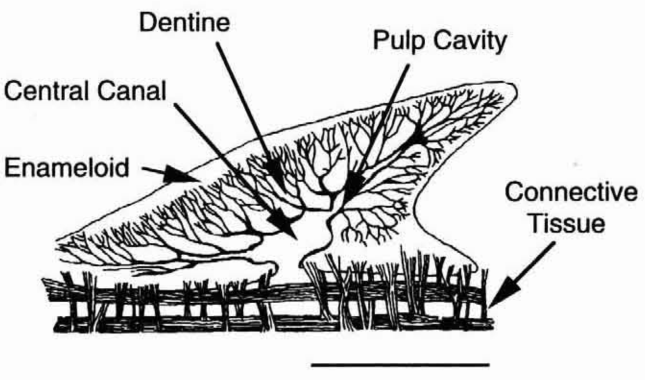


Figure 18. Sagittal section of a placoid scale showing detailed histology, *Dalatias licha*. Scale line = 0.5 mm.

Placoid scales cover the entire external surface of the shark and also line the inside of the mouth (**stomodeal denticles**), pharynx and branchial arches. Scales are not all identical but have different shapes depending on body location. This is illustrated by scanning electron microscope (SEM) photomicrographs of placoid scales in the modern thresher sharks *Alopias vulpinus* and *Alopias superciliosus* (Figure 20).

In most rays, placoid scales are generally scattered sparsely and unevenly across the upper surface of the head, body and pectoral fins. They are absent in living electric rays.

Placoid scales are found in many fossil deposits. However, because of their small size (<1 millimeter), special sediment washing, sieving and sorting techniques are required to collect them. See Figure 19 below for some examples of fossil placoid scales.

Dermal Denticles

Dermal denticles are enlarged bulbous to thorn-like placoid scales found along the midline of the back and tail in many rays (Figure 21). They are common throughout the Cretaceous of Texas (Figure 19). Large scales (>1 cm) are called **bucklers**.

Fin Spines

Eight genera of living squaloids (spiny dogfish sharks) and the heterodontid (bullhead shark) *Heterodontus* have spines in front of each dorsal fin. Species of another living squaloid, *Squaliolus* Smith and Radcliffe 1912, have a short spine in the first dorsal fin. It is either exposed at the tip or wholly enclosed in the skin. The second dorsal fin is without a spine.

Dorsal fin spines are found in several Paleozoic and Mesozoic hybodontid, squaloid and heterodontid sharks (Figure 22). Among rays, dorsal fin spines

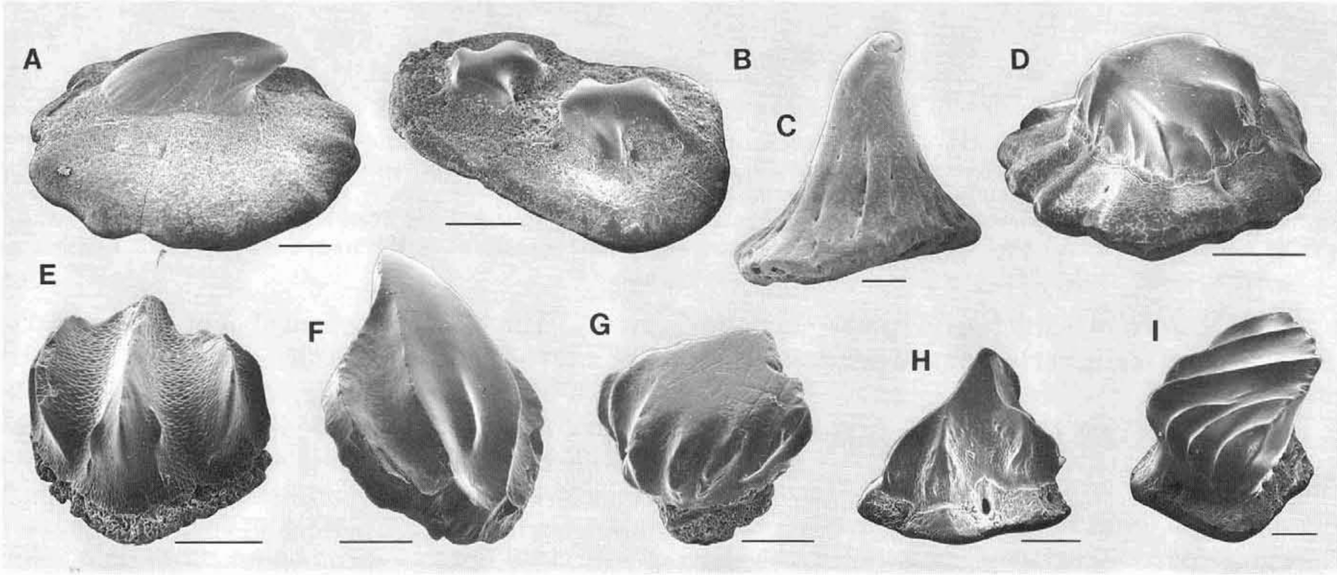


Figure 19. Fossil dermal denticles and placoid scales from the Cretaceous of Texas. A-D) dermal denticles, E-I) placoid scales; Woodbine Formation, Cenomanian, Denton County. Scale line = 0.5mm (A-D) and 0.2 mm (E-I).

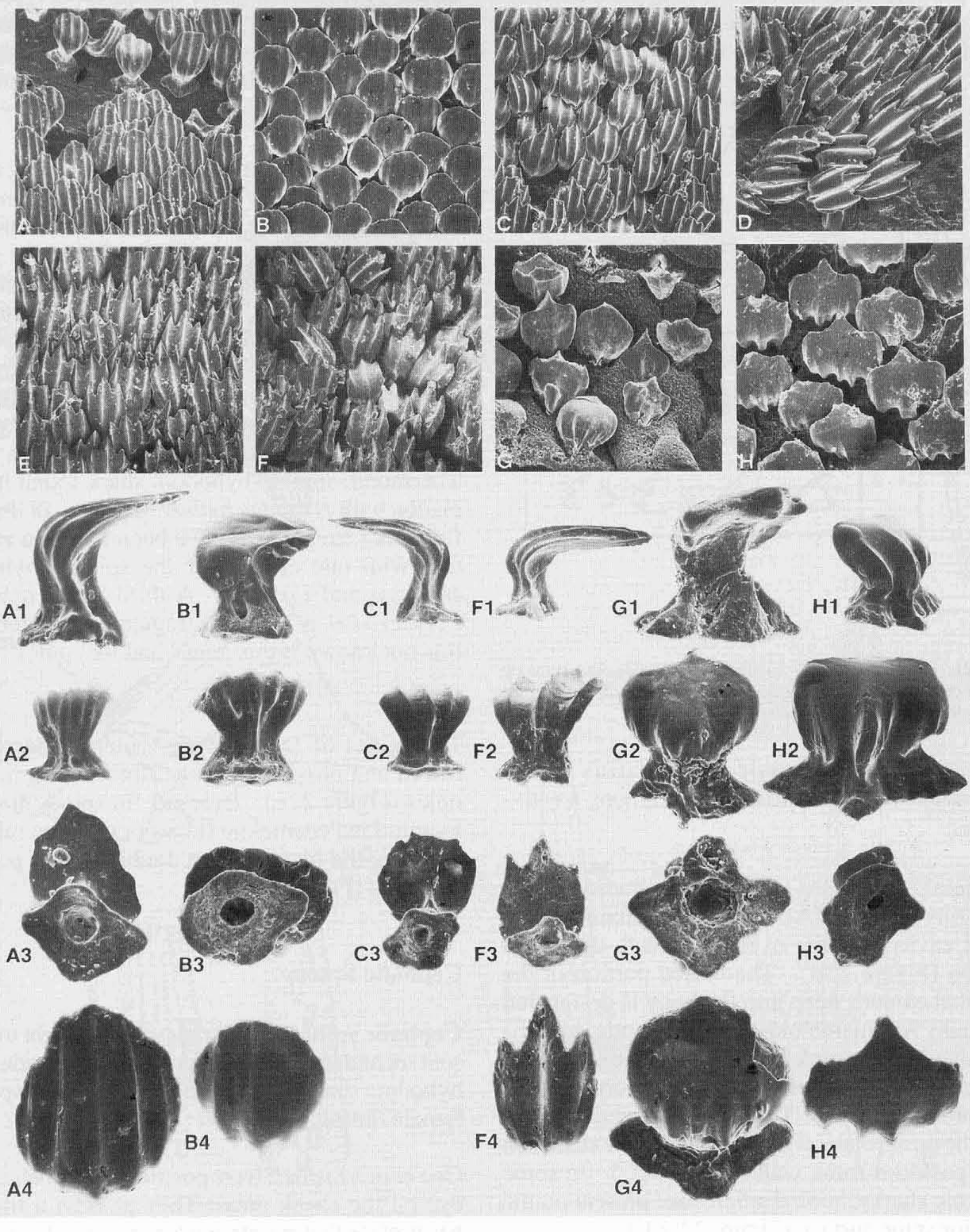


Figure 20. Variation in placoid scale morphology in the Thresher shark *Alopias vulpinus* (A-G) and *Alopias superciliosus* (H). A) scales from the left lateral surface of the tail, taken midway between the ventral lobe and the dorsal tip; B) scales from the dorsal surface of the head between the eyes; C) scales from the dorsal surface of the left pectoral fin taken midway between the posterior fin insertion and the distal fin tip; D) scales from the left lateral surface just below the second dorsal fin; E) scales from the dorsal midline, midway between the first dorsal insertion and the second dorsal fin origin; F) scales from the left lateral surface just above the pectoral fin and slightly anterior of the first dorsal fin; G) palatine scales; H) palatine scales. Individual scale positions include 1) lateral view; 2) anterior view; 3) basal view; 4) dorsal view. Isolated scale positions A-C and F-H correspond to scale patch locations A-H. Scale line = 100 microns.

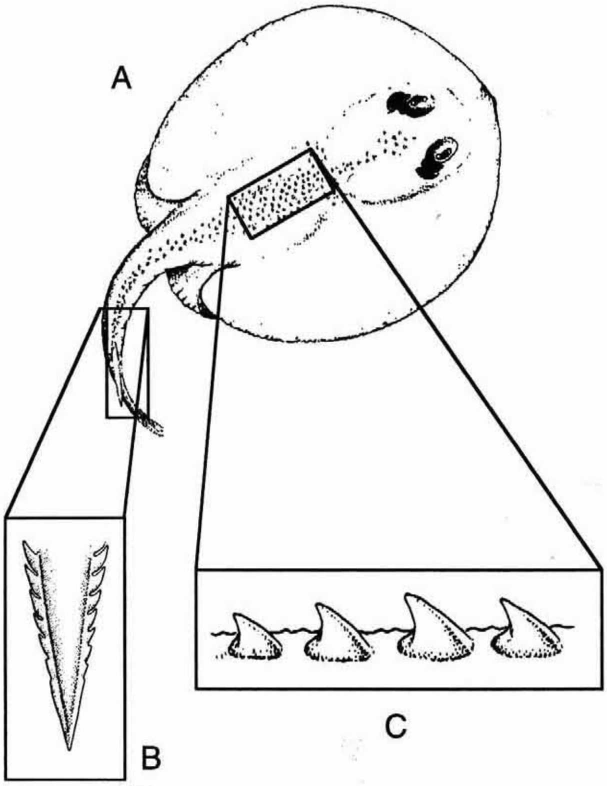


Figure 21. Dermal denticles. A) the stingray *Urolophus*, showing enlarged dermal denticles along the midline of the back and tail: B) tail stinger; C) enlarged denticles.

occur in some Jurassic rhinobatids (e.g., *Belemnobatis*, *Spathobatis*), but not among any living rays.

In general, spines are located just anterior to the dorsal fins (Figure 22A). The spine contains a large central cavity that fits over a cartilage of the fin skeleton (Figure 22B). The buried portion of the spine that extends deep into the body is designated the trunk. An enameloid-covered mantle superficially overlies the trunk forming most of the exposed spine and, in some fossil sharks, the ornamented anterior spine surface. This mantle extends back as far as the posterolateral margin but never extends on to the posterior trunk wall (Figure 22C). In some Mesozoic sharks, hook denticles are present on the posterior spine surface (Figure 22D-E).

Fin spines are retained and grow throughout life, unlike teeth and placoid scales, which are periodically shed and replaced.

In the Texas Cretaceous, fin spines (Figure 22D) have been found in the Albian Paluxy Formation in north-central Texas (Thurmond 1971) and in the Cenomanian Woodbine Formation in Denton and Tarrant counties.

In the absence of complete skeletons having associated spines and oral teeth, it must be assumed that these spines belong to species found in the same locality that are known to have dorsal fin spines. Usually, this association is easy to demonstrate. For example, Thurmond (1971) referenced dorsal fin and cephalic spines from a site in the Albian Paluxy Formation to *Hybodus butleri* by association with the teeth of this spine-bearing genus at the same locality. More recently, Duffin (1985) suggested that these spines may belong to *Lissodus anitae* Thurmond, another hybodont shark found in association with *Hybodus butleri*. To date, all the fossil fin spines from Texas have been found in association with one or both of the spinose hybodonts *Hybodus* and *Lissodus*. A third Texas hybodont, *Polyacrodus*, is based on fragmentary material and it is not known if this genus had fin spines.

The spines of *Lissodus* are flattened, deeply furrowed and possess only one row of posterior denticles (Figure 22E). *Hybodus* fin spines may have longitudinal enameloid ridges or rounded tubercles covering the mantle and a double row of posterior denticles (Figure 22D).

Cephalic Spines

Cephalic spines (head spines) are thought to represent secondary sexual structures found in adult male hybodont sharks and may have aided in grasping the female during copulation (Figure 23).

One or more spines were positioned just behind each eye on the cheek area. They possess a triradiate basal plate that points posteriorly and from which arises a single sigmoidally arched and enameled spine. The tip of this spine often bears a single barb.

Cephalic spines have been found in association with fin spines and teeth of the hybodontid *Lissodus* *selachos* (Estes 1964) from the late Cretaceous Lance Formation of Wyoming, and Patterson (1966) figured cephalic spines of *Lissodus* from the English Wealden. Cephalic spines referred to *Hybodus butleri* were described by Thurmond (1971) from the Albian Paluxy Formation (Trinity) in north-central Texas

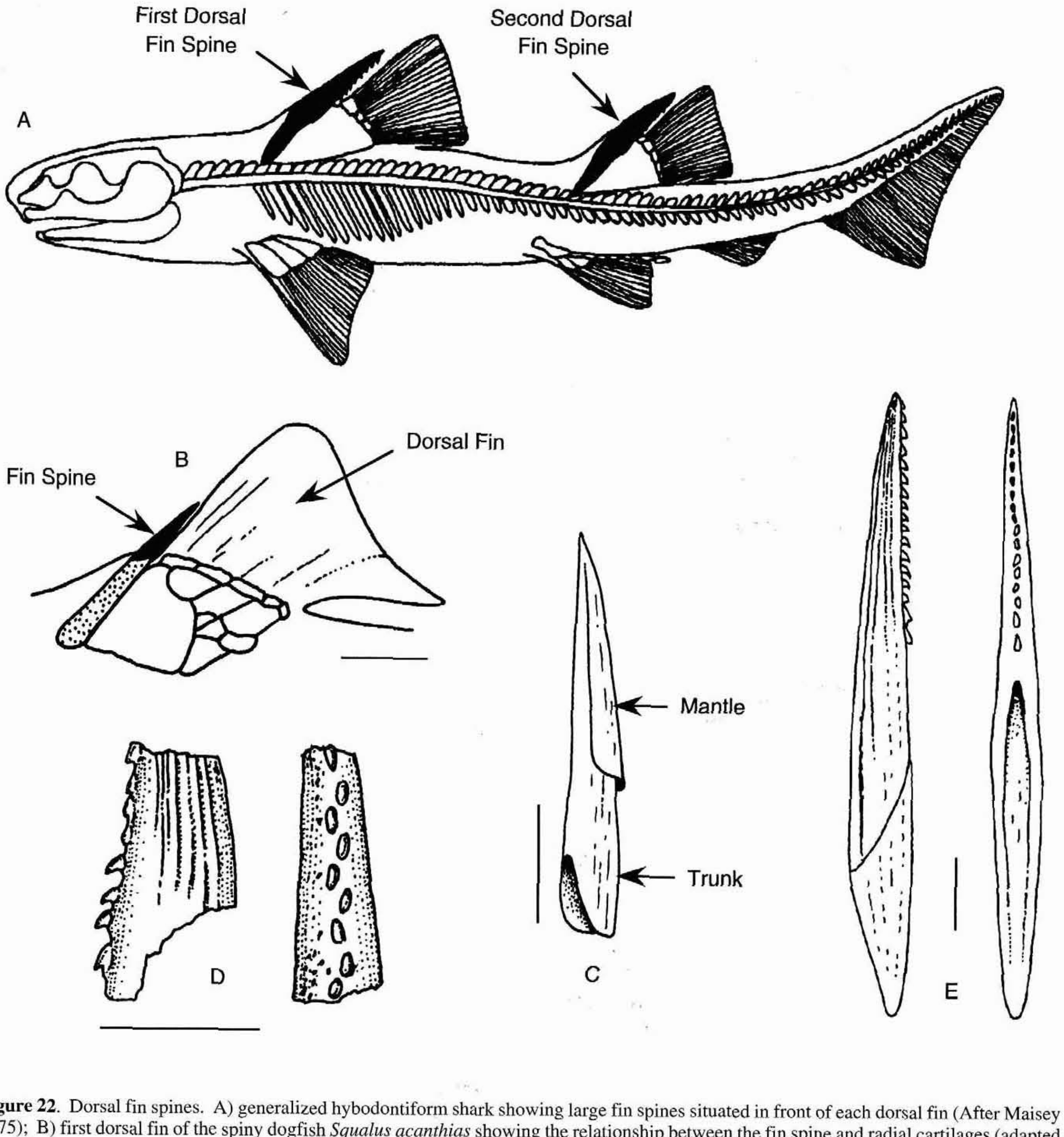


Figure 22. Dorsal fin spines. A) generalized hybodontiform shark showing large fin spines situated in front of each dorsal fin (After Maisey 1975); B) first dorsal fin of the spiny dogfish *Squalus acanthias* showing the relationship between the fin spine and radial cartilages (adapted from Bigelow and Schroeder 1957); C) general structure of the shark fin spine showing differentiation into trunk and mantle (after Maisey 1975); D) Fin spine of *Hybodus butleri* from the Butler Farm local fauna, middle Paluxy Formation (Albian), Wise County (after Thurmond 1971); E) *Lissodus* sp., lateral and posterior view showing single row of denticles; Weald Clay, Isle of Wright, England (after Patterson 1966). Scale line = 1 cm.

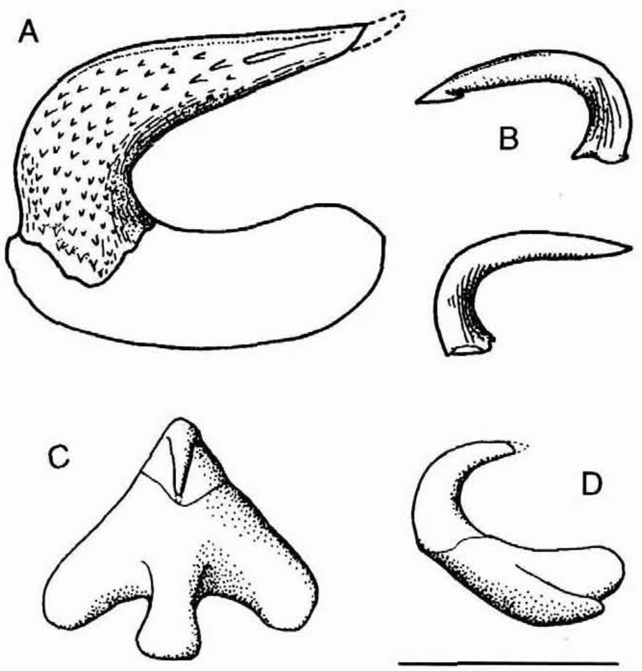


Figure 23. Cephalic spines of hybodontiform sharks. A) *Lissodus selachos*, Lance Formation, late Cretaceous, Wyoming; lateral view (after Estes 1964); B) *Hybodus butleri*, lateral views of spine, Butler Farm local fauna, middle Paluxy Formation, Wise County (after Thurmond 1971); C-D) *Lissodus* cephalic spine, posterior and lateral views, Wadhurst Clay, Brede, Hastings, Sussex, England (after Patterson 1966). Scale line = 5 mm.

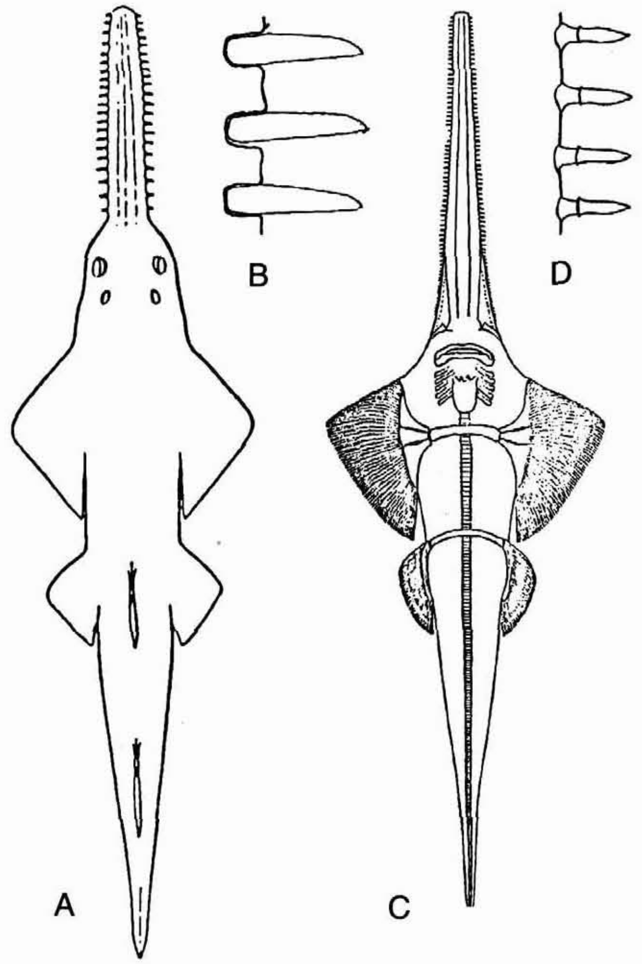


Figure 24. Modern and fossil sawfishes. A) living sawfish *Pristis*; B) section of *Pristis* rostrum showing teeth set in sockets (after Herman 1977); C) Cretaceous sawfish, *Sclerorhynchus atavus*, Senonian, Lebanon (after Arambourg 1940); D) section of *Sclerorhynchus* rostrum showing teeth attached to the lateral margin of the snout.

(Figure 23B). Also, we have examined specimens from the Woodbine Formation in Denton County.

Rostral Teeth

Rostral teeth are spine-like structures, aligned anteroposteriorly on the lateral margins of the rostrum (snout) in modern sawfishes (Pristidae), sawsharks (Pristiophoridae) and extinct Cretaceous sawfishes (Sclerorhynchidae) (Figure 24).

The rostral teeth of pristids are firmly set in sockets and grow continuously throughout life. In sawsharks and sclerorhynchid rays, rostral teeth are replaced throughout life and are not embedded in sockets.

A sclerorhynchid rostral tooth consists of a crown and a weak to strongly bilobate root. The root lobes are separated from one another by an anteroposterior furrow. The crown is enameloid covered, smooth or ornamented and, depending on the genus, either histologically osteodont or orthodont (see section on histology).

The crown may have a cutting ridge, and barbs are present in some genera (e.g., *Onchopristis* and *Sclerorhynchus*).

Both rostral and oral teeth of sclerorhynchid sawfishes are found in the Texas Cretaceous. Presently, five genera are recognized on the basis of isolated rostral teeth including *Ischyrhiza, Sclerorhynchus, Onchosaurus, Onchopristis* and *Schizorhiza.* Oral teeth rarely exceed 3 millimeters in size. Rostral teeth are usually less than 10 millimeters long, although some exceed 90 millimeters in length (e.g., *Onchosaurus pharao*).

Vertebrae

In the earliest sharks, the backbone (notochord) was unsegmented and the vertebrae were not mineralized. Among modern sharks and rays (including their fossil representatives and some extinct groups of Mesozoic and Cenozoic sharks), the notochord is segmented and the vertebral centra are calcified, thus making them preservable as fossils.

Elasmobranch vertebrae consist of a series of externally simple disks called **amphicoelous** centra that are anteroposteriorly biconcave and hour-glass shaped (Figure 25A). The **centrum** represents the main body of the vertebra after all the projecting cartilaginous parts (arch cartilages and ribs) are removed. These centra are aligned anteroposteriorly in a series held together by connective tissue and have projecting **neural** and **hemal arches** composed of cartilaginous plates (Figure 25C). The articular processes and facets that characterize the vertebrae of bony fishes, reptiles, birds and mammals are absent. Neural and hemal arch cartilages originate from paired holes in the dorsal and ventral margins of the centrum (**basidorsal** and **basiventral insertions**). As viewed in transverse section (Figure 25B), these holes are cone-shaped and radiate outward from the middle of the centrum. The areas between these four cones are termed **intermedialia** and are calcified to some degree in almost all modern sharks and rays.

The calcification patterns found in elasmobranch vertebrae range from simple to complex. Several studies have shown that species and genera, which on other grounds are considered closely related, also have very similar vertebral calcification patterns (Figures 25D-F). Unrelated shark and ray groups generally have dissimilar vertebral calcification patterns (Figures 25G-J) although this is not always true. For example, concentric calcifications are found in the basking shark *Cetorhinus* (Cetorhinidae), the whale shark *Rhincodon*, the angel shark *Squatina* and in two fossil genera, *Ptychodus* (Ptychodontidae) and *Squalicorax* (Anacoracidae). This situation is the result of convergence of one morphology within diverse and unrelated shark groups.

The total number of vertebrae in modern sharks ranges from a low of 61 in the deep-water squaloid *Euprotomicrus bispinatus* to 419 in the thresher shark *Alopias vulpinus*. For most families of modern sharks, the vertebral count averages between 150 and 200 (Springer and Garrick 1964).

Fossil vertebral calcification patterns are studied by one of two methods. The centrum is either transversely sliced with a rock saw or it can be x-rayed.

Although shark vertebrae are fairly common in the Texas Cretaceous (Figure 26), many collectors find it difficult to distinguish bony fish vertebrae from those of sharks. In fact, this is one of our most frequently asked questions. The answer is very easy. A fossil shark vertebra consists only of the disk-shaped centrum; neural and hemal arch cartilages are almost never preserved. With several exceptions, all shark vertebrae have two hole pairs, one dorsal and one ventral. Bony fish vertebrae differ from those of sharks in having spiny neural and hemal processes. These processes are usually broken off, but close inspection usually shows their broken bases. Fish bone is also porous or spongy and platy or lamellar, whereas calcified cartilage is very fine grained or porcelain-like in texture.

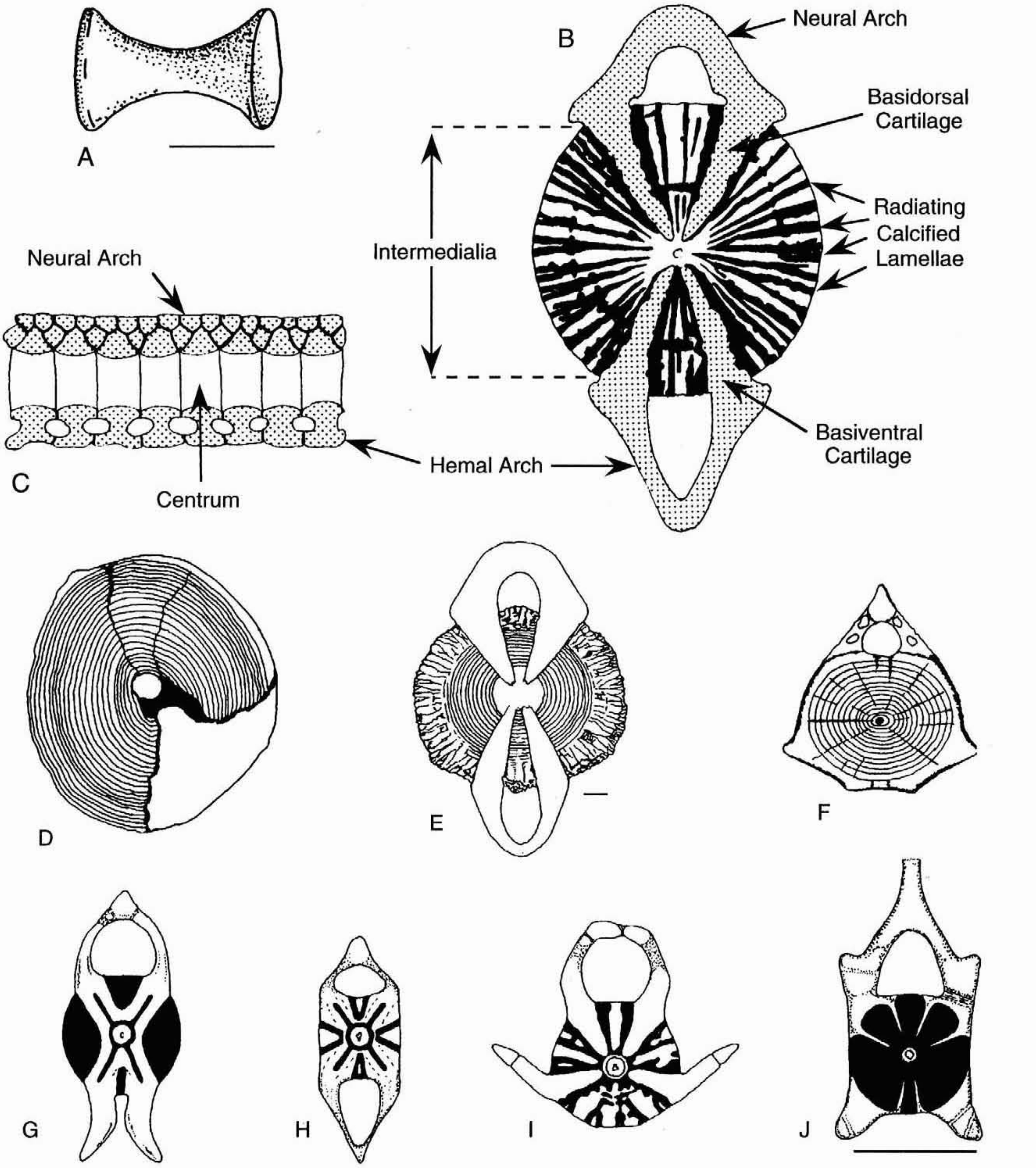


Figure 25. Shark vertebrae and their calcification patterns. A) simple amphicoelous (double cone) vertebra; B) transverse section of an anterior tail vertebra of the great white shark *Carcharodon carcharias* illustrating vertebral terminology; C) side view of a shark vertebral column showing a series of centra and associated neural and hemal arch cartilages. Concentric vertebral calcifications, D) *Squalicorax* sp., Eagle Ford Group (Turonian), Dallas County; E) Basking shark *Cetorhinus maximus*; F) Angel shark *Squatina squatina*. Diverse calcification patterns, G) Hammerhead shark *Sphyrna blochii*; H) Cat shark *Scyliorhinus marmoratus*; I) Orectolobid shark *Stegostoma tigrinum*; J) Guitarfish *Rhinobatos granulatus*. Figures A,B,E-J are modified from Ridewood (1921). Scale line = 5 mm.

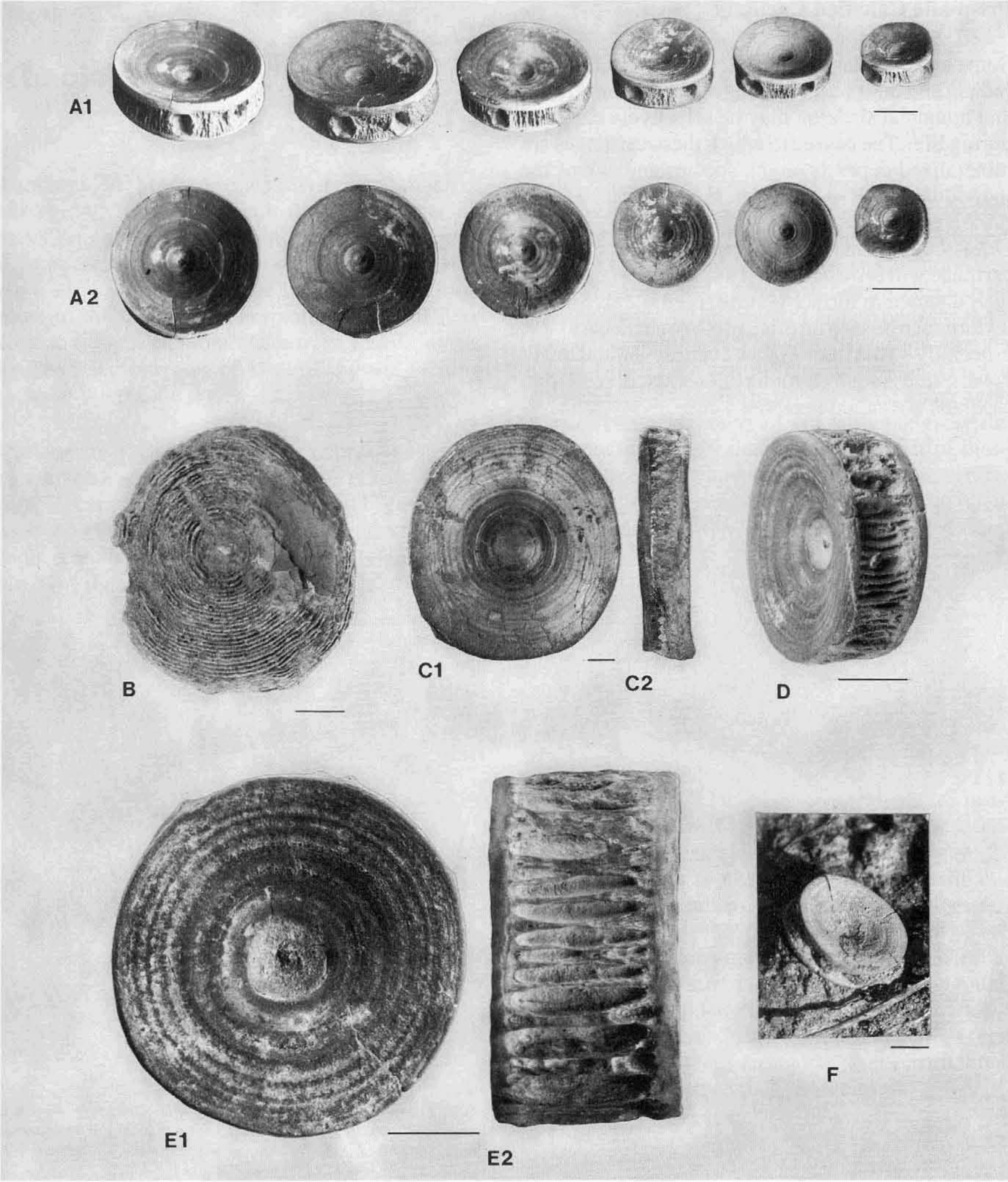


Figure 26. Fossil shark vertebrae. A) associated vertebrae of an unidentified cretoxyrhinid from the lower Eagle Ford Group (Cenomanian), Dallas County, A1) side view, A2) anterior or posterior view; B) transverse section of *Squalicorax* sp. showing concentric calcifications, Weno Formation (Albian), Tarrant County; C) ?*Squalicorax* sp. DMNH 746, basal Eagle Ford Group, Tarrant County, (C1) vertebral face, (C2) side view; D) Cretoxyrhinid vertebra, basal Atco Formation of the Austin Group (Coniacian), Dallas County; E) large cretoxyrhinid vertebra, (E1) vertebral face, (E2) side view; F) vertebra exposed at an outcrop of Eagle Ford Group (Cenomanian), Denton County. Scale lines = 1 cm.

Prismatic Calcified Cartilage

Some arch cartilages associated with vertebrae, fin radials and their basal cartilages, the cranium, jaws and branchial skeleton may be selectively calcified during life. The degree to which these cartilages are mineralized depends on the species and age of the individual.

Occasionally, small patches of prismatic calcified cartilage will be fossilized. These are recognized by their distinctive surface texture (Figure 27). Similar textures can be seen on dried modern shark cartilage, especially on the flat surfaces of the upper and lower jaws. Individual cuboidal elements of calcified cartilage are called **tesserae**.

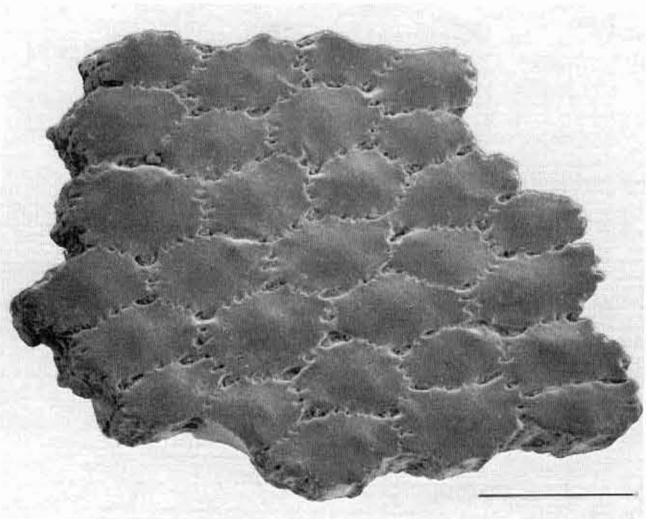


Figure 27. Fossilized cartilage from the late Albian Weno Formation, Tarrant County. Scanning electron microscope photomicrograph. Scale line = 0.5 mm.

Chapter 4

Ichnology

Ichnology, the study of trace fossils, is a branch of paleontology concerned with the investigation of tracks, trails, burrows, feeding scars or any other features created by an organism, but not the organism itself. For example, the fossil dinosaur footprints in the Glen Rose Formation at the Paluxy River in Somervell County are trace fossils, as are the fossilized burrows of shrimp and the feeding tracks of worms.

Shark or ray trace fossils include depressions (resting and feeding traces) made by rays in soft sand or mud, fecal pellets or **coprolites** (Figure 28), **enterospirae** (fossilized intestines) and knife-like slices, grooves and scrapes made by teeth cutting into bone during feeding (Figure 29).

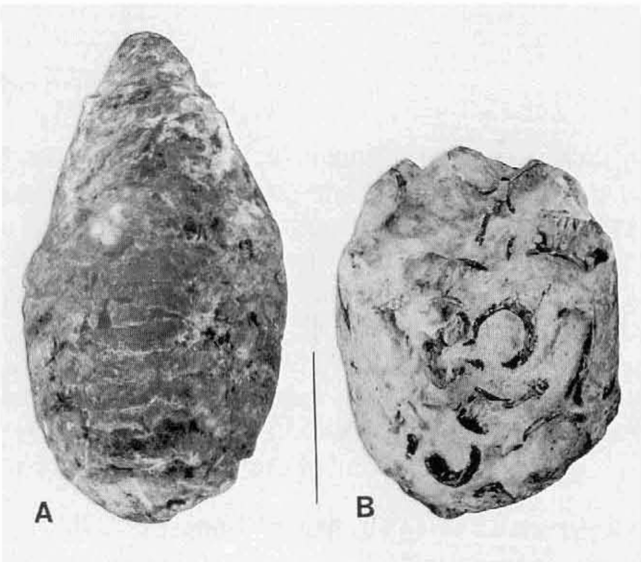


Figure 28. Possible shark coprolites from the Eagle Ford Group, Tarrant Formation (Cenomanian), Dallas County. A) coprolite showing spiral structure, B) coprolite containing fish bones. Scale line = 1 cm.

COPROLITES

Many paleontologists have attributed coprolites having a helical or spiral shape to an elasmobranch origin (Figure 28A). There is considerable debate over the true "ownership" of these structures, but a shark or ray origin is reasonable. It is not uncommon to find fish bones within these coprolites (Figure 28B) and, aside from finding a whole shark with stomach contents preserved, coprolite analysis is the only way of directly deciphering the diet of these fishes. Experience has also shown that concentrations of coprolites are usually associated with phosphatic condensed sections and abundant shark and ray teeth. Coprolites are common throughout most formations of the Eagle Ford Group.

FEEDING TRACES

In much the same way that modern sharks feed on dead whales and sea lions, many of the larger Cretaceous sharks (most lamnoids and *Squalicorax*) must have fed on mosasaurs, plesiosaurs and the occasional dinosaur that floated out to sea. Figure 29 shows a Campanian mosasaur vertebra having numerous elongate grooves and scratches on the centrum and vertebral processes, which were undoubtedly made by a shark, probably *Squalicorax*. Shark teeth are often found in abundance around large skeletons and are usually interpreted as teeth lost during predation. However, ocean currents can also concentrate teeth around bottom obstructions (e.g., a skeleton, large rock or tree trunk).

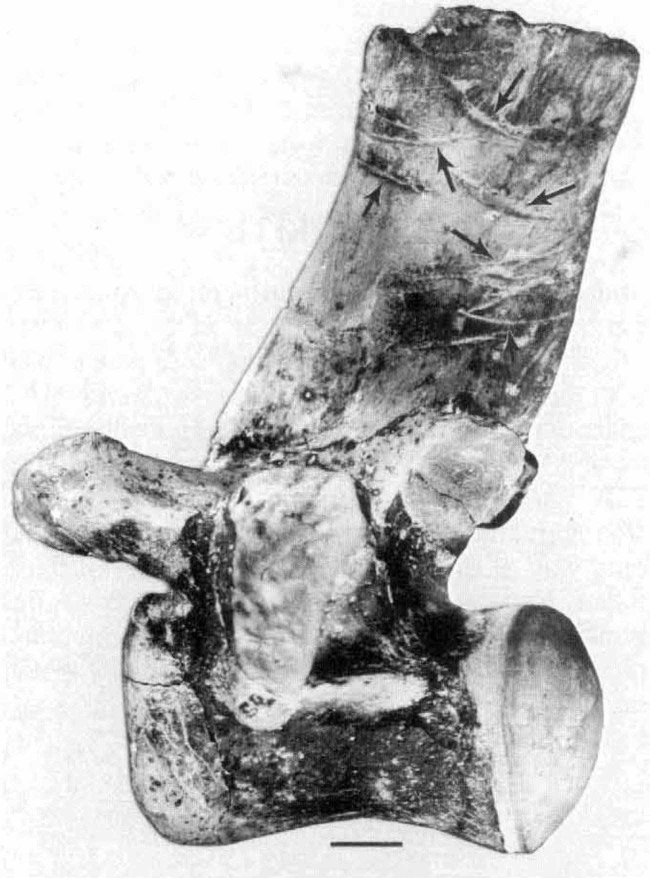


Figure 29. Mosasaur vertebra with ?shark bite marks (see arrows) on the neural spine. DMNH collection, Campanian, Taylor Group, North Sulphur River, Fannin County. Scale line = 1 cm.

Chapter 5

Texas Cretaceous Sharks and Rays

In order to discuss the various kinds of Texas Cretaceous sharks and rays, we must use standardized names that are understood or recognized by students in every part of the world. For this reason, Latin names, or latinized forms, are employed as the official medium for nomenclature.

NAMES AND NOMENCLATURE

It is not at all necessary to have a knowledge of Latin to identify a tooth, nor is it supposed that one should remember all of the names. It does add to the enjoyment of the study to absorb the names of a few of the more common species. This allows us to better communicate with peers, as well.

Scientific Names

Each unique biological creature is given a scientific name that has two parts – the **genus**, which is akin to a surname such as Smith or Jones, and the **species**, which is akin to a first name such as John or Bill. The generic name is always capitalized, but the specific name that comes after the genus name is not, e.g., *Squalicorax falcatus* or *Ptychodus whipplei*. Scientific names are always italicized, underlined or printed in bold letters. In this publication, generic and specific names are italicized.

It is also customary to add the name of the person who described the species after the scientific name (e.g., *Hybodus butleri* Thurmond). Some authorities may put the author's name in parentheses for different purposes, for example *Cretoxyrhina mantelli* (Agassiz). This means that the species was first described by Agassiz under a different generic name, in this case *Oxyrhina*, but later was assigned to the genus *Cretoxyrhina*. A date following the author's name is the year the species was originally published, e.g., *Hybodus butleri* Thurmond 1971.

Name Changing

There is nothing more annoying than having a well known and frequently used scientific name changed. The field of shark taxonomy seems to have the lion's share of tossing out old friends for utter strangers. There are two basic kinds of changes – zoological and nomenclatorial. Everyone will condone the former for it is obvious that, as our knowledge increases, certain genera, or even species, will be found to be mixtures. This necessitates separating and applying new names. For example, not very long ago, *Cretoxyrhina mantelli* was known as *Oxyrhina mantelli*. To make matters more confusing, the genus *Oxyrhina* Agassiz 1843 is a junior synonym of *Isurus* Rafinesque 1810. Cretaceous fossils once referred to the genus *Isurus* were reassigned to *Cretoxyrhina* once paleontologists found that this fossil form differed significantly from living and Tertiary species of *Isurus*.

Nomenclatorial name changing is harder to accept. Frequently, species may be given several different names by various paleontologists. The **International Commission for Zoological Nomenclature (ICZN)** has set up an extensive set of rules for naming species. Among these is the rule of priority by which the earliest valid name is chosen if several names are available. Unfortunately, the earliest name may have been overlooked for many years and its subsequent discovery will eliminate one that has been in use for a long time.

What Is a Species?

Volumes have been written in answer to this question. The subject is one of continuous investigation by many biologists working with all forms of animals and plants.

Mayer (1942) defines species as groups of actually or potentially interbreeding natural populations, which are reproductively isolated from other such groups by geographical, physiological or ecological barriers. Unfortunately, this biological concept of species can only be applied indirectly to fossil populations for it is based on attributes that are only observable in living organisms. Therefore, paleontologists base their species on what has been called the **morphological species concept**. That is, the morphological differences observed in teeth are described and used as a basis for defining and separating one fossil species from another. The obvious question, and one that is a problem to all paleontologists, is "how much of a difference must there be to warrant the recognition of a new species?"

Shark paleontologists working with isolated teeth and tooth sets generally recognize different fossil species within the same genus, where the magnitude of tooth differences in the fossil teeth is similar to that observed between closely related modern species. However, be careful! The range of ontogenetic tooth variation within a species can exceed that observed between two closely related species at the same growth stage.

Subspecies

To a biologist working with living animals, a **subspecies** (variety) represents a population of individuals that has become morphologically differentiated (structurally different) because of isolation from other populations of the same species. It follows that true subspecies are not found living together in the same geographic and ecologic setting and therefore as fossils they generally would not be found together in the same collecting site. Since time may operate to modify the form and structure of animals in a manner exactly analogous to that effected by geographic isolation and change of environment, subspecies may be distinguished that differ slightly in geologic age. Indeed, the paleontologist generally has no means for discriminating subspecies that originated as the result of geographic and ecologic separation from those that were produced by evolution during a part of geologic time.

Generally, paleontologists have attempted to define subspecies of fossil sharks where minor morphological differences, such as an increase in tooth size through time, are observed. For example, Slaughter and Steiner (1968) use subspecies to describe morphological differences in the sawfish *Ischyrhiza*, and Thurmond recognized different subspecies of *Onchopristis* between Albian and Cenomanian forms. Herman (1972) applied a subspecies concept to his review of *Ptychodus,* and Meyer (1975) made extensive use of the subspecies or varieties concept in his unpublished study of Texas Cretaceous *Ptychodus* and *Cretoxyrhina.*

The questions and problems associated with the use of the subspecies concept in shark paleontology are beyond the scope of this book. Where subspecies have been published for Texas Cretaceous sharks or rays, they are discussed in the following section under the appropriate species. The numerous subspecies that appear in Meyer's unpublished dissertation, and are known to many Texas tooth collectors, were never published, have no taxonomic standing, and are consequently not included in this book.

SPECIES IDENTIFICATION

There are many difficulties involved with identifying with certainty the isolated teeth of fossil sharks and rays. For some genera, identification can only be approximated by the beginner, and in still others, even the specialist will find difficulty in making an identification. The Tooth Terminology section of this book clearly illustrates the many morphological features exhibited by shark and ray teeth used for identifying species and in determining the evolutionary relationships existing between members of the higher categories, such as genera, families or orders. It must be realized that, in some shark groups, certain tooth attributes, such as number of cusplets, serrated crown edges or root shape are used to distinguish species, while in other groups, these will prove useless and reliance may have to be put on a different set of dental attributes. The key diagnostic tooth characters for each species are specified in the Identification section.

The tooth differences that result from various patterns of heterodonty (dental, sexual or ontogenetic) are often difficult to distinguish from those that are genetic or are a naturally inherent character of the species. It is not an easy problem, even for the professional, to define the limits of a species.

The Identification Guide

The following Identification Guide provides important information on the Texas Cretaceous sharks and rays covered in this book. Each species is illustrated with numerous examples selected to show the range of tooth variation in the dental series. The accompanying text provides the reader with a thorough description of each species, tooth morphology and heterodonty, distinguishing characteristics, geologic occurrence and geographic distribution in Texas, general comments pertaining to natural history or collecting tips and a list of relevant published references.

The Identification Guide is a series of Species Data Sheets; usually one, but in some instances, a two-page summary of technical information and illustrations for every species. The first page always follows a standardized format. The specific pieces of information given for this format are explained below.

At the top right corner of each page are the Genus and Species of the shark or ray. The Order and Family to which the species belongs is in the upper left corner. Immediately below and between the parallel lines are three additional pieces of information: on the left is the **Chronologic Range** of the species in Texas; in the center is **Occurrence**, a qualitative statement of tooth abundance (Rare, Common or Abundant); and on the right is the **Maximum Size** of the oral or rostral tooth (in millimeters) observed, so far, in Texas. The measurement is of the greatest dimension of the tooth. For all sawfishes, maximum rostral tooth (R) and oral tooth (O) sizes are given. We emphasize "**in Texas**" because many of the species illustrated in this book are found in Cretaceous deposits elsewhere in North America, and many of the larger species have worldwide distributions. The chronologic range and maximum tooth size can and do vary somewhat according to geographic location. The author and publication date of the genus and species are listed below the chronologic range. Junior synonyms (invalid names) are not given.

Description: Significant tooth features and tooth histology. This section uses the tooth terminology defined in Chapter 3.

Heterodonty: The type(s) of heterodonty characteristic of the species.

Distinguishing Characteristics: Tooth features that most readily identify this species or help to distinguish it from similar species.

Stratigraphic Occurrence in Texas: Geologic formations and chronologic ages for presently known occurrences of this species in Texas.

Comments: Additional taxonomic information, natural history notes, collecting and occurrence data and other general information of interest.

References: A list of important paleontological references which the reader can pursue for additional information on the species.

Figures: Photographs, scanning electron microscope photomicrographs and line drawings abundantly illustrate each species. Specimens have been selected to show typical features, as well as ranges in tooth size and position in the mouth. Wherever possible, the complete dentition of a species is illustrated, based on natural, associated or artificial tooth sets; all illustrations are referenced to a scale line.

Arrangement of the Species Identification Guide

The species of Texas Cretaceous sharks and rays are presented in systematic order, following the classification hierarchy outlined in this chapter. The most primitive shark taxa are listed first followed by progressively more advanced forms. The batoids or rays follow the sharks and are likewise arranged in the same primitive to advanced order. Species follow alphabetically within each genus.

Scope of the Material Included

In spite of the large number of genera and species reviewed in this book, a substantial Texas Cretaceous shark and ray fauna remains to be described. Generally, we excluded most of this undocumented material except where major taxonomic groups are otherwise unrepresented in the published literature or in cases where the undescribed species is commonly encountered by collectors. Included in this category are teeth of the Etmopterinae, Somniosinae, selected Lamniformes, Scyliorhinidae, Triakidae, *Squatirhina*, Rajidae, Myliobatidae and dasyatid sting rays.

Abbreviations

A number of abbreviations used here are intended to denote possible relationships or some level of uncertainty in the generic or specific identification. These are: (**?**) indicates considerable uncertainty in the identification; (**cf.**) means "compares favorably" but expresses slight doubt; (**aff.**) for affinity, or a strong relationship but not the same taxon; (**spp.**) meaning more than one species, e.g., *Hybodus* ssp., for which there are probably two or three species which have yet to be sorted out and named.

Several figured specimens have been borrowed and photographed from museum collections. The institutional abbreviations are as follows: **DMNH** = Dallas Museum of Natural History; **SMUSMP** = Southern Methodist University, Shuler Museum of Paleontology, Dallas; **TMM** = Texas Memorial Museum, Austin; **USNM** = United States National Museum, Smithsonian Institution.

Identification Tips

There are many different approaches one can take to the identification of fossil shark and ray teeth. The method you choose will depend on experience and your personal preference. Most people will take a strictly visual approach, comparing one-to-one their fossil teeth with the illustrations given in the following sections. This book is ideally suited to this identification method, with the photographs on the outer part of each page for easy 'thumb-through', while also providing abundant supporting technical documentation for each species.

Diagnostic tooth characters are generally easy to see on large teeth, but determining their presence or absence on much smaller specimens requires the use of a hand lens or low-powered (15x) binocular microscope. Identifying teeth, regardless of size, takes patience, careful observation and attention to detail.

Your ability to critically examine and discriminate one species from another will be greatly facilitated if you have a comfortable working knowledge of the tooth terms defined in Chapter 3. This nomenclature has been consistently applied to all species descriptions and its use is required to effectively communicate differences between taxa at all systematic levels. A correctly identified tooth should conform to the descriptive attributes and distinguishing characteristics cited for the species. In most instances, the chronologic range of the species should match that cited here, but new range extensions are always possible.

CLASSIFICATION

The purpose of zoological classification is to arrange animals into groups based on fundamental similarities and differences that reflect evolutionary relationships. Students of fossil and modern sharks must be prepared to find that different writers use different systems of classification. These differences are chiefly of two sorts. First, there is the use of different names for the same group; for example, the terms 'Ganopristidae' and 'Sclerorhynchidae' refer to the same Family of Cretaceous sawfishes. Second, there is the placing of the same group into different systematic categories, as in the designation of a group as a Class by one writer, but as an Order by another. Discrepancies of the second sort are so common that it is advisable not to have a fixed concept of the taxonomic rank of a particular group, but rather to remember that it is a part of a certain superior group and can be divided into a number of subordinate groups. Thus, it is not so important to decide whether the Lamniformes represent a Superorder or Order as it is to know that the group is a major subdivision of the Elasmobranchii and that it includes the Lamnidae, Cetorhinidae, Mitsukurhinidae, Cretoxyrhinidae and so on.

The classification of Texas fossil sharks and rays followed in this book is outlined on following pages and represents a combination of many different authors' views on the interrelationships of modern and fossil sharks and rays as summarized by Compagno (1973) and Cappetta (1987). The name given in parentheses after each family is the common name, if one exists, for the family. If all genera in the family are extinct, a closely related modern family name may be given. An asterisk (*) denotes the genus is extinct.

CLASS Chondrichthyes (Cartilaginous Fishes)
SUBCLASS Elasmobranchii (Sharks, Skates, Rays)
COHORT Euselachii
SUPERFAMILY Hybodontoidea
ORDER Hybodontiformes
FAMILY Hybodontidae
* *Hybodus butleri* Thurmond 1971
* *Hybodus* sp.
FAMILY Polyacrodontidae
* *Polyacrodus* cf. *brevicostatus* (Patterson 1966)
* *Polyacrodus illingsworthi* (Dixon 1850)
* *Polyacrodus* aff. *parvidens* (Woodward 1916)
* *Lissodus anitae* (Thurmond 1971)
* *Lissodus selachos* (Estes 1964)
* *Lissodus* spp.
FAMILY Ptychodontidae
* *Ptychodus anonymus* Williston 1900
* *Ptychodus connellyi* MacLeod & Slaughter 1980
* *Ptychodus decurrens* Agassiz 1839
* *Ptychodus latissimus* Agassiz 1843
* *Ptychodus mammillaris* Agassiz 1839
* *Ptychodus mortoni* Agassiz 1843
* *Ptychodus occidentalis* Leidy 1868
* *Ptychodus polygyrus* Agassiz 1839
* *Ptychodus rugosus* Dixon 1850
* *Ptychodus whipplei* Marcou 1858
* *Ptychodus* sp.
SUBCOHORT Neoselachii
SUPERORDER Squalomorphii
ORDER Hexanchiformes
FAMILY Hexanchidae (Sixgill Sharks)
Hexanchus microdon (Agassiz 1843)
ORDER Squaliformes
FAMILY Squalidae (Dogfish Sharks)
Squalus sp.
SUBFAMILY Etmopterinae, genus and species undetermined
SUBFAMILY Somniosinae, genus and species undetermined
ORDER Squatiniformes
FAMILY Squatinidae (Angel Sharks)
Squatina hassei Leriche 1929
ORDER Heterodontiformes
FAMILY Heterodontidae (Horn Sharks)
Heterodontus canaliculatus (Egerton 1850)
ORDER Orectolobiformes

FAMILY Hemiscylliidae
Chiloscyllium greeni (Cappetta 1973)
FAMILY Ginglymostomatidae
* *Cantioscyllium decipiens* Woodward 1889
Ginglymostoma lehneri Leriche 1938
FAMILY Parascylliidae
* *Pararhincodon groessenssi* Herman 1982
FAMILY Orectolobidae (Carpet Sharks)
* *Cretorectolobus* sp.
FAMILY ?Rhincodontidae (Whale Sharks)
* Genus and Species Undetermined
ORDER Lamniformes
FAMILY Odontaspididae (Sand Tiger Sharks)
Carcharias amonensis (Cappetta & Case 1975)
Carcharias tenuiplicatus (Cappetta & Case 1975)
Carcharias sp. A
Carcharias sp. B
FAMILY Mitsukurinidae (Goblin Sharks)
* *Scapanorhynchus raphiodon* Agassiz 1844
* *Scapanorhynchus texanus* (Roemer 1849)
FAMILY Cretoxyrhinidae (Extinct)
* *Cretodus crassidens* (Dixon 1850)
* *Cretodus semiplicatus* (Munster in Agassiz 1843)
* *Cretoxyrhina mantelli* (Agassiz 1843)
* *Cretolamna appendiculata* (Agassiz 1843)
* *Cretolamna woodwardi* Herman 1976
* *Leptostyrax macrorhiza* (Cope 1875)
* *Paraisurus compressus* Sokolov 1978
* *Protolamna* aff. *sokolovi* Cappetta 1980
FAMILY Serratolamnidae (Extinct)
* *Serratolamna serrata* (Agassiz 1843)
FAMILY Alopiidae (Thresher Sharks)
* *Paranomotodon* sp.
FAMILY Anacoracidae (Extinct)
* *Squalicorax curvatus* Williston 1900
* *Squalicorax falcatus* Agassiz 1843
* *Squalicorax kaupi* Agassiz 1843
* *Squalicorax pristodontus* Agassiz 1843
* *Squalicorax* sp.
* *Microcorax crassus* Cappetta & Case 1975
* *Pseudocorax granti* Cappetta & Case 1975
ORDER Carcharhiniformes
FAMILY Scyliorhinidae (Cat Sharks)
?*Scyliorhinus* spp.

FAMILY Triakidae (Leopard Sharks)
Galeorhinus sp.
* *Palaeogaleus* sp.
SUPERORDER Batomorphii
ORDER Rajiformes
FAMILY Rhinobatidae (Guitarfishes)
Rhinobatos casieri Herman 1975
Rhinobatos incertus Cappetta 1973
Rhinobatoidei incertae sedis
* *Protoplatyrhina renae* Case 1978
* *Pseudohypolophus mcnultyi* (Thurmond 1971)
* *Squatirhina* sp.
FAMILY Rajidae (Skates)
* Genus and Species Undetermined
FAMILY Sclerorhynchidae (Extinct Sawfishes)
* *Ischyrhiza avonicola* Estes 1964
* *Ischyrhiza mira* Leidy 1856
* *Ischyrhiza texana* Cappetta & Case 1975
* *Onchopristis dunklei* McNulty & Slaughter 1962
* *Onchosaurus pharao* (Dames 1887)
* *Schizorhiza* cf. *weileri* Serra 1933
* *Sclerorhynchus* sp.
* *Ptychotrygon agujaensis* McNulty & Slaughter 1972
* *Ptychotrygon hooveri* McNulty & Slaughter 1972
* *Ptychotrygon slaughteri* Cappetta & Case 1975
* *Ptychotrygon texana* (Leriche 1940)
* *Ptychotrygon triangularis* (Reuss 1844)
ORDER Myliobatiformes
FAMILY Myliobatidae (Bat Stingrays)
* *Brachyrhizodus wichitaensis* Romer 1942
* Genus and Species Undetermined
FAMILY Rhombodontidae (Extinct)
* *Rhombodus binkhorsti* Dames 1881
FAMILY Dasyatidae (Diamond Stingrays)
Dasyatis spp.
* Genus and Species Undetermined

VISUAL IDENTIFICATION KEY

Figure 30 illustrates representative teeth of the 47 genera of sharks and rays known from the Cretaceous of Texas. This visual key provides a quick-look identification aid. Use this visual approach as a means of selecting one or more generic candidates, then consult the appropriate species data sheet(s) for more information. Most of the teeth in Figure 30 are illustrated larger than their natural size.

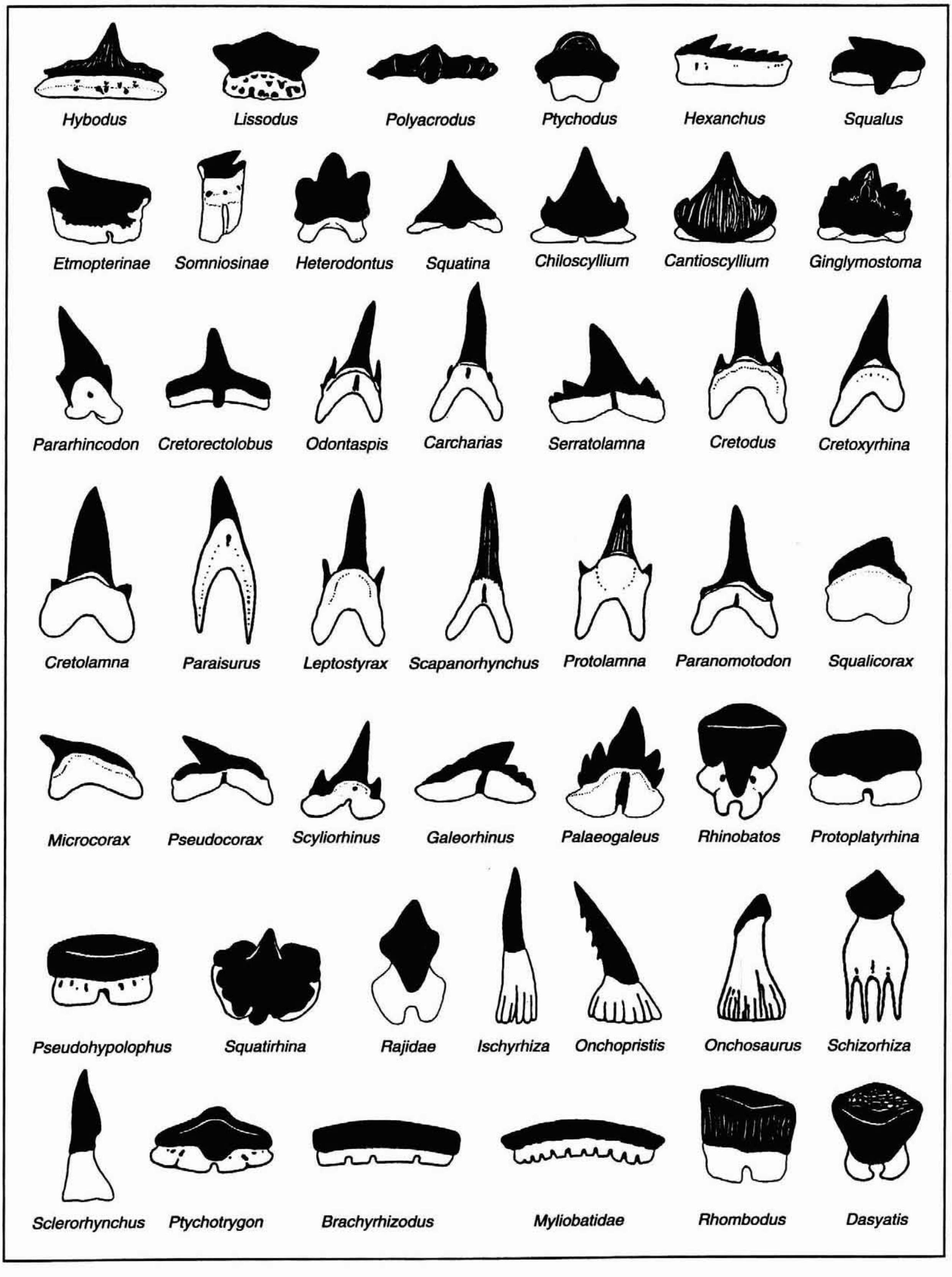


Figure 30. Visual identification key to the genera of Texas Cretaceous sharks and rays. The figures are *not* drawn to scale.

Order Hybodontiformes

The most primitive sharks in the Texas Cretaceous belong to the Order Hybodontiformes, a group which first appears with certainty in the Lower Triassic, and reaches extinction at the end of the Cretaceous Period. Although complete or partial skeletons have been found for several hybodont genera, most of what we know about these sharks is based on the study of their isolated teeth and fin and cephalic spines.

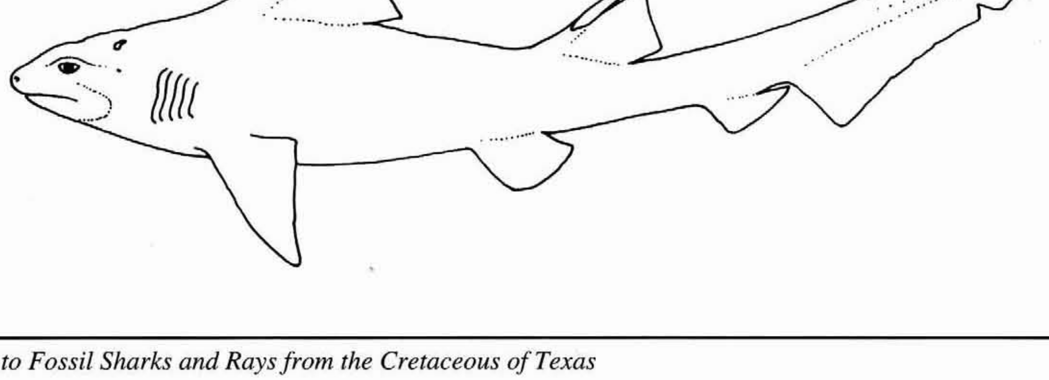
As a group, hybodontiforms lack calcified vertebrae (although vertebral calcifications have been found in the genus *Ptychodus*) but have calcified neural and hemal arch cartilages and ribs. Their upper jaw (palatoquadrate) cartilages are firmly held to the skull, in contrast to the very flexible and protrusable jaw suspensions typical of modern sharks. In the genus *Hybodus*, the mouth is situated under the snout (subterminal) as in most living elasmobranchs.

Many hybodonts appear to have cephalic and dorsal fin spines. The latter are characterized by a double longitudinal row of posterior denticles. Their dentition ranges from prehensile to crushing pavement teeth and their roots are anaulacorhizous.

The order includes approximately fifteen genera arranged in five families. Four genera (*Hybodus, Polyacrodus, Lissodus* and *Ptychodus*) and three families (Hybodontidae, Polyacrodontidae and Ptychodontidae) are found in the Cretaceous of Texas.

Hybodonts are most diverse within the Texas Lower Cretaceous where *Hybodus butleri* (Family Hybodontidae), *Polyacrodus* aff. *parvidens, P.* cf. *brevicostatus* and *Lissodus anitae* (Family Polyacrodontidae) have all been described from shallow coastal marine, brackish and fresh water deposits within the Glen Rose and Paluxy formations (Thurmond 1971). In the Upper Cretaceous, *Hybodus* teeth are abundant in shallow marine and brackish water deposits of the Woodbine Formation and less commonly found in the Pepper (Cenomanian) and overlying Eagle Ford Group (Cenomanian-Turonian) and basal Austin Group (Coniacian). Although very rare, teeth of *Lissodus* do occur in the Woodbine (Cenomanian), Ozan (Campanian), Aguja (Campanian) and Kemp (Maestrichtian) formations of the Upper Cretaceous.

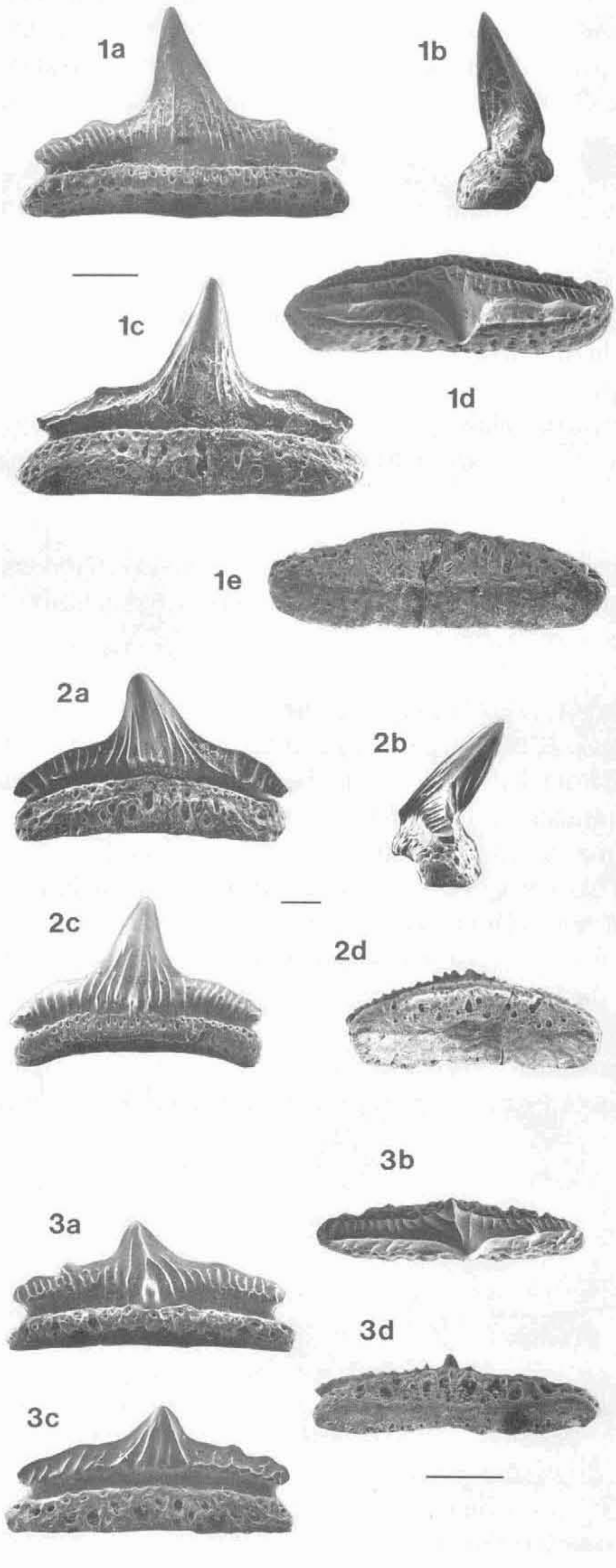
Teeth of the hybodont *Ptychodus* are among the largest found in Texas, occurring in Albian through early Campanian strata. Attributes of this genus are described in detail under the Family Ptychodontidae.



HYBODUS BUTLERI

Superfamily HYBODONTOIDEA Zangerl 1981
Family HYBODONTIDAE Owen 1846

Maximum Size: **6 mm** | Occurrence: **Common** | Chronologic Range: **Aptian-Albian**



Genus ***Hybodus*** Agassiz 1837
Hybodus butleri Thurmond 1971

DESCRIPTION: Teeth small; crown low with a moderately short median cusp and well developed, low mesial and distal blades; cusplets never developed; lateral teeth have a shorter, distally inclined cusp following a normal gradient monognathic pattern; longitudinal ridges on labial and lingual crown faces are vertical and extend from the crown base apically about half the crown height; lingual crown protuberance absent; root anaulacorhizous; histology osteodont.

Fin spines have a striated double row of posterior barbs; cephalic spines typical of the genus.

HETERODONTY: Very weak dignathic and moderate gradient monognathic heterodonty.

DISTINGUISHING CHARACTERISTICS: The teeth of *Hybodus butleri* differ from all other Texas hybodonts by lacking lateral cusplets, having a short median cusp and having longitudinal ridges that only extend halfway up the crown face.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Travis Peak (Aptian + Albian) and Paluxy (lower Albian) formations in north-central Texas.

COMMENTS: This species occurs in fresh and brackish water deposits (Thurmond 1971). The teeth of *H. butleri* are small and difficult to collect without bulk sampling and microscopic sorting of the fossil concentrate.

REFERENCES: Thurmond (1971, 1974).

***Hybodus butleri* Thurmond 1971: Anterior (1), lateral (2) and posterior (3) teeth; Paluxy Formation (early Albian), Parker County. Tooth orientation: (1a, 2c, 3a) labial view; (1c, 2a, 3c) lingual view; (1d, 3b) occlusal view; (1e, 2d, 3d) basal view; (1b, 2b) distal view. Scale line = 1 mm.**

Superfamily HYBODONTOIDEA Zangerl 1981
Family HYBODONTIDAE Owen 1846

HYBODUS SP.

Chronologic Range: **Cenomanian-Coniacian** | Occurrence: **Abundant** | Maximum Size: **7 mm**

Genus ***Hybodus*** Agassiz 1837
Hybodus sp.

DESCRIPTION: *Hybodus* teeth with a single, tall median cusp and one pair of widely spaced lateral cusplets; labial and lingual crown faces have strong, widely spaced longitudinal ridges which originate at the crown foot and extend apically for a distance of approximately half the cusp height; longitudinal ridges extend to the apex on all lateral cusps; cutting ridges continuous between cusps and cusplets; root anaulacorhizous; histology osteodont.

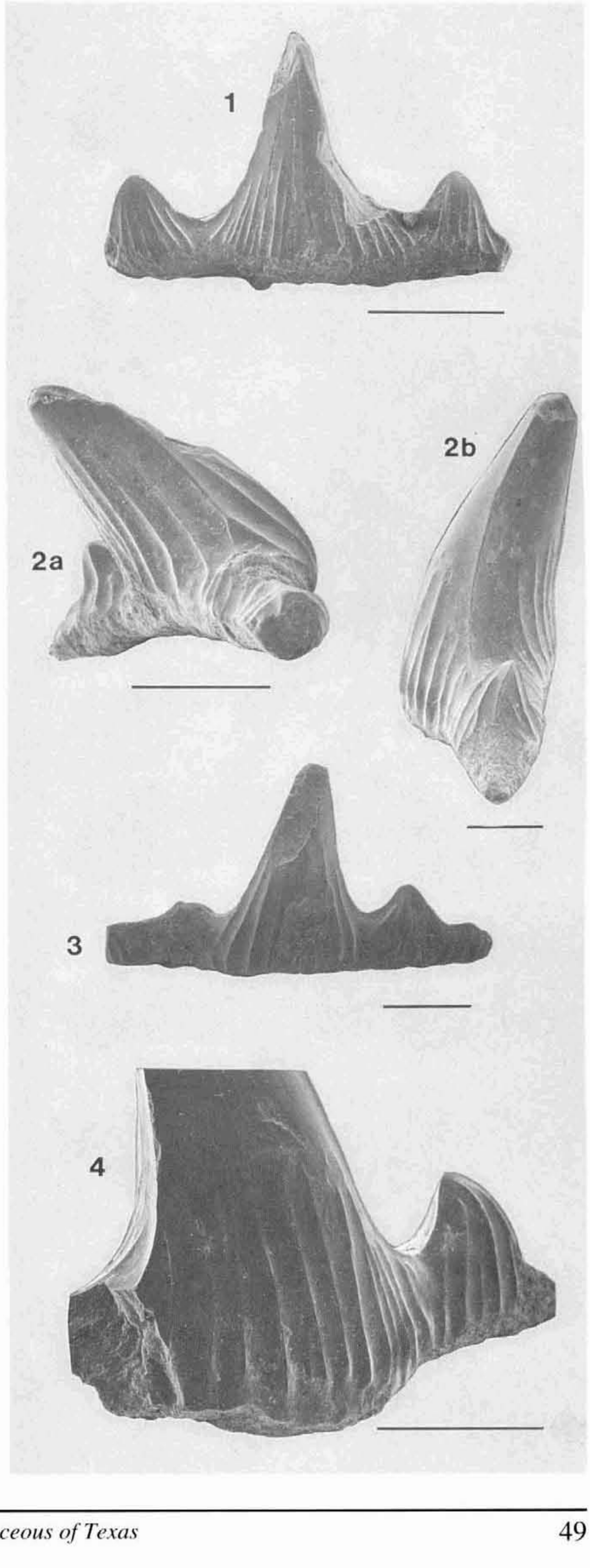
HETERODONTY: Probably has very weak dignathic and moderate gradient monognathic heterodonty.

DISTINGUISHING CHARACTERISTICS: The teeth of *Hybodus* sp. are almost always fragmentary and roots are rarely preserved. These teeth differ from *H. butleri* in having lateral cusplets and more extensive crown ornamentation.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Cenomanian through early Coniacian including the Woodbine and Pepper formations, the Eagle Ford Group and basal Austin Group formations. These teeth are commonly found in nearshore marine and marginal marine depositional environments and are especially abundant in the Woodbine Formation.

COMMENTS: Additional work is required to determine if these upper Cretaceous teeth of *Hybodus* are new or belong to one of many described species.

REFERENCES: Thurmond (1971, 1974).

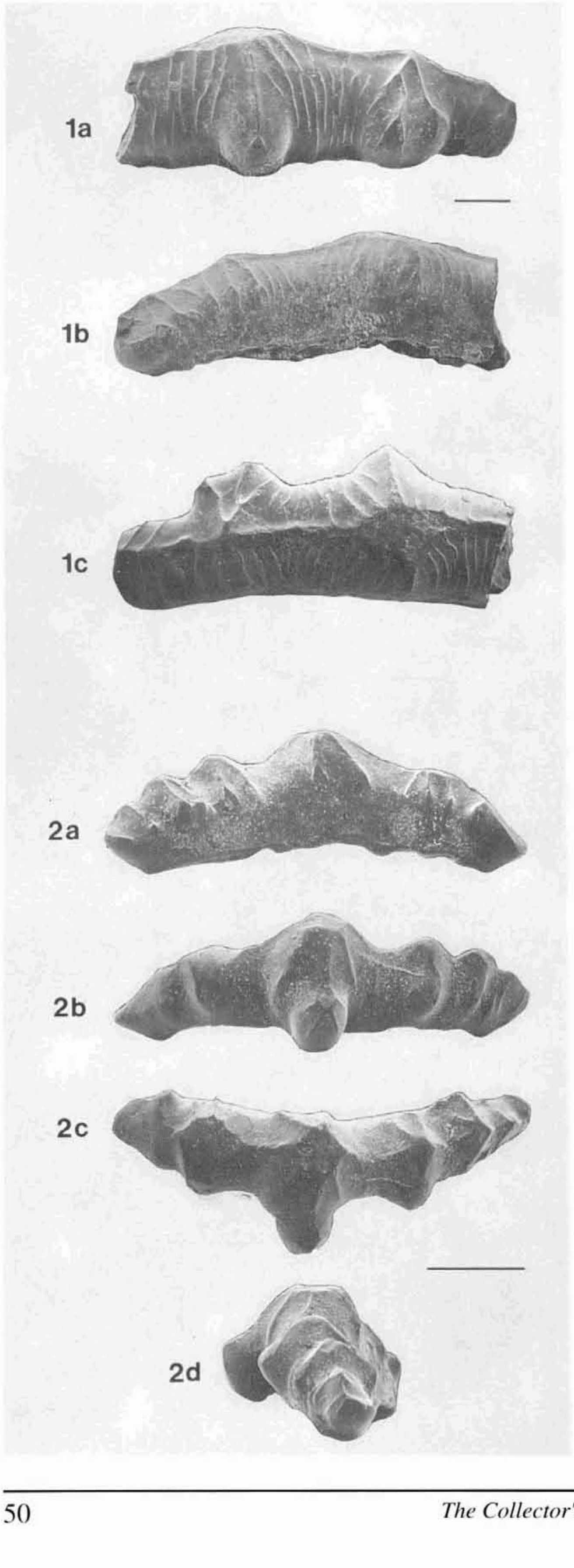


***Hybodus* sp.: Tooth crowns lacking roots; Lewisville Member, Woodbine Formation (Cenomanian), Denton County. Tooth orientation: (1, 3, 4) labial view; (2a) distal view; (2b) mesial view. Scale line = 1 mm (1, 2, 3) and 0.5 mm (4).**

POLYACRODUS cf. *BREVICOSTATUS*

Superfamily HYBODONTOIDEA Zangerl 1981
Family POLYACRODONTIDAE Gluckman 1964

Maximum Size: **15+ mm** Occurrence: **Rare** Chronologic Range: **Albian**



Genus ***Polyacrodus*** Jaekel 1889
Polyacrodus cf. ***brevicostatus*** (Patterson 1966)

DESCRIPTION: Teeth moderately large, some exceeding 15 mm wide; cusp massive, mesodistally broad and low; one or two pairs of short, wide cusplets; labial and lingual crown faces moderately convex; labial protuberance strong, extended basally from the cusp; crown ornamented with strong, branching longitudinal ridges that originate from a transverse cutting ridge and do not reach the crown foot; root anaulacorhizous; histology orthodont.

HETERODONTY: Gradient monognathic and weak dignathic heterodonty with medial, anterolateral and posterior tooth rowgroups in both jaws.

DISTINGUISHING CHARACTERISTICS: *Polyacrodus* cf. *brevicostatus* differs from all other Texas hybodonts by the following combination of characters: low, rounded cusplets, a strong labial protuberance, very low median cusp and longitudinal ridges that do not reach the crown foot.

STRATIGRAPHIC DISTRIBUTION IN TEXAS: Middle and upper Paluxy Formation, Parker and Wise counties (Albian-Lower Cretaceous).

COMMENTS: This species was originally described from the Lower Cretaceous (Wealden) of England and referred to the genus *Hybodus* by Patterson (1966). Thurmond (1971) suggested that several teeth from the Albian of Texas might be closely related to *P. brevicostatus*; however, the Texas material may represent an undescribed species.

REFERENCES: Patterson (1966); Thurmond (1971).

***Polyacrodus* cf. *brevicostatus* (Patterson 1966): Paluxy Formation (early Albian), (1) Parker County and (2) Wise County. Tooth orientation: (1a, 2b) labial view; (1b, 2a) lingual view; (1c, 2c) apical view; (2d) distal view. Scale lines = 1 mm.**

Superfamily HYBODONTOIDEA Zangerl 1981
Family POLYACRODONTIDAE Gluckman 1964

POLYACRODUS ILLINGSWORTHI

Chronologic Range: **Turonian** Occurrence: **Rare** Maximum Size: **32 mm**

Genus ***Polyacrodus*** Jaekel 1889
Polyacrodus illingsworthi (Dixon 1850)

DESCRIPTION: Teeth large, up to 32 mm wide; crown low, much shorter than root, with one short medial cusp, three to four pairs of low and rounded cusplets, and a weak labial crown protuberance; longitudinal ridges numerous, extend from crown foot to apex of cusp and cusplets; root anaulacorhizous; histology orthodont.

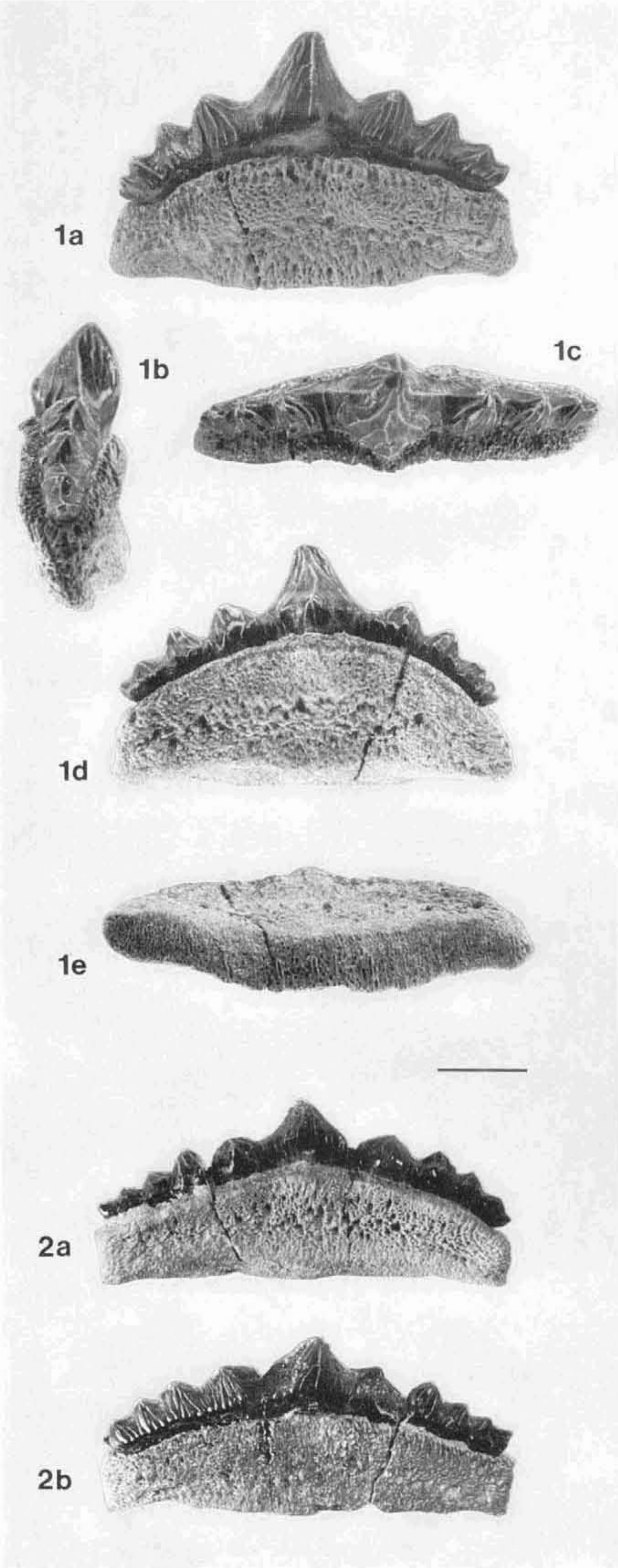
HETERODONTY: Unknown, probably strong gradient monognathic and very weak dignathic heterodonty.

DISTINGUISHING CHARACTERISTICS: Teeth of *Polyacrodus illingsworthi* are most likely to be confused with those of *P. brevicostatus*. *P. illingsworthi* differs from the latter species by possessing a much weaker labial crown protuberance and by having longitudinal ridges on both crown faces that reach the crown foot.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Kamp Ranch Limestone of the Eagle Ford Group (Turonian), Dallas County.

COMMENTS: Only two teeth of this species are presently known from the Texas Cretaceous. Both specimens, figured on this page, were collected from the Kamp Ranch Limestone of the Eagle Ford Group in Dallas County.

REFERENCES: Dixon (1850); Woodward (1889); Leriche (1929).

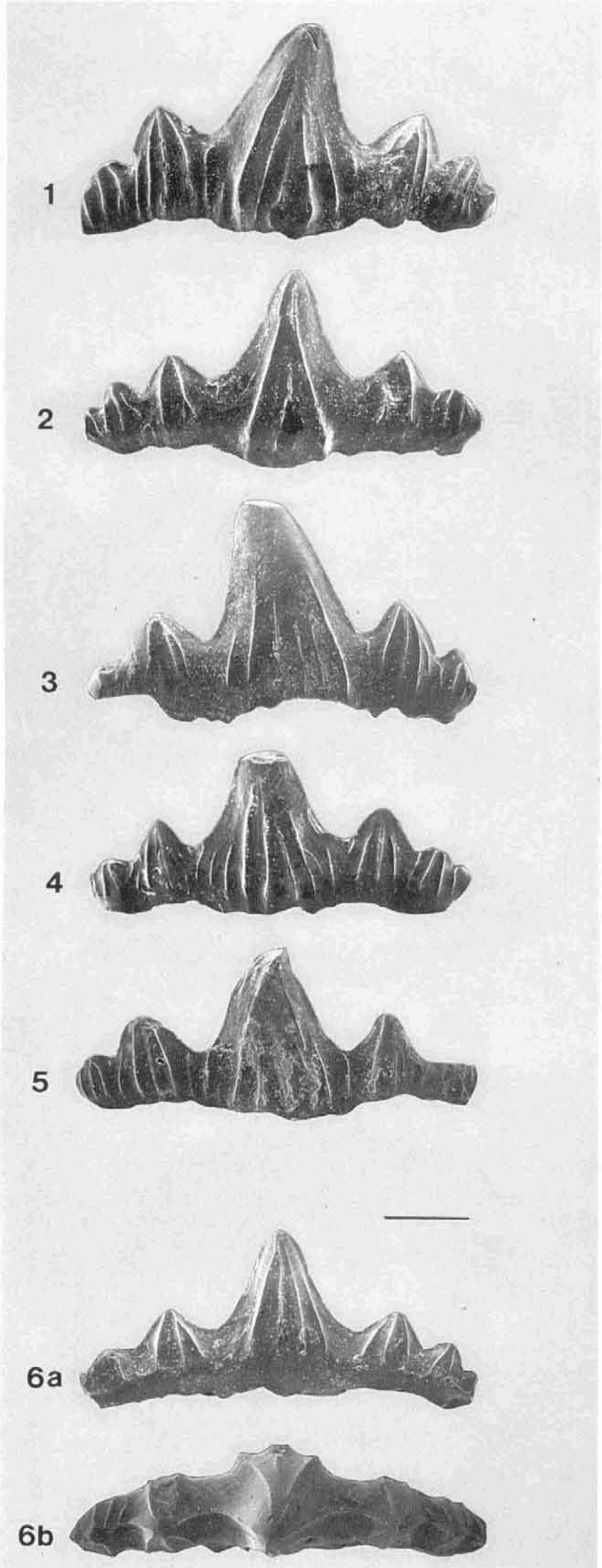


***Polyacrodus illingsworthi* (Dixon 1850): Kamp Ranch Limestone (Turonian), Eagle Ford Group, Dallas County. Tooth orientation: (1a, 2b) lingual view; (1b) mesial view. (1d, 2a) labial view; (1c) apical view; (1e) basal view. Scale line = 1 cm.**

POLYACRODUS aff. PARVIDENS

Superfamily HYBODONTOIDEA Zangerl 1981
Family POLYACRODONTIDAE Gluckman 1964

Maximum Size: **6 mm** | Occurrence: **Common** | Chronologic Range: **Albian**



Genus ***Polyacrodus*** Jaekel 1889
Polyacrodus aff. ***parvidens*** (Woodward 1916)

DESCRIPTION: Crown broad with a large central cusp and one or two pairs of shorter cusplets; labial and lingual crown faces moderately convex; labial crown protuberance weakly developed or absent; longitudinal ridges widely spaced and well developed on labial crown face; lingual crown face may be almost smooth, lacking longitudinal ridges; many ridges extend from crown foot to cutting ridge of cusp and cusplets; root anaulacorhizous; histology orthodont.

HETERODONTY: Weak gradient monognathic and dignathic heterodonty.

DISTINGUISHING CHARACTERISTICS: The combination of a high central cusp, well developed cusplets, weak labial crown protuberance and widely spaced longitudinal crown ridges are features of *P.* aff. *parvidens* that separate this species from other Texas hybodonts.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Middle and upper Paluxy and Travis Peak formations (Albian), Hood, Parker and Wise counties.

COMMENTS: These teeth were described from the Paluxy and Travis Peak formations by Thurmond (1971). This species occurs in both marine and brackish water deposits of the Paluxy, Church, Granbury and Springtown local faunas in Hood, Parker and Wise counties. Bulk sampling methods generally must be used to collect teeth of this species.

REFERENCES: Patterson (1966); Thurmond (1971).

***Polyacrodus* aff. *parvidens* (Woodward 1916): Anterolateral teeth, Paluxy Formation (early Albian), Parker County. Tooth orientation: (1-5, 6a) labial view; (6b) apical view. Scale line = 1 mm.**

Superfamily HYBODONTOIDEA Zangerl 1981
Family POLYACRODONTIDAE Gluckman 1964

LISSODUS ANITAE

Chronologic Range: **Albian** | Occurrence: **Rare** | Maximum Size: **1.6 mm**

Genus ***Lissodus*** Brough 1935
Lissodus anitae (Thurmond 1971)

DESCRIPTION: Teeth very small, generally about 1 mm in mesodistal width; crown high, transversely expanded with a weak central cusp and up to three pairs of cusplets; transverse crest of crown more or less continuous and undulating; central labial crown protuberance strong; longitudinal ridges weakly developed labially and absent lingually; crown foot constricted and overhangs root; root flat and more or less perpendicular to crown axis; root anaulacorhizous; histology orthodont.

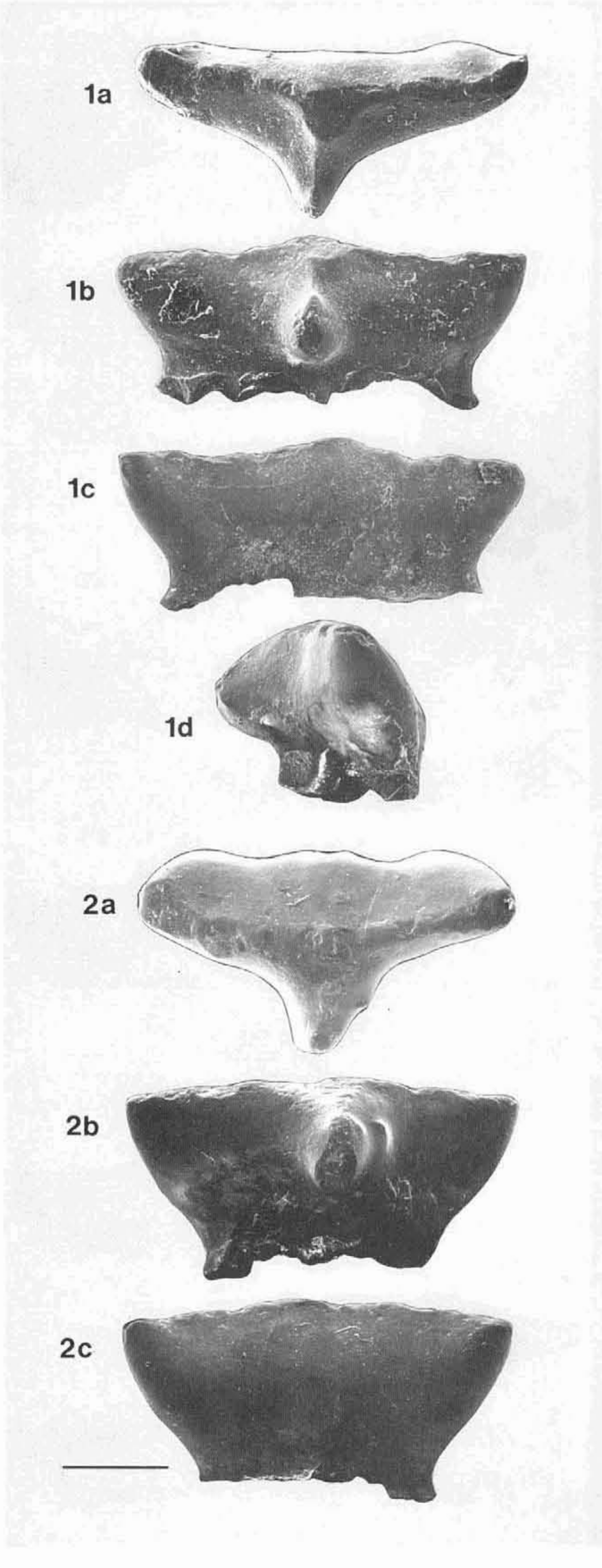
HETERODONTY: Based on the associated dentition of the genotype, *Lissodus africanus* (Broom 1909), the teeth are arranged in an alternate row pattern and several series are functional. Strong gradient monognathic and weak dignathic heterodonty (Duffin 1985).

DISTINGUISHING CHARACTERISTICS: A cuspate transverse crown ridge and extremely small tooth size distinguish *Lissodus anitae* from all other *Lissodus* in Texas. At present, *L. anitae* is the only lower Cretaceous *Lissodus* in Texas.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Paluxy Formation (Albian), Butler Farm Local Fauna, Wise County (Thurmond 1971).

COMMENTS: These teeth are extremely small and can only be collected by bulk sampling and microscopic sorting. This species was originally placed in the genus *Lonchidion* Estes 1964 by Thurmond (1971); however, *Lonchidion* has since been shown to be a junior synonym of the genus *Lissodus* Brough 1935 (Duffin 1985).

REFERENCES: Thurmond (1971); Duffin (1985).

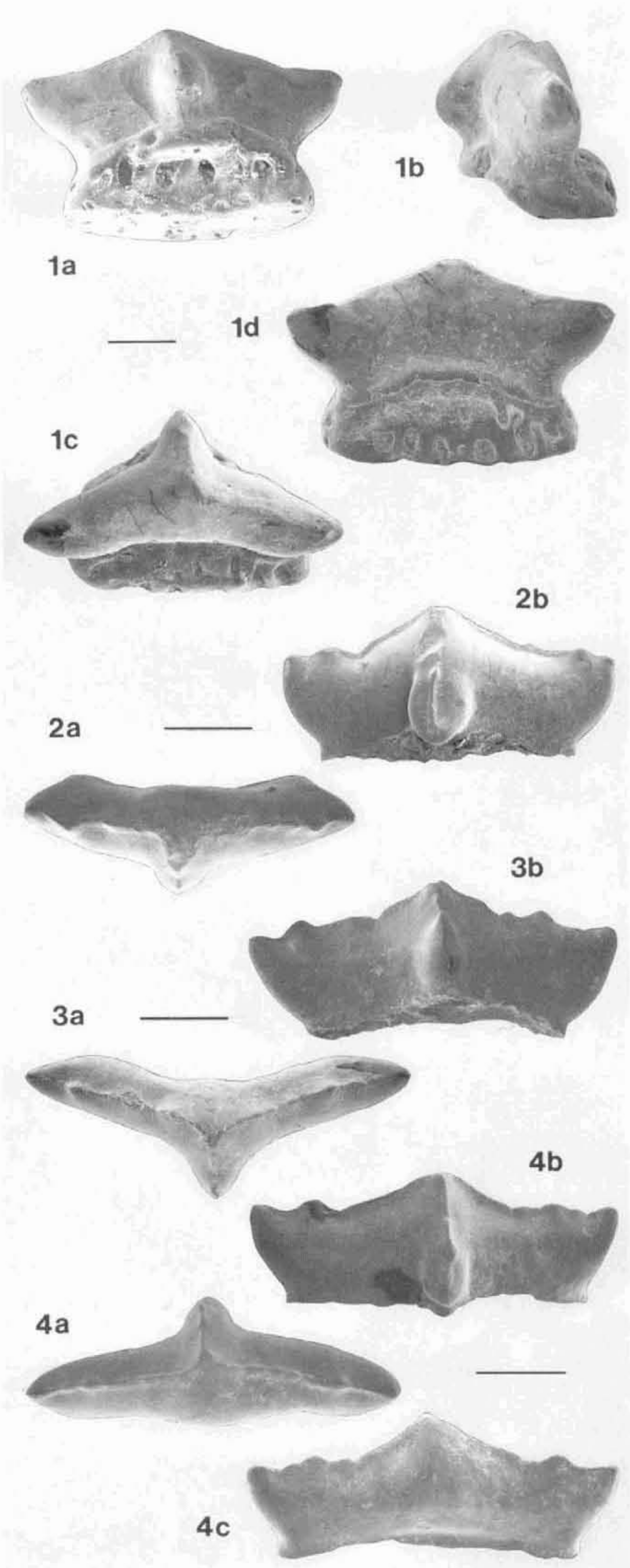


Lissodus anitae **(Thurmond 1971): Worn crowns lacking roots; Paluxy Formation (early Albian), Wise County. Tooth orientation: (1a, 2a) apical view; (1b, 2b) labial view; (1c, 2c) lingual view; (1d) distal. Scale line = 0.5 mm.**

LISSODUS SELACHOS

Superfamily HYBODONTOIDEA Zangerl 1981
Family POLYACRODONTIDAE Gluckman 1964

Maximum Size: **4.5 mm** | Occurrence: **Common** | Chronologic Range: **Campanian**



Genus ***Lissodus*** Brough 1935
Lissodus selachos (Estes 1964)

DESCRIPTION: Teeth with a moderately developed labial crown protuberance; transverse cutting ridge continuous, generally crenulated and bears a number of small or incipient mesial and distal cusplets; cusp low and broadly triangular; apex of cusp connected to the labial crown protuberance by a prominent ridge; lingual crown face below cusp is inflated; labial and lingual crown faces smooth; root anaulacorhizous; histology orthodont.

HETERODONTY: Strong gradient monognathic and weak dignathic heterodonty.

DISTINGUISHING CHARACTERISTICS: The teeth of *Lissodus selachos* can be distinguished from *L. anitae* by their larger size, greater mesodistal width, and lower crown height. Other undescribed Texas species of *Lissodus* have generally smooth, noncuspate crowns.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Aguja Formation, Brewster County (Campanian).

COMMENTS: *Lissodus selachos* was originally described from the Lance Formation, Maestrichtian, of eastern Wyoming (Estes 1964). This species is close to *L. griffisi* Case 1987 from the late Campanian of Wyoming but differs by the presence of well developed and more numerous (up to five) cusplets with a prominent median cusp.

REFERENCES: Estes (1964); Duffin (1985); Case (1987).

***Lissodus selachos* (Estes 1964): (1) complete tooth with a well preserved root; (2-4) crowns lacking roots; Aguja Formation (Campanian), Brewster County. Tooth orientation: (1a, 2b, 3b, 4b) labial view; (1d, 4c) lingual view; (1c, 2a, 3a, 4a) apical view; (1b) distal view. Scale lines = 0.5 mm.**

Chronologic Range: **Cenomanian–Maestrichtian**	Occurrence: **Rare**	Maximum Size: **4 mm**

Genus ***Lissodus*** Brough 1934
Lissodus spp.

DESCRIPTION: At least two additional undescribed species of *Lissodus* occur in the Cretaceous of Texas. Their teeth all lack roots and range from 2 to 4 mm in mesodistal width. Their crowns are low to high, having nearly flat occlusal surfaces in Cenomanian and Maestrichtian forms. Labial and lingual crown faces are smooth, lacking any type of ornamentation, and the labial crown protuberance is of moderate size in Cenomanian teeth and very large in Maestrichtian teeth; roots anaulacorhizous; histology orthodont.

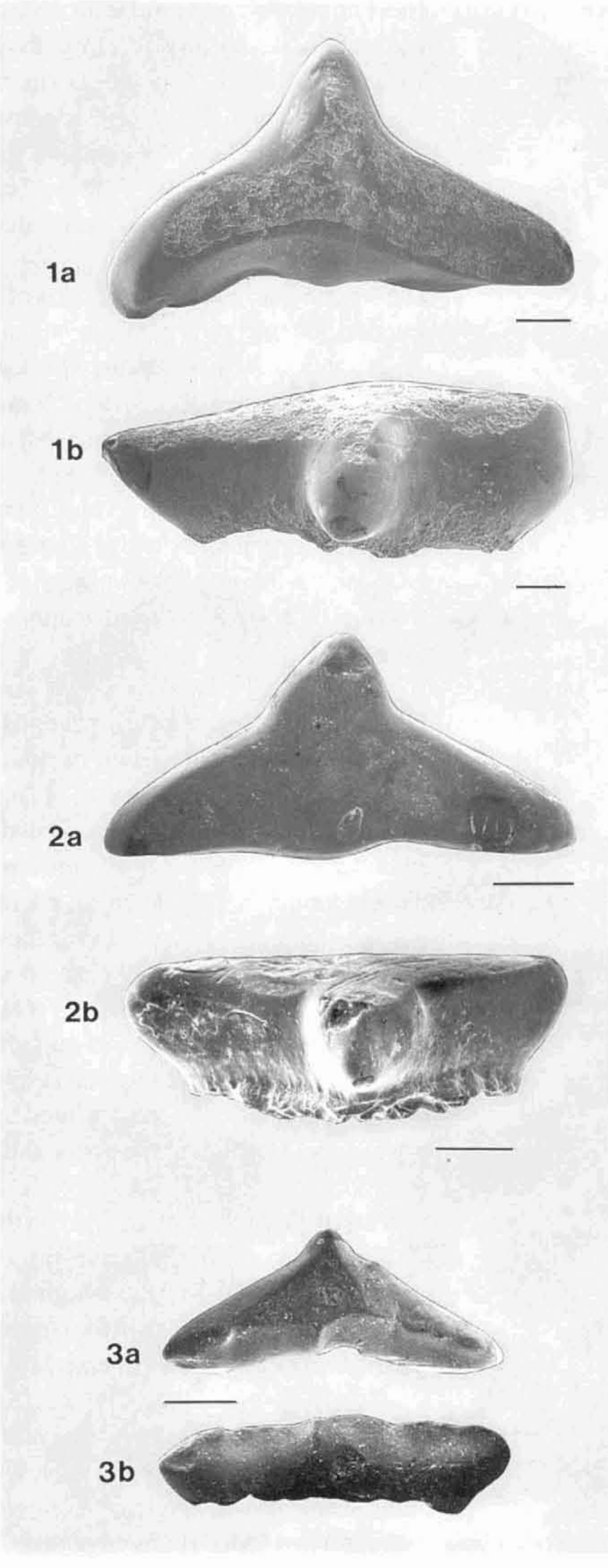
HETERODONTY: Unknown but assumed to be the same as for the other species of *Lissodus*; strong gradient monognathic and weak or absent dignathic heterodonty.

DISTINGUISHING CHARACTERISTICS: Cenomanian Lissodus from the Woodbine Formation differ from *L. anitae, L. selachos,* and *Lissodus* sp.. from the Kemp Formation, in having low crowns and a broad, weakly differentiated labial crown protuberance. Maestrichtian *Lissodus* from the Kemp Formation differ from all other Texas *Lissodus* by having an extremely large and robust lingual crown protuberance. These teeth are comparable in size to *L. selachos* but appear to lack its characteristic cuspate crown.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Woodbine Formation (Cenomanian), Denton and Dallas counties and late Campanian-Maestrichtian, upper Taylor and Kemp formations, Hunt County.

COMMENTS: Undescribed Woodbine and Kemp formation teeth of *Lissodus* are clear evidence that further study will reveal a diverse hybodont fauna in the Texas Upper Cretaceous. These teeth are part of the microfauna, which can only be collected through bulk sampling, sieving and microscopic sorting of concentrated residues. Teeth of *Lissodus* appear to be especially common in sediments of fresh and brackish water origin.

REFERENCES: Duffin (1985).



***Lissodus* spp.: (1-2) Navarro Group, Kemp Formation (Maestrichtian), Hunt County; (3) SMUSMP 63192, Lewisville Member, Woodbine Formation (Cenomanian), Denton County. Tooth orientation: (1a, 2a, 3a) occlusal view; (1b, 2b, 3b) labial view. Scale lines = 0.5 mm.**

Family Ptychodontidae

The Family Ptychodontidae includes the well known shark genus *Ptychodus* and two lesser known genera; *Hylaeobatis* from the lower Cretaceous of England and *Steinbachodus* from the Upper Triassic of Southern Germany. Since the mid-1800s, various paleontologists have considered *Ptychodus* to be a bony fish, a ray intermediate between the Dasyatidae and Myliobatidae and, most recently, a shark closely related to living species (neoselachians). We have adopted the view taken by most current students of fossil sharks and place *Ptychodus* among the hybodont sharks with which it shares an anaulacorhizous root structure.

The chronostratigraphic succession of *Ptychodus* in Texas is almost uninterrupted from the Albian (Fredericksburg) through Campanian (Taylor) groups, and worldwide, this exclusively Cretaceous shark has approximately the same geologic range. Among the largest Cretaceous shark teeth from Texas are those of *Ptychodus polygyrus* (Turonian, Eagle Ford Group, Travis County), measuring 52 millimeters in mesodistal width.

Partly articulated vertebrae and numerous complete dentitions are known for a number of *Ptychodus* species; however, those skeletal elements that would contribute the most toward establishing the true relationships of *Ptychodus* (e.g., neurocrania, fin skeletons, presence or absence of a synarcual and features of its jaw articulation and branchial structure) remain unknown.

The teeth of *Ptychodus* are arranged in parallel rows (row-locking configuration) forming a crushing pavement dentition in both upper and lower jaws. A single median row of small symmetrical teeth in the lower jaw, opposed by a median row of much larger symmetrical teeth in the upper dentition, is flanked distally by progressively smaller asymmetrical teeth of anterolateral and posterior rowgroups. The largest teeth in the dentition are found in the upper median tooth row. All teeth have a massive anaulacorhizous root that is weakly bilobate. The crown is large and expanded over the root on all faces. Its apical (occlusal) surface ranges from flat (*P. connellyi*) to highly developed with a prominent cusp (*P. whipplei*) and always bears a series of distinct radiating or transverse enameloid ridges surrounded by a marginal area of varying width. This marginal crown surface may be ornamented with concentric, radial, granular, bifurcating or anastomosing enameloid ridges and bumps. In general, the dentition of *Ptychodus* may be characterized as having moderate gradient monognathic heterodonty and weak dignathic heterodonty (excluding the upper and lower symphysial rowgroups).

Species of *Ptychodus* are defined on the basis of crown shape and cusp development, the number and arrangement of transverse ridges and the relationship of these ridges to the width and ornamentation covering the marginal area. The diagnostic tooth characteristics for each species of *Ptychodus* are best seen in the largest and most symmetrical teeth. These are located in the most central two or three rows in each jaw.

Teeth of the eleven species of *Ptychodus* described herein can be categorized as belonging to one of three morphological types: 1) low or flat crowned (*Ptychodus decurrens, P. latissimus*); 2) intermediate crown height (*P. connellyi, P. polygyrus, P. rugosus,* and *P. occidentalis*); and 3) high crowned forms (*P. mammillaris, P. anonymus, P. mortoni, P. whipplei* and *Ptychodus* sp.).

Superfamily HYBODONTOIDEA Zangerl 1981
Family PTYCHODONTIDAE Jaekel 1898

PTYCHODUS ANONYMUS

Chronologic Range: **Cenomanian-Turonian** | Occurrence: **Common** | Maximum Size: **14 mm**

Genus ***Ptychodus*** Agassiz 1835
Ptychodus anonymus Williston 1900

DESCRIPTION: Teeth usually less than 1 cm in greatest dimension; crown moderately inflated; cusp conical, high and rounded; transition from cusp to marginal area smooth, not angular; approximately twelve fine transverse ridges extend across apex, down sides of cusp, then divide and curl around as they enter marginal area; margin narrow with bumpy granular pattern, not crossed by transverse ridges; deep triangular lingual depression above crown foot; anterolateral teeth low crowned with concentric ridges in marginal area; root anaulacorhizous; histology osteodont.

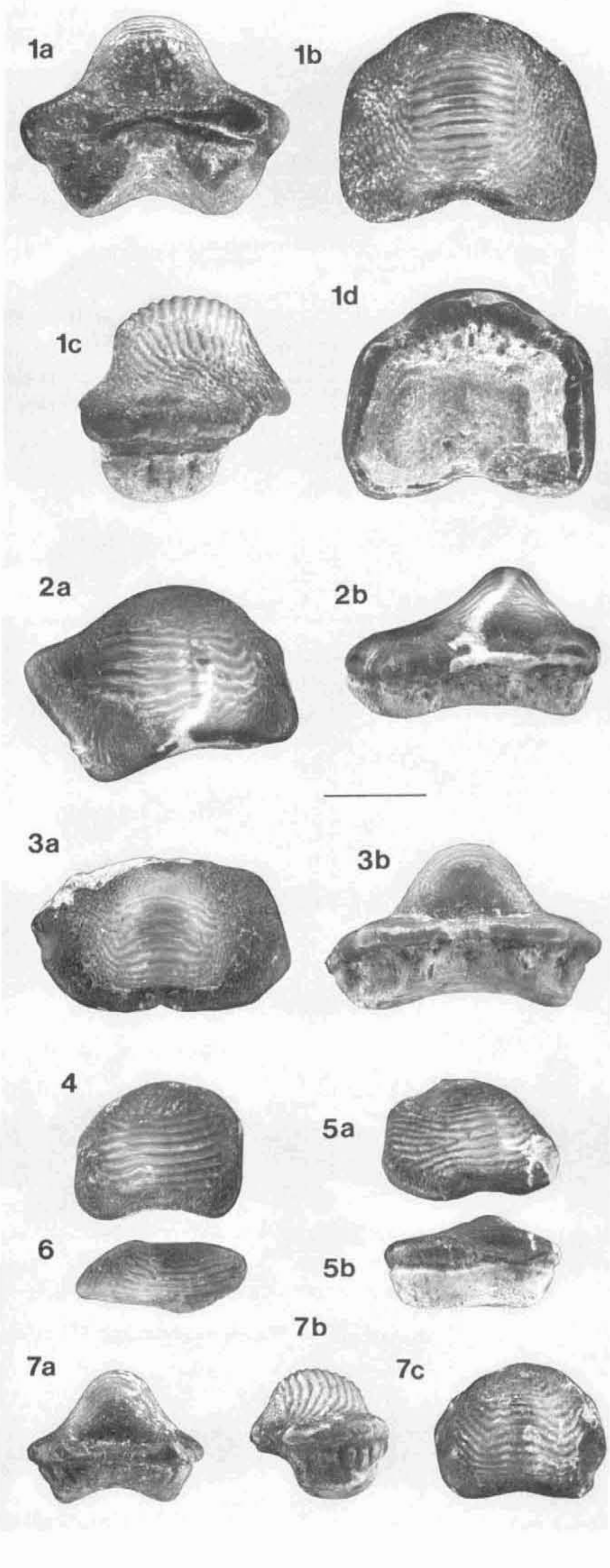
HETERODONTY: Assumed to be typical for the genus.

DISTINGUISHING CHARACTERISTICS: Small tooth size, fine transverse ridges, weakly conical high cusp, gentle transition between cusp and granular marginal area separate this species from other Texas *Ptychodus*.

STRATIGRAPHIC OCCURRENCE IN TEXAS: A very common species in late Cenomanian and Turonian Eagle Ford Group throughout Texas.

COMMENTS: This species was described by Williston (1900) from the Benton Formation of Kansas. Herman (1977) considered it to be a subspecies of *P. mammilaris* (*P. mammilaris anonymus*); however, we believe that it represents a distinct species.

REFERENCES: Williston (1900), Herman (1977).

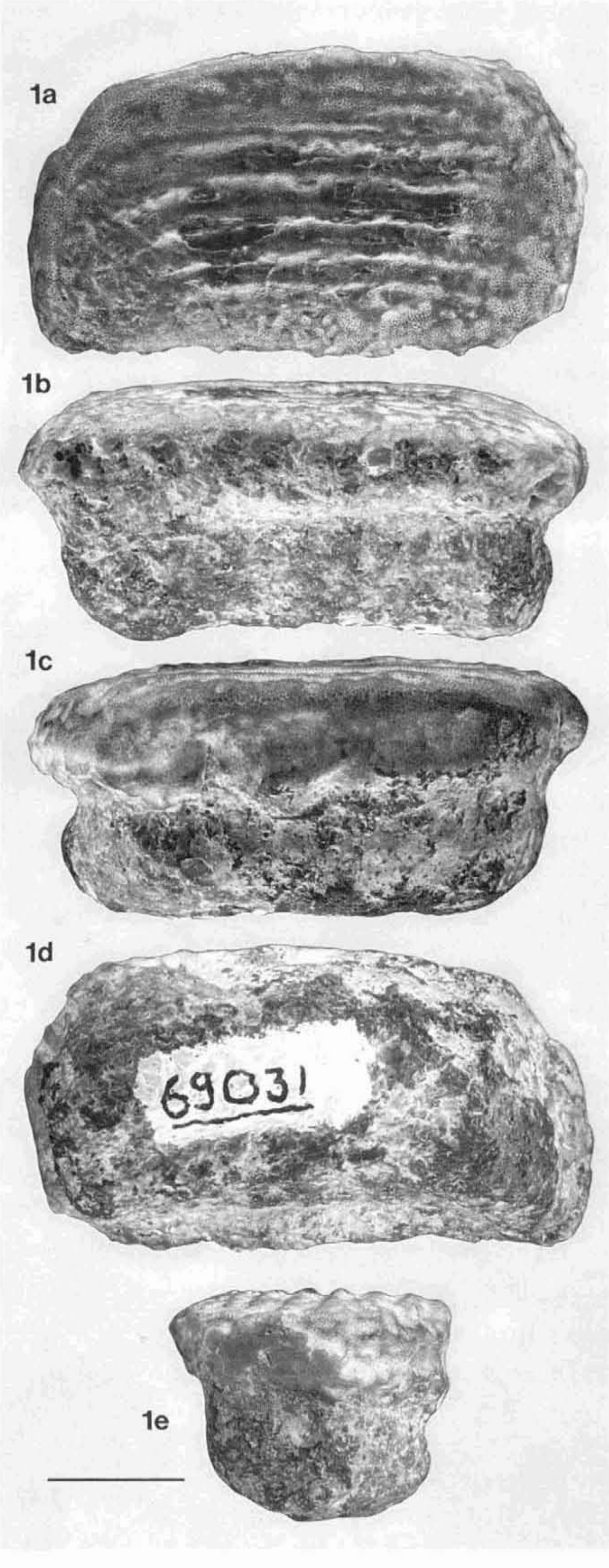


***Ptychodus anonymus* Williston 1900: (1, 7) anterior teeth; (3, 4) lateral teeth; (2, 5, 6) posterior teeth; Bouldin Flags Formation (Cenomanian), Eagle Ford Group, Travis County. Tooth orientation: (1a, 2b, 3b, 5b, 7a) lingual view; (1b, 2a, 3a, 4, 5a, 6, 7c) occlusal view; (1c) distal view; (7b) mesial view; (1d) basal view. Scale line = 5 mm.**

PTYCHODUS CONNELLYI

Superfamily HYBODONTOIDEA Zangerl 1981
Family PTYCHODONTIDAE Jaekel 1898

Maximum Size: **32 mm** Occurrence: **Rare** Chronologic Range: **Campanian**



Genus ***Ptychodus*** Agassiz 1835
Ptychodus connellyi Macleod and Slaughter 1980

DESCRIPTION: Species known by one tooth, the holotype; crown extremely flat; no inflation of the occlusal surface; eight thin, nearly straight transverse ridges extend from mesial to distal crown margin and several loop around at their ends, connecting with an adjacent ridge; marginal area very narrow or absent; labial and lingual crown faces flattened, labial face being the widest; root anaulacorhizous; histology osteodont.

HETERODONTY: Details unknown; row-group pattern assumed to be typical for the genus.

DISTINGUISHING CHARACTERISTICS: An extremely flat occlusal crown face, a very narrow marginal area (or its absence), numerous transverse ridges, some of which loop at their ends distinguish this species from all other Texas *Ptychodus*.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Roxton Member of the Gober Chalk (Campanian), Fannin County.

COMMENTS: *Ptychodus connellyi* is known with certainty by only one tooth, the holotype. Several incomplete teeth from the early Campanian Ozan Formation in Ellis County may be referable to this species. *Ptychodus connellyi* represents one of the youngest known occurrences for the genus, which became extinct worldwide by the end of the Campanian.

REFERENCES: MacLeod and Slaughter (1980).

Ptychodus connellyi **Macleod and Slaughter 1980: Holotype, SMUSMP 69031; Roxton Member of the Gober Chalk (Campanian), Fannin County. Tooth orientation: (1a) occlusal view; (1b) lingual view; (1c) labial view; (1d) basal view; (1e) distal view. Scale line = 1 cm.**

Superfamily HYBODONTOIDEA Zangerl 1981
Family PTYCHODONTIDAE Jaekel 1898

PTYCHODUS DECURRENS

Chronologic Range: **Late Albian-Cenomanian** Occurrence: **Rare** Maximum Size: **29 mm**

Genus ***Ptychodus*** Agassiz 1835
Ptychodus decurrens Agassiz 1843

DESCRIPTION: A low crowned species of *Ptychodus* with roughly rectangular and mesodistally elongated teeth in medial and anterior-most rows of anterolateral teeth; crowns moderately flattened to convex in anterolateral rowgroups, less convex in more distal anterolaterals; large symmetrical upper medial and anterolateral teeth in both jaws have about ten strong transverse ridges; number of ridges decreases to five or six in more distal anterolateral rowgroups; distal ends of transverse ridges bifurcate within the marginal area and new smaller and finer ridges form between them; all ridges extend across the marginal area and lie perpendicular to the crown edges; root anaulacorhizous; histology osteodont.

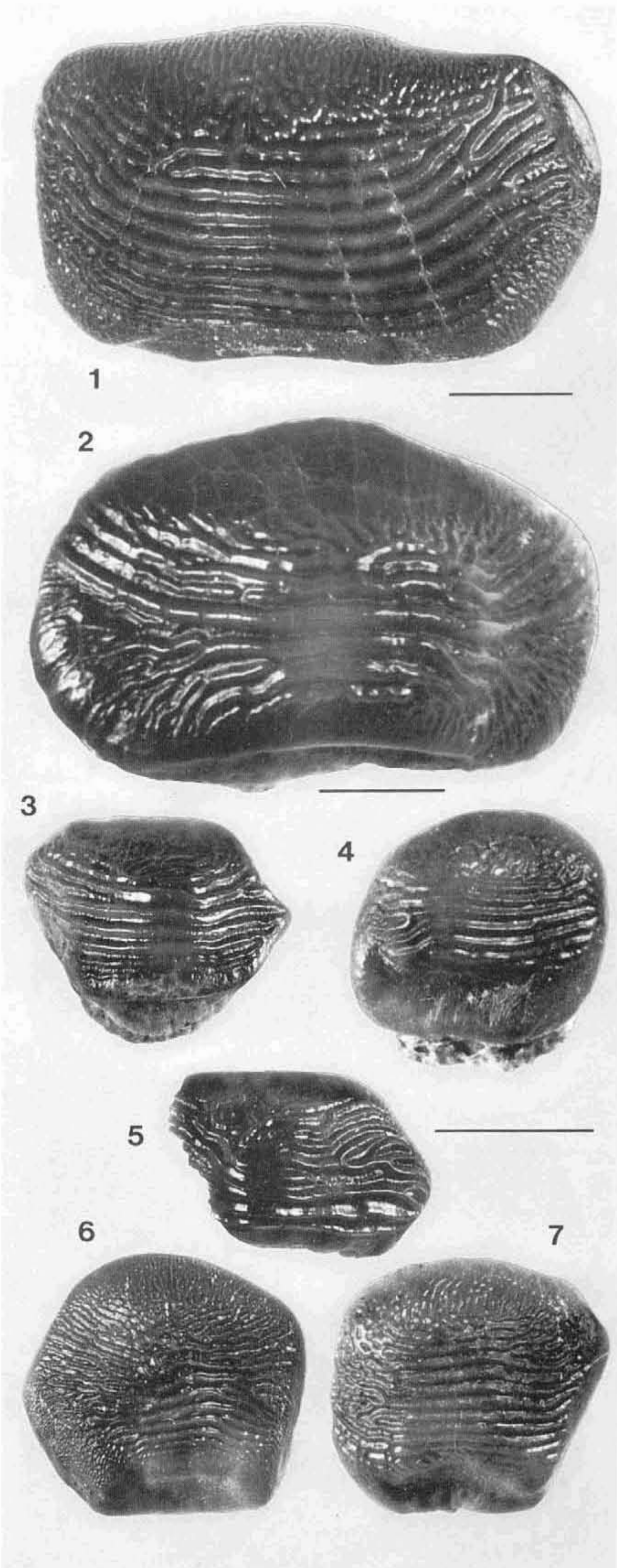
HETERODONTY: Strong disjunct monognathic and weak dignathic heterodonty (except for upper medial rowgroup) with medial, anterolateral and posterior rowgroups.

DISTINGUISHING CHARACTERISTICS: *Ptychodus decurrens* differs from all other Texas *Ptychodus*, except *P. occidentalis*, in having the distal ends of the transverse ridges and marginal area ridges oriented perpendicular to the crown border. *P. decurrens* never develops the high, inflated crown typical of *P. occidentalis*.

STRATIGRAPHIC OCCURRENCE IN TEXAS: This species is found in the Walnut, Duck Creek, Weno, Pawpaw and Grayson formations (Albian), the Pepper Formation (Cenomanian) of Texas and in the Cenomanian formation of the Eagle Ford Group.

COMMENTS: Numerous European subspecies and varieties of *Ptychodus decurrens* have been described since the mid 1800s. The nomenclature of this species "complex" requires careful reconsideration and the taxonomy adopted here is conservative. With the exception of *P. anonymus*, most of the Texas *Ptychodus* of Cenomanian age and all Albian teeth are referable to *P. decurrens*. Teeth of this species are never common.

REFERENCES: Dibly (1911); Woodward (1911); Herman (1977).

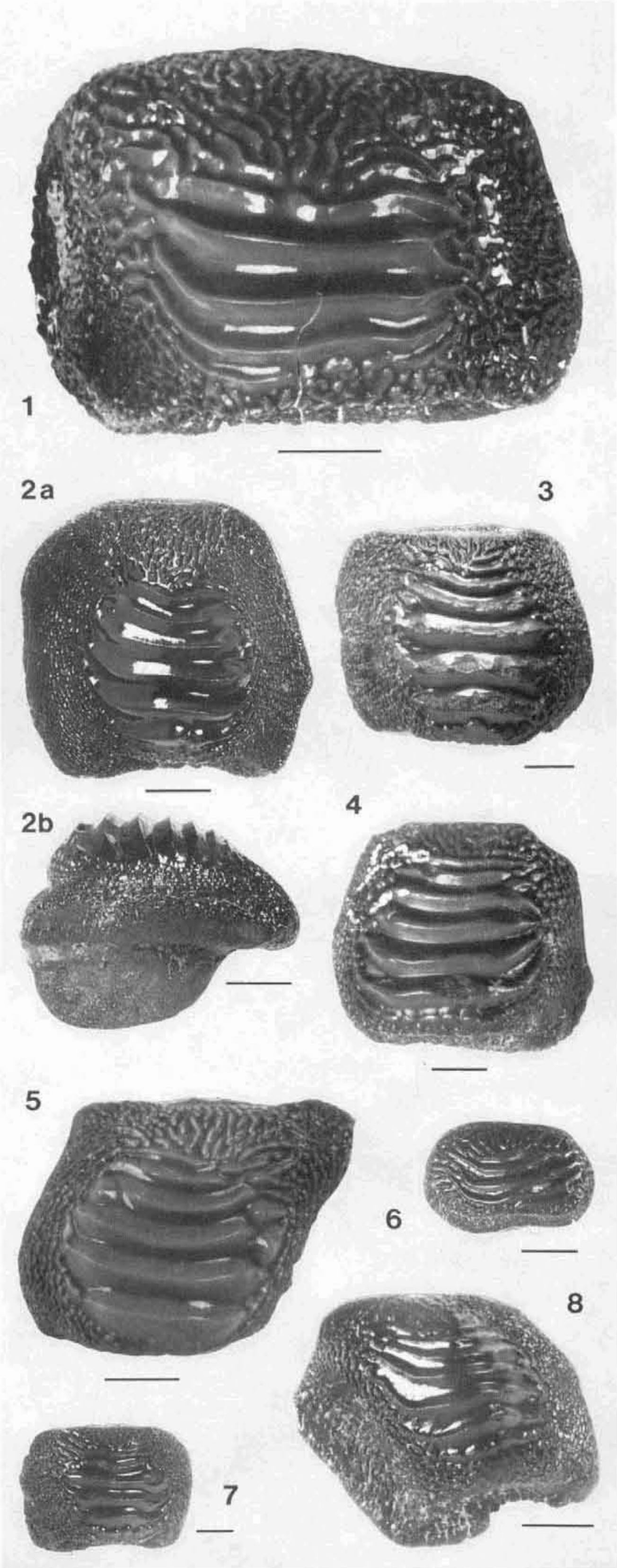


Ptychodus decurrens **Agassiz 1843: Weno Formation (Albian), Tarrant County; (1-2, 6-7) anterolateral teeth; (3-5) posterior teeth. Tooth orientation: (1-7) occlusal views. Scale lines = 2 mm (1, 2) and 0.5 mm (3-7).**

PTYCHODUS LATISSIMUS

Superfamily HYBODONTOIDEA Zangerl 1981
Family PTYCHODONTIDAE Jaekel 1898

Maximum Size: **30 mm** Occurrence: **Common** Chronologic Range: **Coniacian-early Campanian**



Genus ***Ptychodus*** Agassiz 1835
Ptychodus latissimus Agassiz 1843

DESCRIPTION: *Ptychodus* teeth with moderately domed crowns; distinct cusp absent; five or six short, massive transverse ridges with tapered ends and slight curvature; marginal area very wide, covered by a rugose or granular texture lacking a distinct pattern; root anaulacorhizous; histology osteodont.

HETERODONTY: Complete dentitions of *Ptychodus latissimus* are not known from Texas but it is assumed to have a general dental pattern typical for the genus.

DISTINGUISHING CHARACTERISTICS: The presence of five or six strong and very distinct transverse ridges, very wide granular marginal area, and weakly inflated crown are attributes of this species which readily separate it from all other Texas *Ptychodus*.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Basal Atco Formation (Coniacian) of the Austin Group (contact horizon) throughout Texas and possibly the basal Ozan Formation (Taylor Group-early Campanian), Ellis County.

COMMENTS: Almost all of the Texas occurrences of this distinctive species are from the basal Atco Formation of the Austin Group (contact horizon).

REFERENCES: Herman (1977).

Ptychodus latissimus **Agassiz 1843: Contact horizon of the Atco Formation (Coniacian), Austin Group, Dallas County; (1-5, 7, 8) anterolateral teeth; (6) posterior tooth. Tooth orientation: (1, 2a, 3-8) occlusal views; (2b) distal view. Scale lines = 5 mm.**

Superfamily HYBODONTOIDEA Zangerl 1981
Family PTYCHODONTIDAE Jaekel 1898

PTYCHODUS MAMMILLARIS

Chronologic Range: **Early Coniacian** | Occurrence: **Rare** | Maximum Size: **24 mm**

Genus ***Ptychodus*** Agassiz 1835
Ptychodus mammillaris Agassiz 1835

DESCRIPTION: Teeth moderately large; cusp high, squared-off and flattened on the occlusal surface; six to ten prominent, regularly spaced, transverse ridges extend across and down the sides of the cusp where they wrap around and merge in a concentric pattern with the marginal area; transition from cusp to marginal area subangular; marginal ornamentation granular to granular ridges arranged in a concentric pattern; root anaulacorhizous; histology osteodont.

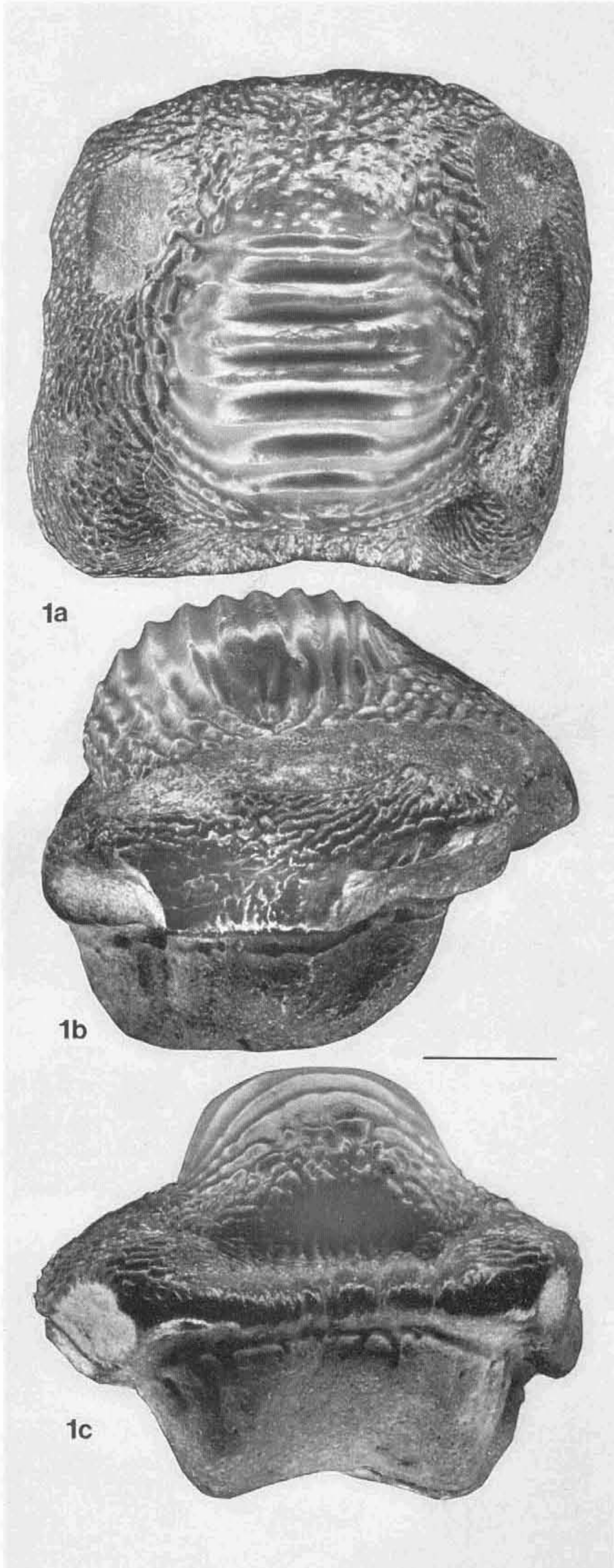
HETERODONTY: Assumed to be typical for the genus. Associated or natural tooth sets of *Ptychodus mammillaris* are unknown from Texas.

DISTINGUISHING CHARACTERISTICS: The presence of a distinct flattening of the occlusal cusp face in upper and lower anterolateral and upper medial teeth, in combination with a concentric pattern on the marginal area, separate these teeth from those of other high crowned species (e.g., *Ptychodus whipplei*, *Ptychodus anonymus* and *Ptychodus* sp.).

STRATIGRAPHIC OCCURRENCE IN TEXAS: Basal Atco Formation of the Austin Group (contact horizon), early Coniacian, throughout Texas.

COMMENTS: Teeth of this species are rare in Texas, although some paleontologists consider *Ptychodus anonymus* to be a junior synonym or subspecies of *Ptychodus mammillaris*.

REFERENCES: Herman (1977).

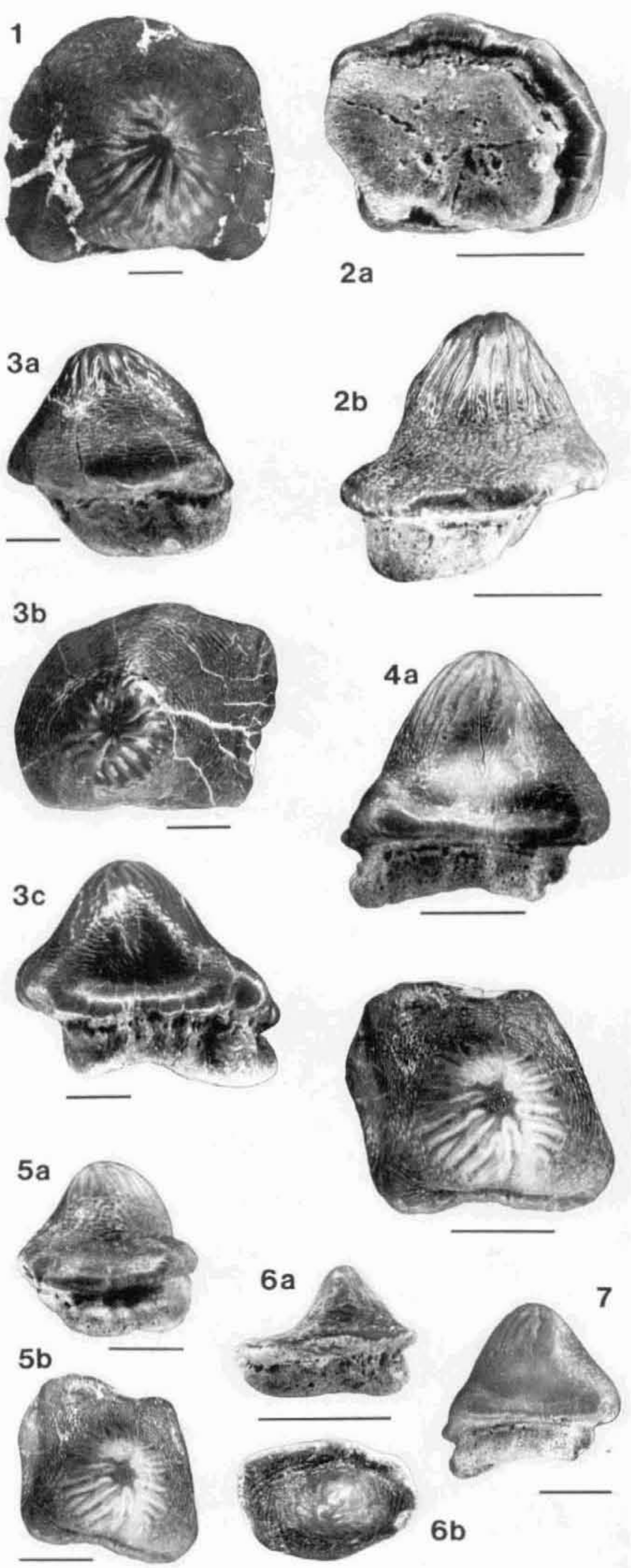


***Ptychodus mammillaris* Agassiz 1835: Contact horizon of the Atco Formation (Coniacian), Austin Group, Dallas County; anterior tooth. Tooth orientation: (1a) occlusal view; (1b) distal view; (1c) lingual view. Scale line = 5 mm.**

PTYCHODUS MORTONI

Superfamily HYBODONTOIDEA Zangerl 1981
Family PTYCHODONTIDAE Jaekel 1898

Maximum Size: **26 mm** | Occurrence: **Rare** | Chronologic Range: **Coniacian-Santonian**



Genus ***Ptychodus*** Agassiz 1835
Ptychodus mortoni Mantell 1839

DESCRIPTION: Teeth with a high conical cusp having a sharp apex; crown ridges strong, radiating in all directions from the apex and terminating basally just above or at the intersection with the marginal area; cusp-crown intersection subangular to subrounded; marginal area wide, finely granular with a concentric pattern around cusp; root anaulacorhizous; histology osteodont.

HETERODONTY: *Ptychodus mortoni* has a rowgroup pattern typical for the genus with upper and lower medial, anterolateral and posterior rowgroups. This interpretation is based on observation of associated dentitions from the Austin Group in Texas and comparison with complete dentitions from the Cretaceous Niobrara Chalk of Kansas.

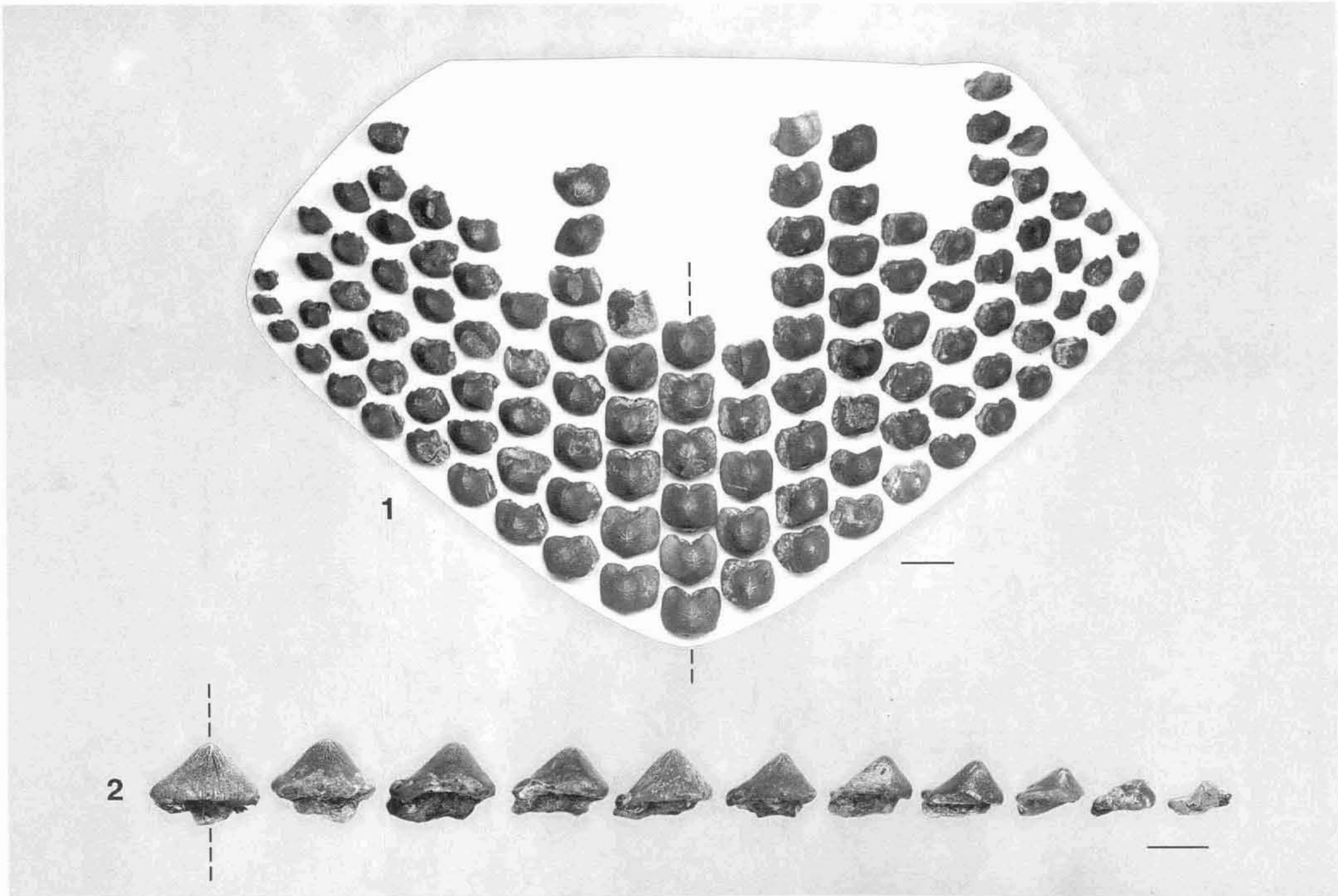
DISTINGUISHING CHARACTERISTICS: The teeth of *Ptychodus mortoni* are easily distinguished from all other Texas species of *Ptychodus* by the presence of high conical cusp with radiating occlusal ridges.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Austin Group (Coniacian-Santonian) throughout Texas.

COMMENTS: Isolated teeth of *Ptychodus mortoni* occur most commonly in the basal Atco Formation (contact horizon) of the Austin Group. Associated dentitions, like the one figured on the next page, have been collected higher in the formation.

REFERENCES: Williston (1900).

***Ptychodus mortoni* Mantell 1839: Contact horizon of the Atco Formation (Coniacian), Austin Group, Travis County; (1-5, 7) anterolateral teeth; (6) posterior tooth. Tooth orientation: (2a) basal view; (3c, 4a, 7) lingual view; (1, 3b, 4b, 5b, 6b) occlusal view; (3a, 5a) mesial views; (2b, 6a) distal views. Scale lines = 5 mm.**

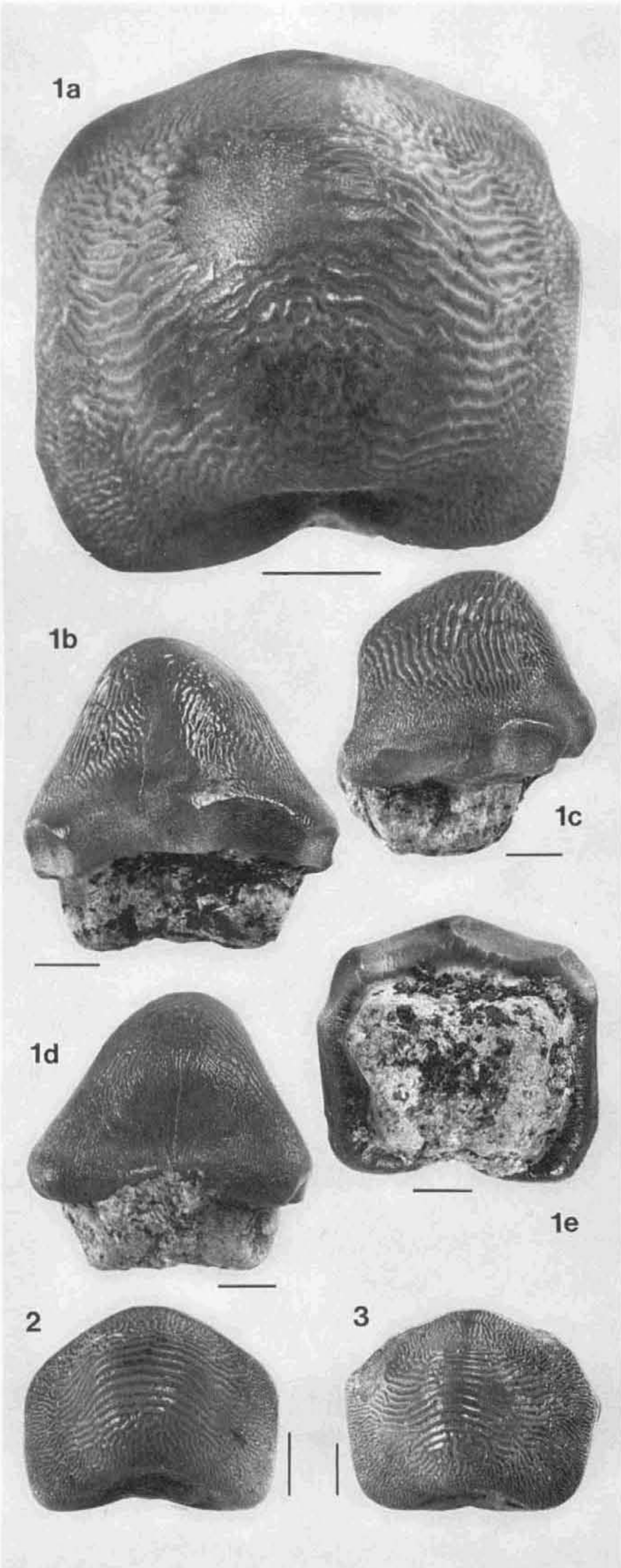


Ptychodus mortoni **Mantell 1839: Reconstructed upper (palatoquadrate) dentition based on an associated specimen from the Atco Formation (Coniacian) of the Austin Group, Dallas County. (1) upper left and right dentition; (2) lingual view of an upper left dental series. Dashed line indicates position of jaw symphysis. Scale line = 2 cm.**

PTYCHODUS OCCIDENTALIS

Superfamily HYBODONTOIDEA Zangerl 1981
Family PTYCHODONTIDAE Jaekel 1898

Maximum Size: **14 mm** | Occurrence: **Rare** | Chronologic Range: **Cenomanian-Turonian**



Genus ***Ptychodus*** Agassiz 1835
Ptychodus occidentalis Leidy 1868

DESCRIPTION: Close to *P*tychodus *decurrens* but having a high bulbous crown lacking or having a very poorly developed cusp; transverse ridges numerous and very fine, numbering about ten in large upper medial and mesial-most anterolateral tooth rows; as in *P. decurrens*, the transverse ridges bifurcate numerous times distally, grading into finer and finer parallel to subparallel ridges which are oriented perpendicular to the crown border, within the marginal area; root anaulacorhizous; histology osteodont.

HETERODONTY: Associated dentitions of *Ptychodus occidentalis* are unknown. It is assumed that this species has a dental heterodonty similar to other high crowned species of *Ptychodus*.

DISTINGUISHING CHARACTERISTICS: A high, bulbous crown in combination with very fine transverse ridges which extend across the marginal area, at right angles to the crown border, separate *Ptychodus occidentalis* from *Ptychodus decurrens* and all other Texas species of *Ptychodus*.

STRATIGRAPHIC OCCURRENCE IN TEXAS: This species is known from the Eagle Ford Group (Cenomanian-Turonian) in Travis, Bell, Dallas and Denton counties; it probably occurs throughout the Eagle Ford Group strata in Texas.

COMMENTS: In Texas, only two species of *Ptychodus* have transverse ridges that extend and bifurcate across the marginal area and are oriented perpendicular to the crown border – *P. decurrens* and *P. occidentalis*. As noted, the latter species is distinguished from *P. decurrens* by its high, bulbous crown. Numerous subspecies of *P. decurrens* have been described in the European Cretaceous. Their validity and relationships to Texas material remain to be studied.

REFERENCES: Leidy (1868).

Ptychodus occidentalis **Leidy 1868: Bouldin Flags Formation (Cenomanian), Eagle Ford Group, Travis County. Tooth orientation: (1a, 2, 3) occlusal view; (1d) lingual view; (1b) labial view; (1c) distal view; (1e) basal view. Scale lines = 5 mm.**

Subfamily HYBODONTOIDEA Zangerl 1981
Family PTYCHODONTIDAE Jaekel 1898

PTYCHODUS POLYGYRUS

Chronologic Range: **Turonian** | Occurrence: **Rare** | Maximum Size: **52 mm**

Genus ***Ptychodus*** Agassiz 1835
Ptychodus polygyrus Agassiz 1839

DESCRIPTION: The largest *Ptychodus* teeth in Texas belong to this rare species; crown roughly pentagonal to rectangular in outline, moderately inflated, lacking a pronounced cusp; transverse ridges moderately strong, discontinuous, somewhat wavy, and their distal ends terminate in concentric ridges in the marginal area; marginal area covered by granular texture and may show a weak concentric pattern near the terminal ends of the transverse ridges; root anaulacorhizous; histology osteodont.

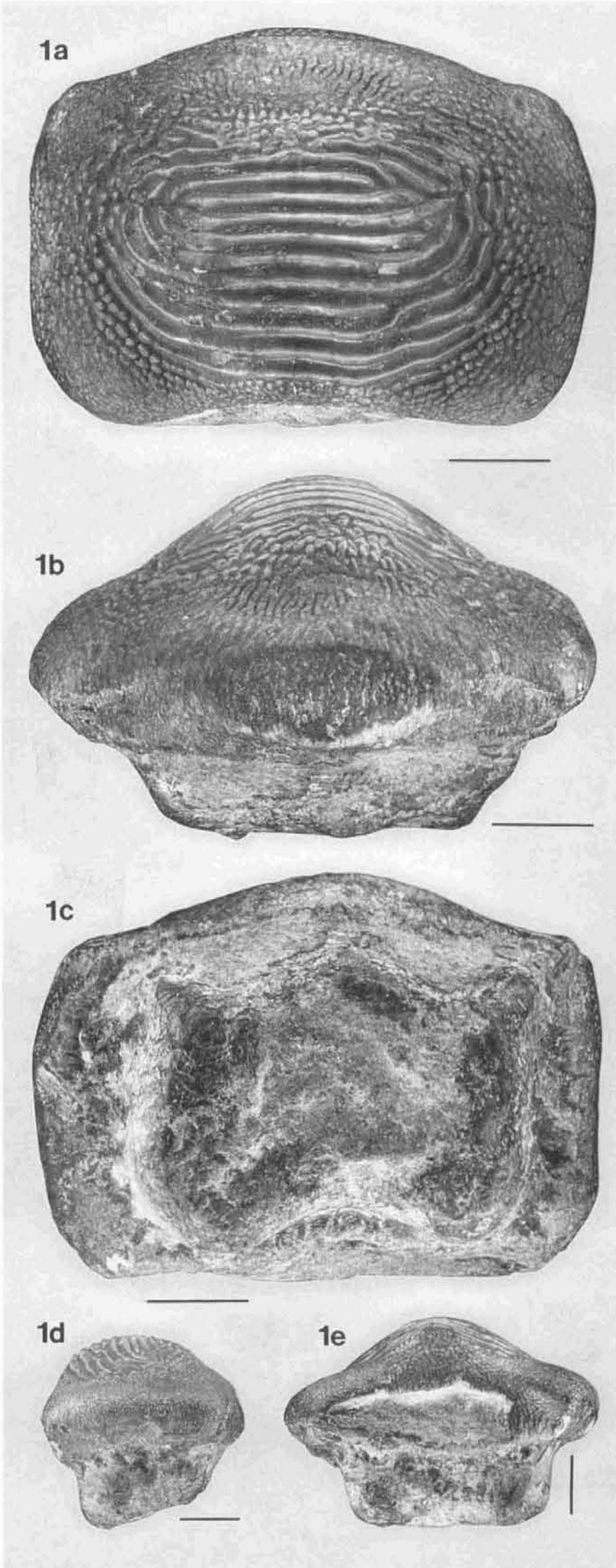
HETERODONTY: Tooth row-group heterodonty typical for the genus.

DISTINGUISHING CHARACTERISTICS: This species is characterized by having a weakly inflated occlusal crown face, eight or nine strong transverse ridges and a tendency to develop a concentric pattern within the marginal area. *Ptychodus polygyrus* is most easily confused with *P. latissimus*, from which it differs in having numerous fine transverse ridges and a much narrower marginal area having a concentric pattern.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Turonian formations of the Eagle Ford Group throughout Texas and especially in the Kamp Ranch Limestone, Dallas County.

COMMENTS: These teeth are most commonly found by carefully splitting and examining fossiliferous slabs of the Kamp Ranch Limestone of the Eagle Ford Group. This species occurs in the Cretaceous of Kansas and Alabama. European teeth of *P. polygyrus* are known to exceed 80 mm in mesodistal width.

REFERENCES: Williston (1900); Applegate (1970); Herman (1977).

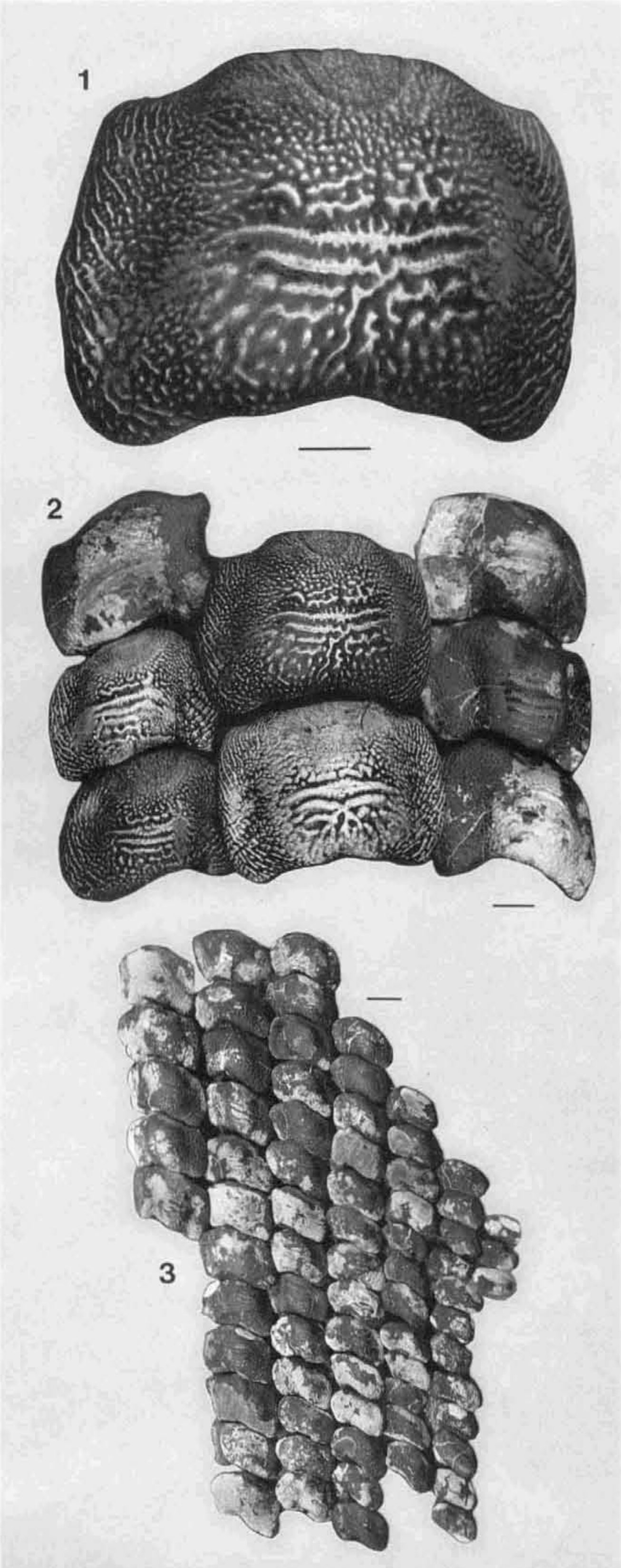


Ptychodus polygyrus **Agassiz 1839: TMM Specimen No. 42281-1, Eagle Ford Group (Turonian), Travis County. Tooth orientation: (1a) occlusal view; (1b) labial view; (1c) basal view; (1d) distal view; (1e) lingual view. Scale lines = 1 cm.**

PTYCHODUS RUGOSUS

Superfamily HYBODONTOIDEA Zangerl 1981
Family PTYCHODONTIDAE Jaekel 1898

Maximum Size: **46 mm** | Occurrence: **Rare** | Chronologic Range: **Santonian**



Genus ***Ptychodus*** Agassiz 1835
Ptychodus rugosus Dixon 1850

DESCRIPTION: A large species of *Ptychodus* having teeth with a broadly rounded, elevated cusp; approximately six irregular, wavy and very discontinuous transverse ridges cross the cusp and do not extend onto the marginal area; only one or two ridges are continuous across the cusp; marginal area has a weakly concentric granular pattern and the entire crown surface has a very "rugose" appearance; root anaulacorhizous; histology osteodont.

HETERODONTY: MacLeod (1982) described a complete upper and lower dentition of *Ptychodus rugosus* from the Austin Group in Dallas County. The specimen consists of an associated and articulated dentition (natural tooth set) having 206 upper teeth and 347 lower teeth. The upper dentition has one median row of large teeth, flanked by eight rows of anterolateral and posterior teeth. The lower dentition has a single, very small row of medials over the mandibular symphysis, flanked by nine rows on either side of anterolateral and posterior teeth; one row has 27 teeth.

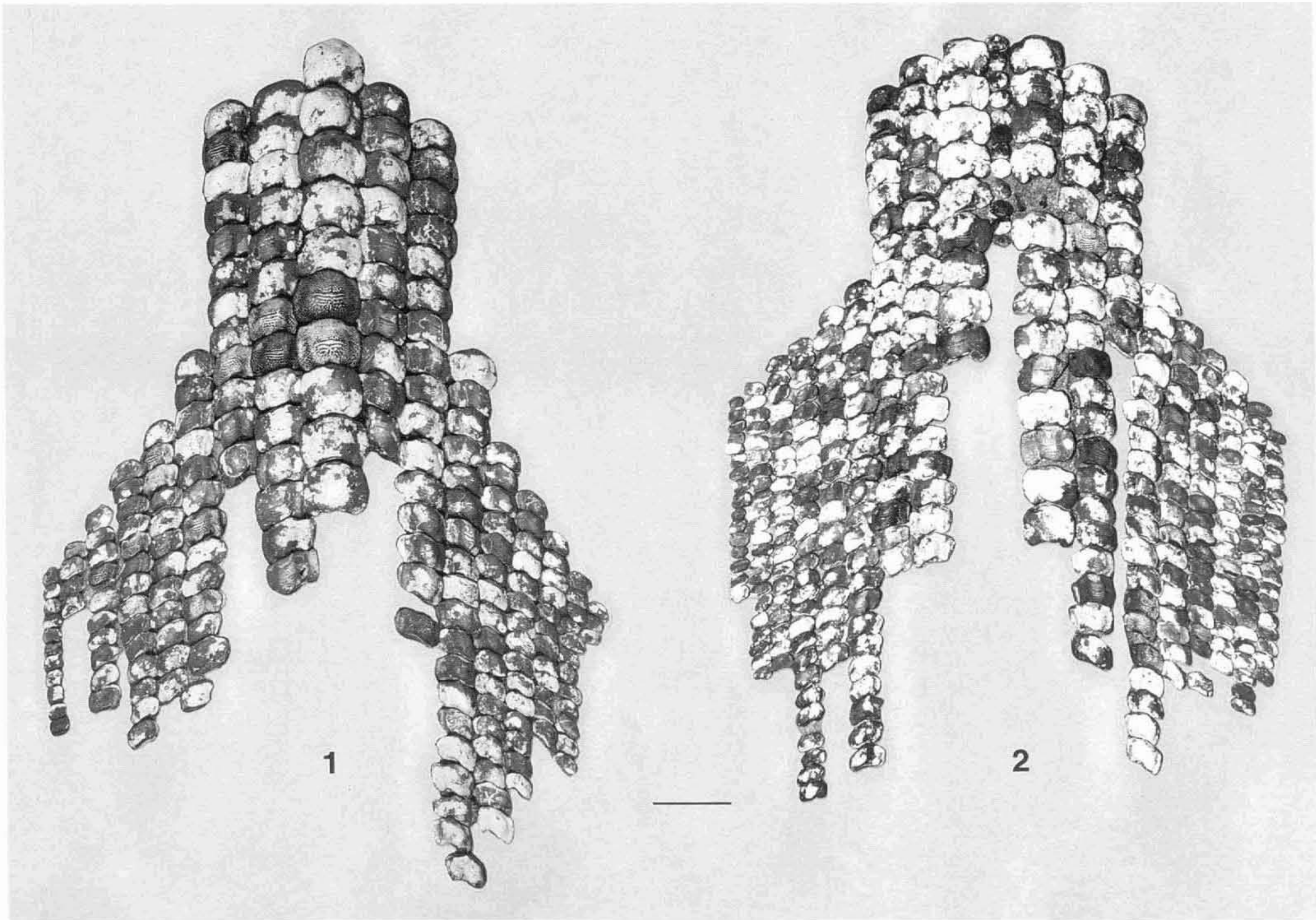
DISTINGUISHING CHARACTERISTICS: This species is characterized by its distinctive pattern of discontinuous, rugose, transverse ridges and moderate cusp development.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Austin Group (Santonian), Dallas County.

COMMENTS: MacLeod's 1982 description of this Santonian species from the Austin Group is its only known Texas occurrence. The teeth of P. rugosus are very distinctive and its apparent absence from rocks both older and younger than Santonian in Texas is consistent with its restricted Santonian age in Western Europe. Although it seems unusual that the only known specimen of *P. rugosus* from Texas is a complete upper and lower dentition (we have not seen any individual, isolated teeth of *P. rugosus*), its rarity can probably be explained by two factors. First, Santonian teeth in Texas are practically unknown because this time period is represented by the relatively unfossiliferous (in terms of elasmobranchs) Austin Group and, secondly, the species is probably rare as well.

REFERENCES: MacLeod (1982).

Ptychodus rugosus **Dixon 1850: SMUSMP Specimen No. 69001, associated teeth from the upper dentition, Austin Group (Santonian), Dallas County; (1) occlusal view of an upper median tooth; (2) occlusal view of upper medial row and two adjacent rows; (3) occlusal view of upper left lateroposterior tooth rows. Scale lines = 1 cm.**

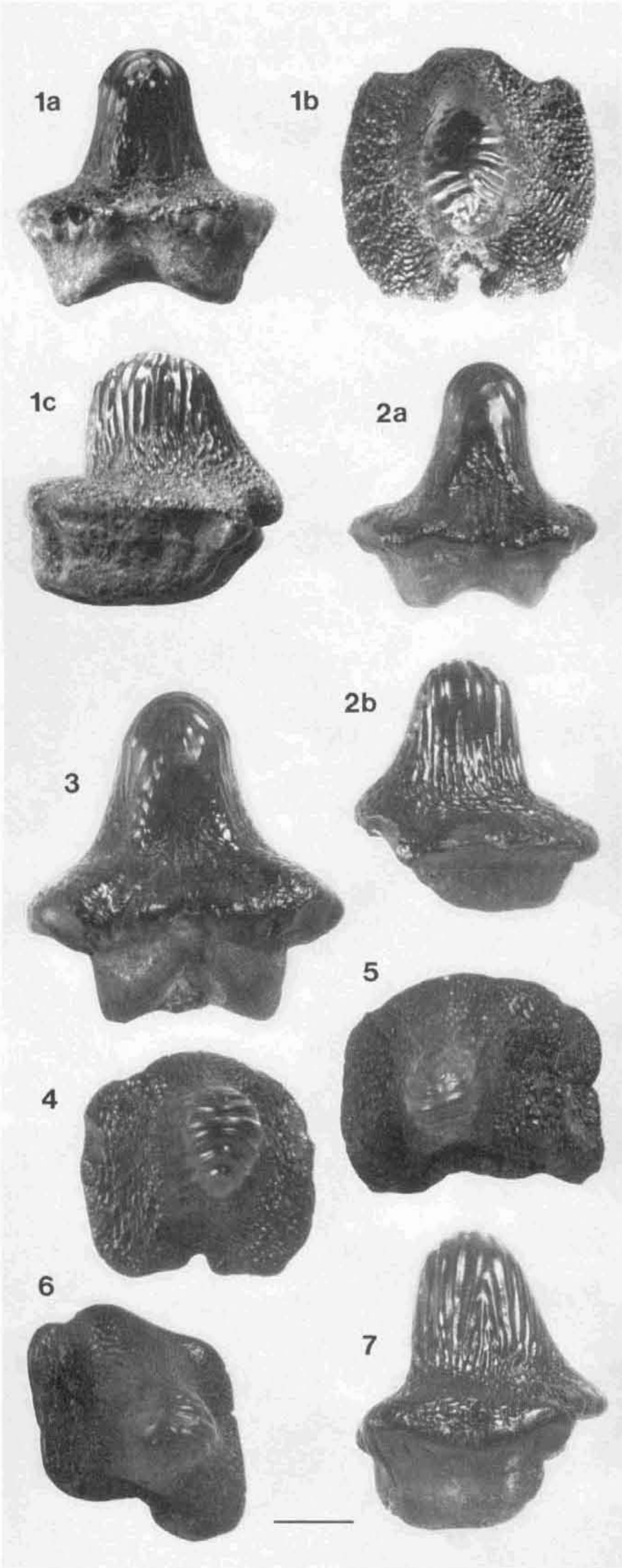


***Ptychodus rugosus* Dixon 1850: Natural tooth sets of (1) the upper dentition (SMUSMP 69001) and (2) the lower dentition (SMUSMP 69002), Austin Group (Santonian), Dallas County. Scale line = 5 cm.**

PTYCHODUS WHIPPLEI

Superfamily HYBODONTOIDEA Zangerl 1981
Family PTYCHODONTIDAE Jaekel 1898

Maximum Size: **29 mm** | Occurrence: **Abundant** | Chronologic Range: **Turonian-Coniacian**



Genus ***Ptychodus*** Agassiz 1835
Ptychodus whipplei Marcou 1858

DESCRIPTION: Intermediate to large size teeth of *Ptychodus* having the highest and most distinctly developed cusp of any Texas species; sides of cusp almost vertical; occlusal face crossed by two to nine parallel transverse ridges which descend part way down the sides; posterior and distal anterolateral teeth have less elevated cusps with strong distal inclination; crown margins are flared and shelf-like with a pronounced basal ledge overhanging the root; marginal area wide, ornamented with closely set prominent granules varying from round to short and irregular tuberculated ridges; pattern of granulations is generally concentric but it may be radial; root anaulacorhizous; histology osteodont.

HETERODONTY: At least three associated partial dentitions of *Ptychodus whipplei* are known from the Cretaceous of Texas. The row-group configuration of this species is typical for the genus. Both upper and lower dentitions display weak disjunct monognathic and dignathic heterodonty except for differences in the upper and lower medial rows.

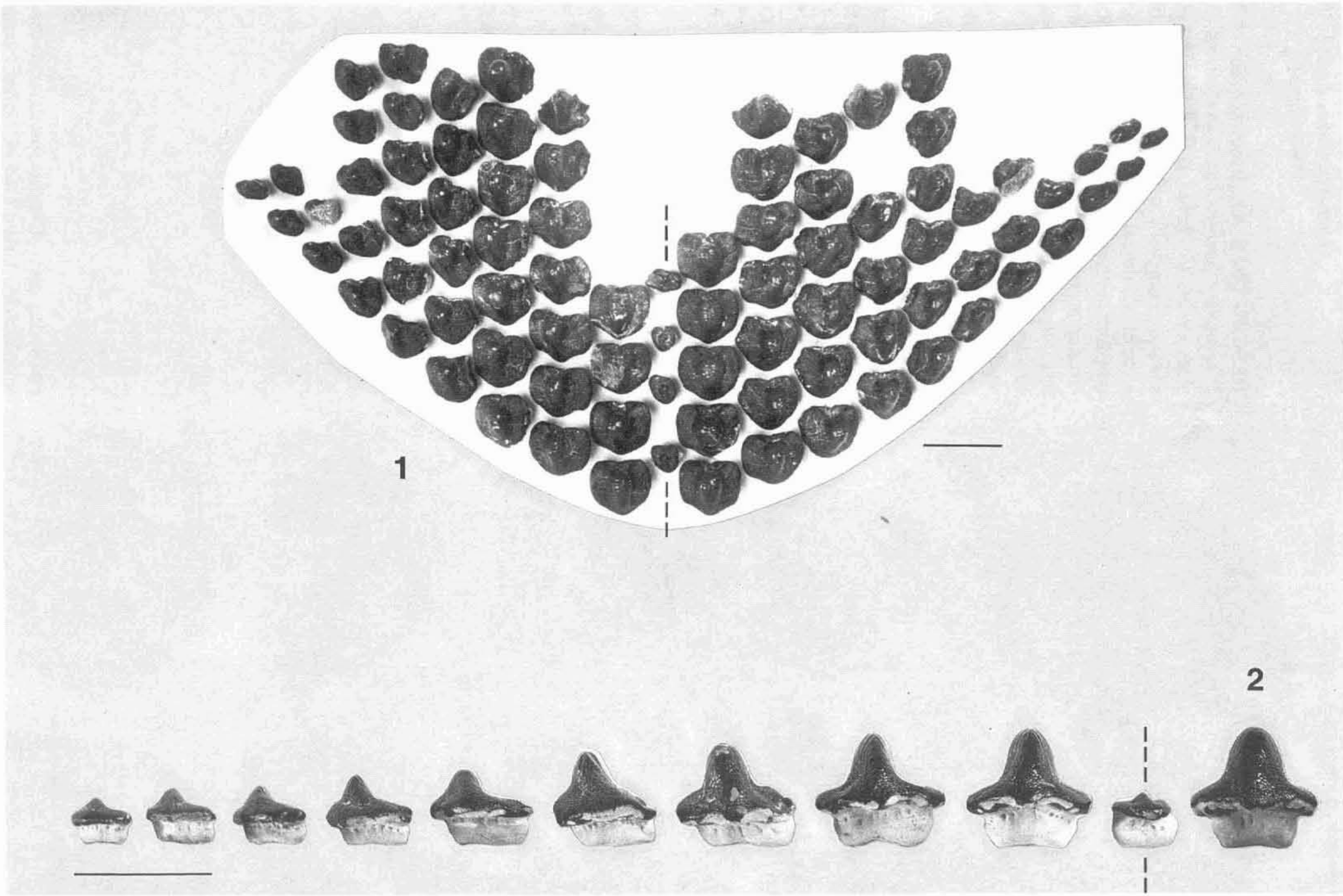
DISTINGUISHING CHARACTERISTICS: The teeth of *Ptychodus whipplei* can be distinguished from all other Texas *Ptychodus* by having an extremely prominent and high cusp with transverse ridges that do not generally reach the marginal area.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Teeth of this species are abundant in Turonian formations of the Eagle Ford Group and in the lower Atco Formation of the Austin Group (Coniacian), wherever exposed in Texas.

COMMENTS: Through time, the teeth of *Ptychodus whipplei* increase in size, attaining their maximum height in the basal Atco Formation of the Austin Group (contact horizon). We have no Texas records of this species in rocks younger than early Coniacian.

REFERENCES: Marcou (1858); Williston (1900); Herman (1977).

***Ptychodus whipplei* Marcou 1858: Contact horizon of the Atco Formation (Coniacian), Austin Group, Dallas County. Tooth orientation: (1a, 2a, 3) lingual view; (1b, 4, 5, 6) occlusal view; (1c, 2b, 7) mesial view. Scale line = 5 mm.**

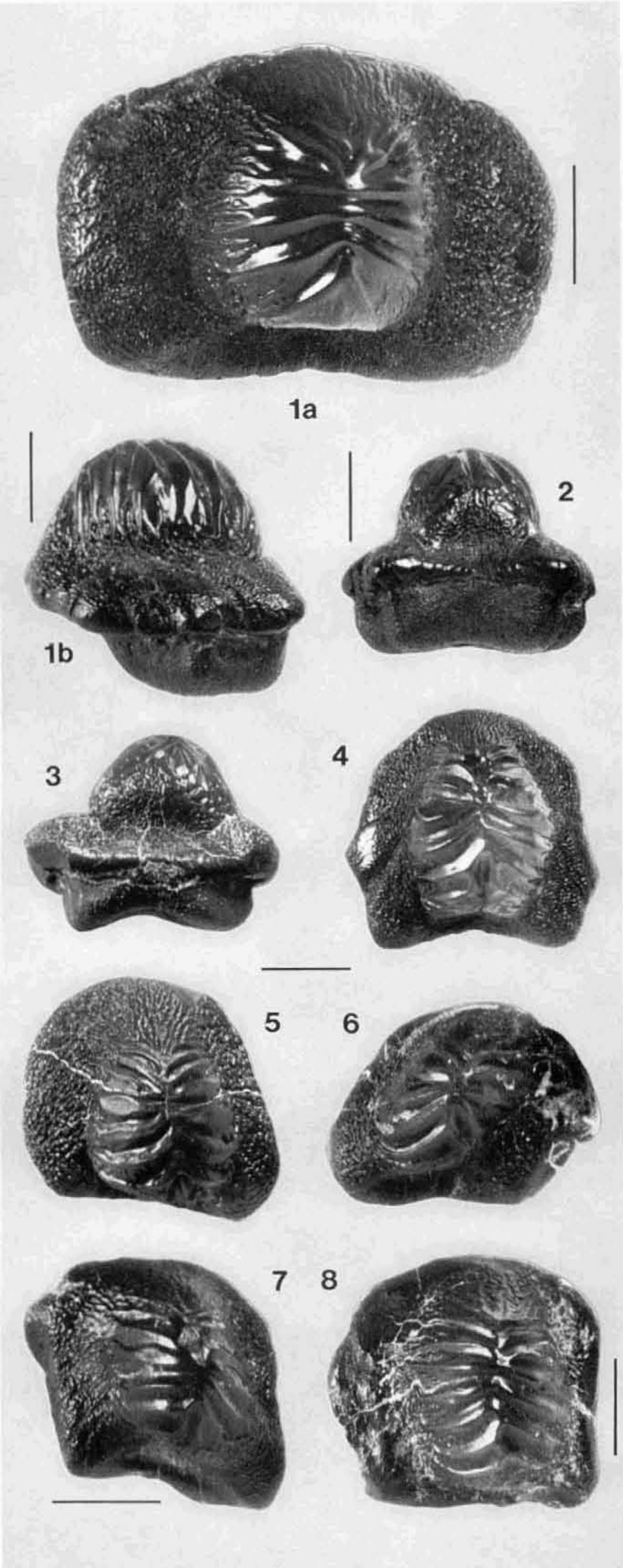


Ptychodus whipplei **Marcou 1858: (1) associated tooth set and (2) complete lower right dental series; Arcadia Park Formation (Turonian), Eagle Ford Group, Dallas County. Dashed line indicates position of jaw symphysis. Scale line = 2 cm.**

PTYCHODUS sp.

Superfamily HYBODONTOIDEA Zangerl 1981
Family PTYCHODONTIDAE Jaekel 1898

Maximum Size: **21 mm** Occurrence: **Common** Chronologic Range: **Coniacian**



Genus ***Ptychodus*** Agassiz 1835
Ptychodus sp.

DESCRIPTION: A high crowned form of *Ptychodus* similar to *P. anonymus*, having an erect, straight-sided cusp; sides of cusp slope steeply to a broad, flaring marginal area, meeting it at a sharp angle lingually, mesially and distally; between five and ten well defined mesial and distal transverse ridges extend from the cusp base, converging apically along a median labiolingual line, creating a very distinctive "chevron" pattern; the first three or four lingual-most transverse ridges converge into a series of labially pointing chevrons; transverse ridges terminate with weakly curved surfaces at the edge of the marginal area; marginal area moderately to coarsely granulated with weakly developed concentric pattern; root anaulacorhizous; histology osteodont.

HETERODONTY: Based on isolated teeth, this taxon appears to have a row-group pattern typical for the genus.

DISTINGUISHING CHARACTERISTICS: A chevron-shaped transverse ridge pattern on the cusp apex, in combination with development of a sharp angle where the cusp meets the marginal shelf are attributes that readily distinguish this species from all other Texas *Ptychodus*.

STRATIGRAPHIC OCCURRENCE IN TEXAS: This undescribed species of *Ptychodus* occurs throughout Texas within the early Coniacian contact horizon of the Atco Formation of the Austin Group.

COMMENTS: This very distinctive species occurs in about the same frequency within the contact horizon as *Ptychodus latissimus*.

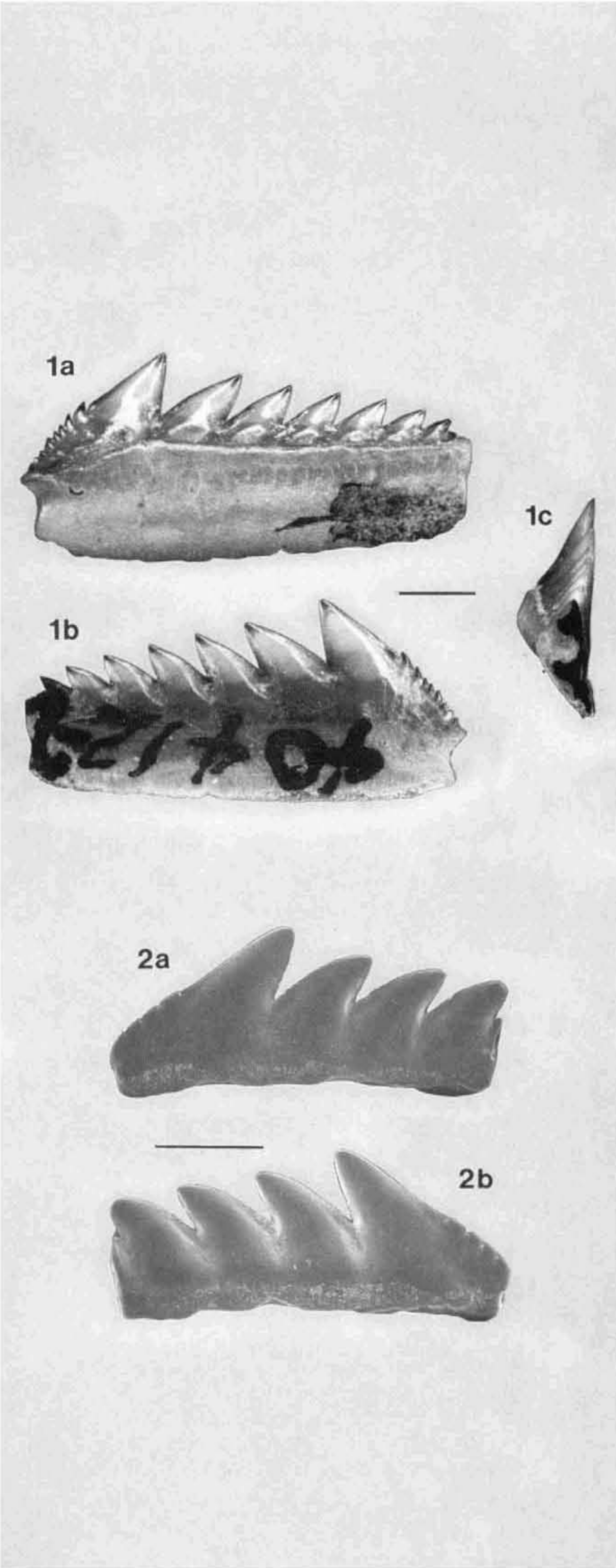
REFERENCES: None.

***Ptychodus* sp.: Contact horizon of the Atco Formation (Coniacian), Austin Group, Dallas County. (1-4) anterior teeth; (5, 7-8) anterolateral teeth; (6) posterior tooth. Tooth orientation: (1a, 4-8) occlusal view; (1b) mesial view; (2, 3) lingual view. Scale lines = 5 mm.**

HEXANCHUS MICRODON

Order HEXANCHIFORMES Buen 1926
Family HEXANCHIDAE Gray 1851

Maximum Size: **17 mm** | Occurrence: **Rare** | Chronologic Range: **Campanian - Maestrichtian**



Genus ***Hexanchus*** Rafinesque 1810
Hexanchus microdon (Agassiz 1843)

DESCRIPTION: Texas specimens of *Hexanchus microdon* include one complete lower right anterolateral tooth and tooth fragments; crown labiolingually compressed with a low distally inclined mesial cusp, followed by a series of six distally inclined cusplets (number of cusplets depends on tooth row position and the age of the individual); cusplets gradually decrease in size distally; mesial cutting edge of cusp serrated; distal cutting edge of cusp unserrated; cusplets unserrated; crown faces are smooth; root labiolingually flattened or tabular, nonbilobate and high; lingual longitudinal protuberance well developed, situated just below crown foot and extends full length of tooth; root anaulacorhizous; histology osteodont.

HETERODONTY: Strong disjunct monognathic and dignathic heterodonty with medial, anterolateral and posterior rowgroups present in the lower dentition and parasymphysial, anterolateral and posterior rowgroups present in the upper dentition. Moderately strong ontogenetic and sexual dental heterodonty known in extant *Hexanchus griseus*.

DISTINGUISHING CHARACTERISTICS: *Hexanchus microdon* lower anterolateral teeth are distinguished from all other Texas shark teeth by the presence of a saw-like crown with numerous cusplets and a flat, highly compressed and tabular, anaulacorhizous root.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Pecan Gap Chalk, Travis and Collin counties (Campanian); Maestrichtian, Kemp and Littig formations, Travis and Hunt counties.

COMMENTS: Teeth of the sixgill shark *Hexanchus* are extremely rare in the Texas Cretaceous and, to our knowledge, have not been previously reported from this state. The scarcity of sixgill shark's teeth in Texas can probably be attributed to the fact that these fishes inhabit cold, deep water and most of the Texas Cretaceous marine deposits were laid down in shallow warm tropical depositional environments.

REFERENCES: Woodward (1886); Arambourg (1952); Herman (1977).

Hexanchus microdon **(Agassiz 1843): (1) TMM Specimen No.140412-1, complete lower right anterolateral tooth, Pecan Gap Chalk (Campanian), Travis County; (2) incomplete lower left anterolateral tooth lacking a root and the distal end of the crown, Kemp Formation (Maestrichtian), Hunt County. Tooth orientation: (1a, 2b) lingual view; (1b, 2a) labial view; (1c) distal view. Scale line = 2 mm.**

Order Squaliformes

Until recently, sharks belonging to the Order Squaliformes were unknown from the Cretaceous of Texas. Several collections of extremely small Campanian teeth, many of which are barely larger than half of a millimeter, provide a tantalizing glimpse of a potentially diverse assemblage representing one family and at least three subfamilies of squalomorph sharks.

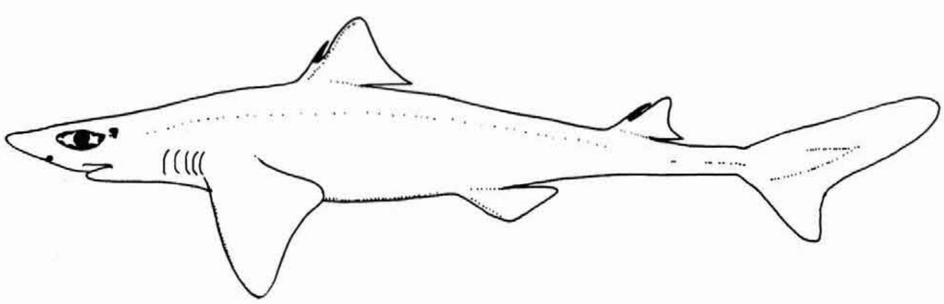
Dogfish sharks of the Order Squaliformes are widely distributed today in Atlantic, Pacific and Indian Oceans in tropical to subarctic and subantarctic latitudes. Some of many species live in shallow water close to shore; others inhabit the deep sea. They vary in length from an average of .5 to 1 meter, to a maximum of 6.5 meters. The earliest undisputed squalomorphs are Lower Cretaceous (Barremian) in age (Thies 1981); however, the late Jurassic genus *Squalogaleus* Maisey 1976 may represent the oldest known squaloid (Cappetta 1987).

The Order Squaliformes is subdivided into the Family Echinorhinidae, which includes modern and fossil bramble sharks, plus the Family Squalidae (dogfish sharks). The latter is broken down into four subfamilies; the Squalinae, Etmopterinae, Somniosinae and Oxynotinae, the first three of which are present in the Texas Cretaceous.

Squaloids are generally characterized by having two dorsal fins, with or without spines, no anal fin, five external gill slits, well calcified vertebrae, and a host of cranial attributes including a trough-shaped rostrum (for a detailed discussion of squaloid morphology see Compagno (1973).

The genus *Squalus* Linnaeus 1758 (Subfamily Squalinae) occurs in Campanian and Maestrichtian strata of the Taylor and Navarro groups respectively. Teeth of this genus may exceed 3 millimeters in length and are found in association with sharks and rays typical of shallow marine depositional environments. These teeth also resemble *Centrophoroides* Davis 1887 and may in fact be referable to this taxon.

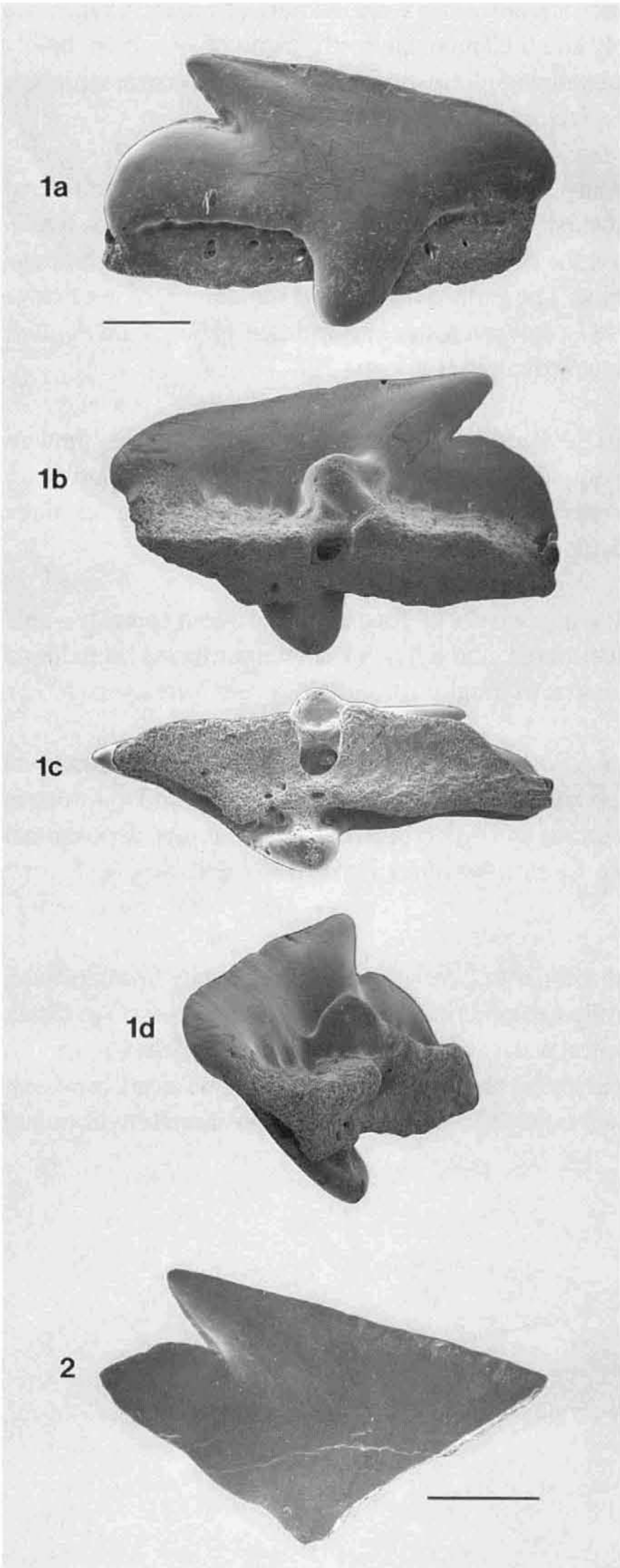
Extremely small and rare Campanian teeth similar to *Centroscymnus* (subfamily Somniosinae) and *Etmopterus* Rafinesque 1810 (Subfamily Etmopterinae) are found in the Pecan Gap Chalk of northeast Texas. The shallow, warm tropical waters which characterize most of the Cretaceous strata in Texas are not likely to yield squaloid teeth, (except *Squalus* or other squalinae); however, the Pecan Gap Chalk appears to represents a ?cooler, mid- to outer-shelf depositional environment favorable to squaloids.



SQUALUS sp.

Order SQUALIFORMES Goodrich 1909
Family SQUALIDAE Bonaparte 1834

Maximum Size: **2 mm** | Occurrence: **Rare** | Chronologic Range: **Campanian-Maestrichtian**



Genus ***Squalus*** Linnaeus 1758
Squalus sp.

DESCRIPTION: Teeth small, generally 2 mm in maximum size; cusp broad, triangular and strongly inclined distally; distal blade well developed; labial flange finger-like, extends basally below crown foot and root; lingual peg protrudes just below cusp at crown foot; cutting ridge and crown faces smooth; root short with a flat or inclined basal attachment surface; transverse lingual ridge-like protuberance is subdivided by a large central lingual foramen just below the lingual crown peg; root holaulacorhizous; histology orthodont.

HETERODONTY: Weak gradient monognathic and very weak dignathic heterodonty. Weak ontogenetic and moderate sexual dental heterodonty base d on modern *Squalus acanthias*.

DISTINGUISHING CHARACTERISTICS: Teeth of *Squalus* are easily identified by their low triangular crown, short root, strong labial flange and lingual peg.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Pecan Gap Chalk (Campanian), Collin County; Kemp and Littig formations (Maestrichtian), Travis and Hunt counties.

COMMENTS: *Squalus* teeth are extremely rare in Texas. Extant *Squalus* are generally small, deep to shallow -cold water sharks and have a spine in front of each dorsal fin.

The possibility exists that these teeth could belong to the genus *Centrophoroides*, close to *C. latidens* (Davis 1887).

REFERENCES: Ledoux (1970); Herman (1977); Cappetta (1980).

***Squalus* sp.: (1) anterolateral tooth from the Pecan Gap Chalk (Campanian), Collin County; (2) incomplete anterolateral tooth from the Kemp Formation (Maestrichtian), Hunt County. Tooth orientation: (1a, 2) labial view; (1b) lingual view; (1c) basal view; (1d) mesial view. Scale line = 0.5 mm.**

ETMOPTERINAE and SOMNIOSINAE

Chronologic Range: **Campanian** Occurrence: **Rare** Maximum Size: **1 mm**

Subfamily Etmopterinae Flower 1934
Subfamily Somniosinae Jordan 1888

GENERAL DISCUSSION: Very small teeth (usually less than 1 mm) which are undoubtedly closely related to the extant *Etmopterus* (Subfamily Etmopterinae) and *Centroscymnus* (Subfamily Somniosinae) occur in the early Campanian Pecan Gap Chalk of Collin County.

Sharks of the Subfamily Etmopterinae are small and possess prominent dorsal fin spines. They have very strong dignathic heterodonty with labiolingually compressed crowns and tabular roots in the lower dentition and smaller teeth with an erect cusp, one or more pairs of lateral cusplets, and distinctly bilobate roots in the upper jaw. Extant species of *Etmopterus* live at bathyal depths up to 2000 m.

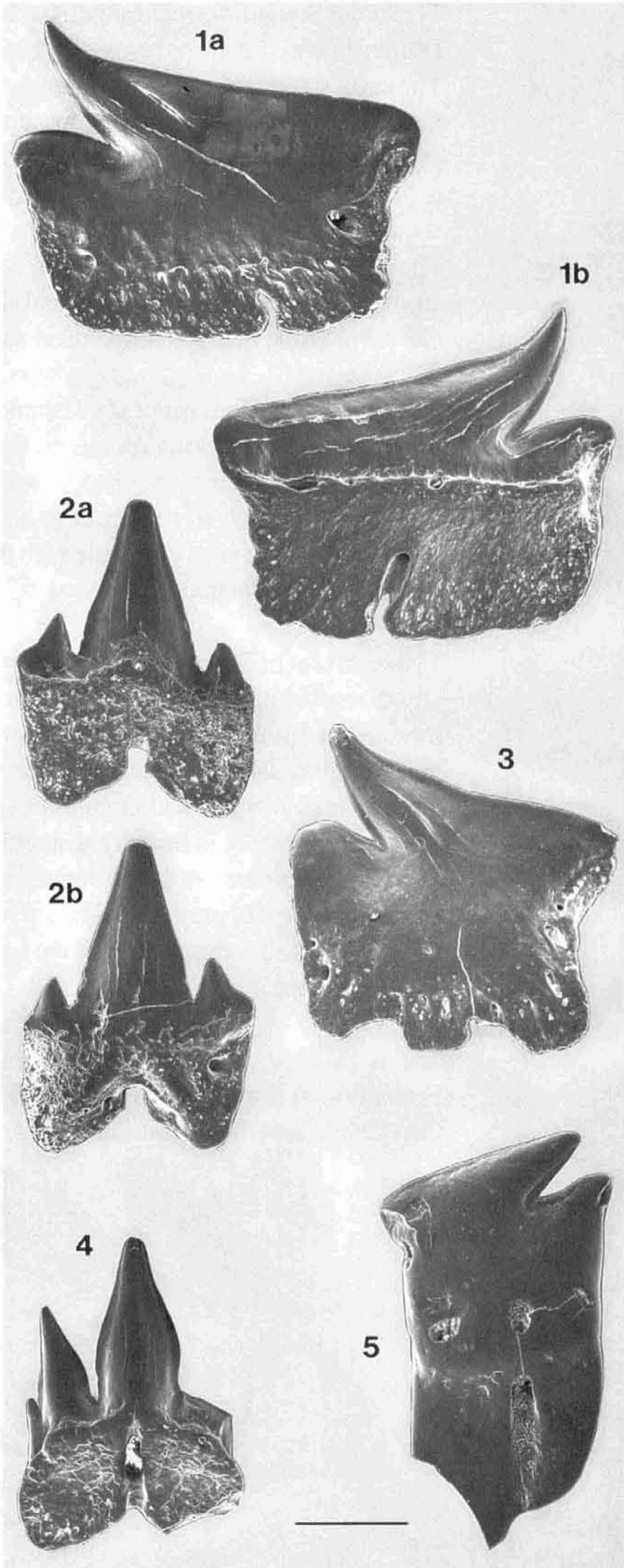
The fossil Etmopterus-like teeth are abundant and show a dental heterodonty close to the living *Etmopterus*. The genus *Etmopterus* has been described from the Campanian of Germany (Muller, 1989).

Of possible affinity to the Subfamily Somniosinae are rare upper and lower teeth resembling the genus *Centroscymnus*. They have very high and narrow tabular roots and a low crown in lower anterolateral teeth. The upper teeth have erect crowns with a single cusp, no lateral cusplets and strongly bilobate roots.

The Subfamily Somnoisinae is represented by four living genera, including *Centroscymnus*, and an extinct genus and species known from the upper Santonian of Lebanon (Cappetta 1980). Modern Somnoisinae live in the bathyal zone up to 1000 m.

Inferences from paleogeography, stratigraphy and the foraminifers associated with these teeth in the Pecan Gap Chalk, suggest that these teeth were deposited at mid to outer shelf depths of between 100 and 200 meters, or considerably shallower than the modern bathymetric distribution of members of either subfamily.

These squaloids are presently being described along with an associated fauna of diverse sharks and rays.



Etmopterinae and Somniosinae: Pecan Gap Chalk (Campanian), Collin County; (1-2) Etmopterinae, lower right anterolateral teeth; (3) Etmopterinae, upper right anterolateral tooth; (4) *Somniosinae*, upper right anterolateral tooth; (5) Somniosinae, lower right anterolateral tooth. Tooth orientation: (1a, 2b, 3) labial view; (1b, 2a, 4-5) lingual view. Scale line = 0.3 mm.

Order Squatiniformes

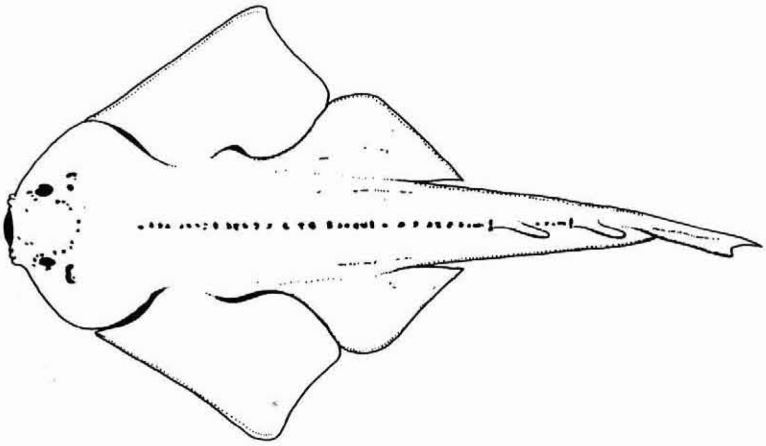
The Order Squatiniformes (angel sharks) includes the Family Squatinidae and one genus *Squatina* Dumeril 1906. *Squatina* has a long fossil record which extends from the Upper Jurassic to Recent. The earliest representatives are known by complete skeletons from Germany; otherwise the fossil history of this shark is based on numerous isolated teeth and scales from strata of Cretaceous and especially Tertiary age. The teeth of *Squatina* have changed very little since the Jurassic and it is often difficult at best to identify any species with certainty.

The interrelationships of the genus *Squatina* to other elasmobranchs have long been debated among students of modern and fossil sharks. Much of the confusion stems from its external ray-like form while detailed anatomical studies clearly show that *Squatina* is a shark.

Squatinoids are dorsoventrally flattened with broad pectoral fins, no anal fin, small posteriorly placed dorsal fins lacking fin spines, five gill slits opening ventrally as in rays, and a mouth which opens anteriorly (terminal) as opposed to opening below the snout (subterminal). Attributes of *Squatina* which clearly relate it to sharks and not rays include the absence of a synarcual or articulation of the pectoral girdle with the vertebral column, absence of spiracles and pectoral fins which are not attached to the head.

The dentition of *Squatina* displays very weak monognathic heterodonty in both jaws and little if any dignathic heterodonty. The teeth are mesodistally elongate with a sharp, erect cusp, long mesial and distal blades, and a complete cutting ridge. A pronounced labial flange extends to the level of the basal attachment surface. A wide dental band extends across the lingual crown foot and partly covers a raised lingual root protuberance. The crown is oriented at ninety degrees to the root. The root is broadly triangular in basal view with a weak to strongly concave basal attachment surface. A deep central lingual foramen rests in a concave depression and a central lingual foramen opens on the lingual root protuberance. The root is very thin in labial view and numerous small foramina pierce the basal attachment surface and lingual root surface just below the crown foot.

The fossil record of *Squatina* in Texas includes one record from the Cenomanian Woodbine Formation in Denton County and a small number of teeth from the Campanian Ozan and Pecan Gap Chalk, and the Maestrichtian Kemp, Escondido and Littig formations.



Order SQUALIFORMES Buen 1926
Family SQUATINIDAE Bonaparte 1838

SQUATINA HASSEI

Chronologic Range: **Campanian-Maestrichtian** | Occurrence: **Rare** | Maximum Size: **9 mm**

Genus ***Squatina*** Dumeril 1906
Squatina hassei Leriche 1929

DESCRIPTION: Teeth small, averaging about 5 mm; cusp short and broadly triangular with a very wide base; labial and lingual crown faces smooth; mesial and distal shoulders low, elongate and poorly differentiated on some teeth; labial flange moderately well developed; cutting edges of the crown smooth and continuous across shoulders and cusp; root distinctively triangular in basal view and projects lingually at a right angle to the crown; basal attachment surface is broad, weakly concave, and possesses a central nutrient foramen; root hemiaulacorhizous; histology orthodont.

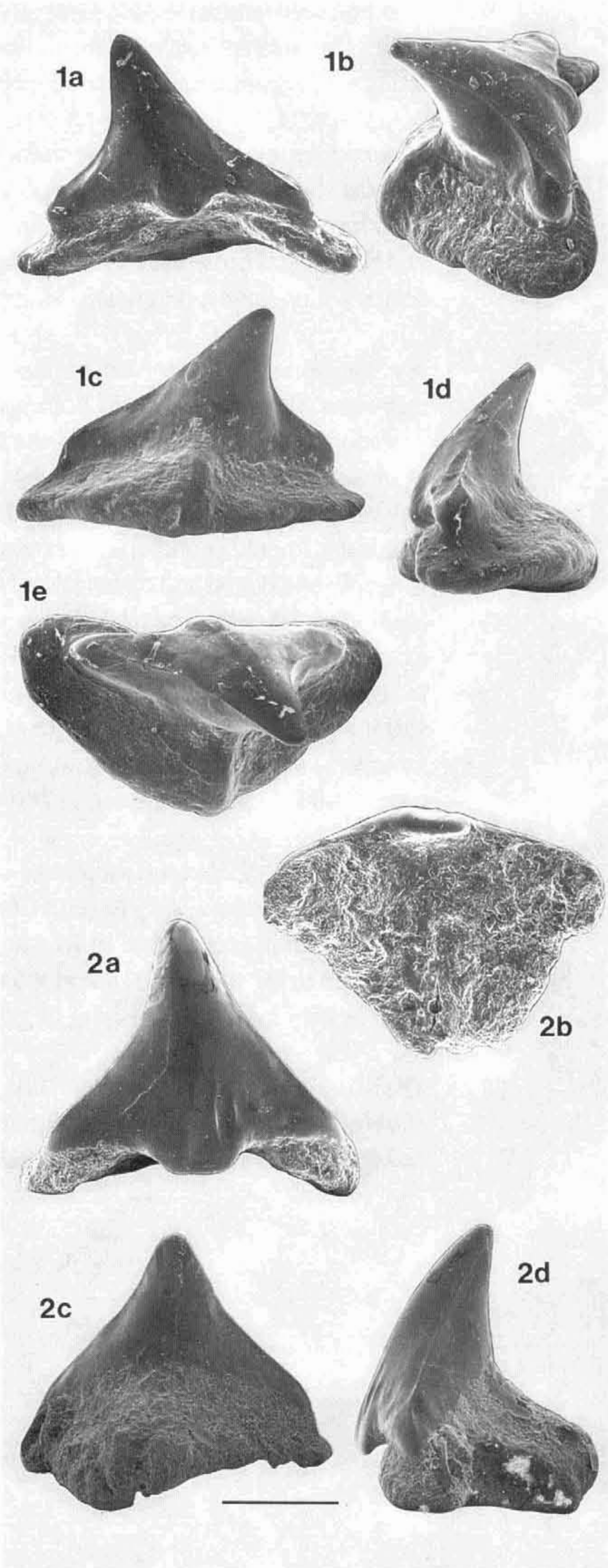
HETERODONTY: Weak gradient monognathic heterodonty in both jaws and extremely weak dignathic heterodonty.

DISTINGUISHING CHARACTERISTICS: The teeth of *Squatina hassei* are characterized by having a triangular root oriented with the basal attachment surface at right angles to the crown, a strong labial flange, and a central basal foramen which is not associated with a nutrient groove. The absence of a nutrient groove readily separates *Squatina* from *Cretorectolobus*.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Pecan Gap Chalk, Collin County; basal Ozan Formation, Dallas and Ellis counties (Campanian); Kemp, Escondido and Littig formations (Maestrichtian), Hunt, Medina and Travis counties.

COMMENTS: The Family Squatinidae includes one extant genus *Squatina* with a fossil record extending back to the Upper Jurassic. In Texas, it's teeth are generally small, never common and must be collected with bulk sampling and microscopic sorting techniques. An undescribed Cenomanian species of *Squatina* also occurs in the Woodbine Formation in Denton County.

REFERENCES: Leriche (1929); Herman (1977).



Squatina hassei **Leriche 1929: (1-2) complete anterolateral teeth from the Taylor Group, Ozan Formation (Campanian), Dallas County. Tooth orientation: (1a, 2a) labial view; (1c, 2c) lingual view; (1e) apical view; (1d, 2d) mesial view; (1b) distal view; (2b) basal view. Scale line = 0.5 mm.**

Order Heterodontiformes

The Family Heterodontidae Gray 1851 and genus *Heterodontus* Blainville 1816 comprise the Order Heterodontiformes. The earliest fossil record of heterodontids, horn sharks, dates back to the Lower Jurassic and the fossil record is relatively unbroken to the present.

Heterodontus is a small benthic shark that rarely exceeds 1 meter in total length and is found today in most shallow tropical and temperate waters worldwide. It has a very short, robust head with prominent ridges above the eyes and a narrow subterminal mouth. The pectoral fins are rounded and both dorsal fins are preceded by sharp spines. The body is covered by moderately large placoid scales which have a diagnostic Maltese Cross crown ornamentation.

As the name *Heterodontus* implies, this shark possesses a dentition with extreme disjunct monognathic heterodonty in both jaws, weak dignathic heterodonty and extreme ontogenetic heterodonty. In adult individuals, the anterior teeth possess a short, erect cusp and one or two pairs of closely attached mesial and distal cusplets. Both crown faces are smooth and a wide flange, having an apically convex basal border, is present labially at the crown foot. A short, horizontal or tabular lingual protuberance extends outward, over a prominent root protuberance. The root is deeply excavated and opens labially. Each root lobe converges lingually forming a V-shape in basal view. A central basal foramen is set in a deep pit and the lingual protuberance is pierced by a central lingual foramen. The lateral teeth are mesodistally elongate and more or less rectangular to sigmoid in occlusal view, having low, convex crowns without a cusp or cusplets. The occlusal surface is often ornamented with deep pits and branching ridges which intersect a median transverse ridge. The root is low, nonbilobate, with a flat basal attachment surface similar to the roots found on posterior teeth in *Ptychodus*.

The dentition of *Heterodontus* has strong ontogenetic heterodonty. The anterior teeth of immature *Heterodontus* may have two to three cusplet pairs while numerous cusplets are positioned along the transverse ridge in lateral teeth. As the individual matures, there is a progressive reduction in the number of anterior tooth cusplets. Cusplets are eliminated all together in lateral teeth as they take on a crushing or grinding function.

The fossil record of *Heterodontus* in Texas is very sparse. Anterior and posterior teeth of *Heterodontus* cf. *canaliculatus* (Egerton 1850) occur in the lower Coniacian of the Austin Group and fragmentary anterior teeth are present in the Campanian Ozan Formation.

HETERODONTUS cf. *CANALICULATUS*

Chronologic Range: **Lower Coniacian–Campanian** Occurrence: **Rare** Maximum Size: **2 mm**

Genus ***Heterodontus*** Blainville 1816
Heterodontus cf. ***canaliculatus*** (Egerton in Dixon 1850)

DESCRIPTION: Adult anterior teeth mesodistally narrow; cusp tall, peg-like and rounded at the apex; one pair of short, robust cusplets which are closely attached to the cusp; crown faces are smooth; labial flange U-shaped along basal border and overhangs crown foot; lingual protuberance horizontal, tabular and extends at right angles over the root, terminating just above a central foramen on the lingual root protuberance; root lobes open labially and unite lingually forming a V-shaped opening; central basal foramina perforate the root attachment surface. Adult anteroposterior teeth are mesodistally elongated and labiolingually narrow with a flat noncuspate crown which functions in crushing food; occlusal crown face with a strong raised transverse ridge, from which extends, at right angles, smaller rugose enameloid ridges; roots hemiaulacorhizous; histology orthodont.

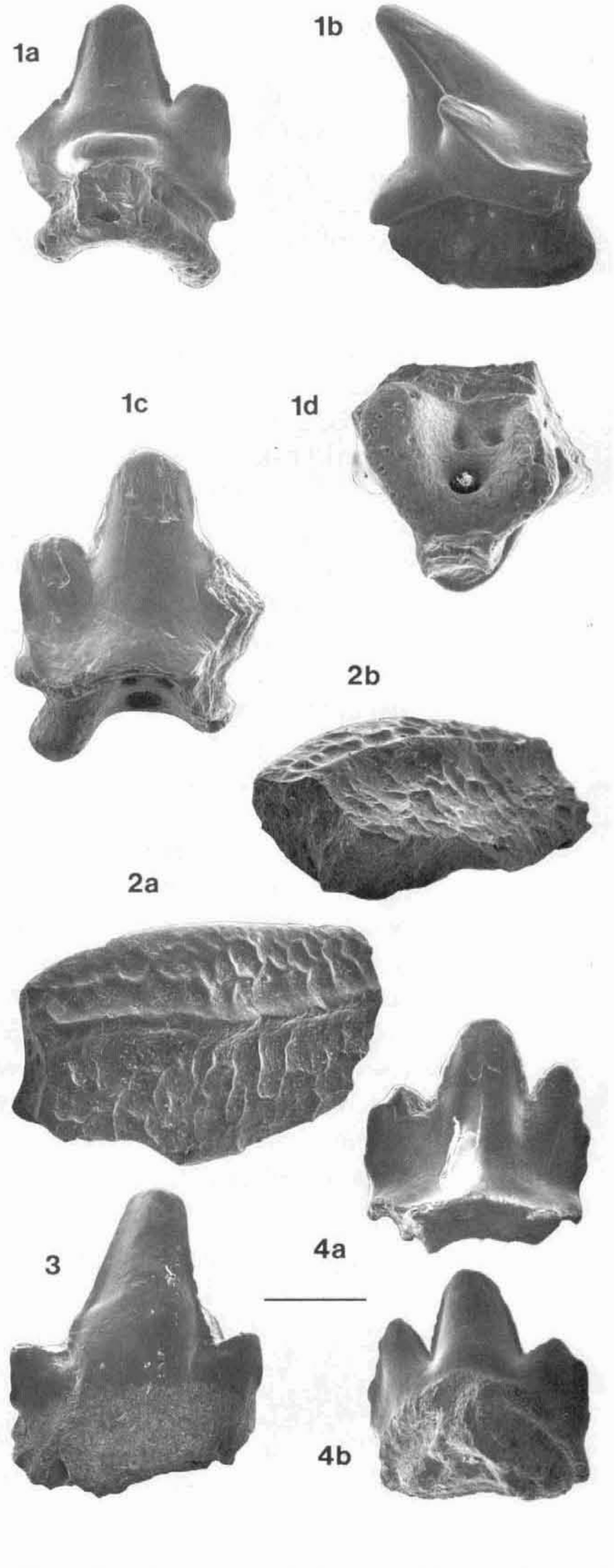
HETERODONTY: Extreme disjunct monognathic heterodonty in both jaws; extreme ontogenetic heterodonty.

DISTINGUISHING CHARACTERISTICS: The anterior teeth of *Heterodontus* differ from orectolobids by having a V-shaped root rather than a U-shaped root. The flat crushing teeth of adult *Heterodontus* have superficial similarities with the posterior teeth in *Ptychodus* but differ in being more symmetrical, having greater mesodistal elongation and in having a persistent median transverse ridge.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Basal Atco Formation of the Austin Group, contact horizon, Travis County (Coniacian); ?basal Ozan Formation (Campanian), Dallas County; Pecan Gap Chalk (Campanian), Collin County.

COMMENTS: Teeth of *Heterodontus* are very rare in Texas and they are presently known with certainty only from one sandy lens near the base of the Austin Group in Travis County. Several fragmentary anterior teeth, possibly referable to *Heterodontus*, are also found in the early Campanian Ozan and Pecan Gap Chalk formations.

REFERENCES: Cappetta (1975, 1987).



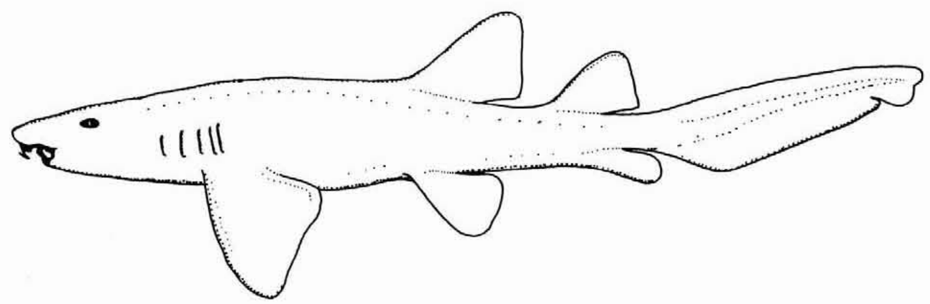
***Heterodontus* cf. *canaliculatus* (Egerton in Dixon 1850): (1, 3-4) anterior teeth; (2) crown of a lateroposterior crushing tooth lacking a root; Contact horizon of the Atco Formation (Coniacian), Austin Group, Travis County. Tooth orientation: (1a, 3, 4b) lingual view; (1c, 4a) labial view; (1b) distal view; (1d) basal view; (2a, 2b) occlusal view. Scale line = 0.5 mm.**

Order Orectolobiformes

Orectolobiforms constitute a diverse group of predominantly small, shallow water, tropical bottom-dwelling sharks. This order also includes the world's largest living shark, *Rhincodon typus* Smith 1829. The earliest known Orectolobids are Jurassic in age and five of the six families comprising this order range chronologically from Cretaceous to Recent. Whale sharks, Family Rhincodontidae, are described from Eocene and younger strata; however, teeth referable to this family may be present in the Cenomanian and Turonian of Texas.

The shallow, tropical to subtropical Cretaceous epicontinental sea which covered Texas supported a diverse orectolobid fauna representing at least five families and six genera including *Chiloscyllium greeni* (Family Hemiscylliidae), *Cantioscyllium decipiens* and *Ginglymostoma lehneri* (Family Ginglymostomatidae), *Cretorectolobus* sp. (Family Orectolobidae), *Pararhincodon groessenssi* (Family Parascylliidae) and problematical teeth of possible affinity to the whale sharks (Family Rhincodontidae). To this list can be added a significant number of undescribed Albian through Maestrichtian orectolobids.

As a group, orectolobiforms are characterized by a blunt snout, narrow mouth (excluding *Rhincodon*), two posteriorly placed dorsal fins lacking spines, very long tails, and numerous teeth arranged in a dense, alternate pattern. Orectolobid teeth are specialized for clutching or crushing rather than tearing or sawing. Most teeth are small, between 1 and 3 millimeters, with notable exceptions being *Cretorectolobus* and especially *Ginglymostoma* which exceeds 5 millimeters, and are moderately to strongly asymmetrical. Crowns range from narrow to moderately wide with a short cusp and from none to two pairs of short cusplets, except *Ginglymostoma* which has up to five distal cusplets. *Cretorectolobus* is very *Squatina*-like, having noncuspate, high mesially and distally elongate blades. Lingual crown faces are smooth and pronounced and a lingual crown protuberance is developed only in *Cantioscyllium* and *Ginglymostoma.* With the exception of *Pararhincodon*, orectolobid teeth possess a labial crown flange which may or may not extend basally to the level of the root attachment surface. The basal profile of this flange ranges from weakly bifid to narrowly constricted and peg-like. Labial crown ornamentation ranges from absent to minor discontinuous enameloid folds and ridges near the crown foot (ridges extensive in *Cantioscyllium* and moderately developed in *Ginglymostoma*). Orectolobid roots are typically low and heart-shaped in basal view with expanded mesial and distal lobes. The basal attachment surface is weakly to strongly concave and has a large central basal foramen. A lingual foramen penetrates the lingual root protuberance and marginal lingual foramina are almost always present. Most orectolobids have hemiaulacorhizous roots though some are holaulacorhizous.



Order ORECTOLOBIFORMES Applegate 1972
Family HEMISCYLLIIDAE Gill 1862

CHILOSCYLLIUM GREENI

Chronologic Range: **Cenomanian - Coniacian** | Occurrence: **Common** | Maximum Size: **1.8 mm**

Genus ***Chiloscyllium*** Muller and Henle 1837
Chiloscyllium greeni (Cappetta 1973)

DESCRIPTION: Teeth small, height less than 2 mm, width less than 1.5 mm; crown smooth with one broadly triangular median cusp; one pair of short, robust lateral cusplets; labial crown flange wide, overhangs crown foot and extends almost to base level of root; crown inflated lingually, developed into a strong protuberance; root strongly bilobate; basal attachment surface concave and oriented at right angles to crown; central basal foramen opens labially into a nutrient groove separating mesial and distal root lobes; lingual root protuberance penetrated by a single foramen; root hemiaulacorhizous; histology orthodont.

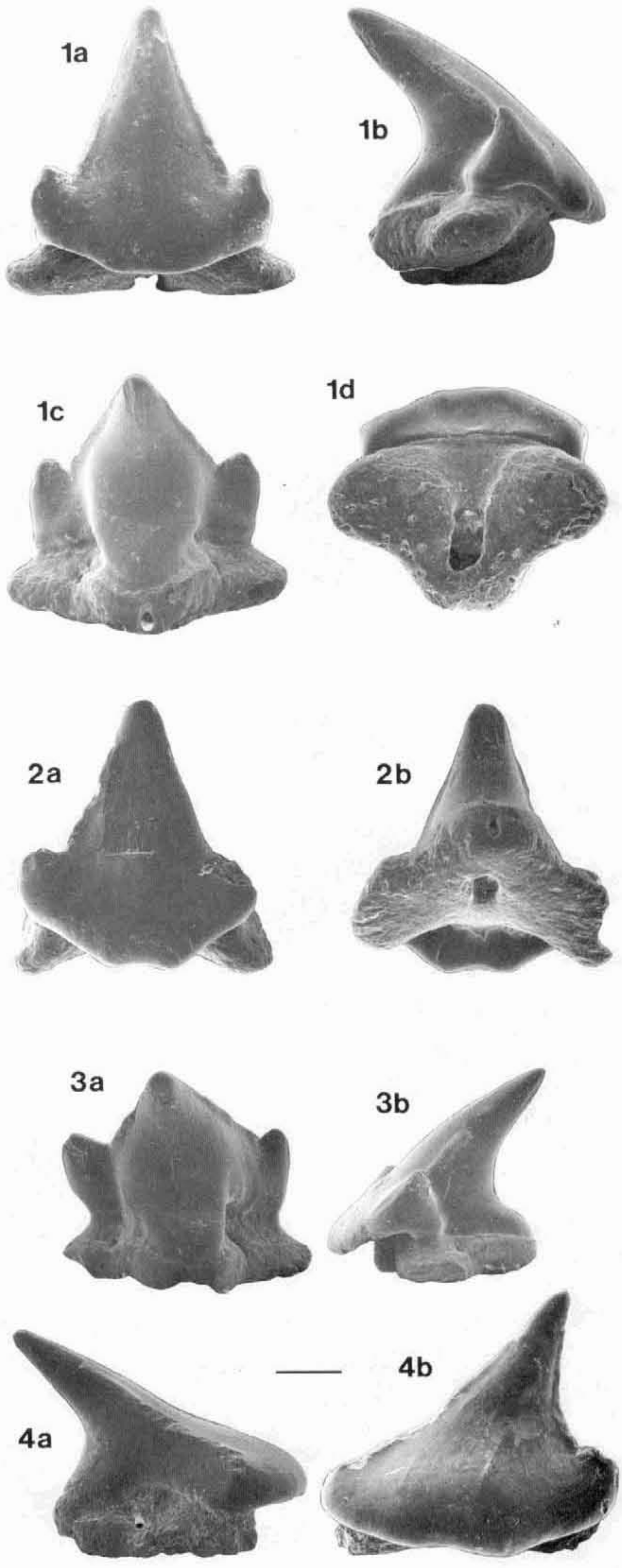
HETERODONTY: Weak gradient monognathic and dignathic heterodonty.

DISTINGUISHING CHARACTERISTICS: This species is easily distinguished from other Texas orectolobids by its small size, smooth crown and presence of a single pair of cusplets.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Pepper and Woodbine formations and Eagle Ford Group formations (Cenomanian); Eagle Ford Group formations (Turonian); basal Atco Formation of the Austin Group (Coniacian).

COMMENTS: This species was first described by Cappetta (1973) from the Turonian Carlile Shale of South Dakota. Subsequently, it has been recognized in the Cenomanian through early Coniacian of Texas where it is especially common in the Turonian Kamp Ranch Limestone of the Eagle Ford Group. Living hemiscyllids are small benthic sharks which are found in warm waters of the Indian and Pacific oceans.

REFERENCES: Cappetta (1973).

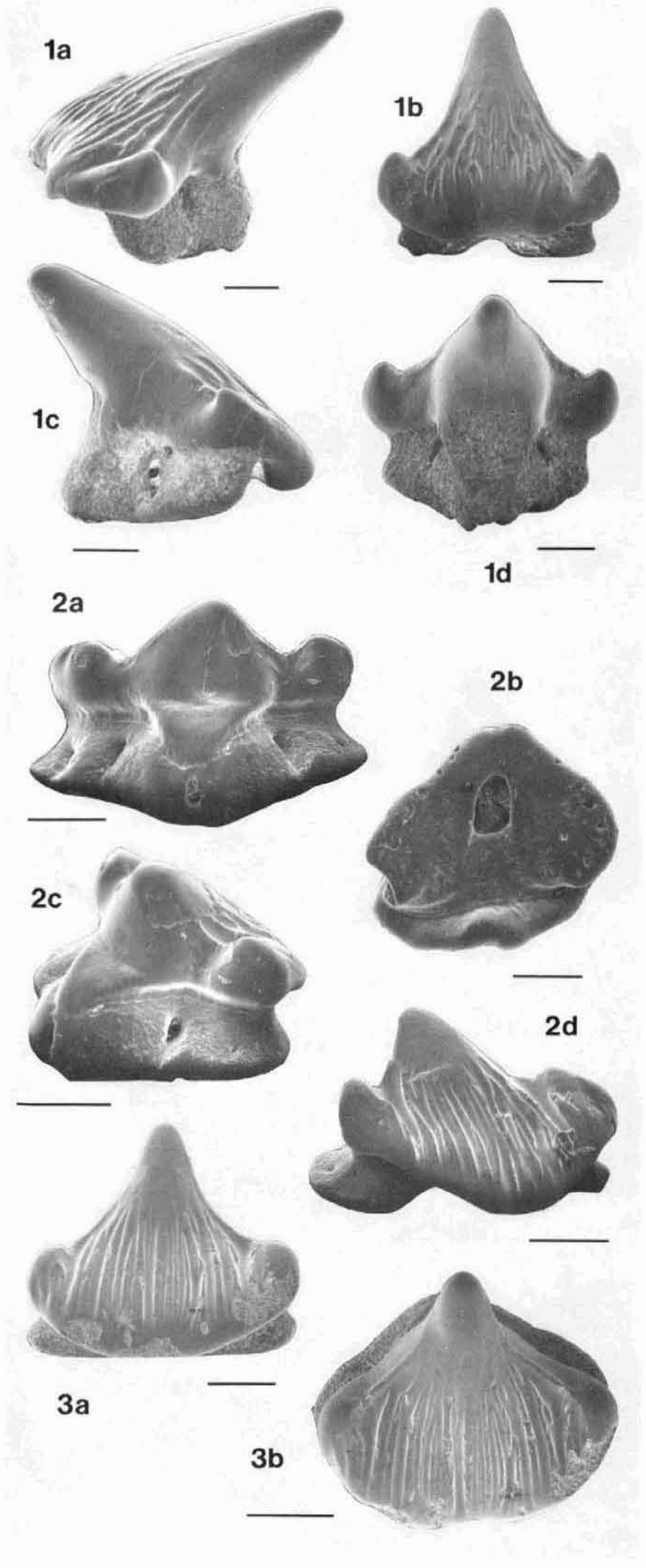


Chiloscyllium greeni **(Cappetta 1973): Anterolateral teeth from the Atco Formation (Coniacian), Austin Group, Travis County. Tooth orientation: (1a, 2a, 4b) labial view; (1c, 2b, 3a) lingual view; (1b, 4a) mesial view; (3b) distal view; (1d) basal view. Scale line = 0.3 mm .**

CANTIOSCYLLIUM DECIPIENS

Order ORECTOLOBIFORMES Applegate 1972
Family GINGLYMOSTOMATIDAE Gill 1862

Maximum Size: **3 mm** | Occurrence: **Common** | Chronologic Range: **Cenomanian - Coniacian**



Genus ***Cantioscyllium*** Woodward 1889
Cantioscyllium decipiens Woodward 1889

DESCRIPTION: Teeth small with a short stout cusp flanked by one to three pairs of small rounded lateral cusplets; lingual protuberance well developed and attached, having a flattened apical surface; labial flange broad, rounded to bilobate, and does not reach basal face of root; longitudinal ridges pronounced, covering lower half of labial crown face but do not reach cusp apex; root triangular in outline, having well defined lobes; attachment surface weakly concave; large central foramen situated on basal face of root; root hemiaulacorhizous; histology orthodont.

HETERODONTY: Dignathic heterodonty weak or absent. Weak gradient monognathic heterodonty with the number of cusplets increasing in more distal tooth rows.

DISTINGUISHING CHARACTERISTICS: These teeth differ from other Texas orectolobids in having robust crowns with numerous, strong labial longitudinal ridges.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Pepper and Woodbine formations (Cenomanian); Eagle Ford Group (Cenomanian - Turonian); basal Atco Formation of the Austin Group (early Coniacian).

COMMENTS: *Cantioscyllium decipiens* is the most common orectolobid in the Texas Cretaceous. These teeth are very small and microscopic techniques should be used to collect them.

REFERENCES: Woodward (1889); Cappetta (1973).

Cantioscyllium decipiens **Woodward 1889: Anterolateral teeth, Pepper Formation (Cenomanian), Bell County. Tooth orientation: (1d, 2a) lingual view; (1b, 2d, 3a) labial view; (2b) basal view; (3b) apical view; (1a, 2c) distal view; (1c) mesial view. Scale line = 0.5 mm.**

GINGLYMOSTOMA LEHNERI

Chronologic Range: **Late Campanian-Maestrichtian** Occurrence: **Common** Maximum Size: **5.5 mm**

Genus ***Ginglymostoma*** Muller and Henle 1837
Ginglymostoma lehneri Leriche 1938

DESCRIPTION: Teeth moderately large for the genus, generally 3 - 4 mm in greatest dimension; crown broadly triangular with short cusp and three to four pairs of mesial and distal cusplets; labial crown foot developed into prominent flange; lingual protuberance massive; lingual crown face smooth; labial crown face has numerous irregular longitudinal enameloid plications or ridges, generally covering labial flange and extending apically to just below base of cusp and cusplets; basal attachment surface of root triangular in outline, deeply concave, with one large central foramen which opens into a labially directed groove, separating mesial and distal root lobes; lingual root protuberance massive and penetrated lingually by a single foramen; root hemiaulacorhizous; histology orthodont.

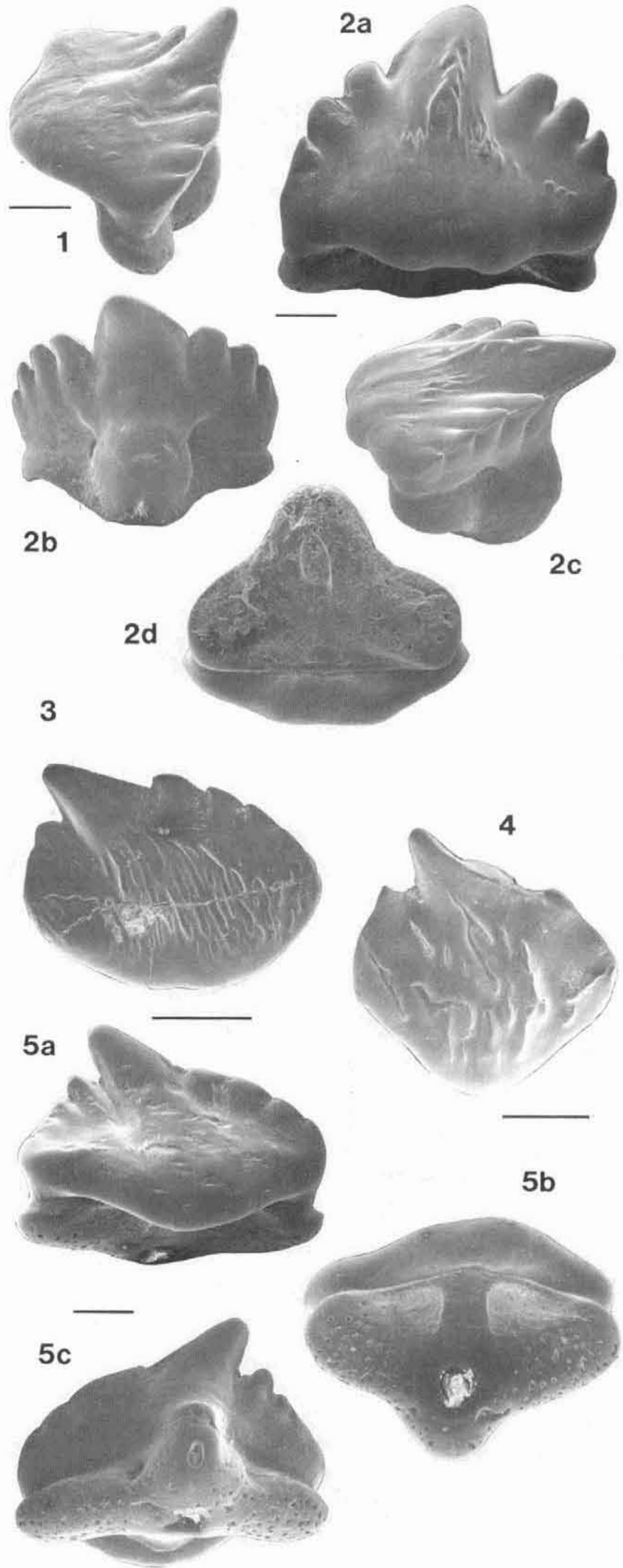
HETERODONTY: Very weak gradient monognathic heterodonty; dignathic heterodonty weak or absent.

DISTINGUISHING CHARACTERISTICS: The teeth of *Ginglymostoma lehneri* differ from other similar orectolobid teeth in having numerous short cusplets flanking a short median cusp, bordering a broadly triangular and high crown. The presence of strong, irregular enameloid ridges on the labial crown face is an important diagnostic feature.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Late Campanian to Maestrichtian, Kemp, Escondido and Littig formations of Hunt, Medina and Travis counties.

COMMENTS: In Texas, teeth of *Ginglymostoma* are restricted to sediments of latest Campanian and Maestrichtian age. *Ginglymostoma lehneri* was originally described by Leriche (1938) from the Cretaceous of Trinidad.

REFERENCES: Leriche (1938); Arambourg (1952).

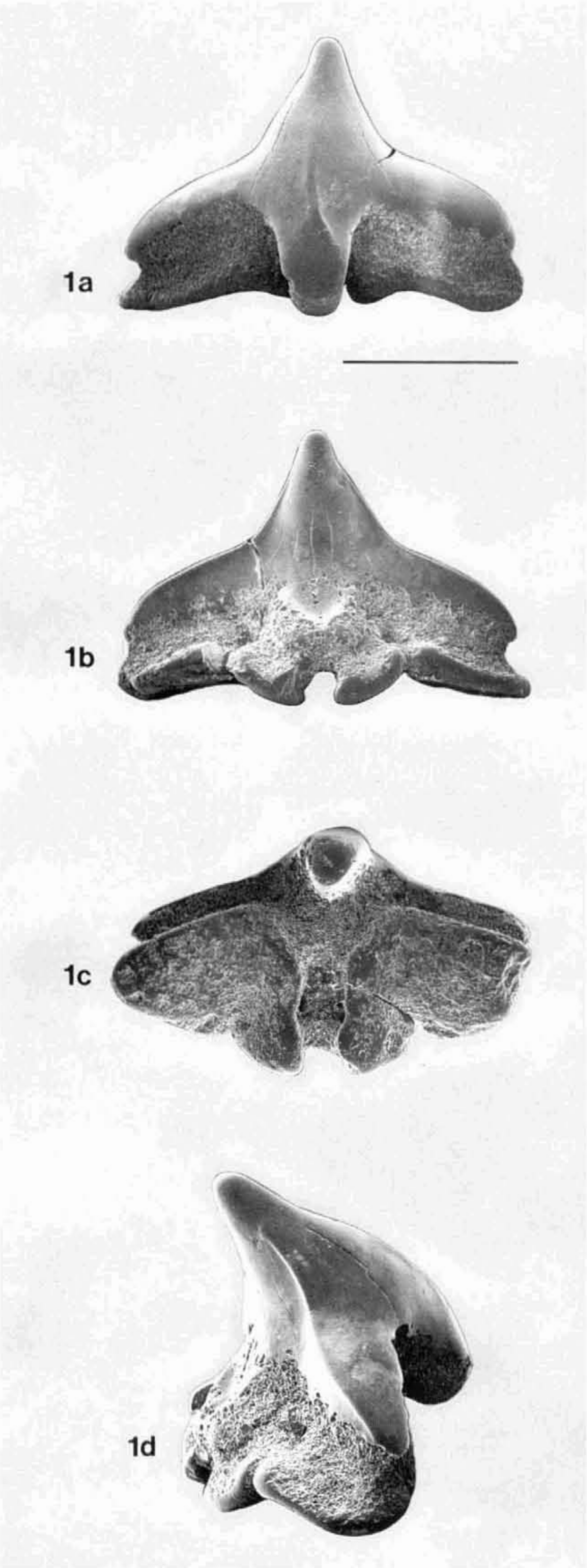


Ginglymostoma lehneri **Leriche 1938: Anterolateral teeth, Kemp Formation (Maestrichtian), Hunt County. Tooth orientation: (2a, 3, 4, 5a) labial view; (2b, 5c) lingual view; (2d, 5b) basal view; (2c) distal view; (1) mesial view. Scale line = 1 mm (1-3, 5), 0.5 mm (4).**

CRETORECTOLOBUS sp.

Order ORECTOLOBIFORMES Applegate 1972
Family ORECTOLOBIDAE Jordan and Fowler 1903

Maximum Size: **3.5 mm** Occurrence: **Rare** Chronologic Range: **Turonian**



Genus ***Cretorectolobus*** Case 1978
Cretorectolobus sp.

DESCRIPTION: Teeth small, rarely exceeding 3 mm and superficially very similar to *Squatina*; crown with a single narrow cusp, flanked by long, low mesial and distal shoulders; cusplets absent; labial flange short to long and narrow, descending well below crown foot to a point about level with basal attachment surface of the root; crown foot extended lingually over a prominent lingual root protuberance; crown faces smooth; cutting ridge continuous across the cusp and shoulders; root triangular to rectangular in basal view; basal attachment surface subdivided by a nutrient groove, extending from lingual protuberance almost to labial flange; root holaulacorhizous; histology orthodont.

HETERODONTY: Weak gradient monognathic heterodonty; dignathic heterodonty weak or ?absent.

DISTINGUISHING CHARACTERISTICS: Teeth of *Cretorectolobus* are most likely to be confused with those of *Squatina* and can easily be distinguished from the latter by the presence of a well defined nutrient groove on the basal attachment surface of the root.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Upper Eagle Ford Group (Taff's Fishbed Conglomerate: Turonian), Collin County.

COMMENTS: At the present time, teeth of *Cretorectolobus* are known from one locality in the Eagle Ford Group, very close to its contact with the overlying Austin Group. Additional teeth from an undescribed West Texas fauna of late Maestrichtian age may also be referable to this genus. Case (1978) originally described the genus *Cretorectolobus* from the Campanian Judith River Formation of Montana.

REFERENCES: Case (1978).

***Cretorectolobus* sp.: Anterolateral tooth, Taff's Fishbed Conglomerate (Turonian), upper Eagle Ford Group, Collin County. Tooth orientation: (1a) labial view; (1b) lingual view; (1c) basal view; (1d) mesial view. Scale line = 1 mm.**

PARARHINCODON GROESSENSSI

Chronologic Range: **Campanian** | Occurrence: **Rare** | Maximum Size: **1.2 mm**

Genus ***Pararhincodon*** Herman 1976
Pararhincodon groessenssi Herman 1982

DESCRIPTION: Teeth extremely small, usually between 0.5 and 1 mm high; crown needle-like, usually bordered by a low, convex mesial blade; mesial cusplet present or absent; distal cusplet incipient to well developed; labial crown foot deeply embayed; labial crown face nearly flat; lingual crown face strongly convex; crown faces lack ornamentation; cutting ridge continuous across cusp, cusplets, and blade; root strongly bilobate, lingual protuberance large with flat mesial and distal root lobe attachment surfaces; root very asymmetrical with large mesial lobe and much smaller distal lobe; root lobes separated by nutrient groove which is open or partly covered; a single foramen penetrates the lingual root protuberance and a large central foramen opens posteriorly between the root lobes; root hemiaulacorhizous; histology orthodont.

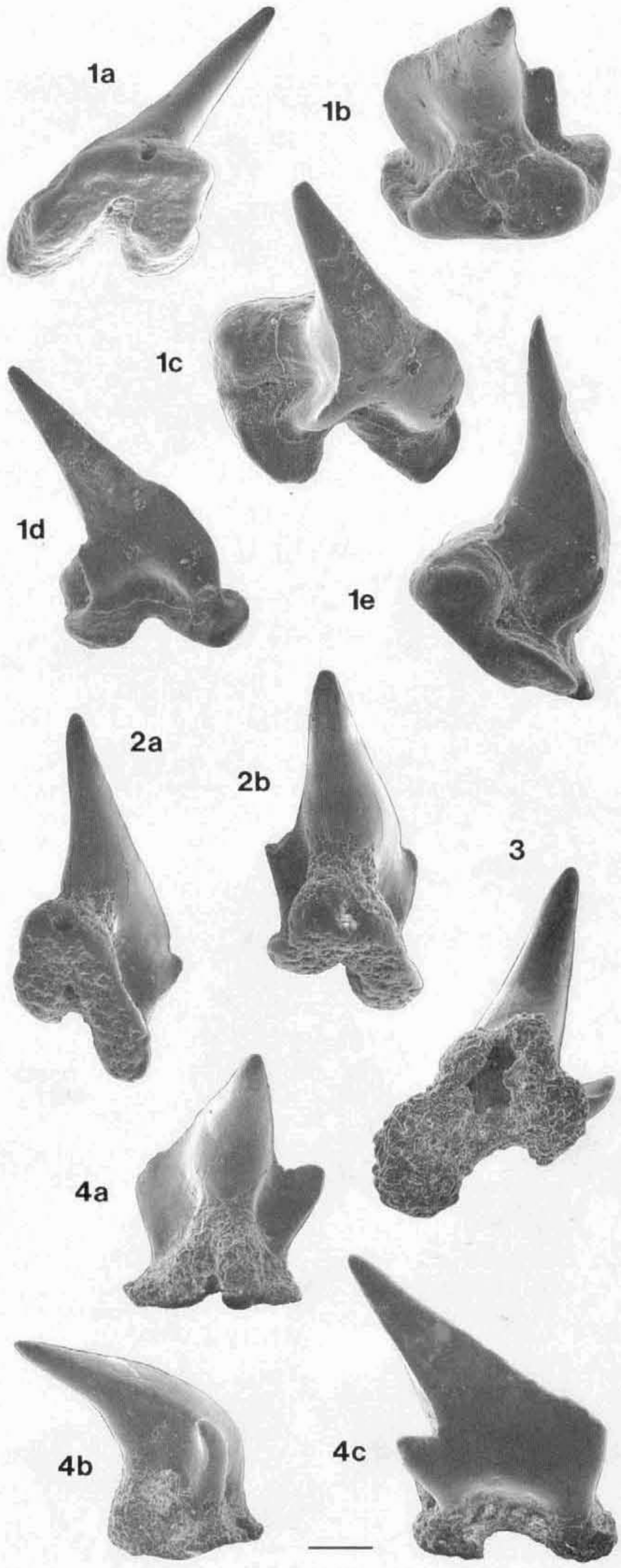
HETERODONTY: Uncertain; probably weak gradient monognathic heterodonty in both jaws; dignathic heterodonty either weak or absent.

DISTINGUISHING CHARACTERISTICS: *Pararhincodon* teeth are extremely small and can easily be recognized by their crown and root asymmetry.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Pecan Gap Chalk and Ozan formations, Dallas and Collin counties (Campanian).

COMMENTS: The genus *Pararhincodon* was first described by Herman (1977) from the Campanian of Belgium. The genus was subsequently reported from an incomplete skeleton from the Cenomanian of Lebanon (Cappetta, 1980) and Herman (1982) described *P. groessenssi* from the Maestrichtian of Germany. Additional but fragmentary Texas teeth of *Pararhincodon* occur in the Pepper and Woodbine (Cenomanian) formations and the Eagle Ford Group (Cenomanian-Turonian).

REFERENCES: Herman (1977, 1982); Cappetta (1980).

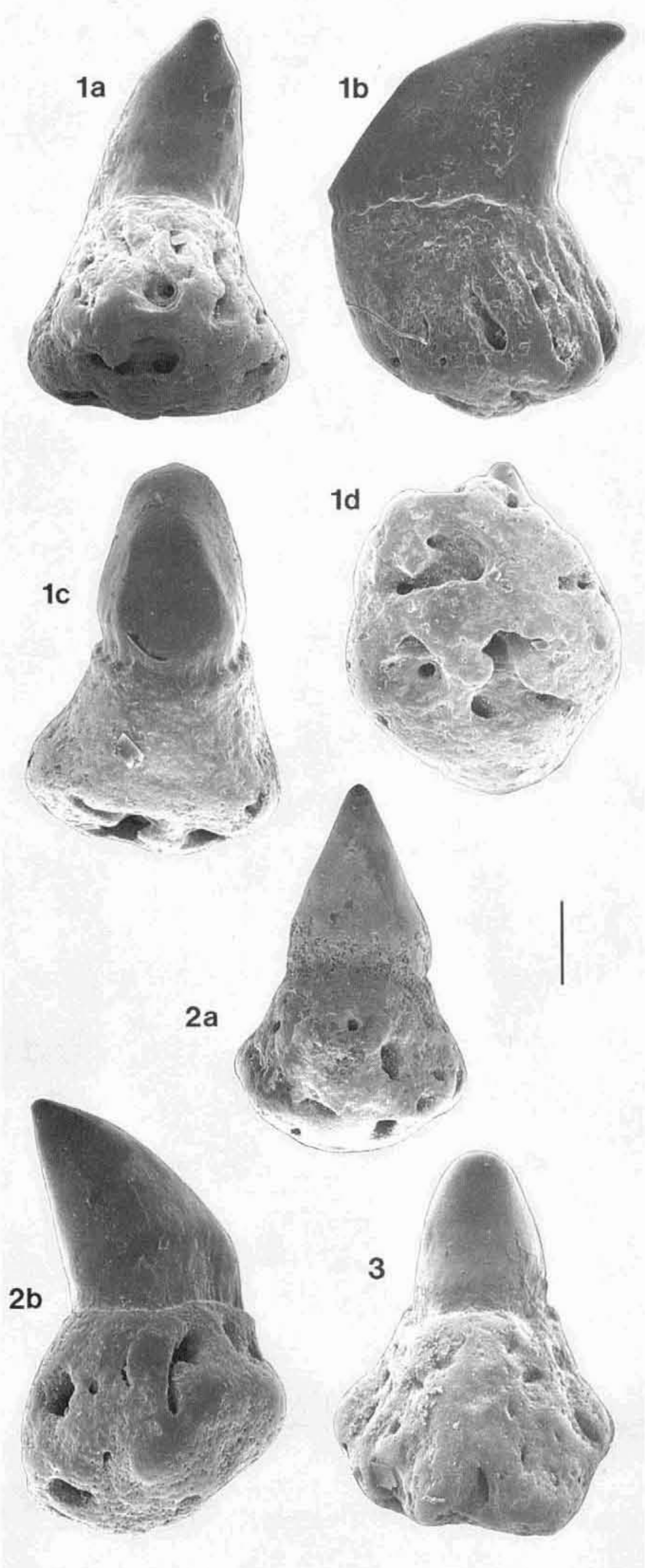


***Pararhincodon groessenssi* Herman 1982: Anterolateral teeth, Taylor Group, Pecan Gap Chalk (Campanian), Collin County. Tooth orientation: (1a, 1b, 2b, 3, 4a) lingual view; (1d, 4c) labial view; (1c) apical view; (1e, 4b) distal view; (2a) mesial view. Scale line = 0.2 mm.**

?RHINCODONTIDAE

Order ORECTOLOBIFORMES Applegate 1972
Family RHINCODONTIDAE Garman 1913

Maximum Size: **2 mm**	Occurrence: **Common**	Chronologic Range: **Cenomanian-Turonian**



Family Rhincodontidae Garman 1913

DESCRIPTION: Teeth small, generally less than 2 mm in greatest dimension, and superficially resembling teeth of the extant whale shark *Rhincodon*; crown very short, robust and often having a pronounced lingual inflection; cutting ridges weakly developed or absent; incipient cusplets (generally on only one side of the cusp and never more than one) present on some teeth, otherwise absent; dentinal band present labially and lingually; crown faces are smooth; root bulbous, rarely bilobate and slightly expanded mesodistally; basal attachment surface is poorly developed, moderately convex and lacks a distinct central foramen; nutrient groove absent; root anaulacorhizous (probably a secondary feature); histology osteodont.

HETERODONTY: Unknown, but possibly approaching a homodont condition or, at least, extremely weak gradient monognathic heterodonty in both jaws.

DISTINGUISHING CHARACTERISTICS: Very small size, simple crown and a bulbous root lacking lobes, a central foramen or nutrient groove.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Eagle Ford Group throughout Texas (Cenomanian-Turonian).

COMMENTS: These teeth are questionably referred to the Family Rhincodontidae based on superficial resemblance to whale shark teeth; otherwise, they do not have an orectolobid root structure. Teeth having a similar morphology are found today among the largest living sharks (e.g., whale and basking sharks) where tooth reduction and simplification has taken place in response to feeding on microscopic marine plankton.

REFERENCES: None.

?Rhincodontidae: Eagle Ford Group, Kamp Ranch Limestone (Turonian), Dallas County. Tooth orientation: (1a, 2a, 3) lingual view; (1c) labial view; (1d) basal view; (1b, 2b) mesial view. Scale line = 0.3 mm.

Order Lamniformes

Without question, the most sought after and impressive teeth to be found in the Texas Cretaceous belong to sharks of the Order Lamniformes. Extant lamniforms are predominantly large predaceous sharks, including the great white *Carcharodon carcharias*, and some of its Cretaceous counterparts were undoubtedly the largest fish predators of the time. Texas lamniform teeth of notable size occur in strata of Albian through Maestrichtian age. The largest teeth belong to *Cretodus crassidens* (lower Coniacian), *Leptostyrax macrorhiza* (Albian) and *Scapanorhynchus texanus* (Campanian).

Collectively, the dentition of this group displays weak to strong disjunct monognathic heterodonty and weak to strong dignathic heterodonty. Anterior, lateral and posterior rowgroups are fairly well differentiated among most genera with symphysial and upper intermediates present among all odontaspids and some of the cretoxyrhinids. Ontogenetic heterodonty is expressed by crowns and roots becoming increasingly robust with age.

In Texas, lamniforms are sparsely distributed throughout marginal marine facies of late Aptian and early Albian age (Thurmond 1971) but they are never abundant until the late Albian. Characteristic Lower Cretaceous taxa include *Protolamna* cf. *sokolovi, Leptostyrax macrorhiza, Cretolamna appendiculata, Paraisurus compressus* and a small odontaspid close to *Carcharias amonensis*. Cenomanian lamniforms are typified by a "Woodbine" assemblage of *Cretolamna appendiculata, Cretoxyrhina mantelli, Leptostyrax* sp., *Carcharias amonensis, C. tenuiplicatus, Scapanorhynchus ?raphiodon, Protolamna* sp. and *Cretodus semiplicatus*. A slightly younger and more marine Eagle Ford assemblage includes a small unnamed odontaspid, rare *Cretolamna appendiculata* and *Cretoxyrhina mantelli*. The Turonian and Coniacian yield *Scapanorhynchus raphiodon, Cretoxyrhina mantelli*, small odontaspids and very large teeth of *Cretodus crassidens*. The alopiid *Paranomotodon* first appears in the Santonian and both *Paranomotodon* and *Scapanorhynchus texanus* are common in the Campanian Taylor Group. Maestrichtian Navarro Group strata yield abundant teeth of *Serratolamna serrata* and at least one species of *Carcharias*.

Texas Cretaceous Lamniformes include the Family Odontaspididae Muller and Henle 1839 (*Carcharias*), Family Mitsukurinidae Jordan 1898 (*Scapanorhynchus*), Family Cretoxyrhinidae Gluckman 1958 (*Cretodus, Cretoxyrhina, Cretolamna, Leptostyrax, Paraisurus* and *Protolamna*), Family Serratolamnidae Landemaine 1991 (*Serratolamna*) and the Family Alopiidae Bonaparte 1838 (*Paranomotodon*).

Family Odontaspididae

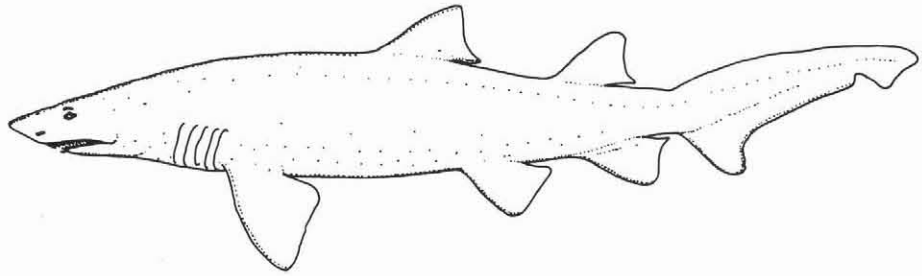
Two living genera occur in the Family Odontaspididae, *Odontaspis* Agassiz 1838 (type species *Squalus ferox* Risso 1826) and *Carcharias* Rafinesque 1810 (type species *Carcharias taurus* Rafinesque 1810). Both are moderately large sharks, the former living in deep water and the latter preferring tropical to warm-temperate coastal environments.

Odontaspids have long prehensile teeth with one to three pairs of lateral cusplets, well defined cutting ridges which may or may not reach the crown foot, a lingual dental band and sigmoid crown profile in mesial or distal view. The labial crown face ranges from nearly flat to strongly convex and is usually smooth but may have short longitudinal ridges near the crown foot. The lingual crown face is convex to some degree and ranges between smooth and highly ornamented with longitudinal ridges depending on the species. A basal ledge may be present at the labial crown foot. The root is strongly bilobate with a pronounced lingual protuberance and narrow, rounded mesial and distal root lobes. A central lingual foramen and nutrient groove are always present.

Odontaspids have disjunct monognathic heterodonty in both jaws and strong dignathic heterodonty with symphysial, anterior, intermediate, lateral and posterior rowgroups present in both *Odontaspis* and *Carcharias*. Tooth histology is osteodont.

It is a relatively easy matter to separate extant odontaspids based on tooth morphology and dental formulae; however, this distinction is not so clear cut when one begins to work with diverse early Tertiary and Cretaceous odontaspids. Odontaspid teeth are large, easily collected and have been the subject of paleontological study for many years. Despite the attention they have received, there remains a perplexing array of named taxa and associated classification schemes, none of which offer a very clear or satisfactory understanding of odontaspid taxonomy and evolution. The generic taxonomy of Texas Cretaceous odontaspids presented here is at best tentative.

The earliest Texas odontaspids are late Albian from the Weno, Pawpaw, Duck Creek and Grayson formations. These teeth are close to *Carcharias amonensis,* but remain unstudied. Two taxa, *Carcharias amonensis* and *Carcharias tenuiplicatus*, are found in the Cenomanian Woodbine and Pepper formations and a small undescribed species of cf. *Carcharias* (*Carcharias* sp.A) is especially abundant in overlying late Cenomanian strata of the Eagle Ford Group. Small unstudied odontaspids also occur throughout the Turonian, sparsely in the Campanian and *Carcharias* (*Carcharias* sp. B) is present in the Maestrichtian Navarro Group.



CARCHARIAS AMONENSIS

Chronologic Range: **Late Albian-Cenomanian** Occurrence: **Common** Maximum Size: **11 mm**

Genus ***Carcharias*** Rafinesque 1810
Carcharias amonensis (Cappetta and Case 1975)

DESCRIPTION: Teeth moderately large, usually between 5 and 8 mm high; crown with a broad-based cusp and generally one pair of cusplets in anterior teeth and up to two pairs of triangular cusplets on most lateral teeth; cusplets closely attached to base of cusp and all have strong distal curvature; crown faces are smooth; lingual dental band well developed; roots are broad and tabular with a V-shaped convergence of the root lobes; lingual root protuberance weakly formed on anteriors; nutrient groove present on all teeth; root holaulacorhizous; histology osteodont.

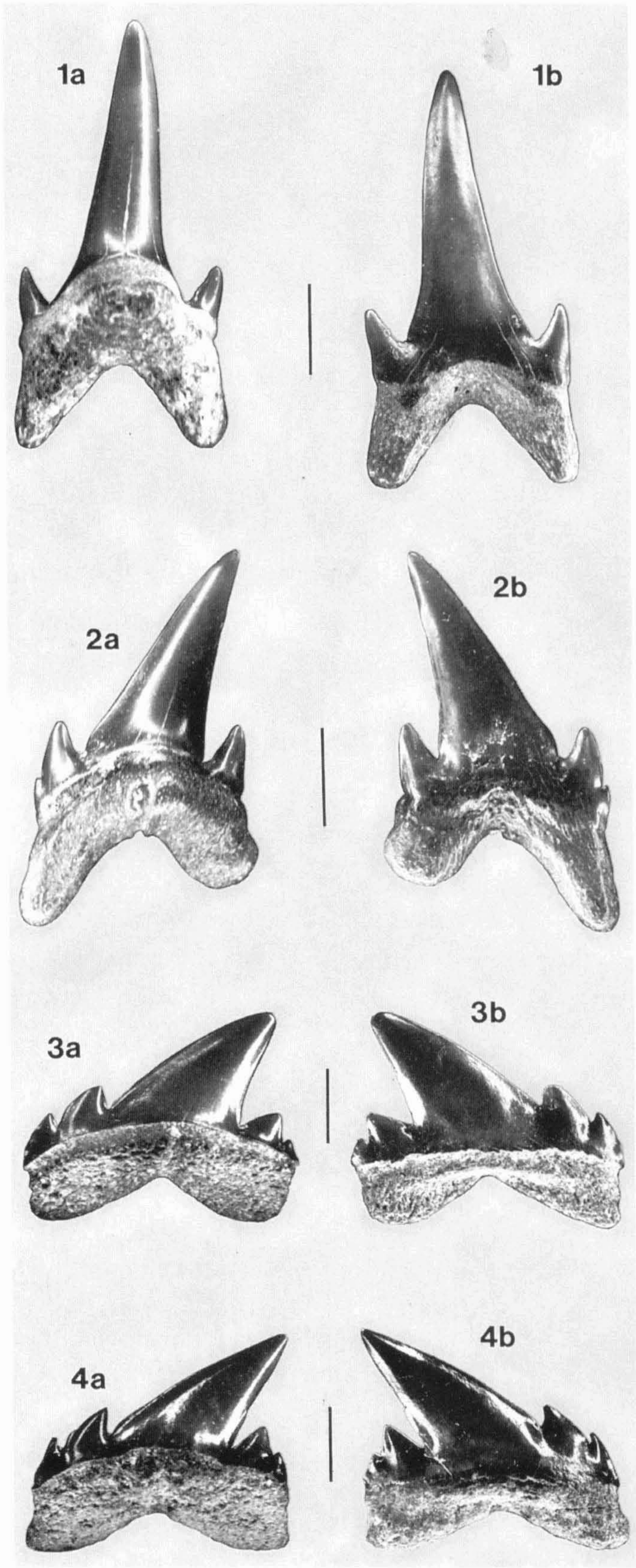
HETERODONTY: Strong disjunct monognathic and dignathic heterodonty with symphysial, anterior, ?intermediate, lateral and posterior rowgroups based on isolated teeth.

DISTINGUISHING CHARACTERISTICS: The teeth of *Carcharias amonensis* differ from other odontaspids in having a broad, smooth and triangular cusp, flanked by up to two pairs of short, wide cusplets which display pronounced distal inclination in almost all tooth positions.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Possibly late Albian through Cenomanian Pawpaw, Pepper and Woodbine formations and the Eagle Ford Group (Cenomanian) in Travis, Bell, Tarrant, Dallas and Denton counties.

COMMENTS: This species is common in shallow water, near-shore environments of the Pepper and Woodbine formations of Cenomanian age. It occurs only sparsely in more open marine settings typical of the Weno and Pawpaw formations and the basal Eagle Ford Group. This species was described by Cappetta and Case (1975) from the Arlington Member of the Woodbine Formation in Tarrant County.

REFERENCES: Cappetta and Case (1975).

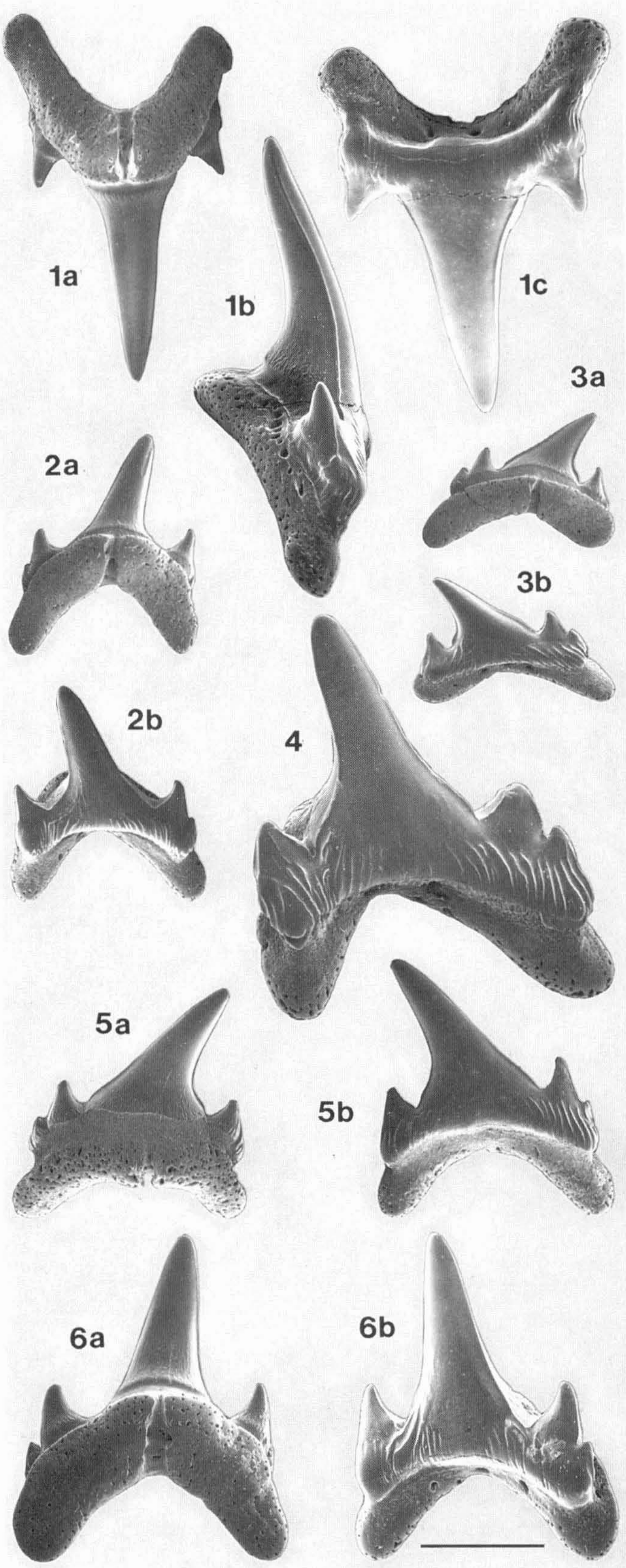


***Carcharias amonensis* (Cappetta and Case 1975): Lewisville Member of the Woodbine Formation (Cenomanian), Denton County; (1-2) anterior teeth; (3-4) lateral teeth. Tooth orientation: (1a, 2a, 3a, 4a) lingual view; (1b, 2b, 3b, 4b) labial view. Scale line = 2 mm.**

CARCHARIAS TENUIPLICATUS

Order LAMNIFORMES Berg 1958
Family ODONTASPIDIDAE Muller and Henle 1839

Maximum Size: **7 mm** | Occurrence: **Common** | Chronologic Range: **Cenomanian**



Genus ***Carcharias*** Rafinesque 1810
Carcharias tenuiplicatus (Cappetta and Case 1975)

DESCRIPTION: Small odontaspid teeth rarely exceeding 5 mm. Crowns moderately high with a broad-based but narrow, moderately sigmoid cusp; one or two pairs of high cusplets; row-group morphology typical for odontaspids with erect anteriors and one pair of cusplets in anteriors and one to two in lateroposteriors; very short, closely spaced longitudinal ridges form a band at the labial and lingual crown foot; labial basal ledge broadly U-shaped and deep; root strongly bilobate; lingual protuberance well developed with a deep nutrient groove; root holaulacorhizous; histology osteodont.

HETERODONTY: This species has a typical odontaspid dentition with strong disjunct monognathic and dignathic heterodonty.

DISTINGUISHING CHARACTERISTICS: *Carcharias tenuiplicatus* differs from all other Texas Cenomanian odontaspids in having wide based cusp and cusplets, a deep labial basal ledge and numerous short, pronounced labial and lingual longitudinal ridges at the crown foot.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Pepper and Woodbine formations (Cenomanian), throughout Texas.

COMMENTS: Cappetta and Case (1975, page 305, Figures 3a and 3b) described this species from the lower Arlington Sandstone Member of the Woodbine Formation in Tarrant County. The holotype illustration shows a small incomplete tooth that is more robust than any of the teeth we have examined. In spite of this, the tooth characters given in the type description seem to agree with those observed in our samples. These teeth may also be close to *Carcharias striatula* (Dalinkevicius 1935) from the Albian of Lithuania.

REFERENCES: Dalinkevicius (1935); Cappetta and Case (1975).

***Carcharias tenuiplicatus* (Cappetta and Case 1975): Pepper Formation (Cenomanian), Bell County; (1) anterior tooth; (2, 4, 6) lateral teeth; (3-5) posterior teeth. Tooth orientation: (1a-3a, 5a, 6a) lingual view; (1c, 2b, 3b, 4, 5b, 6b) labial view; (1b) distal view. Scale line = 2 mm.**

CARCHARIAS sp. A

Chronologic Range: **Cenomanian** Occurrence: **Abundant** Maximum Size: **4.7 mm**

Genus ***Carcharias*** Rafinesque 1810
Carcharias sp. A

DESCRIPTION: A very small odontaspid with teeth rarely exceeding 4.5 mm. Crown with a moderately long, wide cusp and generally one pair of narrow, high cusplets; paired cusplets sometimes occur in lateral teeth; lingual crown face smooth or with weak longitudinal ridges restricted to an area just above a well defined dental band at the crown foot; longitudinal ridges strongly developed in lateroposterior teeth; labial crown faces smooth or with very sparse longitudinal ridges; cusplets continuous with crown; crown faces strongly convex; cutting ridges continuous across cusp and cusplets; strong labial basal ledge at crown; root has a strong lingual protuberance and a deep, well developed nutrient groove; root holaulacorhizous; histology osteodont.

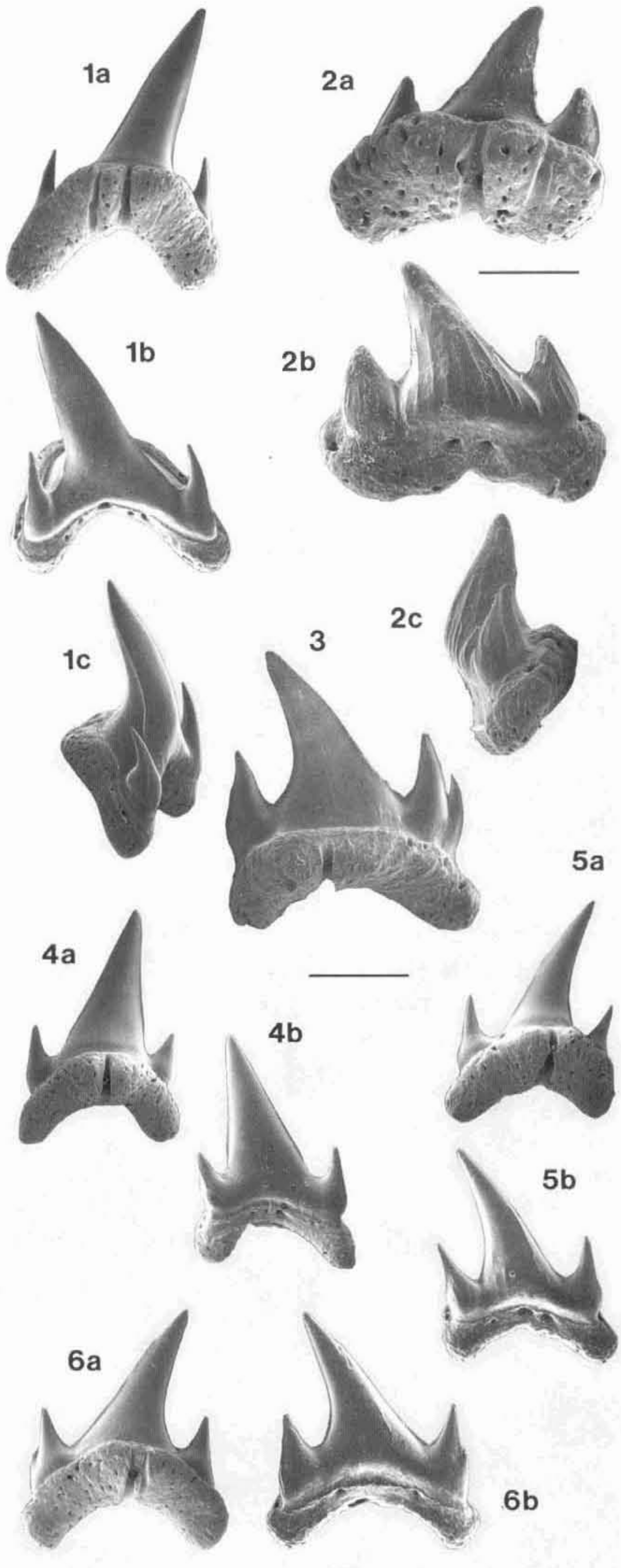
HETERODONTY: Strong disjunct monognathic and dignathic heterodonty typical of odontaspids including symphysial, anterior, intermediate, lateral and posterior rowgroups.

DISTINGUISHING CHARACTERISTICS: Small size, nearly smooth crown in anterior and lateral teeth and a single pair of high, needle-like cusplets on most teeth readily distinguish these teeth from other Texas odontaspids.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Lower Eagle Ford Group (Cenomanian) throughout Texas.

COMMENTS: Teeth of *Carcharias* sp. A are very common in the open marine Cenomanian facies of the Eagle Ford Group. These teeth are almost always found in association with *Cretoxyrhina mantelli* and *Squalicorax falcatus*. Meyer (1975) recognized that this small odontaspid is an undescribed taxon; however, the species has not been named.

REFERENCES: Meyer (1975).

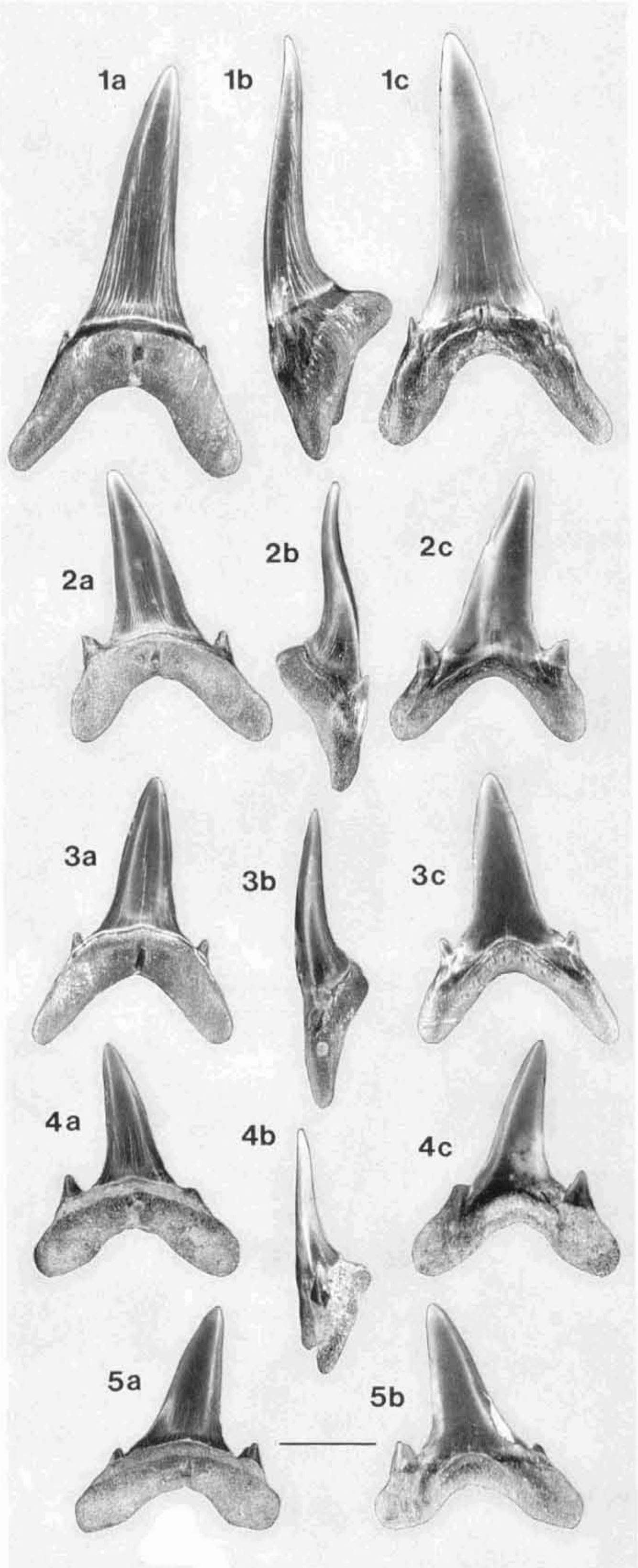


***Carcharias* sp. A: Eagle Ford Group, Britton Formation (Cenomanian), Dallas County; (1) anterior tooth; (2) posterior tooth; (3-6) lateral teeth. Tooth orientation: (1a, 2a, 3, 4a-6a) lingual view; (1b, 2b, 4b-6b) labial view; (2c) mesial view; (1c) distal view. Scale line = 2 mm (1, 3-6), 1 mm (2).**

CARCHARIAS sp. B

Order LAMNIFORMES BERG 1958
Family ODONTASPIDIDAE Muller and Henle 1839

Maximum Size: **20 mm** | Occurrence: **Common** | Chronologic Range: **Maestrichtian**



Genus ***Carcharias*** Rafinesque 1810
Carcharias sp. B

DESCRIPTION: Teeth large, up to 20 mm high in anterior teeth; crown with a moderately wide cusp in all tooth positions; one pair of very small, narrow cusplets in anteriors; cusplets of laterals larger and triangular in shape; lingual crown face strongly convex with fine, parallel longitudinal ridges extending from crown foot almost to apex; labial crown face weakly convex and smooth; strong basal ledge developed at the labial crown foot; dental band wide lingually in anteriors and narrow on laterals; cusps weak to moderately sigmoid; cutting ridges continuous from apex to crown foot on cusp and cusplets; roots typical of *Carcharias* with a deep nutrient groove positioned on a very pronounced lingual root protuberance; root holaulacorhizous; histology osteodont.

HETERODONTY: Strong disjunct monognathic and dignathic heterodonty with symphysial, anterior, intermediate, lateral and posterior rowgroups.

DISTINGUISHING CHARACTERISTICS: *Carcharias* sp. B can be distinguished from all other Texas odontaspids by its much larger adult tooth size, wider cusp bases and more extensive lingual crown ornamentation.

COMMENTS: *Carcharias* sp. B is the youngest Texas odontaspid. There are numerous late Cretaceous species of *Carcharias*, some of which are close to *Carcharias* sp. B; however, none of these taxa appear to represent this Texas form. Modern *Carcharias* is a large, near-shore coastal fish-eating shark in warm temperate and tropical waters.

REFERENCES: Arambourg (1952); Cappetta and Case (1975); Case (1978).

***Carcharias* sp. B: Navarro Group, Kemp Formation (Maestrichtian), Hunt County; (1-3) anterior teeth; (4-5) lateral teeth. Tooth orientation: (1a-5a) lingual view; (1b-3b) mesial view; (4b) distal view; (1c-4c, 5b) labial view. Scale line = 5 mm.**

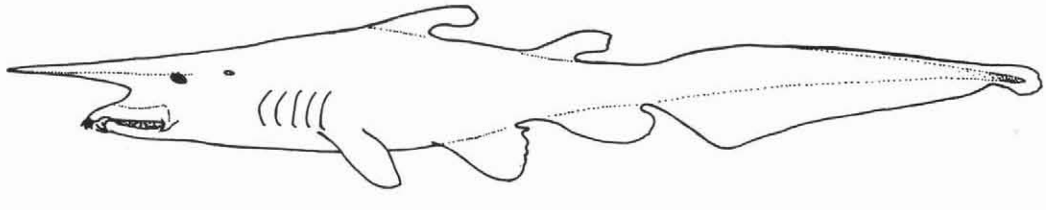
Family Mitsukurinidae

The genotype for the Family Mitsukurinidae is the living deep-sea goblin shark *Mitsukurina owstoni* Jordan 1898. *Mitsukurina* is distinguished by its unusually long, thin snout, very long tail, greatly protruding jaws and eyes set over the corners of the mouth. It grows to at least 3.5 meters in Japanese waters. These sharks live on or near the bottom at water depths in excess of 500 meters. Fossil evidence suggests that they have remained in this habitat throughout the Tertiary.

Other genera in this family are *Anomotodon* Arambourg 1952 and *Scapanorhynchus* Woodward 1889, isolated teeth of the latter being particularly common in the Texas Upper Cretaceous Woodbine Formation and throughout the Eagle Ford, Austin and Taylor groups.

The genus *Scapanorhynchus* is entirely Cretaceous with earliest occurrences in the Aptian and Albian of Japan (Itoigawa et al. 1977). It is especially well known by complete skeletons from the upper Santonian of Sahel Alma, Lebanon, and also by numerous isolated teeth. The overall external appearance and skeletal morphology of *Scapanorhynchus* is very close to that of *Mitsukurina*. The main difference between the two genera concerns the fins: in *Scapanorhynchus*, the anal fin is very long and the caudal fin shows well-developed lower and apical lobes while in *Mitsukurina*, the anal is short, the lower lobe of the caudal has disappeared and the apical lobe is reduced.

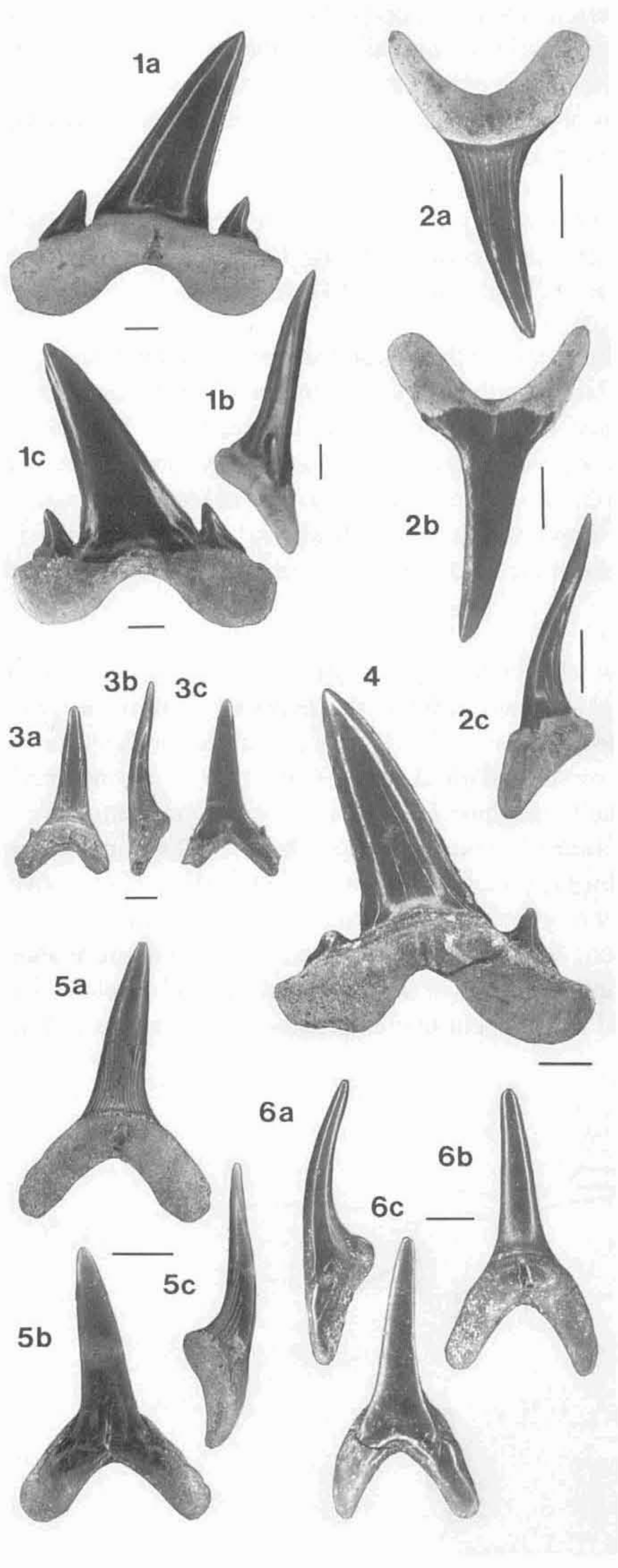
The anterior teeth of *Scapanorhynchus* have tall, slender, highly sigmoid cusps with a very convex lingual face having closely spaced, parallel longitudinal ridges that may extend from the crown foot to the apex. The lingual crown foot often shows a weak bulge just above a narrow dental band. The labial cusp face is nearly flat and the mesial and distal cutting edges may or may not reach the crown foot. Most anterior teeth from the Texas Upper Cretaceous have no more than one very reduced pair of lateral cusplets or, more commonly, none. The root is high with long and narrow mesial and distal lobes and bears a strong lingual protuberance with a short, deep nutrient groove. Lateral teeth have a considerably different morphology, being labiolingually flattened - almost thin - and mesodistally wide with smooth labial and lingual crown faces (may have short enameloid ridges at the crown foot) and up to two pairs of short, triangular lateral cusplets. The root lobes are spatulate and rounded and a prominent lingual protuberance retains a distinct nutrient groove.



SCAPANORHYNCHUS RAPHIODON

Order LAMNIFORMES Berg 1958
Family MITSUKURINIDAE Jordan 1898

Maximum Size: **38 mm** | Occurrence: **Common** | Chronologic Range: **Turonian-Coniacian**



Genus ***Scapanorhynchus*** Woodward 1889
Scapanorhynchus raphiodon (Agassiz 1844)

DESCRIPTION: Anteriors with a high, narrow cusp; cusplets absent or a single small pair may be present; lingual crown face with strong longitudinal ridges extending almost to apex; labial crown face smooth; roots widely separated, spatulate; lingual root protuberance strong with a deep nutrient groove; lateral teeth with a broad-based, labiolingually compressed cusp and one pair of short, triangular cusplets; crown faces smooth; root lobes rounded or spatulate; root holaulacorhizous; histology osteodont.

HETERODONTY: Strong disjunct monognathic and dignathic heterodonty with symphysial, anterior, lateral and posterior rowgroups.

DISTINGUISHING CHARACTERISTICS: Teeth of *Scapanorhynchus raphiodon* can be distinguished from *S. texanus* by a combination of smaller overall size, narrower crowns and weaker crown striations; cusplets possible on anterior teeth and relatively larger cusplets on lateral teeth.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Upper Eagle Ford Group (Turonian) and basal contact horizon of the Atco Formation of the Austin Group (Coniacian). This species may also occur in the Cenomanian of Texas.

COMMENTS: *Scapanorhynchus raphiodon* is a problematic taxon that has not been satisfactorily characterized in the Texas Cretaceous. Additional material and more study are necessary to ensure that these teeth have been correctly identified. Teeth of *Scapanorhynchus* are moderately abundant in the basal Atco Formation (contact horizon) of the Austin Group; otherwise, they occur only sparsely in Texas pre-Campanian formations.

REFERENCES: Herman (1977); Cappetta (1987).

***Scapanorhynchus raphiodon* (Agassiz 1844): Contact horizon of the Atco Formation (Coniacian), Austin Group, Dallas County; (1, 4) lateral teeth; (2, 3, 5, 6) anterior teeth. Tooth orientation: (1a-3a, 4, 5a, 6b) lingual view; (1c, 2b, 3c, 5b, 6c) labial view; (1b, 2c, 3b, 5c, 6a) distal view. Scale line = 2 mm.**

Genus ***Scapanorhynchus*** Woodward 1889

Order LAMNIFORMES Berg 1958
Family MITSUKURINIDAE Jordan 1898

SCAPANORHYNCHUS TEXANUS

Chronologic Range: **Campanian-Maestrichtian** | Occurrence: **Common** | Maximum Size: **48 mm**

Scapanorhynchus texanus (Roemer 1849)

DESCRIPTION: The teeth of *Scapanorhynchus texanus* change considerably along the dental series from anteriors to laterals; anterior teeth have slender, straight cusps and, if present, one pair of diminutive cusplets; lower third of cusp is mesodistally narrower (constricted) than the upper third; lingual crown face strongly convex with numerous parallel longitudinal ridges extending from crown foot to near apex; lingual crown foot has a distinctive bulge just above a narrow dental band; labial crown face flat and generally smooth; roots have well-developed high and narrow lobes; lingual protuberance large; nutrient groove short and deep; lateral teeth have a mesodistally broad cusp that is flattened and blade-like relative to anteriors; one or two pairs of cusplets; crown faces range from weakly striated to smooth, unlike anteriors, that are heavily striated; roots are mesodistally expanded, having a rounded or tabular outline; roots holaulacorhizous; histology osteodont.

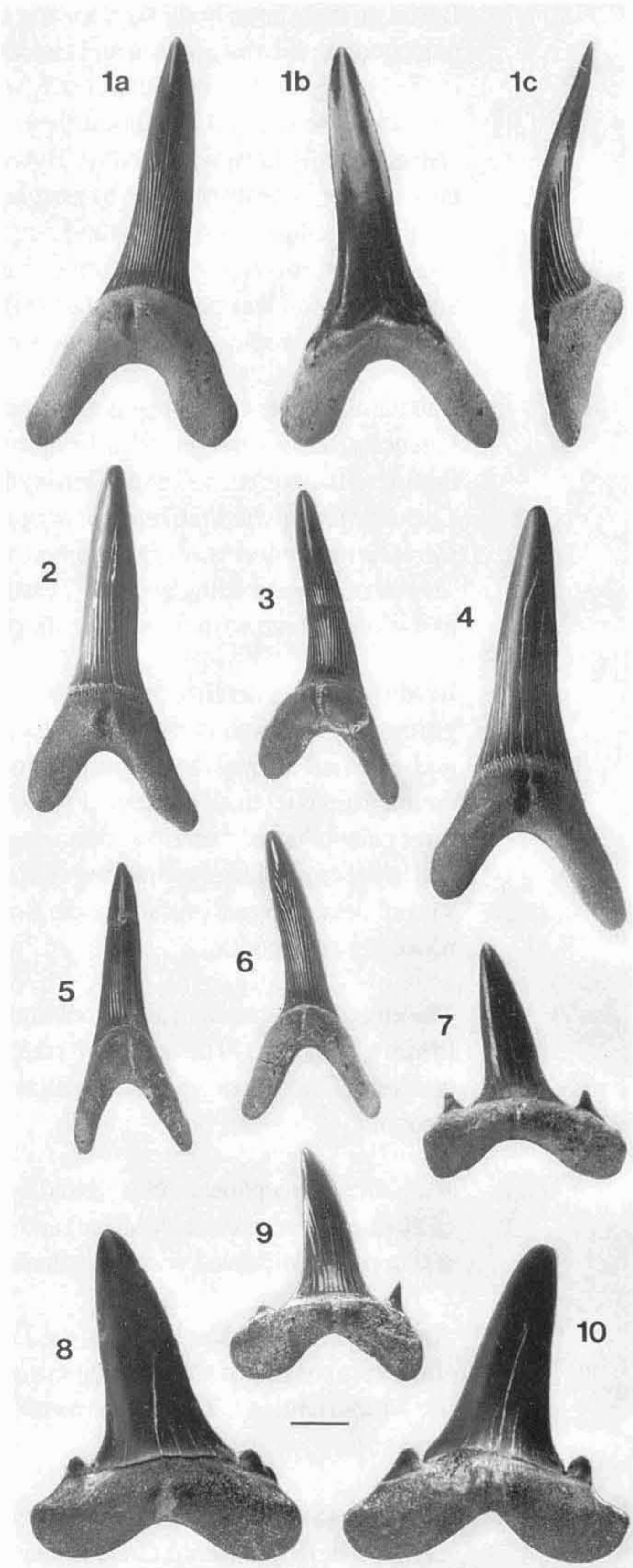
HETERODONTY: Strong disjunct monognathic and dignathic heterodonty with symphysial, anterior, lateral and posterior rowgroups.

DISTINGUISHING CHARACTERISTICS: Anterior teeth are distinguished from striated odontaspids and *Leptostyrax* by the minute size or absence of cusplets; very long, strong and parallel lingual crown striations, and a bulge at the base of the lingual crown foot. Lateral teeth can be confused with laterals of *Cretolamna*, but differ in having rounded rather than squared or angular root lobes and flattened or compressed crowns.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Campanian through Maestrichtian; especially abundant in the Campanian Taylor Group. Ozan, Wolf City, Kemp and Littig formations of Travis, Fannin, Hunt, Ellis and Dallas counties.

COMMENTS: This species is usually placed in synonymy with *Scapanorhynchus raphiodon*. Cappetta and Case (1975) note that the anterior teeth of *S. texanus* differ from *S. raphiodon* in having a larger size, stronger striations, smaller cusplets on lateral teeth and their frequent absence on anterior teeth.

REFERENCES: Roemer (1849), Cappetta and Case (1975).



***Scapanorhynchus texanus* (Roemer 1849): Taylor Group, Ozan Formation (Campanian), Fannin County. (1-6) anterior teeth; (7-10) lateral teeth. Tooth orientation: (1a, 2-10) lingual view; (1b) labial view; (1c) mesial view. Scale line = 5 mm.**

Family Cretoxyrhinidae

Based on their large body size, tearing or prehensile dentition, inferred patterns of heterodonty, paleogeographic distribution and the depositional environments in which they are found, sharks of the Family Cretoxyrhinidae clearly were the largest and most voracious of all fish predators in Cretaceous seas. In all likelihood, they occupied a niche equivalent to that filled by large mackerel sharks (Family Lamnidae) today. Based on what is known about the form and function in living lamnoids, it is probably safe to assume that many of the cretoxyrhinids were swift predators, having torpedo-shaped bodies and large tail fins with two lobes of nearly equal size. As in their living counterparts (e.g., great white shark, *Carcharodon carcharias*; makos and bonitos, *Isurus*; and the salmon and porbeagle, *Lamna*), they were coastal as well as oceanic fishes, and found worldwide in tropical, warm temperate and temperate seas.

The Family Cretoxyrhinidae is almost exclusively Cretaceous, ranging from late Aptian through Paleocene and is represented in Texas by six genera having a collective range from the late Aptian through Maestrichtian. Texas Cretoxyrhinidae include *Cretodus crassidens* and *C. semiplicatus, Cretoxyrhina mantelli, Cretolamna appendiculata* and *C. woodwardi, Leptostyrax macrorhiza, Paraisurus compressus*, *Protolamna* aff. *sokolovi* and several unnamed species referable to several of the preceding genera. Texas Cretaceous cretoxyrhinids reach their greatest diversity in the late Albian with five of the six genera occurring together at some localities.

It is difficult to generalize the tooth attributes of cretoxyrhinids because, as is typical of many shark groups (e.g., Orectolobiformes, Squaliformes, Hybodontiformes), there are always exceptions and aberrant forms that depart from more "typical" morphologies. In general, however, cretoxyrhinid teeth all possess: 1) intermediate to high and, in adults, massive crowns with up to three pairs of broad to narrow, often diverging cusplets; 2) smooth to strongly ornamented lingual and labial crown faces with strong cutting ridges; and 3) bilobate to sometimes massive roots with a pronounced lingual protuberance. Nutrient grooves are absent or are weakly developed. Tooth histology is osteodont.

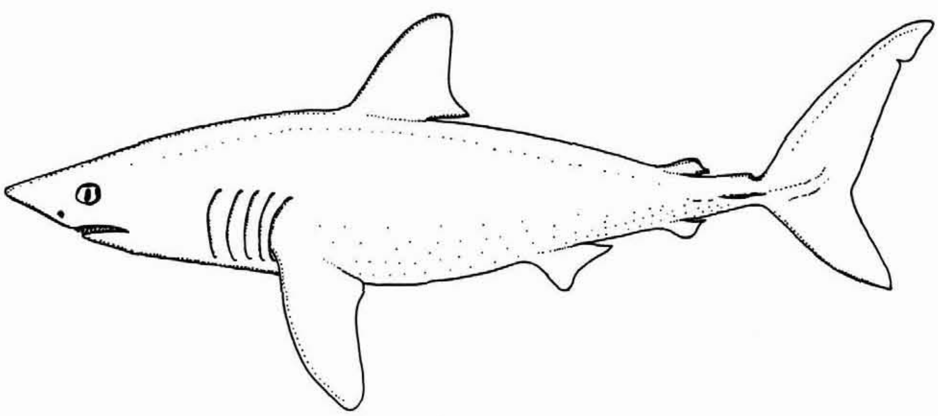
The largest shark teeth in Texas belong to *Cretodus crassidens* of the late Turonian and especially lower Coniacian. These highly prized teeth are relatively common in the lower Coniacian condensed section or so-called 'contact horizon' at the base of the Atco Formation of the Austin Group.

A number of exceptional cretoxyrhinid fossils have been found in Texas, including associated dentitions of *Paraisurus compressus* (Albian) and *Cretoxyrhina mantelli* (Cenomanian) and several associated and/or partly articulated vertebral columns of *Cretoxyrhina mantelli* (Cenomanian).

As is typical of other shark groups (e.g. *Ptychodus*, *Squalicorax*, odontaspids and *Scapanorhynchus*), some cretoxyrhinids show a progressive increase in tooth size from the Albian or Cenomanian to the Maestrichtian. This phenomena is found in the teeth of *Cretolamna*, *Cretoxyrhina* and *Cretodus*.

Because of their large size most Texas Cretaceous shark collections are dominated by cretoxyrhinid teeth; especially those of *Cretolamna appendiculata*, *Cretodus semiplicatus*, *C. crassidens* and

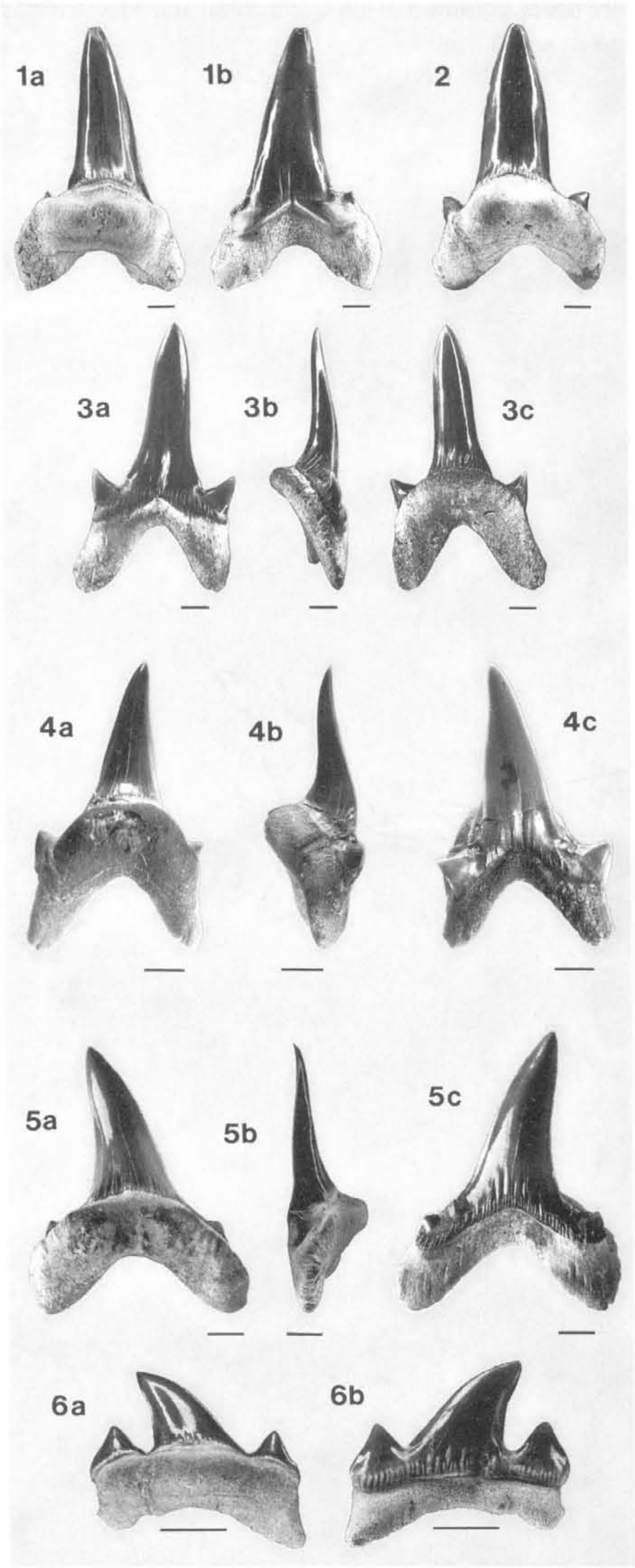
Cretoxyrhina mantelli. Cretoxyrhinids are not as common in the Campanian and Maestrichtian where the largest teeth belong to *Scapanorhynchus texanus.*



CRETODUS CRASSIDENS

Order LAMNIFORMES Berg 1958
Family CRETOXYRHINIDAE Gluckman 1958

Maximum Size: **66 mm** | Occurrence: **Common** | Chronologic Range: **Turonian-Coniacian**



Genus ***Cretodus*** Sokolov 1965
Cretodus crassidens (Dixon 1850)

DESCRIPTION: Anterior and lateral teeth high crowned, robust, with weak distal inclination; all rowgroups generally have one pair of short triangular cusplets except some anteriors and rarely laterals, which may have low, irregularly serrated blades; dental band well developed lingually; crown faces smooth except for short longitudinal ridges and enameloid plications at the crown foot on cusp and cusplets; root massive with a prominent lingual protuberance forming horizontal ridge spanning width of crown foot; nutrient groove, if present, small and poorly developed; root holaulacorhizous; histology osteodont.

HETERODONTY: Strong disjunct monognathic and moderate dignathic heterodonty with anterior, lateral and posterior rowgroups based on artificial tooth sets. Symphysials and intermediates are not present in the samples studied. Ontogenetic heterodonty is strongly expressed by development of massive crowns and roots in large teeth. Longitudinal striations generally become fewer in number and may disappear with age.

DISTINGUISHING CHARACTERISTICS: This species is characterized by its large, massive teeth, generally smooth crown faces with ridges only at the crown foot and roots having a shelf-like lingual root protuberance. *Cretodus crassidens* differs from *C. semiplicatus* in having a higher crown, larger overall tooth size and weaker longitudinal ridge development at the crown foot.

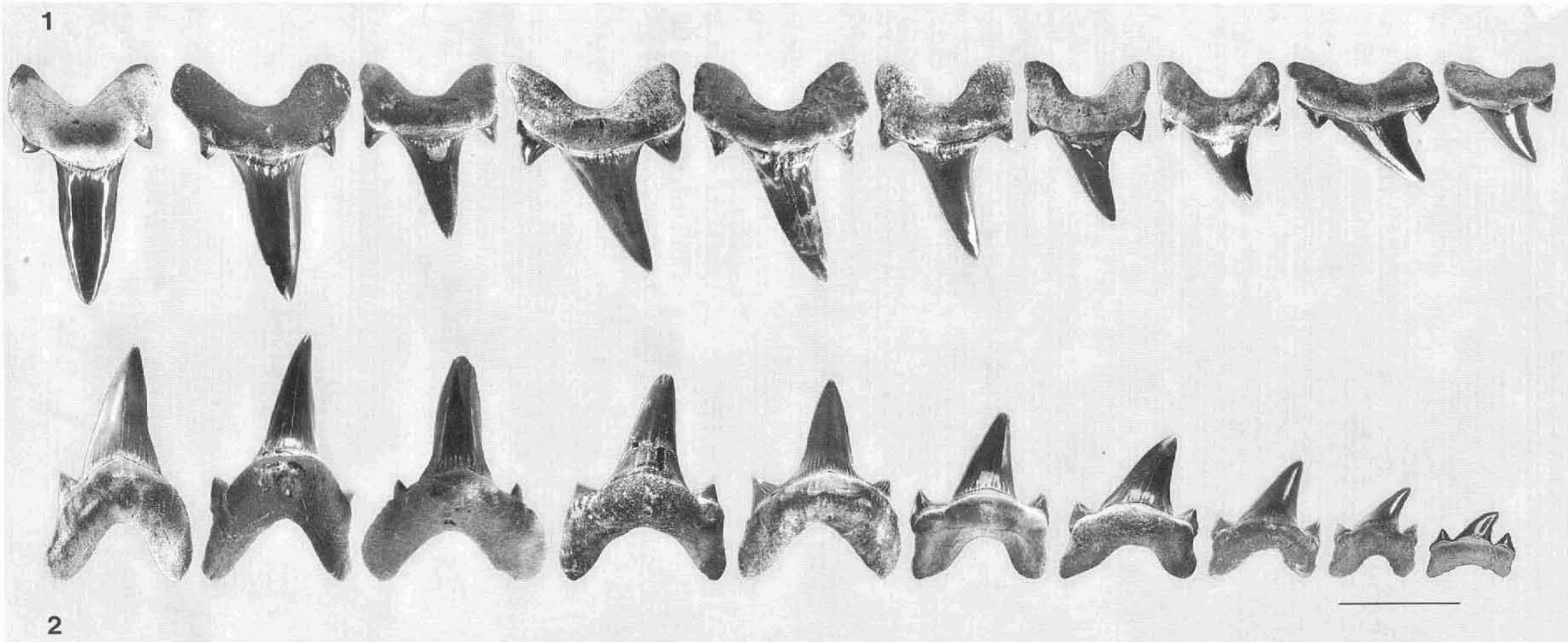
STRATIGRAPHIC OCCURRENCE IN TEXAS: Arcadia Park Formation, Eagle Ford Group (Turonian) and basal Atco Formation (contact horizon) of the Austin Group (Coniacian).

COMMENTS: With few exceptions, the largest teeth of *Cretodus* are found in the basal Atco Formation (contact horizon) of the Austin Group and many have been collected in commercial limestone quarries throughout the Austin outcrop belt. Leidy (1873) described teeth of this species from the Arcadia Park Formation of the Eagle Ford Group, which he referred to *Otodus divaricatus*. However, Dixon (1850) had already described the same species from the English Chalk under the name *Lamna crassidens*.

REFERENCES: Dixon (1850); Leidy (1873).

Cretodus crassidens **(Dixon 1850): Contact horizon of the Atco Formation (Coniacian), Austin Group in Travis (1) and Dallas (2-6) counties; (1) first upper right anterior tooth; (2) upper left first anterior tooth; (3) anterior tooth; (4) second lower right anterior tooth; (5) upper right lateral tooth; (6) lower left posterior tooth. Tooth orientation: (1a, 2, 3c, 4a-6a) lingual view; (1b, 3a, 4c, 5c, 6b) labial view; (3b) mesial view; (4b, 5b) distal view. Scale line = 5 mm.**

CRETODUS CRASSIDENS

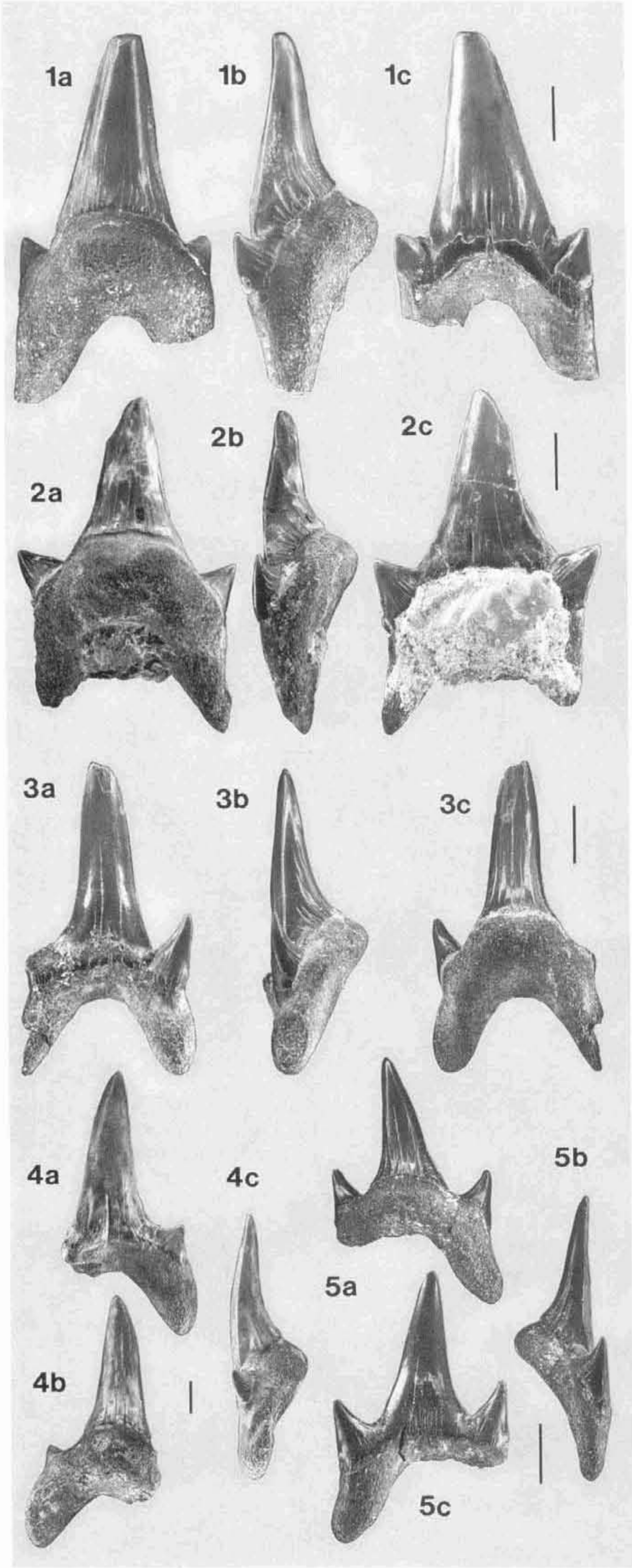


Cretodus crassidens **(Dixon 1850): Artificial tooth set of the (1) upper right and (2) lower right dental series constructed from teeth collected from the contact horizon at the base of the Atco Formation (Coniacian), Austin Group in Dallas County. Dashed line indicates the position of the jaw symphysis. Scale line = 1 cm.**

CRETODUS SEMIPLICATUS

Order LAMNIFORMES Berg 1958
Family CRETOXYRHINIDAE Gluckman 1958

Maximum Size: **41 mm** | Occurrence: **Common** | Chronologic Range: **Cenomanian**



Genus ***Cretodus*** Sokolov 1965
Cretodus semiplicatus (Munster in Agassiz 1843)

DESCRIPTION: Teeth of moderately large size, reaching 41 mm in anterior teeth; crown high and narrow, slightly flattened lingually near the crown foot and weakly convex labially; one pair of triangular cusplets ranging from broad and low to pointed and always strongly divergent; cusplets are continuous with cusp; labial and lingual cusp and cusplets have well defined longitudinal ridges although they are weaker labially than lingually; a weak labial basal ledge bearing deeply folded enameloid plications may occur on larger teeth; roots are strongly bilobate and U-shaped with a prominent bulbous lingual protuberance having one or two very small foramina; nutrient groove absent; roots holaulacorhizous; histology osteodont.

HETERODONTY: Strong disjunct monognathic and dignathic heterodonty with anterior, lateral and posterior rowgroups. Poor sample size precludes confirmation of other rowgroups (e.g., symphysials and intermediates). Ontogenetic heterodonty strong and expressed by development of massive crowns and roots.

DISTINGUISHING CHARACTERISTICS: Teeth of this species can be separated from *Cretodus crassidens* by their smaller adult size, stronger longitudinal crown ridges, more pronounced but centralized lingual protuberance and more elongate and U-shaped roots.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Pepper, Woodbine and basal Eagle Ford Group formations (Cenomanian) throughout Texas.

COMMENTS: These are the largest Cenomanian teeth in Texas. Earlier workers referred all Texas *Cretodus* to *C. semiplicatus*; however, it is now known to represent a distinctly smaller species than the late Turonian and early Coniacian *C. crassidens* of the upper Eagle Ford Group and basal Atco Formation contact horizon.

REFERENCES: Leidy (1873); Cappetta (1987).

Cretodus semiplicatus **(Munster in Agassiz 1843): Arlington Member of the Woodbine Formation (Cenomanian), Dallas County; (1-4) anterior teeth; (5) lateral tooth. Tooth orientation: (1a, 2a, 3c, 4b, 5a) lingual view; (1c, 2c, 3a, 4a, 5c) labial view; (1b, 3b, 5b) mesial view; (2b, 4c) distal view. Scale line = 5 mm.**

CRETOXYRHINA MANTELLI

Chronologic Range: **Cenomanian-Coniacian** | Occurrence: **Common** | Maximum Size: **63 mm**

Genus ***Cretoxyrhina*** Gluckman 1958
Cretoxyrhina mantelli (Agassiz 1843)

DESCRIPTION: Teeth large, very similar to the living mako shark *Isurus oxyrinchus*; crowns broad-based, moderately high, with strong distal inclination; a single pair of short blade-like cusplets may develop on the extreme ends of the crown foot in some lateral and posterior, but not anterior, rowgroups; most teeth of *C. mantelli* lack cusplets and the crown faces are always smooth; cutting ridge continuous to crown foot; broad dental band is present lingually; roots strongly bilobate and rounded with a strong lingual protuberance in anterior teeth; nutrient groove never developed; central lingual foramen, if present, is small; root holaulacorhizous; histology osteodont.

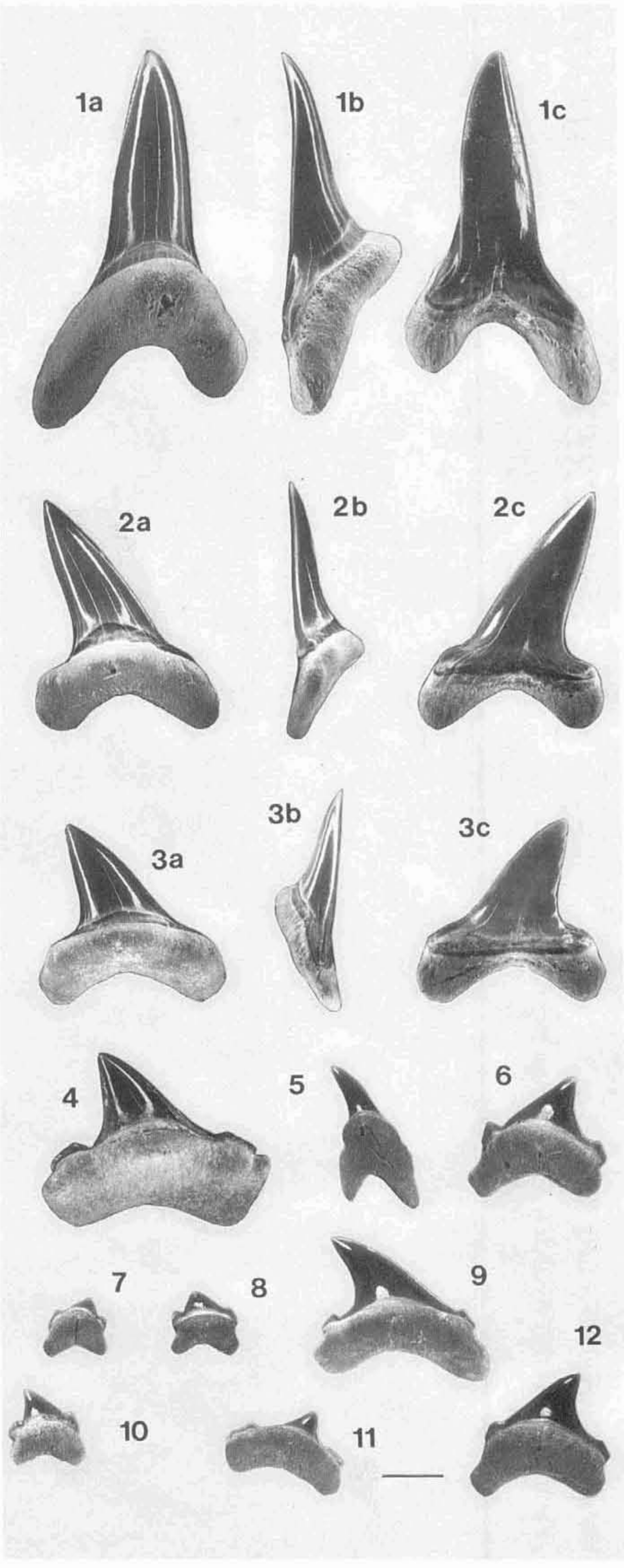
HETERODONTY: Moderate disjunct monognathic and dignathic heterodonty with anterior, intermediate, lateral and posterior rowgroups.

DISTINGUISHING CHARACTERISTICS: The teeth of *Cretoxyrhina mantelli* are most likely to be confused with *Cretolamna* and *Paranomotodon*. The absence of cusplets in anterior teeth (and usually in the rest of the teeth as well) distinguishes *C. mantelli* from *Cretolamna*, and the absence of a nutrient groove on the lingual root protuberance separates the former from *Paranomotodon*.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Eagle Ford Group and Atco Formation of the Austin Group (Cenomanian-Coniacian) throughout Texas.

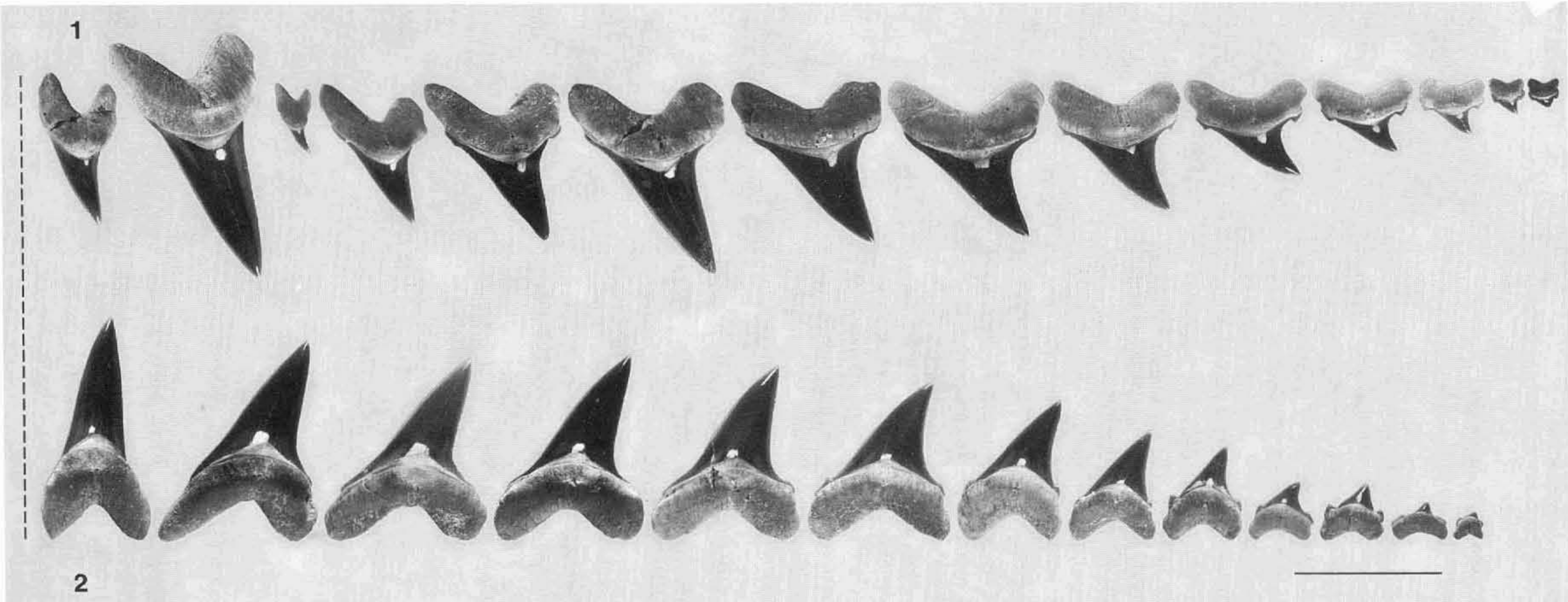
COMMENTS: Complete skeletons of *Cretoxyrhina mantelli* from the Cretaceous of Kansas exceed 6 m in length. In Texas, this species occurs most abundantly in the Tarrant and Britton formations of the Eagle Ford Group. The largest known Texas tooth of *C. mantelli* (63 mm) was collected in stream gravels derived from Coniacian or Santonian Austin Group sediments in Grayson County.

REFERENCES: Cappetta (1987).



Cretoxyrhina mantelli **(Agassiz 1843): Eagle Ford Group, Britton Formation (Cenomanian), Dallas County; (1-2) anterior teeth; (3,9) lateral teeth; (5) intermediate tooth; (4, 6, 7-8, 10-12) posterior teeth. Tooth orientation: (1a, 2a, 3a, 4-12) lingual view; (1c, 2c, 3c) labial views; (1b, 3b) mesial view; (2b) distal view. Scale line = 5 mm.**

CRETOXYRHINA MANTELLI



Cretoxyrhina mantelli **(Agassiz 1843): Britton Formation (Cenomanian), Eagle Ford Group, Dallas County. Upper (1) and lower (2) right dental series reconstructed from the associated dentition of one individual. Dashed line indicates the position of the jaw symphysis. Scale line = 1 cm.**

CRETOLAMNA APPENDICULATA

Chronologic Range: **Albian-Maestrichtian** | Occurrence: **Common** | Maximum Size: **26 mm**

Genus ***Cretolamna*** Gluckman 1958
Cretolamna appendiculata (Agassiz 1843)

DESCRIPTION: Teeth moderately large, often exceeding 1.5 cm. in anterior teeth; crowns with an erect, narrow cusp and one pair of triangular cusplets closely attached to cusp; labial and lingual crown faces smooth; labial face almost flat and lingual face strongly convex; cusp very weakly sigmoid in outline; roots bilobate, squared with a U-shaped interlobe area in upper teeth and a V-shaped interlobe profile in lower dentition; lingual attachment surface flat with a weak lingual protuberance, elongated below the crown foot; lingual dental band narrow; a small central lingual foramen often penetrates lingual root protuberance; nutrient groove never developed; root holaulacorhizous with secondary loss of nutrient groove; histology osteodont.

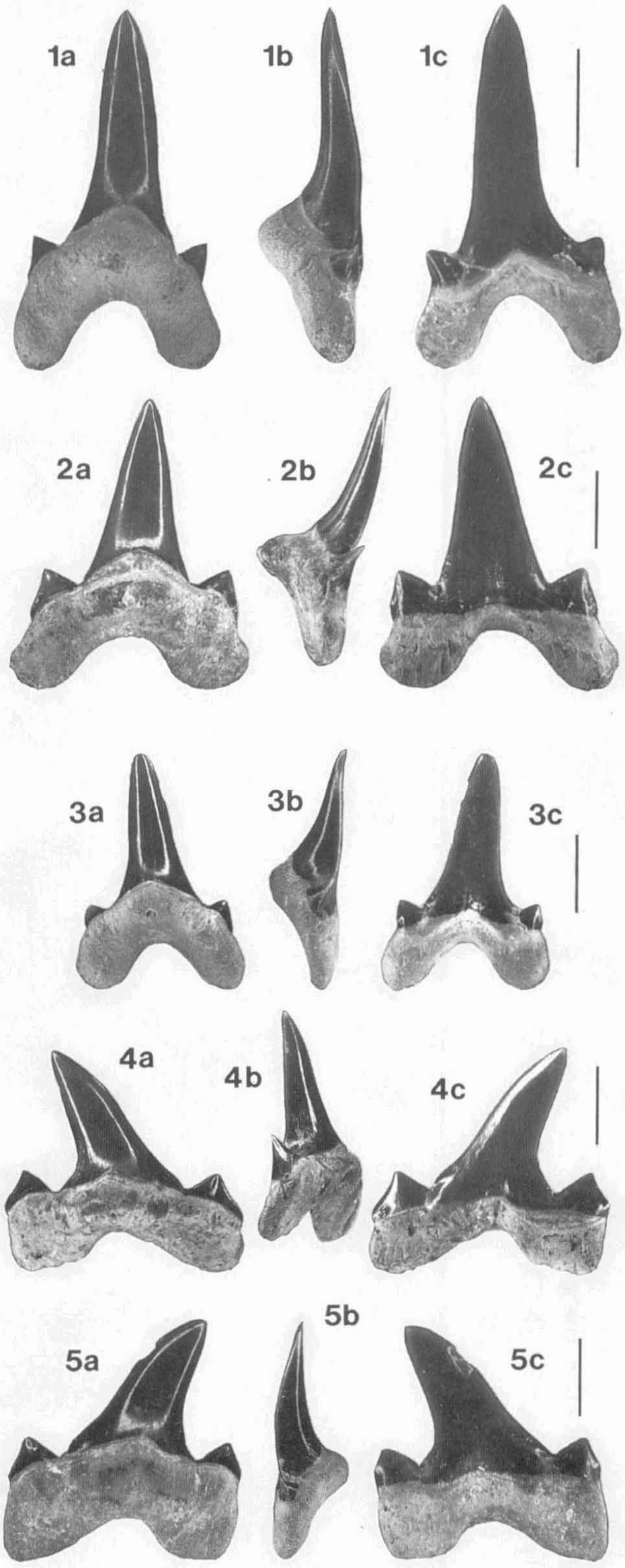
HETERODONTY: Moderate dignathic and disjunct monognathic heterodonty with anterior, intermediate, lateral and posterior tooth rowgroups. The presence of an upper intermediate rowgroup, as shown in our reconstructed artificial tooth set, is questionable.

DISTINGUISHING CHARACTERISTICS: The teeth of *Cretolamna appendiculata* differ from other lamnoids by the following characters in combination: a smooth crown, one pair of broad triangular cusplets, angular root lobes, especially in the lower dental series, and the absence of a nutrient groove on the lingual root protuberance.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Albian through Maestrichtian throughout Texas.

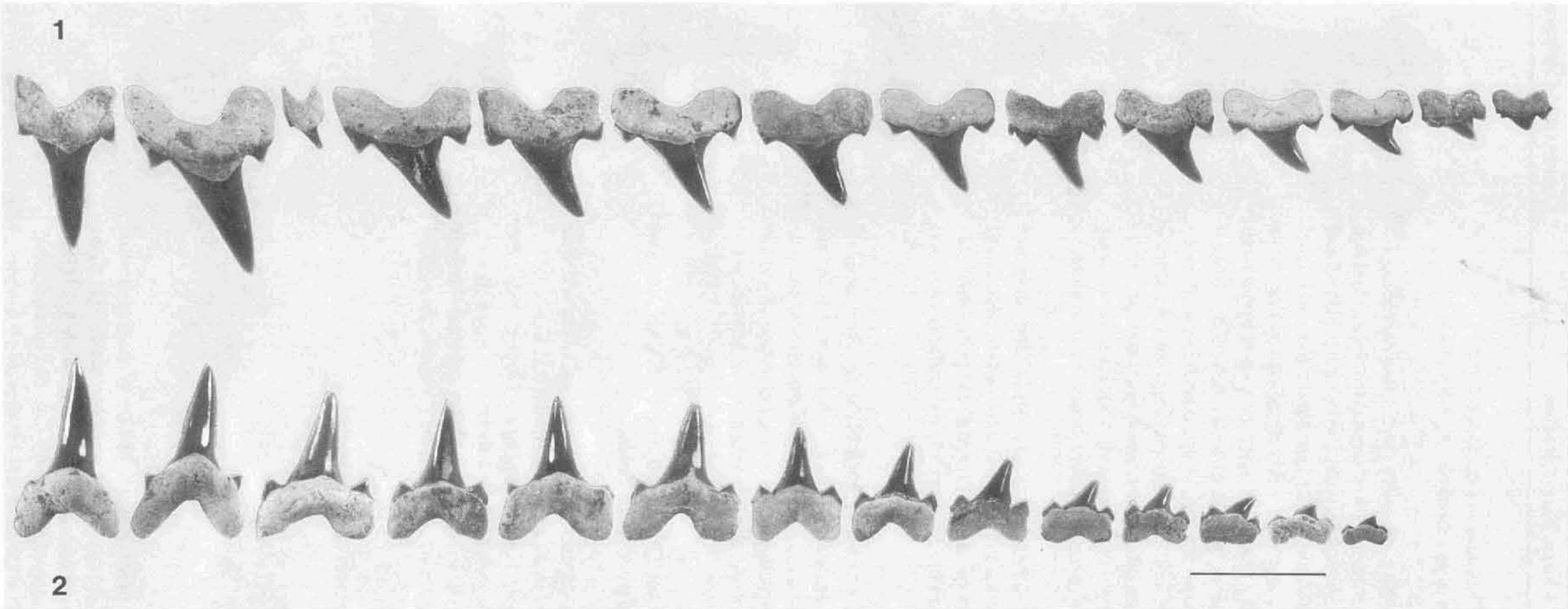
COMMENTS: This species is widespread in Texas and it is especially abundant in strata of upper Albian and Cenomanian (post Woodbine – Eagle Ford Group) age. Through time, the teeth of *Cretolamna appendiculata* appear to increase in size, beginning with the smallest teeth in the Albian and reaching their largest size in the Maestrichtian. More then one species may be represented.

REFERENCES: Herman (1977).



Cretolamna appendiculata **(Agassiz 1843): Weno Formation (Albian), Tarrant County; (1, 3) anterior teeth; (2, 4, 5) lateral teeth. Tooth orientation: (1a-5a) lingual view; (1c-5c) labial view; (1b, 2b, 4b) distal view; (3b, 5b) mesial view. Scale line = 5 mm.**

CRETOLAMNA APPENDICULATA



Cretolamna appendiculata **(Agassiz 1843): Weno Formation (Albian), Tarrant County. Artificial tooth set of upper (1) and lower (2) right dental series. Dashed line indicates the position of the jaw symphysis. Scale line = 1 cm.**

CRETOLAMNA WOODWARDI

Chronologic Range: **Turonian** | Occurrence: **Rare** | Maximum Size: **23 mm**

Genus ***Cretolamna*** Gluckman 1958
Cretolamna woodward Herman 1977

DESCRIPTION: Teeth similar to *Cretolamna appendiculata* but much more robust; cusp massive with broadly convex mesial and distal cutting edges; a single pair of narrow, peg-like, divergent cusplets are well attached to the crown foot; crown faces smooth; lingual dental band is well developed; roots massive, rounded, with a large lingual protuberance; foramina indistinct; nutrient groove never developed; lateral teeth are also massive, although they very closely resemble those of *C. appendiculata*; root holaulacorhizous; histology osteodont.

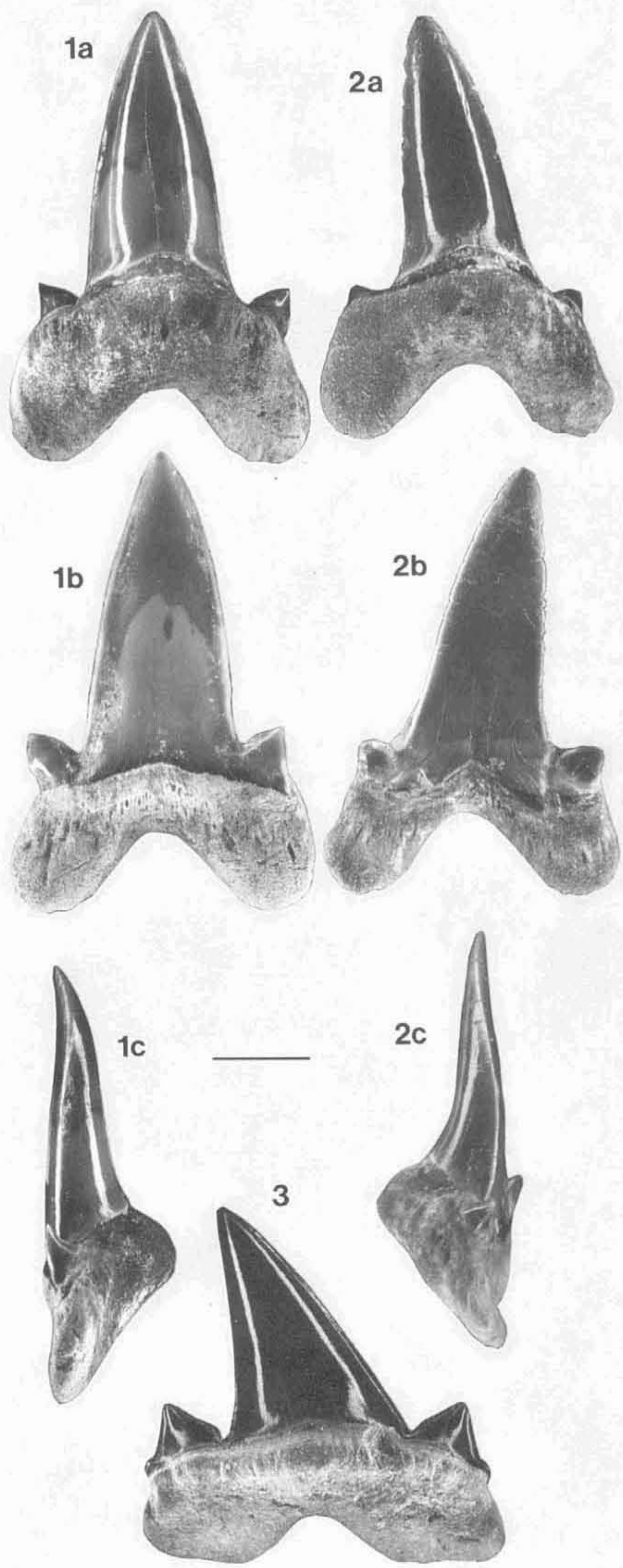
HETERODONTY: Unknown for the species but it is probably close to *Cretolamna appendiculata*.

DISTINGUISHING CHARACTERISTICS: The teeth of *Cretolamna woodwardi* are very rare and known only from large teeth. The diagnostic features of this species are best observed on anterior teeth. They differ from *C. appendiculata* in having more robust roots and larger crowns with convex mesial and distal cutting edges.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Kamp Ranch Limestone and Arcadia Park Formation (Turonian), Eagle Ford Group.

COMMENTS: Herman (1977) named this species on the basis of an associated dentition from the English Chalk. The teeth referred here to *Cretolamna woodwardi* compare very closely to his figured material. There is a possibility that *C. woodwardi* is an ontogenetic variant of *C. appendiculata*, especially since the specific characters which define the taxon are only expressed in very large teeth. Also, it has not been possible to isolate smaller (i.e., ontogenetically younger) teeth in the Eagle Ford which have the specific attributes of *C. woodwardi*.

REFERENCES: Herman (1977).

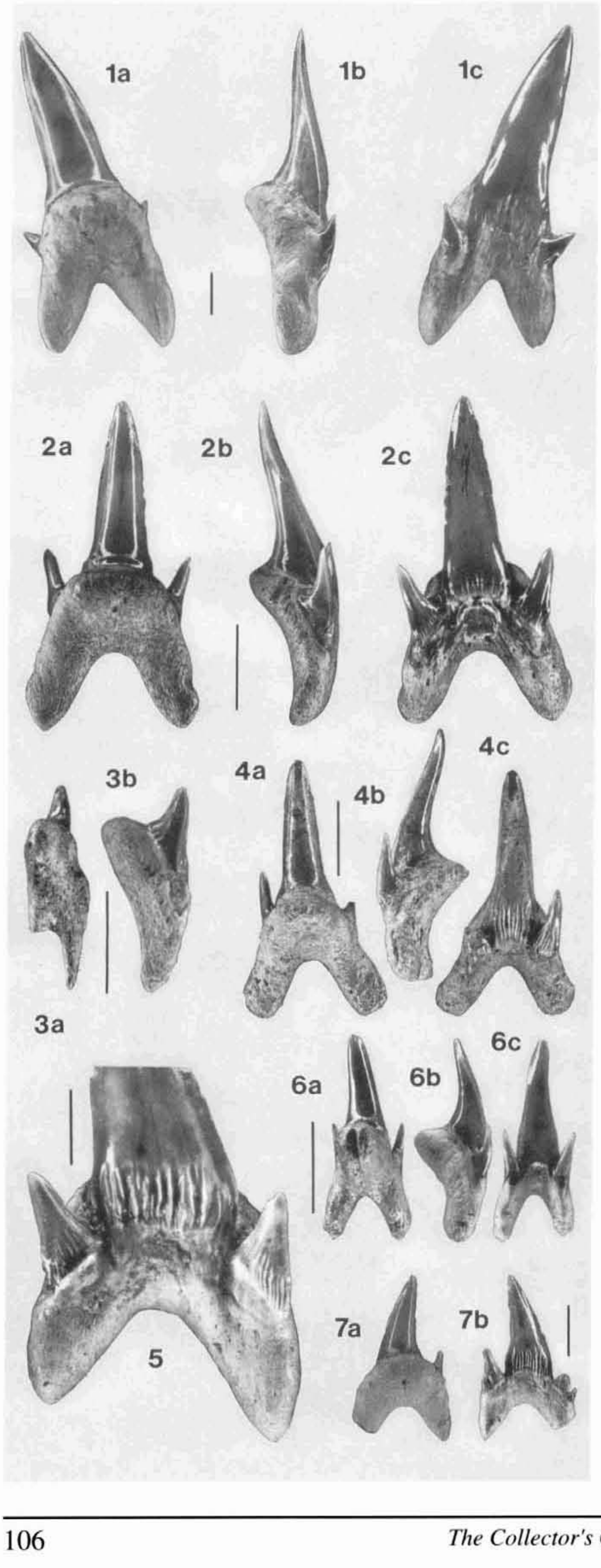


***Cretolamna woodwardi* Herman 1977: Arcadia Park Formation (Turonian), Eagle Ford Group, Dallas County; (1-2) anterior teeth; (3) lateral tooth. Tooth orientation: (1a, 2a, 3) lingual view; (1b, 2b) labial view; (1c, 2c) mesial view. Scale line = 5 mm.**

LEPTOSTYRAX MACRORHIZA

Order LAMNIFORMES Berg 1958
Family CRETOXYRHINIDAE Gluckman 1958

Maximum Size: **49 mm** | Occurrence: **Common** | Chronologic Range: **Albian-Cenomanian**



Genus ***Leptostyrax*** Williston 1900
Leptostyrax macrorhiza (Cope 1875)

DESCRIPTION: Large teeth having narrow and very high crowns, constricted just above crown foot; cusplets needle-like, tall, one pair, situated lateral to and in front of cusp; crown strongly sigmoid, both faces convex; lingual crown face smooth with sparse, short ridges occasionally occurring at crown foot; short, strong longitudinal ridges cover the crown foot labially on the cusp and cusplets; root lobes well developed, may become somewhat tabular at their distal ends, and diverge basally in a fashion similar to *Mitsukurina*; attachment surface of root strongly concave and all teeth have a large and massive lingual protuberance; nutrient groove absent; root holaulacorhizous; histology osteodont.

HETERODONTY: Based on an artificial tooth set, *Leptostyrax* has weak disjunct monognathic heterodonty in both jaws; dignathic heterodonty is weak or absent. Very little distal crown flexure occurs along the dental series. Symphysial teeth are definitely found in the dentition but the presence of an intermediate rowgroup is questionable.

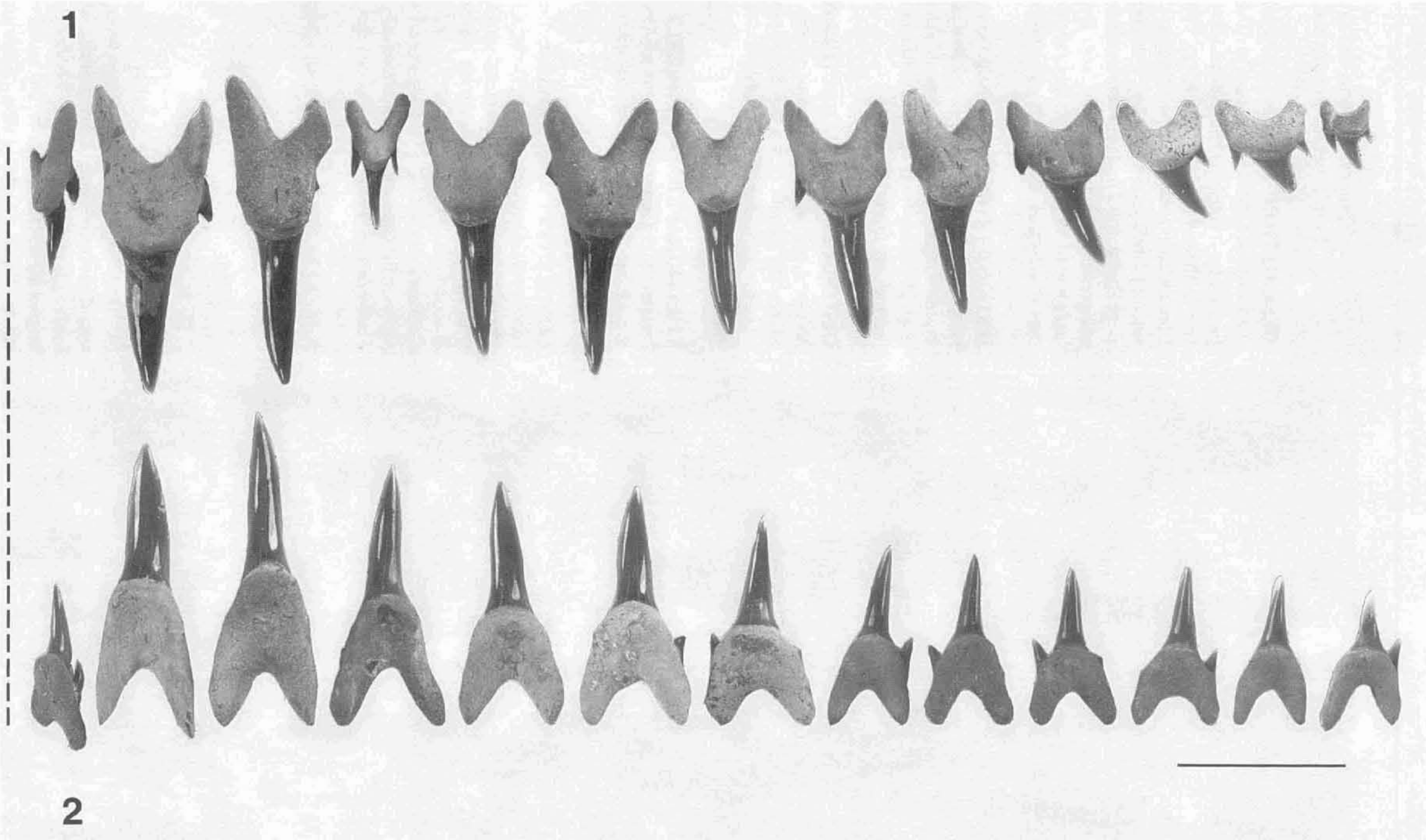
DISTINGUISHING CHARACTERISTICS: The teeth of *Leptostyrax* are unique in appearance and easily distinguished from other lamnoids based on the following combination of characters: divergent root lobes, a large lingual root protuberance, absence of a nutrient groove, needle-like cusplets situated in front (more lingual) of the cusp, and a narrow cusp with strong labial ridges at the crown foot.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Weno, Pawpaw, Duck Creek, Grayson and Del Rio formations (Albian); Woodbine and Pepper formations (Cenomanian); throughout Texas.

COMMENTS: The largest Albian teeth in Texas belong to this species. Cappetta (1987) pointed out that teeth described by Cope in 1875 as *Lamna macrorhiza*, from the Albian of Texas, are laterals of Williston's *Leptostyrax bicuspidatus* which he described from Kansas in 1900: Cope's species takes priority. Teeth of *Leptostyrax*, but not *L. macrorhiza*, are found in the Cenomanian through early Coniacian in Texas.

REFERENCES: Cope (1875); Williston (1900); Cappetta (1987).

Leptostyrax macrorhiza **(Cope 1875): Weno Formation (Albian), Tarrant County; (1) anterior tooth; (2, 4-7) lateral teeth; (3) symphysial tooth. Tooth orientation: (1a-4a, 6a, 7a) lingual view; (1c, 2c, 4c, 5, 6c, 7b) labial view; (1b, 6b) mesial view; (2b-4b) distal view. Scale line = 5 mm.**

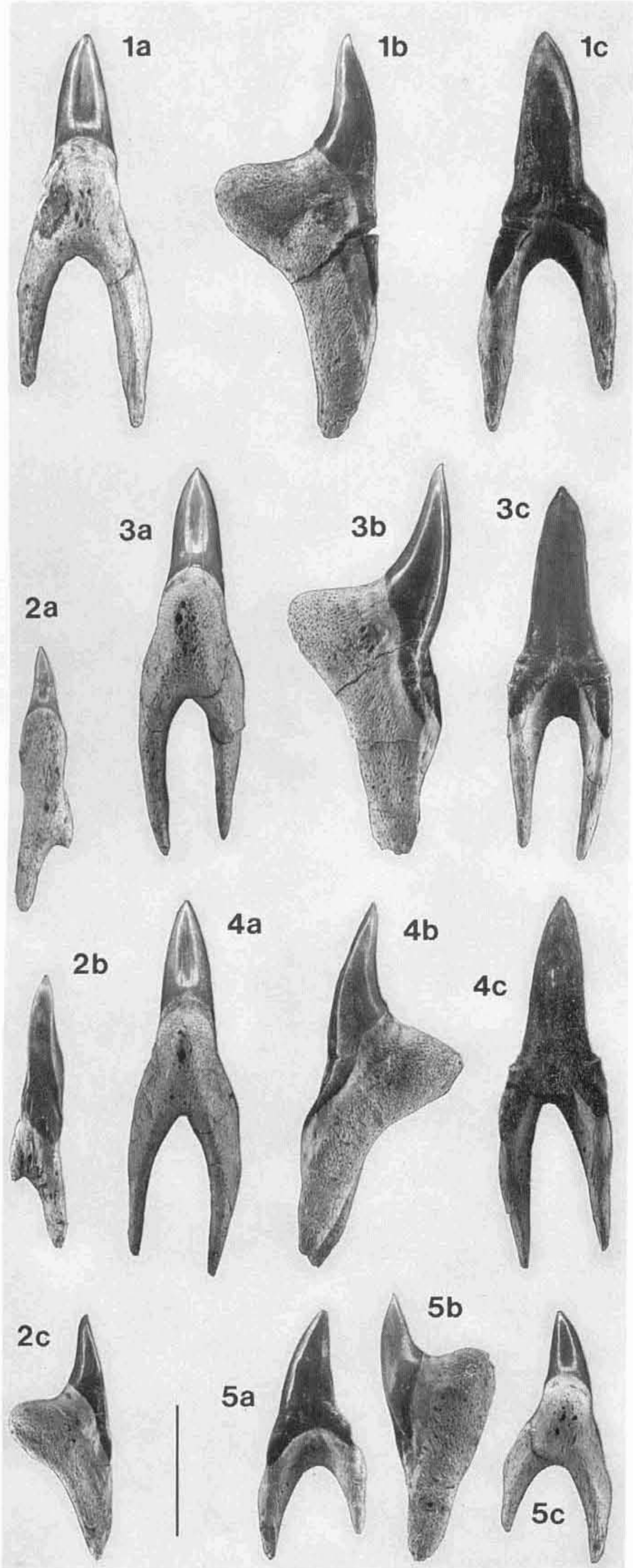


Leptostyrax macrorhiza **(Cope 1875): Artificial tooth set of the upper (1) and lower (2) right dental series based on isolated teeth from one locality in the Weno Formation (Albian), Tarrant County. Dashed line indicates the position of the jaw symphysis. Scale line = 1 cm.**

PARAISURUS COMPRESSUS

Order LAMNIFORMES Berg 1958
Family CRETOXYRHINIDAE Gluckman 1958

Maximum Size: **30 mm** | Occurrence: **Rare** | Chronologic Range: **Albian-?Cenomanian**



Genus ***Paraisurus*** Gluckman 1957
Paraisurus compressus Sokolov 1978

DESCRIPTION: Teeth mesodistally compressed; crown short with long, thin shoulders; mesial and distal cusp edges roughly parallel for a considerable distance above the crown foot, then turn in sharply forming cusp apex; cutting ridges continuous from the cusp apex to the distal ends of shoulders; crown faces smooth; labial crown face has a distinct median longitudinal ridge above crown foot; cusplets never developed; roots highly compressed with an unusually large lingual protuberance that lacks a nutrient groove; root lobes are labiolingually wide and mesodistally thin, long and fragile; histology osteodont.

HETERODONTY: *Paraisurus* has weak gradient monognathic heterodonty in both jaws. Dignathic condition unknown but assumed to be very weak or absent. An associated dentition of over 250 teeth from one individual clearly shows the weak heterodonty in *Paraisurus*.

DISTINGUISHING CHARACTERISTICS: The highly compressed crown and root, extremely large lingual root protuberance, short smooth crown lacking cusplets, and thin, long root lobes are attributes of *Paraisurus* that readily separate it from other lamnoids.

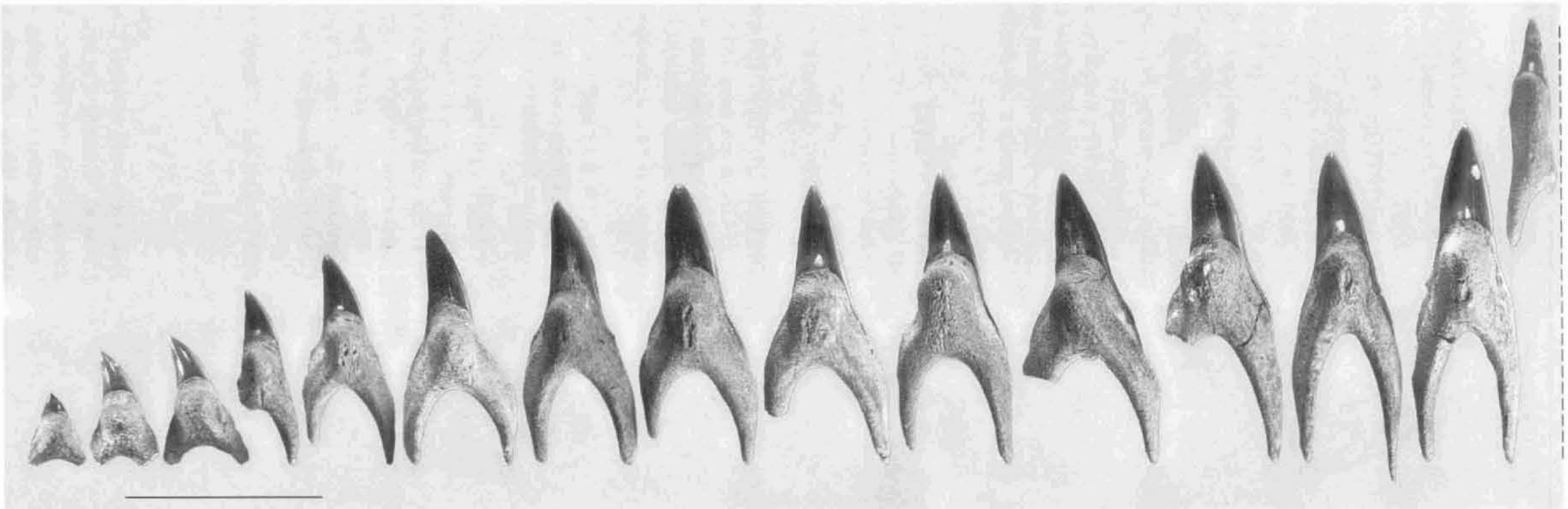
STRATIGRAPHIC OCCURRENCE IN TEXAS: Weno-Pawpaw and Grayson formations (Albian) and possibly the Woodbine Formation (Cenomanian), Tarrant, Denton and Grayson counties.

COMMENTS: One Cenomanian tooth of *Paraisurus compressus* is known to us from Texas; all others are late Albian. These teeth are never common and usually occur in association with *Squalicorax* sp., *Cretolamna appendiculata*, *Leptostyrax macrorhiza*, *Protolamna* aff. *sokolovi* and the sawfish *Onchopristis dunklei*. An undescribed species of *Paraisurus* occurs in the Coniacian 'contact horizon' of the Atco Formation, Austin Group. Teeth with unbroken root lobes are uncommon.

REFERENCES: Sokolov (1984); Cappetta (1987).

***Paraisurus compressus* Sokolov 1978: Weno Formation (Albian), Tarrant County; Teeth from an associated dentition of one individual; (1,3-4) anterior teeth; (5) anterolateral tooth; (2) symphysial tooth. Tooth orientation: (1a-4a, 5c) lingual view; (1c, 2b, 3c, 4c, 5a) labial view; (1b, 2c) mesial view; (3b, 4b, 5b) distal view. Scale line = 1 cm.**

PARAISURUS COMPRESSUS

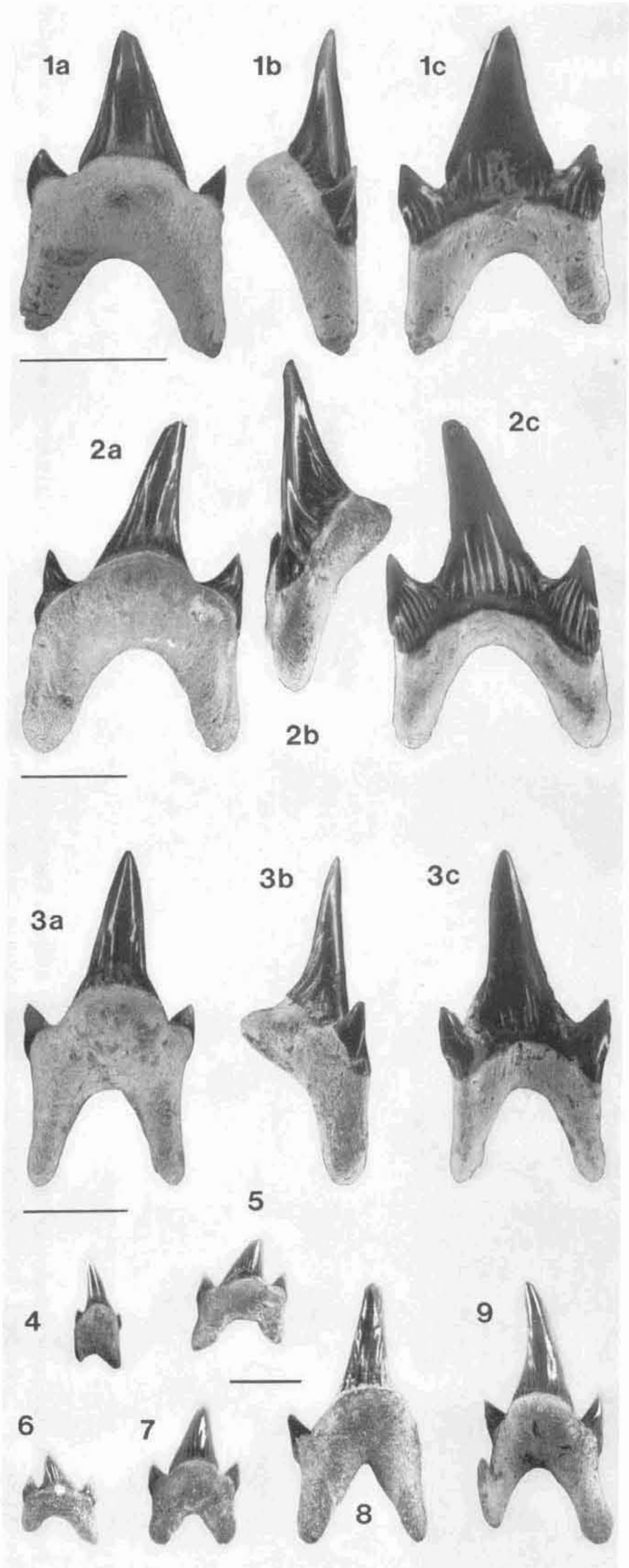


***Paraisurus compressus* Sokolov 1978: Weno Formation (Albian), Tarrant County. Lower left or upper right dental series reconstructed from an association of 250+ teeth from one individual. Dashed line indicates the position of the jaw symphysis. Scale line = 1 cm.**

PROTOLAMNA aff. *SOKOLOVI*

Order LAMNIFORMES Berg 1958
Family CRETOXYRHINIDAE Gluckman 1958

Maximum Size: **18 mm** | Occurrence: **Common** | Chronologic Range: **Albian-Cenomanian**



Genus ***Protolamna*** Cappetta 1980
Protolamna aff. ***sokolovi*** Cappetta 1980

DESCRIPTION: Teeth of *Protolamna* have a proportionally large root and small, broad-based but narrow and fairly straight crown; crown and root are approximately equal height; one pair of short, broad and sharply divergent cusplets are set low on crown and appear to be widely separated from cusp in lingual view; labial crown face nearly flat; basal ledge well developed; strong longitudinal ridges extend from crown foot, apically for about half the crown height and almost reach apex on cusplets; crown face convex lingually with strong longitudinal ridges extending almost to the apex; narrow lingual dental band; roots strongly bilobate with a pronounced lingual protuberance that often bears one or more small central foramina and only rarely a short nutrient groove; root lobes roughly subparallel and have a U-shaped profile in labial or lingual view; root holaulacorhizous; histology osteodont.

HETERODONTY: Based on an artificial tooth set of *Protolamna* aff. *sokolovi* from the Weno Formation (Albian), Tarrant County; this taxon has weak gradient monognathic and very weak dignathic heterodonty. Anterior, intermediate, lateral and posterior rowgroups are differentiated along the dental series.

DISTINGUISHING CHARACTERISTICS: The teeth of *Protolamna* are most likely to be confused with species of *Cretodus* and differ from the latter in being smaller, having narrower crowns, a relatively larger root, narrower and higher cusplets and a more pronounced lingual root protuberance.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Weno, Pawpaw, Grayson and Duck Creek (Albian) and the Pepper and Woodbine formations (Cenomanian).

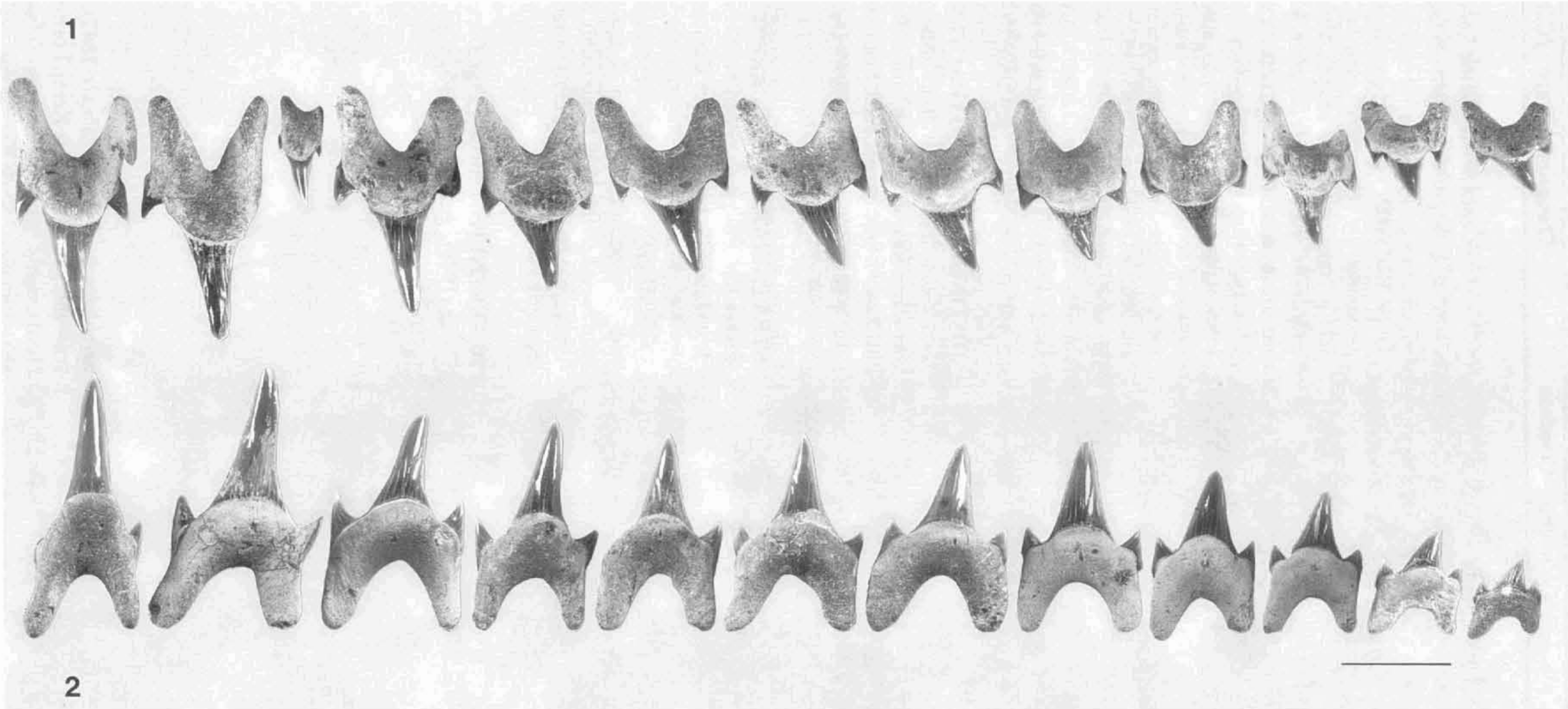
COMMENTS: The type species *Protolamna sokolovi* Cappetta 1980 is very close to *Protolamna* aff. *sokolovi* from the Albian of Texas, but slight differences in crown characters preclude its placement in this species with certainty. The genus *Protolamna* also occurs elsewhere in Texas; including the Eagle Ford Group (Turonian), the Austin Group (Coniacian-Santonian), the Taylor Group (Campanian) and the Maestrichtian Kemp Formation.

REFERENCES: Cappetta (1980, 1987).

***Protolamna* aff. *sokolovi* Cappetta 1980: Weno Formation (Albian), Tarrant County. (1-2) lateral teeth; (3, 8, 9) anterior teeth; (4) ?intermediate tooth; (5-7) posterior teeth. Tooth orientation: (1a-3a, 4-9) lingual view; (1c-3c) labial view; (1b-3b) mesial view. Scale line = 5 mm.**

Order LAMNIFORMES Berg 1958
Family CRETOXYRHINIDAE Gluckman 1958

PROTOLAMNA aff. *SOKOLOVI*

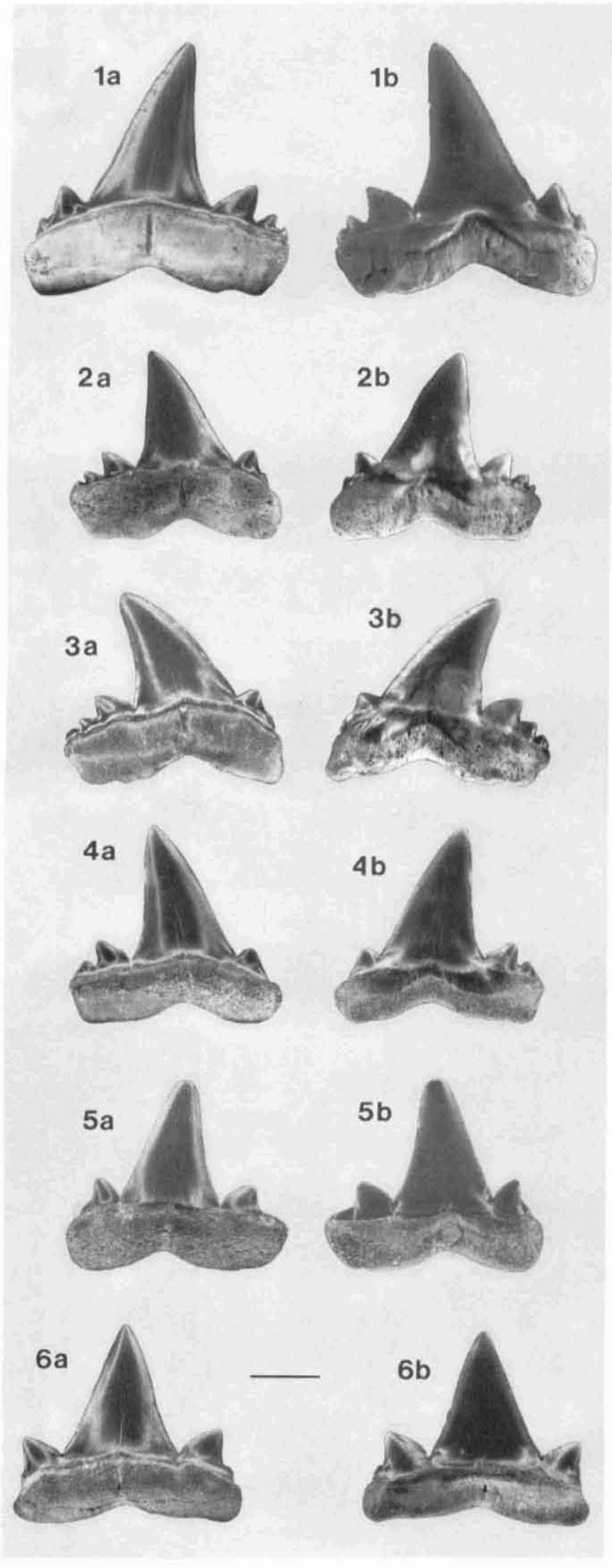


***Protolamna* aff. *sokolovi* Cappetta 1980: Weno Formation (Albian), Tarrant County. Artificial tooth set of the upper (1) and lower (2) right dental series. Dashed line indicates position of jaw symphysis. Scale line = 1 cm.**

SERRATOLAMNA SERRATA

Order LAMNIFORMES Berg 1958
Family SERRATOLAMNIDAE Landemaine 1991

Maximum Size: **17 mm** | Occurrence: **Common** | Chronologic Range: **?Campanian-Maestrichtian**



Genus ***Serratolamna*** Landemaine 1991
Serratolamna serrata (Agassiz 1843)

DESCRIPTION: Crown broad-based with a wide, flattened (labiolingually compressed) cusp that is smooth on both faces; one to three pairs of diverging, asymmetric cusplets; distal cusplets recurve distally, often outnumber mesial cusplets which recurve in a mesial direction; dental band well defined lingually; labial crown foot only weakly developed into a basal ledge; root lobes separated by a V-shaped notch, weakly bilobate and expanded horizontally; root lobes distinctly asymmetrical with the distal lobe longer than the mesial one; nutrient groove is situated high on the lingual protuberance; root holaulacorhizous; histology osteodont.

HETERODONTY: Unknown, but probably moderate disjunct monognathic and dignathic heterodonty.

DISTINGUISHING CHARACTERISTICS: The teeth of *Serratolamna serrata* are easily distinguished from *Cretolamna appendiculata*, and all other lamnoids, by the following features in combination: pronounced tooth asymmetry, multiple and diverging cusplets, smooth crown faces and the presence of a short nutrient groove.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Kemp, Escondido, Littig and upper Taylor Marls in Medina, Hunt, Travis and Ellis counties (?late Campanian-Maestrichtian).

COMMENTS: *Serratolamna serrata* is rare in the upper Taylor and common in the Navarro of Texas. Another species, *S. caraibaea* Leriche 1938 and possibly *S. biauriculata* (Wanner 1902) are also similar to late Cretaceous taxa which may occur in the Littig Formation.

REFERENCES: Leriche (1938); Dartevelle and Casier (1943); Casier (1943); Arambourg (1952).

Serratolamna serrata **(Agassiz 1843): Anterolateral teeth from the Navarro Group, Kemp Formation (Maestrichtian), Hunt County. Tooth orientation: (1a-6a) lingual view; (1b-6b) labial view. Scale line = 1 cm.**

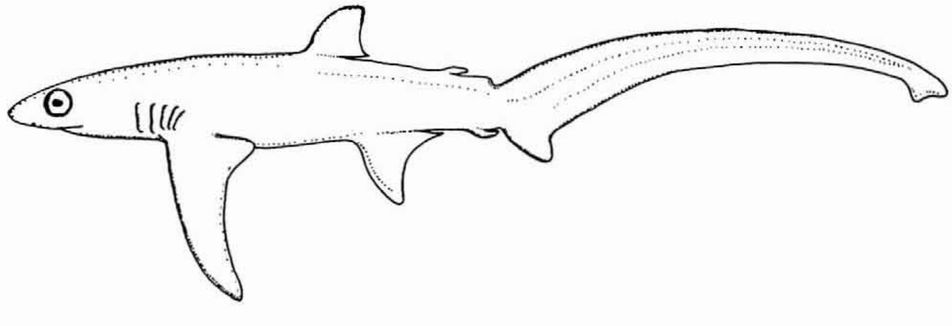
Family Alopiidae

Thresher sharks, Family Alopiidae Bonaparte 1838, are a small family of sharks found worldwide in tropical to temperate seas. The most notable feature of *Alopias* Rafinesque 1810, the only extant genus in the family, is its exceptionally long upper tail lobe, that may exceed the length of the body. Other attributes include a short and rounded snout, small mouth, numerous small teeth for the body size (excluding *A. supersciliosus*) and long, narrow pectoral fins. Threshers average about 3 or 4 meters in length but may exceed six meters. The common name "thresher" relates to the feeding behavior of injuring or killing small schooling fish or squid by thrashing them with their tail. Alopiids generally live near the surface in the open ocean, but some venture into shallow, near-shore waters.

The fossil record of *Alopias* ranges from the Lower Eocene to Recent; however, the family is reported from the Cenomanian through Campanian strata of the Upper Cretaceous based on occurrences of the genus *Paranomotodon* Herman (in Cappetta and Case 1975). Inclusion of this genus in the Alopiidae is somewhat problematical and based on similarities between the teeth of *Paranomotodon* and the bigeye thresher *Alopias superciliosus* (Lowe 1840).

The anterior teeth of Texas *Paranomotodon* have narrow cusps with complete cutting ridges. They are strongly convex lingually and have a weakly convex labial face. Both crown faces are smooth and there is a pronounced basal ledge at the labial crown foot. The roots are bilobate and are morphologically close to *Isurus*. The lingual protuberance is large with a well developed nutrient groove. Lateral teeth have mesodistally expanded and shorter crowns, broad roots and very characteristic low, horizontal mesial and distal blades. A small cusp may develop at the distal end of each blade. A nutrient groove is present on all lateral teeth and the histology is osteodont.

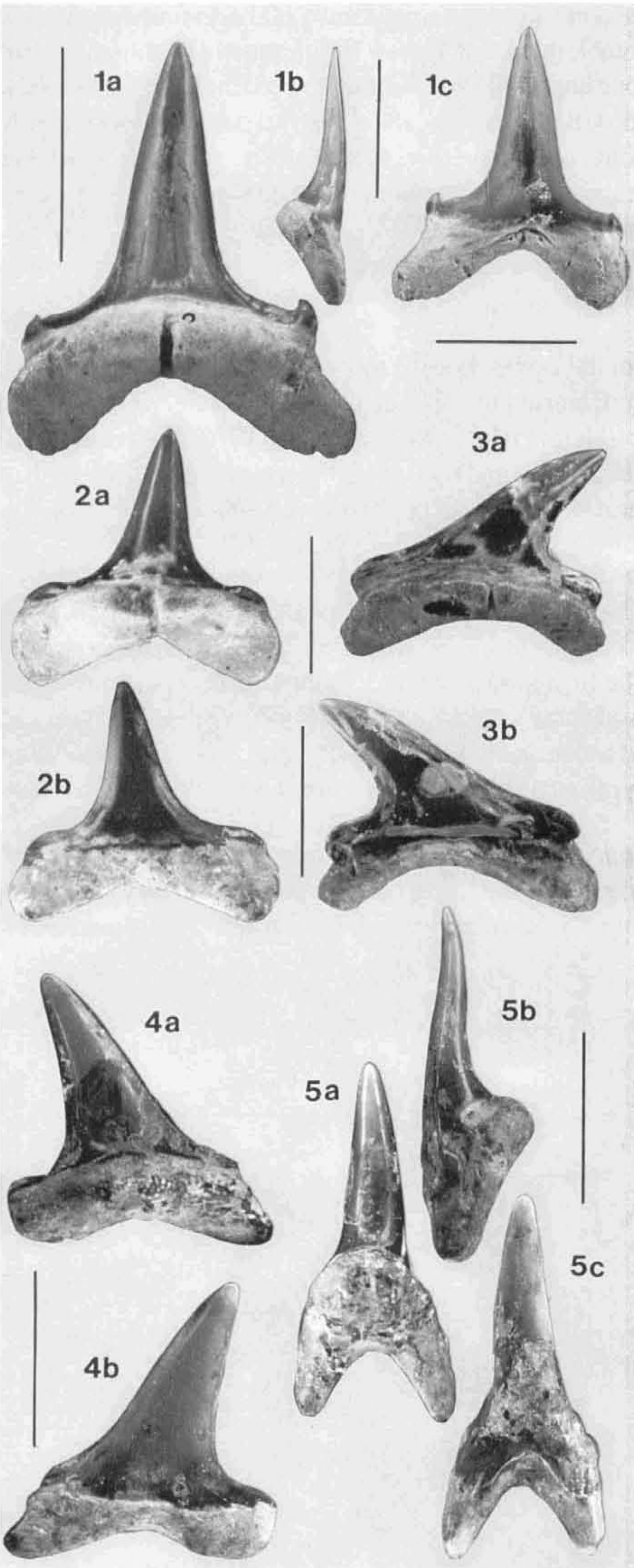
In Texas, isolated teeth of *Paranomotodon* occur in Santonian horizons of the Austin Group and are relatively abundant in overlying Campanian strata of the Taylor Group. Teeth of this genus from Texas do not compare favorably with any described species and most likely represent a new taxon.



PARANOMOTODON sp.

Order LAMNIFORMES Berg 1958
Family ALOPIIDAE Bonaparte 1838

Maximum Size: **17 mm** | Occurrence: **Common** | Chronologic Range: **Santonian-Campanian**



Genus ***Paranomotodon*** Herman in Cappetta and Case 1975
Paranomotodon sp.

DESCRIPTION: The teeth of *Paranomotodon* are moderately large, up to 17 mm high; teeth close to *Cretoxyrhina*; cusps high with smooth labial and lingual faces; mesial and distal shoulders are very diagnostic of this genus, being high and nearly horizontal, especially in lateral teeth; incipient blade-like cusplets develop on some teeth; in lateral teeth, mesial cutting edge expanded basally, almost eliminating the blade; dental band well developed; root lobes not particularly large; lingual root protuberance low and always bears a distinct nutrient groove; root holaulacorhizous; histology osteodont.

HETERODONTY: Moderate disjunct monognathic and dignathic heterodonty.

DISTINGUISHING CHARACTERISTICS: The teeth of *Paranomotodon* are most likely to be confused with *Cretoxyrhina mantelli* but differ from the latter in having very distinct, high and horizontal mesial and distal blades (lateral teeth) and a clear nutrient groove on the lingual root protuberance.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Austin Group (Santonian), Ozan, Wolfe City, Pecan Gap (Campanian) and Kemp (Maestrichtian) formations, Ellis, Hunt and Fannin counties.

COMMENTS: *Paranomotodon* occurs sparsely in the Austin Chalk but is relatively common in the overlying Campanian Ozan, Wolfe City, Pecan Gap Chalk and Maestrichtian Kemp formations. It appears that there are at least one or two undescribed species.

REFERENCES: Cappetta and Case (1975); Herman (1977); Cappetta (1987).

***Paranomotodon* sp.: (1) upper Austin Group (Santonian), Ellis County; (2-5) Taylor Group, Ozan Formation (Campanian), Ellis County; (1-4) lateral teeth; (5) anterior tooth. Tooth orientation: (1a-5a) lingual view; (1c, 2b-4b, 5c) labial view; (1b) distal view; (5b) mesial view. Scale line = 5 mm.**

Family Anacoracidae

Three genera of sharks comprise the extinct crow shark family Anacoracidae found in the Texas Cretaceous: *Squalicorax* Whitley 1939, *Pseudocorax* Priem 1897 and *Microcorax* Cappetta and Case 1975.

The most notable genus in the family, and one that is familiar to almost all Texas collectors, is *Squalicorax* with its highly serrated and moderately large teeth (up to almost 3 centimeters in *S. pristodontus*), reminiscent of the modern tiger shark *Galeocerdo*. Isolated teeth and vertebrae of this genus range from late Albian through Maestrichtian in Texas and include a primitive undescribed species (late Albian), *S. curvatus* (Cenomanian), *S. falcatus* (Cenomanian-Coniacian or Santonian), *S. kaupi* (Campanian) and *S. pristodontus* (Campanian-Maestrichtian). This stratigraphic and chronologic succession of species approximates a lineage with the attributes of one species grading into those of the next higher (younger) species. Albian forms have weakly serrated, almost smooth crowns with low and strongly bilobate roots while Maestrichtian teeth possess highly inflated crowns with very strong serrations and high, flat or almost tabular, weakly bilobate roots.

The genus *Microcorax* was originally described by Cappetta and Case (1975) from the Arlington member of the Woodbine Formation in Dallas County and contains only the type species *Microcorax crassus* Cappetta and Case 1975. This species occurs commonly in the Woodbine and Pepper formations and in Cenomanian formations of the Eagle Ford Group.

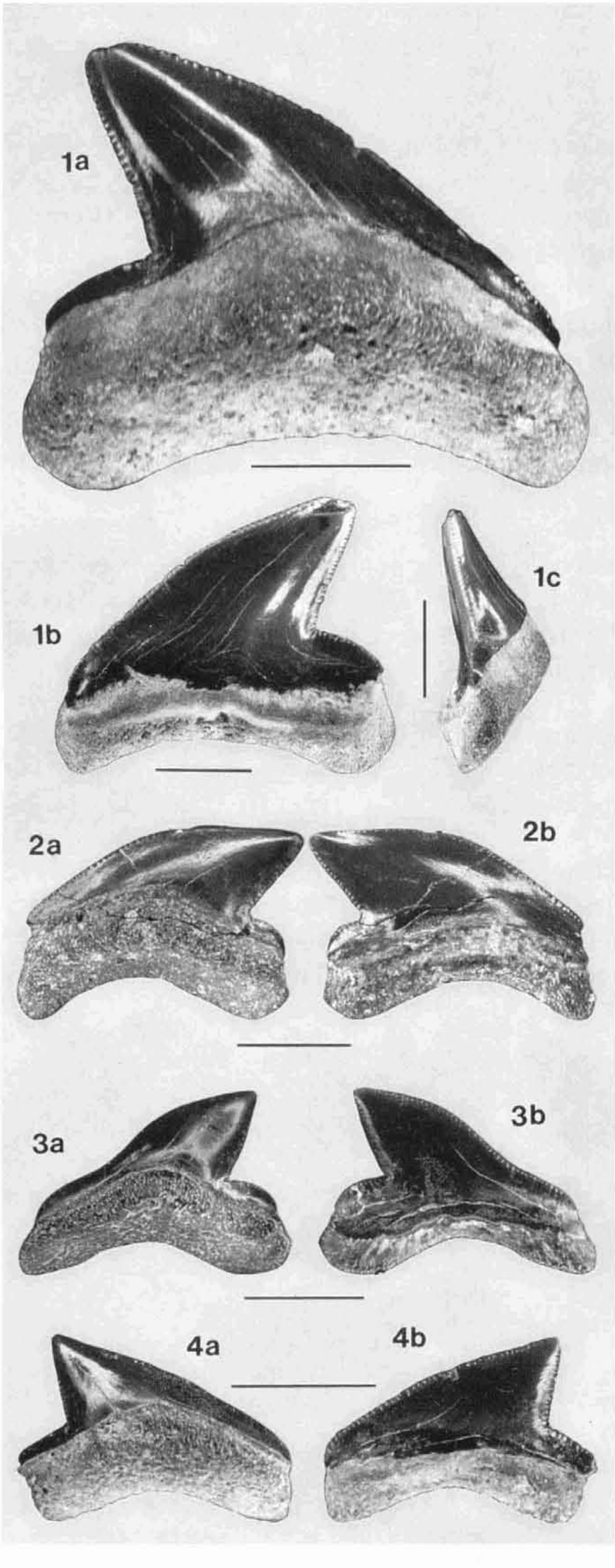
A third anacoracid, *Pseudocorax*, and only Texas species *Pseudocorax granti* Cappetta and Case 1975 first appears in the lower Coniacian of the basal Austin Group and is especially abundant in the overlying Campanian formations of the Taylor Group.

Considerable uncertainty exists over the relationships of the Anacoracidae at both the ordinal and familial levels. These sharks have been classified with the Hexanchiformes and at various times placed in one of three different families of Lamniformes. Justification for each interpretation of relationship stems from consideration of either a root, vertebral or histologic attribute.

SQUALICORAX CURVATUS

Order LAMNIFORMES Berg 1958
Family ANACORACIDAE Casier 1947

Maximum Size: **21 mm** | Occurrence: **Common** | Chronologic Range: **Cenomanian**



Genus ***Squalicorax*** Whitley 1939
Squalicorax curvatus (Williston 1900)

DESCRIPTION: Teeth labiolingually thick, moderately low crowned with a narrow cusp and acute apex; mesial cutting ridge angular; cutting edges finely serrated; distal blade is low, serrated, meets cusp at sharp angle; basal ledge flat and shelf-like; labial crown face is distinctly concave or curved, hence the specific name "*curvatus*"; root low; lingual protuberance weak; nutrient groove absent; root anaulacorhizous; histology osteodont.

HETERODONTY: Weak gradient monognathic and dignathic heterodonty.

DISTINGUISHING CHARACTERISTICS: A low, massive crown with an acute cusp apex, angular mesial cutting ridge, convex labial crown face, and a low root are tooth characters which, in combination, separate *Squalicorax curvatus* from all other species of *Squalicorax*.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Pepper and Woodbine formations (Cenomanian); Bell, Tarrant, Denton and Dallas counties.

COMMENTS: Williston (1900) described *Squalicorax curvatus* from the Cenomanian Benton Formation of Kansas. This species appears to be somewhat advanced over more primitive Albian squalicoracids but retains the low crown and root that are lost in Turonian and younger species.

REFERENCES: Williston (1900).

Squalicorax curvatus **(Williston 1900): Anterolateral teeth from the Lewisville Member of the Woodbine Formation (Cenomanian), Denton County (1, 2, 4) and from the Pepper Formation (Cenomanian), Bell County (3). Tooth orientation: (1a-4a) lingual view; (1b-4b) labial view; (1c) distal view. Scale line = 5 mm.**

Order LAMNIFORMES Berg 1958
Family ANACORACIDAE Casier 1947

SQUALICORAX FALCATUS

Chronologic Range: **?Cenomanian-Santonian** | Occurrence: **Common** | Maximum Size: **22 mm**

Genus ***Squalicorax*** Whitley 1939
Squalicorax falcatus (Agassiz 1843)

DESCRIPTION: Teeth small to moderately large depending on stratigraphic occurrence; crowns of anterior teeth narrow and erect; laterals and posteriors have low and distally inclined crowns; apex of cusp acute to obtuse and all cutting ridges finely serrated; mesial and distal cutting edges range from slightly sinuous to moderately convex depending on tooth rowgroup position; distal blade well developed, intersects cusp at a sharp angle; basal ledge strong; dental band wide lingually; root intermediate in height, bilobate; nutrient groove absent; root anaulacorhizous; histology osteodont.

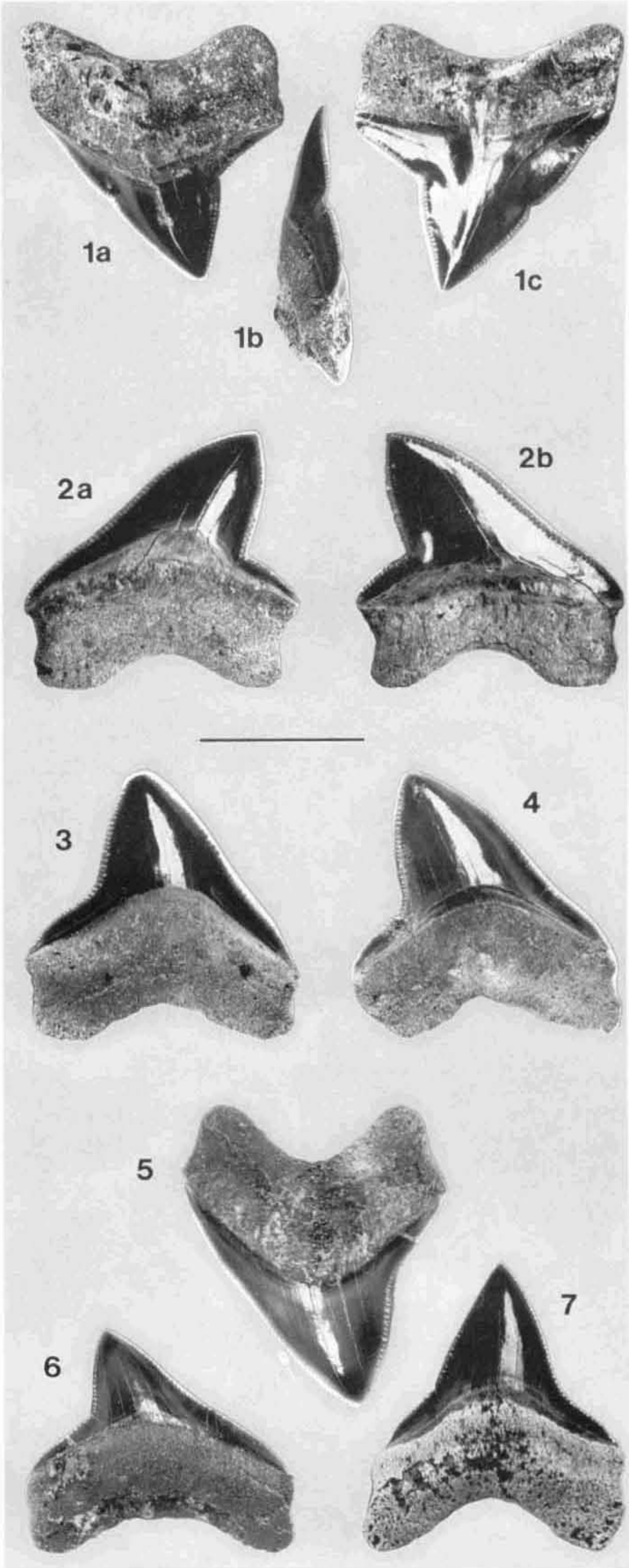
HETERODONTY: Weak gradient monognathic heterodonty in both jaws. Dignathic heterodonty weakly developed.

DISTINGUISHING CHARACTERISTICS: The mesial crown cutting ridge in *Squalicorax falcatus* is only weakly convex in comparison to *S. kaupi* or *S. pristodontus* and the root is much lower than in either of the latter two species. The crown and root are both higher in *S. falcatus* than in either *Squalicorax* sp. of the Albian or *S. curvatus*.

STRATIGRAPHIC OCCURRENCE IN TEXAS: ?Cenomanian-Santonian Pepper and Woodbine formations, Eagle Ford and Austin groups.

COMMENTS: We included a morphologically broad range of *Squalicorax* teeth in the species "*falcatus*" and strongly suspect that more than one species is represented. The teeth of this taxon show a progressive increase in size from the Cenomanian to Santonian. The Cenomanian Pepper and Woodbine formations and lower Eagle Ford Group teeth are much smaller than the later Turonian, Coniacian and Santonian teeth of the upper Eagle Ford and Austin Groups. The older teeth have crowns that are more erect, have finer serrations, and are not as inflated as their younger counterparts. The teeth that most closely compare with the type "*falcatus*" figured by Agassiz (1843) are found in the late Turonian Eagle Ford shale, and especially in the Coniacian and Santonian of the Austin Group.

REFERENCES: Agassiz (1843).

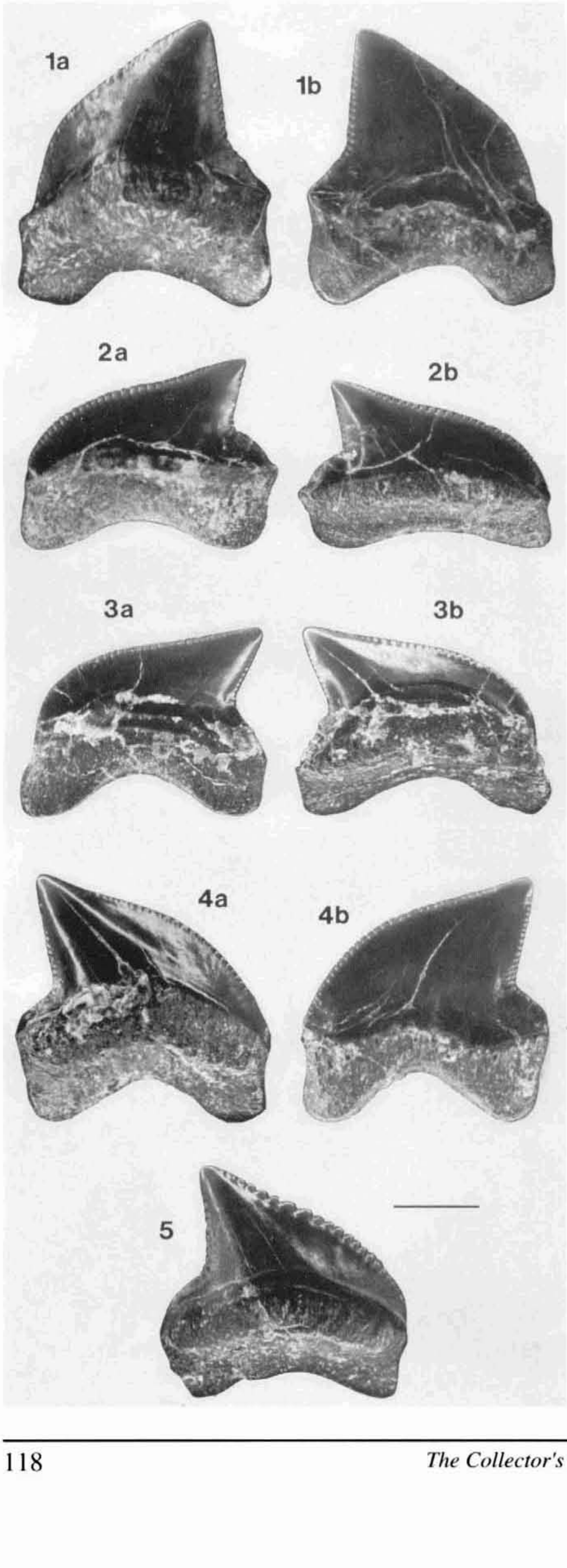


***Squalicorax falcatus* (Agassiz 1843): Anterolateral teeth from the Eagle Ford Group, Atco Formation contact horizon (Coniacian), Dallas County. Tooth orientation: (1a, 2a, 3-7) lingual view; (1c, 2b) labial view; (1b) mesial view. Scale line = 1 cm.**

SQUALICORAX KAUPI

Order LAMNIFORMES Berg 1958
Family ANACORACIDAE Casier 1947

Maximum Size: **16 mm** | Occurrence: **Common** | Chronologic Range: **Campanian**



Genus ***Squalicorax*** Whitley 1939
Squalicorax kaupi (Agassiz 1843)

DESCRIPTION: *Squalicorax* with teeth up to 16 mm in greatest dimension; crown high with a very inflated and convex mesial cutting edge; distal cutting edge of cusp nearly vertical and cusp apex less acute than in *S. falcatus* or *S. curvatus*; distal blade low with a nearly straight apical surface, sloping downward at a high angle from cusp; cutting edge serrations very coarse and some are compound (small serrations on the edges of larger serrations); crown faces weakly convex and entire tooth, including root, is labiolingually compressed or thin; basal ledge always very weak or absent; root almost as high as the crown lingually; lingual protuberance practically nonexistent; nutrient groove absent; root anaulacorhizous; histology osteodont.

HETERODONTY: Weak gradient monognathic heterodonty; weak or no dignathic heterodonty.

DISTINGUISHING CHARACTERISTICS: These Campanian teeth are characterized by having a high, rounded mesial crown edge, coarse serrations, and a low, divergent mesial blade. This species is most likely to be confused with *Squalicorax pristodontus* from which it differs by having a lower root and well-defined distal blade.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Ozan, Wolfe City, Pecan Gap Chalk (Campanian), in Ellis, Hunt, Bell and Dallas counties. This species should occur in all Campanian age marine strata in Texas.

COMMENTS: *Squalicorax kaupi* is exclusively Campanian and occurs abundantly in most shark assemblages of this age.

REFERENCES: Bilelo (1969); Cappetta (1987); Cappetta and Case (1975).

Squalicorax kaupi **(Agassiz 1843): Taylor Group, Ozan Formation (Campanian), Dallas County; (1, 3-5) antero-lateral teeth; (2) posterior tooth. Tooth orientation: (1a, 2b, 3b, 4a, 5) lingual view; (1b, 2a, 3a, 4b) labial view. Scale line = 5 mm.**

Order LAMNIFORMES Berg 1958
Family ANACORACIDAE Casier 1947

SQUALICORAX PRISTODONTUS

Chronologic Range: **Campanian-Maestrichtian** | Occurrence: **Common** | Maximum Size: **29 mm**

Genus ***Squalicorax*** Whitley 1939
Squalicorax pristodontus (Agassiz 1843)

DESCRIPTION: This is the largest species of *Squalicorax* in Texas with teeth reaching 29 mm in greatest dimension; teeth high with very erect crowns and obtuse cusp apex; mesial cutting ridge not strongly convex; distal cutting edge angles distally; distal blade not always differentiated and its intersection with distal cusp edge is a curved surface rather than an angular junction; cutting edge serrations very coarse; root high, over two-thirds of tooth height in lingual view on some teeth; root labiolingually thin, often with well-developed mesial and distal root lobes; lingual protuberance weak; teeth may have a pronounced curvature in side view (i.e., lingual face is strongly convex and labial face is concave); root anaulacorhizous; histology osteodont.

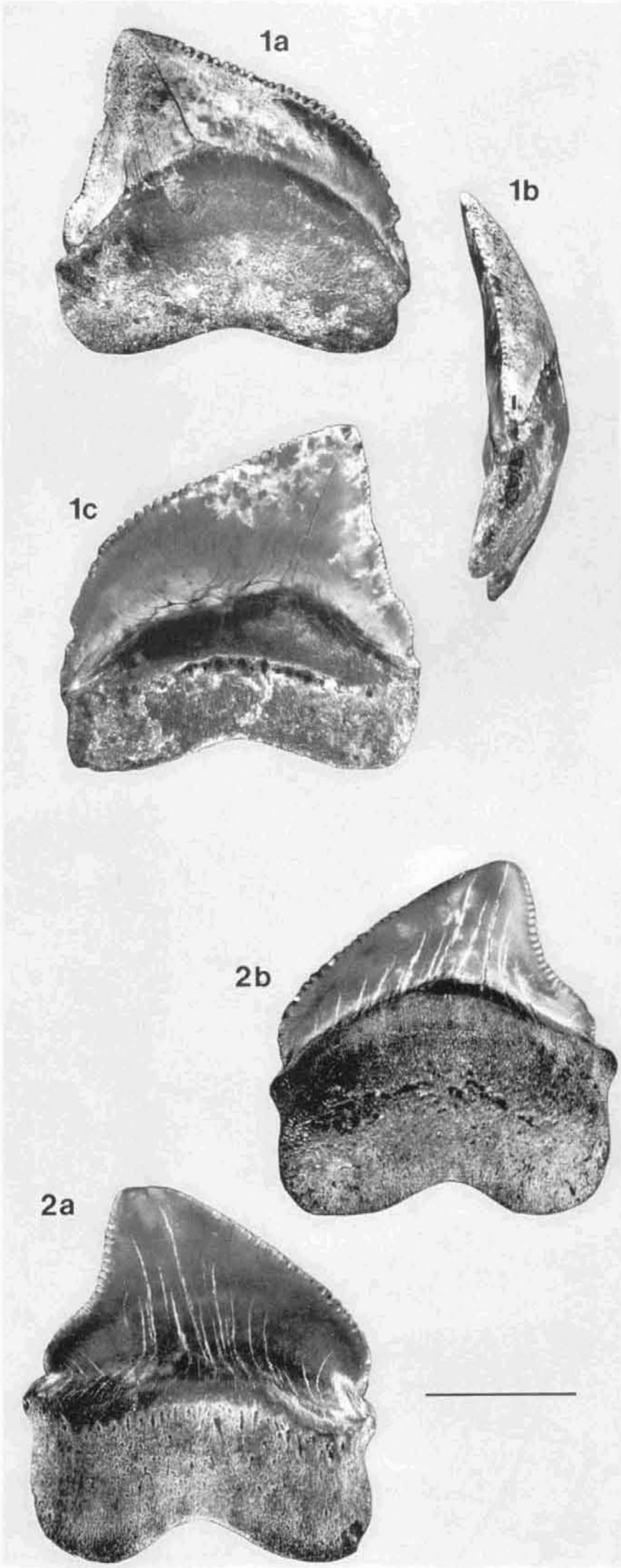
HETERODONTY: Unknown, assumed to be as in other *Squalicorax* with weak gradient monognathic and weak or no dignathic heterodonty.

DISTINGUISHING CHARACTERISTICS: These teeth are very similar to *Squalicorax kaupi* but differ in having a much higher root and in lacking a distinct distal blade.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Found throughout Texas in marine strata of Campanian and Maestrichtian age, including, but not restricted to, the upper Taylor Marl, Kemp, Escondido and Littig formations in Travis, Bell, Hunt, Fannin and Medina counties.

COMMENTS: This is the largest species of *Squalicorax* in Texas. It is most abundant in rocks of Navarro age (Maestrichtian) and many specimens come from the Kemp and Escondido formations.

REFERENCES: Bilelo (1969).

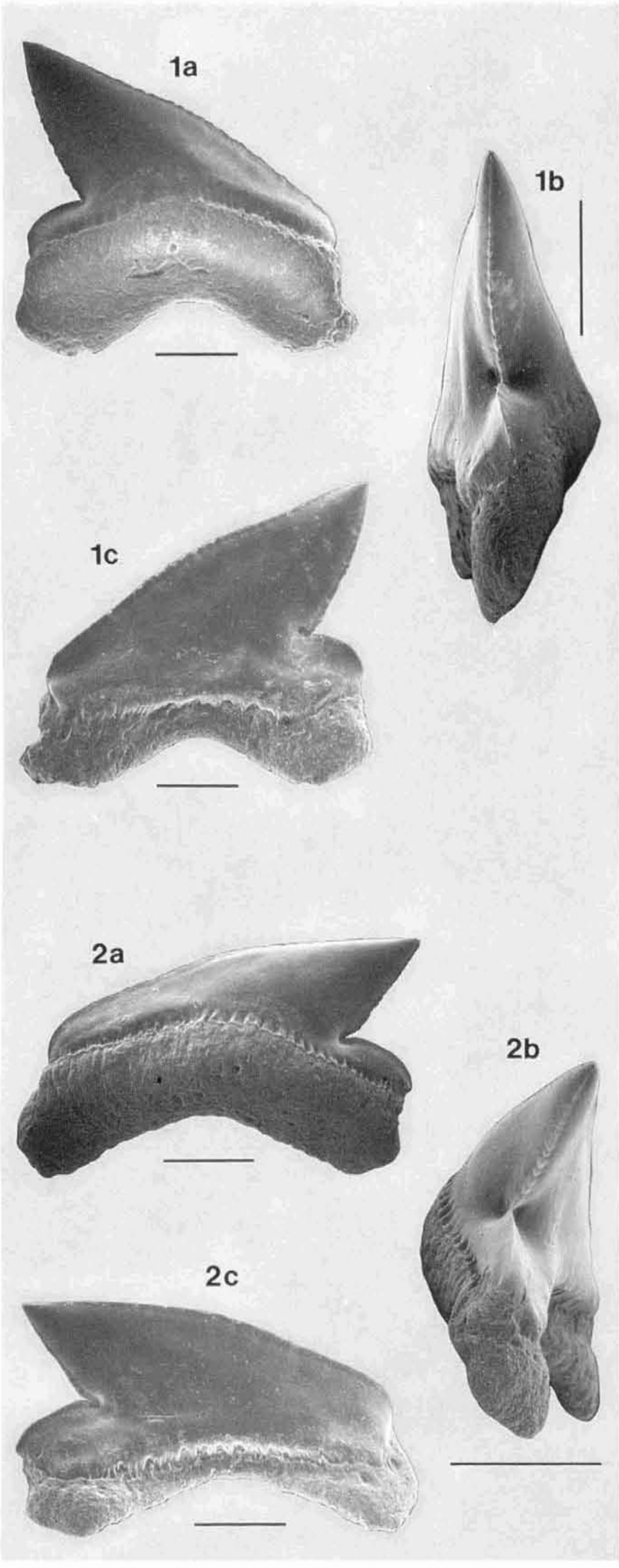


Squalicorax pristodontus **(Agassiz 1843): Anterolateral teeth from the Taylor Group (Campanian), Fannin County. Tooth orientation: (1a, 2b) lingual view; (1c, 2a) labial view; (1b) distal view. Scale line = 1 cm.**

SQUALICORAX sp.

Order LAMNIFORMES Berg 1958
Family ANACORACIDAE Casier 1947

Maximum Size: **14 mm** | Occurrence: **Common** | Chronologic Range: **Albian**



Genus ***Squalicorax*** Whitley 1939
Squalicorax sp.

DESCRIPTION: Teeth small, usually not exceeding 10 mm in mesodistal width; crowns of anterior teeth never fully erect and those of more distal teeth are low and have strong distal inclination; crowns in lower dental series are narrower than their upper counterparts; mesial cutting edge ranges from straight to weakly convex or slightly angular; cutting edges range from almost smooth to irregularly or finely serrated; distal blade long, low and intersects cusp at sharp angle; crowns labiolingually thick; basal ledge pronounced; crown faces smooth; dental band narrow lingually; root low and lobes widely divergent; nutrient groove never present; root anaulacorhizous; histology osteodont.

HETERODONTY: Weak gradient monognathic and moderate dignathic heterodonty with ?medial, anterolateral and posterior rowgroups. Teeth of the lower dental series have narrower crowns with a sinuous mesial cutting edge and cusps with an acute, upturned apex. Upper teeth are interpreted to have broader crowns with more convex mesial cutting edges.

DISTINGUISHING CHARACTERISTICS: This unnamed species of Albian *Squalicorax* differs from other squalicoracids in having small, narrow, thick and low crowns with weakly serrated cutting edges.

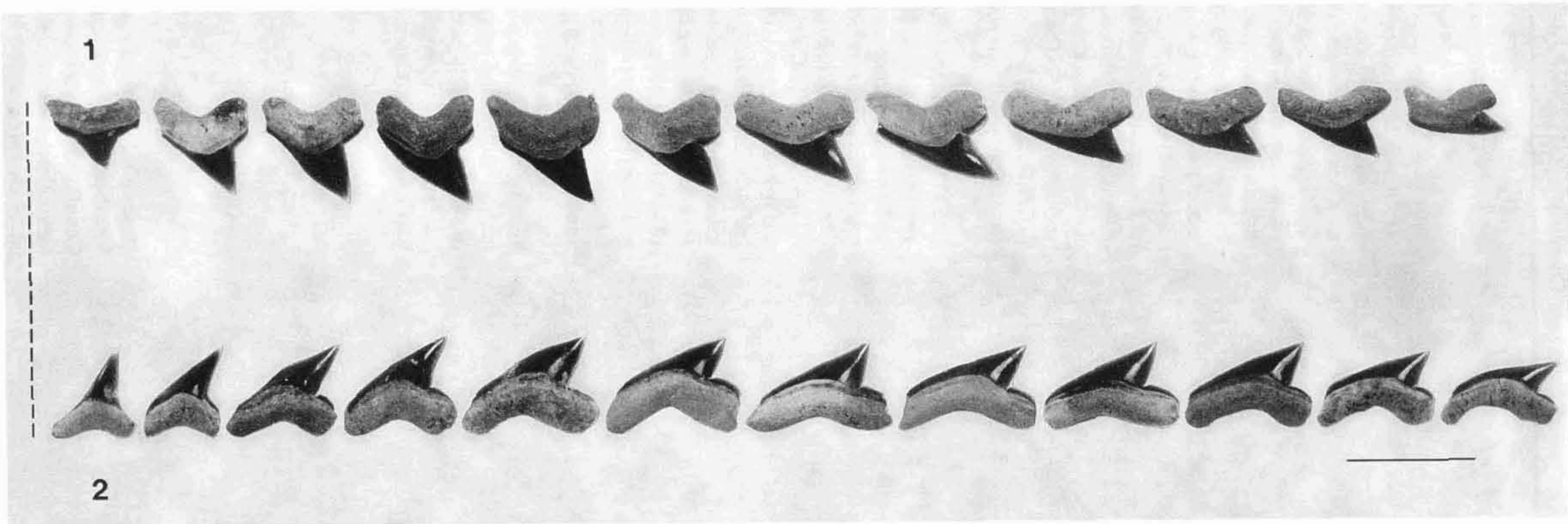
STRATIGRAPHIC OCCURRENCE IN TEXAS: Albian Weno and Pawpaw formations, Tarrant County.

COMMENTS: This is the most primitive species of *Squalicorax* found in the Texas Cretaceous. In contrast with Campanian and Maestrichtian species (e.g., *S. pristodontus* and *S. kaupi*), these teeth have very low narrow crowns, a sharp or acute cusp apex, and very weak cutting edge serrations. Considerable confusion exists over the specific taxonomy of *Squalicorax*. In recent years, the problem has been compounded by the naming of numerous "stratigraphically defined" species from the former Soviet Union. There is a strong possibility that *Squalicorax* sp. from Texas has already been described in the Russian literature.

REFERENCES: Bilelo (1969).

***Squalicorax* sp.: Weno Formation (Albian), Tarrant County; (1) anterolateral tooth; (2) posterior tooth. Tooth orientation: (1a, 2a) lingual view; (1c, 2c) labial view; (1b, 2b) distal view. Scale line = 2 mm.**

SQUALICORAX sp.

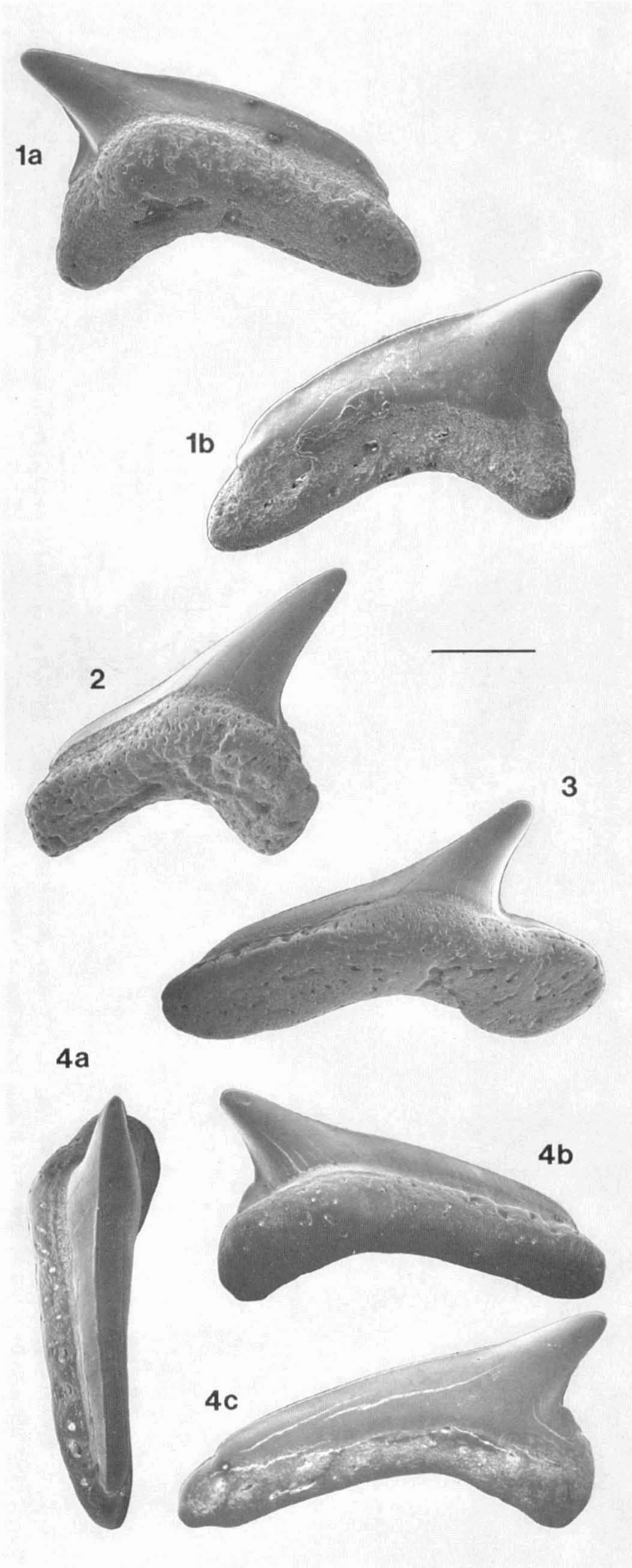


***Squalicorax* sp.: Weno Formation (Albian), Tarrant County. Artificial tooth set of the upper (1) and lower (2) right dental series based on teeth from one locality. Dashed line indicates position of jaw symphysis. Scale line = 5 mm.**

MICROCORAX CRASSUS

Order LAMNIFORMES Berg 1958
Family ANACORACIDAE Casier 1947

Maximum Size: **4 mm**	Occurrence: **Common**	Chronologic Range: **Cenomanian**



Genus ***Microcorax*** Cappetta and Case 1975
Microcorax crassus Cappetta and Case 1975

DESCRIPTION: Teeth small and asymmetrical with a very broad-based crown and short, narrow cusp; midpoint of the cusp base is positioned over the distal third of the crown foot, resulting in a very short distal blade and an extremely long and low mesial blade; serrations absent; crown faces convex and smooth; lingual dental band weak; basal ledge never formed; cusplets never present; root simple, rounded and low; lingual protuberance weak; root penetrated by numerous foramina, especially near lingual crown foot; pronounced central foramen rarely present; nutrient groove absent; lingual face of the root may flatten into a broad basal attachment surface in lateral and posterior teeth; root anaulacorhizous; histology osteodont.

HETERODONTY: Strong gradient monognathic heterodonty and probably weak dignathic heterodonty.

DISTINGUISHING CHARACTERISTICS: The pronounced tooth asymmetry, distal position of the cusp, long mesial blade and absence of a nutrient groove are tooth characters which, in combination, separate *Microcorax* from other sharks.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Pepper and Woodbine formations, lower Eagle Ford Group (Cenomanian) in Travis, Bell, Tarrant, Dallas and Denton counties. Widespread in Cenomanian marine strata throughout Texas.

COMMENTS: *Microcorax crassus* was described by Cappetta and Case (1975) from the lower Arlington Sandstone Member of the Woodbine Formation in Tarrant County. These small teeth are relatively common elsewhere in the Woodbine and Pepper formations and the lower Cenomanian portions of the Eagle Ford Group. The relationship of *Microcorax* to other anacoracids is unclear. Bulk sampling and microscopic sorting techniques are required to collect this species.

REFERENCES: Cappetta and Case (1975).

Microcorax crassus **Cappetta and Case 1975: Lewisville Member of the Woodbine Formation (Cenomanian), Denton County; (1) lateral tooth; (2) anterior tooth; (3-4) posterior teeth. Tooth orientation: (1a, 2, 3, 4b) lingual view; (1b, 4c) labial view; (4a) apical view. Scale line = 1 mm.**

PSEUDOCORAX GRANTI

Chronologic Range: **Coniacian-Campanian** | Occurrence: **Common** | Maximum Size: **9 mm**

Genus ***Pseudocorax*** Priem 1897
Pseudocorax granti Cappetta and Case 1975

DESCRIPTION: The teeth of *Pseudocorax granti* are labiolingually compressed (thin) and relatively fragile; anterior teeth mesodistally short with erect crowns, whereas lateral teeth are very broad-based with considerable crown inclination; all teeth have a distal blade, most pronounced in laterals; mesial blade long, convex, low and poorly differentiated from cusp; cusp may be narrow or broad-based depending on tooth position; in lateral teeth, cusp appears to be constricted at its base by the convergence with mesial and distal blades; cutting edges smooth and very thin; crown faces smooth; basal ledge strong; root thin and asymmetrical with a larger, basally angled mesial lobe; lingual protuberance well defined; nutrient groove deep; numerous foramina occur near the crown foot on both faces; root often expanded at the crown foot into short knob-like projections on larger lateral teeth; root holaulacorhizous; histology osteodont.

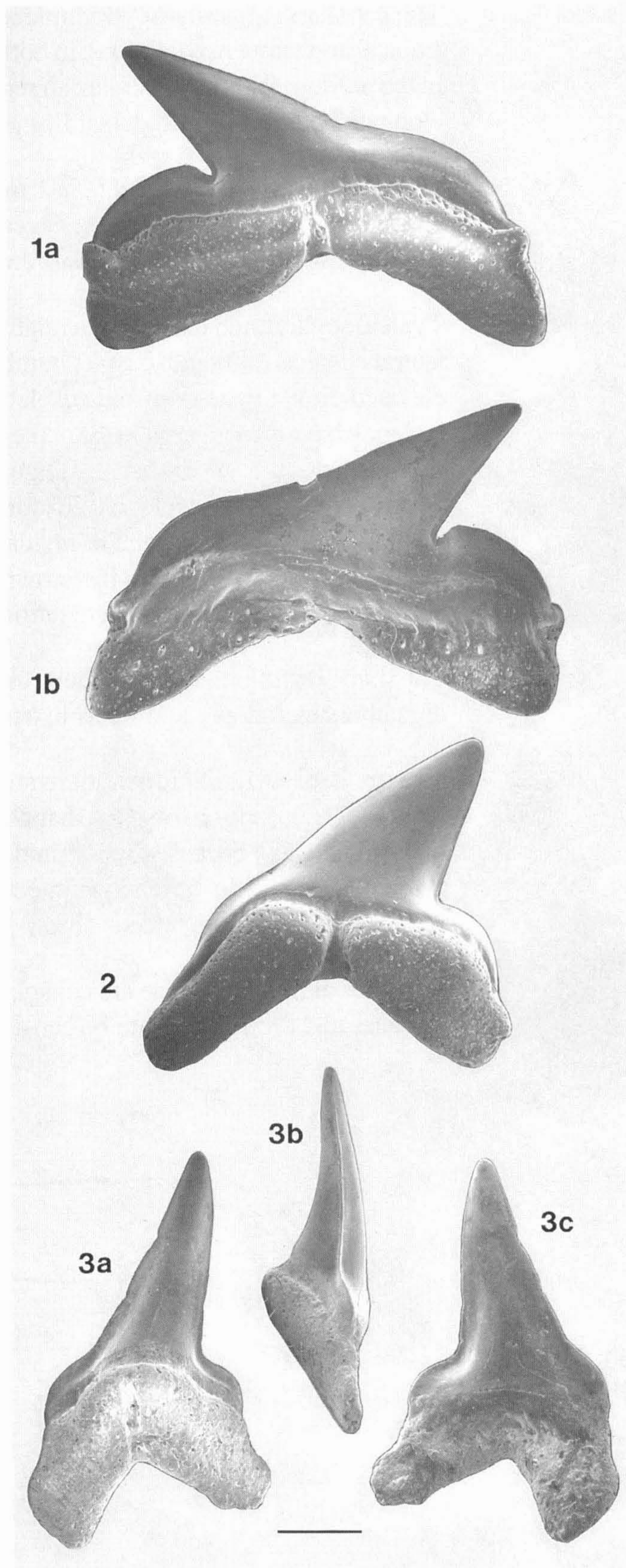
HETERODONTY: Moderate disjunct monognathic heterodonty and probably substantial dignathic heterodonty. Insufficient sample size precludes us from constructing an artificial tooth set but considerable heterodonty is suggested from the diverse morphologies represented in Coniacian and Campanian samples.

DISTINGUISHING CHARACTERISTICS: These teeth are easily recognized by their overall asymmetry; very thin, smooth crowns; smooth and sinuous mesial cutting edge; strongly bilobate roots with a deep nutrient groove and strong basal ledge developed at the labial crown foot.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Coniacian-Campanian, from the basal Atco Formation (contact horizon), of the Austin Group and throughout the Campanian Taylor Group. We have not found *Pseudocorax* in the Maestrichtian and it is not known to occur below the Austin Group, although it is very abundant in phosphatic sands which may occur one meter or so above the contact horizon.

COMMENTS: *Pseudocorax granti* was described by Cappetta and Case (1975) with its type locality in the Campanian Taylor Marl, along the North Sulphur River at Ladonia, Fannin County.

REFERENCES: Cappetta and Case (1975); Herman (1977).



Pseudocorax granti **Cappetta and Case 1975: Taylor Group, Ozan Formation (Campanian), Dallas County (1-2) and Ellis County (3); (1) lateral tooth; (2, 3) anterior teeth. Tooth orientation: (1a, 2, 3a) lingual view; (1b, 3c) labial view; (3b) distal view. Scale line = 1 mm.**

Family Scyliorhinidae

The cat sharks, Family Scyliorhinidae Gill 1862, are generally small bottom-living sharks in tropical and temperate latitudes, in both deep and shallow waters. They are most abundant today in the western Pacific, Australasian region and Indian Ocean to South America. Cat sharks have elongate bodies with two dorsal fins placed toward the tail and a long caudal fin.

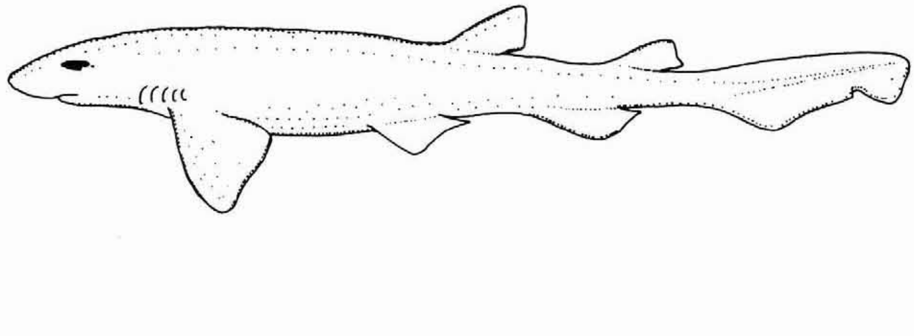
The average cat shark is less than 1 meter long with teeth on the order of 2 or 3 millimeters in greatest dimension. The dental series consists of numerous, closely spaced rows of sharp crowned teeth that are effective for grabbing and holding prey.

Typical scyliorhinid teeth have a relatively narrow, sharp cusp and generally one or two pairs of lateral cusplets (although cusplet number ranges from none to three or more in some taxa) on an elevated crown. The cusp and cusplets are closely connected. The labial crown face is convex and may have a deep basal ledge at the crown foot and ornamentation in the form of longitudinal ridges may be present or absent. Lingually, the crown face may be smooth or ornamented and the dental band is well developed. Cutting ridges are often not continuous. The root is strongly bilobate with a very prominent lingual protuberance and a very flat basal attachment surface, oriented at a sharp angle to the crown. The root is most often anaulacorhizous or hemiaulacorhizous; however, a complete nutrient groove (holaulacorhizous) occurs in some taxa.

Cat shark dentitions have gradient to disjunct monognathic heterodonty in both jaws, weak dignathic heterodonty and variable ontogenetic and sexual dental heterodonty.

Most modern scyliorhinid dentitions are poorly described and, as a consequence, very little serious work has been done on fossil cat sharks. The paucity of described species is not a reliable measure of fossil diversity because scyliorhinid teeth are abundant in many Cretaceous and Tertiary fossil assemblages. In the absence of modern comparative studies, paleontologists generally refer scyliorhinid teeth to the genus *Scyliorhinus* Blainville 1816.

The teeth of Scyliorhinidae are conspicuous elements in Albian and younger shark assemblages in Texas and there appears to be considerable taxonomic diversity represented by this material.



Chronologic Range: **Albian–Maestrichtian** | Occurrence: **Common** | Maximum Size: **3 mm**

Genus and Species Undetermined

DESCRIPTION: Very small and highly ornamented teeth representing multiple genera and species of cat sharks, Family Scyliorhinidae. Crowns generally tall, cusp needle-like, flanked by low shoulders, or more commonly, at least one pair of cusplets; crown smooth or highly ornamented with fine to coarse longitudinal ridges; cutting ridge continuous across cusp, shoulders and cusplets; cutting edges never serrated; basal ledge strong; cusp with a straight or sigmoidal profile; root strongly bilobate with tabular mesial and distal lobes that have rounded outlines in labial or lingual view; lingual protuberance large, bulbous to flat, ridge-like and positioned well in front of (lingual to) the root lobes; a central lingual foramen penetrates the root protuberance; nutrient groove ranges from completely covered to open; basal attachment surface of the root is flat and a second large foramen opens between the root lobes; root holaulacorhizous to secondarily hemiaulacorhizous; histology orthodont.

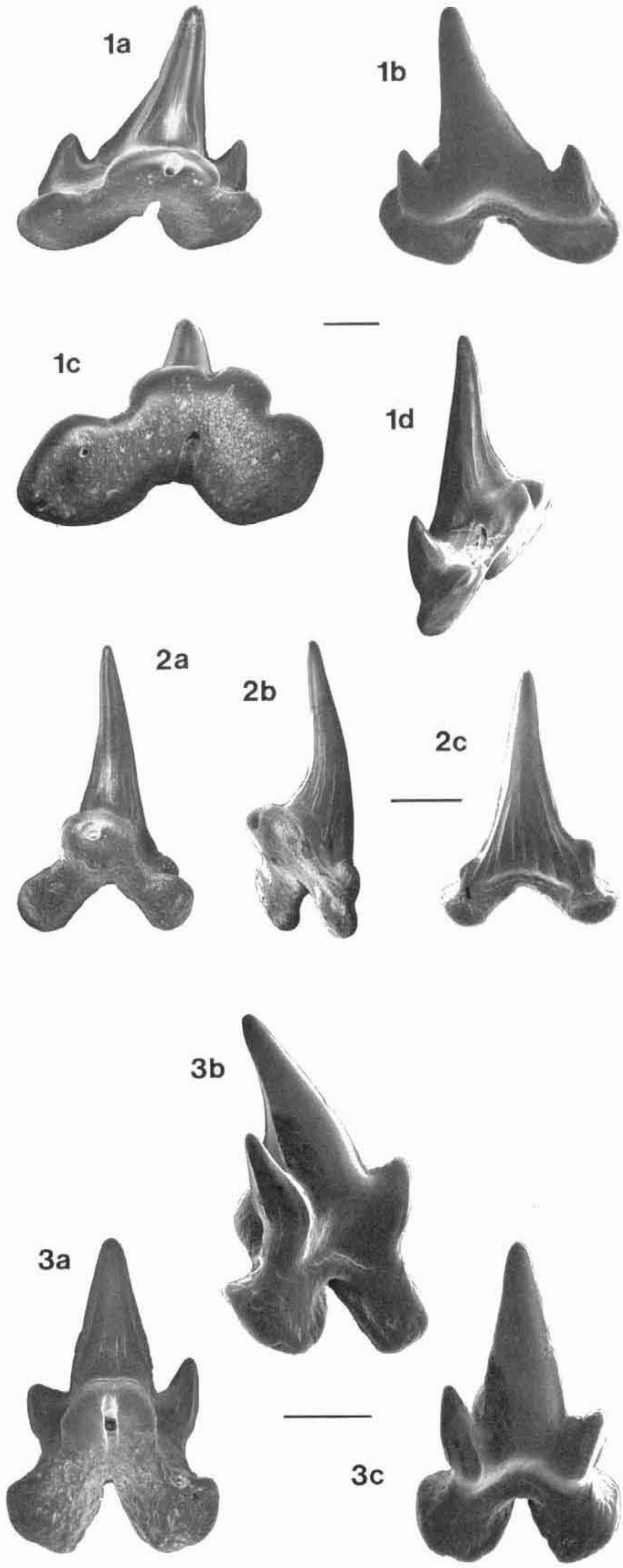
HETERODONTY: Variable, but most scyliorhinids have weak gradient monognathic heterodonty and dignathic heterodonty is weak or absent.

DISTINGUISHING CHARACTERISTICS: The presence of a large lingual protuberance, very flat basal attachment surface, the general absence of a nutrient groove (hemiaulacorhizous condition), and the presence of widely divergent root lobes are attributes of scyliorhinid teeth that separate them from other sharks. Also, these teeth are very small, often 1 mm or less in height.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Albian-Maestrichtian strata throughout Texas.

COMMENTS: Considerable work remains to sort out the genera and species of scyliorhinids in Texas. Unidentified teeth of scyliorhinids are included here for the purpose of documenting the presence of this family in the Texas Cretaceous. Cat shark teeth are often abundant elements of the microfauna and to collect them requires special techniques described in Chapter 6.

REFERENCES: None.



Scyliorhinidae: Pepper Formation (Cenomanian), Bell County; unidentified anterolateral catshark teeth belonging to two different species, species A (1, 3) and species B (2). Tooth orientation: (1a-3a) lingual view; (1b, 2c, 3c) labial view; (1c) basal view; (1d, 2b) mesial view; (3b) distal view. Scale line = 0.5 mm.

Family Triakidae

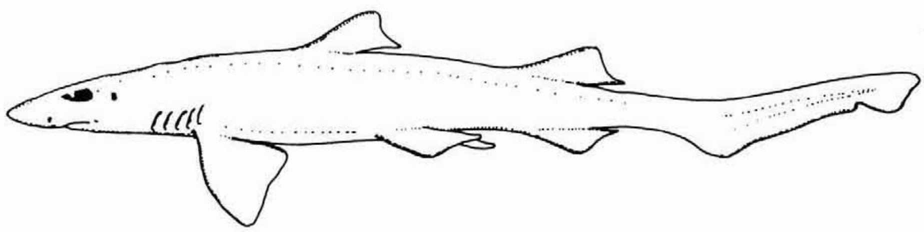
Texas Cretaceous sharks belonging to the Family Triakidae Gray 1851 include the extant soupfin shark *Galeorhinus* Blainville 1816 and an extinct genus *Palaeogaleus* Gurr 1962. Most triakids are small to moderately large (less than 2 meters in total length), slender-bodied sharks with elongated to nearly circular eyes, broad fins and numerous small, relatively low crowned teeth.

Soupfin sharks live in schools close to the bottom at depths ranging from very shallow to 200 meters and feed primarily on bottom-living fish and crustaceans. They are most abundant in tropical and warm temperate seas. Those that occur in temperate seas are often seasonal migrants. The soupfin shark *Galeorhinus zyopterus* grows to a length of slightly over 2 meters.

Worldwide, the genus *Galeorhinus* first appears in the lower Turonian and has a more or less continuous fossil record up to the present. In Texas, *Galeorhinus* sp. occurs only in Maestrichtian strata of the Upper Cretaceous Kemp Formation.

The second triakid, *Palaeogaleus*, was originally described by Gurr (1962) from the Paleocene of England and has subsequently been recognized from strata as old as Campanian in Europe, Greenland and North Africa. Texas occurrences of this genus correspond with its earliest European records, being a common taxon in the early Campanian Taylor Group and overlying Maestrichtian Kemp Formation.

Both *Galeorhinus* and *Palaeogaleus* may be referable to new taxa as the Texas specimens do not compare favorably with any named species.



Order CARCHARHINIFORMES Compagno 1973
Family TRIAKIDAE Gray 1851

GALEORHINUS sp.

Chronologic Range: ?**Late Campanian-Maestrichtian** | Occurrence: **Common** | Maximum Size **6 mm**

Genus ***Galeorhinus*** Blainville 1816
Galeorhinus sp.

DESCRIPTION: Teeth small, up to 6 mm in greatest dimension; crown long and thick with a single distally inclined, robust cusp and three to four smaller mesial cusplets; cusplets decrease in size toward distal end of tooth; mesial cutting ridge of crown long, slightly convex and may have a crenulated cutting edge near crown foot; crown foot has a narrow lingual dental band; basal ledge strong; crown faces are smooth except for very short longitudinal ridges labially at crown foot; root has a broad, flat attachment surface and is separated into triangular mesial and distal lobes by a deep nutrient groove; root barely visible when tooth is examined in labial view; root holaulacorhizous; histology orthodont.

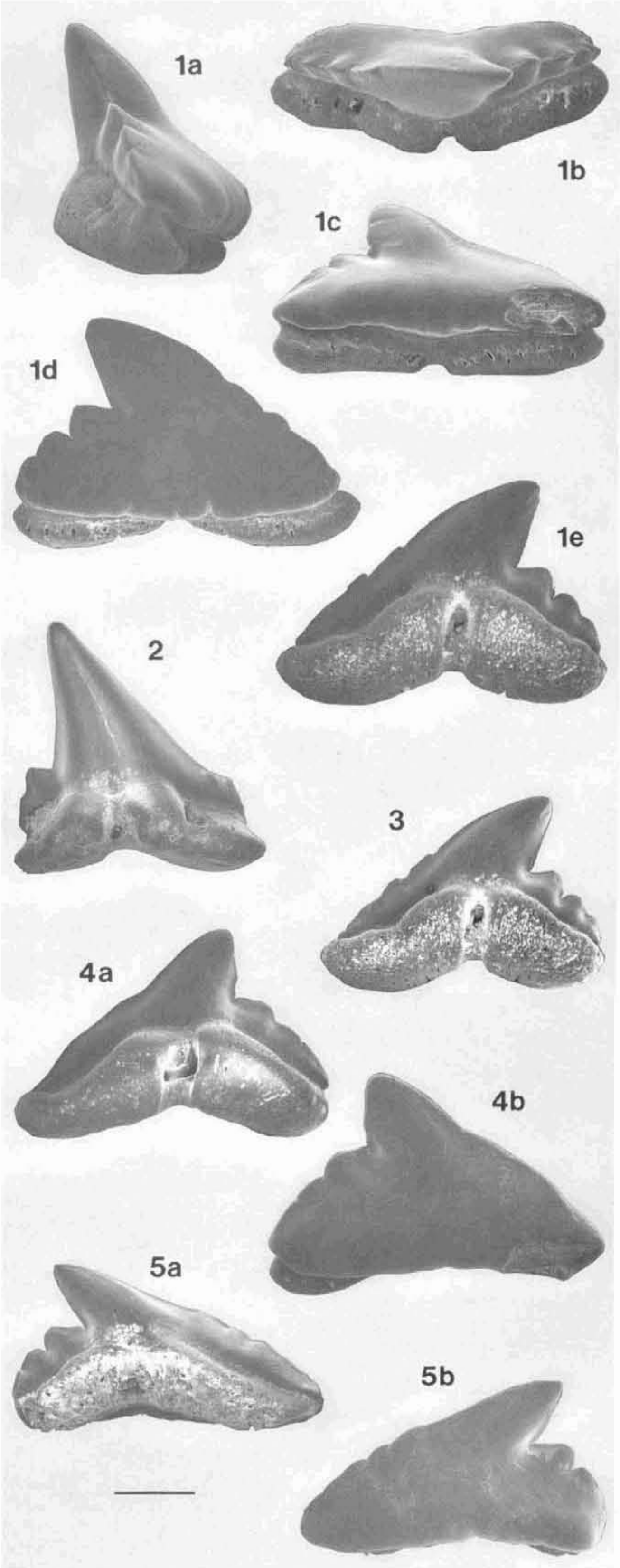
HETERODONTY: Moderate gradient monognathic and weak dignathic heterodonty.

DISTINGUISHING CHARACTERISTICS: The presence of a robust, distally inclined cusp, followed by three or four distal cusplets, the absence of cusplets on the mesial cutting edge of the crown and a root that is barely visible in labial crown view, are characteristics of *Galeorhinus* teeth that readily separate them from all other Texas sharks.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Upper Taylor Marls, Escondido, Kemp and Littig formations (?late Campanian-Maestrichtian), Medina, Travis and Hunt counties.

COMMENTS: In Texas, *Galeorhinus* teeth are only abundant in the Maestrichtian and they do not compare favorably with any described species. The fossil record of *Galeorhinus* extends back to the Turonian (upper Eagle Ford time). It is a very common Tertiary shark and there are a number of living species.

REFERENCES: Herman (1977).

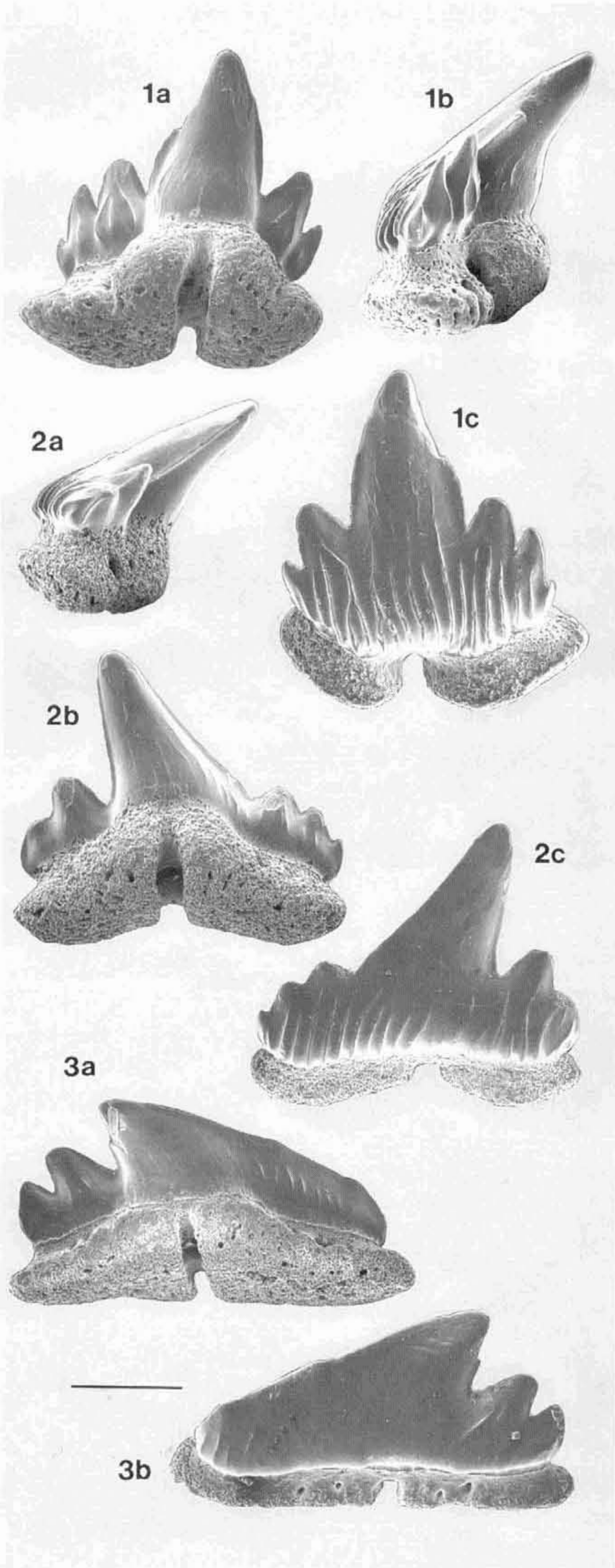


***Galeorhinus* sp.: Anterolateral teeth, Navarro Group, Kemp Formation (Maestrichtian), Hunt County. Tooth orientation: (1e, 2, 3, 4a, 5a) lingual view; (1c, 1d, 4b, 5b) labial view; (1b) apical view; (1a) distal view. Scale line = 1 mm.**

PALAEOGALEUS sp.

Order CARCHARHINIFORMES Compagno 1973
Family TRIAKIDAE Gray 1851

Maximum Size: **3 mm** | Occurrence: **Common** | Chronologic Range: **Campanian-Maestrichtian**



Genus ***Palaeogaleus*** Gurr 1962
Palaeogaleus sp.

DESCRIPTION: Teeth small, up to 3 mm with robust crown and root; crown with a moderate lingual flexure; cusp thick, lingual base inflated; number and position of cusplets varies considerably along dental series, ranging from two pairs (an incipient third pair on some teeth) flanking the cusp in anterior teeth to posterior teeth where they are absent on the mesial blade; cutting ridge smooth and continuous across cusp and cusplets; basal ledge overhangs root labially; dental band absent; longitudinal ridges numerous, evenly spaced on labial face of anterior and lateral teeth, weakly developed on posteriors, extending a little more than halfway up the crown; labial crown face with scattered, short ridges, otherwise smooth; root massive with wide, triangular root lobes having broad basal attachment surfaces; nutrient groove wide and deep with a large central foramen; smaller foramina are scattered just below crown foot lingually and labially; root holaulacorhizous; histology orthodont.

HETERODONTY: Strong gradient or weak disjunct monognathic heterodonty in both jaws; dignathic heterodonty unknown.

DISTINGUISHING CHARACTERISTICS: The teeth of *Palaeogaleus* might be confused with the anteriors of *Galeorhinus* but are easily distinguished by their strong labial longitudinal ridges and pronounced development of cusplets.

STRATIGRAPHIC OCCURRENCE IN TEXAS: *Palaeogaleus* occurs throughout the Taylor and Navarro Groups and is particularly abundant in strata of Maestrichtian age.

COMMENTS: The genus *Paleogaleus* Gurr 1962 is based on the type species *Paleogaleus vincenti* (Leriche 1902) from the early Tertiary of Belgium. This genus is well known from the Campanian and Maestrichtian of Europe. Microcolleting techniques are usually needed to collect these teeth.

REFERENCES: Gurr (1962); Herman (1977).

***Palaeogaleus* sp.: Anterolateral (1, 2) and posterior (3) teeth from the Navarro Group, Kemp Formation (Maestrichtian), Hunt County. Tooth orientation: (1a, 2b, 3a) lingual view; (1c, 2c, 3b) labial view; (1b) mesial view; (2a) distal view. Scale line = 0.5 mm.**

Order Rajiformes

The Rajiformes are generally referred to as skates and rays but also include the sawfishes, guitarfishes and electric rays. Skates are distinguished from rays by their lack of a tail stinger (caudal spine). Most Rajiformes have bodies that are flattened dorsoventrally, and the pectoral fins extend widely and seem to be part of the body. The tail section is more or less defined from the body, the eyes and spiracles are dorsal and the mouth and all gill openings are ventral. The sawfishes, however, are shark-like in general appearance. They are classified among the order Rajiformes on skeletal considerations as well as for the relationship of pectorals to gills. The majority of guitarfishes have a shape resembling a cross between shark-like and skate-like forms.

Most Rajiformes live on the bottom or close to it and are comparatively sluggish. Some of them lie buried in sand or mud most of the time and are poor swimmers. The skates are capable of swift propulsion when necessary, although they usually swim slowly and close to the bottom. Sawfishes also spend a good part of time along the bottom, but rise to pursue fish at mid-depths or higher. Skates and rays subsist on a variety of animal food, including all available invertebrates that inhabit sandy or muddy bottoms.

Rajiformes are widely distributed in latitude and depth in the Atlantic, Pacific and Indian oceans, including adjacent seas. They also cover a broad thermal range, from cold polar waters to warm tropical seas. The most numerous group, the skates, are found primarily in the temperate belts of the two hemispheres.

The fossil record of Rajiformes collectively dates back to the Lower Jurassic with the earliest representatives among the Family Rhinobatidae Muller and Henle 1838. Within Texas, there are three families of rajiforms; Family Rhinobatidae (Aptian-Maestrichtian); Family Rajidae (Campanian and Maestrichtian); Family Sclerorhynchidae (Albian through Maestrichtian).

Guitarfishes, Family Rhinobatidae, are found in most Texas Lower and Upper Cretaceous fossil assemblages and all teeth are presently referred to the genus *Rhinobatos* Linck 1790. The earliest skates, Family Rajidae Bonaparte 1831 are Cenomanian from Lebanon. In Texas, teeth close to true *Raja* occur in Campanian and Maestrichtian rocks of the Taylor and Navarro groups. The extinct sawfishes, Family Sclerorhynchidae Cappetta 1974 are especially abundant in Texas where both oral and rostral teeth representing six genera occur in strata of Albian through Maestrichtian age. In addition to these, there are a number of rajiforms of questionable affinity, including *Ptychotrygon* Jaekel 1894 (Cenomanian-Maestrichtian), ?*Squatirhina* Casier 1947 (Cenomanian), *Protoplatyrhina* Case 1978 (Maestrichtian) and *Pseudohypolophus* Cappetta and Case 1975 (Albian-Cenomanian).

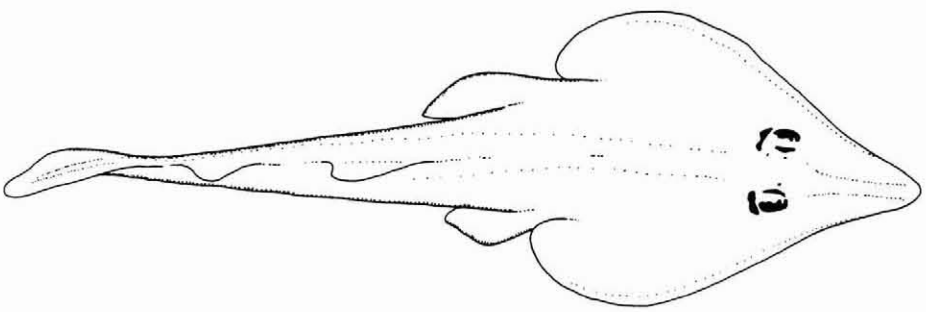
Family Rhinobatidae

Guitarfishes of the Family Rhinobatidae Muller and Henle 1838 have a distinct ray-like body with the forward part rounded or heart-shaped. The snout is wedge-shaped, and the tail is not clearly distinguished from the body. The caudal fin is relatively short and thick while both the dorsal and anal fins are well developed. Guitarfishes are found in tropical and subtropical seas around the world and sometimes found in fresh water. Most species are 1.5 to 2 meters long; the giant guitar fish, *Rhynchobatus djiddensis*, of the Indo-Pacific region reaches a length of over 3 meters. Like typical rays, guitarfishes are bottom feeders, eating mainly small crustaceans and mollusks.

Isolated teeth of *Rhinobatos* Linck 1790 occur in Aptian through Maestrichtian strata in Texas. The dentition of this genus has gradient monognathic heterodonty in both jaws and strong sexual dental dimorphism. Teeth are arranged in compact alternating rows, thus forming a dense grasping and crushing pavement.

Texas teeth of *Rhinobatos* rarely exceed 1.5 millimeters. The crown is massive, apically convex with a thick, rounded labial face and strong basal ledge. The occlusal crown face bears a single curved transverse ridge just above the abrupt vertical lingual crown face. Lingually, the crown face possesses a long median protuberance and, to either side, much shorter secondary protuberances. The root is strongly bilobate and angled sharply in a lingual direction, at a high angle to the occlusal crown surface. The basal attachment surface of each lobe is convex, and the root flares outward just below the secondary protuberances. Single mesial and distal marginal foramina are set in deep pits just below and adjacent to the mesial and distal sides of the lingual protuberance. The root lobes are separated by a deep, wide nutrient groove that bears a large central basal foramen.

In addition to *Rhinobatos*, three additional ray genera of uncertain affinities in the Texas Cretaceous are collectively placed in Rhinobatoidei incertae sedis. These include: *Protoplatyrhina renae* Case 1978, which was originally described from the Campanian of Montana and is found in the early Maestrichtian Kemp Formation of northeast Texas; *Pseudohypolophus mcnultyi* (Thurmond 1971), a very common ray in marginal marine and possibly fresh-water environments of the Paluxy and Woodbine formations; and small Cenomanian ray teeth with a short cusp and highly scalloped crown margins which are questionably referred to the genus ?*Squatirhina* Casier 1947.



RHINOBATOS CASIERI

Chronologic Range: **Campanian** | Occurrence: **Common** | Maximum Size: **1.5 mm**

Genus ***Rhinobatos*** Linck 1790
Rhinobatos casieri Herman 1977

DESCRIPTION: Crown mesodistally expanded, high and labiolingually narrow; lingual face convex, smooth, with a gently convex transverse ridge; labial crown margin subangular; lingual crown foot has a narrow, moderately long median protuberance, flanked by smaller mesial and distal protuberances; root slightly wider than crown, lingually displaced with relatively narrow, short, basally convex root lobes; transverse notch wide with one or more large central foramina; lingual face of each root lobe has a large foramen situated between the central and lateral crown protuberances; mesial and distal borders of root lobes are constricted below lateral protuberances; teeth display strong labiolingual compression; root holaulacorhizous; histology orthodont.

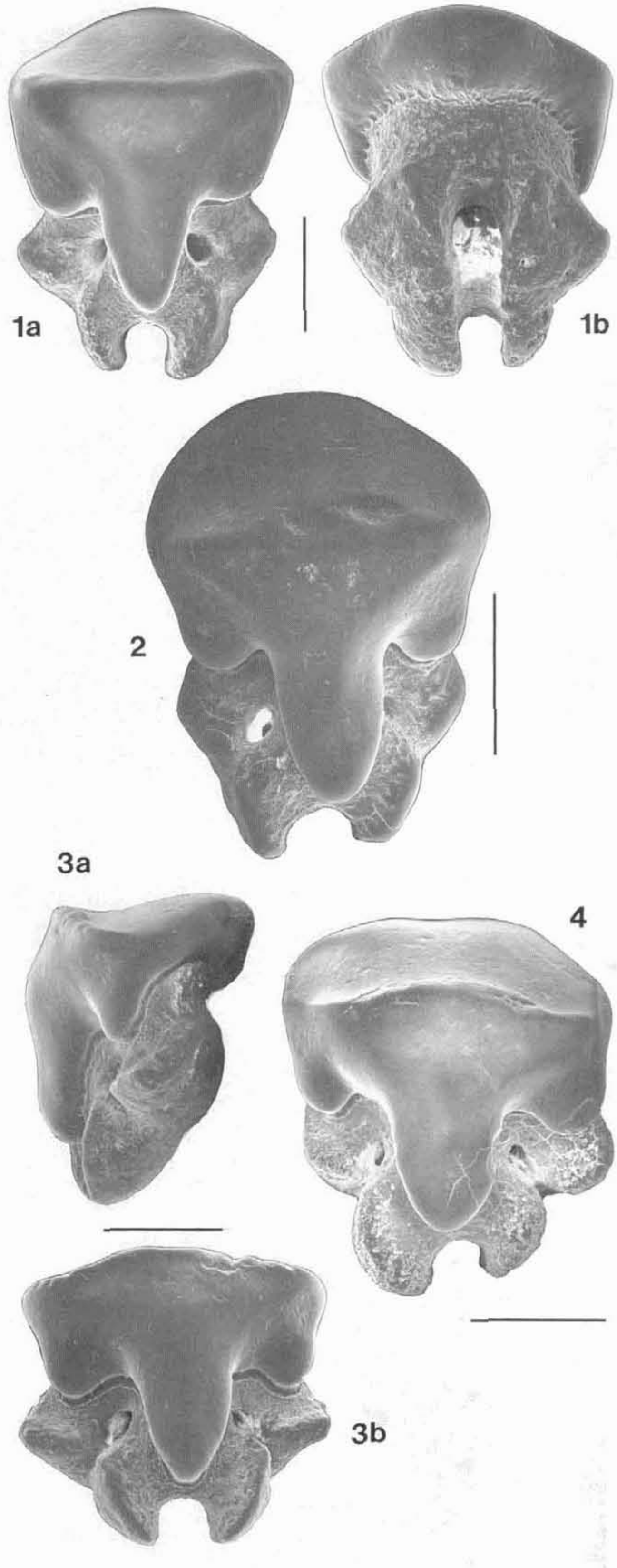
HETERODONTY: Weak gradient monognathic heterodonty in both jaws. Sexual dental heterodonty strong; inferred male teeth are high crowned, almost cuspate; female teeth are blunt crowned.

DISTINGUISHING CHARACTERISTICS: The teeth of *Rhinobatos casieri* differ from those of *R. incertus* in having a much thinner and mesodistally narrower and higher crown, in lacking a distinct cusp, having narrower and sharper lingual protuberances, less expansive root lobes and a much wider nutrient groove.

STRATIGRAPHIC OCCURRENCE IN TEXAS: This species occurs throughout the Taylor Group (Campanian) in Texas.

COMMENTS: These teeth are very common in the Taylor Group and because of their small size, microscreening techniques are required to collect them.

REFERENCES: Cappetta and Case (1975); Herman (1977).

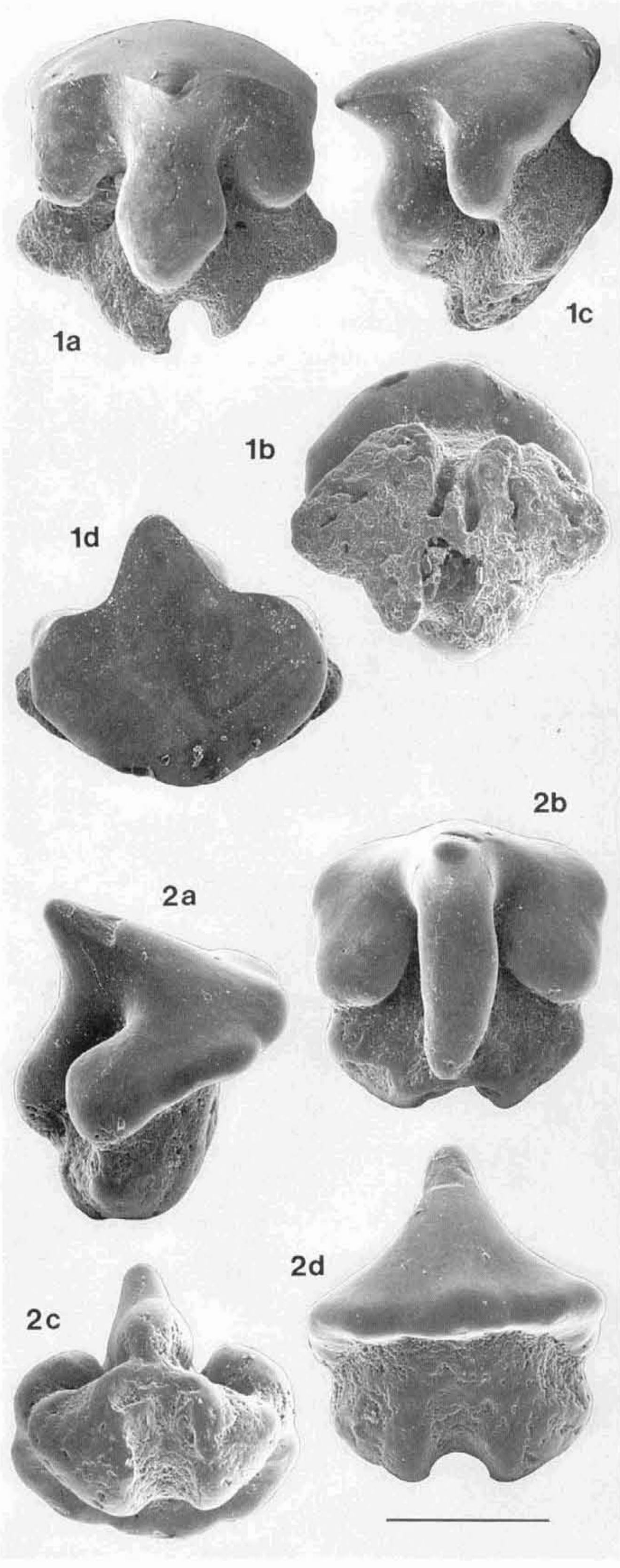


Rhinobatos casieri **Herman 1977: Navarro Group, Kemp Formation (Maestrichtian), Hunt County. Tooth orientation: (1a, 2, 3b, 4) lingual view; (1b) labial view; (3a) mesial view. Scale line = 0.5 mm.**

RHINOBATOS INCERTUS

Order RAJIFORMES Berg 1940
Family RHINOBATIDAE Muller and Henle 1838

Maximum Size: **1 mm** Occurrence: **Rare** Chronologic Range: **Turonian-Coniacian**



Genus ***Rhinobatos*** Linck 1790
Rhinobatos incertus Cappetta 1973

DESCRIPTION: Crown mesodistally wide and not very high, smooth with a single narrow cusp which grades from pronounced to absent; cusp positioned more or less in center of crown and lacks cutting edges; labial crown foot rounded, not angular, and lingually there is a short, rounded protuberance below cusp, flanked by smaller mesial and distal protuberances; root triangular in basal view with a flat attachment surface and narrow nutrient groove separating root lobes; root not displaced lingually as in *Rhinobatos casieri* but rather is situated more or less directly beneath crown; root holaulacorhizous; histology orthodont.

HETERODONTY: Weak gradient monognathic heterodonty in both jaws and strong sexual dental heterodonty with males having more cuspate crowns than females.

DISTINGUISHING CHARACTERISTICS: *Rhinobatos incertus* differs from *R. casieri* in having a much wider, cuspate crown with shorter and more robust lingual crown protuberances and a root that is not lingually extended.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Eagle Ford (Turonian) and basal Austin Group, contact horizon (Coniacian), throughout Texas.

COMMENTS: Cappetta (1973) described *Rhinobatos incertus* from the Turonian of South Dakota, and the species appears to be very common in rocks of similar age in Texas. Acid etching and microscopic sorting of both the Kamp Ranch Limestone of the Eagle Ford and the basal Austin Group Atco Formation yield numerous teeth of this species.

REFERENCES: Cappetta (1973).

Rhinobatos incertus **Cappetta 1973: Eagle Ford Group, Kamp Ranch Limestone (Turonian), Dallas County; (1) low-crowned (female) and (2) high-crowned (male) teeth. Tooth orientation: (1a, 2b) lingual view; (2d) labial view; (1b, 2c) basal view; (1d) apical view; (1c, 2a) distal view. Scale line = 0.5 mm.**

PROTOPLATYRHINA RENAE

Chronologic Range: **Maestrichtian** | Occurrence: **Common** | Maximum Size: **2 mm**

Genus ***Protoplatyrhina*** Case 1978
Protoplatyrhina renae Case 1978

DESCRIPTION: Teeth small, rarely exceeding 2 mm wide; crown thick, smooth, globular with rounded margins and roughly hexagonal in outline; a narrow basal ledge overhangs root on all sides; lingual flange weakly developed or indistinguishable; root short, less than half crown height, strongly bilobate, and does not extend beyond limits of crown foot; nutrient groove shallow and expanded around central basal foramen; basal attachment surface flat; lingual root face with one large foramen on each root lobe; root holaulacorhizous; histology orthodont.

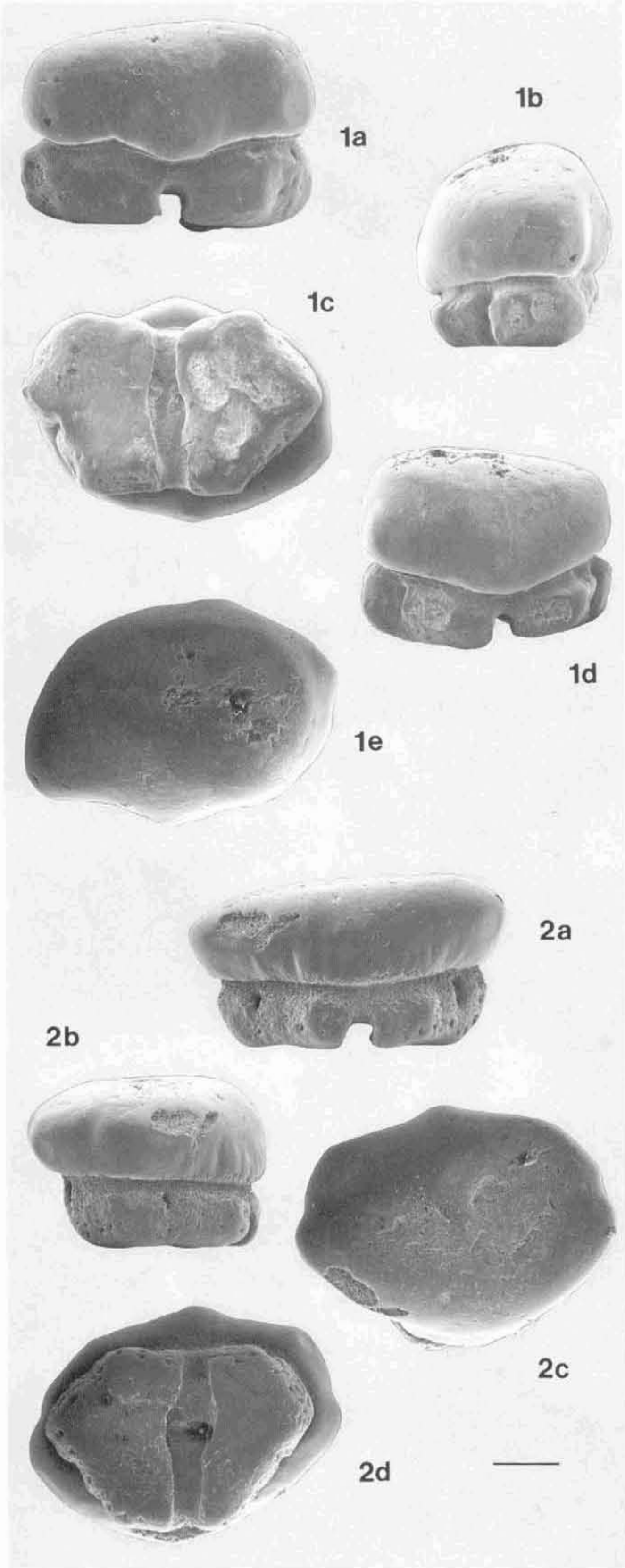
HETERODONTY: Weak gradient monognathic heterodonty inferred from observations of the morphological diversity of isolated teeth.

DISTINGUISHING CHARACTERISTICS: A bulbous crown lacking distinct faces, weak lingual protuberance, short root which is not expanded beyond the crown foot are attributes of *Protoplatyrhina* which distinguish it from other Texas rays.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Kemp formation (Maestrichtian), Hunt County.

COMMENTS: *Protoplatyrhina renae* was described by Case (1978) from the Judith River Formation (Campanian) of Montana. At present, it is known only from the Maestrichtian in Texas. Microcollecting techniques must be used to collect these teeth.

REFERENCES: Case (1978).

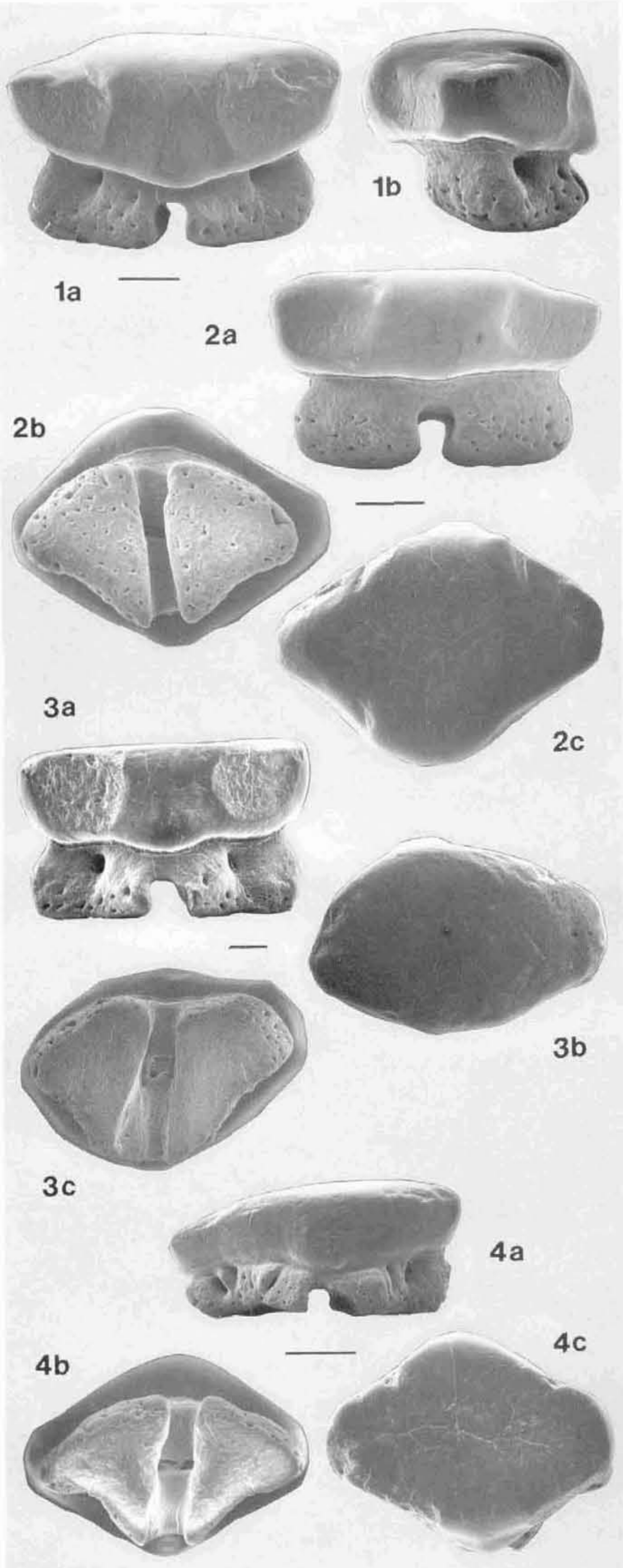


Protoplatyrhina renae **Case 1978: Navarro Group, Kemp Formation (Maestrichtian), Hunt County. Tooth orientation: (1a, 2a) lingual view; (1d) labial view; (1c, 2d) basal view; (1b, 2b) distal view; (1e, 2c) occlusal view. Scale line = 0.5 mm.**

PSEUDOHYPOLOPHUS MCNULTYI

Order RAJIFORMES Berg 1940
Family RHINOBATOIDEI incertae sedis

Maximum Size: **5 mm** Occurrence: **Common** Chronologic Range: **Aptian-Cenomanian**



Genus ***Pseudohypolophus*** Cappetta and Case 1975
Pseudohypolophus mcnultyi (Thurmond 1971)

DESCRIPTION: Small teeth with a low, rounded hexagonal crown and weakly convex occlusal face; crown surfaces are smooth and a basal ledge overhangs the root on all sides; root simple, bilobate, with one or more central basal foramina within a deep nutrient groove; numerous small foramina pierce the root just below the crown foot; root holaulacorhizous; histology orthodont.

HETERODONTY: There are no known associated dentitions of *Pseudohypolophus mcnultyi*. However, its teeth are extremely abundant in the Woodbine Formation and show little overall variation, suggesting very weak heterodonty in either jaw.

DISTINGUISHING CHARACTERISTICS: These teeth are distinguished from other Texas rays by their smooth, unornamented and rounded hexagonal crowns and simple bilobate root.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Glen Rose, Paluxy, Walnut, Weno, Pawpaw, Grayson, Pepper, Woodbine and lower Eagle Ford formations (Aptian-Cenomanian) throughout Texas.

COMMENTS: Thurmond (1971) proposed the name ?*Hypolophus mcnultyi* for small rhombic ray teeth from the Albian Paluxy Formation in Parker County. According to Thurmond (1971:page 221), these teeth are also identical to those described, but not named by McNulty (1964) from the upper Woodbine Formation (Cenomanian) of Tarrant County. Subsequently, ?*Hypolophus mcnultyi* was placed in a new genus, *Pseudohypolophus*, by Cappetta and Case (1975). Teeth of this species are known only from Texas where they occur abundantly in sediments representing offshore marine and brackish bay depositional environments. Teeth of *P. mcnultyi* are abundant in the Cenomanian of Texas.

REFERENCES: McNulty (1964); Thurmond (1971); Cappetta and Case (1975).

Pseudohypolophus mcnultyi **(Thurmond 1971): Glen Rose Formation (Albian), Parker County. Tooth orientation: (1a-4a) lingual view; (1b) distal view; (2b, 3c, 4b) basal view; (2c, 3b, 4c) apical view. Scale line s= 0.5 mm.**

?*SQUATIRHINA* sp.

Chronologic Range: **Albian-Cenomanian** | Occurrence: **Rare** | Maximum Size: **2 mm**

Genus ***Squatirhina*** Casier 1947
?***Squatirhina*** sp.

DESCRIPTION: Teeth small, rarely exceeding 1.5 mm in width; crown weakly convex and oval in apical view with a single, lingually placed, short narrow cusp with strong lingual inclination; bulbous lingual protuberance situated immediately below cusp and deeply incised on mesial and distal edges; entire crown margin irregularly and deeply scalloped; crown surface smooth; root asymmetrical, strongly bilobate, and divided by a sigmoidal nutrient groove; two or three anteriorly placed foramina situated within the nutrient groove and smaller foramina pierce the root lingually and labially, just below the crown foot; root lobes do not extend beyond crown margin; root holaulacorhizous; histology orthodont.

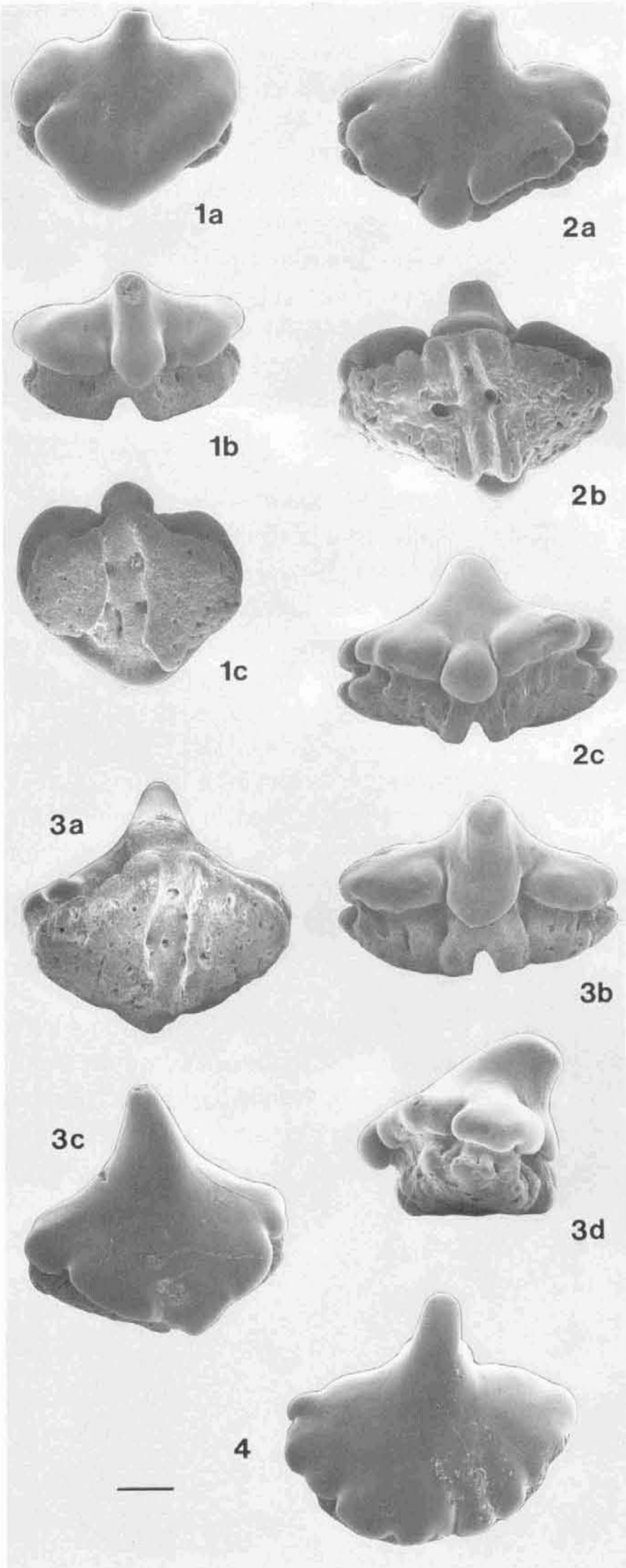
HETERODONTY: Uncertain, but all teeth are similar suggesting weak gradient monognathic heterodonty; degree of dignathic heterodonty is unknown.

DISTINGUISHING CHARACTERISTICS: A scalloped crown margin separates these teeth from all other Texas rays.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Weno Formation (Albian), Tarrant County and the Pepper Formation (Cenomanian), Bell County.

COMMENTS: These teeth represent an undescribed species of ray and their generic allocation to *Squatirhina* is questionable. The type species *S. lonzeensis* Casier comes from the lower Santonian of Belgium, as does a younger Maestrichtian species, *S. kannensis*, which was described by Herman (1977). Due to the small size of these teeth, microcollecting techniques must be used to effectively collect them.

REFERENCES: Casier (1947); Herman (1977).



?*Squatirhina* **sp.: Pepper Formation (Cenomanian), Bell County. Tooth orientation: (1a, 2a, 3c, 4) apical view; (1b, 2c, 3b) lingual view; (1c, 2b, 3a) basal view; (3d) mesial view. Scale line = 0.5 mm.**

Family Rajidae

In skates, Family Rajidae, the dorsal and anal fins are greatly reduced in size, and the pelvic fins are deeply notched so that they appear as four fins rather than two. The pectoral fins are large and wing-like, joined at the front of the head to form a shelf-like snout. The tail is moderately slender.

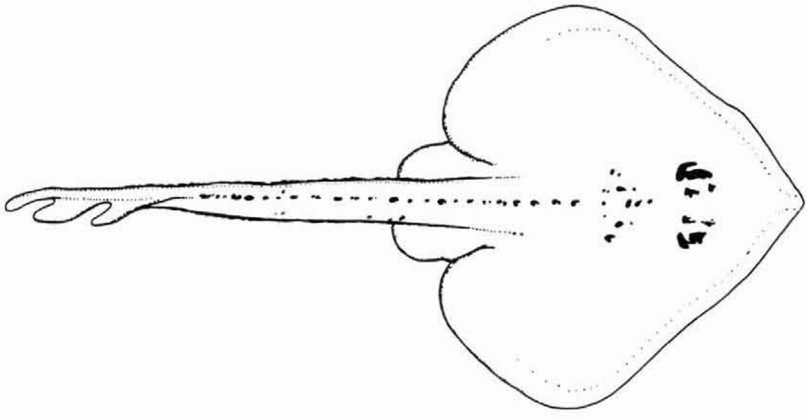
Skates are essentially bottom dwellers, usually lying quietly half-buried in the sand or mud during the daylight hours and stirring to feed on small fish, shellfish and crustaceans. Skates are found in cool to temperate waters throughout the world and most live in rather shallow water and close to shore, but there are also some deep-water species. For example, the Pacific abyssal skate, *Raja bathyphila*, has been taken at depths greater than 2100 meters and other species live at depths in excess of 6000 meters.

Some of the largest skates reach lengths up to 2.5 meters (*Raja binoculata*) but most are much smaller, being in the range of between 0.5 and 1.5 meters.

Rajids have numerous rows of closely spaced teeth, arranged in alternate or imbricate patterns such that a grasping or crushing pavement typifies most species. The heterodonty is gradient monognathic, rarely pronounced disjunct monognathic in either jaw and dignathic heterodonty is rare. Sexual dental heterodonty is pronounced in some species (e.g., the big skate *Raja binoculata*); males have narrow teeth with a long, high cusp and females have larger, mesodistally expanded teeth with a low, blunt cusp.

Texas Cretaceous skate teeth of Campanian and Maestrichtian age are characterized by being mesodistally narrow with moderately high, smooth and rounded cuspate crowns. They have a narrow but inflated lingual crown protuberance that extends well below the level of the mesial and distal crown foot, and labially, the crown foot develops a prominent basal ledge. The crown is connected to the root by a narrow neck and the root lobes are widely flaring, separated by a deep, wide nutrient groove. The basal attachment surface of each root lobe is weakly convex and as a whole, the root is angled lingually.

At least two different rajids, close to the genus *Raja*, occur in the Texas Cretaceous. One form, which is not figured here, is quite small and extremely rare in Campanian strata of the Pecan Gap Chalk. The second form, which is included, is abundant in Maestrichtian rocks of the Kemp and Escondido formations of Texas.



Order RAJIFORMES Berg 1940
Family RAJIDE Bonaparte 1831

RAJIDAE

Chronologic Range: **Maestrichtian** | Occurrence: **Common** | Maximum Size: **3.5 mm**

Genus and Species Undetermined

DESCRIPTION: Small rajiform teeth rarely exceeding 3 mm in height; crown higher than root, mesodistally narrow, somewhat inflated, strongly overhanging root labially, smooth on all faces and rounded on all margins; cusp high, erect, broad-based and robust; cutting ridges continuous from apex to a point just above crown foot; lingual flange thick, short, lobate and projects lingually well below level of labial crown foot; high-angle labial face of cusp grades gently into low-angle labial prominence of crown; mesial and distal edges of crown flare outward at terminus of cutting ridges; labial crown foot projected downward toward root, having a strongly convex or lobate outline; projecting basal ledge at crown foot overhangs root on all faces; root narrow at crown foot with a distinct neck, then flares outward; root lobes labiolingually elongate, short, and shifted lingually under crown; basal attachment surfaces weakly convex and oriented at approximately a 45-degree angle to crown foot: in basal view, attachment surfaces have a "foot-print" shaped outline and a large central basal foramen is situated between them within the nutrient groove; root holaulacorhizous; histology orthodont.

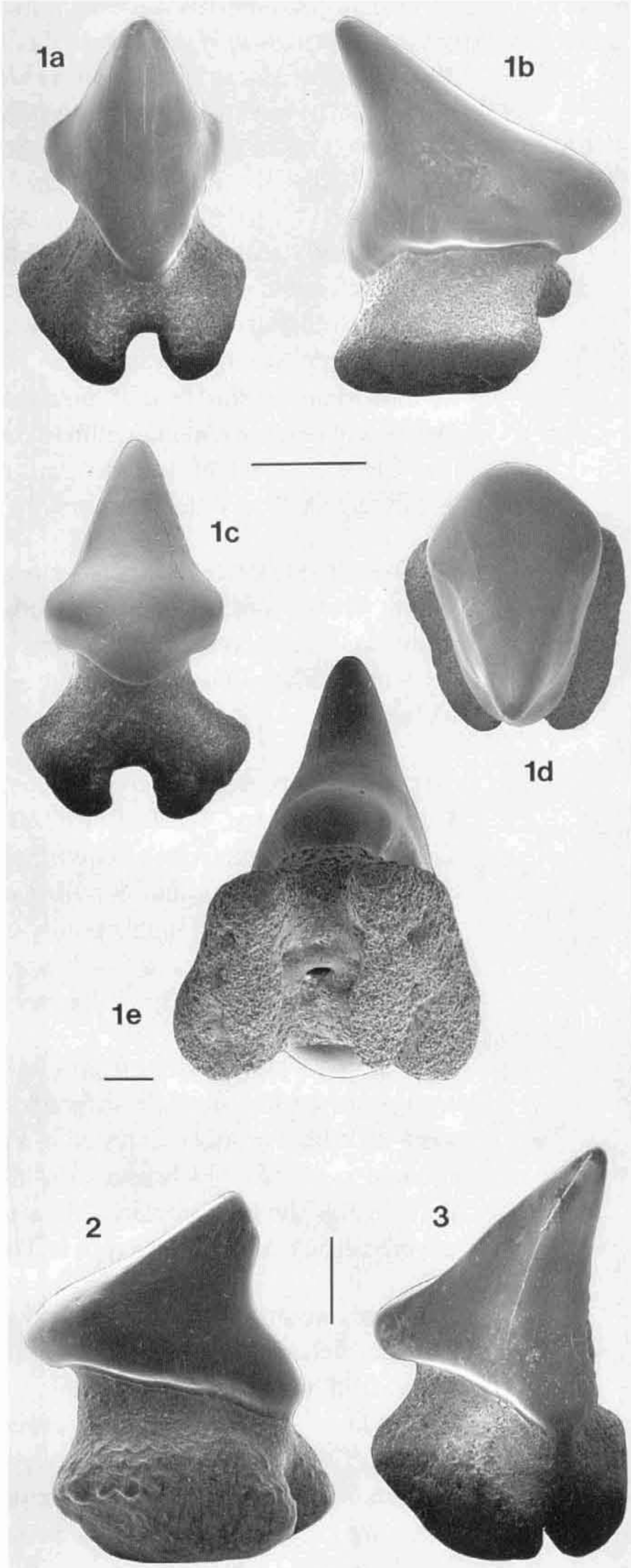
HETERODONTY: Probably has weak gradient monognathic heterodonty; strong sexual dental heterodonty, as occurs in modern rajids, not apparent from available sample.

DISTINGUISHING CHARACTERISTICS: The narrow, erect, smoothly rounded cuspate crown with short bilobate, outwardly flaring root lobes, and a very narrow neck are attributes of these teeth that readily separate them from all other Texas rays.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Kemp and Escondido formations (Maestrichtian), Medina and Hunt Counties.

COMMENTS: These small Maestrichtian teeth are very similar to some modern skates (rays in the Family Rajidae) and especially those belonging to the genus *Raja* (e.g., *Raja binoculata*). These teeth are the only true skates in the Texas Cretaceous and represent an undescribed genus and species. These small teeth require microcollecting techniques.

REFERENCES: None.



Rajidae, genus and species undetermined: Kemp Formation (Maestrichtian), Hunt County. Tooth orientation: (1a, 3) lingual view; (1c) labial view; (1d) apical view; (1e) basal view; (1b, 2) distal view. Scale lines = 0.5 mm (except 1e = 0.2 mm).

Family Sclerorhynchidae

All Cretaceous sawfishes belong to the Family Sclerorhynchidae Cappetta 1974, which encompasses approximately 15 genera having a collective fossil record spanning the early Albian through latest Maestrichtian worldwide. Sclerorhynchids generally resemble modern sawfishes (Pristidae) by having a long and slim shark-like body with ventral gill slits, pectoral fins attached to the head, and a long snout or rostrum armed with a row of spines (rostral teeth) on each lateral margin.

It is probably reasonable to assume that the sclerorhynchid rays occupied an ecological and functional niche equivalent to that presently filled by modern sawfishes. Today, pristids are bottom dwellers, but they will rise toward the surface to slash their way through a school of fishes, turning to pick up any that are stunned or wounded. The long snout is also used to probe into sand or mud to dig up shellfish. If molested, a sawfish turns this food-getting snout into a powerful weapon of defense and may inflict serious injury. Some of the modern sawfishes, like many of the Cretaceous sclerorhynchids, are cosmopolitan in distribution in warm to tropical seas, inhabiting shallow waters and straying into brackish or even fresh water.

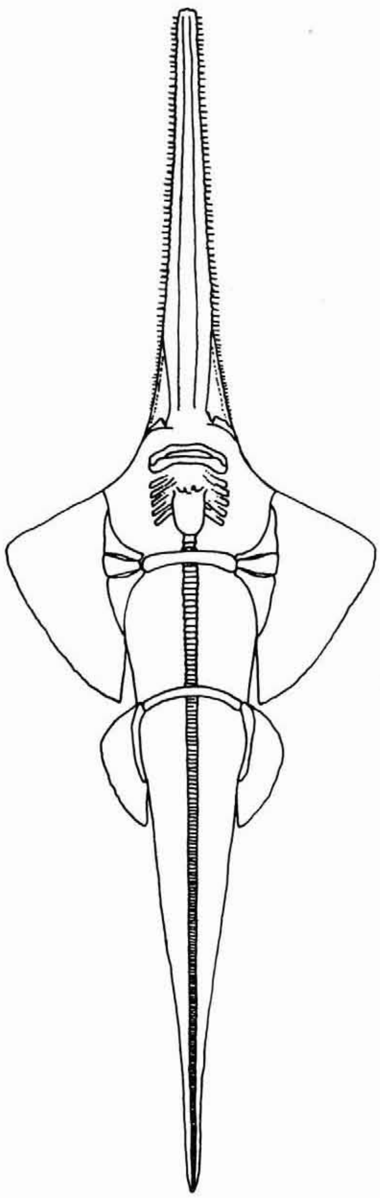
The smalltooth sawfish, *Pristis pectinata*, is commonly 4.5 meters long, sometimes reaching a length in excess of 6 meters. Certainly, some of the fossil sclerorhynchids must have been of equivalent length considering the large size of some rostral teeth (e.g., *Onchosaurus pharao* rostral teeth exceed 90 millimeters in length and some species of *Ischyrhiza* and *Onchopristis* are almost as large).

At present, there are seven species representing five genera of sclerorhynchid sawfishes from the Cretaceous of Texas. These include *Onchopristis* Stromer 1917 (Albian-Coniacian), *Onchosaurus* Gervais 1852 (Campanian), *Ischyrhiza* Leidy 1856 (Turonian-Maestrichtian), *Schizorhiza* Weiler 1930 (Maestrichtian), and *Sclerorhynchus* Woodward 1889 (Coniacian-Campanian). Also provisionally included in this family are five additional species of Cenomanian-Maestrichtian rays belonging to the genus *Ptychotrygon* Jaekel 1894. The teeth of *Ptychotrygon* are similar to those of true sclerorhynchids, but species in this genus lack a toothed rostrum.

Rostral spines or teeth range from 1 millimeter to 90+ millimeters in length and are usually found along with shark teeth while surface collecting. In life, they attached to the surface of the rostrum via a wide base or root that rested in a shallow groove or straddled the rostral cartilage. Unlike modern sawfishes which have ever-growing rostral teeth set in deep sockets, sclerorhynchids periodically shed and replaced their teeth. Sclerorhynchid rostral teeth have an enameloid-covered crown attached to a root and the histology may be osteodont or orthodont.

Oral teeth are small, rarely exceeding 3 millimeters in greatest dimension, and are most likely to be recovered using microscopic washing and sorting techniques. They are wider than long (mesodistally expanded) and usually cuspate with a weak to strong labial flange and basal ledge. Crown faces are smooth or often covered by enameloid folds oriented in a transverse or radial pattern. The lingual crown face is vertical to weakly concave, having a short lingual flange that projects basally, ending just above the nutrient groove notch. A cutting ridge is usually continuous across the cusp and one or more transverse ridges often cross the crown. Roots are symmetrical and triangular in basal view with weakly convex basal attachment surfaces. The root does not extend much beyond the crown margins, and a deep nutrient groove with a central basal foramen is always present.

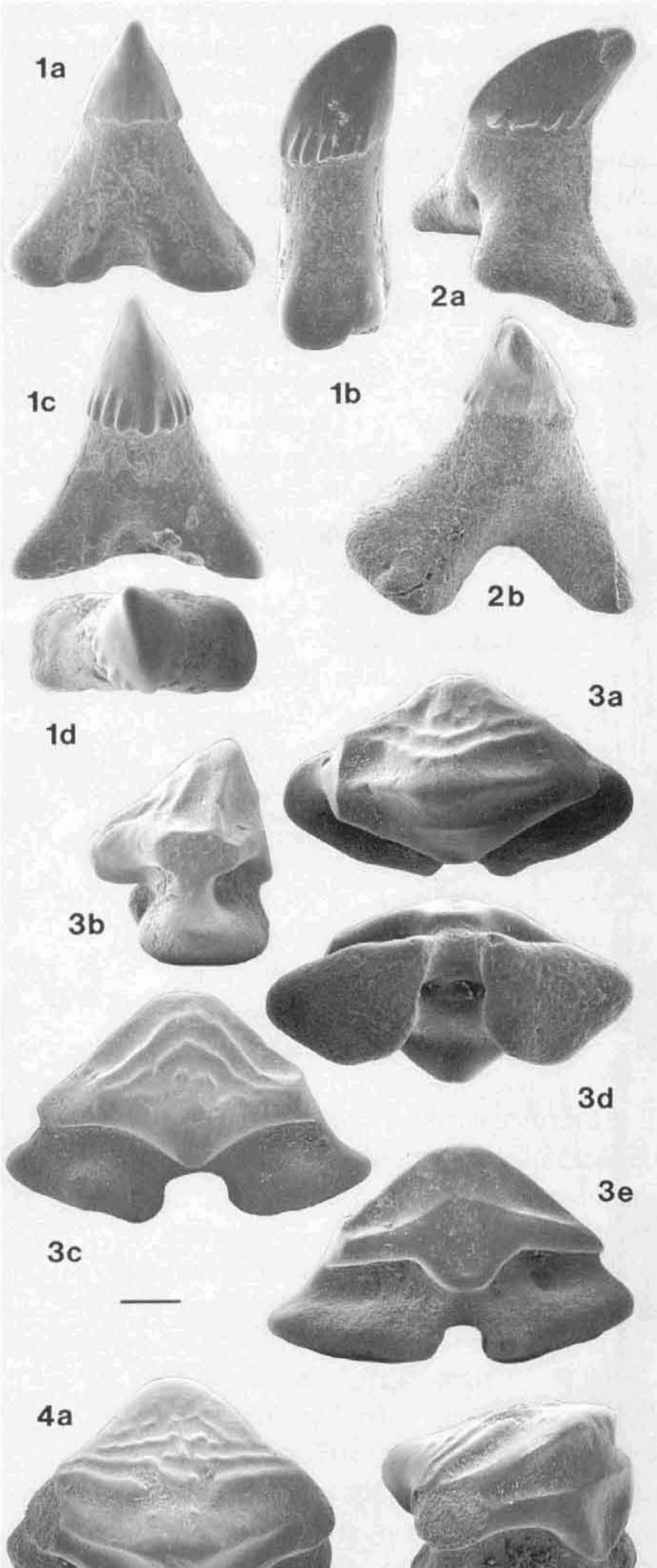
Sclerorhynchid fossils were first reported from Texas by Dunkle (1948) and subsequently by McNulty and Slaughter (1962, 1964), Slaughter and Steiner (1964, 1968), Thurmond (1971), Cappetta and Case (1975), Lehman (1989) and Werner (1990).



ISCHYRHIZA AVONICOLA

Order RAJIFORMES Berg 1940
Family SCLERORHYNCHIDAE Cappetta 1974

Maximum Size: **R-4 mm/O-1.5 mm** Occurrence: **Common** Chronologic Range: **Campanian-Maestrichtian**



Genus ***Ischyrhiza*** Leidy 1856
Ischyrhiza avonicola Estes 1964

DESCRIPTION: **Rostral teeth**: small and short; crown less than half tooth height, posteriorly inclined with a convex anterior cutting ridge that extends from apex to crown foot; longitudinal ridges coarse, short, restricted to the crown foot and directed toward apex; root widely splayed and expands continuously from crown foot to base. **Oral teeth**: very small, less than 2 mm in mesodistal width, being wider than long; crown inflated with a rounded apical edge that lacks a distinct cusp; lingual face slightly inclined labially with a weakly differentiated protuberance; labial face slopes at a high angle to the crown apex and has a rounded to subangular, nearly horizontal flange that overhangs the root; both crown faces possess numerous transverse ridges that break up labially and lingually into rugosities near the crown foot; root lobes widely separated, extended well past crown base, and are subdivided by a deep, wide nutrient groove; root holaulacorhizous; histology orthodont.

HETERODONTY: Rostral teeth vary in size along the snout; oral teeth probably have very weak gradient monognathic heterodonty in both jaws.

DISTINGUISHING CHARACTERISTICS: *Ischyrhiza avonicola* rostral teeth differ from other *Ischyrhiza* in having a very short crown with strong enameloid folds and a wide root. Absence of a distinct crown cusp, rugose ornamentation and robust tooth shape are distinctive attributes of this species' oral teeth.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Taylor and Navarro Groups; Campanian and Maestrichtian rocks throughout Texas.

COMMENTS: This species of *Ischyrhiza* was originally described from the Late Cretaceous Lance Formation of Montana by Estes (1964). Slaughter and Steiner (1968) referred teeth from the Turonian and Coniacian of Texas to *I. avonicola*; however, these teeth are probably best referred to *I. schneideri* or *I. texana* and *I. avonicola* is restricted to strata of Campanian and Maestrichtian age. See microcollecting techniques in Chapter 6.

REFERENCES: Estes (1964); Slaughter and Steiner (1968).

***Ischyrhiza avonicola* Estes 1964: (1) Rostral tooth, Escondido Formation (Maestrichtian), Medina County; (2) Rostral tooth and (3, 4) oral teeth, Kemp Formation (Maestrichtian), Hunt County. Tooth orientation: (1a, 2b) posterior view; (1b, 2a) dorsal view; (1c) anterior view; (1d) apical view; (3a, 4a) apical view; (3e) lingual view; (3c) labial view; (3d) basal view; (3b, 4b) mesial view. Scale line = 0.5 mm.**

Chronologic Range: **Campanian-Maestrichtian** Occurrence: **Common** Maximum Size: **R-50+ mm/O-6 mm**

Genus ***Ischyrhiza*** Leidy 1856
Ischyrhiza mira Leidy 1856

DESCRIPTION: **Rostral Teeth**: crown thick with smooth enameloid, slightly sinuous and shorter than the root; anterior and posterior cutting edges are sharp, extending from the crown apex toward the base but not intersecting the crown foot; crown shows little posterior inclination relative to the root; root tall, massive, and basally expanded with a median longitudinal furrow and deeply scalloped root lobes. **Oral Teeth**: crown mesodistally expanded with a single high cusp and long, low mesial and distal shoulders; labial flange long, basally directed and expanded below the crown foot with a weaker lingual flange well developed; crown smooth except for a few enameloid folds near crown foot; root high, strongly bilobate with a flat attachment surface, subdivided by a deep nutrient groove; root holaulacorhizous; histology orthodont.

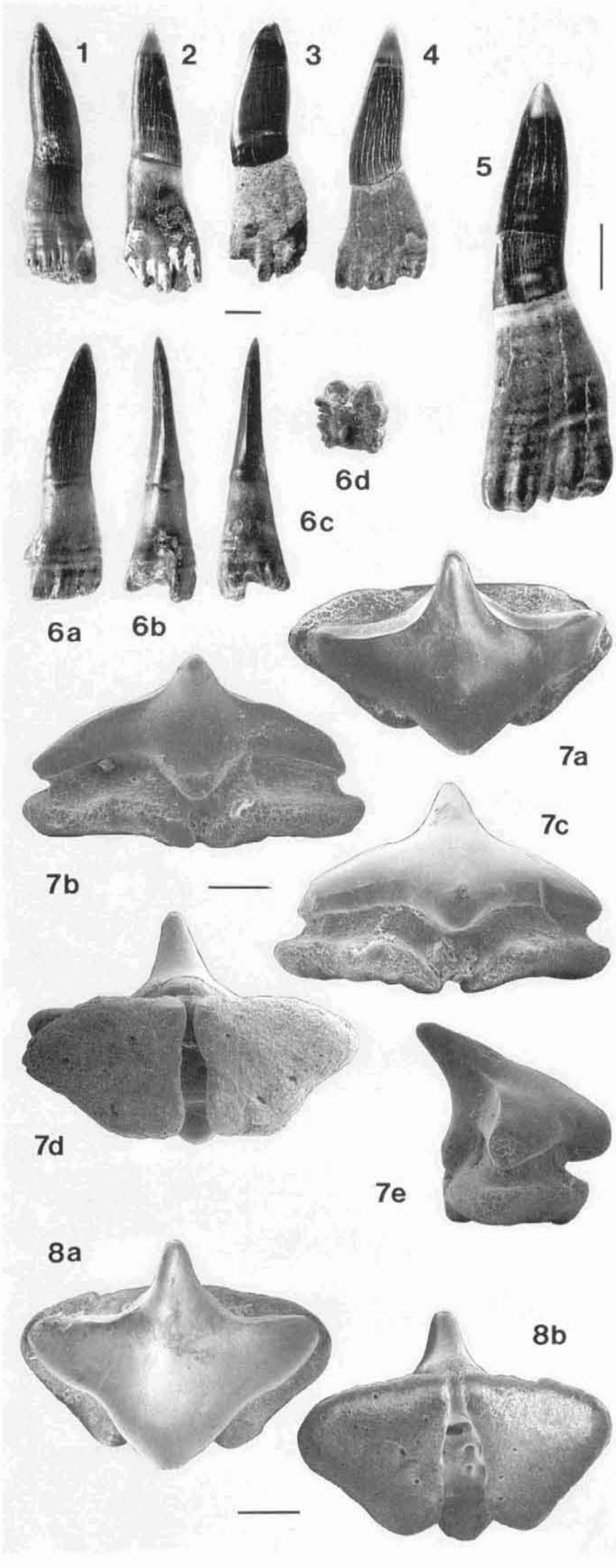
HETERODONTY: Rostral teeth show a wide range in size and especially crown height depending on position along the rostrum. Oral teeth have weak gradient monognathic heterodonty.

DISTINGUISHING CHARACTERISTICS: A thick sinuous crown that is shorter than the root and the absence of barbs along the posterior cutting edge are characters which, in combination, separate *Ischyrhiza mira* from other Texas sclerorhynchids. The oral teeth can be more difficult to identify, but in general their pronounced cusp, expanded low shoulders and long labial flange distinguish them from other batoids.

STRATIGRAPHIC OCCURRENCE IN TEXAS: This species occurs in the Taylor and Navarro Groups (Campanian and Maestrichtian) throughout Texas.

COMMENTS: In our opinion, the species *Ischyrhiza mira* occurs only within the Campanian and Maestrichtian in Texas and is equivalent to the subspecies *I.* sp. aff. *I. mira* from the lower Campanian of Arkansas, proposed by Slaughter and Steiner (1968). The Turonian and Coniacian rostral teeth described as *I. mira schneideri* by Slaughter and Steiner (1968) are a species distinct from *I. mira* and can be associated with oral teeth of *I. texana* which Cappetta and Case (1975) named from the basal Atco Formation (contact horizon) of the Austin Group (Coniacian).

REFERENCES: Slaughter and Steiner (1968); Cappetta and Case (1975).

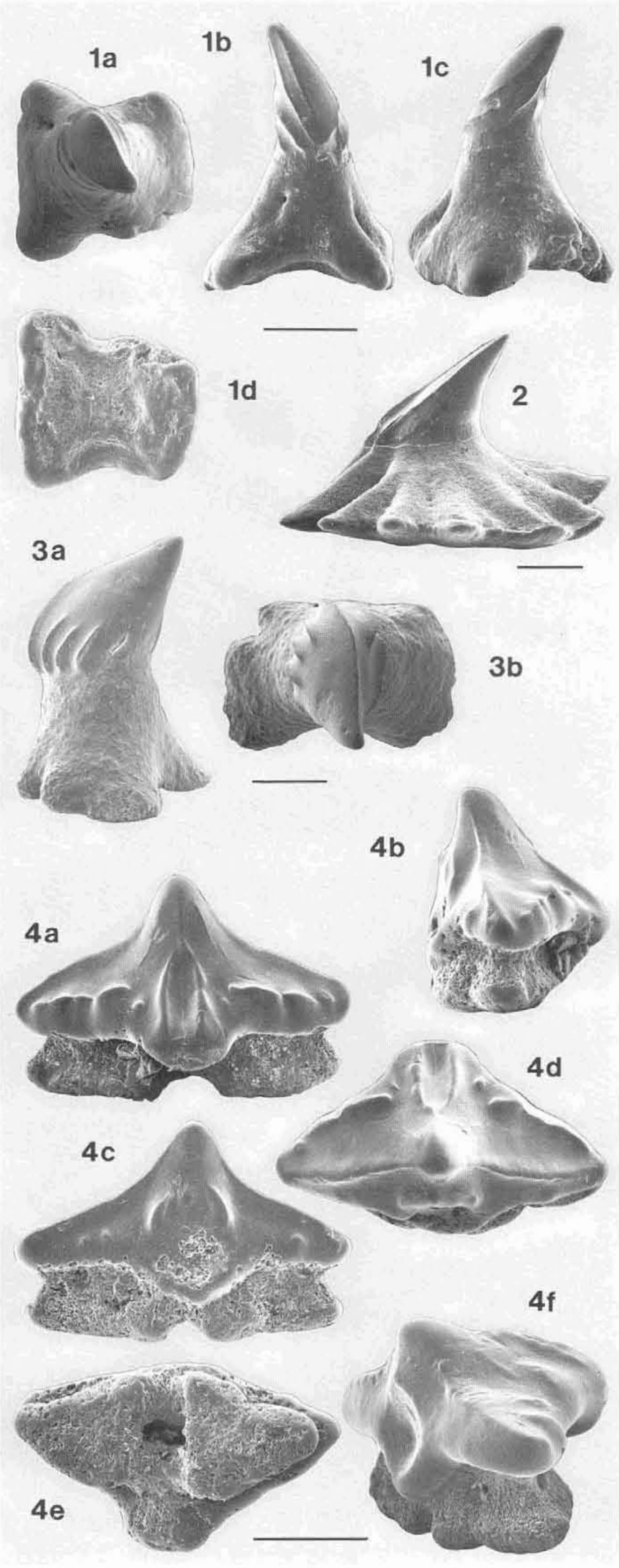


Ischyrhiza mira **Leidy 1856: (1-6) rostral teeth, Taylor Group (Campanian), Hunt County; (7-8) oral teeth, Ozan Formation (Campanian), Dallas County. Tooth orientation: (1-5, 6a) dorsal view; (6b) posterior view; (6c) anterior view; (6d) basal view; (7b) lingual view; (7a, 8a) apical view; (7c) labial view; (7d, 8b) basal view; (7e) distal view. Scale line = 5 mm (1-6) and 0.5 mm (7-8).**

ISCHYRHIZA TEXANA

Order RAJIFORMES Berg 1940
Family SCLERORHYNCHIDAE Cappetta 1974

Maximum Size: **R-4 mm/O-1.5 mm** Occurrence: **Common** Chronologic Range: **Turonian-Coniacian**



Genus ***Ischyrhiza*** Leidy 1856
Ischyrhiza texana Cappetta and Case 1975

DESCRIPTION: **Rostral Teeth**: large teeth with erect, twisted and posteriorly directed crowns that are smooth except for moderately long, apically directed, oblique enameloid ridges at the crown foot; cutting ridges occur on both anterior and posterior crown edges; root at crown foot unconstricted and rectangular to square in basal view; posterior rostral teeth are short and stubby, having prominent enameloid folds, and widely expanded basal attachment surfaces. **Oral Teeth**: crowns mesodistally expanded; cusp erect and narrow; lateral blades high and sloping away from cusp; labial flange lobate, frequently having two parallel longitudinal enameloid ridges, uniting apically on cusp; crown faces generally smooth; crown shows weak lingual inclination and cusplets may develop on mesial and distal blades; root high, with somewhat inflated mesial and distal lobes, separated by a deep nutrient groove; root holaulacorhizous; histology orthodont.

HETERODONTY: Rostral tooth variation typical for sclerorhynchids; oral teeth have weak gradient monognathic heterodonty in both jaws.

DISTINGUISHING CHARACTERISTICS: The rostral teeth of *Ischyrhiza texana* are smaller than those of *I. mira* and have more posteriorly-directed crowns with basal enameloid ridges. The oral teeth of *I. texana* lack the massive labial flange and broad mesial and distal shoulders of *I. mira*.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Upper Eagle Ford (Turonian) and Austin Group formations (Coniacian), throughout Texas.

COMMENTS: Slaughter and Steiner (1968) erected the subspecies *Ischyrhiza mira schneideri* for rostral teeth of Turonian and Coniacian age in Texas. In 1975, Cappetta and Case named *I. texana* based on oral teeth from the basal Atco Formation (contact horizon) of the Austin Group. No mention was made of the rostral teeth of *Ischyrhiza* found in the same deposit, nor was the relationship of *I. texana* to *I. mira schneideri* discussed. We consider the oral teeth of *I. texana* and the rostral teeth of *I. m. schneideri* to belong to the same species.

REFERENCES: Slaughter and Steiner (1968); Cappetta and Case (1975).

***Ischyrhiza texana* Cappetta and Case 1975: (1-3) rostral teeth and (4) oral tooth from the Atco Formation contact horizon (Coniacian), Austin Group, Travis County. Tooth orientation: (1a, 3b) apical view; (1d) basal view; (1b, 1c) posterior view; (2, 3a) dorsal view; (4a) labial view; (4b) mesial view; (4c) lingual view; (4d) apical view; (4e) basal view; (4f) distal view. Scale line = 0.5 mm.**

Order RAJIFORMES Berg 1940
Family SCLERORHYNCHIDAE Cappetta 1974

ONCHOPRISTIS DUNKLEI

Chronologic Range: **Albian-Coniacian** Occurrence: **Common** Maximum Size: **R-30+ mm/O-2 mm**

Genus ***Onchopristis*** Stromer 1917
Onchopristis dunklei McNulty and Slaughter 1962

DESCRIPTION: Rostral Teeth: crown narrow, high and posteriorly inclined with two to five barbs along posterior edge; crown enameloid smooth, lacking longitudinal or oblique longitudinal ridges, and an anterior cutting edge develops on some teeth; root very short and flares conspicuously from the crown foot; basal face deeply concave anteroposteriorly for attachment to the rostrum; root crenulations deep and follow the orientation of the crown but may branch basally. **Oral Teeth**: crown with a single tall, robust, lingually inclined cusp, one pair of weakly developed blade-like cusplets, a very long, curved and narrow labial crown protuberance, and narrow lingual protuberance; labial cusp face usually has a sharp median longitudinal ridge; in basal view, root lobes are triangular in outline and a deep nutrient groove sometimes divides basal attachment surface; root hemi- to holaulacorhizous; histology orthodont.

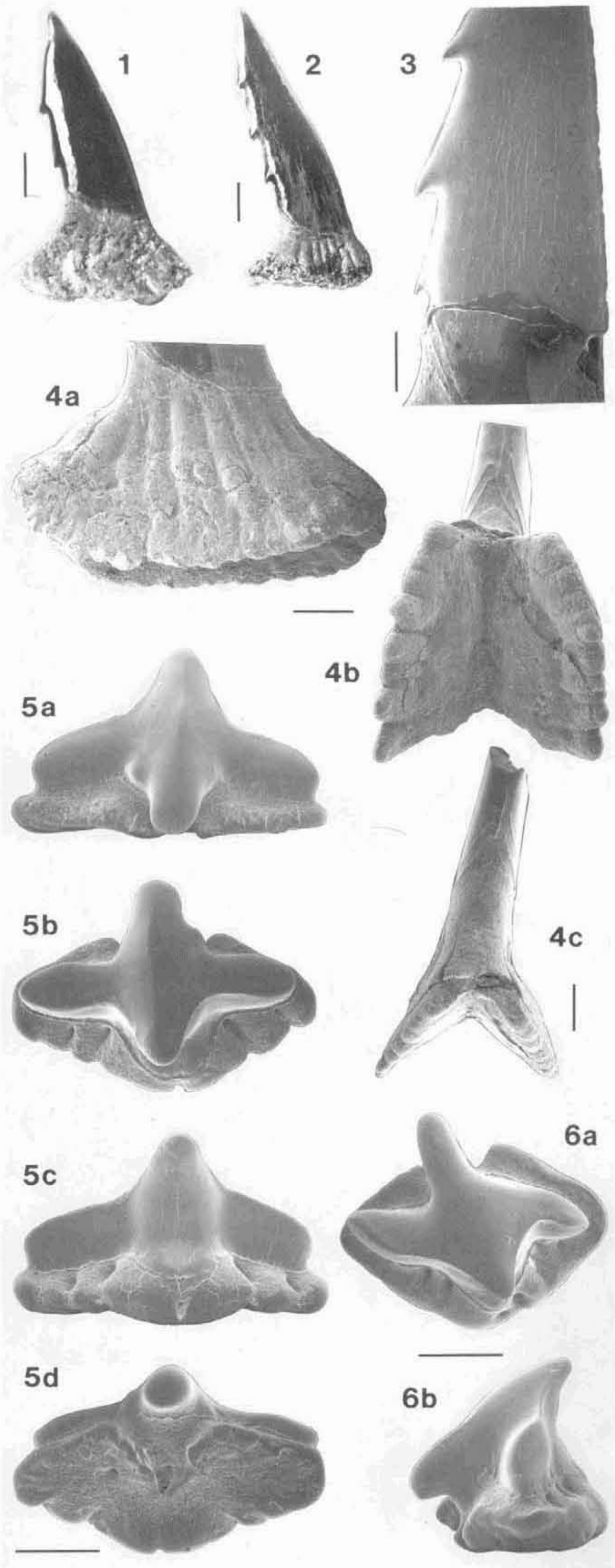
DISTINGUISHING CHARACTERISTICS: The presence of two or more barbs on the posterior edge of rostral teeth separate *Onchopristis* from all other sclerorhynchids. *Onchopristis* oral teeth differ from those of other Cretaceous sawfishes in having a very high cusp and a long, narrow labial flange.

HETERODONTY: The rostral teeth seem to vary primarily in height and number of posterior barbs, ranging from two to five. Little variation in the oral teeth suggests weak gradient heterodonty; dignathic heterodonty indeterminate.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Albian-Coniacian: Walnut, Weno, Pawpaw, Grayson, Pepper and Woodbine formations, Eagle Ford Group and Austin Group Atco Formation (contact horizon) throughout the Texas Cretaceous.

COMMENTS: The species was described by McNulty and Slaughter (1962) on the basis of Cenomanian rostral teeth from the Woodbine Formation in Tarrant County. Thurmond (1971) described an Albian subspecies, *Onchopristis dunklei praecursor*, from the Walnut Formation in Bosque County. Cappetta's 1987 interpretation of the oral teeth of *O. dunklei* was refuted by Werner (1990) who assigned the same teeth, based on the unpublished figures of Meyer (1975) to a new species *Sechmetia cruciformis*. We believe that Cappetta was probably correct in referring these oral teeth to *O. dunklei* and his interpretation is followed here.

REFERENCES: Dunkle (1948); McNulty and Slaughter (1962); Thurmond (1971); Cappetta (1987); Werner (1990).

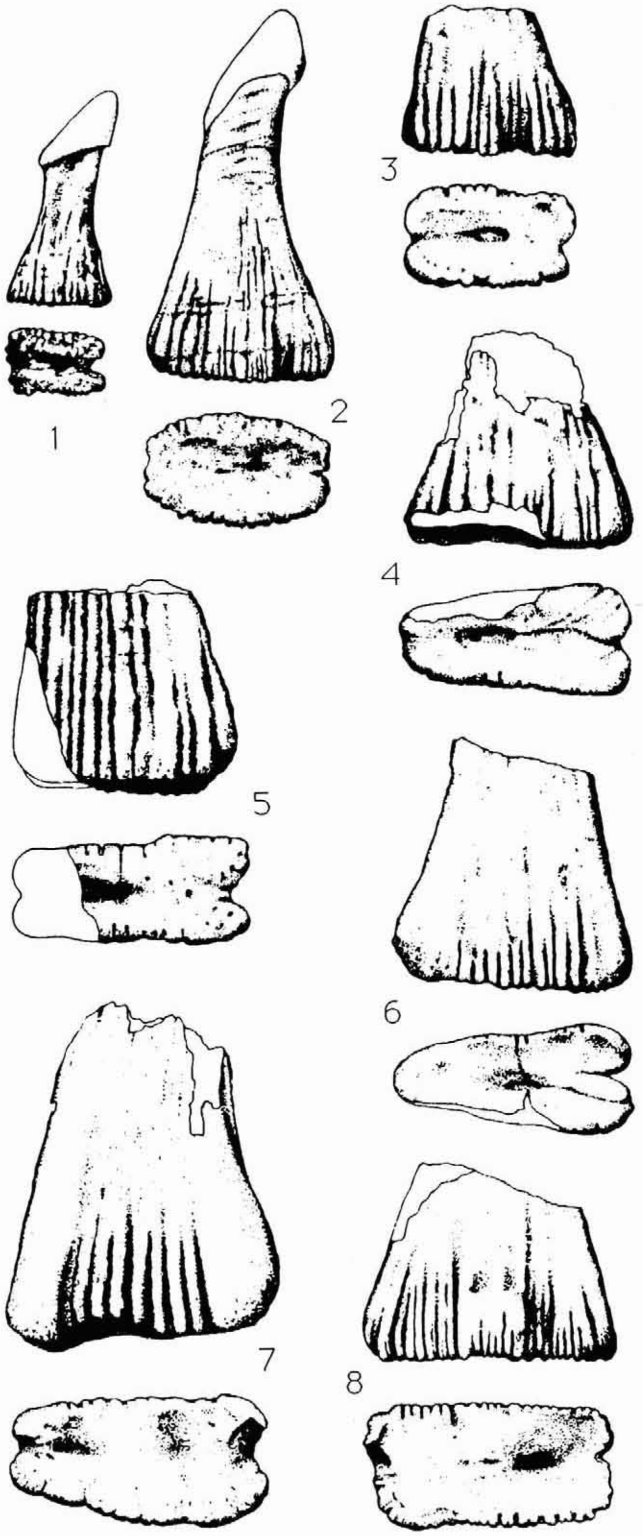


***Onchopristis dunklei* McNulty and Slaughter 1962: (1-4) rostral teeth and (5-6) oral teeth, Weno Formation (Albian), Tarrant County. Tooth orientation: (1-3, 4a) dorsal view; (4b) basal view; (4c) posterior view; (5a) labial view; (5b, 6a) apical view; (5c) lingual view; (5d) basal view; (6b) mesial view. Scale line = 5 mm (1, 2) and 0.5 mm (3-6).**

ONCHOSAURUS PHARAO

Order RAJIFORMES Berg 1940
Family SCLERORHYNCHIDAE Cappetta 1974

Maximum Size: **R-90+ mm** | Occurrence: **Rare** | Chronologic Range: **Campanian**



Genus ***Onchosaurus*** Gervais 1852
Onchosaurus pharao (Dames 1887)

DESCRIPTION: Lehman (1989) described the only known Texas specimens of *Onchosaurus* as follows: none of the specimens is complete; only the peduncle and parts of the elongate peduncular "shafts" of the teeth are preserved; crowns are lacking; peduncle (root just below crown foot) is rectangular in basal cross section; teeth are slightly wider on posterior surface than they are on anterior surface; teeth slightly curved posteriorly and have a pronounced groove running entire length of the posterior surface of peduncle and shaft; anterior surface has only a short groove, or none at all; dorsal and ventral surfaces of the peduncle have from nine to sixteen deep striations on each face; attachment surface of the root is shallowly indented; a small centrally located pit extends from the attachment surface a short distance into the root; pulp cavity lacking; histology osteodont.

HETERODONTY: Rostral teeth - heterodonty pattern typical for sclerorhynchids.

DISTINGUISHING CHARACTERISTICS: These rostral teeth are much larger than those of *Ischyrhiza mira* and differ primarily in having a very short crown (none of the Texas specimens of *Onchosaurus* have the crown preserved).

STRATIGRAPHIC OCCURRENCE IN TEXAS: Campanian, San Carlos Formation, Presidio County.

COMMENTS: The specimens described by Lehman from Texas are larger than rostral teeth reported for any other sawfish. Based on the proportions of complete specimens of *Onchosaurus pharao* figured by Arambourg (1940), the largest of the San Carlos specimens would have been about 90 mm in length. The occurrence of *Onchosaurus* in Texas represents a significant geographic and stratigraphic range extension for the genus, which has previously been reported from France, north and west Africa and South America.

REFERENCES: Lehman (1989).

Onchosaurus pharao **(Dames 1887): Rostral teeth from the San Carlos Formation (Campanian), Presidio County (after Lehman 1989). Rostral teeth of *Onchosaurus* in dorsal view and in basal view showing the attachment surface; (1) *Onchosaurus pharao* and (2) *O. radicalis* (redrawn from Arambourg 1940); (3-8) fragmentary rostral teeth of *O. pharao* from the San Carlos Formation; (3) TMM 40817-2; (4-8) TMM 42531-1. Scale line = 1 cm.**

Order RAJIFORMES Berg 1940
Family SCLERORHYNCHIDAE Cappetta 1974

SCHIZORHIZA cf. *WEILERI*

Chronologic Range: **Maestrichtian** Occurrence: **Rare** Maximum Size: **R-15 mm**

Genus ***Schizorhiza*** Weiler 1930
Schizorhiza cf. ***weileri*** Serra 1933

DESCRIPTION: **Rostral tooth**: crown diamond shaped and about one-third total tooth length; tooth has very weak posterior flexure and is tightly constricted at the crown foot; anterior and posterior cutting edges sharp and unserrated; root expands below narrow crown foot into two flat lobes that are separated by a deep furrow that extends almost to base of crown; root lobes comb-like, having four thin basal projections; histology osteodont.

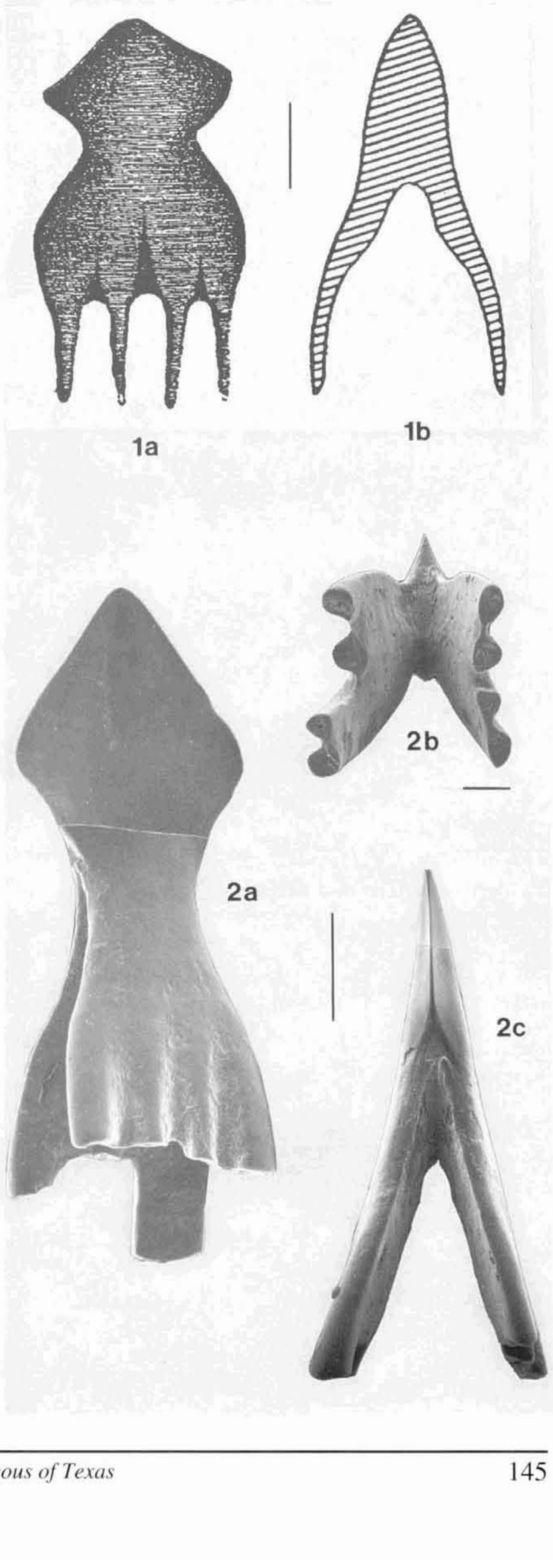
HETERODONTY: The morphological variation in rostral tooth shape is unknown for Texas *Schizorhiza*.

DISTINGUISHING CHARACTERISTICS: The rostral teeth of *Schizorhiza* are strikingly different from all other Texas sclerorhynchids in having a small and short diamond-shaped crown and a comb-like bilobate root with lobes separated by a very deep V-shaped furrow.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Maestrichtian, Escondido Formation, Maverick County.

COMMENTS: Dunkle (1948) reported on the occurrence of a rostral tooth of *Schizorhiza* cf. *weileri* Serra 1933 in the Escondido Formation, Maverick County. Rostral teeth of this genus are known only from isolated teeth and the type species, *S. stromeri* Weiler 1930, was described from the Late Cretaceous of Egypt. Dunkle considered the rostral tooth from Texas to be more closely comparable with *S. weileri* Serra 1933 noting that "it differs only in the more pronounced asymmetry of the crown profile in dorsoventral aspect and in exhibiting a greater size than reported by Serra" (Dunkle 1948: page 175). *Schizorhiza* oral teeth have not been reported from Texas.

REFERENCES: Dunkle (1948).

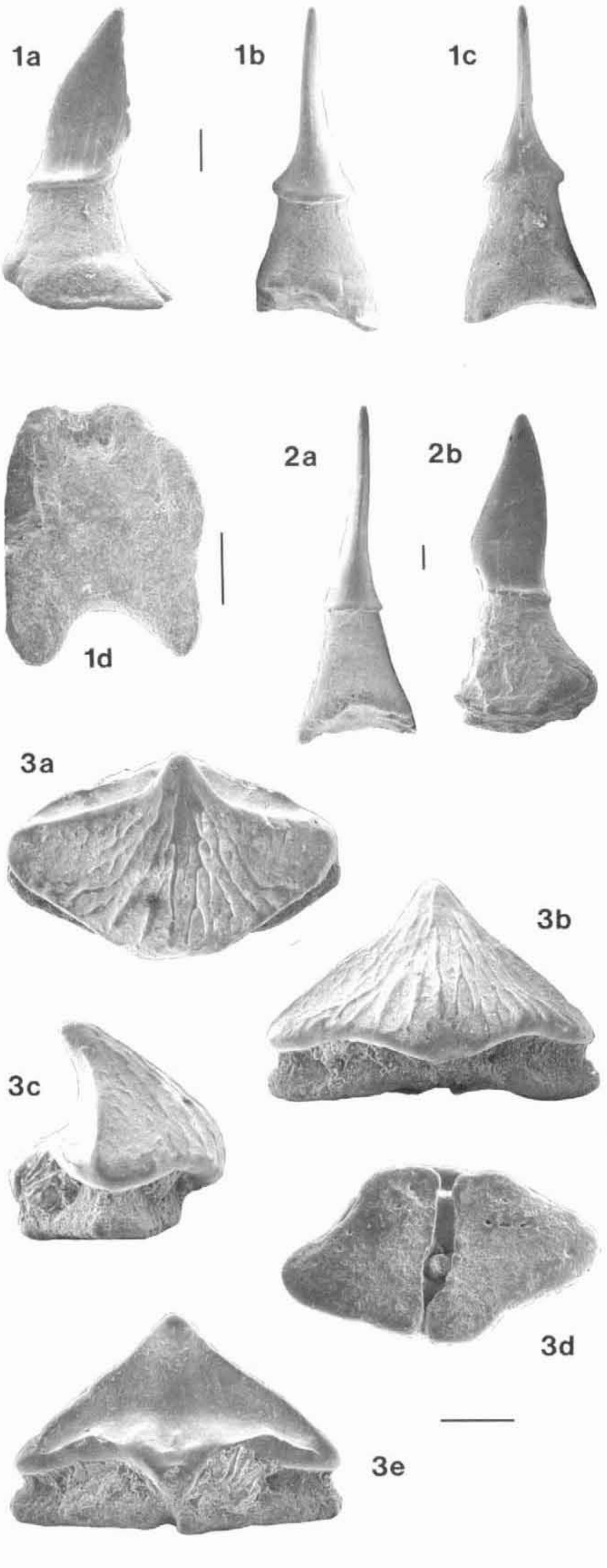


***Schizorhiza* cf. *weileri* Serra 1933: Escondido Formation (Maestrichtian), Maverick County; rostral tooth, figure 1a and 1b reproduced from Dunkle (1948: figures 2A and 2B, page 174); (1a) dorsal view and (1b) cross section; (2a-2c) rostral tooth of *Schizorhiza stromeri*, Dukamje Formation (Maestrichtian), Lgdaman, Niger; (2a) dorsal view; (2b) basal view; (2c) posterior view. (1a, 1b) Scale line = 0.5 mm, (2a, 2c) scale line = 2 mm, (2b) scale line = 1 mm.**

SCLERORHYNCHUS sp.

Order RAJIFORMES Berg 1940
Family SCLERORHYNCHIDAE Cappetta 1974

Maximum Size: **R-8 mm/O-2 mm** Occurrence: **Abundant** Chronologic Range: **Coniacian-Campanian**



Genus ***Sclerorhynchus*** Woodward 1889
Sclerorhynchus sp.

DESCRIPTION: **Rostral Teeth**: cusp highly compressed, tall, with a convex anterior edge and pronounced posterior expansion just above crown foot; weak hook or barb-like, posterior-basal projection occurs in some teeth and both anterior and posterior crown edges are sharp; crown enameloid always smooth; root weakly bilobate and shorter than crown with scalloped basal edges; root base almost square in cross section with a marked posterior expansion of both root lobes; root subdivided anteroposteriorly by a shallow groove; basal attachment surface deeply concave; histology orthodont. **Oral Teeth**: small, usually about 1 mm, with a weakly cuspate, short, triangular crown having a single transverse cutting ridge; lingual protuberance strong and projects basally below crown foot; labial flange short and not well developed; root simple and bilobate; labial crown face highly ornamented, having radiating enameloid ridges, between which enameloid is finely punctate; root holaulacorhizous; histology orthodont.

HETERODONTY: Rostral tooth heterodonty typical of sclerorhynchids in general. Oral Teeth have weak gradient monognathic heterodonty in both jaws.

DISTINGUISHING CHARACTERISTICS: A thin, smooth crown having an expanded posterior-basal border and short, smooth root differentiates *Sclerorhynchus* rostral teeth from other Texas sclerorhynchids. The oral teeth of *Sclerorhynchus* are unique in having a radiating enameloid ridge pattern on the labial crown face.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Austin Group (Coniacian-Santonian) and overlying Taylor Group (Campanian) throughout Texas. Both oral and rostral teeth of *Sclerorhynchus* are common in the basal Atco Formation (contact horizon) of the Austin Group, and especially in younger Campanian Ozan, Wolfe City and Pecan Gap Chalks.

COMMENTS: According to Cappetta (1987), the Texas oral teeth of *Sclerorhynchus* are not conspecific with *S. atavus* Woodward 1889 and represent an undescribed species.

REFERENCES: Woodward (1889); Slaughter and Steiner (1968); Cappetta (1987).

***Sclerorhynchus* sp.: (1-2) rostral teeth and (3) oral tooth, Ozan Formation (Campanian), Dallas County. Tooth orientation: (1a) ventral view; (2b) dorsal view; (1c, 2a) posterior view; (1b) anterior view; (1d) basal view; (3a) apical view; (3b) labial view; (3c) ?mesial view; (3d) basal view; (3e) lingual view. Scale line = 0.5 mm.**

Order RAJIFORMES Berg 1940

Family SCLERORHYNCHIDAE Cappetta 1974

PTYCHOTRYGON AGUJAENSIS

Chronologic Range: **Campanian**	Occurrence: **Common**	Maximum Size: **2.5 mm**

Genus ***Ptychotrygon*** Jaekel 1894
Ptychotrygon agujaensis McNulty and Slaughter 1972

DESCRIPTION: Teeth small, generally 2 mm or less in mesodistal width; crowns low, only slightly raised above lingual flange, noncuspate with four or five closely spaced, irregularly corrugated transverse ridges on occlusal face; lingual flange very flat with a median depression; labial crown protuberance narrow and overhangs root; root holaulacorhizous; histology orthodont.

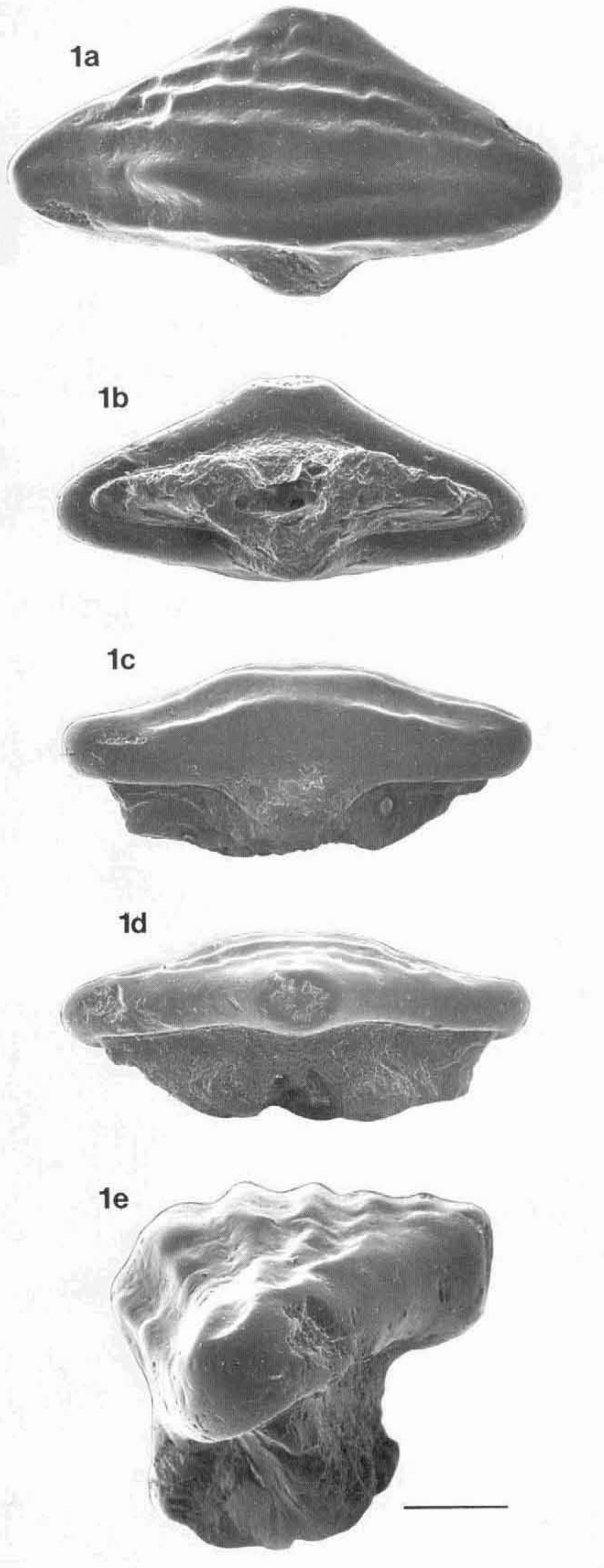
HETERODONTY: Weak gradient monognathic heterodonty in both jaws.

DISTINGUISHING CHARACTERISTICS: *Ptychotrygon agujaensis* is distinguished from *P. triangularis* by the larger number, closer spacing, and lower, more rounded form of the transverse ridges. Also, the crown is usually lower than in any other species (McNulty and Slaughter 1972).

STRATIGRAPHIC OCCURRENCE IN TEXAS: Aguja Formation (Campanian), Brewster County. Known only from the type locality.

COMMENTS: The majority of specimens of *Ptychotrygon agujaensis* are distinctly compressed in the crown and root, particularly the latter which is often so short that it is fragile and usually broken. Some specimens have longer and higher crowns, approaching *P. triangularis* and suggesting derivation from them (McNulty and Slaughter 1972). It is best to use microcollecting techniques to successfully collect these teeth.

REFERENCES: McNulty and Slaughter (1972).

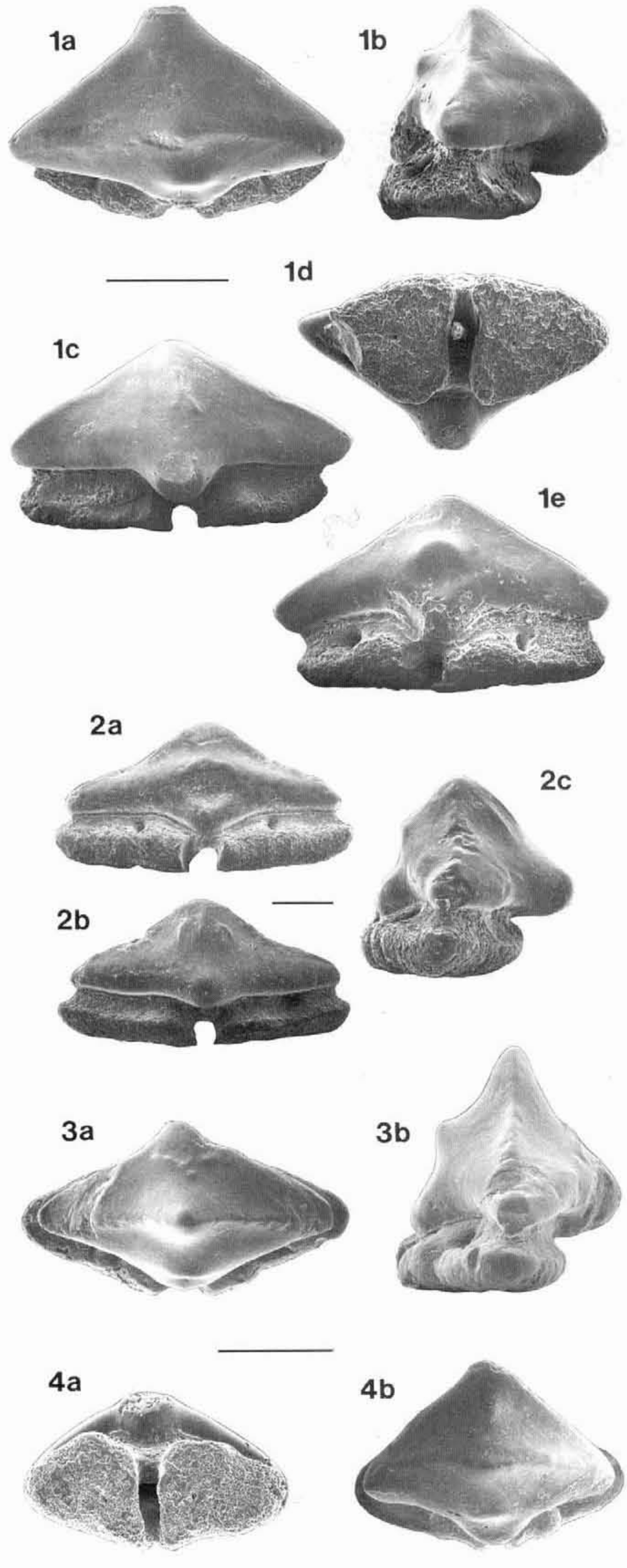


***Ptychotrygon agujaensis* McNulty and Slaughter 1972: Aguja Formation (Campanian), Brewster County. Tooth orientation: (1a) occlusal view; (1b) basal view; (1c) lingual view; (1d) labial view; (1e) mesial view. Scale line = 0.5 mm.**

PTYCHOTRYGON HOOVERI

Order RAJIFORMES Berg 1940
Family SCLERORHYNCHIDAE Cappetta 1974

Maximum Size: **3.2 mm** Occurrence: **Abundant** Chronologic Range: **Cenomanian-Coniacian**



Genus ***Ptychotrygon*** Jaekel 1894
Ptychotrygon hooveri McNulty and Slaughter 1972

DESCRIPTION: Crown narrow, high and triangular; cusp weakly developed; cutting ridge distinct, separating labial and lingual crown faces; crown smooth, lacking transverse ridges; however, very short, discontinuous enameloid bumps or ridges may occur along midline of labial face, just above labial flange; root holaulacorhizous; histology orthodont.

HETERODONTY: Typical of *Ptychotrygon* with weak gradient monognathic heterodonty in both jaws.

DISTINGUISHING CHARACTERISTICS: *Ptychotrygon hooveri* differs from all other species of *Ptychotrygon* in having a narrow, high crown that is smooth, or at least has only sparse ornamentation along the midline of the labial crown face.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Pepper and Woodbine formations and lower Eagle Ford Group (Cenomanian); upper Eagle Ford Group (Turonian); Atco Formation of the Austin Group (Coniacian).

COMMENTS: According to McNulty and Slaughter (1972), irregular corrugations (enameloid ridges) of low relief may occur on the labial faces, particularly on lower portions of the crown. The holotype of *Ptychotrygon hooveri* comes from the Bells Sandstone Member (late Turonian) of the Eagle Ford Group, Dallas County. Teeth of this species are very common in the Kamp Ranch Limestone. Microcollecting techniques must be used to collect these teeth.

REFERENCES: McNulty and Slaughter (1972).

Ptychotrygon hooveri **McNulty and Slaughter (1972): Taff's Fishbed Conglomerate (Turonian), Eagle Ford Group, Collin County. Tooth orientation: (1a, 3a, 4b) occlusal view; (1c, 2b) labial view; (1e, 2a) lingual view; (1d, 4a) basal view; (1b, 2c, 3b) distal view. Scale line = 0.5 mm.**

Order RAJIFORMES Berg 1940
Family SCLERORHYNCHIDAE Cappetta 1974

PTYCHOTRYGON SLAUGHTERI

Chronologic Range: **Cenomanian** | Occurrence: **Abundant** | Maximum Size: **1.5 mm**

Genus ***Ptychotrygon*** Jaekel 1894
Ptychotrygon slaughteri Cappetta and Case 1975

DESCRIPTION: Teeth with a moderately wide and tall triangular crown, having a sharp cusp and continuous transverse cutting edge; labial protuberance ranges from narrow to broad and lingual flange is typical for the genus; crown faces are ornamented with discontinuous transverse and irregular longitudinal enameloid ridges; lingually, ridges are short and node-like, aligned transversely just below cutting edge; labial crown face has a single sinuous transverse ridge which follows labial crown margin, converging in broad loops at the midline of cusp; above and below this ridge, which itself may be discontinuous, are much shorter transverse and longitudinal ridges, also converging at midline; root holaulacorhizous; histology orthodont.

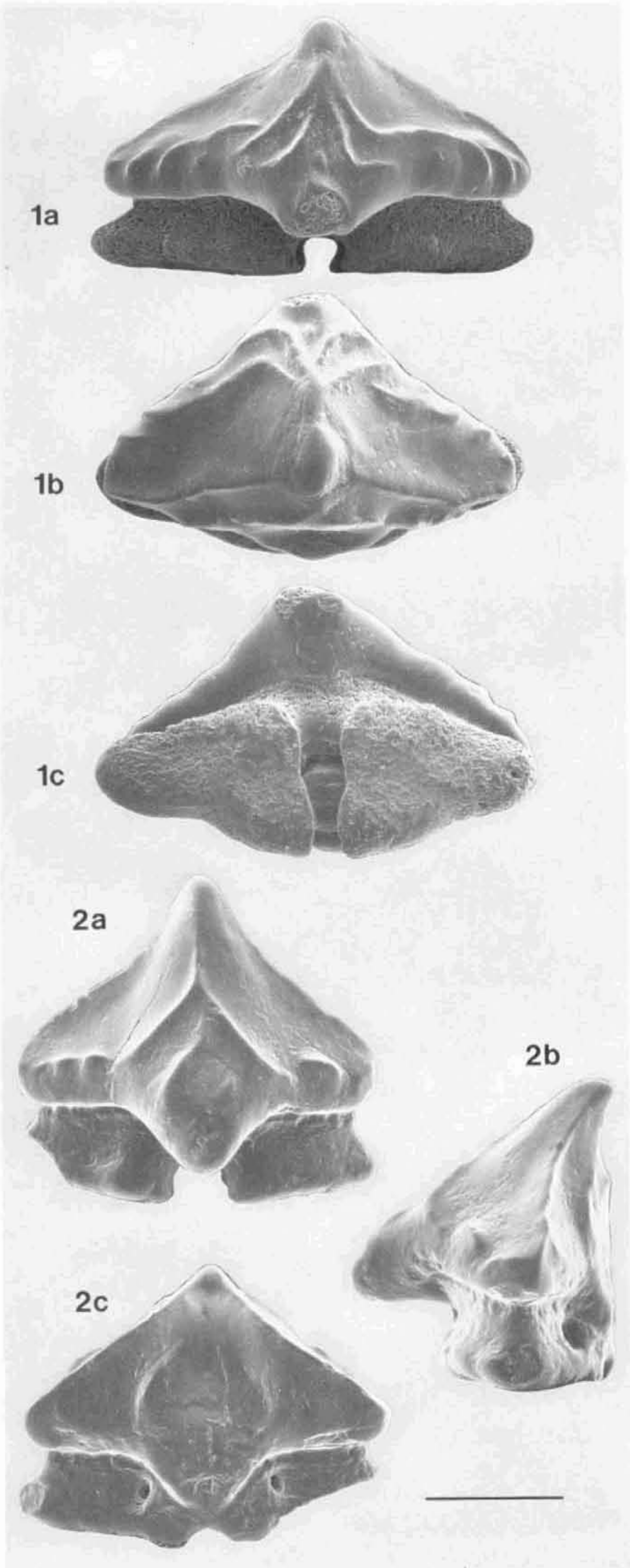
HETERODONTY: Weak gradient monognathic heterodonty in both jaws; dignathic heterodonty weak or absent.

DISTINGUISHING CHARACTERISTICS: The teeth of *P. slaughteri* are intermediate in morphology between *P. triangularis* and *P. hooveri*. *Ptychotrygon slaughteri* teeth have fewer transverse ridges than *P. triangularis* and the crown faces are much more ornamented than in *P. hooveri*.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Pepper and Woodbine formations (Cenomanian), Bell, Tarrant, Dallas and Denton counties.

COMMENTS: This species was described by Cappetta and Case (1975) for teeth from the Cenomanian Woodbine Formation in Tarrant County. Teeth of *Ptychotrygon slaughteri* had previously been figured by McNulty and Slaughter (1972, Plate 1, Figures 16-17) under the name *P. triangularis*. McNulty and Slaughter figured these teeth because they illustrated a crown ornamentation intermediate between *P. triangularis* and *P. hooveri*. Due to the extremely small size of these teeth, microcollecting techniques must be used to collect them

REFERENCES: McNulty and Slaughter (1972), Cappetta and Case (1975).

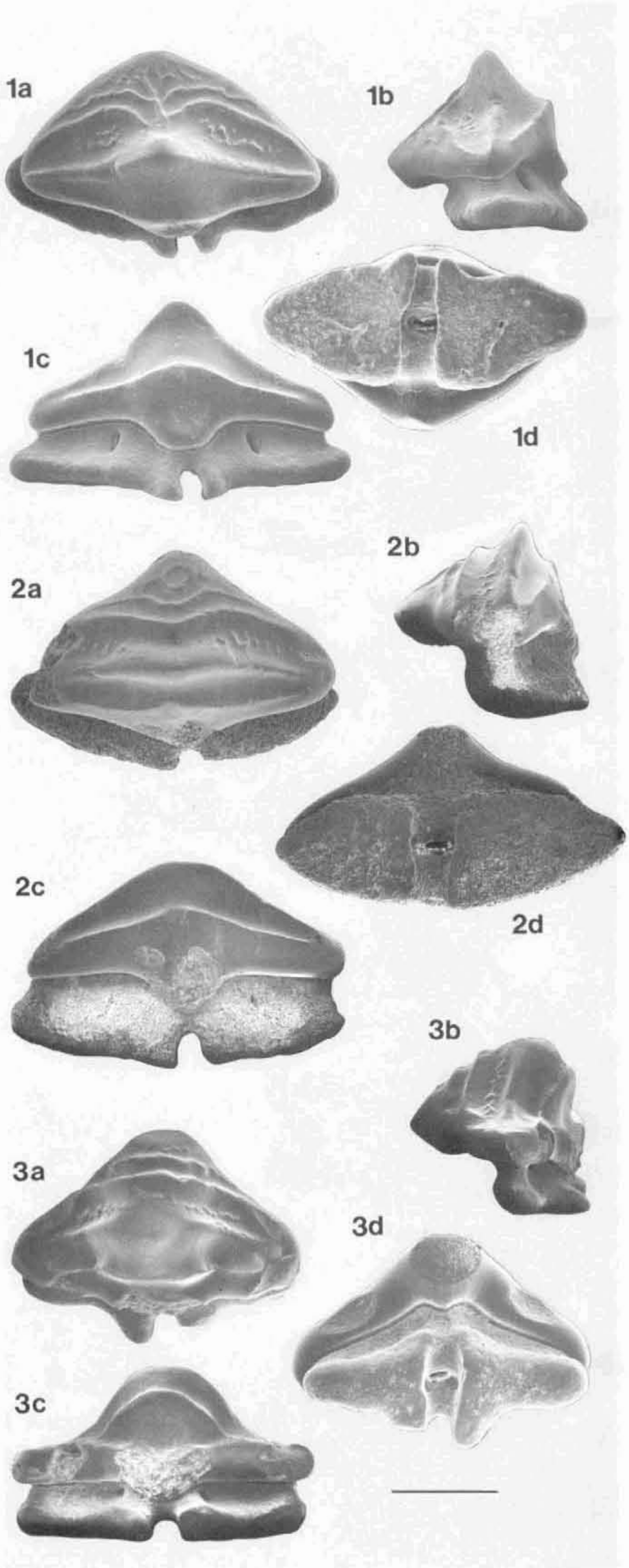


Ptychotrygon slaughteri **Cappetta and Case 1975: Arlington Sandstone Member, Woodbine Formation (Cenomanian), Tarrant County. Tooth orientation: (1a, 2a) labial view; (1b) occlusal view; (1c) basal view; (2b) mesial view; (2c) lingual view. Scale line = 0.5 mm.**

PTYCHOTRYGON TEXANA

Order RAJIFORMES Berg 1940
Family SCLERORHYNCHIDAE Cappetta 1974

Maximum Size: **2 mm** | Occurrence: **Common** | Chronologic Range: **Maestrichtian**



Genus ***Ptychotrygon*** Jaekel 1894
Ptychotrygon texana (Leriche 1940)

DESCRIPTION: Crown very high with almost conical cusp; cutting ridge weakly defined or absent; crown faces smooth, lacking any ornamentation; lingual flanges with a deep depression; labial crown flange weakly developed; root holaulacorhizous; histology orthodont.

HETERODONTY: Weak gradient monognathic heterodonty in both jaws; dignathic heterodonty weak or absent.

DISTINGUISHING CHARACTERISTICS: *Ptychotrygon texana* differs from *P. hooveri* in being mesodistally wider, having a higher, more conical cusp, and lacking all subordinate crown ornamentation.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Escondido and Kemp formations (Maestrichtian) in Medina, Hunt and Bastrop counties; Midway Formation (Paleocene reworked), Travis County.

COMMENTS: Leriche (1940) described *Raja texana* from the Midway Formation, based on a single specimen (USNM Cat. 11680) collected in Bastrop County. McNulty and Slaughter (1972) recognized that Leriche's specimen was a ptychotrygonid but were unable to obtain additional examples from the type locality or from the nearby Littig pit. Leriche's tooth either came from the Navarro Formation or had been reworked into the basal Midway (Paleocene). McNulty and Slaughter were unsure about the identity of *P. texana* because of inadequate information in the original description. They noted that it seemed similar to *P. hooveri*. Microcollecting techniques must be used to collect these very small teeth.

REFERENCES: Leriche (1940); McNulty and Slaughter (1972).

Ptychotrygon texana **(Leriche 1940): Navarro Group, Kemp Formation (Maestrichtian), Hunt County. Tooth orientation: (1a-3a) occlusal view; (1c, 2c, 3c) lingual view; (1d, 2d, 3d) basal view; (1b) mesial view; (2b, 3b) distal view. Scale line = 1 mm.**

Order RAJIFORMES Berg 1940

Family SCLERORHYNCHIDAE Cappetta 1974

PTYCHOTRYGON TRIANGULARIS

Chronologic Range: **Cenomanian-Maestrichtian** | Occurrence: **Abundant** | Maximum Size: **5 mm**

Genus ***Ptychotrygon*** Jaekel 1894

Ptychotrygon triangularis (Reuss 1844)

DESCRIPTION: Crown high and triangular; three prominent, well separated transverse ridges are situated along middle of lingual face, along junction of lingual and labial faces, and across middle of labial face; smaller transverse ridges also occur on the lower portion of the labial crown face; root holaulacorhizous; histology orthodont.

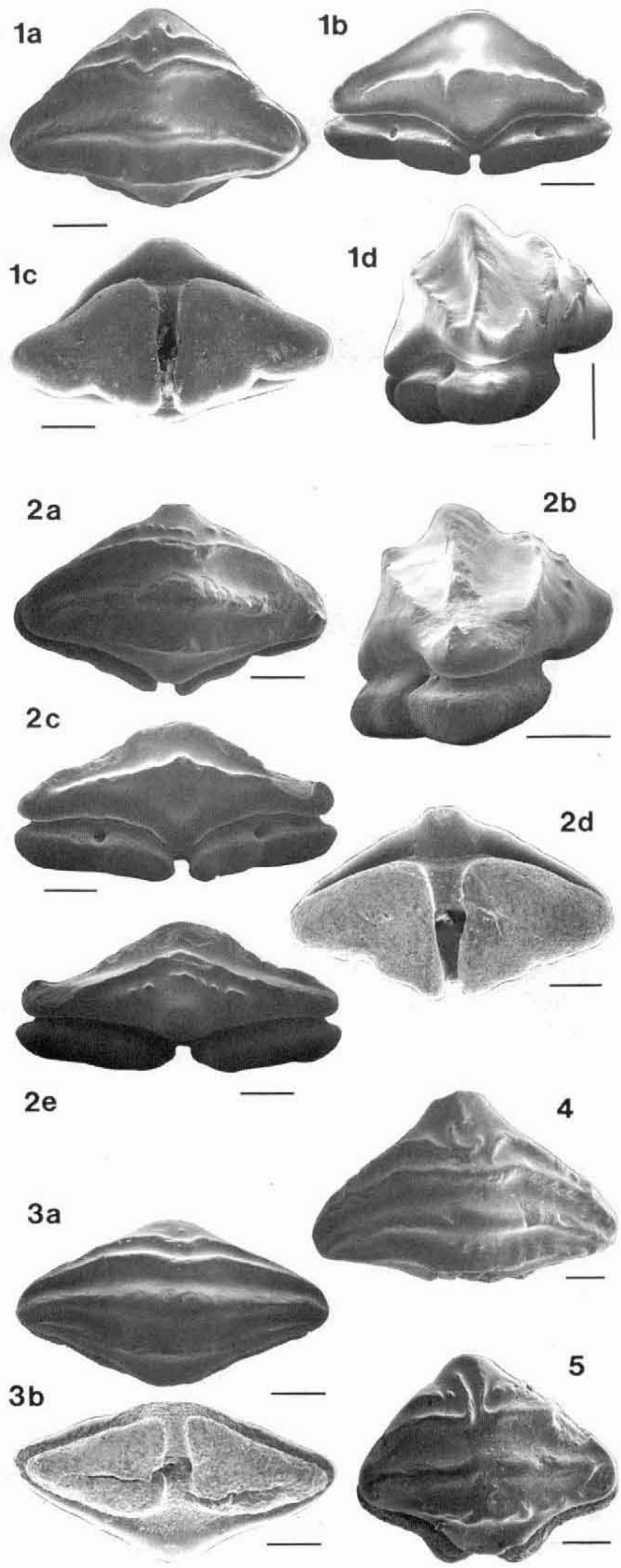
HETERODONTY: Weak gradient monognathic heterodonty in both jaws.

DISTINGUISHING CHARACTERISTICS: *Ptychotrygon triangularis* may be distinguished from *P. agujaensis* by the relative prominence, sharpness and separation of major transverse ridges, absence of smaller ridges and by having a higher and more elongate crown. *P. triangularis* differs from *P. hooveri* by the presence of strong transverse ridges and a more pyramidal crown.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Woodbine and Pepper formations (Cenomanian), Eagle Ford Group (Cenomanian-Turonian), Austin Group (Coniacian-Santonian) and the Taylor and Navarro groups of Campanian and Maestrichtian age.

COMMENTS: The broad temporal range of *Ptychotrygon triangularis* is unusually long for any species. More critical study of the Texas material referred to *P. triangularis* will probably result in a narrowing of its stratigraphic distribution and the recognition of at least one new taxon. Characteristic forms of this species occur abundantly in the Turonian Eagle Ford Group and especially the early Coniacian of the basal Atco Formation (contact horizon) of the Austin Group. Microcollecting techniques are best used to collect these teeth.

REFERENCES: McNulty and Slaughter (1972).



Ptychotrygon triangularis **(Reuss 1844): Atco Formation contact horizon (Coniacian), Austin Group, Travis County. Tooth orientation: (1a-3a, 4, 5) occlusal view; (1b, 2c) lingual view; (1c, 2d, 3b) basal view; (2e) labial view; (1d) mesial view; (2b) distal view. Scale line = 0.5 mm.**

Order Myliobatiformes

The Order Myliobatiformes Compagno 1973 includes the eagle rays (Family Myliobatidae Bonaparte 1838), the stingrays (Family Dasyatidae Jordan 1888 and Family Urolophidae Gray 1851), the butterfly rays (Family Gymnuridae Fowler 1934), cownose rays (Family Rhinopteridae Jordan and Evermann 1896), manta rays (Family Mobulidae Gill 1893), and an extinct family of Cretaceous rays (Family Rhombodontidae Cappetta 1987).

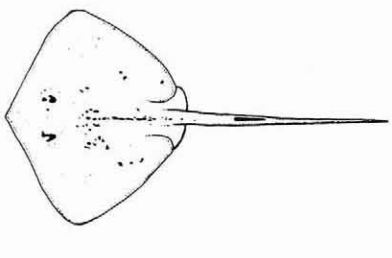
With exception of the mantas, eagle rays (Family Myliobatidae) are among the most pelagic of the rays. They are primarily benthic feeders, probing the bottom for shellfish and crustaceans which they crush with their powerful flat pavement teeth. Myliobatids have a distinct head region, with the eye and spiracles located on each side rather than on top, and most species have one or more poisonous spines at the base of the tail. Eagle rays occur in all warm and tropical seas and some are seasonal migrants in temperate waters.

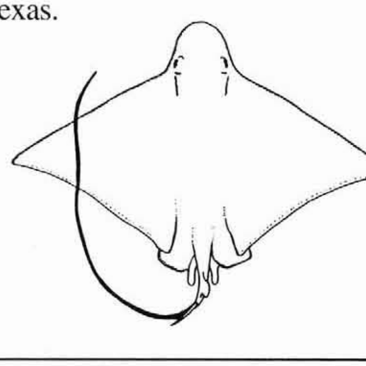
Dasyatid stingrays (Family Dasyatidae) are best known for their long, slim, whip-like tails that are armed with one to several spines near the base. When caught or stepped on, a stingray lashes its tail and invariably manages to impale a spine in its molester. Stingrays generally lie on the bottom, almost completely buried in the sand or soft sediment. Nearly a hundred species of stingrays are distributed in warm, shallow waters around the world and a few stray into brackish and fresh water. They range in size from 0.3 to over 2 meters across their pectoral fins (greatest dimension).

The fossil record of Myliobatiformes in Texas is impressive for having some of the earliest occurrences of these rays anywhere in the world. Of the seven families listed, three (Myliobatidae, Dasyatidae and Rhombodontidae) are currently represented in the Cretaceous of Texas but remain largely unstudied.

Although very rare, true myliobatids close to the modern *Myliobatis* Cuvier 1817 and other allied genera occur in the Campanian Ozan Formation of Ellis and Hunt counties. These median-row pavement teeth have a polyaulacorhizous root structure much more advanced than *Brachyrhizous* Romer 1942 and predate the Maestrichtian genus *Igdabatis* Cappetta 1972. *Brachyrhizodus* Romer 1942 was originally described from Texas; however, it is very rare and we have yet to see unequivocal evidence of this species in any of the fossil assemblages examined to date.

The Family Rhombodontidae is represented by high crowned crushing and grinding teeth of *Rhombodus binkhorsti* Dames 1881 from the Maestrichtian Kemp and Escondido formations. Isolated teeth of *Dasyatis* Rafinesque 1810, plus teeth of another unnamed dasyatid ray, occur in Cenomanian through Maestrichtian strata throughout Texas.





BRACHYRHIZODUS WICHITAENSIS

Chronologic Range: **?Santonian-Campanian** Occurrence: **Rare** Maximum Size: **20+ mm**

Genus ***Brachyrhizodus*** Romer 1942
Brachyrhizodus wichitaensis Romer 1942

DESCRIPTION: Myliobatid pavement teeth with mesodistally elongate, thick and smooth crowns generally having a hexagonal occlusal outline; root has two to five deep nutrient grooves; root polyaulacorhizous; histology osteodont.

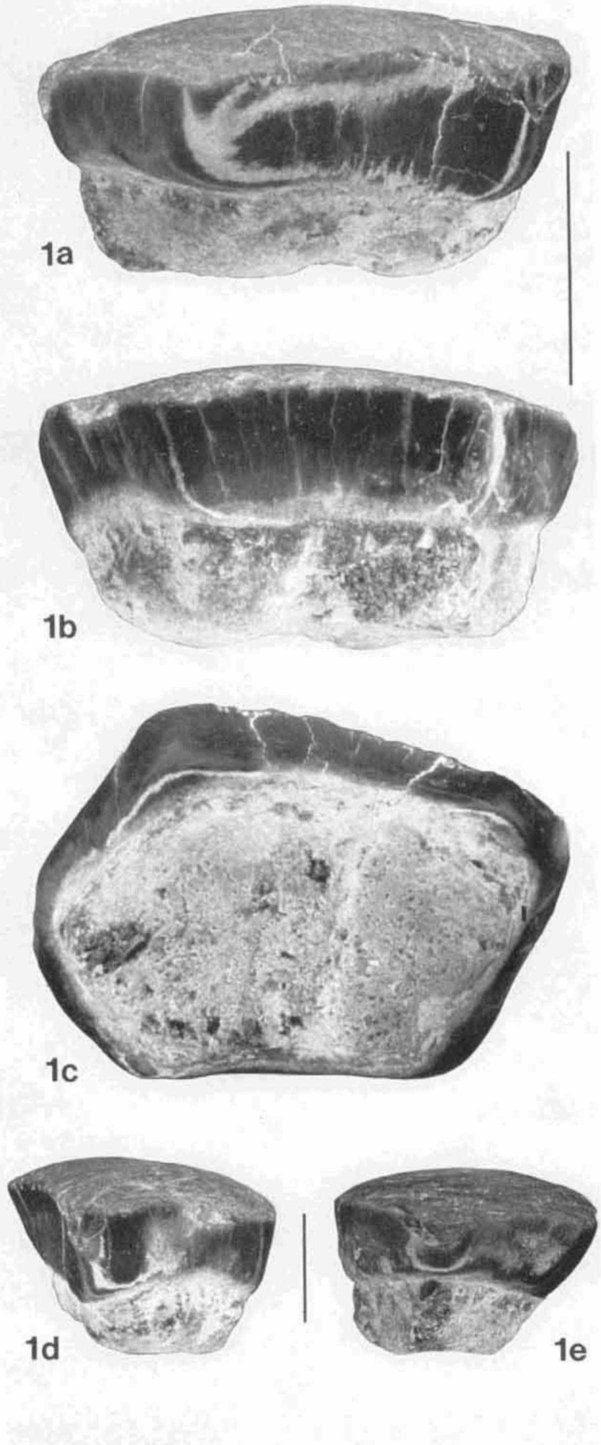
HETERODONTY: *Brachyrhizodus* appears to have a dentition similar to the modern stingray *Rhinoptera*, with two rows of larger parasymphysial teeth, flanked by at least two rows of smaller teeth, some having bilobate roots. *Brachyrhizodus* apparently lacks the stair-stepped, labiolingual interlocking mechanism present in modern Myliobatid rays (and present in the lower Campanian myliobatids of the Ozan Formation).

DISTINGUISHING CHARACTERISTICS: *Brachyrhizodus* is similar to other Texas myliobatid rays but can be distinguished by its thicker crown and fewer, widely spaced nutrient grooves on the basal attachment surface.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Burditt Marl Formation (Campanian), Travis County, and in Campanian strata of the Big Bend region (stratigraphic position unknown).

COMMENTS: This species is rare in the Texas Cretaceous and we have not observed unequivocal specimens of it elsewhere in the state. Romer (1942) described *Brachyrhizodus* from Baylor County and originally thought it was Permian in age. The type material of *Brachyrhizodus wichitaensis* was collected from Pliocene gravels composed of reworked Cretaceous clasts and fossils.

REFERENCES: Romer (1942); Cappetta and Case (1975).

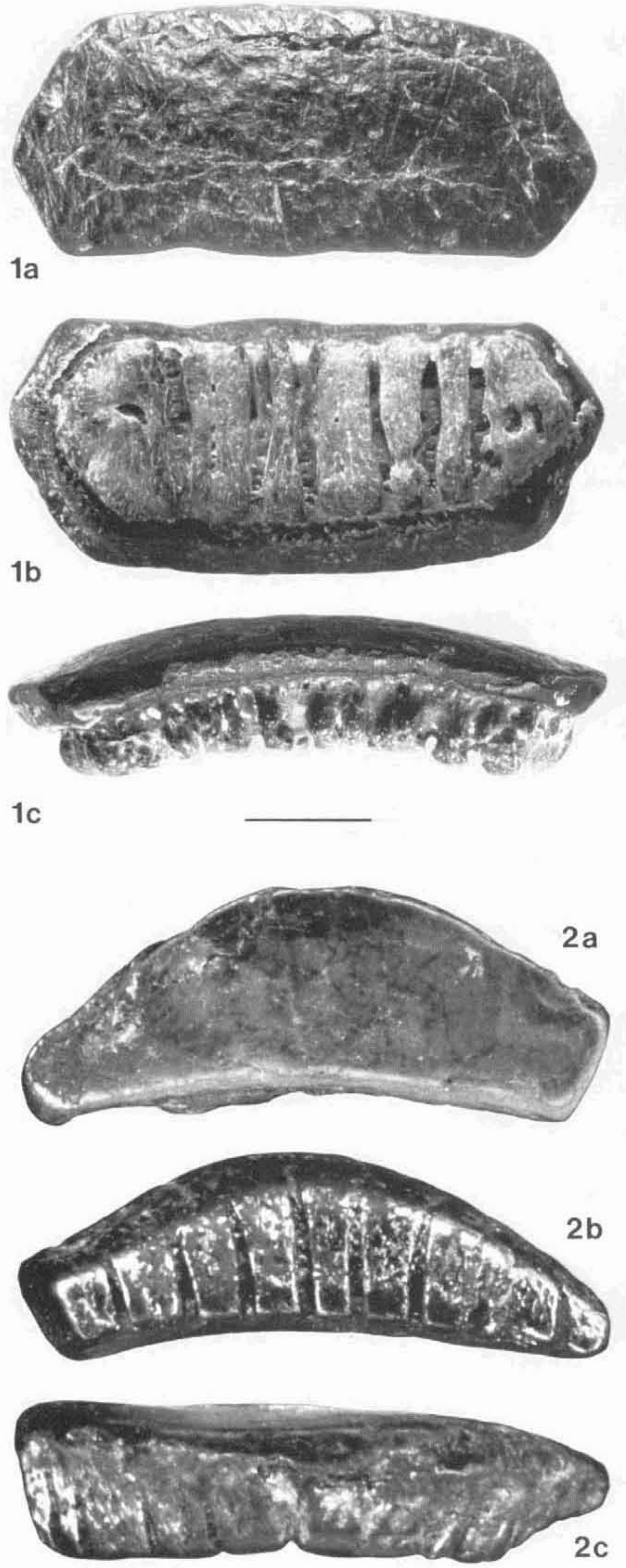


Brachyrhizodus wichitaensis **Romer 1942: TMM 42363-2, Burditt Marl Formation (Campanian), Travis County. Tooth orientation: (1a) lingual view; (1b) labial view; (1c) basal view; (1d) distal view; (1e) mesial view. Scale line = 5 mm.**

MYLIOBATIDAE

Order MYLIOBATIFORMES Compagno 1973
Family MYLIOBATIDAE Bonaparte 1838

Maximum Size: **12 mm** | Occurrence: **Rare** | Chronologic Range: **Campanian**



Myliobatidae Genus Undetermined

DESCRIPTION: The upper and lower dentition of myliobatid rays consist of a series of interlocking rectangular, arcuate or chevron-shaped plates, arranged in labiolingual rows of varying width and number depending on the genus. These pavement teeth are flat, relatively thin and have unornamented occlusal crown faces. The mesial and distal ends of each tooth or plate are usually triangular in shape so that it can interlock with teeth in adjacent rows. Each tooth plate also interlocks with adjacent teeth (labially and lingually) in the same row, thus forming a strong crushing surface. The basal attachment surface of the root is flat or weakly concave and crossed labiolingually by numerous deep nutrient grooves; root polyaulacorhizous; histology osteodont.

HETERODONTY: Strong disjunct monognathic heterodonty and very weak dignathic heterodonty. Modern myliobatid rays have sexual dental heterodonty.

DISTINGUISHING CHARACTERISTICS: The isolated tooth plates of true myliobatid rays are most likely to be confused with those of the genus *Brachyrhizodus*, or possibly large teeth of *Pseudohypolophus*. Myliobatid ray teeth figured here have many more nutrient grooves crossing the basal attachment surface (e.g., polyaulacorhize root) than either of the above two genera.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Ozan and possibly Wolfe City formations, Ellis and Fannin counties (Campanian).

COMMENTS: Texas myliobatid ray teeth are extremely rare and they represent the earliest known unquestionable representatives of the family. Figured here are probably two different species, if not genera, of undescribed rays from the lower Campanian. It is interesting to note that both these specimens are morphologically closer to modern bat rays than is *Brachyrhizodus*.

REFERENCES: Cappetta and Case (1975); Cappetta (1987).

Myliobatidae indeterminate: Median tooth plates, (1) Taylor Group (Campanian), Fannin County and (2) Ozan Formation (Campanian), Ellis County. Tooth orientation: (1a, 2a) occlusal view; (1b, 2b) basal view; (1c) lingual view; (2c) labial view. Scale line = 2 mm.

Order MYLIOBATIFORMES Compagno 1973
Family RHOMBODONTIDAE Cappetta 1987

RHOMBODUS BINKHORSTI

Chronologic Range: **Maestrichtian** | Occurrence: **Abundant** | Maximum Size: **10 mm**

Genus ***Rhombodus*** Dames 1881
Rhombodus binkhorsti Dames 1881

DESCRIPTION: Teeth high; crown massive with a roughly rhombic outline; labial and lingual crown faces concave; numerous vertical folded and wrinkled enameloid ridges cover all crown faces except the occlusal surface, which is smooth; roots are bilobate and generally less than one-half to one-third of crown height; a deep nutrient groove divides a flat basal face into two triangular root lobes; root holaulacorhizous; histology osteodont.

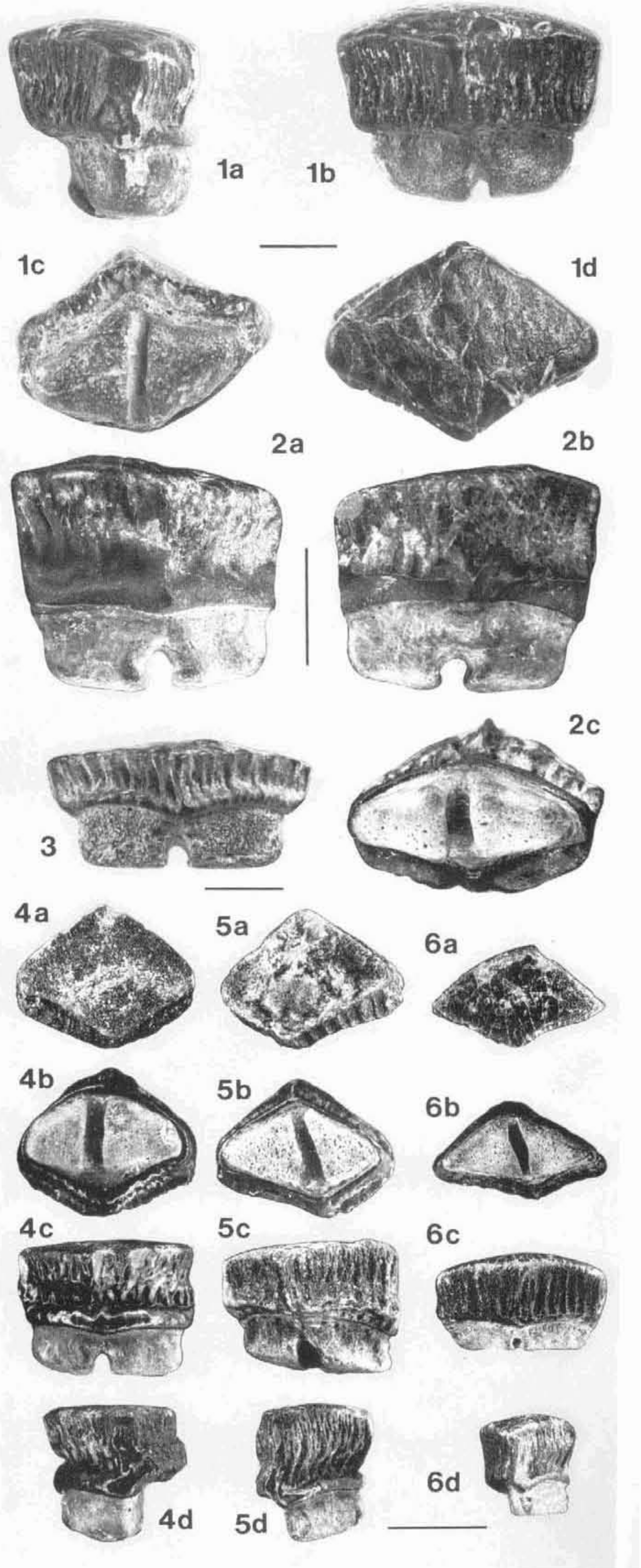
HETERODONTY: Based on isolated teeth, *Rhombodus* appears to have some differentiation of rowgroups, suggesting weak disjunct or strong gradient monognathic heterodonty.

DISTINGUISHING CHARACTERISTICS: *Rhombodus* differs from other rays in having a very thick and high rhombic-shaped crown with numerous deep longitudinal enameloid folds on all vertical faces.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Kemp, Escondido and Littig formations (Maestrichtian), Travis, Medina and Fannin counties. Present in all Maestrichtian marine strata we have examined.

COMMENTS: *Rhombodus* teeth are common in the Maestrichtian of Texas but they have not, to our knowledge, been found in Campanian or older rocks.

REFERENCES: Dames (1881); Herman (1977).

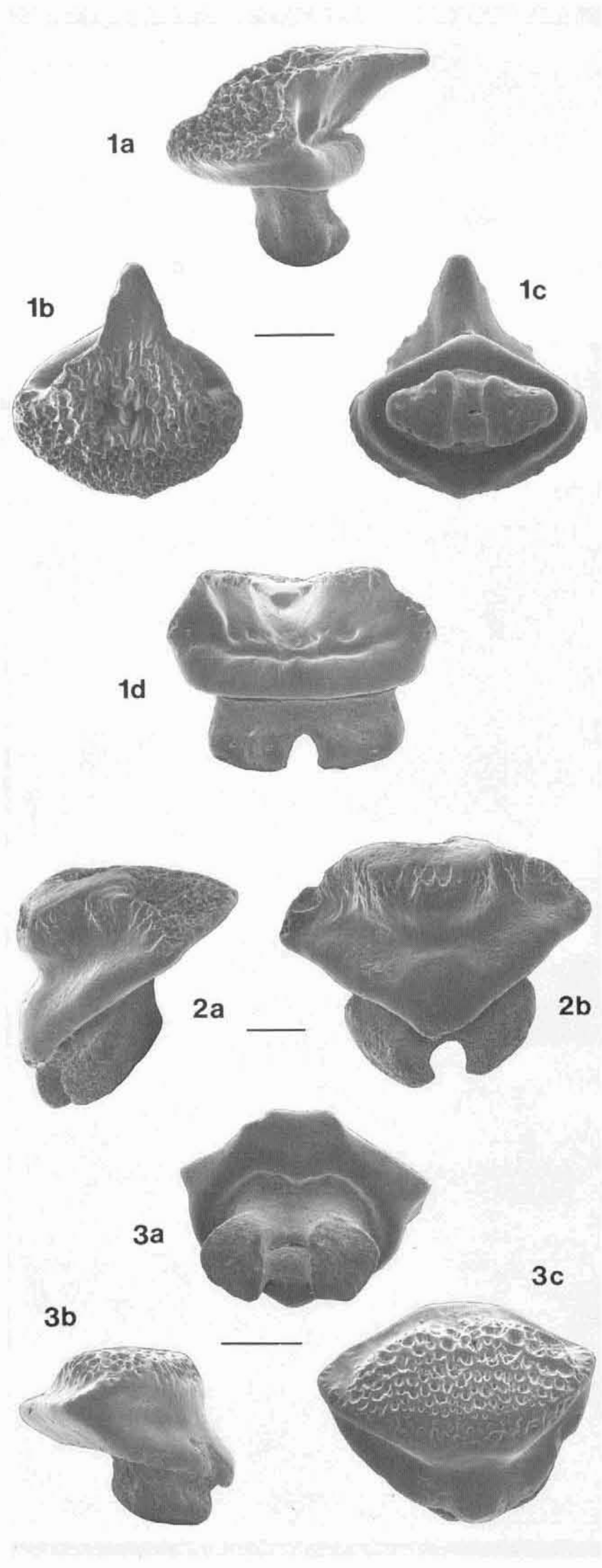


Rhombodus binkhorsti **Dames 1881: Navarro Group, Kemp Formation (Maestrichtian), Hunt County. Tooth orientation: (1b, 2a, 3, 4c-6c) lingual view; (2b) labial view; (1c, 2c, 4b-6b) basal view; (1d, 4a-6a) occlusal view; (1a, 5d, 6d) distal view; (4d) mesial view. Scale line = 5 mm.**

DASYATIS spp.

Order MYLIOBATIFORMES Compagno 1973
Family DASYATIDAE Jordan 1888

Maximum Size: **3 mm** | Occurrence: **Abundant** | Chronologic Range: **Cenomanian-Maestrichtian**



Genus ***Dasyatis*** Rafinesque 1810
Dasyatis spp.

DESCRIPTION: Teeth small, generally less than 3 mm in the Texas Cretaceous; crown strongly convex with or without a distinct cusp depending on the species and sex (strong sexual dimorphism); a transverse ridge separates a flat occlusal or labial face from a broadly sloping, often concave and smooth lingual face; labial face often covered by deep, coalescing pits and irregular cusp-like ridges may develop along transverse crest; labially, crown overhangs root, which is strongly bilobate and projected lingually; tips of each root lobe project lingually, beyond limits of crown, and their attachment surface is weakly convex; root lobes are widely separated by a deep nutrient groove that contains one or more central basal foramina; root holaulacorhizous; histology osteodont.

HETERODONTY: Strong gradient to weak disjunct monognathic heterodonty in both jaws and moderate dignathic heterodonty. Sexual dental dimorphism is pronounced in dasyatid rays.

DISTINGUISHING CHARACTERISTICS: Dasyatid teeth differ from those of other Texas Cretaceous rays in having a flattened occlusal crown surface, long and sloping lingual crown face and lingually projecting, widely separated, bilobate roots.

STRATIGRAPHIC OCCURRENCE IN TEXAS: Cenomanian-Maestrichtian; Woodbine and Pepper formations, Eagle Ford and Austin groups, and throughout the Taylor and Navarro groups.

COMMENTS: The diverse ray fauna of the Texas Cretaceous remains largely unstudied and this applies especially to the dasyatid rays. Lumped here under *Dasyatis* spp. are a diverse group of dasyatiform ray teeth having the general characteristics of the genus, but most likely representing a host of diverse forms, including undescribed genera and species. Teeth of this size are best collected using microcollecting techniques. See Chapter 6.

REFERENCES: Cappetta (1987).

Dasyatis **spp.: Navarro Group, Kemp Formation (Maestrichtian), Hunt County. (1) male tooth and (2, 3) female tooth. Tooth orientation: (1a, 2a, 3b) mesial view; (1b, 3c) occlusal view; (1c, 3a) basal view; (1d, 2b) lingual view. Scale line = 0.5 mm.**

Order MYLIOBATIFORMES Compagno 1973
Family DASYATIDAE Jordan 1888

?DASYATIDAE

Chronologic Range: **Albian-Cenomanian** | Occurrence: **Common** | Maximum Size: **3 mm**

Family ?Dasyatidae
Genus and Species Undetermined

DESCRIPTION: Teeth small, rarely exceeding 3 mm, having some resemblance to genus *Dasyatis*; two distinct tooth morphologies present, here termed Type 1 and Type 2; **Type 1 teeth** have thick, rectangular crowns with rounded sides in occlusal view; crown overhangs root on all faces; lingual and labial protuberances absent; occlusal crown face with one irregular transverse ridge displaced slightly lingually from a median position; higher parts of crown margins and all of occlusal crown face deeply pitted and scalloped with much smaller pits lining surface of larger pits; root narrower than crown, lacking a distinct neck; basal attachment surface weakly convex and triangular in basal view; lingual tip of root lobes project lingually; nutrient groove wide and deep with a central basal foramen; small foramina pierce labial and lingual root faces. **Type 2 teeth** are taller and narrower than Type 1; crown circular or oval with a dome to cusp-like median prominence; crown faces rugose and sculptured as in Type 1 teeth but lack a transverse ridge; root very high, generally narrower than crown with a constricted neck just below crown foot; lingual root lobe tips project lingually, well beyond crown foot; basal attachment surface of root almost flat; nutrient groove wide and deep; roots holaulacorhizous; histology ?osteodont.

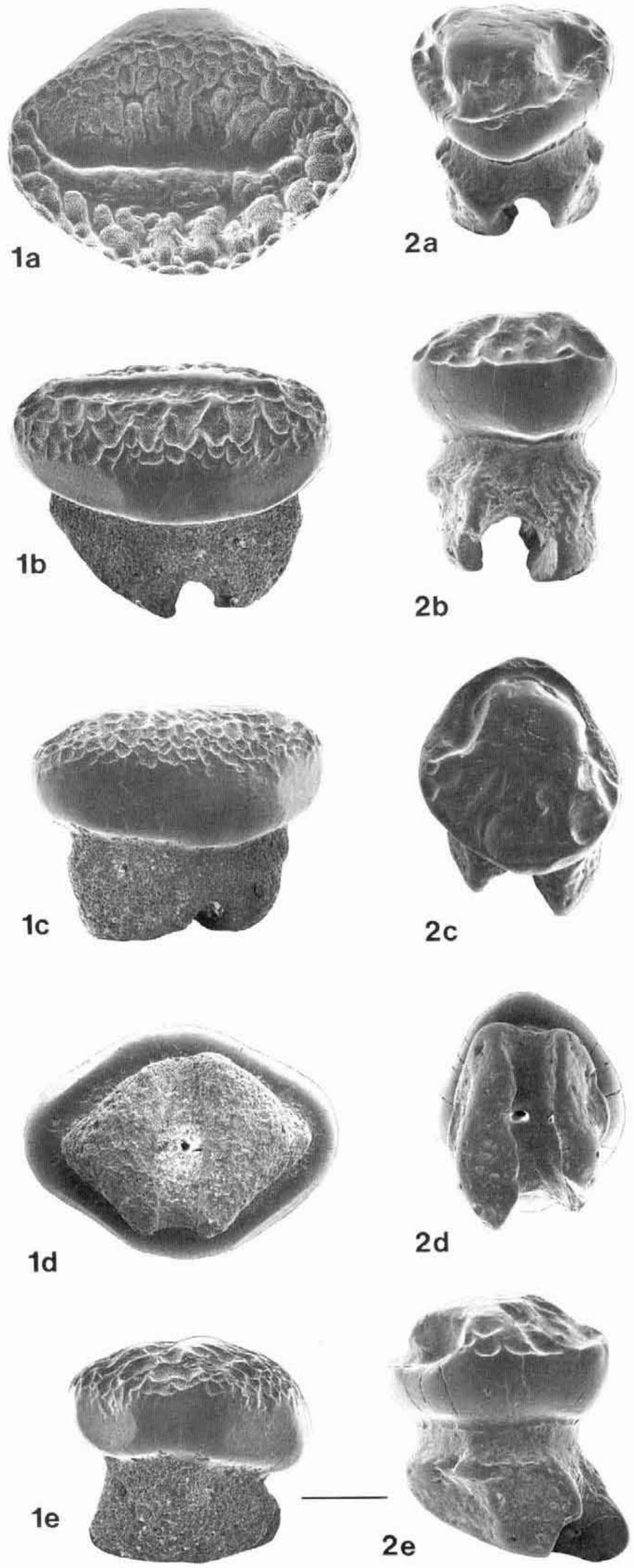
HETERODONTY: Two distinct tooth types suggest either strong disjunct monognathic heterodonty or dignathic heterodonty, or both. Disjunct monognathic heterodonty is not uncommon among modern dasyatid rays.

DISTINGUISHING CHARACTERISTICS: These teeth are most likely to be confused with those of *Dasyatis*. They differ by lacking a lingual protuberance, a long, sloping lingual crown face and by having massive and labiolingually elongate root lobes.

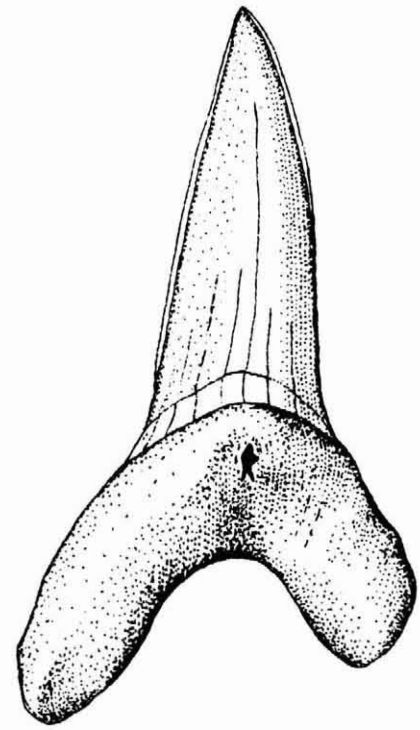
STRATIGRAPHIC OCCURRENCE IN TEXAS: Weno Formation (Albian), Tarrant County and the Pepper Formation (Cenomanian) of Hill County.

COMMENTS: These teeth possess crown and root characters that suggest affinities to both dasyatid stingrays and other rays similar to *Pseudohypolophus*. Meyer (1975) recognized that these small ray teeth represented a new genus and species and provided a taxonomic description that has never been published.

REFERENCES: Meyer (1975).



?Dasyatidae genus and species unidentified: Pepper Formation (Cenomanian), Bell County; (1) anterolateral teeth (Type 1) and (2) ?symphysial tooth (Type 2). Tooth orientation: (1a, 2c) occlusal view; (1b, 2b) lingual view; (1c, 2a) labial view; (1d, 2d) basal view; (1e, 2e) mesial view. Scale line = 0.5 mm.



Chapter 6

Tooth Collecting

Instructions for collecting shark and ray teeth are much akin to revelations of the secrets of good cooking. Everyone has their favorite methods and despite the most expert advice you may obtain from books, experience is the surest path to success. There are, however, a number of fundamentals that will help guide you to finding teeth with the least amount of trouble and wasted effort.

The most successful collectors mix four ingredients to obtain what appears to most of us as "blind luck" in finding good teeth. These are a knowledge of the local geology where you will be collecting, critical observation of where the teeth are occurring within the stratigraphic section, a sensible choice of collecting equipment and, perhaps most important, a large measure of perseverance. The first three may be acquired, to some degree, from books and from the advice of veteran collectors, but only keen observation in the field and many hours of trial collecting will develop satisfactory techniques. It is true, of course, that walking or crawling the more productive outcrops at certain times of the year, especially after rains, will produce encouraging results. However, soon the largest teeth will have been collected and only the smallest and broken teeth remain. The moment a collector ceases to be a casual observer and begins to search for shark teeth using geologic intuition and experience, unlimited possibilities unfold for acquiring a remarkably diverse and complete collection.

WHERE TO COLLECT

Teeth are found in all types of sediments, from clays to conglomerates and limestones. However, unless the rocks are unusually fossiliferous, teeth generally are concentrated within a specific horizon or bed, sometimes only a few centimeters thick. The reasons for this are related to the environment at the time of deposition. Sedimentologic processes (waves and bottom currents) often concentrate teeth and other fossils into lag deposits that appear as thin lenses of sand that contain shell debris and pebbles (Figure 31).

Figure 31. Fossil bearing lens of oysters, pebbles and shark teeth occurring within a shallow marine sequence of sandstone and mudstone. Fossils are concentrated by current transport and these accumulations are excellent places to look for shark teeth.

Fossiliferous lenses are also formed by the deep water accumulation of organic matter on the sea floor during a period when little sedimentation was taking place. These deposits are termed "condensed sections" and they accumulate over many thousands of years. Condensed sections usually contain abundant shark and ray teeth, fish bones and coprolites (Figure 32).

One always remembers the locality where teeth are abundant, but for every "rich" site, there are many sparse localities that produce only the occasional tooth. Here, the teeth are not concentrated into distinct beds but are scattered throughout the strata.

Where fossiliferous sediments are exposed by rivers or streams, teeth may be eroded from bank exposures and redeposited downstream in gravel bars. Such is the case along the North Sulphur River in Fannin County (Figure 33).

Figure 32. A very fossiliferous condensed section (locally known as 'the Contact') occurs at the base of the Austin Chalk along Kiest Avenue in Dallas. This 0.3 meter thick phosphatic zone contains numerous shark and ray teeth.

Figure 33. Collectors picking late Cretaceous shark and ray teeth from gravel bars along the North Sulphur River in Fannin County. The teeth were eroded from the surrounding Taylor Group sediments.

WHEN TO COLLECT

As long as you can reach an outcrop, you can collect teeth at any time. However, as collectors pick over popular sites, teeth become much harder to find. Many experienced collectors know that, after a rain, teeth are exposed as a result of erosion and can be collected from a formerly barren site. At some Texas Cretaceous localities, it is not uncommon to find a popular site crowded with collectors immediately following a heavy rain!

Periodic flooding, which is so common in Texas, results in the erosion, redistribution and exposure of new teeth at river bank and gravel bar collecting sites. These localities are excellent places to collect at low water following each flood.

Housing, industrial and highway construction sites provide many of the best tooth-collecting localities in Texas. These man-made exposures usually must be "washed" by one or more good rains before they reach their best collecting condition. Unfortunately, these sites are also temporary and collecting opportunities may be limited.

The angle of lighting on an outcrop can affect your collecting success. Some like to collect only when the sun is out, whereas others find that teeth are easier to see on an overcast day. Those who like bright sun tend to find teeth by locating the reflection of light from their shiny enameloid crowns. Collectors preferring overcast days find teeth by searching for shape and color. For many other collectors, lighting is of no consequence and they are equally successful under all conditions. What's best for you can only be acquired through experience.

HOW TO COLLECT

Professionals use a few common practices and procedures in the field. The following are some suggestions and considerations that should help you.

Collecting Methods

Four generalized methods commonly used to collect fossil shark and ray teeth are shown in Figure 34. These are:

1) **Walking** the outcrop and picking up teeth as you see them from a standing or stooping position,

2) **Crawling** on hands and knees with your nose close to the ground to find smaller, more difficult-to-see teeth,

3) **Field Sieving** (wet or dry) unconsolidated shark-tooth bearing sediments, and

4) **Bulk Sampling** of a highly fossiliferous bed for later screening and visual and microscopic sorting at home or in the laboratory.

The walking and crawling methods are self explanatory. If you are surface collecting for teeth in soft, easily weathered rock, a plastic vial or small bag may be all the equipment you need. Many collectors carry an ice pick, awl or knife to probe the sediment and loosen teeth from semi-consolidated rock or dried mud. A hand lens aids in examining small teeth and evaluating the fossil content of the matrix. Remove teeth found in hard limestone by chiseling away the surrounding matrix or use a geologic hammer to reduce the block size to something you can carry.

Apply clear shellac or dilute white glue to harden fragile or broken teeth or to glue broken pieces back into place in the field. A whisk broom or small paint brush is handy for cleaning rock surfaces while excavating or to get a better look at a specimen. Whenever possible, protect teeth, even if you think it's unnecessary. Unnoticed microfractures in otherwise solid looking specimens can lead to breakage or unnecessary damage. Toilet tissue is excellent for wrapping small specimens, while larger fossils can be wrapped in newspaper. Secure the wrapped specimens with masking tape and write your field number on the tape. Be sure to include a label with your field number on it in all your bags and vials.

Wet or dry sieving of unconsolidated fossiliferous sediment can effectively reduce the volume of matrix that must be carried home. This method involves passing sediment through a stacked series of 10-, 5-, 2.5-, 1- and 0.5-millimeter mesh sieves. Pick teeth from the coarse screens (10- and 5-millimeter meshes) in the field and carry the remaining finer-sieved sediment home for subsequent washing and microscopic sorting. This method can eliminate most of the bulk volume of unfossiliferous clay, silt and very fine sand in the field, leaving a rich fossil concentrate. Sieve mesh size selection is determined by your collecting purpose and the size distribution of teeth at the locality.

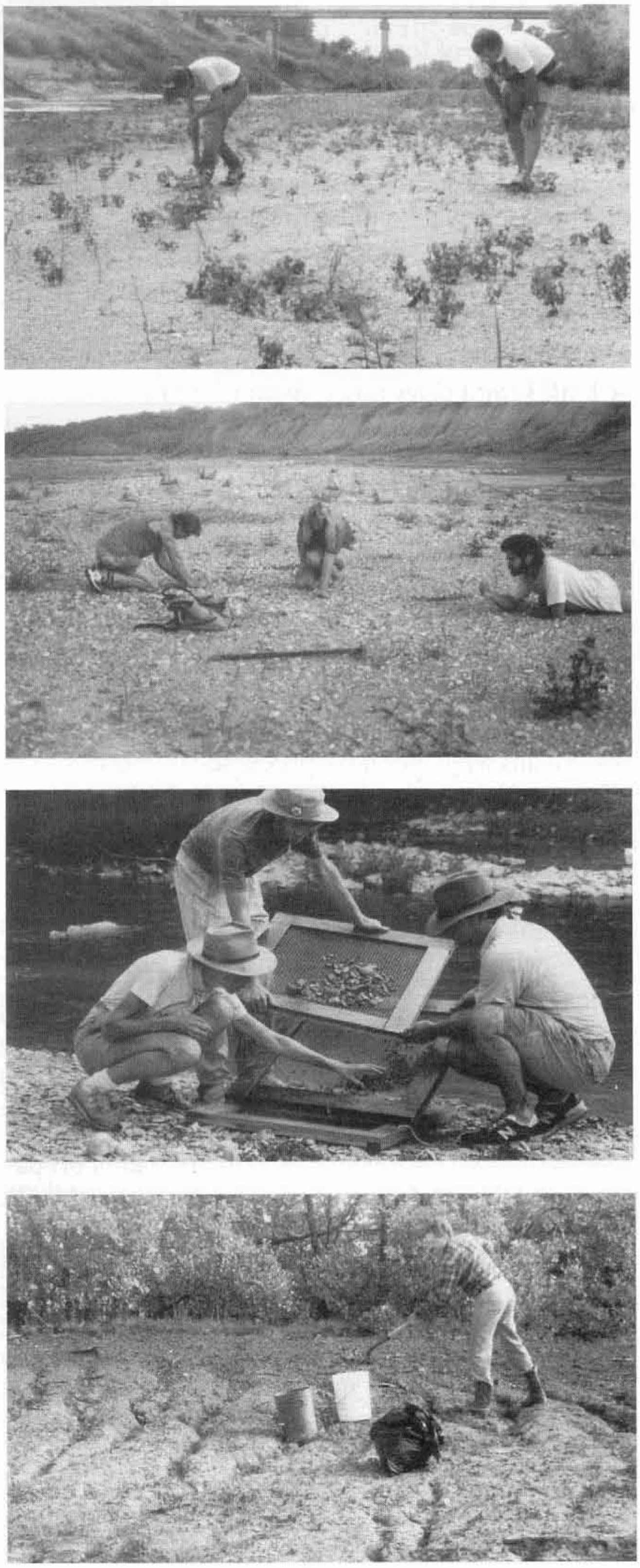


Figure 34. Collecting methods. From top down; walking the outcrop, crawling on hands and knees for a better look, picking teeth from a field-sieved sample, bulk collecting a rich fossil horizon.

Bulk sampling simply means that you dig and bag some volume of fossiliferous sediment from a given horizon or bed and transport it back to the home or laboratory for detailed washing and sorting. In contrast to other collecting methods, which tend to exclude small and microscopic teeth, the bulk sample contains 100% of the teeth in the sediment. Field sieving is equivalent to bulk sampling if the finest mesh size captures the smallest teeth in the sediment.

A bulk sample can range from one to hundreds of kilograms. Since this process involves substantial sediment washing and microscopic sorting, it is advisable to process only the most fossiliferous matrix. To do this, begin by carefully examining the sediment to be sampled, breaking it along bedding planes, looking for teeth and bone fragments. If teeth are visible, the sediment is probably very fossiliferous and worth the effort to bulk sample. If you cannot see teeth in the matrix but find them weathering out on the surface, take a sample and wash it anyway. We have processed numerous sites where teeth turned out to be common in the concentrate but were rarely spotted in the matrix.

Collecting bulk matrix usually requires digging with a pick and shovel and sacking the matrix in burlap sacks, heavy-duty plastic bags or large buckets. Be sure to include a tag with your field number on it inside and one attached to the outside of each bag and bucket. When rock is moist, ensure that the ink will not run and the tag will not disintegrate. For hard rocks, bulk sampling means hauling home blocks of matrix for later mechanical or acid preparation. Here, sledge hammers, pry bars and chisels will be useful for reducing larger blocks to manageable sizes. You can write your field number directly on the blocks with a pen or marker.

Given the above four collecting methods, which one should you use? The answer to this question depends on your specific collecting goals and on the way teeth are dispersed or are found at the collecting site. Also, it depends on the ease of getting to and from the locality.

If you are interested in only collecting large teeth, greater than 1 centimeter, then the walking method will suit your purposes very well. If your goal is to collect all teeth regardless of size, you must use the sieving or bulk sampling method.

Some outcrops appear to yield only large teeth, but this is a rare occurrence. Almost all formations, once carefully sampled and analyzed, usually produce diverse assemblages of shark and ray teeth.

Collecting Bias

The term **Collecting Bias** as used here refers to the process of selectively collecting only large teeth and excluding smaller ones, either deliberately or unknowingly.

The following experiment was conducted as a demonstration of how collecting bias impacts the relative abundance and number of shark and ray species found at any locality. A 90-kilogram bulk matrix sample was collected from a very fossiliferous layer in the Woodbine Formation of Denton County. The sample was washed, acidized and sieved down to 350 micrometers (0.350 millimeter) then all teeth were picked by eye and with the aid of a binocular microscope. A total of 1410 teeth, having a size distribution between 0.4 and 19 millimeters and representing 12 species of sharks and rays, were recovered. Figure 35 shows the distribution of teeth by size. Figure 36 gives the tooth size range for each species.

If all 1410 teeth were exposed at the surface of an outcrop, and if we assume that, by only walking the outcrop, one would find all teeth larger than 10 millimeters, then only 23 teeth (1.6% of the total sample) would have been found.

By crawling this outcrop, we estimate that approximately 46% of the teeth (all teeth 3 millimeters and larger) and 54% of the species would be collected.

Clearly, both collecting methods do a poor job of sampling the total number of teeth and species present. The walking method not only ensures that the resulting collection will be highly biased toward large teeth, but yields a very inaccurate picture of species diversity. In the example, the most common species in terms of numerical abundance, found by

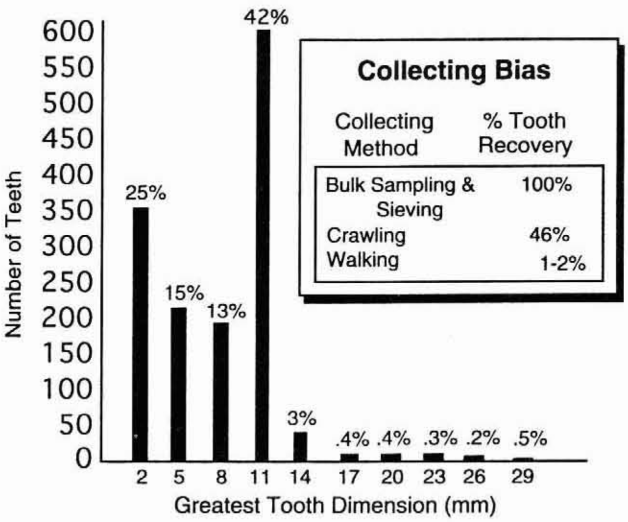


Figure 35. Histogram showing the total distribution of tooth size within one 90-kg bulk sample collection of 1410 teeth from the Cenomanian Woodbine Formation, Denton County.

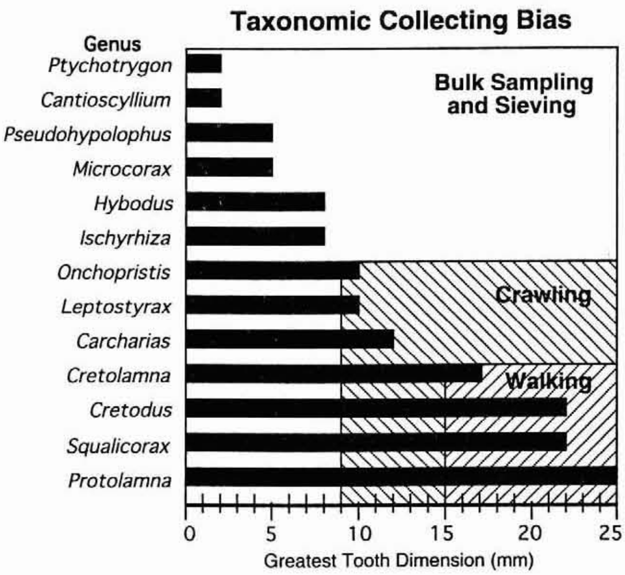


Figure 36. Histogram showing the tooth size distribution for each species in a 90-kg bulk sample of the Cenomanian Woodbine Formation, Denton County.

walking, is actually rare relative to other species when compared with the total bulk matrix assemblage.

The collecting style we recommend is to walk or crawl a selected exposure until teeth are spotted. Once found, check to see if the teeth are weathering out of a specific layer. If so, concentrate your efforts here and collect along its lateral extent. This interval is also a prime candidate for bulk sampling or field sieving.

Collecting Equipment

Whenever you head into the field to collect fossils, you should always be well equipped. The last thing you want is to inadvertently damage a fossil because you didn't have the correct collecting tools. The equipment needed for collecting shark and ray teeth is easily obtained and relatively inexpensive. With more experience at specific collecting sites, you will select the appropriate tools. Improvisation and originality are the marks of an experienced collector!

Figure 37 provides a list of commonly used collecting equipment, grouped by activity and collecting method.

Locality Description and Field Notes

Taking good field notes and accurately describing the geologic context and location of your fossil discovery are necessary skills that will improve with practice. A field notebook for recording your observations should accompany you at all times. Acquire topographic maps of your collecting area and take these maps with you so that sites can be exactly located. A measuring tape will come in handy for determining bed thicknesses and for describing the geology and outcrop section. Photograph the locality if possible and include a print with your field notes or locality file. Finally, bring any geologic or paleontologic literature to the site or general area with you. Often, having this information available can help answer questions that are only resolvable at the outcrop. More about this in Chapter 8.

Plaster Casting

Placing a plaster-of-Paris cast or jacket around a fragile specimen is a widely used and reliable method to ensure the safe collection and transport of fossils. It might be difficult to justify casting an isolated

COLLECTING EQUIPMENT

Locality Description / Field Notes

- Field Note Book
- Topographic Maps
- Highway Maps
- Pencils & Pens
- Measuring Tape
- Brunton Compass
- Camera
- Geologic and Paleontological Site Literature

Surface Collecting

- Plastic Vials (Film Cans)
- Plastic Bags - Assorted Sizes
- Awls and/or Knife
- Whisk Broom
- 1" Wide Paint Brush
- Hand Lens
- Masking Tape
- Roll of Toilet Paper
- Newspaper
- Glue
- Clear Shellac
- Black Indelible Marker
- Labeling Paper and Tags
- Sieves (1/2" to 1/32")
- Knee Pads
- Geology Pick

Bulk Sampling

- Shovel
- Large Pick
- Pry Bars
- Sledge Hammer
- Burlap Sacks, Large Plastic Bags or 5-Gal. Buckets
- Gloves
- Eye Goggles

Plaster Casting

- Plaster of Paris
- Burlap Strips
- Mixing Bowls, Water
- Newspaper & Toilet Paper

Figure 37. Collecting Equipment.

tooth; however, if you were to find an associated dentition of one animal (or something larger, such as an entire skeleton or associated cartilages), a plaster cast would be appropriate. Casts are used to remove specimens when you want to keep the association and position unchanged for study, or to collect fragile specimens that would otherwise disintegrate without casting. The best policy to follow is: ***when in doubt, cast it out.*** Casting does not damage the specimen, almost always ensures that the fossil will be successfully collected and the cast is easily removed at a later date.

The materials required for casting are simple. You need plaster-of-Paris in sufficient quantity to do the job, newspaper or toilet tissue, water, a mixing bowl and strips of damp burlap.

Stabilize the fossil to be cast with a hardener, like clear shellac or Glyptol. Next, dig a trench around the fossil so that it ends up on a slightly undercut pedestal of rock. Cover the fossil and most of the rock pedestal with wet toilet tissue or newspaper to prevent the plaster from adhering to the fossil. Finally, dip moist burlap strips into the freshly mixed plaster and wrap them around the block, ultimately covering it with at least one, preferably two or more layers. For large blocks, more burlap layers and reinforcing boards or steel rods may have to be added for strength. After the plaster hardens, break the block at the base of the pedestal, turn it over and plaster all exposed rock to fully encase the block. The fossil is now ready for transport to the home or laboratory.

Collection Contamination

Accurate locality descriptions, detailed field notes and labeling fossils with field numbers are all done with one purpose in mind — to ensure that important scientific data are captured with every fossil. Most paleontological studies are founded on detailed analysis of the total fossil assemblage at any given locality, the geologic features of the rocks at the collecting site and the fossils themselves. If fossil localities are not listed correctly and a fossil is assigned to the wrong site, it may be very difficult, if not impossible, to correct the mistake. Erroneous interpretations and conclusions may follow.

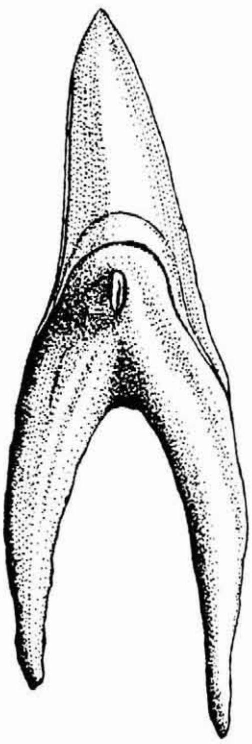
In addition to mislabeling specimens or confusing locality data, several other sources of collection contamination are:

1) Specimens collected at one site are discarded at another.

2) Teeth collected from one site may not have been cleaned out of a sample bag or vial that is being reused at a subsequent locality. Teeth can also stick in sieves and contamination can occur when the sieves are used at a different locality.

3) Where two or more fossiliferous horizons occur at one locality, teeth may erode from a higher (and different) level and be redeposited in the underlying section.

To avoid these problems, clean your pack after every trip and make sure that you do not unnecessarily reuse paper or plastic bags. Always wash your sieves and scrub the screen surface with a stiff brush to dislodge any remaining teeth. Be aware of these problems and use common sense while collecting.



Chapter 7

Fossil Preparation

Fossil preparation is a task eagerly undertaken by many amateur and professional paleontologists. Careful preparation determines the ultimate appearance and presentation of your fossil. It requires a steady hand, patience, a knowledge of anatomy, the proper tools and even some artistic talent. Preparation is also a serious endeavor. Many fine fossils have been inadvertently damaged or destroyed by inexperienced but well-intentioned preparators using inappropriate **mechanical** or **chemical** techniques. Also,

Don't let haste create waste!

Many fossil shark and ray teeth are found exposed on the outcrop surface and require very little cleaning other than a light brushing in water. These teeth are collected at sites where natural weathering processes have eroded soft fossiliferous claystones and marls, leaving behind perfectly cleaned teeth (Figure 38).

Figure 38. Naturally cleaned shark tooth lying on an outcrop.

Unfortunately, not all Texas Cretaceous shark and ray teeth require as little preparation.

Aside from the preparation of display specimens and the application of hardeners and glues to stabilize or repair broken and crumbling teeth, the most commonly employed preparation techniques focus on mechanical and chemical methods for disaggregating, freeing and concentrating teeth from hard rock. As an example, a bulk matrix sample of hard calcareous mudstone can be dried and disaggregated using kerosene and hot water. The resulting mud is sieved down to 0.5 millimeter, thus reducing the rock volume by 90%. The remaining carbonate fraction of the residue (shells, calcareous sediment and microfossils) is eliminated by dissolution in 10% formic acid, resulting in a 97% rock-volume reduction! The remaining phosphatic material is termed a **concentrate** and consists of shark and ray teeth, fish bones and coprolites. This concentrate contains only that portion of the original rock volume that is of interest. It will take about an hour to pick this concentrate by eye and with the aid of a binocular microscope. In the absence of this concentrating process, it would take weeks or months to pick the same sample, and many of the teeth could be overlooked.

This method of producing a fossil concentrate can also be used on originally unconsolidated sediments. If the appropriate minerals are present, field-screened concentrates can be further reduced in volume by the application of either acid or clay reduction treatments.

MECHANICAL PREPARATION

Individual teeth can be removed from rock using small hand-held grinders, air scribes (micro-sandblasters), pneumatic and electric scribes and assorted awls, needles, dental picks and other hand tools (Figure 39).

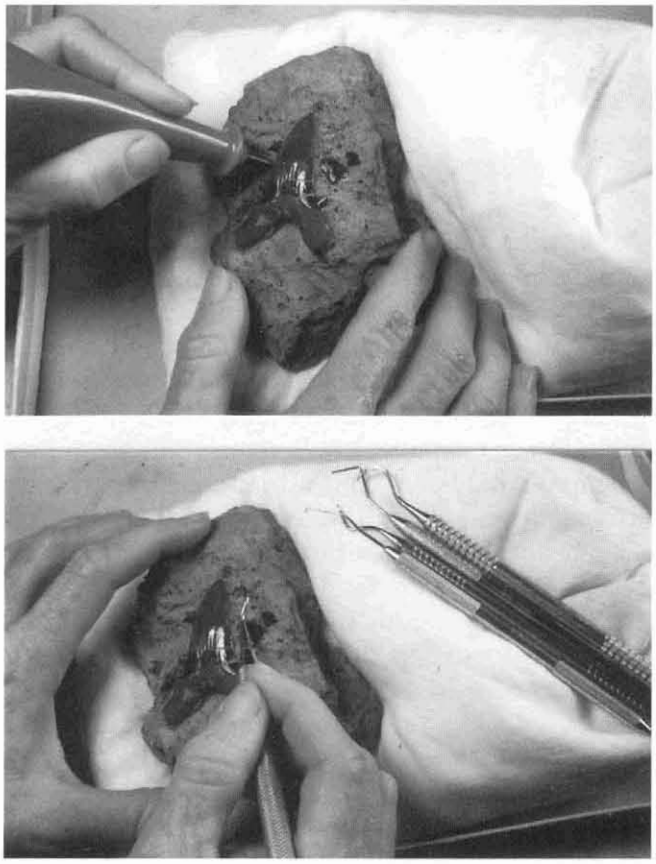


Figure 39. Mechanical preparation techniques. Electric scribe (top), assorted hand tools (bottom).

CHEMICAL PREPARATION

There are several chemical techniques available for removing teeth from hard or semi-consolidated matrix and these are usually specific to the rock type. The methods described here are relatively simple; the materials include hot water, kerosene, 10% formic acid and 10% acetic acid.

Disaggregation of Clay Cemented Rock

Rocks that are hard and appear to be cemented by clay (not carbonate) can be disaggregated by simply soaking them in water. This is the simplest of all processes available yet if done incorrectly can yield poor results.

Two different methods are available. First, the rock must be thoroughly dried by heating (about 150 degrees Fahrenheit) in a conventional or microwave oven. Allow the rock to cool then cover it with boiling water. The clay matrix should expand, turning the rock to mud within an hour or so. This procedure may need to be repeated several times. The second method requires drying the rock as described, allowing it to cool, then soaking the rock in kerosene for several hours. Pour off the kerosene and then cover the rock with hot water. If the process works, the rock will begin to disintegrate immediately. In either case, if the rock turns to mud, be sure to sieve it in water and check the fine fraction for small teeth.

Disaggregation of Carbonate Cemented Rock

Teeth can be removed from carbonate-cemented quartz sandstone, siltstone, claystone, chalk or limestone by dissolving these rocks in acetic or formic acid. These are relatively weak acids and if used in concentrations of 5% to 10% will not damage the phosphatic teeth. **DO NOT USE stronger acids such as hydrochloric (muriatic), sulfuric or nitric**. They will destroy teeth! Acidizing rock can be done in plastic buckets. The process may take days or weeks depending on the amount of rock to be dissolved and could require several acid changes. Once the carbonate dissolves, all that remains is an insoluble residue of bone, teeth and noncarbonate rock fragments (Figure 40). After washing this concentrate in water to remove any remaining acid, sieve it through assorted mesh sizes and pick the fossiliferous residue microscopically.

When working with acids always be sure to use appropriate safety equipment in a properly ventilated building or outdoors. If you have never worked with acids, be sure to seek advice from someone knowledgeable in this process before attempting it yourself.

Applying a Tooth Hardener

Most Texas Cretaceous shark and ray teeth need little or no special surface hardener. However, if the

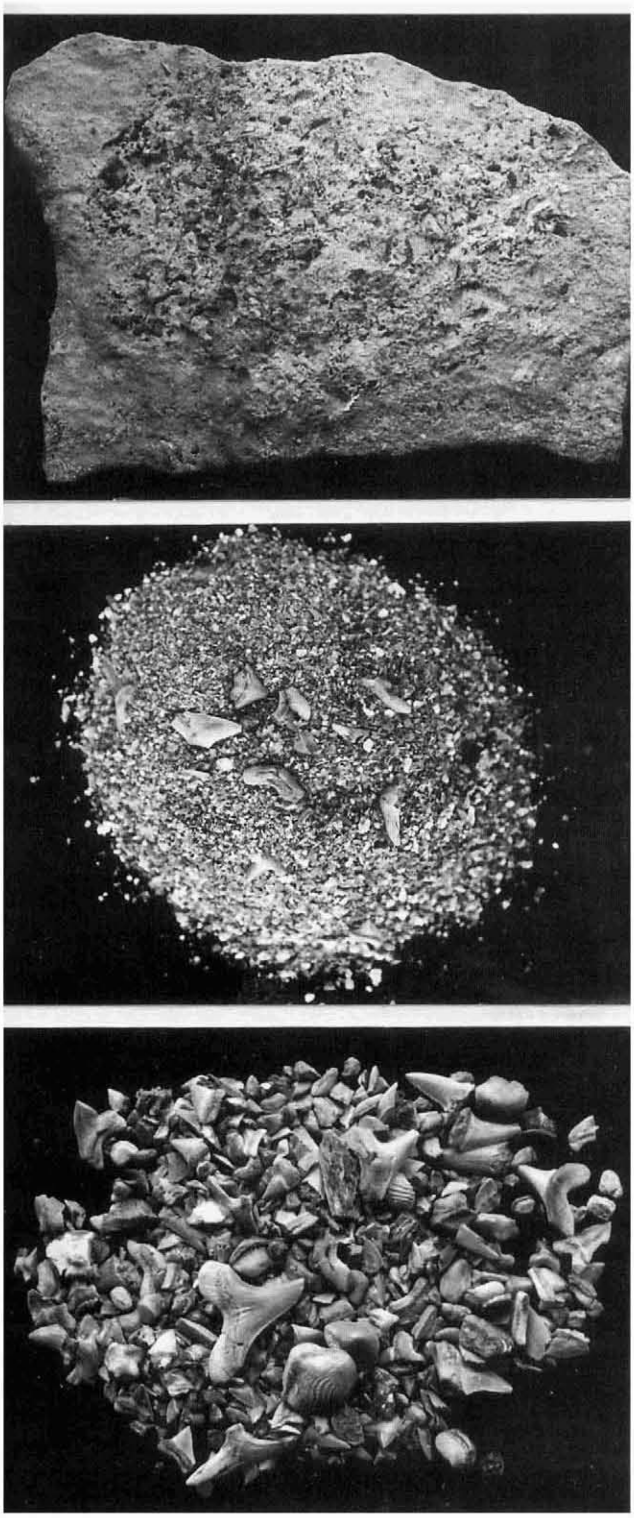


Figure 40. Acid disaggregation of a Kamp Ranch Limestone block of the Eagle Ford Group (Turonian), Dallas County. Unacidized limestone block containing fish bones and teeth (top). Unsieved, insoluble phosphatic residue remaining after complete 10% Formic Acid dissolution of the block (middle). Microscopically picked teeth from residue, ranging in size from 12 mm to 0.4 mm (bottom).

tooth requires stabilization because of a crumbly root or crown, apply a thin, clear shellac or spray-on plastic (Figure 41).

Pieces of a broken tooth can be glued back in place using water-soluble white glue or epoxy-based glues (Super-Glue).

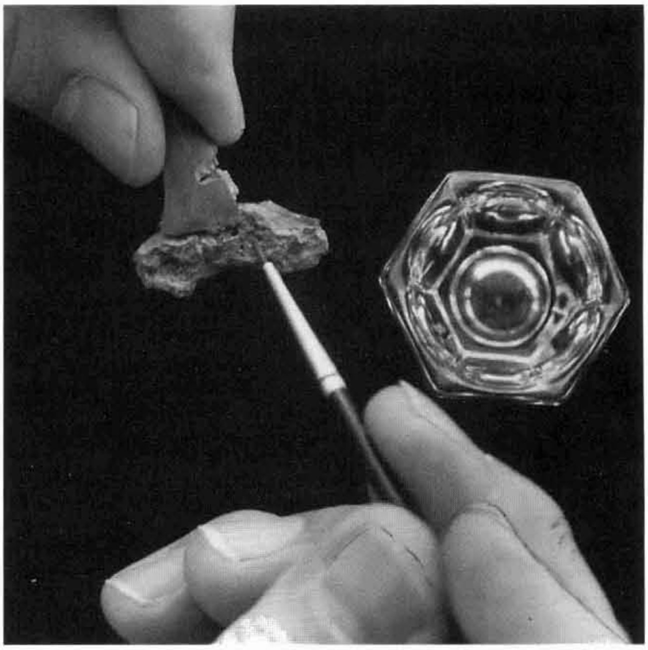
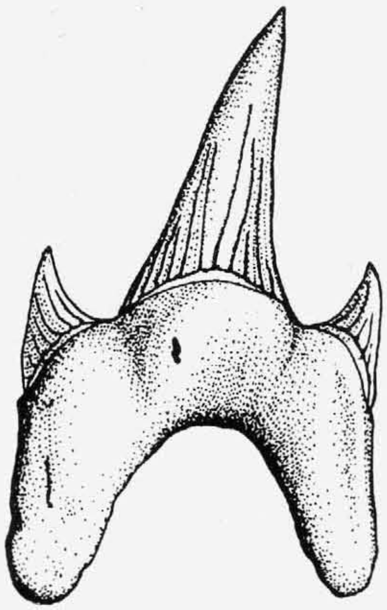
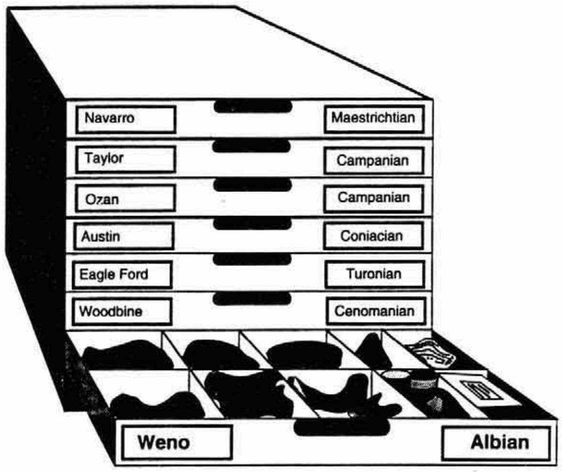


Figure 41. Hardening a poorly preserved tooth with clear shellac.



Chapter 8

Taking Care of Your Collection



Collection management, or the systematic cataloging, organization and storage of your fossils, is one of the most important yet often neglected aspects of this hobby. Taking care of your collection can give many hours of enjoyment, and a properly curated collection is an accomplishment to be proud of.

Every fossil is unique and, therefore, irreplaceable. A fossil's value to science is based first on its inherent nature, preservation and completeness, and second, on the geologic, geographic and paleontologic context in which it was found. A collector can do very little about fossil quality, other than to ensure that a specimen is not damaged in the field or preparation laboratory. However, acquisition and retention of geologic, locality and other types of information are entirely the collector's responsibility.

This chapter on taking care of your collection introduces you to all the basic elements of good collection management.

LOCALITY INFORMATION

Shark teeth and other fossils are collected by many people for many different reasons, but *everyone*, regardless of motivation, should preserve the scientific value of the specimen by accurately recording the exact location where the fossil was found.

Setting Up a Locality Catalog

A locality catalog should contain all the information on the form shown in Figure 42. We recommend that you copy this form and use it for your own locality file. The information can be kept in a notebook or ledger, on index cards or in a computer file. Assign a number to each locality and make sure that this number is stored with each and every fossil.

Locality Number: Establish a locality numbering system that is different from your specimen catalog number, discussed later. For example, 1993-1, 1993-2 or T-1, T-2 and so on. Be sure to keep this locality number with all fossils from that locality. This number should also be recorded with each fossil in the specimen catalog.

Locality Name: Give each locality a general name like "TXI Quarry" or "Keller Avenue".

Township/Range/Section: Read these coordinates directly from a topographic map.

Latitude and Longitude: Read these coordinates directly from a topographic map and record them in degrees, minutes and seconds.

Elevation: Record the elevation of the locality by interpolating between contour values on the topographic map.

Formation: Record geologic formation and member if one exists.

Map: List the map used to plot your locality. For example: U.S.G.S. 7.5 minute, 1986 edition, topographic, Dallas Quadrangle, Texas.

Age: Record the geologic age as accurately as possible with period first, followed by other finer subdivisions based on available biostratigraphic information (e.g., Cretaceous, Comanche, upper Albian and ammonite or foraminiferal zone).

Locality Description Catalog

Locality Number: ____________________

Locality Name: ____________________

Country: ____________ State: ____________ County: ____________

Township/Range/Section: ____________________

____

Latitude: ____________ Longitude: ____________ Elevation: ____________

Map: ____________________

Formation: ____________________

Age: ____________________

Locality Description: ____________________

____

____

____

____

____

Material: ____________________

____

Described By: ____________________ Date: ____________

Figure 42. Locality description form.

Description: Describe the exact geologic occurrence of the site, distances to surrounding topographic and cultural features and any other information that will help someone find the exact locality. Include hand-drawn sketches of the stratigraphic section and notes about rock type, bedding and structure.

Material: List the kinds of fossils found at the site (e.g., shark teeth, plesiosaur vertebrae, etc.).

Locality Maps

In addition to a locality catalog file, a map file should also be maintained with each locality number plotted on the map (Figure 43). For this purpose use United States Geological Survey topographic maps (7.5 minute) or a *Roadways of Texas* map atlas.

Do not use locality numbers sparingly! Different stratigraphic intervals on the same outcrop may yield different fossil assemblages and, if recognized, should be given separate locality numbers. Specimens from adjacent zones should not be commingled (Figure 44).

COLLECTION CURATION

After identifying your teeth with the assistance of this book, you will want to preserve this information for future reference and store the specimens in some systematic order. This process of cataloging, labeling and storing a collection is termed **curation** and a person who does this as a profession is a **curator**.

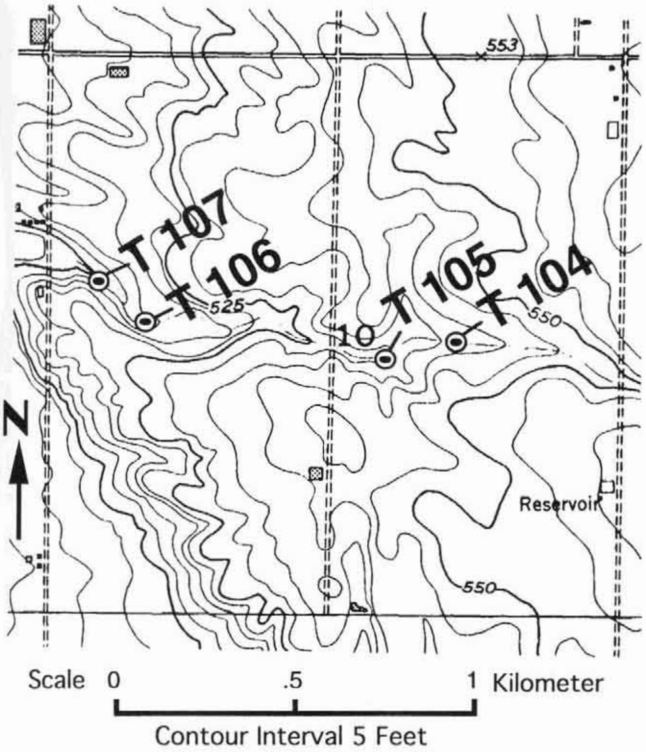


Figure 43. Topographic map showing fossil localities T104-T107.

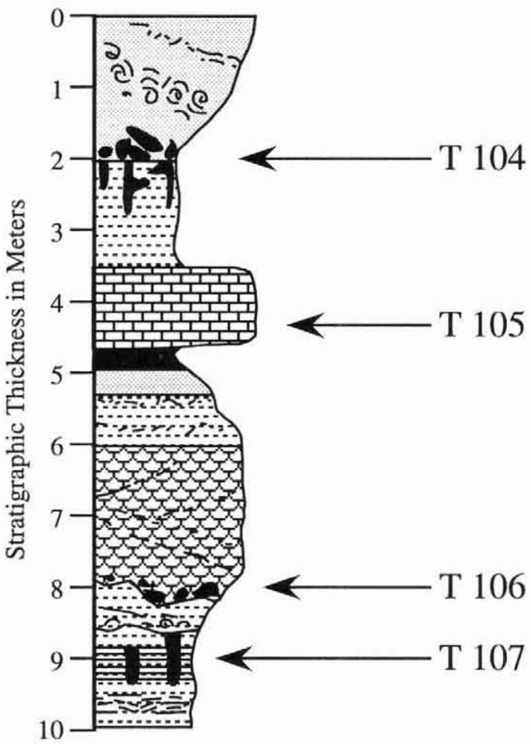


Figure 44. Stratigraphic section with the four fossil localities shown in Figure 43 in vertical sequence.

The Specimen Catalog

A specimen catalog is a place to record specific information about each fossil in your collection. A unique specimen number is assigned to every fossil and referenced back to the catalog entry. Specimen catalogs can be kept in notebooks or ledgers, on index cards or in a computer database. A typical specimen catalog card containing the data that we recommend you record is shown in Figure 45.

Specimen Numbers

When establishing a specimen catalog, you must decide on a numbering system. We recommend a simple numbered sequence beginning with 1.

Many people prefer to use their initials as an acronym preceding every specimen number. Be sure your specimen number is not the same as your locality number; this can lead to confusion.

Generally, a specimen number is assigned to every tooth. If this is done, a label bearing the specimen number and locality number should be stored with the fossil. If the tooth is large, this information can be written in indelible ink on the fossil. Smaller teeth are stored in vials or small bags to which a label can be attached or enclosed.

Batch Cataloging

If a large collection is made from one locality and there is no reason to record specific information on a tooth-by-tooth basis, then all the teeth of one species can be cataloged under one specimen number and stored that way. Batch cataloging saves time and unnecessary work while not compromising on data capture. Single teeth can always be assigned unique specimen numbers at a later date.

Specimen Storage

Shark teeth are generally small and therefore ideally suited for storage in low, flat drawers. Map cabinets make ideal storage units and professional museum specimen cabinets are available but expensive.

Specimen Catalog

Specimen No: ______________________ Field No. ______________________

Taxon: ______________________

Family: ______________________

Formation: ______________________

Age: ______________________

Locality: ______________________

____

Material: ______________________

Collector: ______________________ Date: ______________

Identified By: ______________________ Date: ______________

Figure 45. Specimen catalog card.

Teeth are best stored in sealed clear plastic bags, vials or plastic boxes so that the contents are easily seen. Avoid storing teeth in open containers to prevent sample mixing.

There are many ways to arrange your collection, and we list five different options. Select one of these systems or design one to meet your specific needs.

Numerical: Specimens are stored in numerical sequence by specimen number.

Locality: Specimens from one locality are stored together and collections are arranged in numerical or alphanumeric order by locality number.

Formation: All teeth from the same formation are stored together. Within each formation, teeth are grouped by locality number and arranged in numerical sequence by specimen number or species.

Age: All teeth of the same age are grouped together. Within each age, they can then be ordered alphabetically by genus and species, chronologically by formation or numerically by specimen number.

Systematically: Teeth are arranged in a systematic order, progressing from the most primitive to the most advanced species following a generally accepted classification scheme.

Specimen Cards

A card listing the information shown in Figure 46 should be stored with each fossil.

Specimen Storage Card

Specimen No. ______________________

Taxon: ______________________

Material: ______________________

Age: ______________________

Formation: ______________________

Locality: ______________________

Figure 46. Specimen storage card.

Chapter 9

Displaying Your Collection

For those of you who want to display your Texas Cretaceous shark and ray teeth, we have good news and we have bad news. The good news is that there are some spectacular teeth to be found and displayed; the bad news is that approximately half the Cretaceous shark and ray species from Texas have teeth so small that showing them off is akin to displaying grains of sand (Figure 47)! The latter is truly unfortunate because what many of these teeth lack in size they make up for in complexity and beauty.

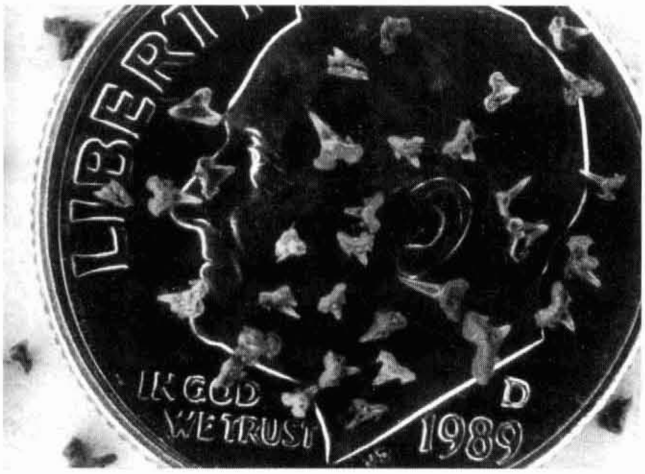


Figure 47. Microscopic teeth of an adult cat shark.

Creating an attractive display really depends on your own originality and creativity. Some of the more commonly used display ideas for both large and small teeth are outlined in this chapter.

DISPLAYING LARGE TEETH

Approximately half (42) of the shark and ray species described in this book, have teeth which, at adult size, are large enough to reasonably display (larger than 4 millimeters, or so). Of these, about 16 species, primarily belonging to *Ptychodus*, the lamnoids, anacoracids and several of the sawfishes (rostral but not their oral teeth), are close to or exceed 2 centimeters in greatest width or height.

Large teeth laid out on clear glass, colored paper or black velvet make beautiful displays. Each tooth or species grouping should be accompanied by a clearly printed identification label. Exceptionally large teeth can be displayed individually in clear plastic boxes, in bell jars (Figure 48) or upright on plastic or glass display stands.

Figure 48. Tooth of *Cretodus crassidens* in a bell jar.

Riker mounts are probably the most popular tooth display and storage method used by Texas collectors. These mounts can be purchased in numerous sizes and consist of a shallow black box filled with soft tissue or cotton over which fits a glass-fronted lid. Teeth are simply arranged in rows or groups and are firmly held in position once the lid is attached. Identification or informative labels are either inserted along with the teeth or written on the back of the mount. A customized Riker-type mount is shown in Figure 49.

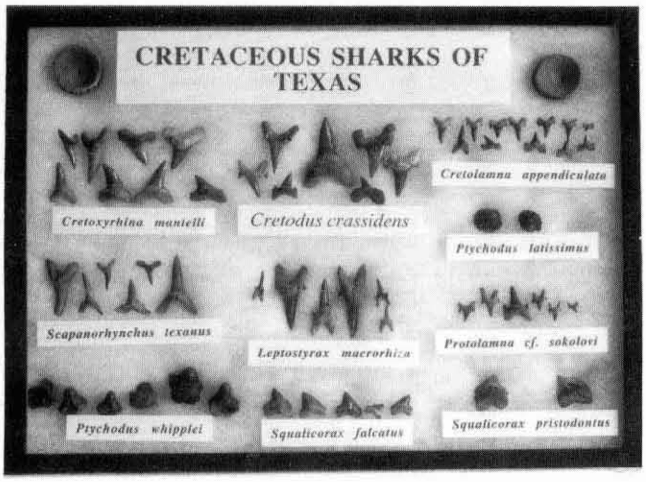


Figure 49. Shark teeth displayed in a Riker mount.

Some collectors construct elaborate display cabinets such as the beautiful oak coffee table shown in Figure 50.

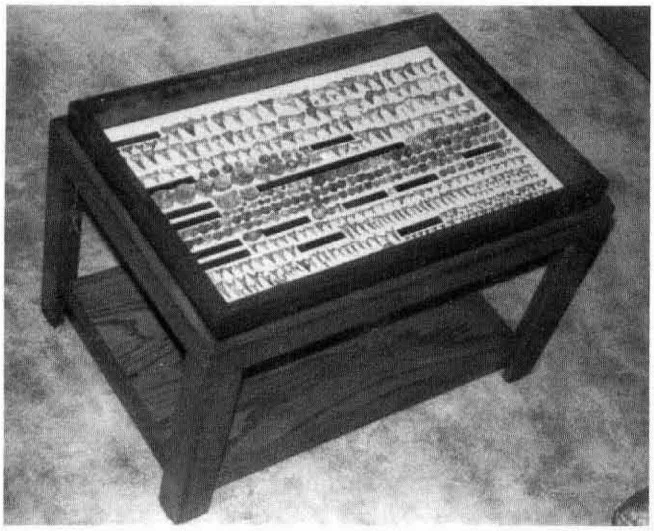


Figure 50. Beautiful oak coffee table specifically designed to display six months worth of collecting near the Coniacian-Turonian boundary in Grayson County. Brass nameplates add an elegant touch.

Teeth that are exposed on one surface but left attached to a block of the original rock are called **matrix specimens** and can be very attractive display items. Matrix specimens can also be prepared by briefly acid etching limestones or chalks containing concentrations of teeth. The skillful use of acid can produce some spectacular tooth displays (Figure 51).

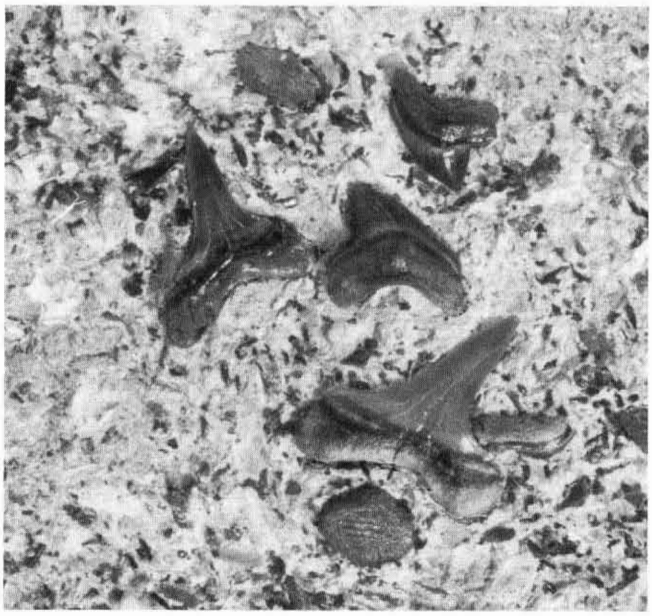


Figure 51. Matrix specimen of teeth exposed on a limestone block after acid-etching (Kamp Ranch Limestone of the Eagle Ford Group, Turonian, Dallas County).

Artificial tooth sets can be attached to boards using double-sided tape or mounted on clear or colored plastic sheets to stand vertically. Exercise caution when using most tapes because they will eventually deteriorate and the teeth will fall off. Water-soluble white glue will hold up for many years and, if desired, can be removed from individual specimens without damaging them. Such is not the case for epoxy-based glues.

DISPLAYING SMALL TEETH

Despite their small size, teeth less than 3 millimeters can be displayed using small, stand-mounted magnifying lenses. Teeth are positioned below the lens, placed on a surface of appropriate contrast or glued to the head of a pin (Figure 52). Small, clear plastic 'thumbnail' boxes with magnifying lids are also available for the display of micro-teeth.

Figure 52. Micro-tooth displayed in a magnifying box.

Alternatively, small teeth can be indirectly exhibited using photographic enlargements. Specimens are displayed in vials or other containers to show the true tooth size and set adjacent to photographs taken by a camera or scanning electron microscope (SEM). These displays can be very attractively done with impressive results (Figure 53).

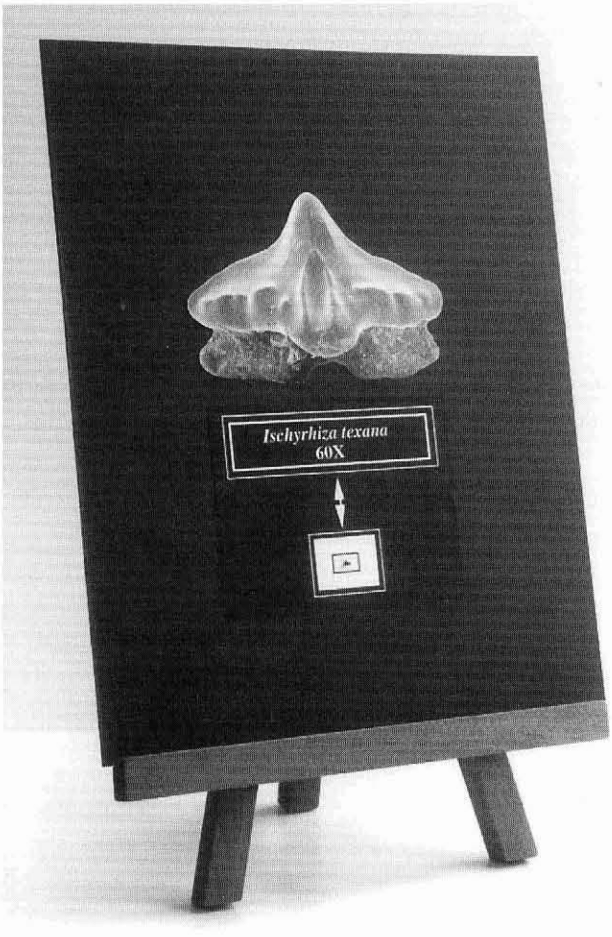
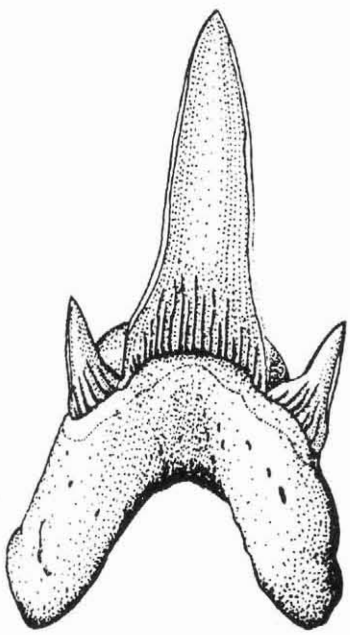


Figure 53. Scanning electron photomicrograph displayed with the actual microscopic tooth.



Chapter 10

Collecting Localities

HOW TO GET STARTED

You will soon discover that there is a large collecting "community" out there, made up of individuals and families who actively spend their weekends, evenings and any other available time in the pursuit of shark teeth. It is a common occurrence to meet other collectors in the field and this is where some of your best information and tips on collecting sites are acquired. The majority of fossil sites are well known to active collectors and their locations are generally passed around by word of mouth. However, not all sites are public knowledge and some collectors treat their localities as closely guarded secrets!

Good locality and collecting information is often available from your local paleontological or mineralogical society. Members are often willing to give site information and most groups offer organized weekend collecting trips.

Remember, every fossil locality was originally discovered by someone who took the time to stop and carefully examine an outcrop. You don't need a Ph.D. in Vertebrate Paleontology to discover a new site. In fact, most localities are found by diligent amateur collectors.

Collecting shark teeth is no different from any other outdoor activity that requires access to public or private land. Always obtain permission before entering private property and be aware that not all public lands (e.g., Bureau of Land Management, National Park Service) are open to collecting. Once allowed on someone's property, be sure to close all gates, pick up your garbage and leave everything as you found it. Unfortunately, some of the best shark tooth sites in Texas are now off limits to fossil hunting because of the actions of a few inconsiderate collectors.

WHERE TO COLLECT

If you have never collected shark teeth in Texas, we recommend that you try one or all three of the sites listed. These localities offer exposure to diverse collecting methods and tooth occurrences in rocks of late Albian, Coniacian and Campanian age.

Locality #1

Name: North Sulphur River
Age: Late Cretaceous-Campanian
Stratigraphy: Taylor Group
Collecting Methods: Walking, crawling (gravel bars) and field sieving/bulk sampling (gravel lenses)

The North Sulphur River is situated north of Commerce and runs from west to east through Fannin, Delta and Lamar counties. It cuts through all formations of the Taylor Group, beginning with the Ozan Formation in the west and ending with the Marlbrook Formation in the east. Shark and ray teeth, mosasaur bones and ammonites are commonly found in the gravel bars at low water, along the river-cut banks in Pleistocene gravel lenses and in outcrops of Taylor Group sediments.

The exposed midstream gravel bars and stream-bank gravel lenses are made up of reworked Cretaceous and Pleistocene fossils, so don't be alarmed if you find a large 80,000,000 year old Cretaceous tooth of *Scapanorhynchus texanus* lying adjacent to a 10,000 year old Pleistocene horse tooth!

A popular gravel bar collecting locality is situated just downstream (east) of the Ben Franklin Bridge on Texas Hwy. 38 in Delta County. Park your car on the south side of the bridge and climb down to the river bed. Teeth are found on the gravel bars and in gravel lenses along the sides of the river.

The teeth most commonly found here include *Scapanorhynchus texanus*, *Squalicorax kaupi* and large rostral teeth of the sawfish *Ischyrhiza mira.*

A note of caution: the water level in the North Sulphur River can rise very quickly because of rains upstream. So be prepared to scamper to higher ground if this happens.

Locality #2

Name: Lake Texoma
Age: Lower Cretaceous, late Albian
Stratigraphy: Duck Creek Formation
Collecting Methods: Walking, crawling and possibly bulk sampling

Lake Texoma is situated on the Texas-Oklahoma border. Outcrops of the late Albian Duck Creek Formation produce shark's teeth from low, 8- to 10-foot high banks along the Texas (south) side of the lake. The best and most accessible site extends from the dam to the west, along the shoreline between two boat ramps. Teeth of *Ptychodus decurrens, Cretolamna appendiculata* and *Leptostyrax macrorhiza* are the most commonly found species at this locality.

Locality #3

Name: White Rock Cuesta
Age: Upper Cretaceous, Coniacian
Stratigraphy: Basal Atco Formation of the Austin Group (contact horizon)
Collecting Method: Walking, crawling and especially bulk sampling

A ridge, which is traceable from Austin to Dallas and northward, is one of the most popular collecting areas in the state. It is formed by the relatively hard Austin Chalk overlaying and protecting the much softer Eagle Ford Shale. Where the chalk has been eroded away, there is rapid and severe erosion of the shale beneath. But at the contact between these two formations is a highly fossiliferous zone locally known as the basal Austin Group "contact horizon".

This "contact horizon" is a thin (0.1 to 1 meter thick), chalky gray, phosphatic, black-pebble conglomerate that produces abundant shark and ray teeth. It is especially well known for yielding large teeth of *Cretodus crassidens*, *Ptychodus whipplei*, *Ptychodus latissimus*, *Squalicorax falcatus* and a very diverse microfauna.

The best contact horizon collecting is done within the numerous commercial limestone quarries situated along the Austin Group outcrop trend between Dallas and Austin. These quarries are not generally open to the public so permission and possibly a liability release form are almost always required before entering the property.

An easily accessible place to view the contact horizon is an exposure along both sides of Kiest Avenue just east of Loop 408, in Dallas County. To reach this site, take the Kiest exit from Loop 408 and turn east for about a quarter of a mile. The high road cuts to your left and right expose the Austin chalk (buff to light gray) and underlying Eagle Ford Group shale (dark gray). The fossiliferous contact horizon occurs at the base of the lowest blocky limestone ledge.

Megascopic teeth are found by carefully searching the weathered chalk surface, or more commonly, by excavating pieces of the phosphatic contact horizon and looking for shiny black teeth.

The contact horizon is an excellent candidate for bulk sampling and acidizing. A 1 kilogram sample (2.2 pounds) can yield between 50 and 100 teeth in the 0.5 to 3 millimeters size range. This rock readily dissolves in weak formic or acetic acid and the resulting concentrate is almost pure phosphate.

NOTE

When you are in the field collecting, be conscious of potential hazards that can spoil your outing - or worse. Injuries can result from contact with plants and animals or from adverse physical conditions. Briars, thorns and poison ivy along with snakes, centipedes and scorpions, ticks and chiggers, mosquitos and spiders can cause discomfort. Loose rock, slippery areas and other unstable situations should be avoided. Remember:

Make sure the risk is worth the fossil.

Any of these dangers that you don't understand, research them before entering an area where they may be present. If not sure which dangers may be an area of interest, find out.

GLOSSARY

abyssal - oceanic depths below 1000 fathoms (6000 feet or 1980 meters).

acanthodians - primitive paleozoic fishes of possible shark ancestry.

aff. - affinity; indicates a specimen or specimens believed to be closely related to but not exactly the same as the named species.

Albian - uppermost Lower Cretaceous time period, between 108 and 96 million years ago.

ammonites - one of a large extinct group of mollusks related to the living chambered nautilus.

amphicoelus - hour-glass shaped vertebra.

anaulacorhizous - flattened or tabular roots of a tooth that are highly porous and lack a nutrient groove.

anastomosing ridges - subparallel ridges having a braided pattern.

anterior - located forward.

anteriors - tooth rowgroup in the front of the mouth situated near the mesial end of the dental series and best developed in the Lamniformes.

anterolaterals - a rowgroup for which anteriors and laterals cannot be distinguished from one another.

apatite - a mineral consisting primarily of calcium phosphate: $Ca_5(PO_4)_3(OH,F,Cl)$.

apical - toward the tip of the crown or cusp of a tooth.

appendicular skeleton - the skeleton of the appendages, e.g., fins, pectoral girdle, claspers.

Aptian - Lower Cretaceous time period, between 113 and 108 million years ago.

articulated - joined together.

artificial tooth set - dental series reconstructed from the teeth of many different individuals.

associated tooth set - a disarticulated tooth set from one individual.

attachment surface - surface of the root that attaches to the dental membrane of a tooth.

axial skeleton - the vertebral column, tail and cranium.

barb - a hook-like projection on the posterior edge of some sawfish rostral teeth.

basal - toward the root.

basal ledge - a ledge formed by the crown overhanging the root at the crown foot of a tooth.

basidorsal cartilage - cartilaginous base of the neural arch of a vertebra.

basiventral cartilage - cartilaginous base of the hemal arch of a vertebra.

batch cataloging - assigning one catalog number to more than one specimen of the same species.

batoids - skates and rays.

benthic - bottom dwelling.

bifurcating - branching.

bilobate - root subdivided into two lobes, mesial and distal.

blade - labiolingually compressed crown projection on a tooth, usually having a cutting edge.

brackish - term applied to waters with salt content that is intermediate between that of fresh and sea water.

branchial arches - structures supporting the gills.

bucklers - enlarged dermal denticles found primarily on rays.

bulk sample - a volume of unsorted fossiliferous sediment that is quarried, sacked and transported home for sieving and sorting.

calcified - biological mineralization of cartilage with calcium phosphate.

calcium phosphate - a mineral (apatite), $Ca_5(PO_4)_3F$ found in nature or precipitated biologically.

Campanian - Upper Cretaceous time period, between 84 and 74 million years ago.

caudal fin - tail fin.

central foramen - a major hole situated centrally on the attachment surface of the root or within a nutrient groove of a tooth.

centrum - main body of a vertebra.

cephalic spine - head spine found on some male hybodont sharks.

cf. - to compare; used in paleontology to indicate that a specimen or specimens are closely comparable to but not the same as a named species.

chalk - sedimentary rock composed of the calcareous shells of micro-organisms.

chondrocranium - cartilaginous brain case found in sharks and rays.

chronostratigraphic - geological time unit.

claspers - male reproductive organs associated with the pelvic fins.

clasper spines - mineralized spines attached to the clasper cartilages.

classification - the formal arrangement of organ-

isms in the groups of a hierarchy of taxonomic categories.
clastics - sedimentary rocks composed of grains of pre-existing rocks that have been moved individually from their places of origin.
collecting bias - an unrepresentative sampling of the total fossil assemblage.
comparative anatomy - the comparison of form and function between two or more species.
condensed section - a highly fossiliferous zone deposited in deep water under conditions of very low sediment influx.
conglomerate - a clastic rock containing rounded fragments corresponding in their grade size to gravel or pebbles.
Coniacian - Upper Cretaceous time period, between 89 and 88 million years ago.
conspecific - belonging to the same species.
contact horizon - condensed section at the base of the Atco Formation of the Austin Group.
coprolite - petrified (fossilized) excrement. The undigestible residue of food eaten and passed through the alimentary canal of some animal.
coquina - limestone composed primarily of shell, coral fragments and other organic debris.
correlation - the determination of the equivalence in geologic age and stratigraphic position of two formations or other stratigraphic units in separated areas.
cosmopolitan - having worldwide distribution.
crenulated - having irregular ridges.
Cretaceous Period - geologic time period of the youngest of three major subdivisions of the Mesozoic Era, between 133 and 66.5 million years ago.
crown - the enameloid-covered portion of the tooth which, unlike the root, is not anchored to the dental membrane.
crown foot - the point at which the crown meets the root of a tooth.
crushing teeth - low crowned teeth forming pavements for crushing rather than slicing.
curation - the process of systematically cataloging, labeling, storing and otherwise taking care of a collection.
cusp - a major crown projection on a tooth.
cuspate - having numerous crown projections (cusp and cusplets) on a tooth.
cusplet - minor crown projection flanking a cusp on a tooth.
cutting ridge - knife-like ridges found on cusps, cusplets, blades and occlusal crown surfaces of a tooth.
delta (deltaic) - a deposit of sediment formed at the mouth of a river either in the ocean or a lake that results in progradation of the shoreline.
dental band - a narrow, smooth, enameloid-free band that occurs at the crown foot of a tooth.
dental formula - a shorthand alphanumerical description giving the tooth rowgroups and number of tooth rows in both jaws.
dental membrane - a tissue on the lingual surface of the jaw cartilage to which teeth are attached.
dentine - a histological term for the hard tissue comprising the root and internal crown structure of a tooth.
dentition - all teeth in a mouth.
depositional environment - all aspects of the specific geographic area where sediment and fossils accumulate.
depression - concave surface found on the crown or root of a tooth .
dermal denticles - enlarged thorn-like placoid scales found primarily on skates and rays.
dermal skeleton - see exoskeleton.
dignathic heterodonty - opposing teeth in the upper and lower jaw have a different shape and/or size.
dimorphism - two distinct forms within a species.
disjunct heterodonty - tooth shape changes abruptly along the dental series.
distal - toward the corners of the jaws, opposite of mesial or furthest from the origin.
dorsal - toward the top.
dorsal fin - a fin on the back (dorsal surface) of a shark or ray.
dorsoventral - referencing top to bottom.
e.g. - abbreviation meaning "for example".
elasmobranchs - sharks, skates and rays.
enameloid - an enamel-like tissue coating the teeth in sharks and rays that is different from mammalian enamel.
endoskeleton - internal skeleton.
enterospirae - fossilized intestines.
epicontinental sea - a sea that extends into the interior of a continent.
erosion - disintegration of rock caused by weathering.
estuary - where fresh water meets sea water, affected by tides.

exoskeleton - external skeleton, the protection surrounding the soft body of an animal, as the shell of brachiopods, pelecypods and insects. In elasmobranchs, exoskeletal elements include teeth, spines, placoid scales and dermal denticles.
exposure - that part of a rock, bed or formation that is subject to weathering; an outcrop where one can look for fossils.
extant - living, modern, opposite of fossil.
faces - the characteristics of a rock unit.
fauna - animals collectively found in a geographic region.
feeding traces - scratches, grooves, slices, sediment disturbances or patterns left by an organism which are caused by feeding activity.
field sieving - the filtering of sediment through various screen mesh sizes in the field to concentrate and high-grade fossiliferous sediment.
fin spines - spines situated in front of one or both dorsal fins in some modern and fossil sharks and rays.
fluvial - pertaining to a river.
foramen - a hole.
formation - the primary unit in stratigraphy consisting of a succession of strata useful for mapping or description.
fossilize - to preserve a trace or remains of a plant or animal in the earth's crust, to petrify.
genotype - the species on which a genus has been defined.
genus - a group of species believed to have descended from a common direct ancestor that are similar enough to constitute a useful unit at this level of taxonomy.
geology - the study of earth history.
gnathic - pertaining to the jaw.
gradient heterodonty - a gradual transition in tooth shape and size along the dental series.
guitarfish - rays belonging to the genus *Rhinobatos*.
hardpart - mineralized skeletal element.
hemal arch - cartilaginous ring attached to the ventral surface of the vertebral centrum.
hemiaulacorhizous - broadly triangular roots of a tooth having a large central basal foramen and lacking a nutrient groove.
heterodonty - variation in tooth size and shape in one species.
heterogeneous - highly variable.
high-grade - to select only the best.
histology - the microscopic study of tissues.
holoaulacorhizous - roots of a tooth having a well-defined nutrient groove that divides the root into mesial and distal lobes.
holotype - single specimen chosen by the original author of a species that is the name-bearer.
homodonty - all teeth in the dentition have the same shape and relative size.
ichnology - the study of trace fossils.
ichthyology - branch of zoology specializing in the study of fish.
I.C.Z.N. - International Commission for Zoological Nomenclature, sets taxonomic standards.
i.e. - abbreviation meaning "that is".
imbricate dentition - teeth along the dental series that articulate mesially and distally with one another by overlapping like roof shingles.
incertae sidis - taxonomic position uncertain.
independent dentition - teeth do not touch, articulate or interlock with adjacent teeth in the series or row.
intermedialia - areas of vertebral calcification situated between the basidorsal and basiventral insertions for the arch cartilages.
junior synonym - an invalid name for a genus or species.
Jurassic Period - the middle of the three periods comprising the Mesozoic Era, between 190 and 133 million years ago.
juxtaposed dentition - teeth along the dental series abut mesially and distally with teeth in adjacent tooth rows.
labial - side of the tooth toward the lips (outer face).
labial flange - a basally directed and flattened crown projection of a tooth that usually extends below the level of the crown foot.
labiolingual - referencing inside to outside of the mouth.
lag deposit - thin lens or bed of sand, pebbles, phosphatic grains, teeth and bones that have been concentrated by wind or ocean currents.
lamella - thin layer.
lateral - situated on the sides.
laterals - a tooth row group situated midway along the dental series.
limestone - sedimentary rocks consisting primarily of calcium carbonate ($CaCO_3$).
lingual - side of the tooth toward the tongue (inner face).
lingual peg - a small crown protuberance on the lingual face of a tooth, usually situated near the

crown foot.

lingual protuberance - lingually expanded or enlarged area of the root situated just below the crown foot and between the root lobes of a tooth.

lithology - physical character of a rock (e.g., sand, clay, silt, chalk).

locality catalog - a file where fossil locality information is stored.

locality description - a concise written and graphic description of the exact location where a fossil was found.

lobate - a rounded tooth protuberance, usually refers to a root.

locality map - a map, generally topographic, on which a fossil collecting site is marked.

longitudinal ridges - enameloid ridges oriented along the length of a tooth that may occur on the labial, lingual and occlusal faces of shark and ray teeth.

lumpers - taxonomists who ignore minor differences in the recognition or definition of species and genera.

Maestrichtian - latest time period of the Upper Cretaceous between 74 and 66.5 million years ago.

mandibular - relating to the mandible or jaw.

marginal area - ornamented shelf-like area surrounding the cusp or coronal knob in teeth of *Ptychodus*.

marl - a calcareous clay or mixture of clay and particles of calcite or dolomite and usually fragments of shells.

matrix - the rock or sediment that contains or surrounds a fossil.

matrix specimen - a fossil for display that has been partially cleaned and remains in the rock.

Meckel's cartilage - lower jaw cartilage in elasmobranchs.

medials - a tooth row group of symmetrical teeth situated over the jaw symphysis.

mesial - side of the tooth toward the symphysis of the jaw; opposite of distal. Toward the origin or front.

mesodistal - referencing front to the back of the jaw.

micrometer - a metric unit of length where 1 mm = 1000 micrometers, abbreviated "micron".

millimeter - one thousandth of a meter of length equal to 0.0394 inch.

mineralize - to petrify; replace with minerals.

monognathic heterodonty - tooth variation along the dental series in either the upper or lower jaw.

morphology - study of the form and structure of animals and plants or their fossil remains.

mya - million years ago.

natural tooth set - the complete upper and lower dental series preserved in life position such that there is no question as to their rowgroup order.

neural arch - cartilaginous ring emanating from the dorsal margin of a vertebral centrum.

nomenclature - systematic naming.

nominal species - all named species within a genus regardless of their validity.

notch - a rectangular groove situated between root lobes of a tooth in labial or lingual view, formed by the termination of the nutrient groove.

notochord - primitive backbone.

nutrient groove - shallow to deep, continuous to discontinuous groove containing a central foramen or foramina and separating the mesial and distal root lobes on the basal or lingual root face.

occlusal - tooth orientation term for the crown surface of a tooth, same as apical.

ontogenetic heterodonty - changes in tooth size and shape throughout life.

ontogeny - development of an individual organism from conception through maturity.

oral teeth - teeth found in the mouth as opposed to rostral teeth.

orthodentine - dense apatitic tooth tissue lacking a spongy texture.

orthodont - teeth consisting of orthodentine and lacking a large pulp cavity.

osteodentine - spongy apatitic tooth tissue found in crowns and roots.

osteodont - teeth consisting of osteodentine and having a well formed pulp cavity.

outcrop - a rock exposure.

palatine scales - scales found on the roof of the mouth.

palatoquadrate - cartilages of the right and left side of the upper jaw.

paleobiology - branch of paleontology dealing with the study of fossils as organisms.

paleontology - study of ancient life based on fossils.

pallial dentine - dense tooth tissue consisting of numerous fibrous tubules.

parasymphysials - tooth rowgroup situated mesial to the anteriors.

pathological - a feature caused by disease or injury.

pectoral fins - large paired fins just posterior to the head.

pectoral girdle - skeletal structure supporting the pectoral fins.

pelagic - marine organisms that live free from direct dependence on bottom or shore.

pelvic girdle - skeletal structure supporting the pelvic fins.

placoderms - primitive Paleozoic jawed fishes.

placoid scales - tooth-like scales found only on sharks and rays.

polyaulacorhizous - roots having multiple nutrient grooves, e.g., *Myliobatis*.

polyphyodont - old teeth shed and replaced by new teeth throughout life.

posterior - located rearward.

posteriors - a rowgroup of usually smaller teeth found at the distal end of the dental series.

prehensile teeth - long, narrow, pointed grasping teeth.

prismatic calcified cartilage - small calcified cubes or tesserae that comprise most mineralized cartilage.

pulp cavity - a central open space inside a tooth crown.

ray - a cartilaginous fish belonging to the class Chondrichthyes, having a dorsoventrally flattened body and ventral gill slits.

replacement tooth - a nonfunctional but fully mature tooth that is ready to replace the functional tooth in the same row.

root - that portion of the tooth that in life is anchored to the dental membrane, is composed of osteodentine and lacks an enameloid covered surface.

root lobes - lobate mesial and distal subdivisions of the root of a tooth.

rostral teeth - spine-like teeth that line the lateral border of the rostrum (snout) in sawfishes.

rostrum - an elongate snout in sawfishes that is armed with a row of teeth along its margin.

row - a labiolingual ontogenetic sequence of teeth arising from one tooth germ.

rowgroup - a series of adjacent rows of teeth that are grouped together on the basis of tooth similarity.

rowlocking - teeth interlock labiolingually in the tooth row by articulation of a labial crown protuberance with a lingual depression.

rugose - having a rough or irregular texture, coarsely wrinkled.

sagittal section - longitudinal vertical plane.

sandblaster - a laboratory device that erodes rock by blasting it with a pressurized stream of abrasive powder (sand, dolomite) and air.

sandstone - sedimentary rock composed chiefly of quartz grains cemented with lime, silica or other minerals.

Santonian - a time period of the Upper Cretaceous between 88 and 84 million years ago.

sediment - solid material transported and deposited by wind, water or ice; chemically precipitated from solution or secreted by organisms.

sedimentation - process of depositing sediment.

selachians - cartilaginous fishes; sharks and rays.

SEM - abbreviation for scanning electron microscope.

series - sequence of teeth in a line oriented mesodistally along the jaw edge; opposite of row.

serrations - saw-toothed ornamentation of the cutting ridge of a tooth.

sexual dental heterodonty - differences in tooth size and shape in teeth of the same relative position in males and females of the same age and species.

shagreen - dried shark skin covered with placoid scales and used for sandpaper.

shale - sedimentary rock composed of laminated layers of fine-grained, clay-like sediments.

shark - a fish having a skeleton of cartilage and belonging to the class Chondrichthyes.

sigmoid - having the shape of the letter S.

skate - a ray-like animal without a tail barb.

spatulate - flattened or tabular, like the end of a spatula.

species - no entirely satisfactory definition can be formulated because theoretical and practical species are not necessarily the same. Ideally, the species concept embraces (a) interbreeding, (b) morphologic similarity, (c) physiologic compatibility, (d) ecologic association, (e) geographic distribution, and (f) continuity in time. Practically, a species is the type specimen (holotype) and other individuals considered to be so closely related and similar that they should be referred to by a single species name.

specimen catalog - a file containing all specimen numbers, identifications and other data associated with each fossil.

specimen number - a unique number assigned to each fossil and recorded along with the specimen identification and locality information in a specimen catalog.

splitters - taxonomists who attribute great significance to minor differences in the recognition or definition of species and genera.

spp. - abbreviation indicating that more than one species is present.

statoliths - mineralized particles found within the otic capsules (ears) of sharks and rays.

stratigraphy - study of rock strata.

stomodeal denticles - placoid scales located on the inside of the mouth and on the gill arches of sharks and rays.

subspecies - recognizable subdivision of a species that occupies a more or less definite geographic, ecologic or chronologic range and grades into neighboring subspecies.

subtropical - between the tropical and temperate zones.

symphysials - tooth rowgroup situated immediately adjacent to the mandibular symphysis.

symphysis - front of each jaw where left and right halves meet.

synarcual - fused cervical vertebrae found in rays.

synonymies - chronological record of scientific names that have been applied to some taxonomic category (i.e., family, genus, species, etc).

systematics - study of similarities and differences in organisms and their relations; includes taxonomy and classification.

taphonomy - the post-mortem history of an organism.

taxa (taxon) - a group of organisms constituting one classified category.

taxonomy - the principles and processes of classifying organisms into categories.

temperate seas - seas of the middle latitude zones lying between about 23 and 66 degrees north and south.

Tertiary Period -geologic time period of the first or oldest part of the Cenozoic Era, between 66.5 and 3.0 million years ago.

tesserae - prismatic calcified cartilage.

tooth set - complete upper and lower right or left dental series; may be artificial, associated or natural.

topography - the shape of the surface of the land.

transverse ridge - enameloid ridge or ridges oriented transversely on the crown face.

Turonian - a time period of the Upper Cretaceous between 92 and 89 million years ago.

trace fossil - fossilized tracks, trails, burrows and feces of an organism but not the organism itself.

tropical seas - warm, equatorial ocean.

type locality - the place where a fossil's species was originally recognized and described.

type specimen - the single specimen on which the original description of a species is based.

uncalcified - soft tissue (e.g., cartilage) lacking biological mineralization.

vascular canals - small canals within the tooth dentine that supplies nutrients during life.

ventral - toward the base.

vertebral centrum - calcified core of a vertebra.

wear facet - a flat, polished or angular crown surface modification resulting from natural tooth occlusion or abrasion. A feature typical of sharks and rays having pavement dentitions.

weathering - physical disintegration and/or chemical decomposition of rock.

wet preserved - biological specimens (e.g., shark jaws) stored in a preserving fluid rather than dried.

REFERENCES

Agassiz, L. 1833-1844. Recherches sur les Poissons fossiles: Neuchatel 1420p.

Applegate, S.P. 1965. Tooth terminology and variation in sharks with special reference to the sand shark *Carcharias taurus* Rafinesque: Contr. Sci., Los Angeles County Museum, no.86, 18p.

Applegate, S.P. 1967. A survey of shark hard parts, *in* sharks, skates, and rays (P.W. Gilbert, R.F. Mathewson, D.P. Rall, eds.): The Johns Hopkins Press, Baltimore, Md, p.37-67.

Applegate, S.P. 1970. The vertebrate fauna of the Selma Formation of Alabama. VIII, The fishes: Fieldiana, Geol. Mem., v.3, no.8, p.383-433.

Applegate, S.P. 1972. A revision of the higher taxa of orectolobids: J. Mar. Biol. Assoc. India, v.14, no.2, p.743-751.

Arambourg, C. 1940. Le groupe des Ganopristines: Bull. Soc. Geol. France, v.5, no.10, p.127-147.

Arambourg, C. 1952. Les Vertebres fossiles des Gisements de Phosphates (Maroc-Algerie-Tunisie): Service Geol. Maroc, Notes et Mem., no.92, 372p.

Barck, A. 1992. Paleontology of the Glen Rose Formation (Lower Cretaceous), Hood County, Texas. Texas Jour. Sci., v.44, no.1, p.3-24.

Berg, L.S. 1940. Classification of fishes, both recent and fossil: Tran. Inst. Zool. Acad. Sci. USSR, v.5, no.2, p.85-517.

Berg, L.S. 1958. System der Rezenten und fossilen Fischartigen und Fische: Hochschulbucher fur Biologie, Berlin, v.4, 310p.

Bigelow, H.B. and **Schroeder, W. C.** 1948. Fishes of the Western North Atlantic: Part I, Mem. Sears Found. Marine Res., v.1, 576p.

Bigelow, H.B. and **Schroeder, W.C.** 1957. A study of the sharks of the suborder Squaloidea: Bull. Mus. Comp. Zool., Harvard, v.117, no.1, 150p.

Bilelo, A.M. 1969. The fossil shark genus *Squalicorax* in North-Central Texas: Texas Jour. Sci., v.20, p.339-348.

Blainville, H.M. Ducroty DE 1816. Prodrome d'une nouvelle distribution systematique du regne animal: Bull. Sci. Soc. Philom., Paris, p.105-124.

Bonaparte, C.L. 1832-1841. Iconografia della fauna Italica: v.3, Pesci (not numbered).

Bonnaterre, J.P. 1788. Ichthyologie *in* Tableau Encyclopedique et Methodique des Trois Regnes de la Nature: Paris, 215p.

Brough, J. 1935. On the structure and relationships of the hybodont sharks: Mem. Manchester Lit. Phil. Soc., v.79, p.35-50.

Cappetta, H. 1972. Les poissons cretaces et tertiaires du Bassin des Iullemmeden (Republique du Niger): Palaeovertebrata, v.5, no.5, p.81-251.

Cappetta, H. 1973. Selachians from the Carlile Shale (Turonian) of South Dakota: J. Paleont., v.47, no.3, p.504-514.

Cappetta, H. 1974. Sclerorhynchidae nov. fam., Pristidae et Pristiophoridae: un exemple de parallelisme chez les selaciens: C.R. Acad. Sci., no.278D, p.225-228.

Cappetta, H. 1975a. *Ptychotrygon vermiculata* n. sp., selacien nouveau du Campanien du New Jersey: C.R. somm. Soc. geol. France, v.17, no.5, p.164-166.

Cappetta, H. 1975b. Selaciens et Holocephale du Gargasien de la region de Gargas (Vaucluse): Geol. Medit., v.2, no.3, p.115-134.

Cappetta, H. 1976. Selaciens nouveaux du London Clay de l'Essex (Ypresien du Bassin de Londres): Geobios, v.9, no.5, p.551-574.

Cappetta, H. 1977. Selaciens nouveaux de l'Albien superieur de Wissant (Pas-de-Calais): Geobios, v.10, no.6, p.967-973.

Cappetta, H. 1980. Modification du statut generique de quelques especes de selaciens cretaces et tertiaires: Palaeovertebrata, v.10, no.1, p.29-42.

Cappetta, H. 1987. Chondrichthyes II. Mesozoic and Cenozoic Elasmobranchii, *in* Schults, H.P., Kuhn, O.(eds.), Handbook of Paleoichthyology: v.3B, 193p., (Fischer), Stuttgart, New York.

Cappetta, H. and **Case, G.R.** 1975a. Contribution a l'etude des selaciens du groupe Monmouth (Campanien- Maestrichtien) du New Jersey: Palaeontographica, ser.A, v.151, no.1-3, 46p.

Cappetta, H. and **Case, G.R.** 1975b. Selaciens nouveaux du Cretace du Texas: Geobios, v.8, no.4, p.303-307.

Case, G.R. 1978. A new Selachian fauna from the Judith River Formation (Campanian) of Montana: Palaeontographica, ser.A, v.160, p.176-205.

Case, G.R. 1987. A new selachian fauna from the late Campanian of Wyoming (Teapot Sandstone Member, Mesaverde Formation, Big Horn Basin): Palaeontographica, ser.A, v.197, 37p.

Casier, E. 1943. Quelques especes nouvelles ou peu connues de Landenien marin de la Belgique: Bull. Mus. Roy. Hist. Natur. Belg., v.19, no.35, 16p.; v.20, no.11, 6p.

Casier, E. 1947a. Constitution et evolution de la racine dentaire des Euselachii. I. Note preliminaire: Bull Mus. Roy. Hist. Natur. Belg., v.23, no.13, 15p.

Casier, E. 1947b. Constitution et evolution de la racine dentaire des Euselachii. II. Etude comparative des types: Bull. Mus. Roy Hist. Natur. Belg., v.23, no.14, 32p.

Casier, E. 1947c. Constitution et evolution de la racine dentaire des Euselachii. III. Evolution des principaux caracteres morphologiques et conclusions: Bull. Mus. Roy. Hist. Natur. Belg., v.23, no.15, 45p.

Compagno, L.J.V. 1970. Systematics of the genus *Hemitriakis* (Selachii-Carcharhinidae) and related genera: Proc. Calif. Acad. Sci., v.33, no.4, p.63-98.

Compagno, L.J.V. 1973. Interrelationships of the living elasmobranchs, *in* Interrelationships of fishes, P.H. Greenwood, R.S. Miles, and C. Patterson (eds.): J. Linn. Soc. (Zool.), v.53, no.4, p.63-98.

Compagno, L.J.V. 1982. Galeomorph sharks *in* Synopsis and classification of living organisms, Parker, S. (ed.): New York, McGraw-Hill, 2 vols., 1232p.

Cope, E.D. 1875. The vertebrates of the Cretaceous formations of the west: Rept. U. S. Geol.Survey Territories, v.2, 303p.

Dalinkevicius, J.A. 1935. On the fossil fishes of the Lithuanian Chalk. I. Selachii: Mem. Fac. Sci. Univ. Vytautas le Grand, v.9, p.245-305.

Dames, W. 1881. Ueber Fischzahne aus der obsersenonen Tuffkreide von Mastricht fur welcheer den Gattungsnamen *Rhombodus* varschlug: Sitz. gesellsch. Natur. Freunde zu Berlin, no.1, 3p.

Dames, W. 1887. Uber *Titanichthys pharao*, nov. gen., nov. sp., aus der Kreideformation Aegypten: Sitz. gesellsch. Natur. Freunde zu Berlin, no.5, p.69-72.

Daniel, J. 1934. The elasmobranch fishes: University of California Press, Berkeley, 322p..

Dartevelle, E. and **Casier, E.** 1943. Les Poissons fossiles du Bas-Congo et des regions voisines: Ann. Mus. Congo Belge, ser. A (miner. geol. paleont.), 1943, ser.3, v.2, no.1, 200p.

Dartevelle, E. and **Casier, E.** 1949. Les Poissons fossiles du Bas-Congo et des regions voisines: Ann. Mus. Congo Belge, ser. A (miner. geol. paleont.), ser.3, v. no.2, p.205-255.

Dibly, G.E. 1911. On the teeth of *Ptychodus* in the English Chalk: Quart. Jour. Geol. Soc. London, v.67, p.263-277.

Dixon, F. 1850. The geology and fossils of the Tertiary and Cretaceous formations of Sussex: London, 422pp.

Duffin, C.J. 1982. Revision of the hybodont selachian genus *Lissodus* Brough (1935): Palaeontographica, ser.A, v.188, p.105-152.

Dumeril, A.M.C. 1806. Zoologie analytique ou methode naturelle de classification animaux: Allais, Paris, 344pp.

Dunkle, D.H. 1948. On two previously unreported selachians from the Upper Cretaceous of North America: Jour. Washington Acad. Sci., v.38, no.5, p.173-176.

Estes, R.E. 1964. Fossil vertebrates from the Late Cretaceous Lance Formation, Eastern Wyoming: Univ. Calif. Publ. Geol. Sci., no.49, 180p.

Fowler, H. 1934. Descriptions of new fishes obtained 1907-1910, chiefly in the Phillipine Islands and adjacent seas: Proc. Acad. Nat. Sci., Philadelphia, v.85, p.233-367.

Garman, S. 1913. The Plagiostomia (sharks, skates and rays): Mem. Mus. Comp. Zool., Harvard College, Cambridge, Mass., v.32, 528p.

Gervais, P. 1852. Zoologie et Paleontologic francaises: Paris, 271p.

Gill, T. 1862. Analytical synopsis of the order of *Squali* and revision of the nomenclature of genera: Annals Lye. Nat. Hist. of New York, p.367-408.

Gluckman, L.S. 1958. Rates of evolution in lamnoid sharks. Doklady Akad. Nauk. U.S.S.R., v.123, no.3, p.568-672.

Gluckman, L.S. 1964. Palaeogene sharks and their stratigraphic importance (in Russian): Moscow, Acad. of Sciences of the U.S.S.R., 228p.

Gluckman, L.S. 1980. Evolution of Cretaceous and Cenozoic Lamnoid sharks: Acad. Nauk USSR; Moscow, 247p.

Gluckman, L.S. and **Shvazhaite, R.A.** 1971. Sharks of the family Anacoracidae from the Cenomanian and Turonian of Lithuania, Volga Region and Middle Asia: Palaeont. Stratigr. Pribalt. Belorus., v.3, p.185-192.

Goodrich, E.S. 1909. Cyclostomes and fishes *in* Lankaster, E., Treatise on Zoology, part 9.

Gray, J.E. 1851. List of the specimens of fish in the collection of the British Museum, Part 1: Brit. Mus. (N.H.), 160p.

Gurr, P.R. 1962. A new fish fauna from the Woolwich Bottom Bed (Sparnacian) of Herne Bay, Kent: Proc. Geol. Assoc., v.73, part 4, p.419-447.

Herman, J. 1973. Les Vertebres du Landenien inferieur (Lia ou Heersien) de Maret (Hameau d'Orp-Le- Grand): Bull. Soc. belg. Geol. Paleont. Hydrol., Bruxelles, v.81, p.191-207.

Herman, J. 1975. Zwei neue Haifischzahne aus der Kreide von Misburg bei Hannover (hoheres Campan): Ber. Naturhist. Ges. Hannover, v.119, p.295-302.

Herman, J. 1977. Les selaciens des terrains neocretaces et paleocenes de Belgique et des contrees limitrophes. Elements d'une biostratigraphique inter-continentale: Mem. Expl.Cartes geol. miner. Belgique, Ser. Geol., v.15, 401p.

Herman, J. 1982. Die Selachier-Zahne aus der Maastricht-Stufe von Hemmoor, Niederelbe (NW=Deutschland): Geol. Jb., ser.A, v.61, p.129-159.

Itoigawa, J., et al. 1977. Cretaceous fossil elasmobranchs from Japan. Bull. Mizunami Fossil Museum, v.1, p.243-262.

Jaekel, O. 1894. Die eocanen Selachier vom Monte Bolca: Ein Beitrag zur Morphogenie der Wiebelthiere, Berlin, 176p.

Jaekel, O. 1889. Die Selachier aus dem oberen Muschel kalk Lothringens: Abh. geol. Spezialk. Elasass- Lothringen, ser.3, v.4, p.273-332.

Jordan, D.S. 1888. Manual of the vertebrates, etc. Edition V.

Jordan, D.S. 1898. Description of a species of fish (*Mitsukurina owstoni*) from Japan, the type of a distinct family of lamnoid sharks: Proc. Calif. Acad. Sci., v.3, no.1, p.199-202.

Jordan, D.S. and **Fowler, H.W.** 1903. A review of the elasmobranch fishes of Japan: Proc. U.S. Nat. Mus., v.26, p.593-674.

Landemaine, O. 1991. Selaciens nouveaux du cretace superieur du sud-ouest de la France quelques apports a la systematique des elasmobranches: Soc. Amicale Geol. Amateurs, Mus. nat. hist. nat., Paris, no.1, 45p.

Ledoux, J.C. 1970. Les dents des Squalides de la Mediterranee occidentale et de l'Atlantique nord-ouest africain: Vie et Milieu, ser.A, v.21, no.2A, p.309-362.

Lehman, T.M. 1989. Giant Cretaceous sawfish (*Onchosaurus*) from Texas: J. Paleont., v.63, n.4, p.533-535.

Leidy, J. 1856. Description of two ichthyodorulites: Proc. Acad. Nat. Sci. Philadelphia, v.8, p.11-12.

Leidy, J. 1868. Notice of American species of *Ptychodus*. Proc. Acad. Nat. Sci. Philadelphia, p.205-208.

Leidy, J. 1873. Contributions to the extinct vertebrate fauna of the Western Territories: Report, USGS of the Territories, v.1, p.14-358.

Leriche, M. 1902. Revision de la faune ichthyologique des terrains cretaces du Nord de la France: Ann. Soc. Geol. Nord., Lille, v.31, p.87-154.

Leriche, M. 1929. Poissons du Cretacemarin de la Belgique et du Limbourg hollandais: Bull. Soc. belge Geol., Paleont. et Hydr., v.37, p.199-299.

Leriche, M. 1938. Contribution a l'etude des poissons fossiles des pays riverains de la Mediterranee Americaine (Venezuela, Trinite, Antilles, Mexique): Mem. Soc. Paleont. Suisse, v.61, 42p.

Leriche, M. 1940. Le synchronisme des formations eocenes marines des cotes d'Atlantique d'apries leur faune ichthyologique. C.R.A.S. Paris, v.210, p.589-592 and 648-649.

Leriche, M. 1942. Contribution a l'etude des faunes ichthyologiques marines des terrains tertiaires de la plaine cotiere atlantique et du centre des Etats-Unis: Mem. Soc. Geol. France, Paris, n. ser.20, v.45, 110p.

Linck, H.F. 1790. Magazin Neuestes aus der Physik und Naturgeschichte, Gotha.

Linnaeus, K. 1758. Systema Naturae: 10th ed., v.1, 824p.

Macleod, N. and **Slaughter, B.H.** 1980. A new ptychodontid shark from the Upper Cretaceous of Northeast Texas. Texas J. Sci., v.32, no.4, p.333-335.

Macleod, N. 1982. The first North American occurrence of the late Cretaceous elasmobranch *Ptychodus rugosus* Dixon: Jour. of Paleontology, v.56, no.2, p.403-409.

Maisey, J.G. 1975. The interrelationships of phalacanthous selachians: N. Jb. Geol. Palaont. Mh., v.9, p.553-567.

Maisey, J.G. 1982. The anatomy and interrelationships of Mesozoic Hybodont sharks: Amer. Mus. Novitates, no.2727, 48p.

Mantell, G. 1839. The wonders of geology. 3rd ed., New Haven and London, 2 vols., 821p.

Marcou, J. 1858. Geology of North America with two reports on prairies of Arkansas and Texas, the Rocky Mountains of New Mexico, and the Sierra Nevada of California: Zurich, Chapter 3, Paleontology, p.33.

McNulty, C.L. 1964. Hypolophid teeth from the Woodbine formation of Texas: Ecolog. Geol. Helv., v.57, no.2, p.537-540.

McNulty, C.L. and **Slaughter, B.H.** 1962. A new sawfish from the Woodbine Formation (Cretaceous) of Texas: Copeia, v.4,p.775-777.

McNulty, C.L. and **Slaughter, B.H.** 1964. Rostral teeth of *Ischyrhiza mira* Leidy from northeast Texas: The Texas Jour. Sci., v.16, no.1, p.107-112.

McNulty, C.L. and **Slaughter, B.H.** 1972. The Cretaceous selachian genus *Ptychotrygon* Jaekel 1894: Eclog. Geol. Helv., v.65, no.3, p.647-656.

Meyer, R.L. 1975. Late Cretaceous elasmobranchs from the Mississippi east Texas embayments of the Gulf Coastal Plain: Unpubl. Ph.D. dissertation, Southern Methodist Univ., Dallas, Texas, 419p.

Muller, A., and **Schollmann, L.** 1989. Neue Selachier (Neoselachii, Squalomorphii) aus dem Campanium Westfalens (NW-Deutschland): N. Jb. Geol. Palaont. Abh., v.178, no.1, p.1-35.

Muller, J. and **Henle, F.G.J.** 1837. On the generic characters of cartilaginous fishes, with descriptions of new genera: Mag. Nat. Hist., II.

Orvig, T. 1951. Histologic studies of placoderms and fossil elasmobranchs: Ark. Zool. ser.2, v.2, p.321-454.

Patterson, C. 1964. A review of Mesozoic acanthopterygian fishes, with special reference to those of the English chalk: Philos. Trans. Roy. Soc. London, B, v.247, p.213-482.

Patterson, C. 1966. British Wealden sharks: Bull. Brit. Mus. (Natural History) Geol., v.11, no.7, p.283-350.

Perkins, B.F. 1960. Biostratigraphic studies in the Comanche (Cretaceous) series of northern Mexico and Texas: Geol. Soc. Amer., Mem. 83, 131p.

Priem, F. 1897. Sur des dents d'elasmobranches de divers gisements senoniens (Villedieu, Meudon, Folx-Les- Caves): Bull. Soc. geol. France, ser.3, v.25, p.40-56.

Radinsky, L. 1961. Tooth histology as a taxonomic criterion for cartilaginous fishes: J. Morphology, v.109, p.73-92.

Rafinesque, C.S. 1810. Caratteri di alcuni nuovi generi e nuove specie di animale e piante della Sicilia: Palermo, 105p.

Reif, W.E. 1976. Morphogenesis, pattern formation and function of the dentition of *Heterodontus* (Selachii): Zoomorphologie, v.83, 47p.

Reuss, A.E. 1844. Geonostische skizzen aus Bohmen: Prague, 304p.

Reuss, A.E. 1845. Die Versteinerungen der bohmischen Kreideformation: Erste Abtheilung, Stuttgart, 58p..

Reuss, A.E. 1846. Die Versteinerungen der bohmischen Kreideformation: Zweite Abtheilung, Stuttgart, 148p..

Ridewood, W.G. 1921. On the calcification of the vertebral centra in sharks and rays: Philosophical Trans. Roy. Soc. London, ser.B, no.210, p.311-407.

Roemer, F. 1849. Texas mit besonderer Berucksichtegung auf deutsche Auswandersund und die physichen verhaltnisse des Landes nach ligener Beobachtung geschildert: Bonn, 502p.

Romer, A.S. 1942. Notes on certain American Paleozoic fishes: Amer. Jour. Sci., v.240, no.3, p.216-228.

Serra, G. 1933. Di una nuova specie di *Schizorhiza* del Maestrichtiano della Tripolitania: Riv. Ital. Paleont., v.2, no.2,3, p.103-107.

Slaughter, B.H. and **Steiner, M.** 1968. Notes on rostral teeth of ganopristine sawfishes, with special reference to Texas material: J. Paleontology, v.42, no.1, p.233-239.

Smith, H.M. and **Radcliffe, L.** 1912. The squaloid sharks of the Philippine Archipelago: Proc. U. S. Nat. Mus., v.41, p.677-685.

Sokolov, M.I. 1965. Teeth evolution of some genera of Cretaceous sharks and a reconstruction of their dentition (in Russian): Biull. Mosk. Obshch. Dispyt. Prirody. Otd. Geol., v.40, no.4, p.133-134.

Sokolov, M.I. 1978. Requins comme fossiles - guides pour la zonation et la subdivision der couches Cretaces de Tourousk: Niedra, Moscou, v.61, 60p.

Springer, V.G. and **Garrick, J.A.F.** 1964. A survey of vertebral number in sharks: Proc. U.S. Nat. Mus., v.116, no.3496, p.73-96.

Stose, G.W. 1946. Compiler, 1946, Geologic Map of North America: Geol. Soc. America.

Stewart, J. D. 1978. Enterospirae (fossil intestines) from the upper Cretaceous Niobrara Formation of western Kansas: The University of Kansas Paleontological Contributions, Paper 89, p.9-16.

Stromer, E. 1917. Edrgebnisse der Forschungsreisen Prof. E. Stromers in den Wusten Agyptens.II. Wirbeitier-Peste der Baharije - Stufe (unterstes Cenoman). 4. Die Sage des Pristiden *Onchopristis numidus* Haug sp. und uber die Sagen der Sagehare: Abh. Kngl. bayer. Wiss, math-phys. kl, v.28, no.8a, 28p.

Thurmond, J.T. 1971. Cartilaginous fishes of the Trinity Group and related rocks (Lower Cretaceous) of North Central Texas: Southeast Geol., v.13, no.4, p.207-227.

Thurmond, J.T. 1974. Lower vertebrate faunas of the Trinity Division in North Central Texas *in* Aspects of Trinity Division Geology, B.F. Perkins (ed.): Geoscience and Man, v. III, Louisiana State University, p.103-129.

Weiler, W. 1930. Fischreste aus dem nubischen Sandstein von Mohamid und Edfu und aus den Phosphaten oberagyptens und der oase Baharije: Abh. Bayer. Akad. Wiss., Math.-naturnkk. Abt. N. F., v.7, p.12-36.

Werner, C. 1990. Die Elasmobranchier-Fauna des Gebel Dist Member der Bahariya Formation (obercenoman) der oase Bahariga, Agypten: Palaeo Ichthyologica, no.5, 112p.

White, E.G. 1937. Interrelationships of the Elasmobranchs with a key to the order Galea: Bull. Amer. Mus. Natur. Hist., v.74, no.2, p.25-138.

Whitley, G.P. 1939. Taxonomic notes on sharks and rays: Aust. Zool., v.9, no.3, p.227-262.

Williams, G.D. and **Stelck, C.R.** 1975. Speculations on the Cretaceous palaeogeography of North America *in* The Cretaceous system in the western interior of North America, Caldwell, W.G.E. (ed.): Geol. Assoc. Can. Spec. Pub.1, p.1-20.

Williston, S.W. 1900. Cretaceous Fishes, Selachians and Ptychodonts: Univ. Geol. Surv. Kansas, v.6, no.2, p.237-256.

Woodward, A.S. 1886. On the paleontology of the selachian genus *Notidanus* Cuvier: Geol. Mag. London, n. ser.3, v.3, p.205-217.

Woodward, A.S. 1889. Catalogue of the fossil fishes in the British Museum: (Brit. Mus. Nat. Hist.), London, Part I, 474p.

Woodward, A.S. 1892. Description of the Cretaceous sawfish *Sclerorhynchus atavus*: Geol. Mag., Decade 3, v.9, no.342, p.529-534.

Woodward, A.S. 1904. On the jaws of *Ptychodus* from the Chalk: Quart. J. Geol. Soc., v.9, p.133-135.

Woodward, A.S. 1911. The fishes of the English Chalk. Part 6: Palaeontographical Soc., London, p.185-224.

Woodward, A.S. 1912. The fishes of the English Chalk. Part 7: Palaeontographical Soc., London, p.225-264.

Woodward, A.S. 1916. The fossil fishes of the English Wealden and Purbeck formations: Palaeontogr. Soc., p.1-48.

Woodward, A.S. 1932. *In* Zittel, Textbook of Paleontology: 2nd english ed., London, v.2, 464p.

Appendix

CHECKLIST OF TEXAS CRETACEOUS SHARKS AND RAYS

The checklist given in Figure 54 is an easy-to-photocopy alphabetical listing of all Texas Cretaceous shark and ray families, subfamilies, genera and species described in this book. The Cretaceous stageages relevant to Texas are given at the top of each column. Opposite the taxon are open boxes provided for your notes and annotations.

Many collectors will keep a current checklist for each of their localities, updating it after every field trip as new specimens are added. These checklists are easily kept in a notebook or file and space is provided at the top of the form to record your locality number, locality name and geological information.

A master checklist that summarizes every species in your collection by age, is a valuable tool for several reasons. First, it immediately shows just how complete, or incomplete, your collection is and where additional sampling needs to be done. Second, the chronologic ranges you record for each species, based on your own collecting and identification efforts, can be compared with those given in this book. A lack of correspondence between ranges might result from an incorrect species identification or uncertainty in the age or geologic position of your collecting locality. On the other hand, you may have discovered a new range extension for the species or perhaps a taxon new to the Texas Cretaceous.

If you are having difficulty identifying a tooth with the illustrations and descriptions given in this book, and if the closest species identification you can make does not fit with the range data cited herein, then the possibility exists that your specimen is either a taxon not previously reported from Texas but described elsewhere, or it is new to science.

CHRONOLOGIC RANGE CHARTS OF TEXAS CRETACEOUS SHARKS AND RAYS

The chronologic ranges for all Texas Cretaceous subfamilies, genera and species are illustrated in Figure 55. Sharks and rays are grouped separately and listed by their first (geologically oldest) appearance and in order of their chronologic range. For example, all sharks that first appear in the Cenomanian are grouped together. Within this assemblage, the taxa that occur no younger than the Cenomanian are listed first, followed in order by species with progressively younger ranges. If two or more species have identical ranges they are listed in alphabetical order by genus first, then species.

An obvious Santonian "gap" exists in almost all ranges that extend across this time interval. In Texas, the sediments deposited during Santonian time are found within relatively unfossiliferous, or at least poorly collected, sections of the Austin Chalk. In all likelihood, species present in the Coniacian and Campanian were also present in Texas during the Santonian and this interpretation is illustrated by light gray shading. Dark shading across the Santonian indicates fossil evidence for the range.

Figure 56 illustrates the chronologic range for every shark and ray family in the Texas Cretaceous. The total family range is based on the sum of all its contained species as given in Figure 55, plus additional unpublished information mentioned under **comments** in the species identification section of this book.

The Santonian "gap" is also apparent on this chart and missing intervals have been shaded light or dark gray for the same reasons.

Sharks	Aptian	Albian	Cenomanian	Turonian	Coniacian	Santonian	Campanian	Maestrichtian
Cantioscyllium decipiens								
Carcharias amonensis								
Carcharias tenuiplicatus								
Carcharias sp. A								
Carcharias sp. B								
Chiloscyllium greeni								
Cretodus crassidens								
Cretodus semiplicatus								
Cretoxyrhina mantelli								
Cretolamna appendiculata								
Cretolamna woodwardi								
Cretorectolobus sp.								
Etmopterinae								
Galeorhinus sp.								
Ginglymostoma lehneri								
Heterodontus cf. canaliculatus								
Hexanchus microdon								
Hybodus butleri								
Hybodus sp.								
Leptostyrax macrorhiza								
Lissodus anitae								
Lissodus selachos								
Lissodus spp.								
Microcorax crassus								
Palaeogaleus sp.								
Paraisurus compressus								
Paranomotodon sp.								
Pararhincodon groessenssi								
Polyacrodus cf. brevicostatus								
Polyacrodus illingsworthi								
Polyacrodus aff. parvidens								
Protolamna aff. sokolovi								
Pseudocorax granti								
Ptychodus anonymus								
Ptychodus connellyi								
Ptychodus decurrens								
Ptychodus latissimus								
Ptychodus mammillaris								

Figure 54. Checklist of Texas Cretaceous sharks and rays.

Sharks	Aptian	Albian	Cenomanian	Turonian	Coniacian	Santonian	Campanian	Maestrichtian
Ptychodus mortoni								
Ptychodus occidentalis								
Ptychodus polygyrus								
Ptychodus rugosus								
Ptychdous whipplei								
Ptychodus sp.								
?Rhincodontidae								
Scapanorhynchus raphiodon								
Scapanorhynchus texanus								
Scylliorhinidae								
Serratolamna serrata								
Somniosinae								
Squalicorax curvatus								
Squalicorax falcatus								
Squalaicorax kaupi								
Squalicorax pristodontus								
Squalicorax sp.								
Squalus sp.								
Squatina hassei								
Rays								
Brachyrhizodus wichitaensis								
?Dasyatidae								
Dasyatis sp.								
Ischyrhiza avonicola								
Ischyrhiza mira								
Ischyrhiza texana								
Myliobatidae								
Onchopristis dunklei								
Onchosaurus pharao								
Protoplatyrhina renae								
Pseudohypolophus mcnultyi								
Ptychotrygon agujaensis								
Ptychotrygon hooveri								
Ptychotrygon slaughteri								
Ptychotrygon texana								
Ptychotrygon triangularis								

Figure 54. Checklist of Texas Cretaceous sharks and rays.

Rays	Aptian	Albian	Cenomanian	Turonian	Coniacian	Santonian	Campanian	Maestrichtian
Rajidae								
Rhinobatos casieri								
Rhinobatos incertus								
Rhombodus binkhorsti								
Schizorhiza cf. weileri								
Sclerorhynchus sp.								
Squatirhina sp.								

Figure 54. Checklist of Texas Cretaceous sharks and rays.

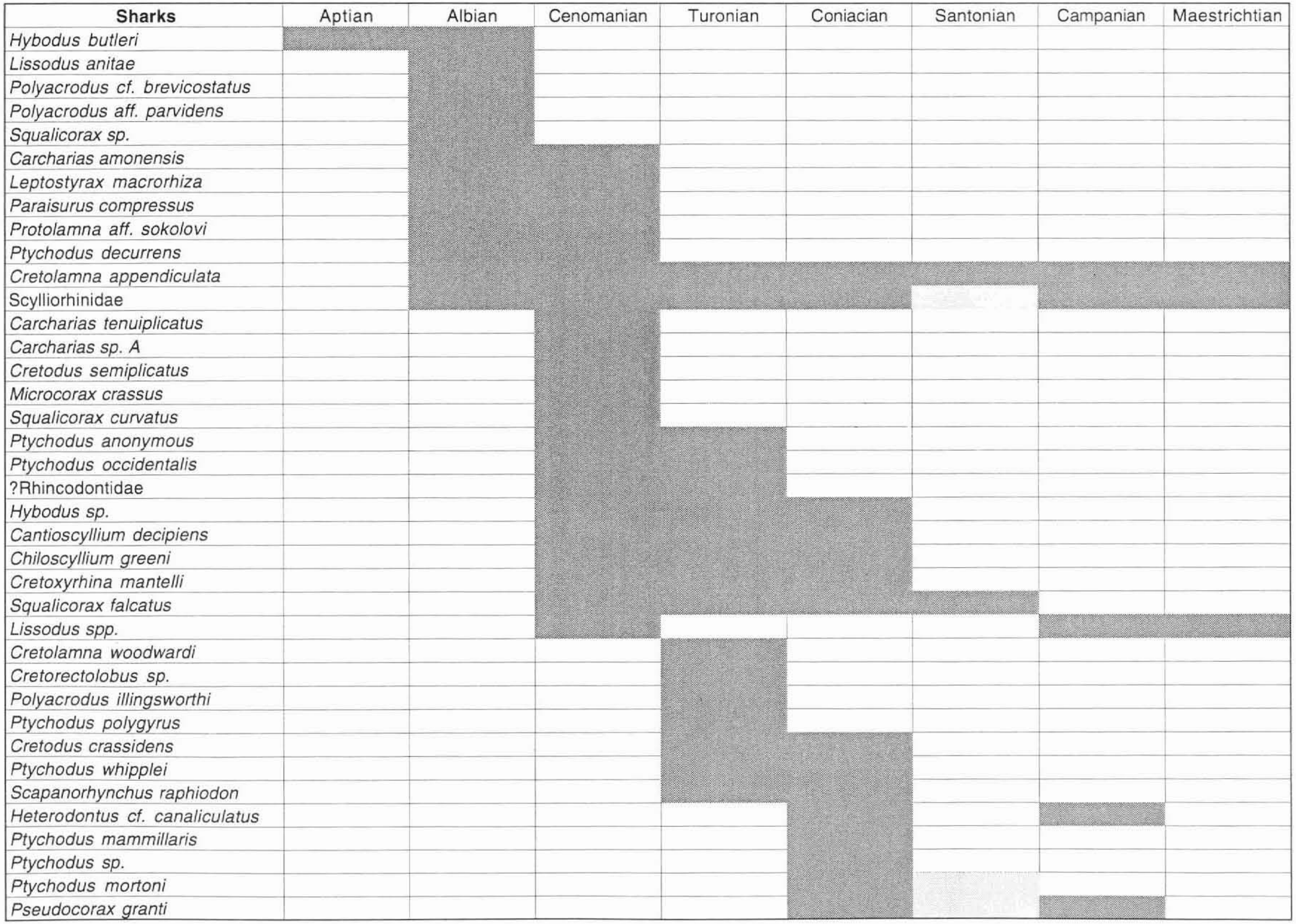


Figure 55. Chronologic range chart of the species, genera and subfamilies of Texas Cretaceous sharks and rays.

Figure 55. Chronologic range chart of the species, genera and subfamilies of Texas Cretaceous sharks and rays.

Rays	Aptian	Albian	Cenomanian	Turonian	Coniacian	Santonian	Campanian	Maestrichtian
Protoplatyrhina renae								
Ptychotrygon texana								
Rajidae								
Rhombodus binkhorsti								
Schizorhiza cf. weileri								

Figure 55. Chronologic range chart of the species, genera and subfamilies of Texas Cretaceous sharks and rays.

Figure 56. Chronologic range chart of the families of Texas Cretaceous sharks and rays.

Index of Families, Genera and Species

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P, Q

The Collector's Guide to

Fossil Sharks and Rays

From the Cretaceous of Texas

Throughout most of the Cretaceous Period (66.5 to 131 million years ago), a great seaway extended across Texas and divided North America into two widely separated land masses. Dinosaurs roamed the shores of this inland sea while its tropical waters supported many different kinds and sizes of now extinct sharks and rays. Today, teeth and other fossilized remains of these predators are abundant, easy to find, and readily identified through the use of this book.

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