THE GEOLOGICAL SURVEY OF WYOMING
Gary B. Glass, State Geologist

BULLETIN 63

PALEONTOLOGY OF THE GREEN RIVER FORMATION, WITH A REVIEW OF THE FISH FAUNA

SECOND EDITION

by
Lance Grande

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Field Museum of Natural History
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Laramie, Wyoming

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Front Cover: *Mioplosus labracoides* with a *Knightia eocaena* in its mouth and throat (FMNHPF10180). From late Early Eocene Fossil Lake sediments of the Green River Formation. Total length of the *Mioplosus* is about 18 cm (7 inches).

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PREFACE TO THE SECOND PRINTING

This second printing of PALEONTOLOGY OF THE GREEN RIVER FORMATION WITH A REVIEW OF THE FISH FAUNA contains few changes from the first printing. Permanent museum catalog numbers for some of the specimens illustrated replace most of the "LG" numbers of the first printing. I have updated taxonomic information on *Diplomystus* and *Knightia.* Taxonomic names for two recently described fish species and two decapod species, published since the first printing, have been added. A few new references have been added to the bibliography, and some — I hope most — of the typographical errors found in the first printing have been corrected. Last (and to many, not least), this second printing comes in a sturdier binding, to counteract what Andrew Miller in his very kind review of the first printing recorded as a tendency toward "a certain degree of disassembly" with regular use.

L.G.
January, 1984

INTRODUCTION

The Green River Formation represents one of the largest documented accumulations of lacustrine sedimentary rock in the world. It extends over an area of more than 65,000 square kilometers (25,000 sq. miles) and averages about 600 meters (2000 feet) in thickness (Bradley, 1929). It covers portions of three states (Wyoming, Colorado and Utah), but most of the paleontological work in the Green River Formation has been done in Wyoming. Not only is the formation widespread, but at many localities there is an intricate record of both flora and fauna of the locality at the time of deposition. Several complex Eocene lake communities, containing organisms from the size of microscopic algae to 5 meter (16 foot) crocodiles, have been frozen in time for 40 to 50 million years to be reconstructed by paleoecologists today.

The "Green River Formation" is presented here not as a homogeneous system, but rather as strata deposited in a complex system of lakes ecologically different from each other and containing ecological differences within themselves. There are some publications concerning Green River community paleocology which consider the Green River Formation as a single community, or combine both Wyoming Eocene lakes (Fossil and Gosiute) as a single community, ignoring differences in both paleoecology and time. It is hoped that this paper will make it apparent that the Green River Formation is a complex collective system including many different lacustrine environments, changing both geographically and chronologically.

Part I discusses the geologic history of the Green River Lake System and gives code numbers to some of the most heavily collected localities in the Green River Formation. These code numbers are referred to throughout this monograph. Part II is a review of the Green River fish fauna, with many figures and simplified tables listing diagnostic features to aid in specific separation. It also includes several tables indicating relative abundances of genera from several localities and comparing the Green River lake faunas with the Middle Eocene lake faunas in Washington State and British Columbia. Parts III-V are basically reference guides to Green River fossils other than fish with tables designed to give specific or familial references and photographic atlases. Appendices I and II include information on preparation and excavation of Green River fossils, Appendix III explains the repository abbreviations used in this paper, and Appendix IV is a glossary. The bibliography is divided into two parts: a "Bibliography of Green River Paleontology," which includes nearly all of the known publications about the paleontology of the Green River Formation, and "Additional References," which includes references cited in this paper not about Green River paleontology.

This monograph analyses the paleontology of the Green River Lake system in a broad community sense with emphasis on the fish community. It is to be hoped that other communities in the Early Tertiary can be examined in a similar way, so that the evolution of North American lacustrine communities can be better understood.

ACKNOWLEDGEMENTS

Several individuals have read and made useful comments on all or parts of this manuscript. I especially wish to thank Ms. Jodi Milske, Ms. Catherine Grande, Dr. Robert E. Sloan, Dr. James C. Underhill, and Mr. Guido Dingerkus for reading the entire manuscript; and Drs. Camm Swift, Donn E. Rosen, and Joseph T. Eastman for reading all of Part II. Discussions with Dr. Gareth Nelson were quite beneficial.

Part I was also read by Drs. Paul Buchheim, Thomas C. Johnson, and Paul McGrew. Dr. Colin Patterson read part of Part II and made helpful suggestions. Part III was read by Drs. Storrs L. Olson and Paul McGrew. In Part IV, the mollusk section was read by Dr. John H. Hanley, the insect section by Dr. William E. Miller, and the decapod section by Dr. Rodney M. Feldman. Discussions with Dr. H.D. MacGinitie were helpful in constructing the plant section of Part V.

Museum curators and technicians who aided the author while examining museum collections include Dr. John R. Bolt, Field Museum of Natural History; Fred Grady and Dr. Robert Purdy, U.S. National Museum of Natural History; Mr. Walter Sorensen and Dr. Bobb Schaeffer, American Museum of Natural History; Bruce R. Erickson, Science Museum of Minnesota; Jeff Eaton, Geology Museum, University of Wyoming; William Reiter, park technician and James V. Court, Superintendent, Fossil Butte National Monument. Dr. John Ostrom, Yale Peabody Museum and Dr. Donald Baird, Princeton University, generously loaned additional specimens to the author for study. Dr. Paul McGrew also generously lent the author well over a hundred x-rays of fish from F-1.

I thank commercial quarry operators James E. and Carolyn Tynsky, Carl and Shirley Ulrich, and Richard W. Jackson for allowing me to work and/or record specimens in their quarries.

I thank Rudolph E. Schummer, Walter O. Zambino, and Peter Ganzel for assistance with some of the photographic work; Wendy J. Gaskill typed the first draft of the manuscript. I thank Mr. Eugene E. Burnham for taking x-rays of several fish specimens, including the one illustrated in figure AI.4.

I also thank my editor, David A. Copeland, for his help in the final production of this publication.

Part I
GEOLOGIC HISTORY

THE GREEN RIVER LAKE SYSTEM

The Green River system of Eocene lakes lay in a series of intermontane basins formed by geologic events that uplifted the Rocky Mountains during early Tertiary time. These basins filled from the drainage of nearby tectonic highlands and eventually contained freshwater lakes supportive of a varied and abundant fauna. Large amounts of ash found in the lacustrine sediments indicate that volcanoes were particularly active periodically throughout the history of this lake system.

The Eocene climate of the Green River lake system was much different from the desert-like climate of that area today. Both the fauna (crocodiles, alligators, boa constrictors, and a few fish families whose extant members are subtropical) and the flora (such as large palm trees and balloon vines; see MacGinitie, 1969, page 40) indicate warm temperate to subtropical conditions. Bradley (1929; 1948), MacGinitie (1969) and others (Roland Brown, E.W. Berry, and F.H. Knowlton, in various papers) have concluded that the climate of most of the area was similar to the present climate of the Gulf Coast and southern Atlantic regions of the United States: subtropical with an annual rainfall of 75 to 100 cm (30 to 40 inches; Bradley, 1929; 1948) and with essentially frostless winters. The average annual minimum temperature was over 2°C (36°F) (MacGinitie, 1964), and the overall average annual temperature was 15 to 21°C (60-70°F).

The Green River system was composed of three lakes: Lake Uinta, Lake Gosiute and Fossil Lake (see figure I.1). Lake Uinta was the first of the Green River lakes to form, and its Paleocene phase has been referred to as Lake Flagstaff by Schaeffer and Mangus (1965), McGrew and Casilliano (1975), and others. Lake Uinta gradually dried up in the south during Late Paleocene time, but expanded eastward into what is now the Uinta Basin while two other lakes were forming in what is now Wyoming.

Lake Gosiute occupied the Green River and Washakie basins; shortly after, Fossil Lake formed in Fossil Basin, a long, narrow, north-south trending synclinal trough in southwestern Wyoming just west of Kemmerer. It is not known definitely that the lakes were connected, but McGrew and Casilliano (1975, page 32) suggest that Lake Gosiute could have been connected by a narrow channel to the southern end of Fossil Lake for a brief period, or periods.

Time ranges for these lakes differ. The short-lived Fossil Lake appears to have existed only in Early Eocene time, whereas Lake Gosiute persisted from Early Eocene to Middle Eocene, and Lake Uinta from Late Paleocene to late Middle Eocene. The time ranges, geographic extents, and locations of these lakes are shown in figures I.1 and I.2.

Besides occupying different time ranges, the three Green River lakes differ

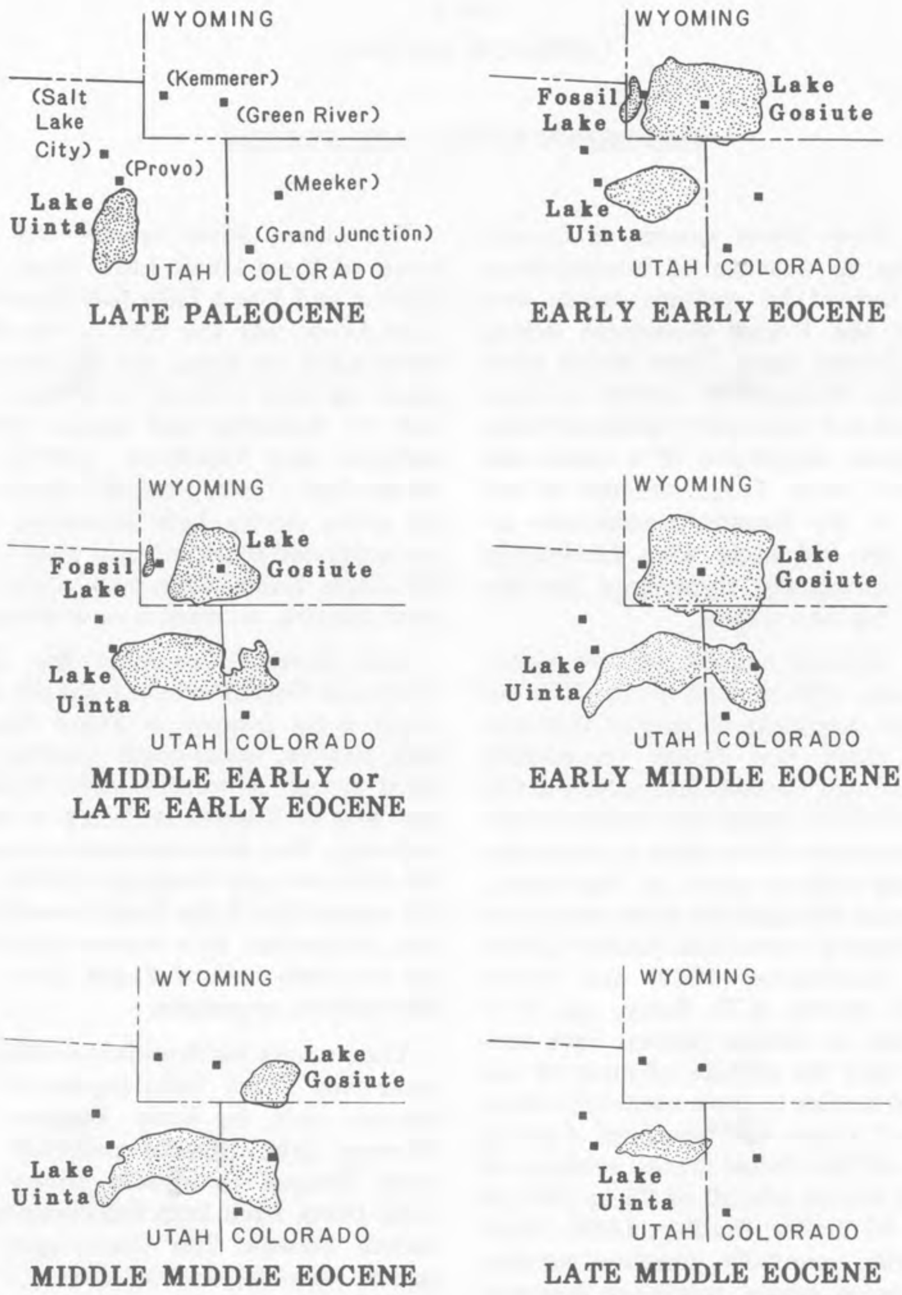


Figure I.1. Approximate locations and areas of the three Green River lakes at six different intervals of time during their history (mostly from McGrew and Casilliano, 1975 and Paul Buchheim, personal communication).

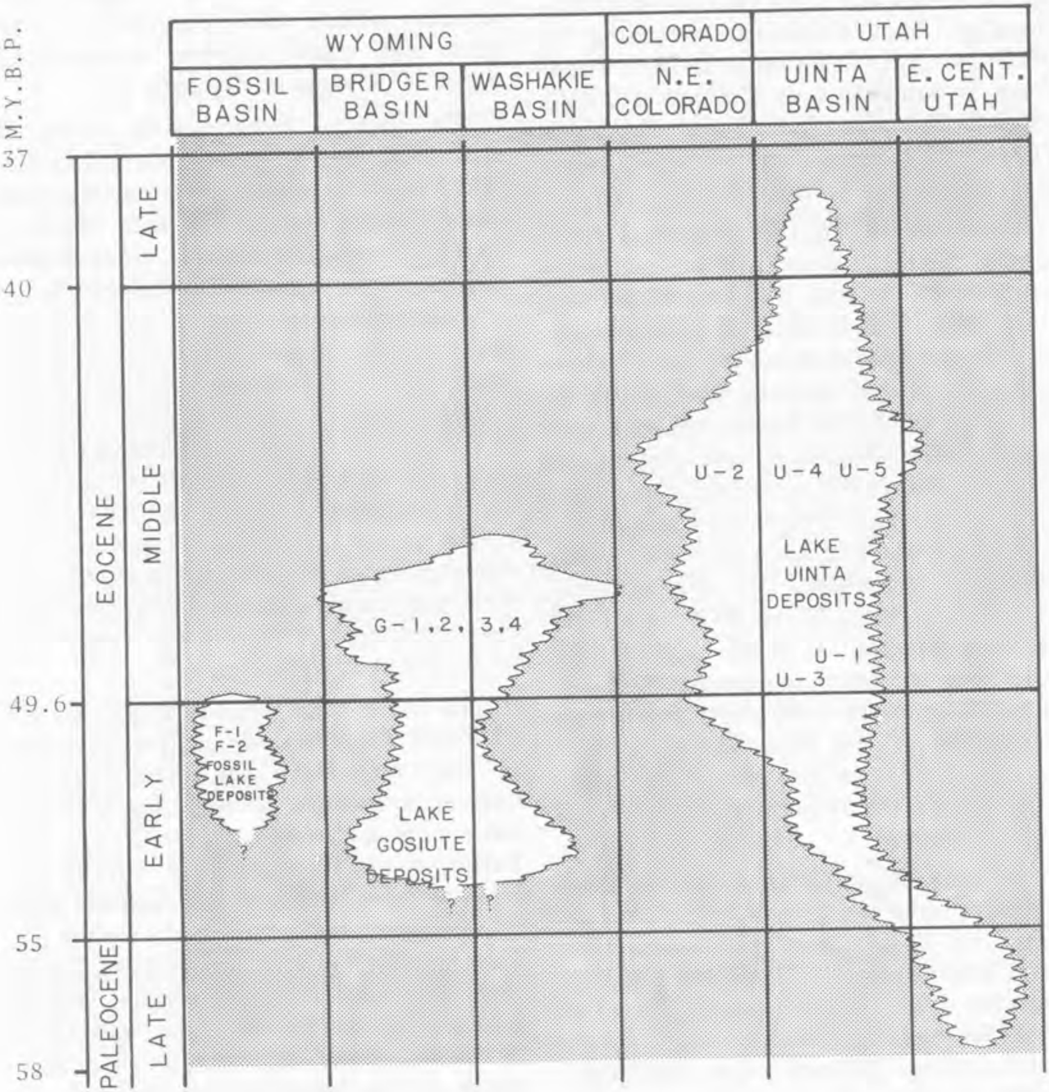


Figure I.2. Geographic distribution and length of existence of the Green River lakes (unshaded areas). (After Schaeffer and Mangus, 1965.) The coded localities (F, U, and G) used in this paper are plotted to show their geologic time relationships. M.Y.B.P. is approximate million years before present (dates from Mauger, 1977).

in geologic structure and sedimentology.

FOSSIL LAKE

The history of Fossil Lake is confined to Early Eocene time (late Wasatchian, possibly Lost Cabinian, according to McGrew and Casilliano, 1975). Fossil Lake is equivalent to McGrew's (1975) "Fossil Syncline Lake" and Bradley's (1948) "unnamed Green River Lake, west of Gosiute Lake."

Fossil Lake had the smallest surface area of the three lakes, and was relatively short lived. It was the deepest of the three lakes during much of its existence, in contrast to the extensive but shallow Lakes Uinta and Gosiute. Evidence from the edge of Fossil Basin indicates that Fossil Lake expanded and contracted several times (McGrew and Casilliano, 1975). Oriel and Tracey (1970) split the Green River Formation of Fossil Basin into two members, the Fossil Butte Member, which is 60 to 80 meters (200 to 260 feet) thick near the center of the Lake, and the overlying Angelo Member, about 60 meters (200 feet) thick near the center of the lake. The main fish-bearing units (the two units most extensively mined for fossils) are in the Fossil Butte Member.

The majority of Green River fossil fish in both public and private collections are from the Fossil Lake area, where they have been commercially mined since before the turn of the century. The two main fish-bearing units in Fossil Lake are the so-called "18-inch" and "split-fish" layers.

The 18-inch layer, a laminated, whitish to buff-colored calcite limestone with light to dark brown laminae of fine organic material (see figure I.3), lies near the top of the Fossil Butte Member. It averages about 18 inches in thickness. The laminae may represent annual cycles of deposition, and for this reason are referred to as varves. The 18-inch layer contains about 4000 couplets of fine light and dark laminae representing about 4000 years of deposition.

The unit is conformably bordered above and below by thin oil shale units (the lowest of which contains abundant plant, insect, and molluscan fossils), possibly the result of minor transgressive and regressive events. The 18-inch layer probably represents a deep area far from shore, on the basis of its lack of clastic material (X-ray analysis indicates a sand, noncarbonate mud, and clay content less than 5%). The excellent preservation of varves and fossils within the 18-inch layer, together with the extreme rarity of bottom dwelling fish (such as catfish, stingrays, and suckers), suggest that the lake was chemically or thermally stratified (meromictic) during the deposition of the 18-inch layer.

The other main fossil-fish-bearing unit of Fossil Basin is commonly referred to as the "split-fish" unit. The split-fish unit is equivalent to the "light-colored limestones and marl" unit of Rosen and Patterson (1969, page 371). Unlike the 18-inch layer, the split-fish beds are only faintly laminated, or not laminated at all. The split-fish matrix is brighter white than the 18-inch layer matrix, and is nearly pure calcite. The name "split-fish" is derived from the manner in which many of the fossils in this unit are exposed (see Appendix I on preparation techniques). The unit is generally about 2 meters (about 6½ feet) thick and is overlain in some areas by a massive, mollusk-rich marlstone. That stingrays and crayfish, both bottom dwelling animals, are much more common in this unit than in the 18-inch layer indicates better circulation of bottom waters.

LAKE GOSIUTE

Lake Gosiute was a broad, shallow lake, currently thought of as a playa lake complex (Eugster and Surdam, 1973;

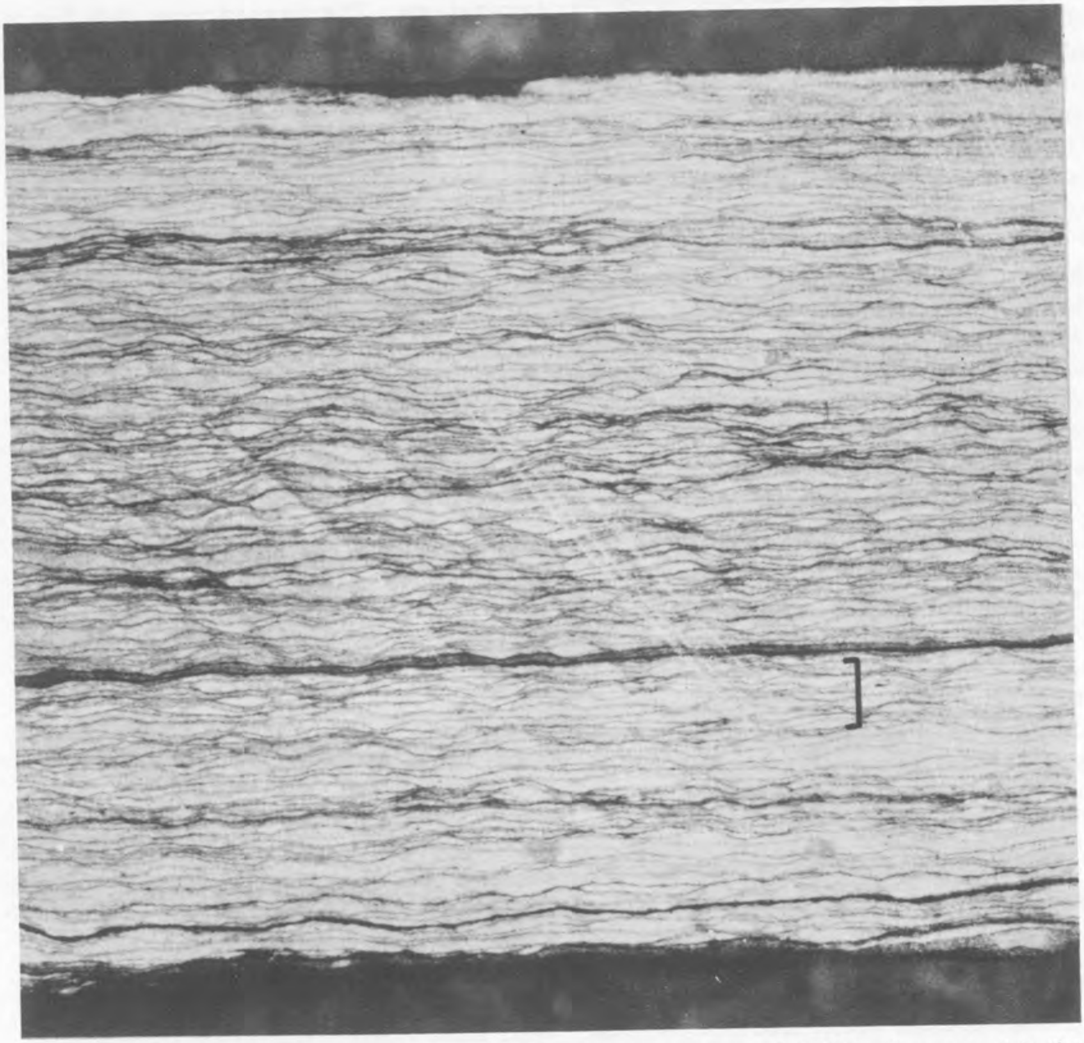


Figure I.3. Polished hand specimen showing the alternating light and dark laminae present in the "18-inch layer." Scale, 1 mm.

Surdam and Wolfbauer, 1975). There is strong evidence of large fluctuations in the position of the shoreline, and at times the lake became quite saline (Surdam and Wolfbauer, 1975). It supported thick algal mats over much of its bottom (Surdam and Wolfbauer, 1975) during several stages of its history, and was probably more eutrophic than Fossil Lake. As with modern lakes, a eutrophic state made it productive of algae and plants, yet not supportive of the variety of fish species present in Fossil Lake. Suckers and catfish were plentiful in Gosiute, but the average size of the fish (such as herring) occupying the upper zones of the lake was smaller than in Fossil Lake. Faunal differences are explained in more detail in the paleontological section of this paper. Lake Gosiute suffered several periods of contraction due to deposition of alluvial sediments, and possibly to periods of decreased rainfall. In the Middle Eocene, Lake Gosiute disappeared.

Most of the fossil fish collected from the lake area have been from the Laney Member, which is Middle Eocene (Bridgerian) in age (Mauger, 1977). During the period of deposition of the Laney Member, the lake was at its greatest areal extent (Bradley and Eugster, 1969). The three main fish-bearing rock types of the Laney Member are the so-called "Farson," "Fontenelle," and "Fish-Cut" types.

The Farson type is a grey, tan, orange, or red siltstone which is often iron-stained and usually preserves the fossils only as external casts and impressions. Most of this material is collected around the Farson Dam near Farson, Wyoming. This is the "iron-stained mudstone" unit referred to by Lundberg and Case (1970, page 451). The unit often produces the most detailed preservation of any of the Green River fossil localities; but it requires special preparation techniques and latex peels to observe maximum detail (see Appendix I).

The Fontenelle type is a tan to light brownish white, muddy, shaley dolomite usually with fine, dark brown laminations. The laminations and fish appear similar in color and state of preservation to those of the 18-inch layer of Fossil Lake, but the matrix is slightly darker and much harder, so needle preparation is much more tedious. These beds are located near the shores of the Fontenelle Reservoir. That several plant and insect beds occur in alternating sequence with small fish beds probably indicates that the area dried up and was reflooded several times.

The Fish-Cut type of fossil-bearing rock is similar to the Fontenelle type, but contains many dark, thin, kerogen-rich layers. The fish-cut units (Hayden, 1871) are equivalent to Roehler's "Laclede Bed" (Roehler, 1973; Paul Buchheim, personal communication).

LAKE UINTA

Lake Uinta was the longest lived of all the Green River lakes, lasting for more than 17 million years, including its late Paleocene history as "Lake Flagstaff." Because of the relatively continuous deposition in Lakes "Flagstaff" and Unita (Fouch, 1975; Schaeffer and Mangus, 1965), Lake Flagstaff is considered in this paper to be synonymous with Lake Uinta. Fouch (1976) reduced the Flagstaff Formation to member status and placed it in the Green River

Formation. This extended the Green River Formation back into Late Paleocene time. The sedimentary rock of Lake Uinta represents one of the thickest documented accumulations of lacustrine sediments in the world, with thicknesses greater than 2100 meters (7000 feet) in places (Cashion, 1967).

Throughout its history, Lake Uinta was very shallow, in spite of its huge geographic extent. Typically, Uinta was lagoonal to shallow lacustrine with many horizons of deltaic deposits, mudstones, shales, sandstone, and siltstones (Baer, 1969). The many zones exhibiting mudcracks interbedded with limestones (Baer, 1969) indicate a fluctuating shoreline.

Lake Uinta deposits include vast quantities of high-grade oil shale containing an estimated 290 billion barrels of oil (Cashion, 1967). Though the economic potential for its oil has been well studied, far less is known of its paleontology than that of Fossil Lake and Lake Gosiute. The most frequently mined macrofossils from the Lake Uinta area are insects and plants. Unfortunately, due to the abundance of fish fossils in the Wyoming Green River Lake localities, the fish fauna of Lake Uinta has been essentially ignored.

The main insect, plant, and vertebrate fossil localities of the Lake Uinta area are Middle Eocene (Bridgerian) in age (Stokes, 1978; Langston and Rose, 1978; Parker, 1970; MacGinitie, 1969; W.B. Cashion, personal communication). Fossil-bearing rock types are described in the locality list at the end of Part I.

HISTORICAL BACKGROUND OF RESEARCH

The first documented records of fossils from what is now called the Green River Formation were in various diaries, journals, and reports of early missionaries such as S.A. Parker (1840) and such explorers as J.C. Fremont (1845). They were reports of invertebrate fossils.

The first record of a fossil fish discovery in the Green River Formation was in 1856: Dr. John Evans, a geologist, collected a fossil fish from near what is now Green River, Wyoming, and sent it to Joseph Leidy, M.D., in Philadelphia. Leidy identified the fish as a herring, which he named *Clupea humilis* (1856), a name later changed to *Knightia eocaena* (as used here). Later, Ferdinand V. Hayden, director of the newly-established United States Geological Survey of the Territories, named this fossil locale the "Green River Shales" (1869).

During the late 1860's, the Union Pacific Railroad, while excavating about 2 miles west of Green River, Wyoming (in the area of Eocene Lake Gosiute), uncovered the first major fossil fish layer of the Green River Formation. A.W. Hilliard and L.E. Ricksecker, employees of the railroad, were first to discover the fish, and collected many specimens which they turned over to Hayden. Hayden referred to this site as the "Petrified Fish Cut" (1871). These specimens were later studied and described by the famous pioneer vertebrate paleontologist Edward Drinker Cope in Hayden's 1871 report. The collection consisted of the genera *Phareodus*, *Knightia*, *Erismatopterus*, and

Asineops. Cope collected specimens from the Fossil Basin area in the later 1870's at "Twin Creek Site" (1884), and described them in several small papers (1877, 1878, 1879, 1885, 1886) and in his classic monograph (1884).

Meanwhile, geologists were reporting additional outcrops of the Green River Formation. In 1876, John W. Powell described sections of the Green River Formation in the foothills of the Uinta Mountains in northern Utah, and A.C. Peale discovered outcrops of the formation in northwestern Colorado. Both Powell and Peale turned their collected fish fossils over to Cope for study and description.

Since publication of Cope's monumental works on the Green River fossil vertebrates, many authors have published papers on fossils of the Green River Formation. These references are listed throughout the paleontological sections of this paper.

HISTORICAL BACKGROUND OF AMATEUR COLLECTION OF GREEN RIVER FOSSILS

There is no way to list all of the thousands of amateur collectors of Green River Fossils, but there are records of a few major amateur collectors. Earliest major collecting by amateurs was confined mainly to 18-inch layer specimens in the Fossil Lake area.

Robert Lee Craig started digging in the 18-inch layer in about 1897 (Powell, 1934) and continued through the late 1930's. David Haddenham joined Craig in about 1918, and the Haddenham family (son David F. and grandson Robert) continued working the area until about 1970. Carl Ulrich and his wife, Shirley, started digging in the area in 1947 and still work the area today with their son, Wallace.

In 1970, Robert Tynsky and his family started digging in the split-fish layers of Fossil Basin. Today, the Tynsky family continues work in the area. Craig, the Haddenham family, the Ulrich family, and the Tynsky family have been responsible for the recovery of the majority of Green River vertebrate fossils in public and private collections all over the world.

LOCALITY LIST AND CODE LETTER KEY TO THE MAIN VERTEBRATE FOSSIL SITES OF THE GREEN RIVER FORMATION

This is a list of Green River fossil localities for specimens used in this paper. Each locality is denoted by a code letter and number which will be referred to throughout the paleontological sections of the paper; these localities are plotted on the map in figure I.4. Figure I.5 shows the correlation of some of the members of the Green River Formation, including all the fossil-

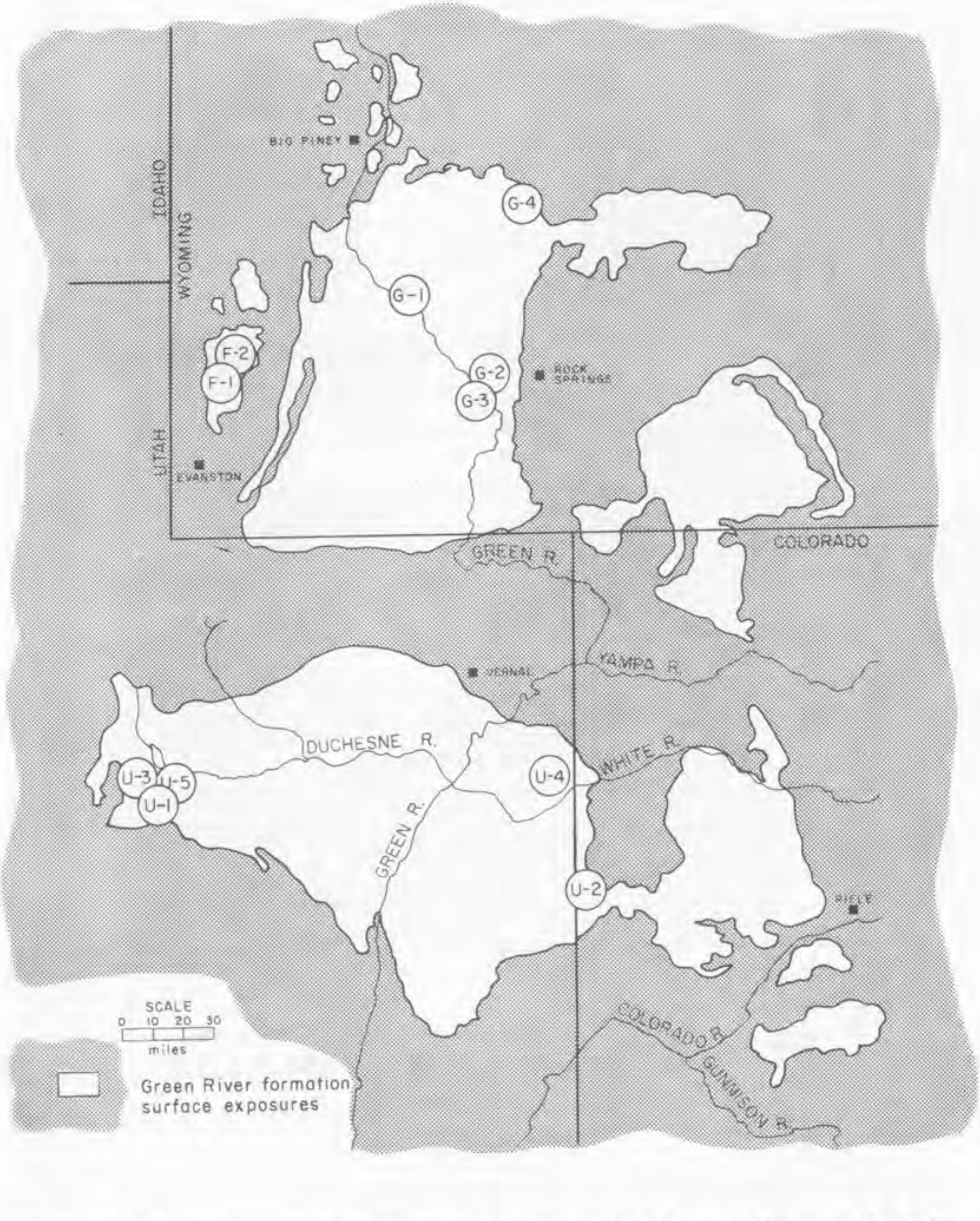


Figure I.4. Surface exposures of the Green River Formation (U.S. Bureau of Mines, *in* MacGinitie, 1969). Code numbers show locations of some of the vertebrate fossil exposures of the Green River Formation.

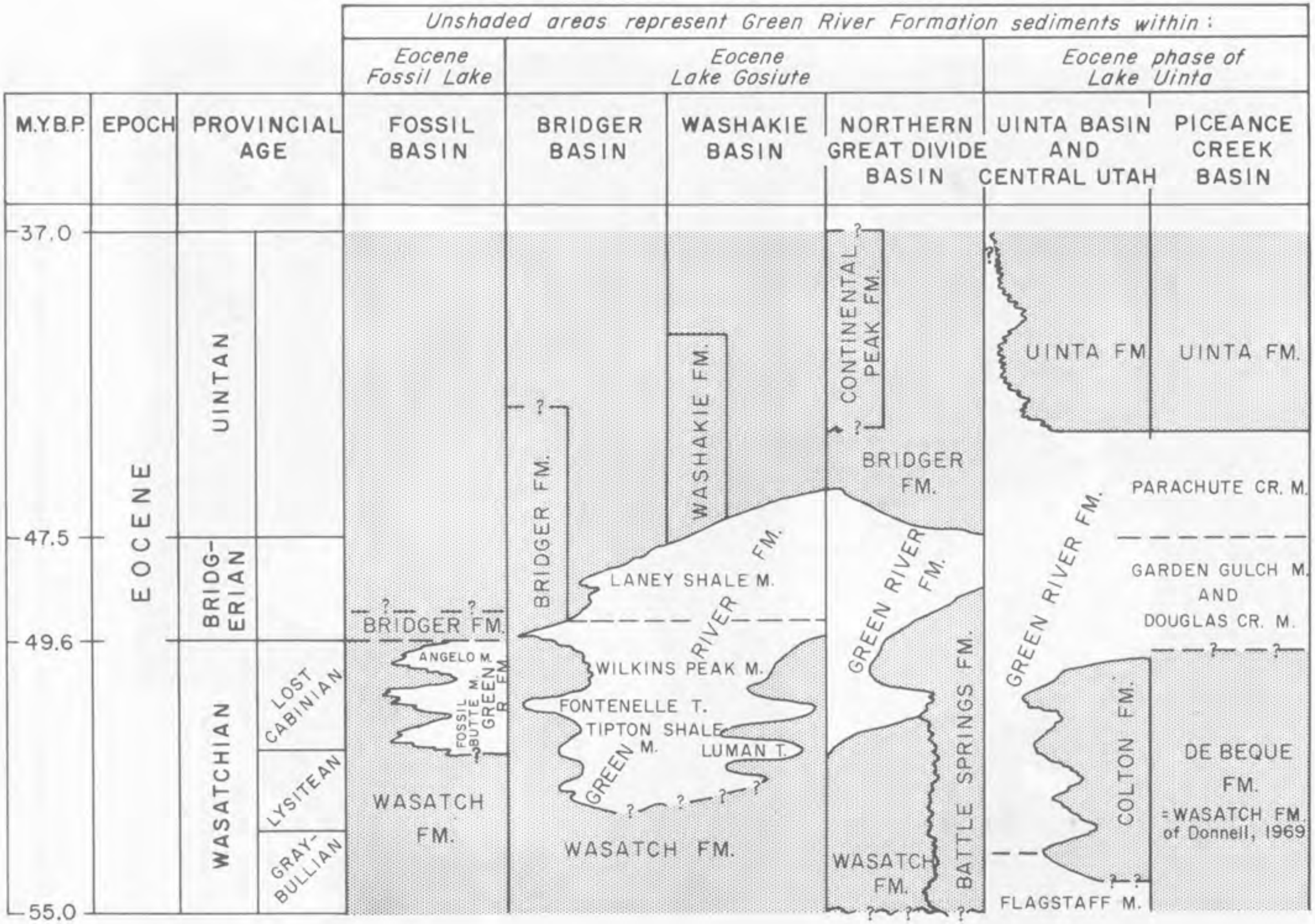


Figure I.5. Correlation of some of the members of the Green River Formation (unshaded areas) in Wyoming, Colorado, and Utah (after Berggren *et al.*, 1978; Mauger, 1977; Fouch, 1976; Cashion and Donnel, 1974; Oriel and Tracey, 1970; MacGinitie, 1969). Locations of these basins are shown in figure I.4.

containing members discussed here. More detailed locality information for the coded localities given here are reposited in the locality files of the Science Museum of Minnesota, St. Paul, Minnesota.

There are, of course, other localities not listed here, both known and yet undiscovered. The listed localities represent the locations where the bulk of the Green River vertebrate fossils in public and private collections were found.

FOSSIL LAKE LOCALITIES

The main Fossil Lake localities are within a few miles of Fossil Butte National Monument, about 9 miles west of Kemmerer, Wyoming, in the Fossil Butte Member of the Green River Formation.

F-1: Locality F-1 designates all of the 18-inch-layer quarries located near the center of what was Fossil Lake. These presently include quarries within Fossil Butte National Monument and on Fossil Ridge just south of the Monument, and various state-leased commercial quarries within sec. 16, T21N, R117W, Lincoln County, Wyoming (Kemmerer 15-minute quadrangle). Specimens labeled Craig, Haddenham, Ulrich, Boundy, Scott-Sommers, or Jackson quarries, or "Fossil, Wyoming" are nearly all F-1 specimens. F-1 is in the upper Fossil Butte Member of the Green River Formation.

F-2: Locality F-2 designates all of the split-fish-layer quarries located in Eocene Fossil Lake, mainly in secs. 16, 22 and 27, T22N, R117W, Lincoln County, Wyoming (Kemmerer 15-minute quadrangle). Specimens labeled Tynsky or Hebdon* quarries are nearly all F-2 specimens. F-2 is in the Fossil Butte Member of the Green River Formation.

A detailed study of the stratigraphy of Fossil Basin is in press by Buchheim and Fremd.

LAKE GOSIUTE LOCALITIES

Most of the main fossil localities are in the Laney Member. Promising sites for vertebrate fossils exist in the Tipton Member also (Paul Buchheim, personal communication), but the Tipton remains virtually uncollected and unstudied today with respect to fish fossils.

G-1: Locality G-1 designates the bluish grey, greyish tan, or brownish buff quartzitic, shaley dolomite, usually with fine dark brown laminations, that outcrops near water level along the northeast shore of the Fontenelle Reservoir. The G-1 fossil units are in the Laney Member.

G-2: Locality G-2 is dark grey, shaley limestone, with fish bones ivory white to buff white, containing mass mortalities of the catfish *Astephus* and the trout perch *Erismatopterus*. The dark grey unit is overlain by a light brown, silty dolomitic shale with a fish fauna of catfish *(Astephus)* and suckers *(Amyzon)* very similar to the fauna of the G-1 locality. The G-2 units are in the Laney Member, usually about 20 meters above the base. This unit is discussed by Buchheim and Surdam (1976).

G-3: Locality G-3 designates Hayden's "Petrified Fish Cut" (Hayden, 1871) in about the lower 10 meters of the Laney Member of the Green River Formation near Green River, Wyoming. G-3 always underlies G-2 and is often found together with it.

*All F-2 specimens referred to in this paper are from Tynsky quarries, sections 16 and 22. The Hebdon quarry appears to be in the same stratigraphic unit, but is located at the Warfield Springs, about 11 miles south of Fossil Butte.

G-4: Locality G-4 designates the localities containing the so-called "Farson Fish." The matrix is a grey, tan, or brown siltstone that is often iron-stained red or orange. Fossils are usually preserved only as external casts and impressions. G-4 is in the Laney Member.

LAKE UINTA LOCALITIES

Among the three Eocene lakes, Lake Uinta is the one whose vertebrate paleontology is least understood. It is better known for its plant and insect fossil localities (Durden and Rose, 1978; MacGinitie, 1969) within the Parachute Creek Member than for its vertebrate localities.

Garfish *(Lepisosteus cuneatus)* are fairly common within several horizons of Lake Uinta strata, probably reflecting the lagoonal environment (Baer, 1969) that persisted through much of its history.

U-1: Locality U-1 designates those grey, medium-grained sandstone deposits (mostly channel sand and trough deposits) containing mass mortalities of the gar *Lepisosteus cuneatus*. These deposits are in Bradley's (1931, plate 3) "second lacustrine phase" or possibly in his "delta facies," and are located near the Soldier Summit area near Provo, Utah. This unit appears to contain gar almost exclusively, with few other fish species (see figure II.17a).

U-2: Locality U-2 designates the "Raydome" locality (Durden and Rose, 1978) near Douglass Pass, Rio Blanco, and Garfield Counties, Colorado. These deposits are in the upper Parachute Creek Member of the Green River Formation. Vertebrates are very scarce and include lizards, small crocodilians, bats, birds, and small fish. U-2 contains vast numbers of some of the best preserved insect and plant fossils known from the Green River Formation.

U-3: Locality U-3 designates a shaley, white limestone unit that contains thousands of bird and invertebrate trackways (and, rarely, mammal trackways) described by Moussa (1968). This horizon is full of mudcracks, and is found in the Spanish Fork Canyon and Soldier Summit areas near Provo, Utah. U-3 is in Bradley's (1931, plate 3) "second lacustrine phase" of the Eocene Green River sediments of Lake Uinta (Moussa, 1968).

U-4: Locality U-4 designates the "Bonanza" locality near Bonanza, Uinta Co., Utah. Like U-2, it is primarily an insect and plant locality, but (rarely) lizard, bird, and crocodillian fragments have been found there, also. One of the lizard fragments from U-4 is pictured in part III of this paper. U-4 is in the upper Parachute Creek Member of the Green River Formation.

U-5: Locality U-5 designates the "Timber Creek" fossil track horizon of Curry (1957). This horizon was first discovered in SE¼ sec. 19, T5S, R9W, Salt Lake Meridian, about 16 kilometers (10 miles) northeast of Soldier Summit. Stratigraphically, it lies well above the U-3 fossil track horizon in Bradley's (1931, plate 3) "barren and saline facies" (W.B. Cashion, personal communication). The ichnofauna of U-5, similar to that of U-3, is predominately bird and invertebrate tracks and, rarely, mammal tracks. For approximate age, see figure I.2 (it has about the same geologic age as the Parachute Creek localities U-2 and U-4; W.B. Cashion, personal communication).

INVERTEBRATE FOSSIL LOCALITIES OF THE GREEN RIVER FORMATION

Invertebrate localities are too numerous to list in this paper, and only a few will be given in the paleontological section on invertebrates.

PART II

A REVIEW OF THE GREEN RIVER FISH FAUNA

INTRODUCTION TO PART II

Part II is not a review of any particular family of fishes; rather, it is a review of the fishes within the fossil communities of the Green River Formation, a community approach rather than a phyletic one.

Some of the Green River fossil fish genera, particularly *Knightia*, *Diplomystus*, *Mioplosus*, *Phareodus* and *Priscacara*, contain species described with insufficient data to warrant specific separation, and some of these species are synonymized here. Many of these species, often those living together in the same communities (mostly at locality F-1), were separated by Cope and other workers mainly on the basis of meristic characters. Since publication of these early descriptions, very large numbers of additional specimens have been found, many with meristic characters intermediate between those of the described species. The resulting ranges made by consolidating nominal species are mostly within the normal meristic variation of a single species, and this is the basis upon which some synonymizations in this paper are made. Many Green River fish genera are still in need of rigorous generic review.

Generic morphological descriptions in Part II are brief, but references to additional information are given. Simplified tables are provided where possible to aid in identification, and specific descriptions are mostly limited to those features which aid in differentiating the Green River species. Additional meristic data are given wherever possible. Differences between separate communities within the Green River Formation are examined at the end of Part II.

BASIC FISH ANATOMY, METHODS, AND SYSTEMATICS

To aid the nonichthyologist in understanding some of the terminology used in Part II, basic fish anatomy (particularly osteology) is illustrated in figures II.1 and II.2. Additional anatomical terminology as used here is defined in the glossary (Appendix IV).

Figure II.1a is a teleost skeleton which exhibits typical skeletal features of bony fish. Figure II.1b is an enlarged view of the skull from figure II.1a. These skull and postcranial elements vary in size, shape, position and number from species to species, but general structure and terminology are much the same for most of the bony fish. For a more detailed look at fish skulls, refer to Gregory (1933), which contains line drawings of several hundred species. Figure II.1c is an enlarged view of the caudal skeleton from figure II.1a. Figure II.2 shows the basic types of caudal fins (tails) present in ray-finned fishes (actinopterygians).

The 17 valid genera of fish presently described from the Green River Formation are presented here by family in taxonomic order using the phyletic classification of Patterson and Rosen (1977). In fin-ray counts, all true spines, no matter how rudimentary or how flexible, are designated by Roman numerals, and all soft rays are designated by Arabic numerals (as in Hubbs and Lagler, 1958). In a dorsal fin containing both spines and soft rays (as in *Priscacara* or *Erismatopterus*), the count for the spines is separated from the soft ray count by a comma. If the spiney-rayed dorsal fin is separated from the soft rays, forming two separate dorsal fins (as in *Mioplosus*), a dash is used to separate the counts of the two fins. For example, if a specimen of *Priscacara* has a dorsal fin consisting of 10 hard spines followed by 12 soft rays, the fin-ray count would be written: Dorsal X,12. In the case of *Erismatopterus*, which generally has 2 rudimentary dorsal spines followed by 6 or 7 soft rays, it would be written: Dorsal II,6-7. True spines are median (unpaired) and unsegmented structures. Soft rays are segmented and usually branched and flexible. See definitions for "major rays" and "accessory rays" in the glossary (Appendix IV) to see how these terms are used in this text with respect to median fin-ray counts.

Caudal fin-ray counts will be listed in the following order: Unbranched principal rays in upper lobe, branched principal rays in upper lobe, branched principal rays in lower lobe, and unbranched principal rays in lower lobe. For example, the genus *Asineops* has one unbranched and 6 branched caudal fin rays in each lobe, and would be written: Caudal 1,6,6,1. Principal rays are those rays which extend to the posterior fin margin (all the way to the end of the tail). Procurrent caudal ray counts are omitted here.

The vertebral counts given in this paper are of three types — caudal, precaudal and "predorsal" (see glossary for definitions of these terms as used here). Because predorsal vertebrae (indicated in text by "PD") are also precaudal, their number is included in the precaudal count. Thus the total vertebral count is equal to the number of caudal plus precaudal vertebrae — the latter includes the PD vertebral count. The predorsal counts are provided because Cope (1884 and elsewhere) often failed to include predorsal vertebrae in his vertebral counts, and consequently his total vertebral counts are usually too low. The last half centrum (the ultimate vertebra), often triangular in outline (see figure II.1c), is included in the caudal vertebrae total.

All counts made here were made in an anterior to posterior direction; *i.e.*, the "first" vertebra or fin ray is the most anterior one. Head length is measured from the tip of the snout to the posterior end of the opercle. Other counts and measurements* follow Hubbs and Lagler (1958), except in catostomids and a few other groups. Predorsal vertebrae are in front of those vertebrae which bear full-length ribs and are usually under the opercle. Radiographs were taken of many of the specimens to get accurate counts of the predorsal vertebrae.

Where new meristic data are given, each count is followed by "n", the number of specimens on which each meristic feature was counted; "$\overline{X}$", the mean of the counts; and "SD", the standard deviation of the counts.

All scales illustrated here are flank scales unless otherwise stated. Since most fish with ctenoid scales also possess cycloid scales (Lagler, 1947), only the predominant scale type is given.

*Due to variability in perservation of fossil material, a peculiar method was used here for measuring "standard length" — see glossary.

A list of abbreviations used here for repositories is given in Appendix III. Excavation and preparation techniques are explained in Appendicies II and I, respectively. Isolated scales illustrated here are shown with no uniform orientation. Preparation of all LG, BMNH, and SMMP specimens illustrated here was done by the author unless otherwise noted in the plate captions.

SUGGESTED REFERENCES FOR ADDITIONAL INFORMATION ON BASIC FISH ANATOMY

Suggested references for additional information on basic fish anatomy are Gosline (1971), Harder (1975), McAllister (1968), Goodrich, F.S. (1958), Hubbs and Lagler (1958), Lagler (1947), and Gregory (1933).

SUGGESTED REFERENCES FOR INFORMATION ON FISH TAXONOMY AND (MODERN) FISH IN GENERAL

Suggested references for information on fish taxonomy and fish in general are Nelson (1976) (an excellent book on all the major fish groups of the world); Scott and Crossman (1973) (Canadian fishes only); Greenwood et al. (1973) (an excellent book on the interrelationships of fishes within most major taxonomic groups), and Patterson and Rosen (1977) (current fish classification).

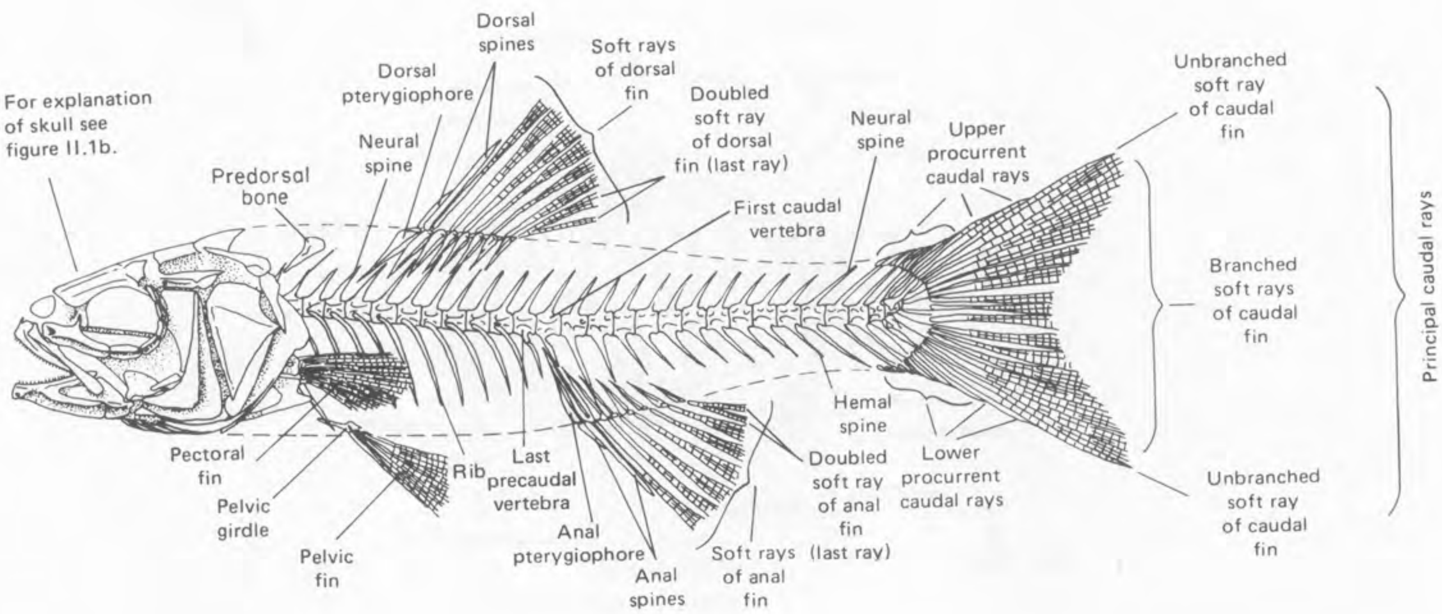


Figure II.1a. Labeled skeletal features of *Erismatopterus levatus* (restored line drawing, modified after Rosen and Patterson, 1969).

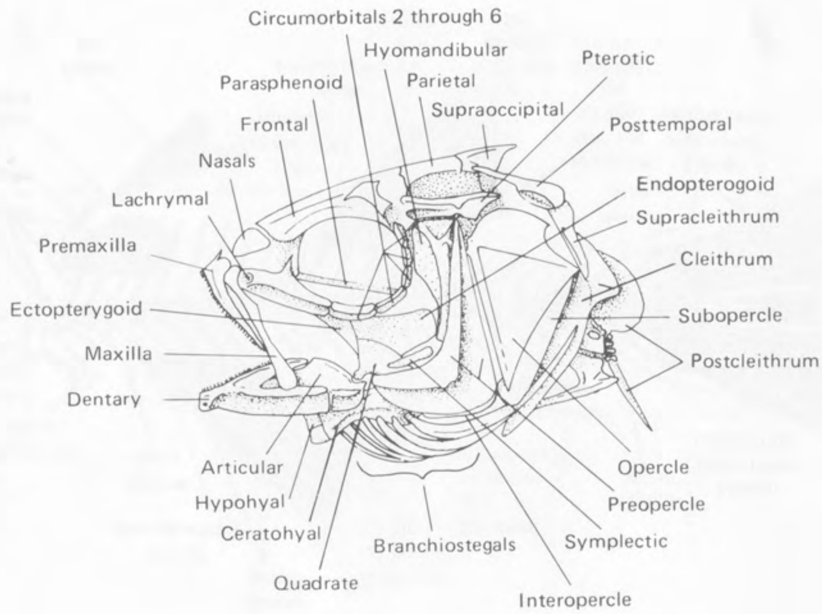


Figure II.1b. Skull from figure II.1a (restored line drawing modified after Rosen and Patterson, 1969).

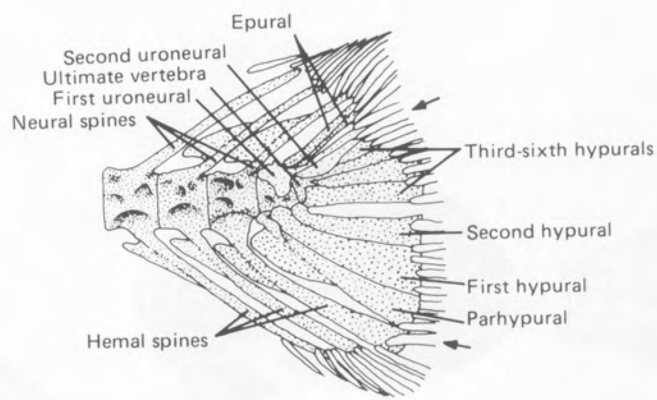


Figure II.1c. Caudal skeleton from figure II.1a (restored line drawing modified after Rosen and Patterson, 1969). Arrows mark the bases of the outermost principal (unbranched) fin rays.

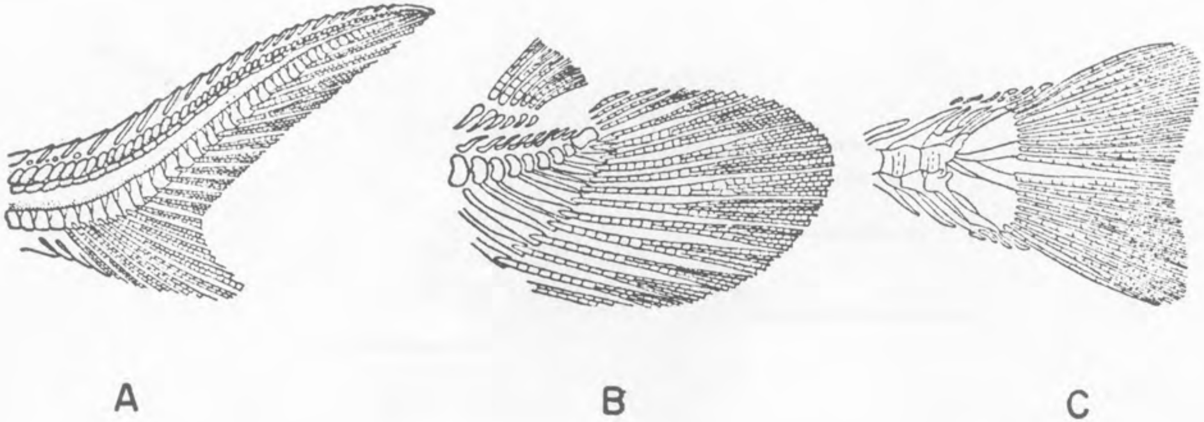


Figure II.2. Types of caudal fins. (A) Heterocercal tail (drawn from *Acipenser fulvescens*); (B) Abbreviate – heterocercal tail (drawn from *Amia calva*); (C) Homocercal tail (drawn from *Micropterus salmoides*). Taken from Hubbs and Lagler, 1958. Courtesy of the University of Michigan Press. *© 1958 The University of Michigan Press.*

DASYATIDAE (TRYGONIDAE)

Genus: *Heliobatis* Marsh 1877 (the stingray)

Species: *H. radians* Marsh 1877 — Figures II.3-11.5, II.7c.

Undescribed genus and species — Figures II.6 - II.7b.

GENERAL INFORMATION

Heliobatis, a stingray, is represented in the Green River lakes by one described species, *Heliobatis radians. Heliobatis* has been reported mainly from Fossil Lake, by over a hundred complete specimens found in the F-1 and F-2 localities. They are more common at F-2. Stingrays are bottom dwellers, often burying themselves in the sediments when not in search of food. The fact that rays are rarer in the F-1 quarries than in the F-2 quarries may be the result of better bottom water circulation in the area of the F-2 quarries providing a better habitat.

Heliobatis ranges from about 8 cm (3 inches) to about 90 cm (3 feet) in total length, but is usually 30-40 cm (12-16 inches) long. Sex can be determined in *Heliobatis* by the presence or absence of pelvic fin appendages called claspers. Figure II.3 shows a male with claspers, and Figure II.4 shows a female (no claspers). *Heliobatis* was armed with a maximum of three barbed spines, and is often found with less than three of these "stingers" remaining. A modern dasyatid ray can swing its very flexible tail against threatening objects in almost any direction, driving the barbed and often venomous spine into its target. The teeth of *Heliobatis* are very small and closely placed in a few series, with crowns developed into triangular cusps with relatively flat functional surfaces pointing backwards as in the modern skate *Raja*. Cope illustrates these with line drawings (1884, plate I, figure 2). Modern stingrays feed on crustaceans, clams, snails, or fish when readily available. The posteriorly pointing crushing teeth of *Heliobatis* were adapted to take small fish, as well as to grind and crush the abundant snails and crustaceans of Fossil Lake. F-2, where *Heliobatis* is most abundant, is the only Green River locality where fossil crayfish and prawns are found.

Figure II.6a shows a particularly interesting F-2 female ray with three very young juveniles around her. The three juveniles are probably newborn individuals, possibly a product of postmortem abortion. The entire stingray family (Dasyatidae) is ovoviviparous: the female hatches her eggs within her body and the young are born alive. The specimens in figures II.6 and II.7 have thick tails covered with a dense series of dermal denticles (placoid scales) bearing curved hooks (see figures II.7a,b). These may represent a new species and are currently being studied by the author. Specimens with dense coverings of dermal denticles on the tail are very rare*, but are found at both F-1 (see figure II.7) and F-2 (see figure II.6a).

*Of nearly 100 Green River stingrays observed by the author, only 4 were of this probably new species.

Today, exclusively freshwater stingrays (potamotrygonids) are found in South America.

GENERIC ETYMOLOGY

Heliobatis: helio — the sun, *batis* — a ray or skate.

NOMENCLATURE, SPECIFIC INFORMATION, REPOSITORIES, AND SUGGESTED REFERENCES

Heliobatis radians was described by Marsh (1877, p. 256) on the basis of the Fossil Lake specimen shown in figure II.7c. His description was quite brief, and he did not publish an illustration of the type. Nevertheless, according to the rules of nomenclature, the description is valid.

Cope (1879) described *Xiphotrygon acutidens*, which is considered here to be a junior synonym of *Heliobatis radians*. Cope (1884) gave a more detailed description of this ray than Marsh, and published an illustration indicating a much better preserved specimen (see his (1884) plate I, figure 1). Fowler's (1947) *Palaeodasybatis discus* is synonymous with *Heliobatis radians*; the holotype for *P. discus* (ANSP 8344) is lost, and this synonymy is based on photographs. Fowler described the single, partly restored, and now lost holotype without illustration, and figure II.5 is the first published illustration of the specimen. His description is meager (he admits that it "is hardly a description, leaving much to be revealed without a figure," (1947, page 1871)), and the only character he gives to differentiate his species from *X. acutidens* Cope (1879) is the "rounded or circular disc-like body" of the former. All known specimens of *Heliobatis* have a rounded disc-like body, except specimens where the fin margins are damaged or missing in part. Cope's nominal type for *Xiphotrygon* (illustrated 1884, plate I, figure 1) also has a round disc-like body, though the fin margins are obviously incomplete, giving it a very slight oval appearance. No additional features were observed on ANSP 8344, or on *Xiphotrygon acutidens*, to warrant specific separation from *H. radians*.

HELIOBATIS RADIANS Marsh 1877

= *Xiphotrygon acutidens*, Cope 1879; *Dasyatis* sp., Haseman 1912; *Palaeodasybatis discus*, Fowler 1947; and *Xiphotrygus* sp., Romer 1971.

Ray taxonomists should be warned that several heavily restored fossil rays exist in both public repositories and private collections. Because of the high commercial value of Green River stingrays, some commercial institutions have cast individual vertebrae and implanted them in damaged specimens, making the resulting restoration difficult to find without close inspection. Meristic counts of stingrays should always be checked with a binocular microscope to make sure the counted features are real. An ultraviolet light ("black light") can also be used to check the authenticity of the specimen, since the true fossil part of the specimen will fluoresce.

The following data are based on the holotype (YPM 528); the type specimen for "*Xiphotrygon acutidens*" Cope (uncataloged Fossil Lake specimen from

Bowdin College, Maine — now lost)*; SMMP 77.27.1 (figure II.4); UW 12309 (illustrated in McGrew and Casilliano, 1975, figure 14); UW 11577; AMNH 7828 (illustrated in Schaeffer and Mangus, 1965); AMNH 4345; AMNH 857(a), SMMP 83.2.4 (figure II.3); and DMNH 1530.

Fin rays (ceratotrichia): Pectoral 85-96 (n=8, $\overline{X}$=88.82, SD=3.81), the last (most posterior) rays usually covered with the pelvic fin and difficult to see; Pelvic 13-20 (n=7, $\overline{X}$=16.0, SD=2.11), often not well enough preserved to distinguish all individual rays; Caudal none observed. Male specimens have claspers.

Vertebrae: Total number 170 to 190 (n=5); the vertebral count is highly variable because the vertebral column, which becomes extremely thin and frail toward the posterior end of the tail, is usually broken off near the tip, resulting in lower counts.

Dimensions: Length of disc about 50 percent of total length (range=49-53 percent, n=7, $\overline{X}$=51.4, SD=1.52). Disc round, nearly circular when pectoral fin margins complete and unfolded.

Other Information: Tail long and very slender, with many short spines running along the dorsal midline as in *Trygon*. No rostrum. Propterygia extend to the anterior tip of disc, giving outline to an acute snout, and are segmented to the tip. Propterygial border longer and contains more rays than the metapterygial, and the posterior border of the pelvic fin extends beyond the posterior border of the pectoral fin. Disc length is defined here as the distance from the anterior tip to the posterior tip of the pectoral fin. Vertebrae fully calcified, and the caudal series becomes very slender distally. The three long caudal spines, closely grouped, insert slightly posterior to the midpoint of the tail, are finely serrated on the lateral edges, and have longitudinal striations. *Heliobatis radians* appears to have a single row of dermal denticles along the dorsal midline of the tail. These show up clearly only on specimens exposed from the dorsal side. The dorsal side can be distinguished by the visibility of the chondocranial fontanelle (see figure II.7b where it is well preserved, and figure II.3 where it is faintly preserved). Cope (1879, 1884) made no mention of the dermal denticles on the tail, but his specimen (1884, figure 1, plate I) was exposed from the ventral side.

For additional descriptive information see Cope (1879; 1884). A redescription of *Heliobatis radians* and a description of the species shown in figures II.6 and II.7 are in progress by the author.

*Because the actual specimen is lost, the data for this specimen is based on Cope's description (1879, 1884) and illustration (1884, plate I, figures 1-5).

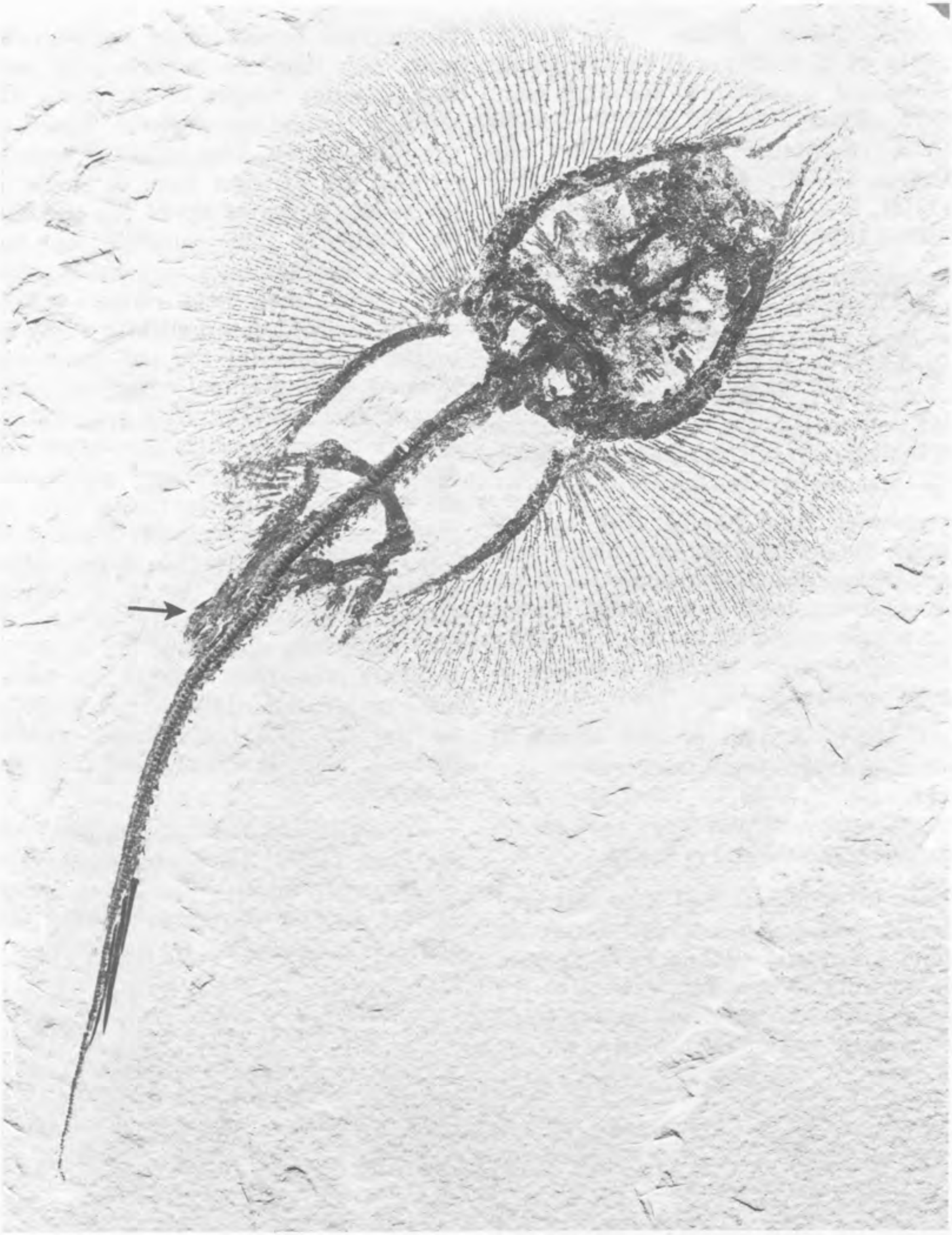


Figure II.3. *Heliobatis radians* ♂ (SMMP 83.2.4) from locality F-2. A male; sex of this specimen is recognized by the presence of claspers (arrow). Total (axial) length is 38 cm (about 15 inches). Dorsal view.

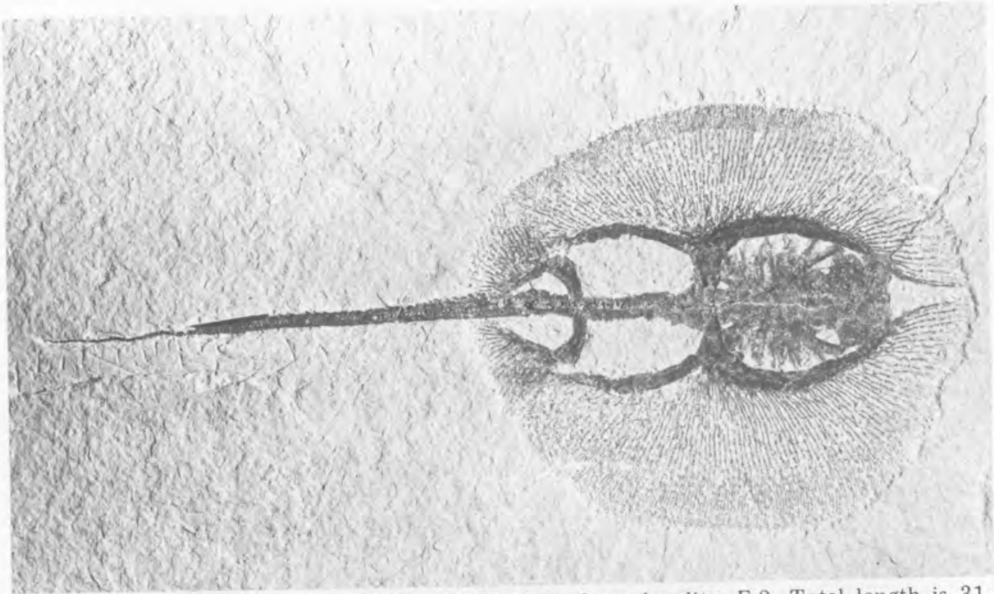


Figure II.4. *Heliobatis radians* ♀ (SMMP 77.27.1) from locality F-2. Total length is 31.5 cm (about 12 inches). The outside edge of the left pectoral fin is partly folded over. Ventral view.

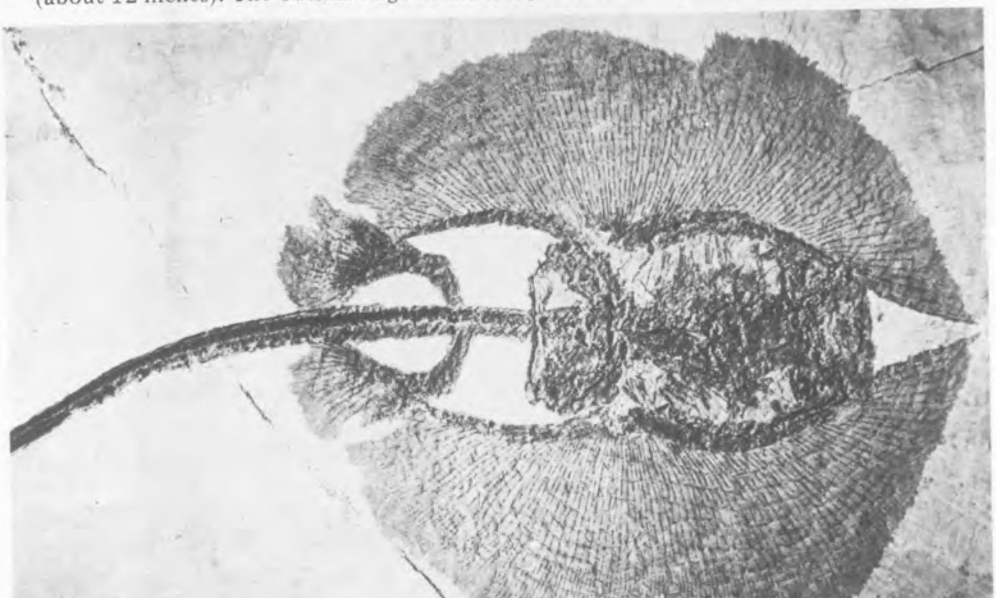


Figure II.5. Holotype for *Palaeodasybatis discus* Fowler (ANSP 8344 = *Heliobatis radians* Marsh) ♀; this is the first published illustration of this specimen. The specimen is painted over with some type of coating which is responsible for the dark regions between the fin rays. Photo courtesy of Gay Vostreys. Ventral view.

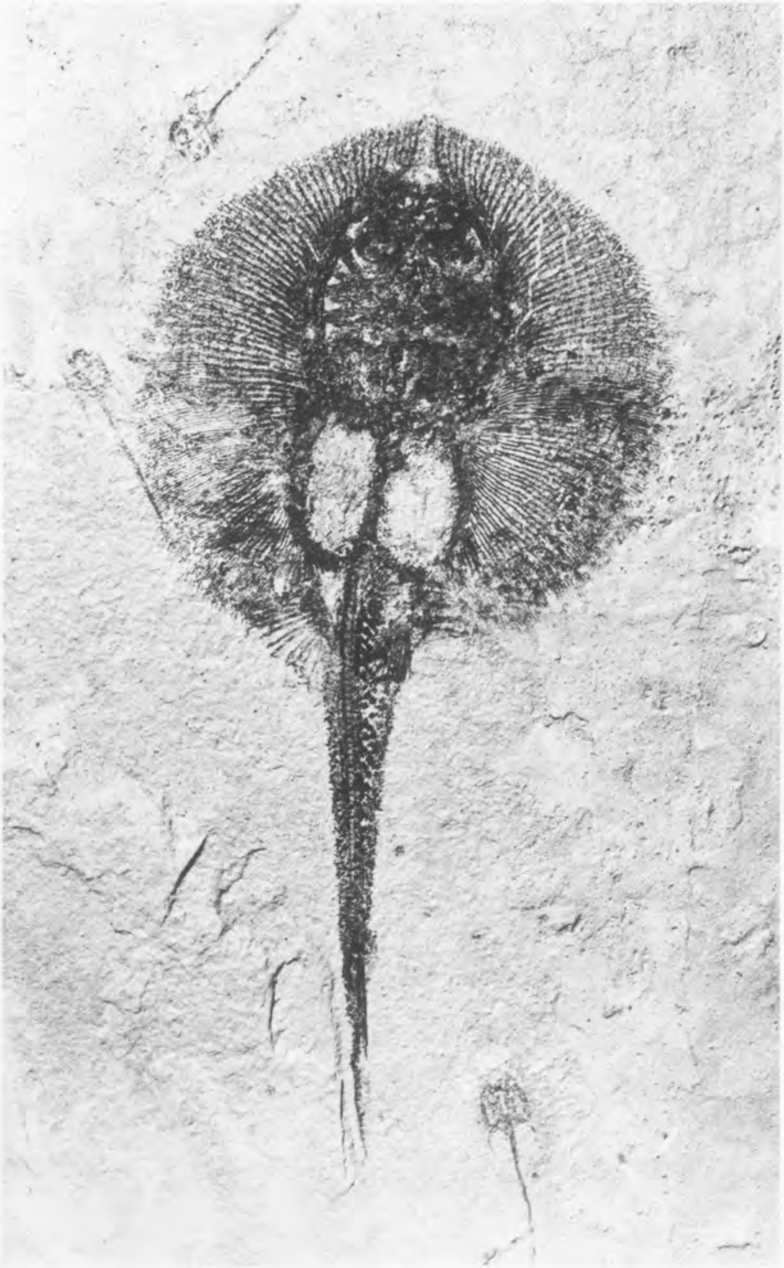


Figure II.6a. An undescribed female ray from F-2 (AMNH 11557). This extremely interesting specimen has a very thick tail covered with hooked dermal denticles and is probably a new species of Green River stingray. Notice the three very young juveniles around her. Total length of adult is about 34 cm (13-½ inches); length of juveniles is about 7.7 cm (3 inches). Ventral View.

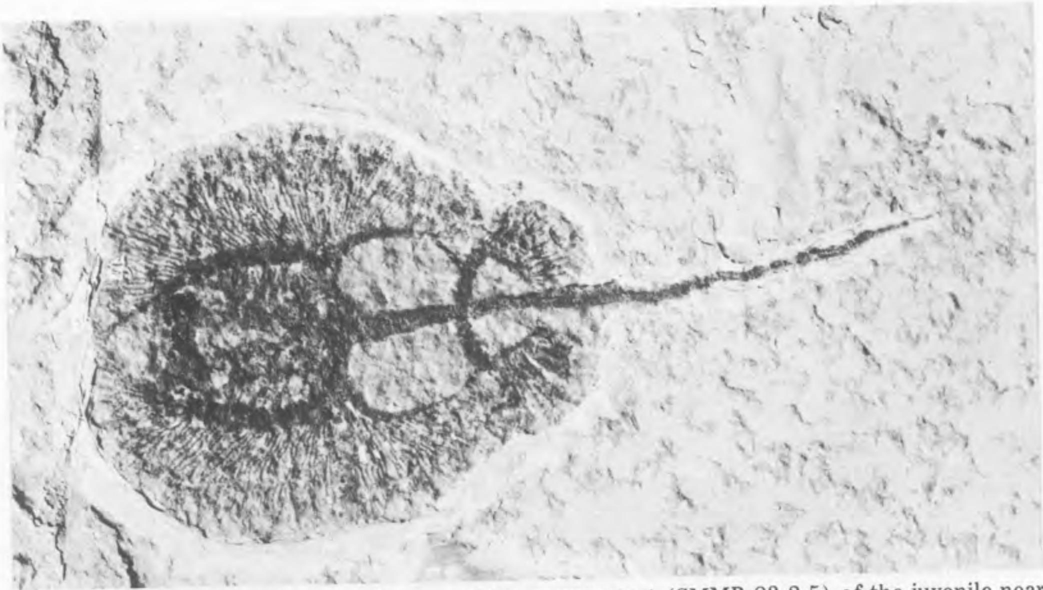


Figure II.6b. Undescribed ray: a closeup of the counterpart (SMMP 83.2.5) of the juvenile near the tail end of the adult in figure II.6a. Total length is about 7.7 cm (3 inches).

Figure II.7a. Dermal denticles from the tail of a specimen similar to that shown in figure II.6a. Scale is 5 mm (from USNM 2028 [see figure II.7b]).

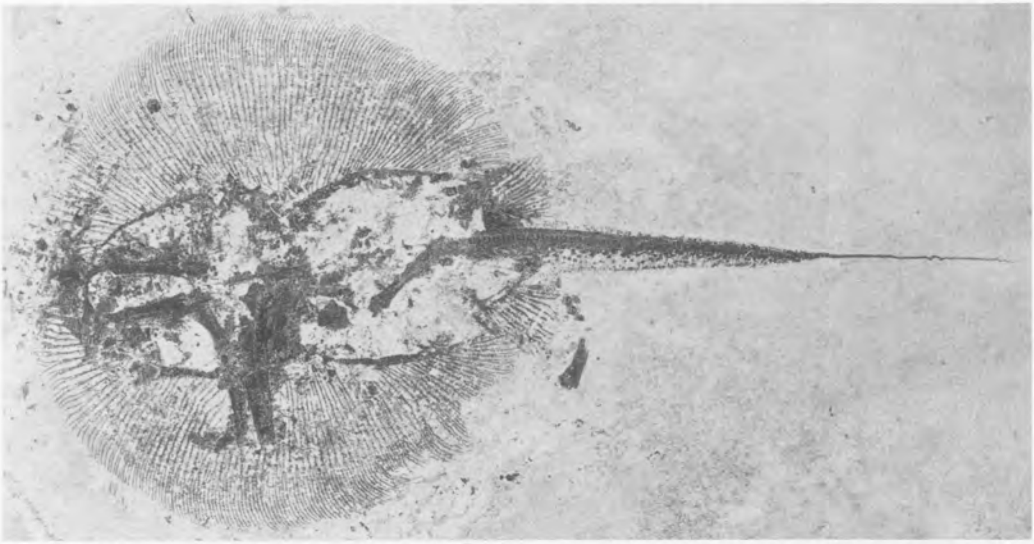


Figure II.7b. Undescribed ray (USNM 2028) from locality F-1. The specimen in figure II.6 is probably of the same species. Note preservation of chondocranium containing a "keyhole" shaped fontanelle similar to that in extant dasyatids. Distal end of tail was probably in the process of being regenerated. Total length about 45 cm (18 inches). Dorsal view.

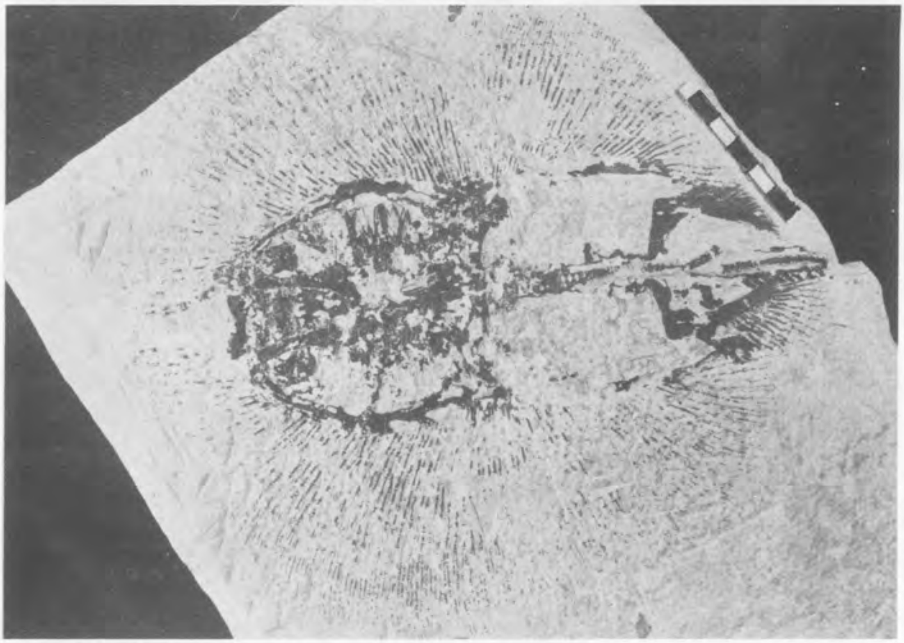


Figure II.7c. *Heliobatis radians* Marsh 1877, holotype, YPM 528, dorsal view. There is no previously published illustration of this specimen. Scale is in centimeters. Photo courtesy of Ms. Amy McCune.

Genus: *Crossopholis* Cope 1883 (the paddlefish)
Species: *C. magnicaudatus* Cope 1883

Figures II.8-II.11

GENERAL INFORMATION

Crossopholis, the paddlefish, is the rarest described fish in the Green River Formation, represented usually by incomplete specimens (partial skulls and tails), and reported only from Fossil Lake deposits (both F-1 and F-2). The specimens shown in figures II.8a and II.8b are the first reported complete specimens of *Crossopholis*.

The postcranial region of *Crossopholis* shows no vertebral column, and its skeleton, like that of the extant North American paddlefish *Polyodon spathula*, is largely unossified (consists mostly of cartilage and notochordal tissue). The skulls are ossified and relatively large, so lack of preservation does not account for the scarcity of paddlefish in the Green River Formation. *Crossopholis* may have preferred the connecting river and streams to Fossil Lake, or its scarcity may be a result of its specialized ecological requirements. Today, the extant paddlefish *Polyodon* is very large as an adult (up to 2 meters or 6½ feet in length and 91 kg or 200 pounds in weight), yet it feeds on tiny crustaceans and planktonic organisms strained from the water by long gill rakers on the inner sides of the gills. When feeding, it simply swims through the water with its mouth wide open. It takes quite a lot of plankton to feed an adult paddlefish; in Fossil Lake, paddlefish may have been in competition for food with the extremely abundant *Knightia*.

The estimated maximum length of *Crossopholis* is about 120 cm (4 feet), but the usual length is 60-90 cm (2-3 feet). The skin of *Crossopholis* is covered with small, comb-like scales (see figure II.9) which do not interlock with each other. *Crossopholis* possessed stronger teeth and a shorter, narrower snout than the living paddlefish *Polyodon*, which MacAlpin (1947, page 226) suggests may indicate that *Crossopholis* was more adapted to "bottom grubbing" and ingestion of organisms larger than the plankton consumed by *Polyodon*. This theory is supported by the teleost bones preserved in the stomach region of the specimen shown in figure II.8b.

The Polyodontidae (paddlefish family) are known from as far back as the Upper Cretaceous Hell Creek deposits of Montana (MacAlpin, 1947). Today, paddlefish live only in two of the world's large river systems. *Polyodon* lives in the Mississippi River system of North America, and *Psephurus*, which is said to achieve a length of 6 meters (20 feet) (Eddy and Underhill, 1974), lives in the Yangtze River system in China.

GENERIC ETYMOLOGY

Crossopholis: cross — fringed, *pholis* — armed with scales.

NOMENCLATURE, SPECIFIC INFORMATION, REPOSITORIES, AND SUGGESTED REFERENCES.

Crossopholis magnicaudatus was first described by Cope (1883, page 1152) on the basis of an incomplete tail and body section (AMNH 2455). Later, Cope (1886, page 161) further described *Crossopholis magnicaudatus* on the basis of AMNH 2455 (illustrated in Cope, 1886, figure 2) and a skull (AMNH 2454, illustrated in Cope, 1886, figure 1). Other specimens of *Crossopholis* in public repositories are UW 12306 (a skull from F-2); UW 13418 (a skull from F-1); an uncataloged UW specimen (a caudal region from F-1); SMMP 78.9.21 (scales only); and SMMP 78.9.35 (a nearly complete fish from F-2). Cope's figured specimens are both F-1 specimens.

CROSSOPHOLIS MAGNICAUDATUS Cope 1883

= *Crassopholis magnicaudatus* Cope, 1883, pages 1152-1153, a typographical error by Cope.

Since there is currently only one known species of *Crossopholis*, lengthy specific description is not included here. Detailed descriptions can be found in Cope (1883, page 1152; 1886, page 161) and MacAlpin (1947). Additional data taken from the specimen in figure II.8a* are as follows:

Fin Rays (all fins imperfect): Pelvic ⩾28; Anal 31-40?; Dorsal ⩾25 ; Caudal about 27 total branched rays in the lower lobe. Dorsal, anal, and pelvic fin margins are very slightly falcate to nearly straight.

Dimensions: Head length (tip of snout to back of lateral extrascapular) 43 percent of the total length; body depth about 15 percent of the total length.

Other Data: About 12-13 dorsal scutes from the posterior base of the dorsal fin to the tip of the upper lobe of the caudal fin. Body depth greatest just behind the pectoral fin insertion, where it is about 15 percent of the total length.

A more complete description of LG 2.1, the specimen in figure II.8a, is in preparation by the author.

*Examination of the specimen illustrated in figure II.8b. (BHI-GR 900) was not completed in time to include results in this manuscript. Morphological data from this recently discovered specimen will undoubtedly greatly increase our knowledge about this species.

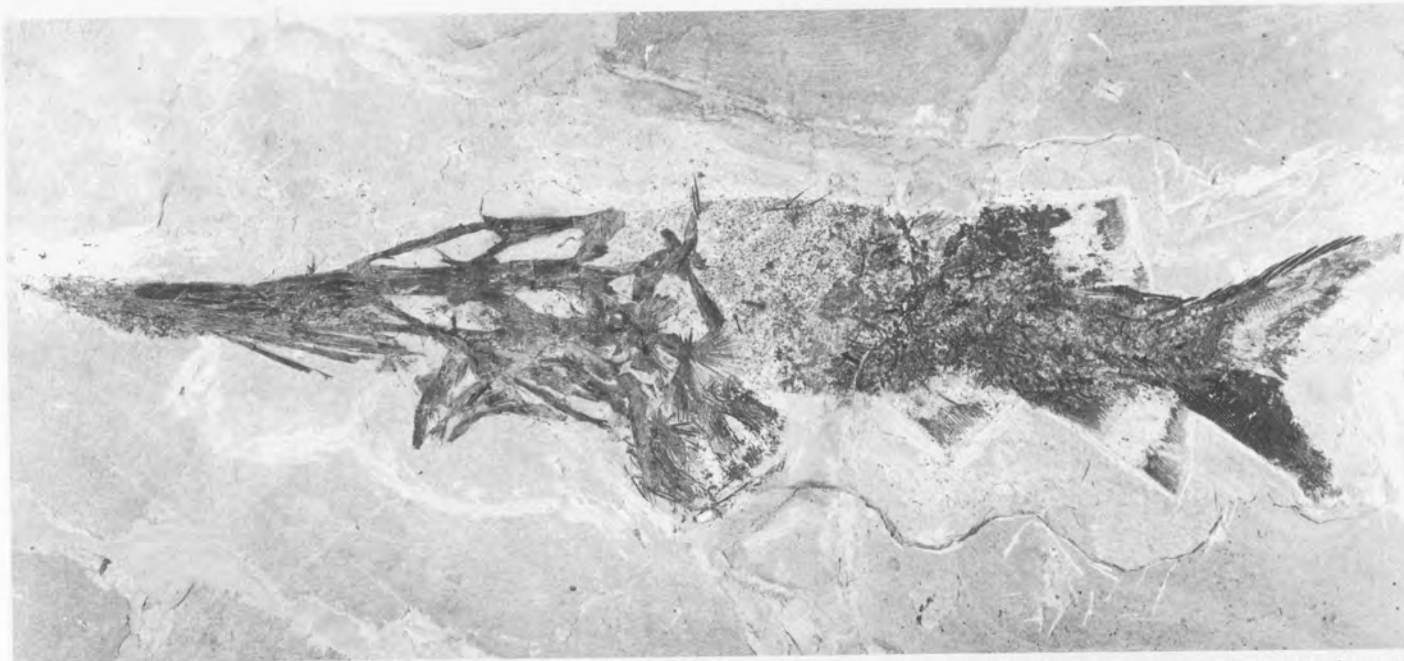


Figure II.8a. Complete specimen of the paddlefish *Crossopholis magnicaudatus* (BMNH P.61227). Complete paddlefish from the Green River Formation are extremely rare. Total length of specimen is about 49 cm (19¼ inches). From locality F-2 (vertebrae in upper lobe of tail are from a small *Diplomystus*). Posterior margins of pelvic, dorsal, and anal fins displaced somewhat during preservation.

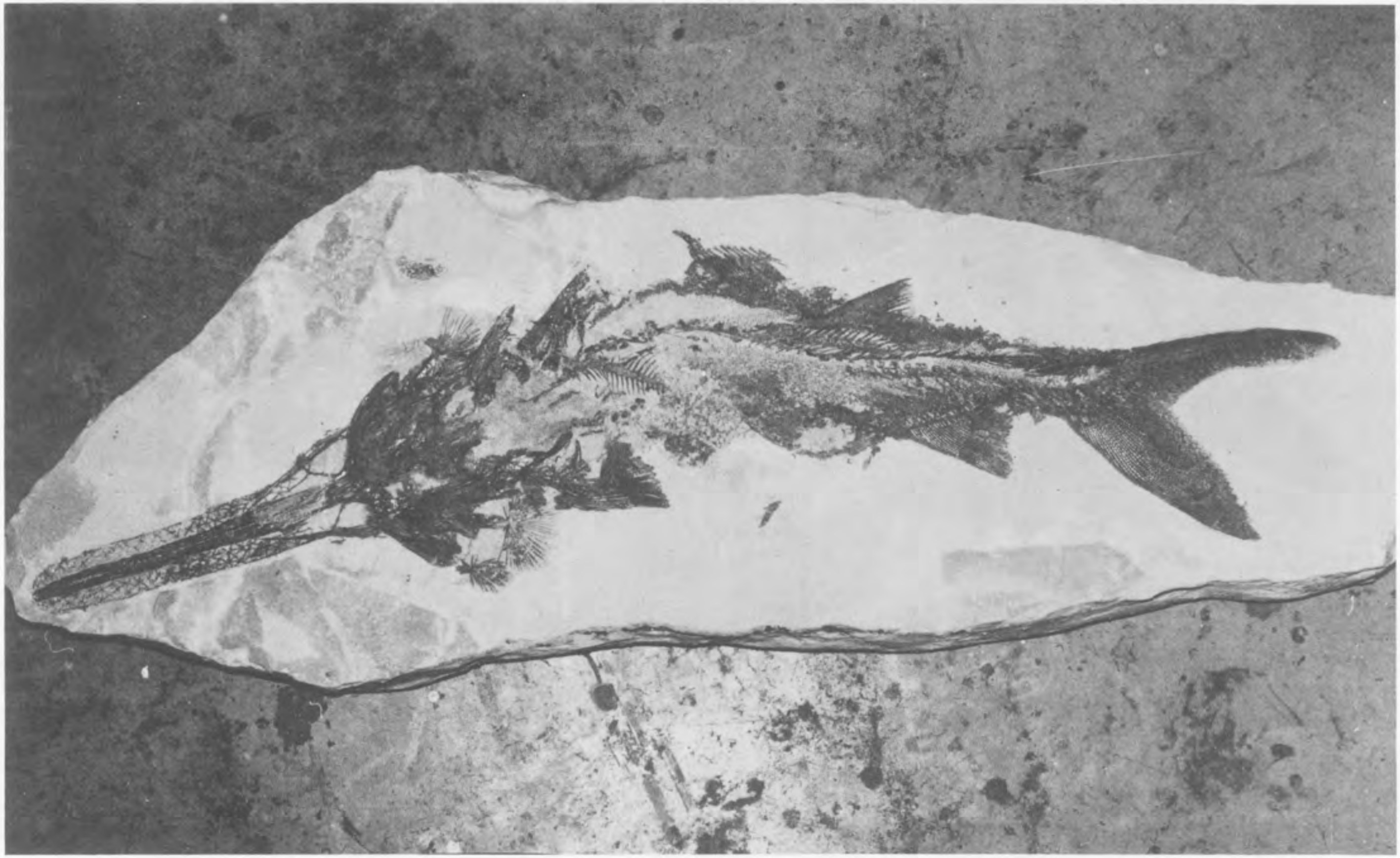


Figure II.8b. Complete specimen of the paddlefish *Crossopholis magnicaudatus* (BHI-GR 900). Total length is about 84 cm (33 inches). From locality F-2. Preserved with a dorsal view of head and trunk. Teleost bones preserved in abdominal region. Photograph courtesy of B.H.I. and Mr. Guido Dingerkus. Anterior end of rostrum is restored.

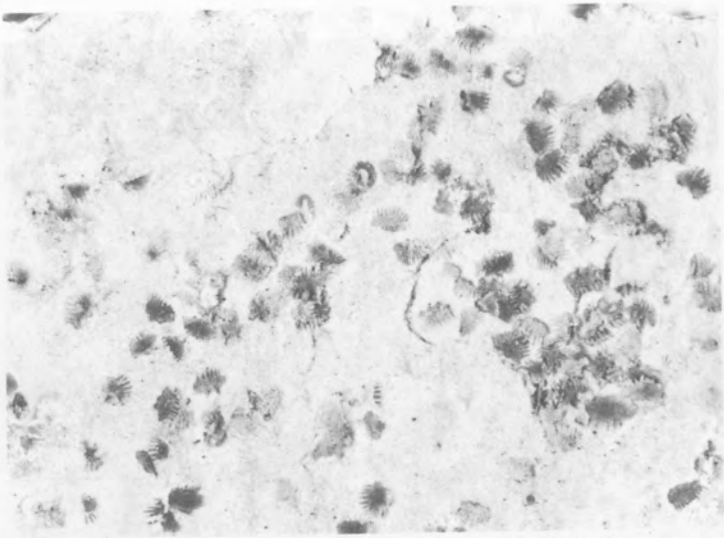


Figure II.9. Closeup of some scales from the specimen in figure II.8a. Each scale is about 1 mm long. (Scales are SMMP 78.9.21).

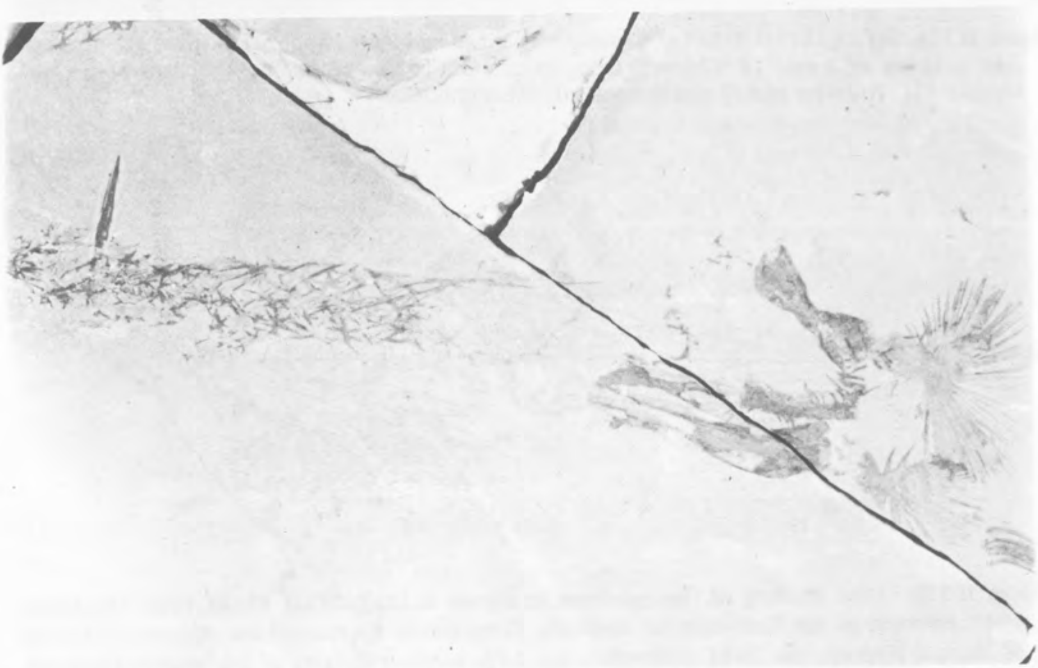


Figure II.10. Skull of *Crossopholis magnicaudatus* with most of the superficial bones missing, but an excellent view of the pharyngeal teeth, strainers (gill rakers), and the many small stellate bones that were in the rostrum or "paddle" of this fish. Length from anterior end of rostrum to posterior end of gill arch 26 cm (about 10 inches). Buffalo Museum of Science, N.Y.

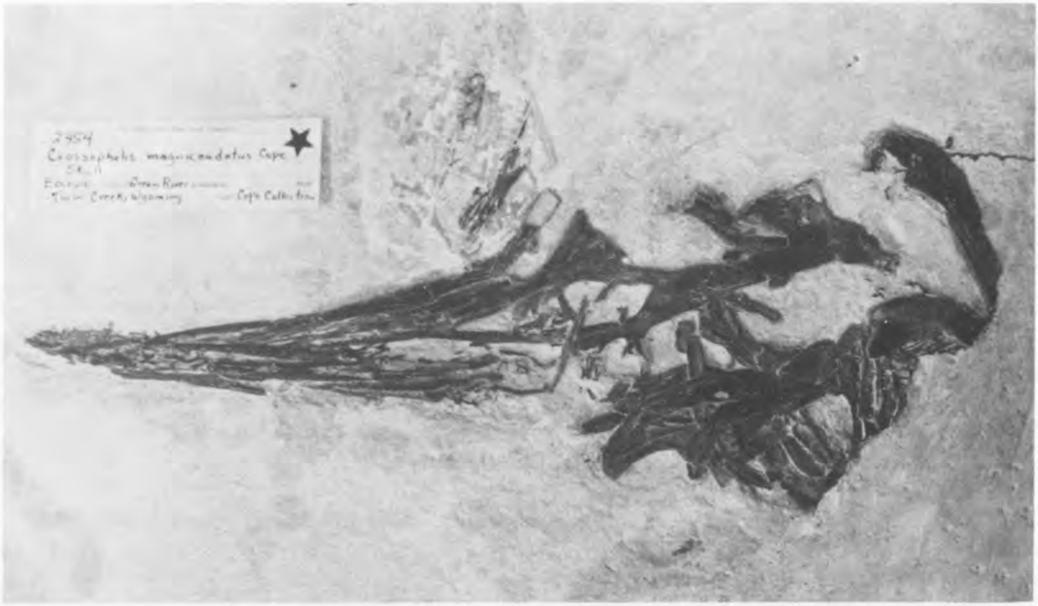


Figure II.11a. Skull (AMNH 2454) of *Crossopholis magnicaudatus* (Cope, 1883). Length of specimen is about 32.5 cm (12-¾ inches) from tip of snout to far end of the supracleithrum. From locality F-1. Anterior end of rostrum (snout) incomplete.

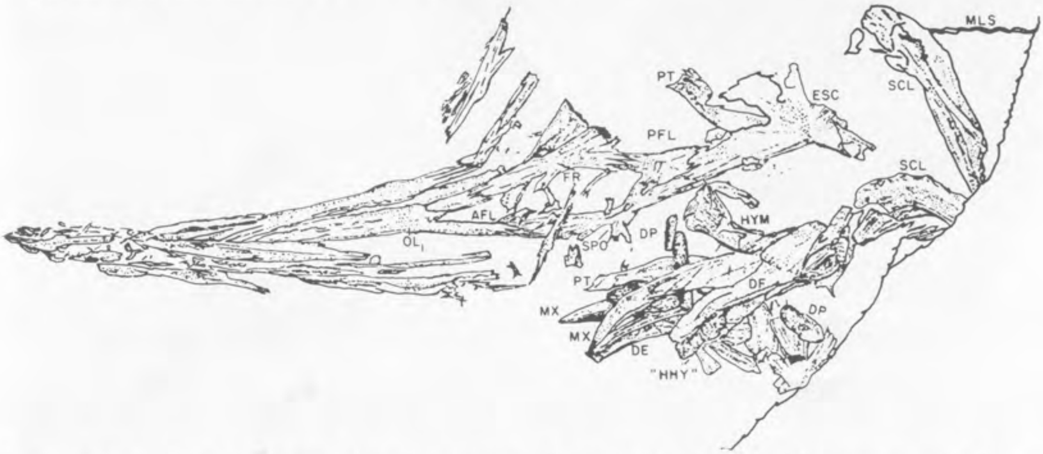


Figure II.11b. Line drawing of the specimen in Figure II.11a (AMNH 2454). From MacAlpin, 1947, courtesy of the University of Michigan. *Crossopholis magnicaudatus.* American Museum of Natural History, No. 2454. Abbreviations: AFL, anterior division of the fenestra longitudinalis; DE, dentary; DP, dentigerous plates; ESC, extrascapular; FR, frontal; "HHY," hypohyals; HYM, hyomandibular; IT, intertemporal; MLS, main laterosensory canal; MX, maxillary; OL, posterior outer lateral dorsorostal; PFL, posterior division of the fenestra longitudinalis; PT, pterygoid; SCL, supracleithrum; SPO, suprapostorbital.

Genus: *Lepisosteus* Lacèpéde 1803 (the gar)

Species:	*L. simplex* (Leidy 1873)	Figures II.12-II.13, II.18
	L. atrox (Leidy 1873)	Figures II.15, II.18
	L. cuneatus (Cope 1877)	Figures II.16-II.18

GENERAL INFORMATION

Lepisosteus, the gar, is represented in the Green River Formation by three described valid species. They are not common in the Green River Formation (with the exception of *L. cuneatus* in some localized Lake Uinta deposits), but they are widespread, and can be found in all of the main fish localities. Within the Green River Formation, *L. cuneatus* (the most common and smallest of the three species) is known only from Lake Uinta deposits. *Lepisosteus atrox* (the rarest and largest of the three species) and *L. simplex* (intermediate in both size and abundance) are known only from Fossil Lake. Two complete *Lepisosteus* specimens are known from Lake Gosiute. One is SMMP 78.9.25 from G-1 (figure II.14), a young juvenile not identifiable to species. The other is a 39 cm (15 inch) specimen with the ventral side of a dorsoventrally compressed skull showing. This larger specimen is also from G-1 (in a private collection) and may be *L. cuneatus*, but positive identification is impossible without preparation of the dorsal side of the skull. The largest known fish from the Green River Formation is the specimen in figure II.15a (*L. atrox*). This is still smaller than the maximum size for the living alligator gar *L. spatula*, which has been reported to exceed 3 meters (10 feet) in total length in the lower Mississippi River Valley (Eddy and Underhill, 1974). The smallest Green River gar specimen known to the author is shown in figure II.14 (possibly *L. simplex*). This 8.5 cm (3⅜ inch) juvenile was found at locality G-1 and shows the lance-shaped upper lobe on the caudal fin which indicates a very young fish.

Modern gar prefer shallow, weedy areas, swampy areas, streams, or rivers, which explains the scarcity of the gar in the deep water lacustrine deposits of F-1 and F-2 and their abundance in the deltaic and stream channel deposits of Lake Uinta (such as U-1). Living gar require a fresh water habitat, although some species frequent brackish and marine coastal waters (Suttkus, 1963). The origin of *Lepisosteus* in the Green River is Cretaceous and Paleocene fresh water rivers of the North American continent.

Gar have long, cylindrical bodies covered with diamond-shaped ganoid scales (see figure II.19). These scales are extremely hard because their surfaces are covered with ganoin, an enamel-like substance which takes a high polish, giving fossil gar scales their shiny appearance. These ganoid scales form a tough, hard, shell-like armor which protects mature *Lepisosteus* from most natural enemies. The only inhabitants of the

Green River Lakes that were able to prey on adult gar were crocodiles and alligators. The diet of adult gar is almost exclusively fish (Scott and Crossman, 1973). The Green River gar, like gar living today, were probably voracious, attacking smaller fish by slashing sideways and securing a firm hold on them with large and numerous teeth. Evidence of voracious dietary habits can be seen in figure II.14, where a young *Lepisosteus simplex* appears to have choked to death on a *Diplomystus*.

The genus *Lepisosteus* still survives today, predominantly in the Mississippi River drainage of North America, but also in Cuba and Central America south to Costa Rica (Nelson, 1976). Fossil gar are known from North America (Cretaceous to Recent), Europe (Cretaceous to Oligocene), Africa (Cretaceous), and India (Cretaceous) (Wiley, 1976).

GENERIC ETYMOLOGY

Lepisosteus: scales of bone

NOMENCLATURE, SPECIFIC INFORMATION, REPOSITORIES, AND SUGGESTED REFERENCES

There are other generic names used for Green River *Lepisosteus* in the literature. *Lepidosteus* was used by Marsh, Leidy, Eastman, and others; *Clastes* was used by Cope; and *Atractosteus* was used by Wiley (1976) for *L. atrox* and *L. simplex*. *Lepidosteus* and *Clastes* were both invalid and the species was assigned to the older genus *Lepisosteus* (Lacépède, 1803, page 331), *Atractosteus* is not well defined with respect to Green River fossil gar, and so *Lepisosteus*, the better known generic name, is used in this paper.

Lepisosteus simplex and *L. atrox* were first described from the Bridger Formation on the basis vertebrae and isolated skull elements (Leidy, 1873). The earliest descriptions of relatively complete gar from the Green River Formation were by Cope (1878: *L. cuneatus*) and Eastman (1900: *L. simplex* and *L. atrox*). Since then, many more complete gar specimens have been found; some of the more complete specimens in public repositories are listed in the specific descriptions given here.

There appear to be three valid species of Green River gar described. The specific information and keys presented here are based on information from Eastman (1900), Cope (1884), Wiley (1976), and a few additional specimens. A detailed review of the Green River gar is still needed. As more complete specimens are found, meristic and measurement data (which are very sparse in the literature) can be added to those presented here.

Some of the main differences between the three species of Green River gar are shown in figure II.18 and in table II.1. All synonymies here follow Wiley (1976).

LEPISOSTEUS SIMPLEX (Leidy 1873)

= *Lepidosteus glaber*, Marsh 1871*; *Lepidosteus simplex*, Leidy 1873; *Clastes glaber*, Cope 1877; *Lepidosteus aganus*, Cope 1877; *Clastes integer*, Cope 1877; *Lepisosteus glaber*, Hay, 1902; *Lepisosteus aganus*, Hay 1902; *Lepisosteus*

*Name rejected by first (Cope), second (Eastman) and third (Wiley) revisors as *Nomen nudum*; but Wiley (1976, page 68) includes it in his list of name synonymies.

intiger, Hay, 1902; *Clastes aganus*, Merril 1907; *Lepidosteus integer*, Loomis 1907: *Atractosteus simplex*, Wiley 1976; and possibly *Clastes cycliferus*, Cope 1872.

The first gar reported from the Green River Formation was a specimen of this species reported by Marsh in 1871; but as he gave neither description nor illustration, Leidy (1873) is given credit for describing and naming *L. simplex*. The type material (USNM P.2174) consists of vertebrae and a basioccipital from the Bridger Formation (see Wiley, 1976). The first articulated specimen described as this species was MCZ P.5168 from F-1 (see Eastman, 1900).

Lepisosteus simplex has an average total length of about 60 cm (2 ft.) and is found at localities F-1 and F-2. It is preserved in the Green River Formation with two different orientations of the skull, which are sometimes mistaken to represent two different species of fish. Because of its slightly broad head, the skull on some specimens is often twisted and compressed in an oblique dorso-ventral position, as in the specimen shown in figure II.12b. Other specimens are preserved in lateral position with no such twisting of the skull and thus have a much thinner looking skull, as in figure II.12a.

The following information is based on PU 14585 (figure II.12a); USNM 4754 (illustrated in Eastman, 1900, plate 1, top); AMNH 7829; UW 12305 (illustrated in McGrew and Casilliano, 1975, figure 15); and the specimen in figure II.12b.

Fin Rays: Pectoral 11 (n=1); Pelvic 5-6 (n=3); Anal 7 (n=4); Dorsal 7 (n=4); Caudal 12 (n=4). The posterior fin margins of the dorsal, anal, and caudal fins are rounded. The base of the dorsal fin is shorter than that of the anal fin (n=3). All fins are weaker than in *L. atrox*.

Scales: Ganoid. Scales along the lateral line number about 44-52 (n=3, $\overline{X}$=47.67) and the flank scales of the posterior part of the body are considerably elongated in an antero-posterior direction (more so than in *L. atrox*).

Dimensions: Maximum body depth about 17-22 percent of the total length (n=4), about 19-25 percent of the standard length (n=4); head length about 25-29 percent of the total lenth (n=4), about 30-34 percent of the standard length (n=4) (head length measured from anter- (n=3) (head length measured from anterior tip of nasals to posterior end of supratemporals; see figure II.19b for location of these skull elements).

For further study and description see Eastman (1900) and Wiley (1976).

LEPISOSTEUS ATROX (Leidy 1873)

= *Lepidosteus atrox*, Leidy 1873; *Lepidosteus notabilis*, Leidy 1873; *Clastes anax*, Cope 1873; *Clastes notabilis*, Cope 1877; *Clastes atrox*, Cope 1877; *Lepisosteus notabilis*, Hay 1902; and *Atractosteus atrox*, Wiley 1976.

This species of Green River gar is the rarest of the three species, known only from a few specimens. *Lepisosteus atrox* is the largest known species of fish in the Green River Formation. Of the two relatively complete specimens known, the specimen in figure II.15a (private collection) is about 168 cm (5 ft. 6 inches) in total length and MCZ P.5168 is 166 cm (5 ft. 5 inches) in total length, giving an average length of 167 cm (5 ft. 5½ inches) (n=2). A third specimen of *L. atrox* (USNM 4755) consists of a skull and small section of the body belonging to a individual which would have measured close to 152 cm (5 ft.) in total length. Both MCZ P.5168 and USNM 4755 are from the Green River deposits of Fossil Lake (USNM 4755 is an F-1 specimen) and not from the Bridger Formation as listed in Wiley (1976, page 111). All known skulls of *L. atrox* are preserved with oblique-dorsal or dorsal views. The holotype (USNM P.2145), from the Bridger Formation, is an anterior vertebra indistinguishable from other large gar species (Wiley 1976). The first articulated gars described as this species were USNM 4754 and MCZ P.5168, both from F-1 (see Eastman, 1900).

The following information is based on MCZ P.5168 (illustrated in Eastman, 1900, plate 1, bottom); USNM 4755 (illustrated in Eastman, 1900, plate 2; Wiley, 1976, figures 61 and 62); and the specimen shown in figures II.15a and II.15b.

Fin Rays: Pectoral (both incomplete) $\geqslant 7$ (n=2); Pelvic 6 (n=2); Anal 8 (n=1); Caudal 12 (n=2), fin margins not visible. The base of the anal fin is shorter than that of the dorsal fin (n=1). All fins are stronger than in *L. simplex*.

Scales: Ganoid. Scales along the lateral line number about 51-60 (n=2, $\overline{X}$=55.50). The flank-scales of the posterior part of the body are not nearly as anteroposteriorly elongated as in *L. simplex* or L. cuneatus.

Dimensions: Maximum body depth about 17-18 percent of the total length (n=2), about 20-22 percent of the standard length (n=2); head length about 28-30 percent of the total length (n=2), about 33-36 percent of the standard length (n=2).

Other Specific Characteristics: Wiley (1976, page 76) found that *L. atrox* also differs from *L. simplex* and *L. cuneatus* in having very thick skull-roofing bones that have high bony ridges with transverse striations capped with minute enameloid tubercles.

For further study and description see Eastman (1900) and Wiley (1976).

LEPISOSTEUS CUNEATUS (Cope 1877)*

= *Clastes cuneatus*, Cope 1877.

This species of Green River gar has been reported only from Lake Uinta deposits and is usually found with a total length of 31-38 cm (12-15 inches) and a maximum total length of about 50 cm (20 inches). It is often less crushed or compressed than *L. simplex* or *L. atrox* because of the less compactable nature of some of Lake Uinta's main fish bearing sediments (sandstone at U-1). It is not uncommon to find *L. cuneatus* preserved "in the round" (almost completely uncompressed), as are many of the specimens in figure II.17 (from U-1).

The following data are based on the holotype (AMNH 2517, illustrated in Cope, 1884, plate I, figure 6); SMMP 66.14.1 (figure II.17); SMMP 66.8.1; SMMP 77.32.1; SMMP 66.14.5; AMNH 4624 A, B; AMNH 4625; and the specimen illustrated in figure II.16.

*Though this species was named by Cope in 1877, it was not described by him until 1884. The holotype (AMNH 2517) is from the "Manti beds" of Lake Uinta (see Cope, 1880). The location of these Green River Formation "beds" is in or near Manti, Utah (Cockerell, 1909c).

Fin Rays: Pectoral 9-10? (n=1); Pelvic 6 (n=6); Anal 7 (n=4); Dorsal 7 (n=4); Caudal 12 (n=5).

Scales: Ganoid. Scales along the lateral line number about 40-44 (n=4, $\overline{X}$=42.00). The flank-scales of the posterior part of the body are enlongate in an anterior-posterior direction and resemble those of *L. simplex* more than *L. atrox*.

Dimensions: Body depth about 23 percent of the standard length (n=2); head length about 27 to 30 percent of the standard length (n=2).

Other Specific Characteristics: *L. cuneatus* differs from the other two species of Green River gar in that the width of the opercle and subopercle is greater than or equal to the distance between the opercle and the posterior-most point of the orbital margin. In *L. simplex* and *L. atrox*, the width of the opercular and subopercular is considerably less than this distance (compare these distances in figure II.16b and figure II.17). Also, the snout is much shorter in *L. cuneatus* than in *L. simplex* or *L. atrox* (see figure II.18; compare figures II.16 with figures II.12 and II.15).

For further study, see Cope (1884, page 55) and Wiley (1976).

Table II.1. Diagnostic characters distinguishing the three species of Green River gar.

	L. simplex	*L. atrox*	*L. cuneatus*
Number of dorsal fin rays	usually 7	usually 8	usually 7
Dorsal fin base	shorter than anal fin base	longer than anal fin base	shorter than anal fin base
Shape of frontal bones, and snout length		SEE FIGURE II.18	
Where found	Fossil Lake deposits	Fossil Lake deposits	Lake Uinta deposits and possibly Lake Gosiute deposits*
Average total length (of known specimens)	about 61 cm (2 feet)	over 1.5 m (5 feet)	31-40 cm (12-16 inches)
Scales along lateral line	44-52 (n=3, $\overline{X}$=47.67)	51-60 (n=2, $\overline{X}$=55.50)	40-44 (n=4, $\overline{X}$=42.00)
Distance between most posterior point of orbital margin and anterior margin of opercle	greater than width of opercle	greater than width of opercle	less than width of opercle

*One complete short-snouted adult specimen is known from G-1 and is either *L. cuneatus* or a new species. Because only a crushed ventral view of the skull is visible, positive identification to species is not possible without further preparation.

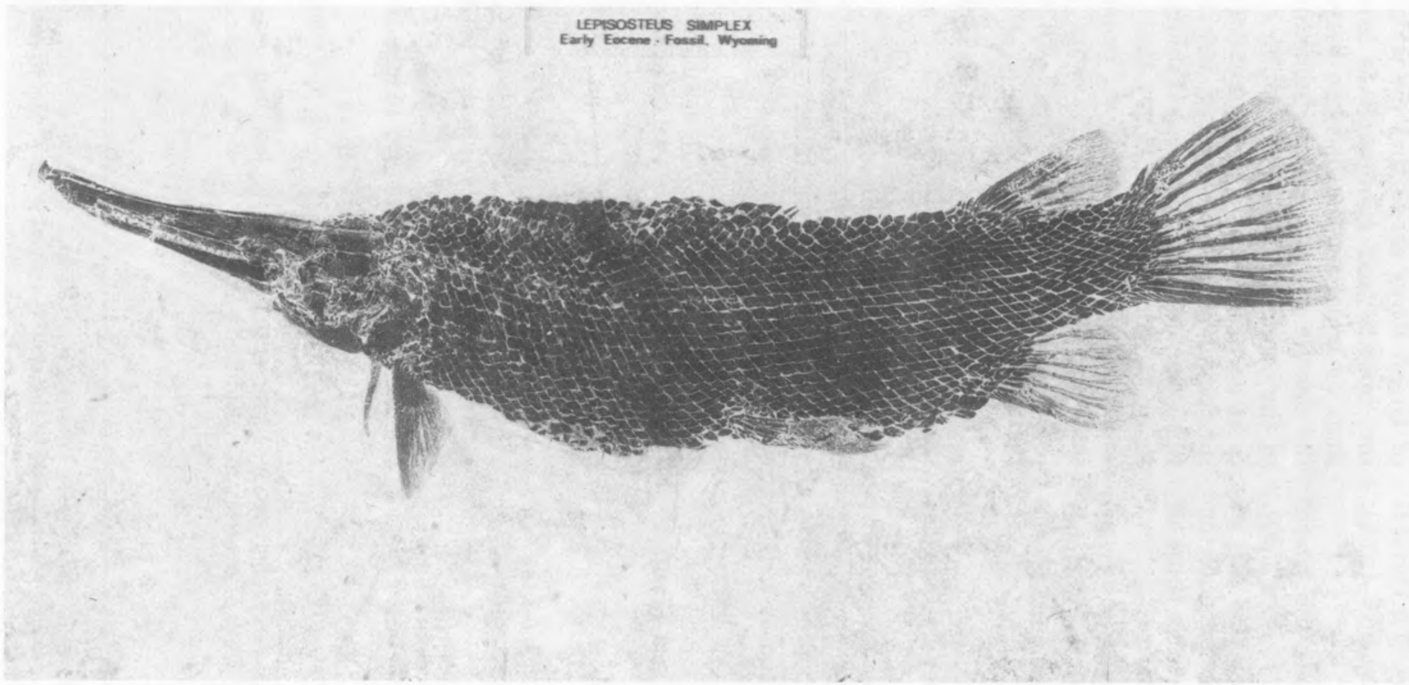


Figure II.12a. Specimen of *Lepisosteus simplex* with a laterally compressed skull (PU 14585). Total length is about 72 cm (28 inches). From locality F-1. Photo courtesy of Willard Starks, Princeton University.

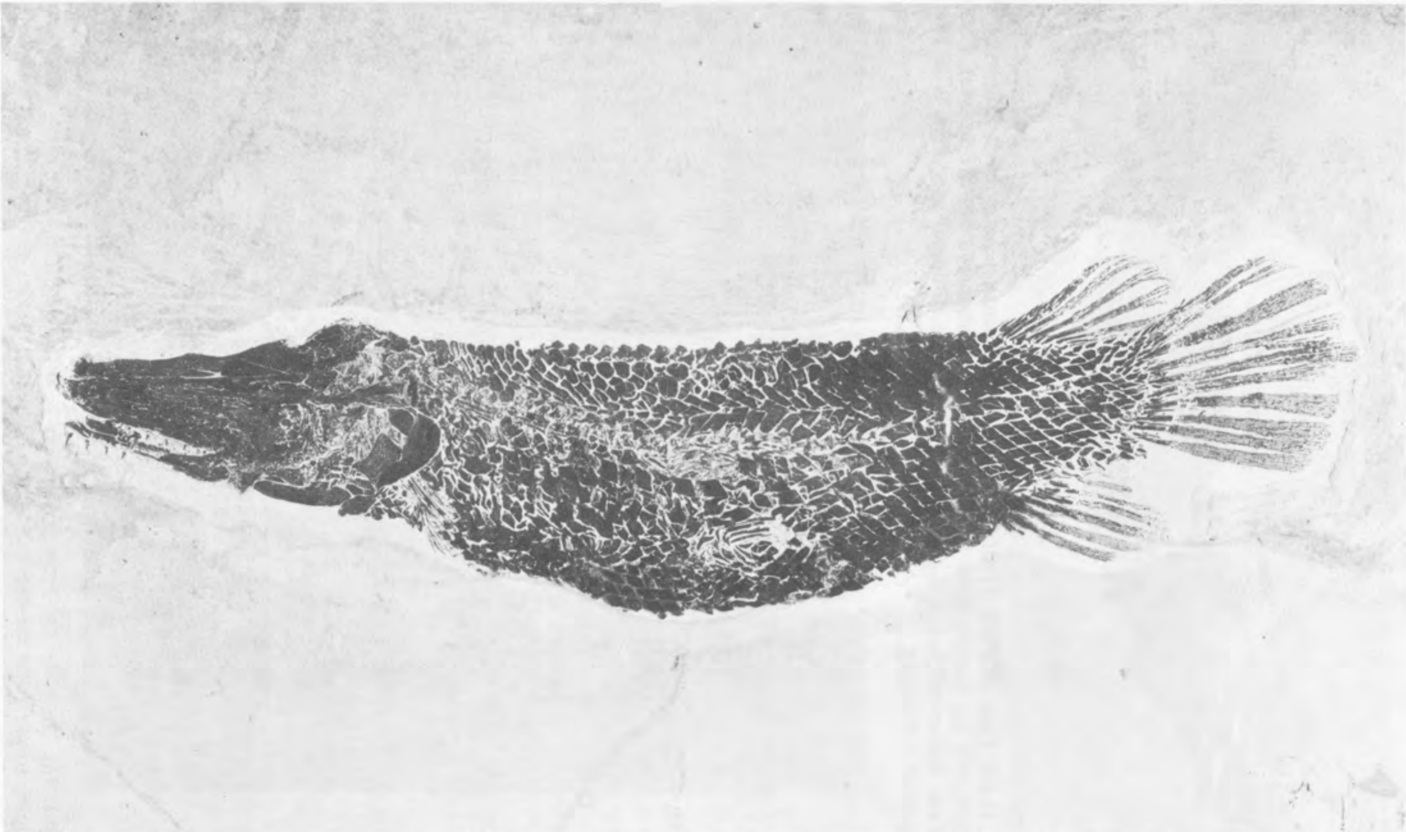


Figure II.12b. *Lepisosteus simplex* with an oblique dorso-ventrally compressed skull (BMNH P.61228). Total length is about 69 cm (27 inches). From locality F-1. Caudal and anal fins incomplete.

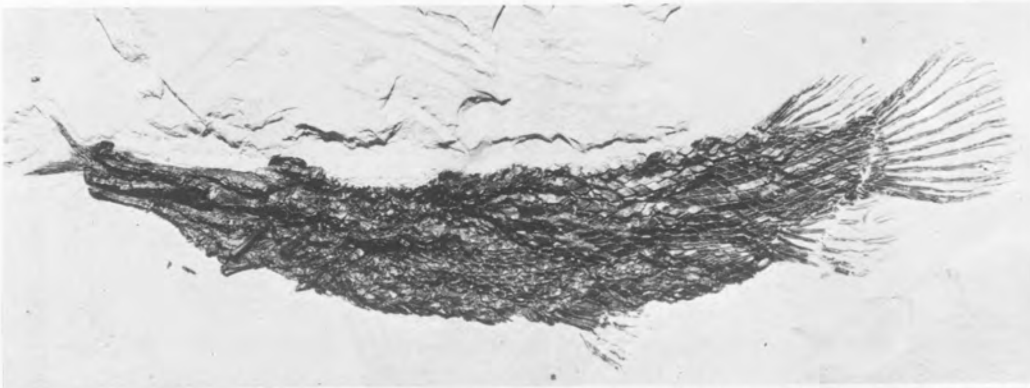


Figure II.13. Cast (FBNM 1) of a specimen of *Lepisosteus simplex* swallowing a specimen of *Diplomystis* sp. Length from tail tip to tail tip is about 41 cm (16 inches). Photo courtesy of William Reiter of the U.S. National Park Service. Original specimen is in the collection of Princeton University.

Figure II.14. Juvenile gar from locality G-1, total length 8.5 cm (3 3/8 inches). Note the lance-shaped upper lobe on the caudal fin, which indicates a very young fish. Latex peel SMMP 78.9.13 (original is BHI-GR 210).

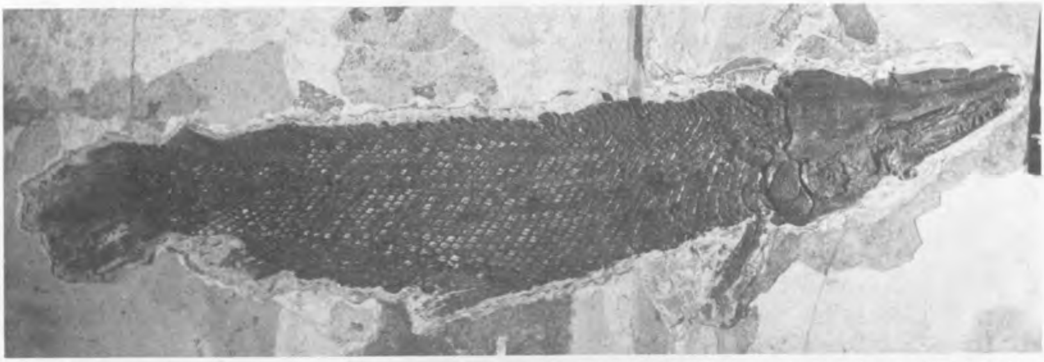


Figure II.15a. *Lepisosteus atrox:* a typically large specimen of this large species of gar. Total length about 1.68 meters (5 feet 6 inches). This specimen is in the collection of Carl Ulrich. Photo courtesy of Carl and Shirley Ulrich.

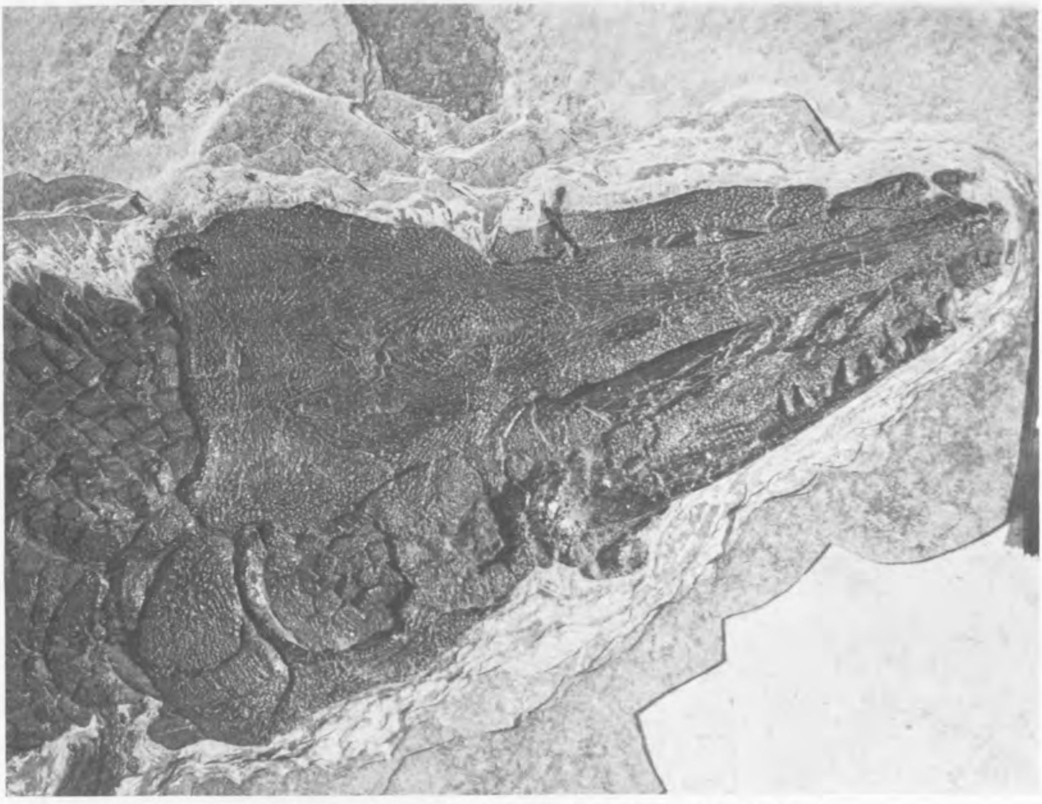


Figure II.15b. Skull from figure II.15a. Skull length about 41 cm (15 inches).

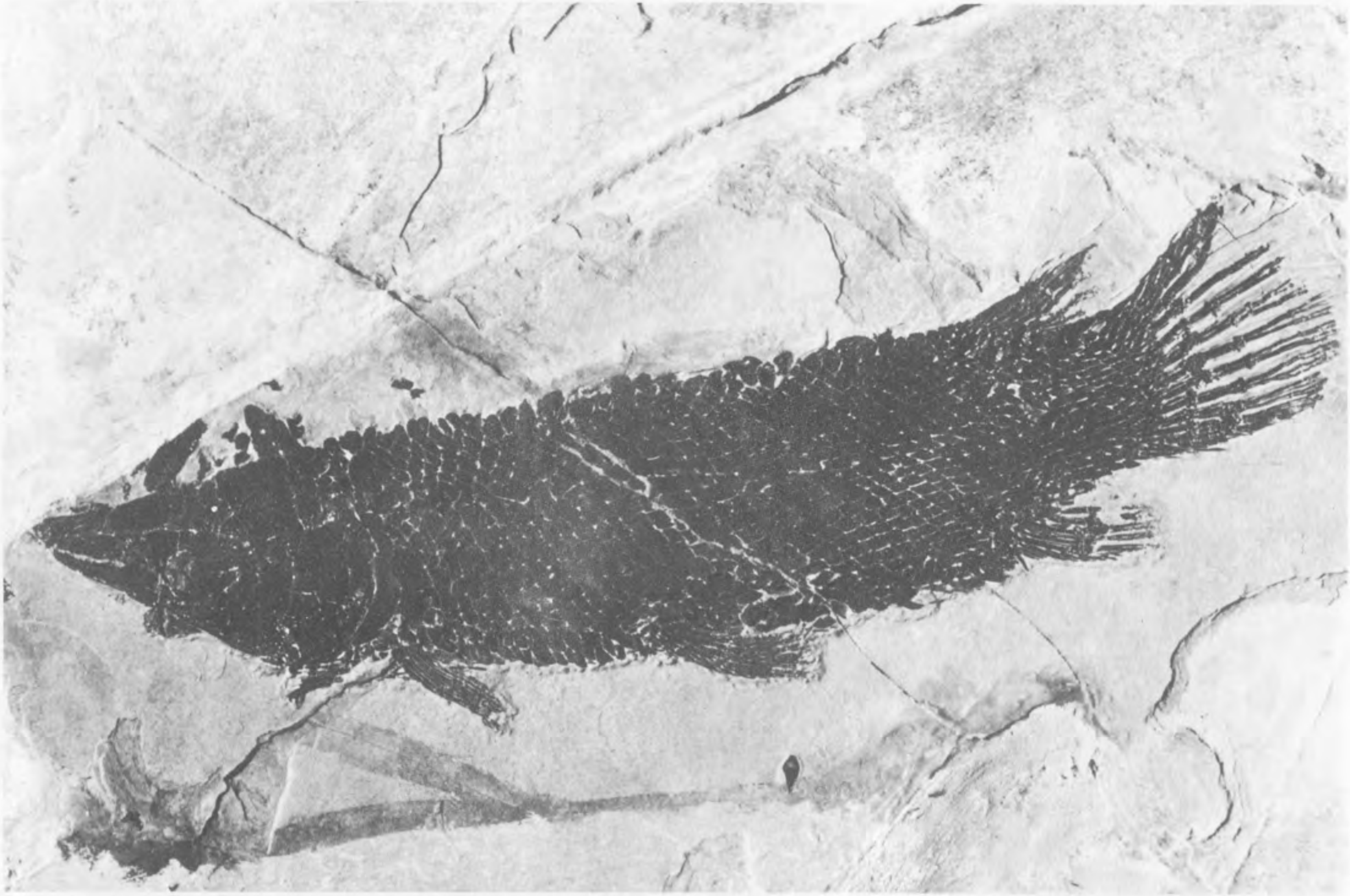


Figure II.16. *Lepisosteus cuneatus*, a complete specimen from Middle Eocene Lake Uinta. Total length 45 cm (18 inches). Note the shorter snout than in *L. simplex* or *L. atrox*. BMNH P.61229. Preparation by Robert Harris.

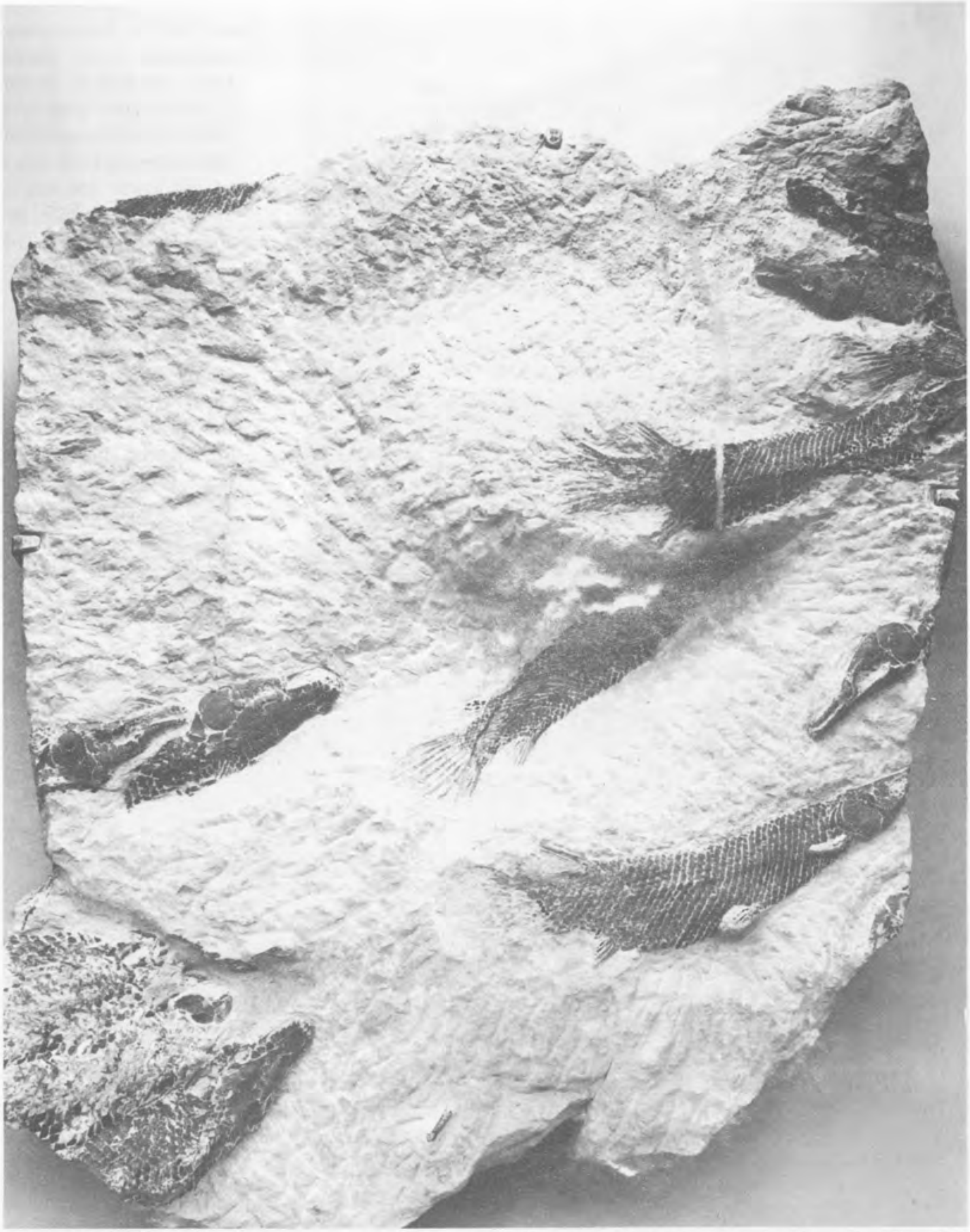


Figure II.17a. *Lepisosteus cuneatus:* a mass mortality slab of this gar species from locality U-1 (SMMP 66.14.1). Average total length of complete specimens about 31 cm (12 inches). Photo courtesy of Bruce Erickson and the Science Museum of Minnesota. Specimen prepared by SMMP.

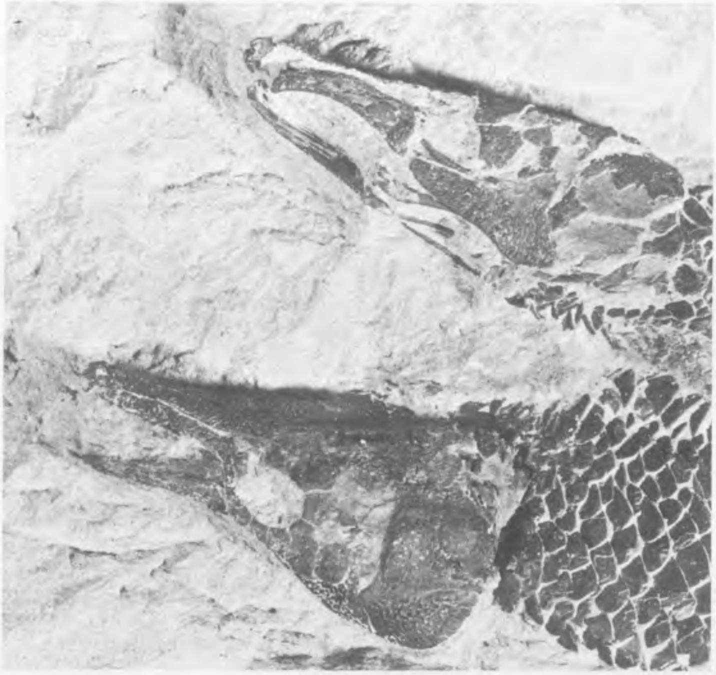


Figure II.17b. *Lepisosteus cuneatus*: two skulls from the slab in figure II.17a. Upper skull is a ventrally oblique lateral view showing both sides of the lower jaw and is about 85 mm (3½ inches) from the tip of the snout to the posterior edge of the opercle; lower skull is a fine lateral view of a skull about 85 mm (3½ inches) from the tip of the snout to the posterior edge of the opercle. Note the extremely short length of the upper and lower jaws, compared with that of all other gar species.

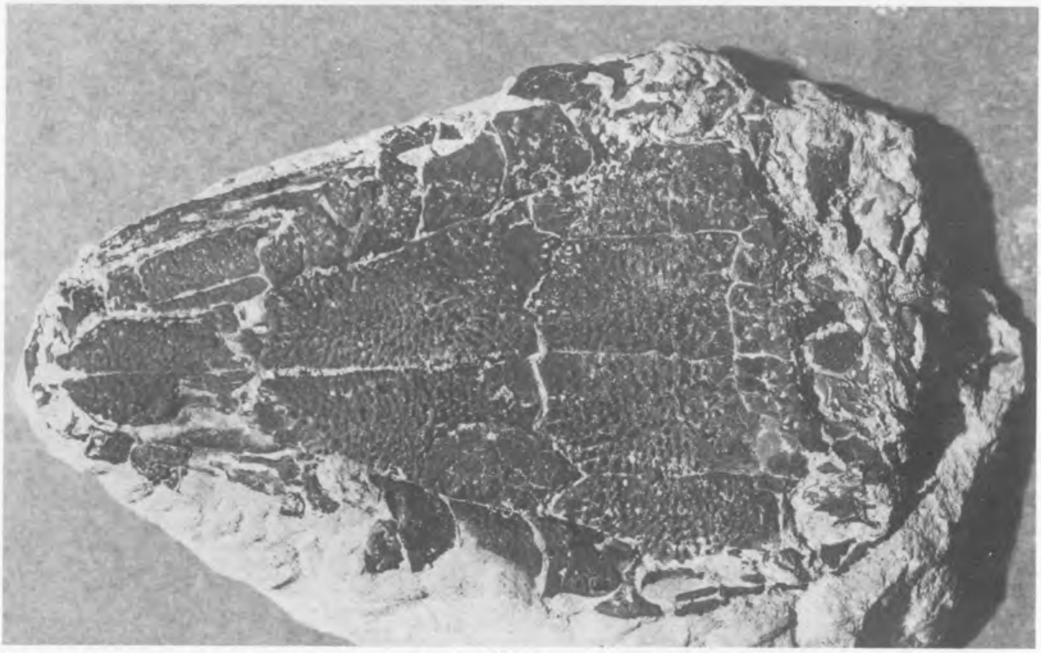


Figure II.17c. *Lepisosteus cuneatus* skull (SMMP 66.14.3), dorsal view; head length 84 mm (about 3½ inches).

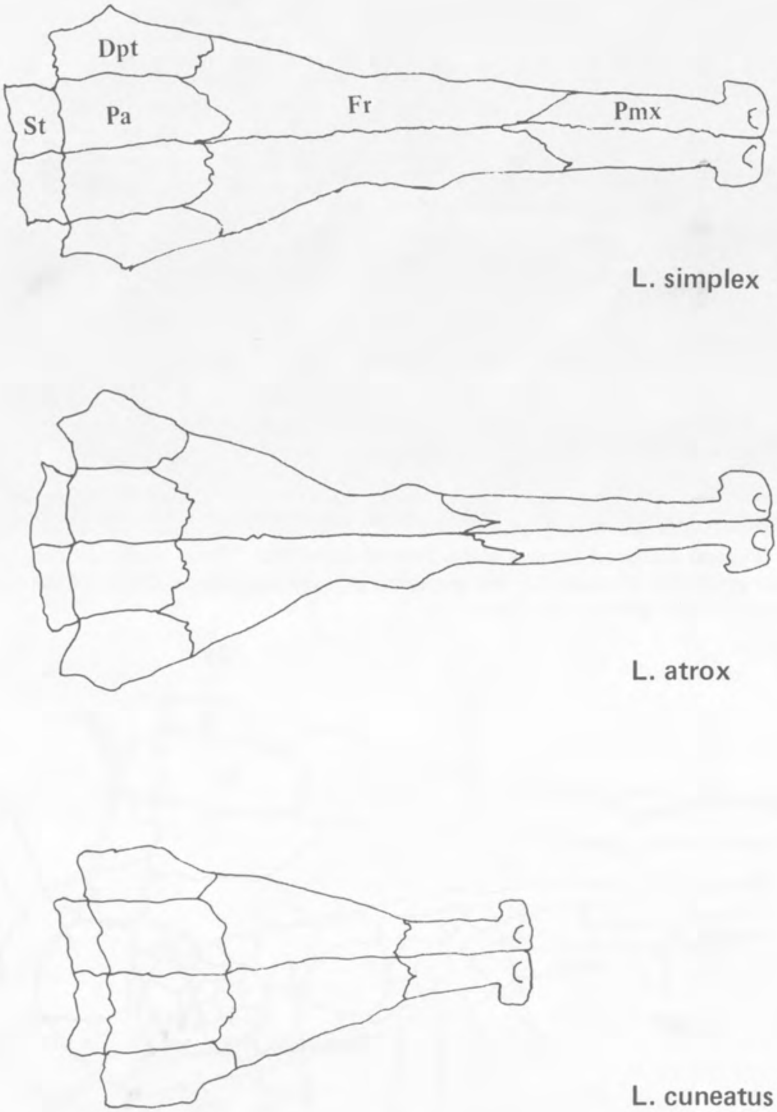


Figure II.18. Comparison of some dorso-cranial elements of the three Green River gar species. Drawings are of average-sized adult specimens; drawings of *L. simplex* and *L. atrox* are modified after Wiley (1976), and the drawing of *L. cuneatus* was made from SMMP 66.14.3. Note the relative shortness of the snout of *L. cuneatus*. Dpt. = dermopterotic; Fr = frontal; Pa = parietal; Pmx = premaxilla; st = supratemporal.

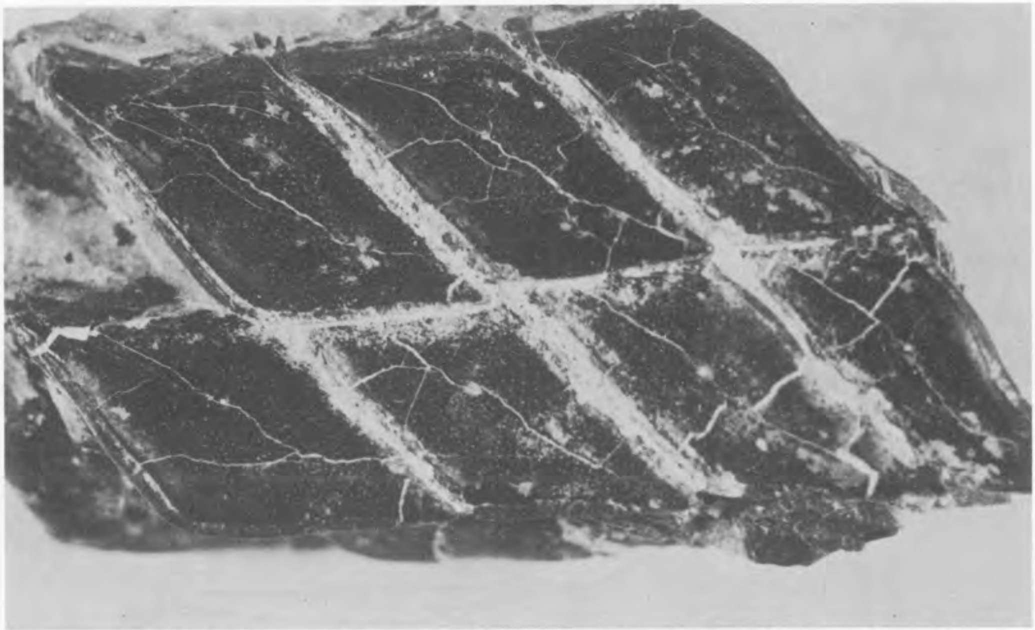


Figure II.19a. Typical diamond-shaped scales from *Lepisosteus*. These scales are very widespread and relatively abundant throughout the lacustrine and stream channel facies of the Green River Formation.

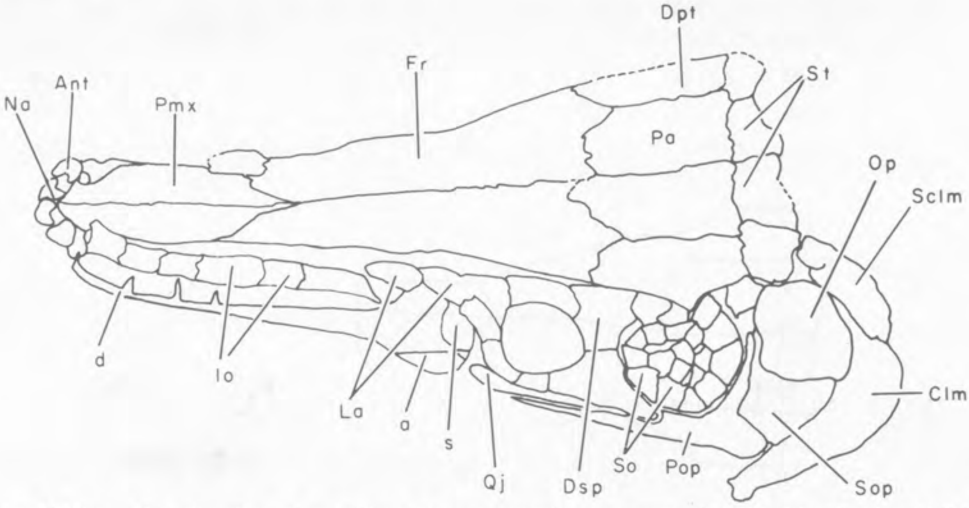


Figure II.19b. Line drawing of an oblique dorso-ventrally compressed skull of *L. simplex* (AMNH P. 4302), from Wiley (1976). Skull length 14.4 cm. a = angular; Ant = antorbital; Clm = cleithrum; d = Dentary; Dpt = dermopterotic; Dsp = dermosphenotic; Fr = frontal; Io = infraorbital; La = lacrimal; Na = nasal; Op = opercle; Pa = parietal; Pms = permaxillary; Pop = preopercle; Qj = quadratojugal; s = surangular; Sclm = supracleithrum; So = suborbital; Sop = subopercle; St = supratemporal.

Genus: *Amia* Linnaeus 1766 (the bowfin)

Species: *A. uintaensis* (Leidy, 1873) — Figures II.20, II.23, II.26

A. fragosa (Jordan, 1927) — Figures II.21-22, II.24-26

GENERAL INFORMATION

Amia, the bowfin or fresh water dogfish, is represented in the Green River Formation by at least two valid species, *A. uintaensis* and *A. fragosa*, with *A. fragosa* the more common species. Complete *Amia* specimens are very rare in the Green River Formation (much rarer than gar specimens), with only about a dozen complete to nearly complete specimens known; but the finding of isolated skull elements, vertebra, and scales of *Amia* in nearly every main Green River fish quarry demonstrates that the genus was widespread.

Amia specimens from the Fossil Lake localities are quite large, with a maximum size of about 1.25 meters (4 feet, 1 inch), larger than the one living species, *Amia calva*, which reaches a maximum length of about 90 cm (3 feet) (Nelson, 1976). Specimens from Eocene Lake Gosiute, such as those in figures II.24 and II.25, tend to be much smaller in average size than Fossil Lake specimens.

Amia is easy to recognize because of its abbreviated heterocercal tail (like that of its distant relative, *Lepisosteus*, the gar) and its long dorsal fin, consisting entirely of soft rays, which arches in a bow over most of the fish's length (hence the common name, "bowfin"). Isolated scales of *Amia* (figure II.23) are easily identifiable by their peculiar rounded-off rectangular shape.

Modern bowfins are voracious, feeding on all kinds of animal life, although fish (including other bowfins) form a large portion of their diet. According to Boreske (1974), the two Green River species of *Amia* were adapted for two different feeding habits. The sharp palatal teeth of *Amia uintaensis* indicate a more predaceous (fish-eating) habit than *A. fragosa's*. That *Amia fragosa's* palatal teeth were more adapted to crushing indicates that it may have fed mainly on the abundant mollusks and crustaceans in the Green River lakes.

Today, the *Amiidae* are represented by one species, *Amia calva*, which inhabits fresh waters of the eastern United States. Fossil *Amia* are known from North America (Early Cretaceous to Recent); Europe (Paleocene to Oligocene) and Asia (Eocene).

GENERIC ETYMOLOGY

Amia: an ancient name of a fish

NOMENCLATURE, SPECIFIC INFORMATION, REPOSITORIES, AND SUGGESTED REFERENCES

Other generic names which have been used for Green River *Amia* in the literature are *Kindleia* by Jordan, *Paramiatus* by Romer and Fryxell, *Protamia* by

Leidy, and *Pappichthys* by Cope, all found by Boreske (1974) to be synonyms of the genus *Amia*. Boreske (1974, page 4) accidentally introduced another genus, *Paramia*, into the literature, which he presented as an unused alternate name for *Paramiatus*.

Amia uintaensis was first described on the basis of anterior trunk vertebrae (ANSP 5558) from the Bridger Formation (Leidy, 1873), and *A. fragosa* on the basis of a partial right dentary from the Edmonton Formation in Alberta, Canada (Jordan, 1927). The earliest descriptions of complete or nearly complete *Amia* from the Green River Formation were by Romer and Fryxell (1928: *A. fragosa*) and by Boreske (1974: *A. uintaensis*). Since these descriptions, additional complete specimens have been found, and a list of complete and nearly complete Green River *Amia* is provided here with the specific descriptions.

Some of the main differences between the two species of Green River bowfin are shown in figure II.26 and table II.2. All synonymizations of Green River *Amia* species given here are explained in detail by Boreske (1974). All vertebral counts given here for *Amia* are total counts, including diplospondylous centra (vertebrae which bear no ribs or arches). I disagree with Boreske's counts for caudal-fin lepidotrichia in *A. fragosa*. I counted 20 or 21 lepidotrichia for both FMNH PF2201 and MCZ 5341. For *A. uintaensis* (specimen PU 13865) I got the same count as Boreske (23). Consequently, caudal-fin lepidotrichia should probably not be used in distinguishing between *A. fragosa* and *A. uintaensis*.

AMIA UINTAENSIS (Leidy 1873)

= *Protamia uintaensis*, Leidy 1873; *Protamia media*, Leidy 1873; *Pappichthys plicatus*, Cope 1873; *Pappichthys sclerops*, Cope 1873; *Pappichthys laevis*, Cope 1873; *Pappichthys symphysis*, Cope 1873; *Pappichthys corsonii*, Cope 1873; and *Pappichthys medius*, Cope 1884.

Amia uintaensis is known from the Green River Formation by two relatively complete specimens, both of which are large: PU 13865 (85 cm or about 2 feet, 8 inches in total length) from F-1, and SMMP 78.5.1 (125 cm or 4 feet, 1 inch in total length) from F-2. The dorsal fin is incomplete on SMMP 78.5.1, so the number of dorsal rays for *A. uintaensis* is still unknown. There are no known complete *A. uintaensis* specimens from Eocene Lake Gosiute or Lake Uinta. *A. uintaensis* is rarer than *A. fragosa* in Fossil Lake.

The following information is based on PU 13865 and SMMP 78.5.1, both nearly complete fish, and AMNH 785, a caudal portion of a fish.

Fin Rays: Pectoral 16 (n=1); Pelvic 7-9 (n=2); Anal 9-10 (n=2); Dorsal (unknown); Caudal about 19-21, branched (n=2). Fin margins incomplete on all specimens.

Pterygiophores: Dorsal (unknown); Anal 9 (n=1).

Vertebrae: Total about 83-85 (n=2).

Scales: Cycloid. On SMMP 78.5.1 there are about 7 scale rows above the vertebral column (at anterior end of dorsal fin).

Dimensions: Maximum body depth about 30 percent of the total length, 37 percent of the standard length (SMMP 78.5.1); head length about 25-27 percent of the total length (n=2), about 30-34 percent of the standard length (n=2).

Other Information: Palatal and vomerine teeth of *A. uintaensis* long, curved, and sharp (see figure II.26).

For more detailed description see Boreske (1974).

AMIA FRAGOSA* (Jordan 1927)

= *Kindleia fragosa*, Jordan 1927; and *Paramiatus gurleyi*, Romer and Fryxell 1928.

Complete specimens are known from Fossil Lake deposits (F-1 and F-2) and Lake Gosiute deposits (G-1 and G-4). The specimens from Fossil Lake are considerably larger than those of Lake Gosiute, but not as large as *A. uintaensis*. Maximum known total length for *A. fragosa* in Fossil Lake deposits is about 70 cm (27½ inches; FMNH PF2201) but the usual length is between 28 and 39 cm (11-15 inches), based on MCZ 5341 from F-1 and three relatively complete specimens in private collections from F-2. The only complete *A. fragosa* from Lake Gosiute known to the author are the specimen in figure II.25 and SMMP 78.9.5.

The following information is based on MCZ 5341; FMNH PF2201, SMMP 78.9.5; and UW 13398 (figure II.25), all complete or nearly complete specimens.

Fin Rays: Pectoral 15-18 (n=3); Pelvic 6-8 (n=4); Anal 8 (n=4); Dorsal 42-45 (n=4), fin margin gently bowed, as in *A. calva*; Caudal 18-19, branched (n=3). Pectoral and anal fin margins are curved (convexed), and caudal fin margin is deeply convexed.

Pterygiophores: Dorsal 43-45 (n=2); Anal 7-8 (n=2).

Vertebrae: Total about 65-73 (n=4, $\overline{X}$=69.00, SD=3.64).

Scales: Cycloid. Scales along vertebral column about 48 (n=1); scale rows above vertebral column at anterior end of dorsal fin about 8-9 (n=1); scale rows below vertebral column at anterior end of anal fin about 7 (n=1).

Dimensions: Head length about 29-32 percent of the standard length (n=4), about 22-25 percent of the total length. The relative maximum body depth appears to increase with length. UW 13398 (standard length 10.2 cm) has a maximum body depth about 27 percent of the standard length, 22 percent of the total length. SMMP 78.9.5 (standard length 13.3 cm) has a maximum body depth about 26 percent of the standard length, 21 percent of the total length. MCZ 5341 (standard length 45.5 cm) has a maximum body depth about 32 percent of the standard length, 26 percent of the total length. FMNH PF2201 (standard length 51.0 cm) has a maximum body depth about 42 percent of the standard length, 31 percent of the total length.

Other Information: Branchiostegal rays 11-12 (n=4). Palatal and vomerine teeth of *A. fragosa* thick, short, styliform crushing teeth adapted for grinding shelled organisms such as crayfish or snails.

*Work in progress by Gaudant (pers. comm.) suggests that the deep bodied amiid from the Green River Formation may not be *A. fragosa*. If this is so, then *gurleyi* would be the valid species name for the Green River form.

For more detailed description see Romer and Fryxell (1928) and Boreske (1974).

Table II.2. Diagnostic characters distinguishing the two species of Green River *Amia.*

	A. uintaensis	*A. fragosa*
Total number of vertebrae	83-85	65-73
Palatal and vomerine teeth (see figure II.26)	Relatively long, sharp, and pointed	Short, blunt, styliform crushing teeth.
Anal fin rays	9-10	Usually 8
Branched caudal fin rays	19-21	18-19

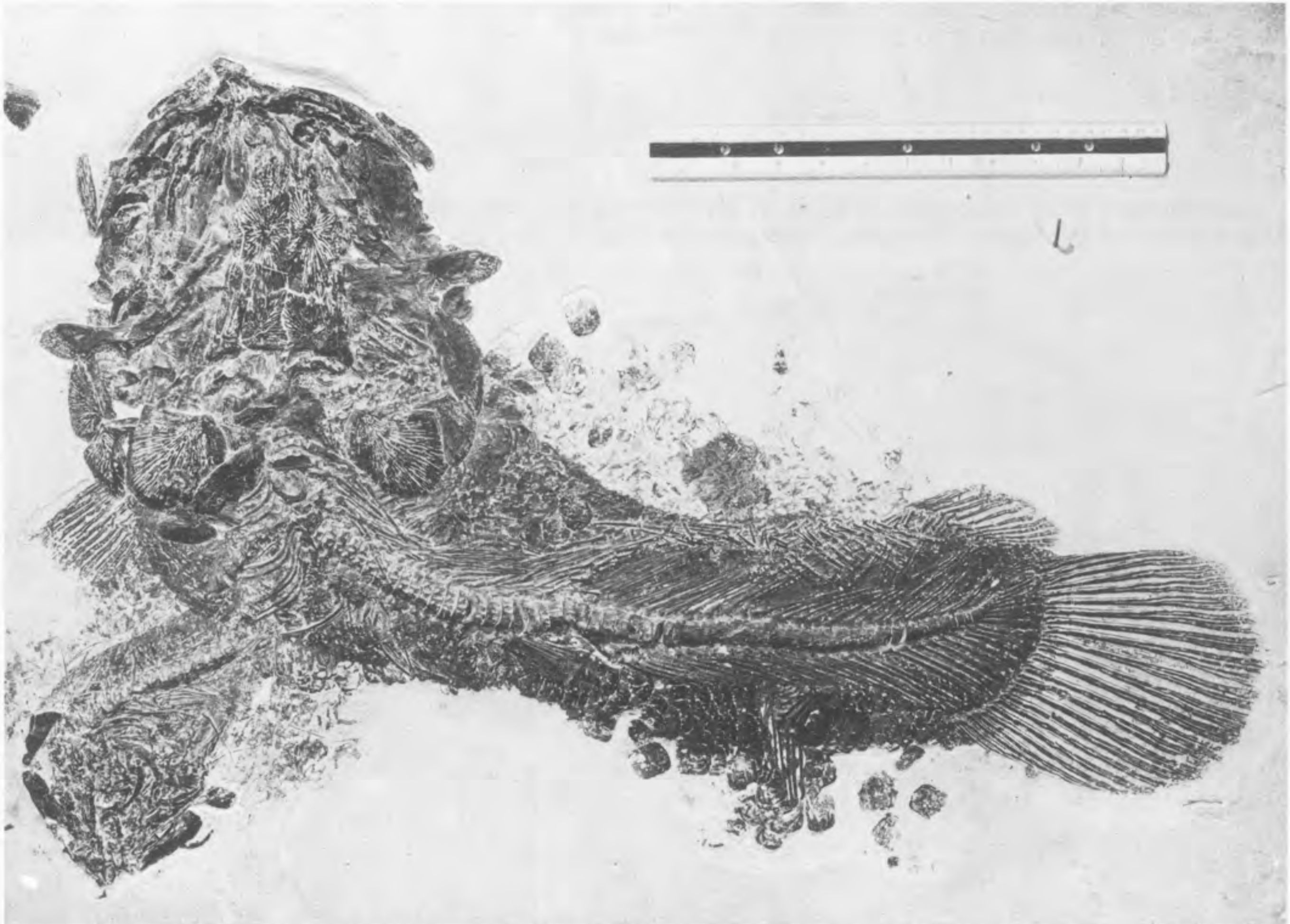


Figure II.20a. *Amia uintaensis* (PU 13865) from locality F-1. Length 85 cm (about 33½ inches). Photo courtesy of Don Baird, Princeton University Museum of Natural History.

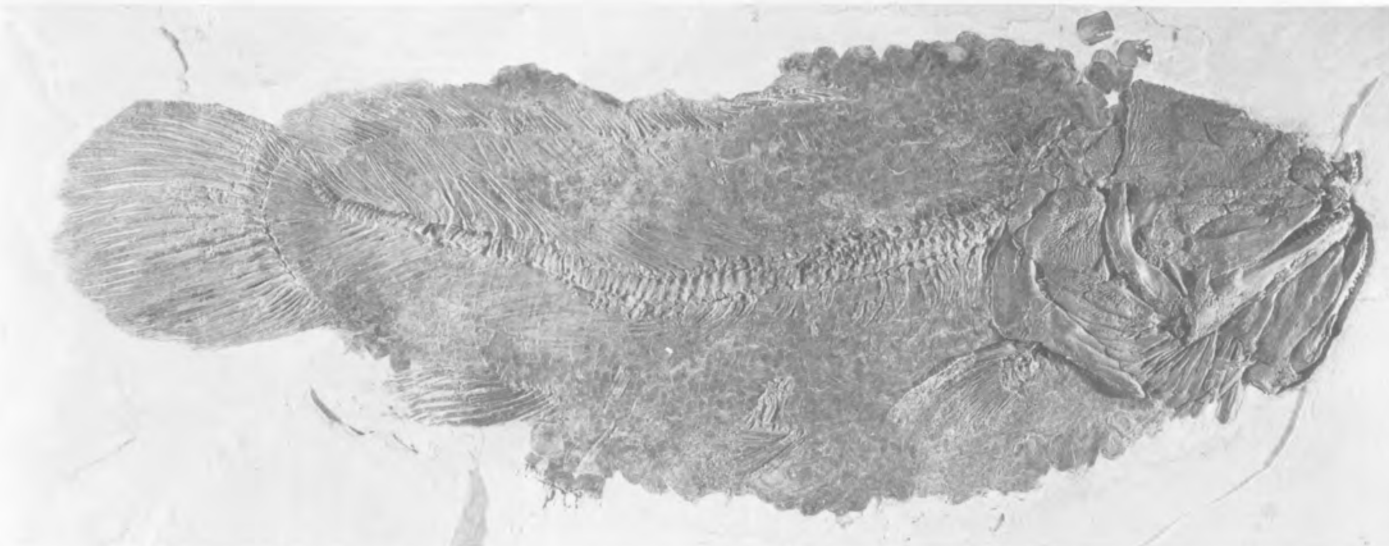


Figure II.20b. *Amia uintaensis* (SMMP 78.5.1) from F-2. Total length 124 cm (49 inches). Preparation by Ronald Mjos. The posterior half of the dorsal fin of this specimen is totally restored, so the true dorsal fin ray count of this species is still unknown.

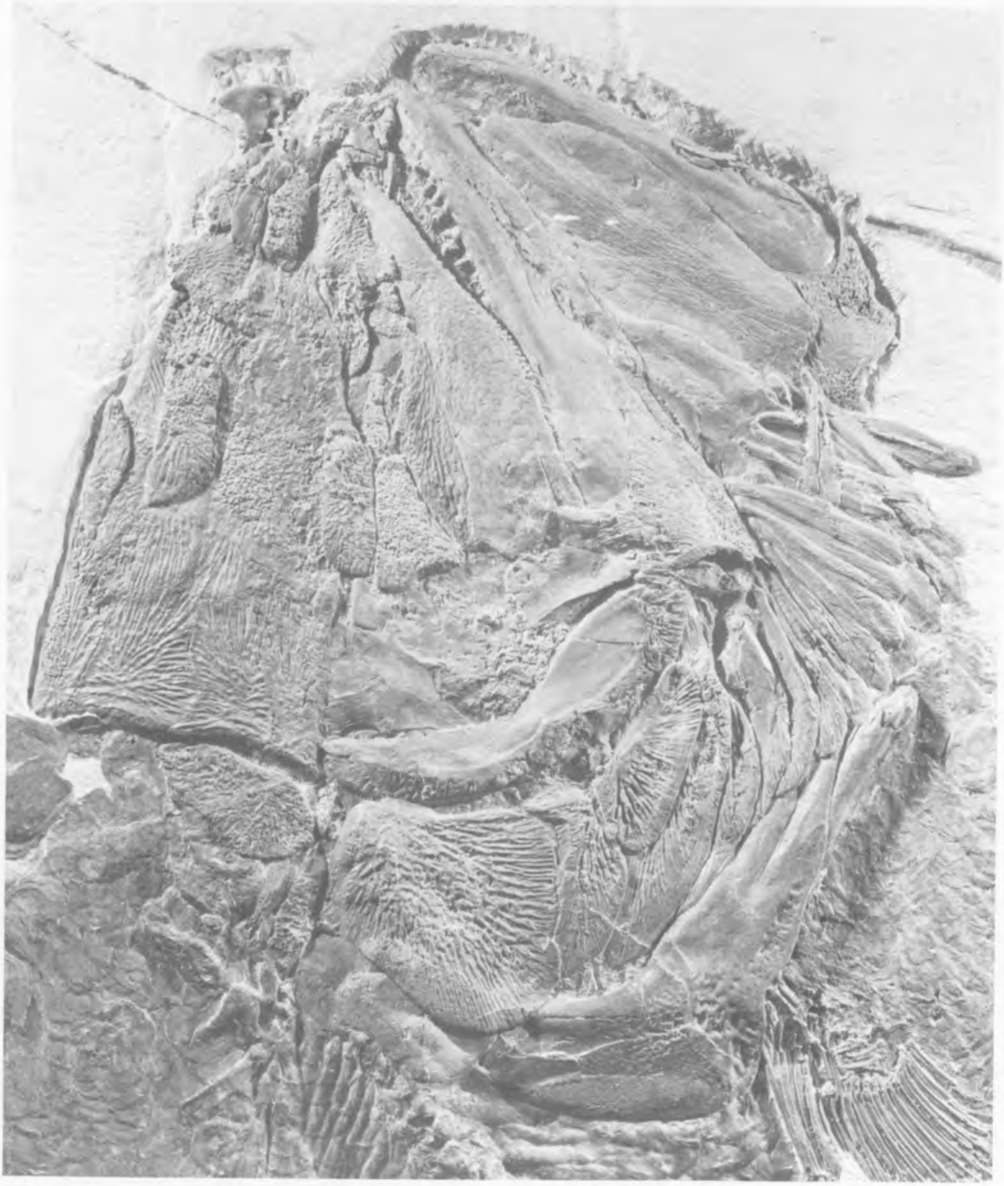


Figure II.20c. *Amia uintaensis* skull from SMMP 78.5.1. Head length 35 cm (14 inches).

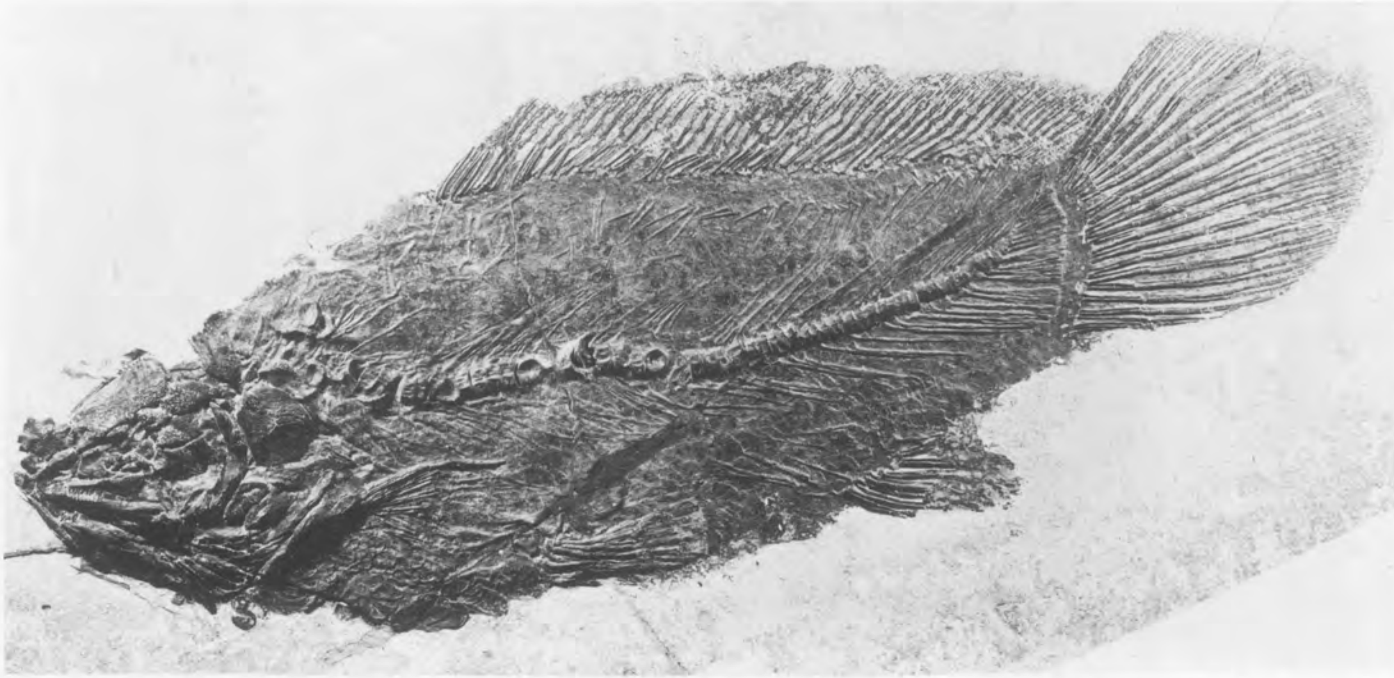


Figure II.21. *Amia fragosa* (FMNH PF2201) from locality F-1. Length 70 cm (27½ inches). Photo courtesy of John Bolt, Field Museum of Natural History.

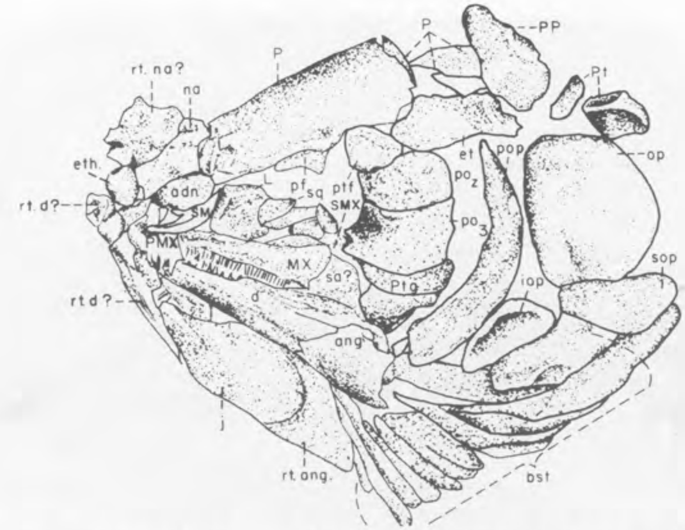


Figure II.22. Line drawing of the skull from FMNH PF2201 (figure II.21), from Romer and Fryxell (1928). Abreviations: adn = adnasal; ang = angular; bst = branchiostegal rays; d = dentary; eth = ethmoid; f = frontal; iop = interopercle; j = jugal; l = lachrymal; mx = maxilla; na = nasal; op = opercle; p = parietal; pp = postparietal; pt = post-temporal; ptg = pterygoid; ptf = post-frontal; pmx = permaxilla; po = preopercle; q = quadrate; sa = supra-angular; sm = septo-maxilla; smx = supra-maxilla; so = suborbital; sop = subopercle; st = supratemporal.

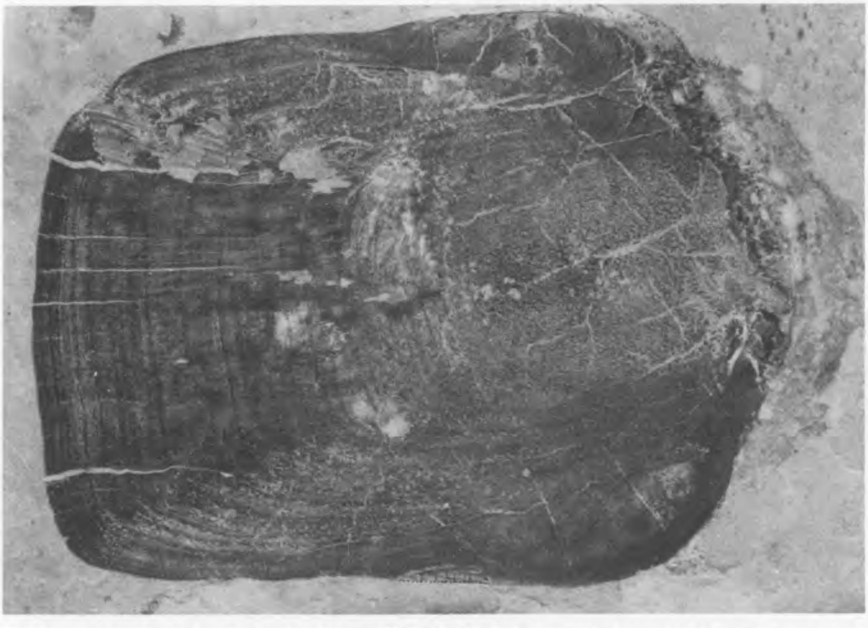


Figure II.23. A typical *Amia* scale from SMMP 78.5.1, *A. uintaensis.* Length 8 cm (3 inches). Photo courtesy of the Science Museum of Minnesota.

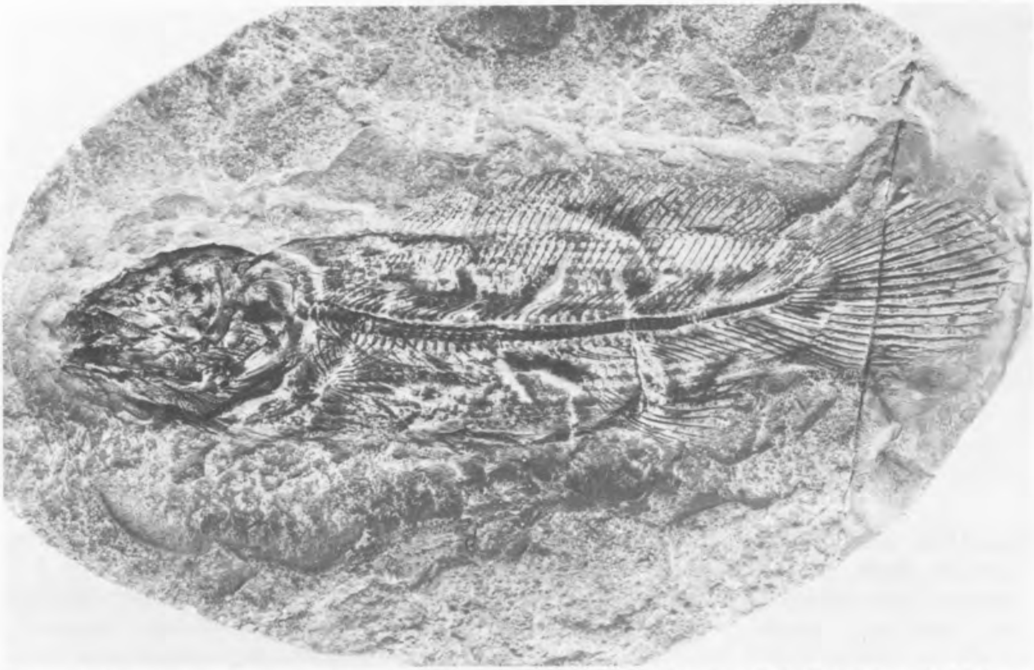


Figure II.24. *Amia fragosa* (SMMP 78.9.5, latex peel) from locality G-4. Total length 16.4 cm (6½ inches). Original specimen is UW 13399.

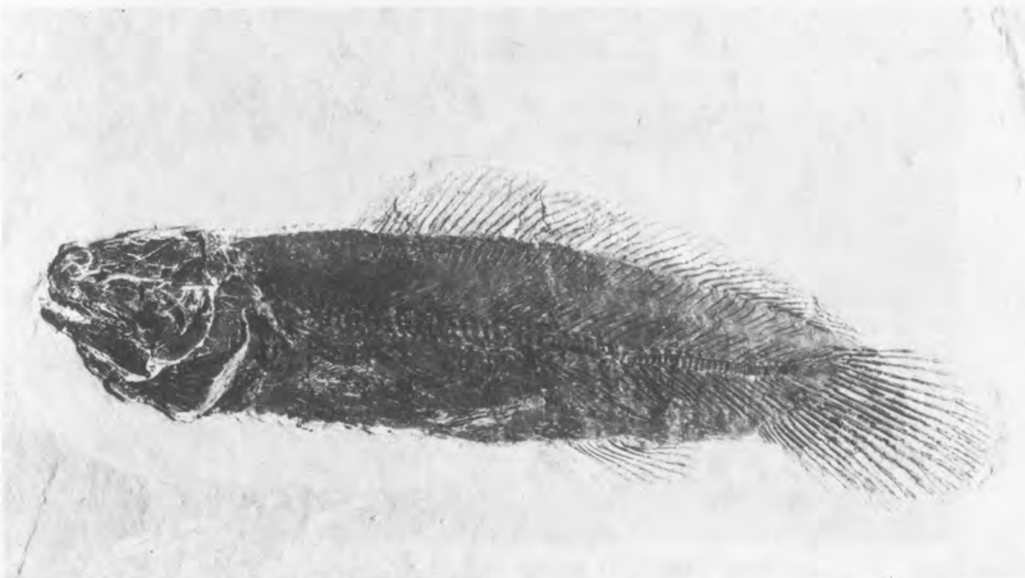


Figure II.25. *Amia fragosa* (UW 13398) from locality G-1. Total length about 13 cm (5 inches).

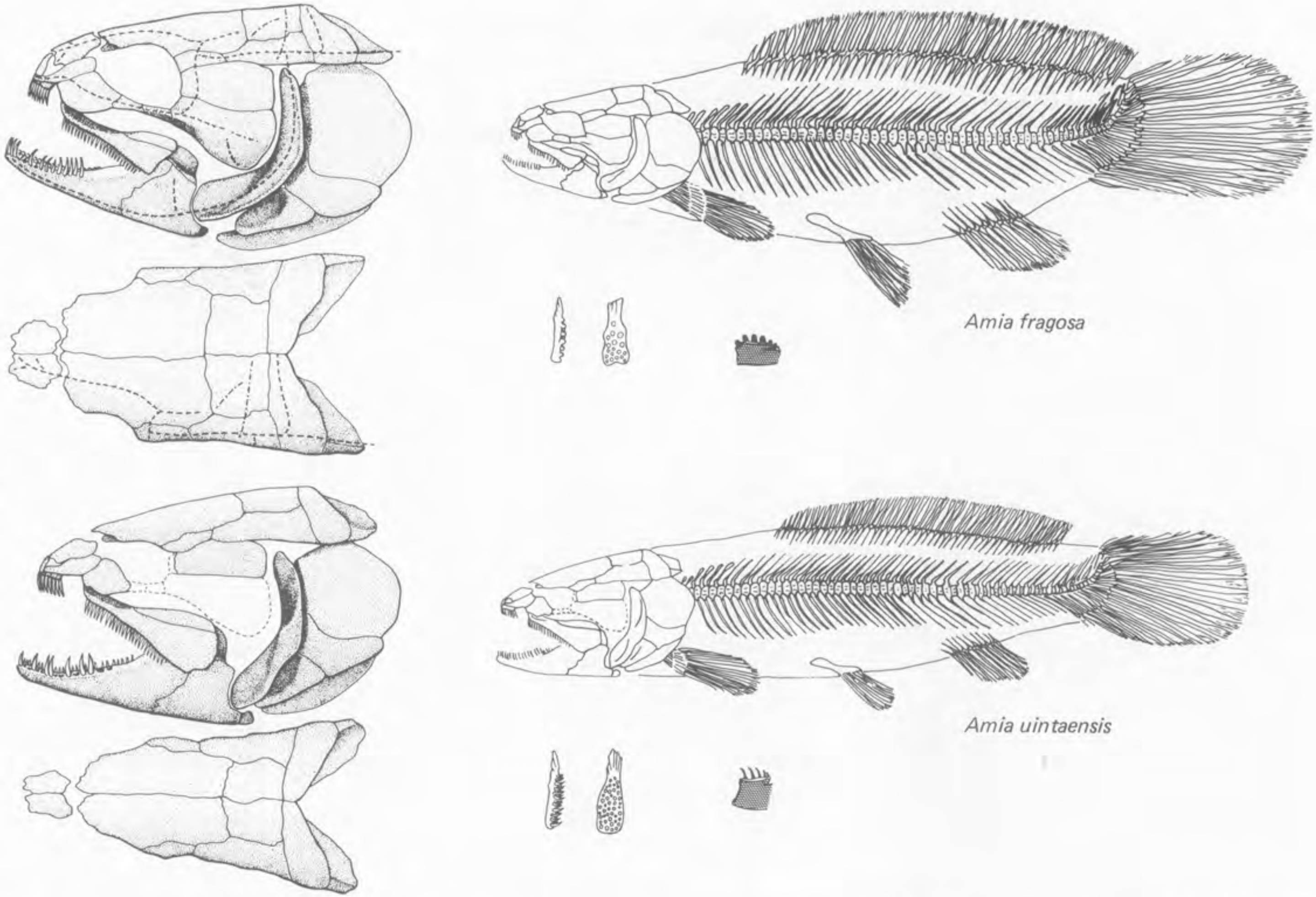


Figure II.26. Line drawing comparison of complete skeletons, skulls, and vomerine and palatal teeth of *A. fragosa* and *A. uintaensis* (from Boreske, 1974).

Genus: *Eohiodon* Cavender 1966 (the Eocene mooneye)

Species: *E. falcatus* Grande 1979 Figures II.27-II.30

GENERAL INFORMATION

Eohiodon, the mooneye, is represented in the Green River Formation by one described species. It is fairly rare in the Green River Formation, and apparently confined to Fossil Lake, as it is known only from localities F-1 and F-2. Amateur collectors have mistaken specimens of *Eohiodon* for *Diplomystus* or damaged *Mioplosus*; however, *Eohiodon* are readily identifiable by their toothed parasphenoid (figure II.28), jaws with relatively large pointed teeth (much larger than those of *Diplomystus* or *Mioplosus*), and forked caudal fin consisting of 18 principle rays, 16 of which are branched. Maximum length known for *Eohiodon falcatus* is about 25 cm (10 inches), and the usual length is about 10-15 cm (4-6 inches).

Today, living hiodontids feed mainly on insects, insect larvae, and a few small fish (Scott and Crossman, 1973). That teeth of *Eohiodon falcatus* are proportionately larger than those of the living representatives of the family may indicate that it was more predaceous than its modern relatives. Alternatively, because it is smaller in average size, *Eohiodon* may have needed the larger teeth to catch the same prey (Grande, 1979).

Eohiodon's scarcity in the Green River Formation may reflect a preferred habitat similar to modern hiodontids. According to Scott and Crossman (1973), modern hiodontids prefer river or swift stream environments. *Eohiodon* may have been a resident of the rivers and streams in the adjacent tectonic highlands that supplied water to Fossil Lake, who occasionally wandered into the lake.

Today, the family *Hiodontidae* is represented by two species and a single genus (*Hiodon*) restricted to North America. It is exclusively a fresh water family. Fossil hiodontids are known from several Eocene and some Oligocene deposits of North America.

GENERIC ETYMOLOGY

Eohiodon: eo - the dawn of, *hiodon* — toothed hyoid; refers to this genus being the earliest hiodontid known at the time of its description.

NOMENCLATURE, SPECIFIC INFORMATION, REPOSITORIES, AND SUGGESTED REFERENCES

EOHIODON FALCATUS Grande 1979

The following information is based on the holotype (UMVP 6499; figure II.27); paratypes (SMMP 77.24.1 and SMMP 77.24.2); and SMMP 83.2.6 (figure II.28), all four specimens relatively complete to complete, and from F-2.

Fin Rays: Pectoral 13 (n=3); Pelvic 8-9 (n=2); Anal 21 or 22 major (one unbranched ray which is the longest ray, followed by 20 or 21 branched rays) (n=2). The major anal rays are preceded by 3 to 4 short accessory rays of which the first 2 or 3 are unsegmented. The last accessory ray is the longest one, about half the length of the first major ray. Dorsal 15 major (one unbranched ray which is the longest ray, followed by 14 branched rays) (n=2). The major dorsal rays are preceded by 4 to 5 short accessory rays of which the first 2 or 3 are unsegmented. The last accessory ray is the longest one, about half the length of the first major ray. Caudal 1,8,8,1* (n=3). Median fin margins falcate (concave in outline), Caudal fin forked.

Pterygiophores: Anal 23 (n=1); Dorsal 16 (n=2).

Vertebrae: Caudal 25 (n=2); Precaudal (2 PD) 24 (n=2).

Scales: Cycloid. Predorsal 28-29 (n=1); rows above vertebral column at anterior end of dorsal fin 9-10 (n=2); rows below vertebral column at anterior end of anal fin 8-10 (n=2).

Dimensions: Head length about 23-27 percent of the standard length (n=3), 18-21 percent of the total length (n=3); maximum body depth usually 33-43 percent (n=3) of the standard length, 27-33 percent (n=3) of the total length. Body form variable (compare figure II.27 with figure II.28), but usually fusiform (figure II.28). Since the major morphological features and meristics do not differ substantially between the fusiform-bodied and the nonfusiform-bodied individuals, they are recognized as a single species here.

Other Information: Parasphenoid with numerous relatively large pointed teeth. Branchiostegals about 9-10 (n=2). About 16 thin, curved intermuscular bones extend nearly to the dorsal surface of the fish between the back of the skull and the dorsal fin (see figure II.29).

For more detailed description see Grande (1979).

*See Basic Fish Anatomy, Methods, and Systematics section at the beginning of Part II for explanation.

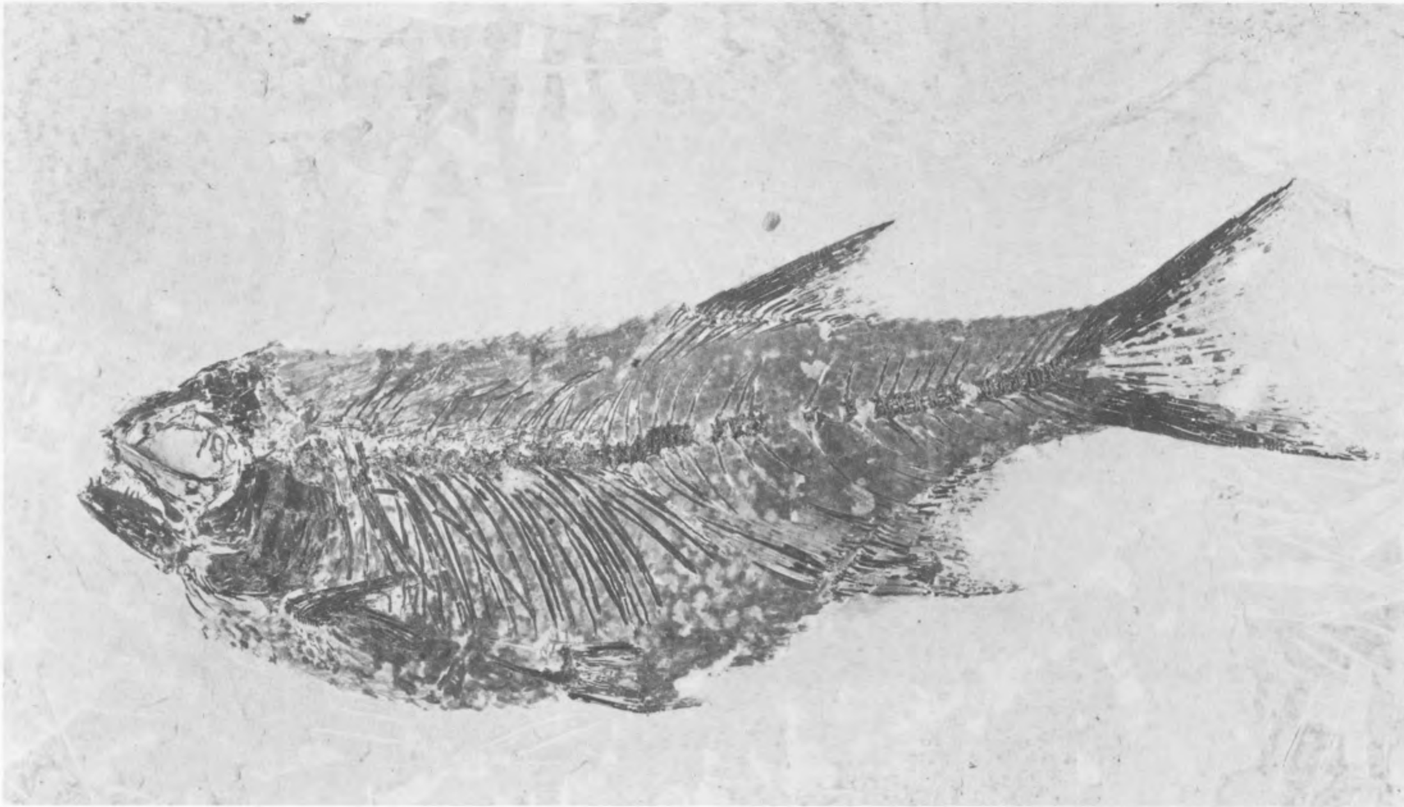


Figure II.27. Holotype of *Eohiodon falcatus* (UMVP 6499) from locality F-2. Total length is about 17.8 cm (7 inches).

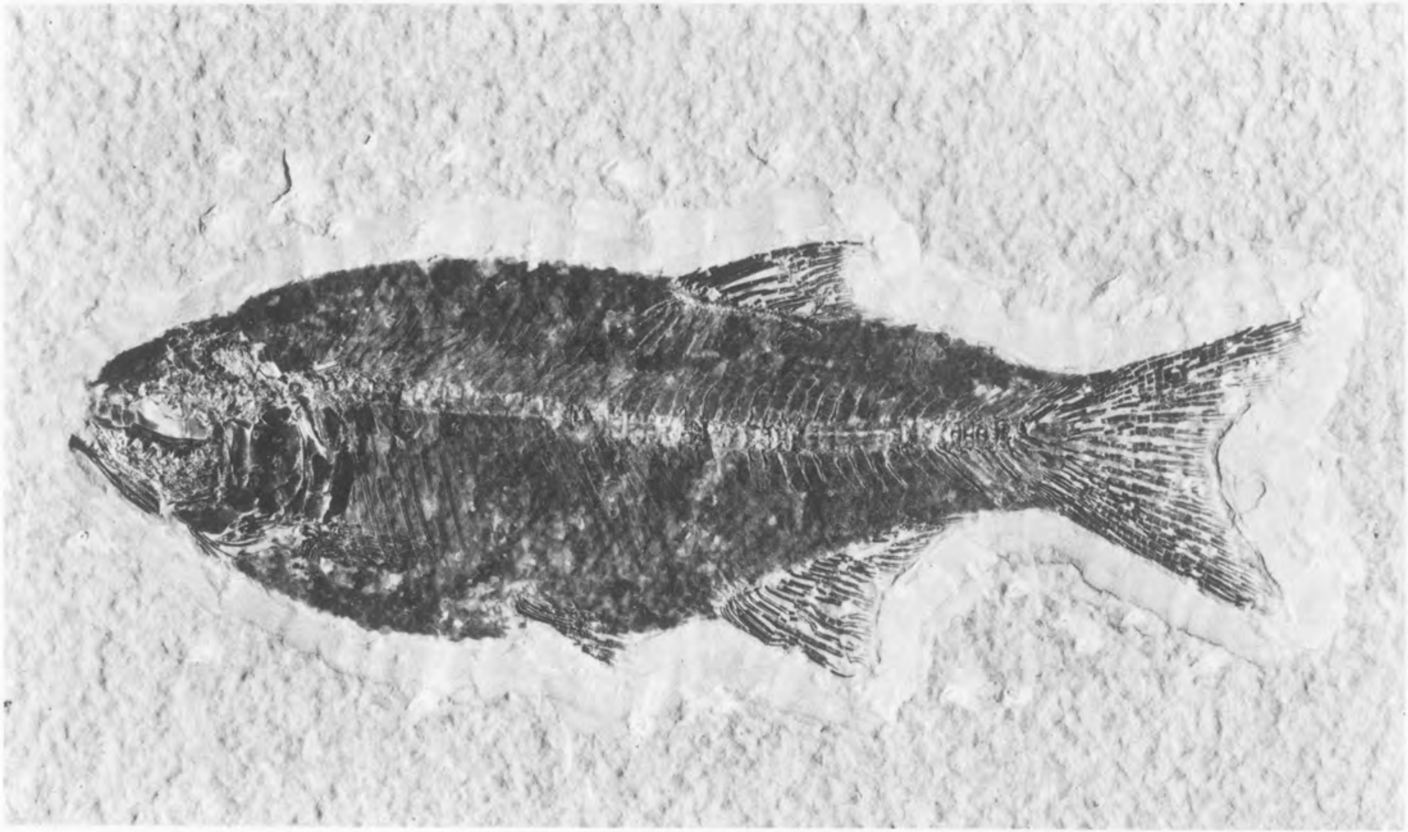


Figure II.28. *Eohiodon falcatus* (SMMP 83.2.6) from locality F-2. Note toothed parasphenoid, characteristic of all hiodontids. Total length is about 9.8 cm (3¾ inches).

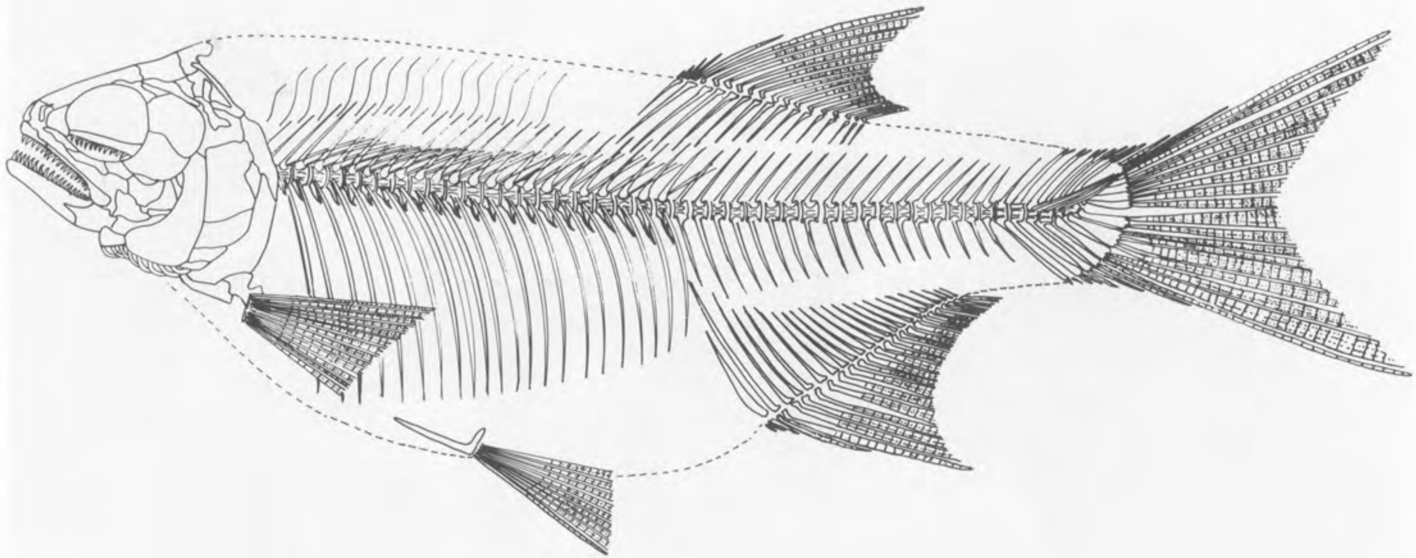


Figure II.29. Line drawing of adult *Eohiodon falcatus* (revised slightly from Grande, 1979).

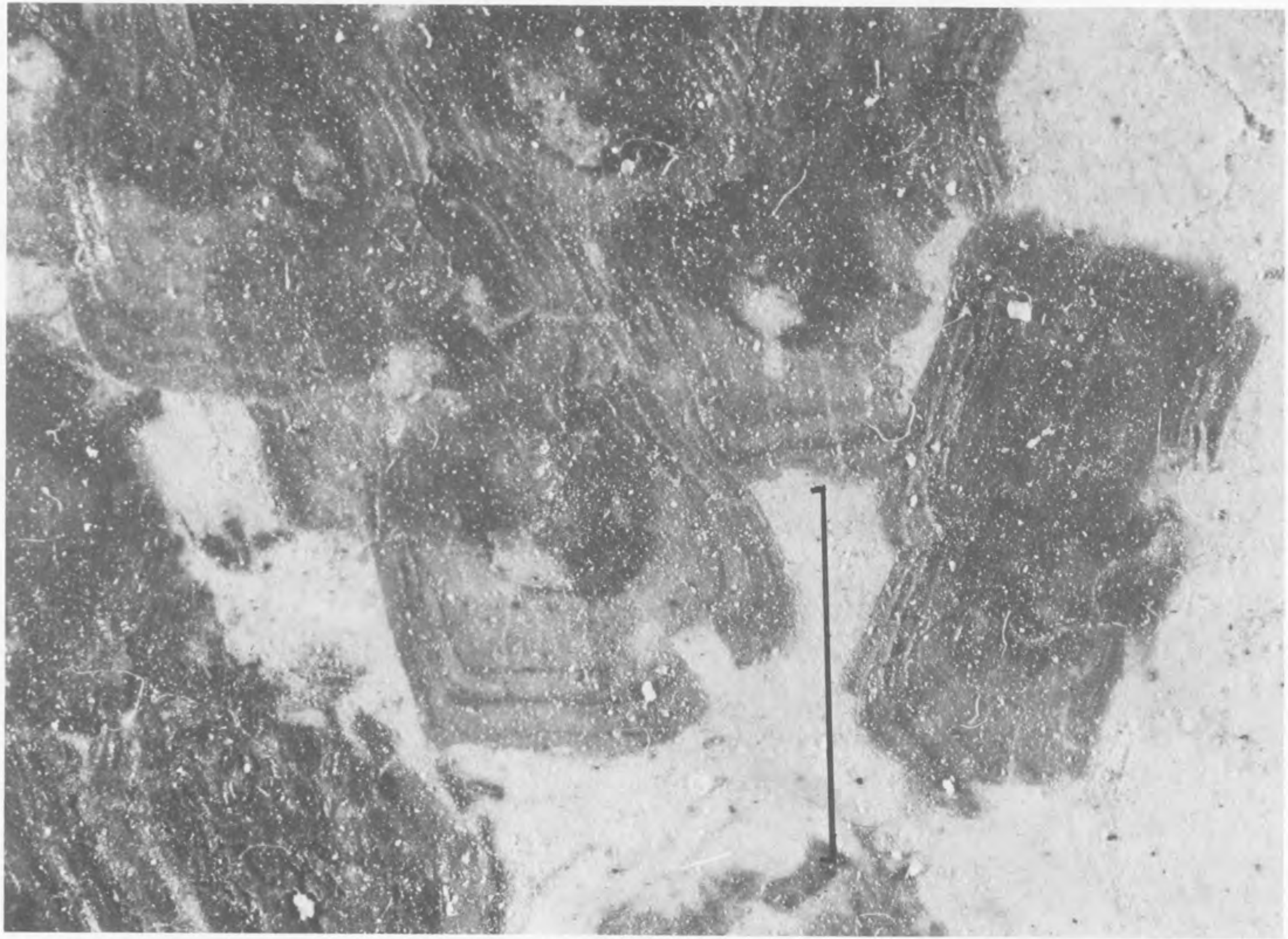


Figure II.30. Isolated scales of *Eohiodon falcatus* (SMMP 74.24.1) from F-2. Scale is about 5 mm. These scales are from the anterior keel and abdominal regions of the specimen.

Genus: *Phareodus* Leidy 1873

Species: *P. encaustus* (Cope 1871) — Figures II.31, II.32, II.33a, II.35, and II.36a-d.

P. testis (Cope 1877) — Figures II.33b, II.34, and II.36e-h.

GENERAL INFORMATION

Phareodus is fairly abundant and very widespread in the Green River Formation, having been found in all three Eocene lakes, though most commonly at localities F-1 and F-2. It is easily recognized by its long pectoral fin, large pointed teeth, large oval scales, and large median fins set close to the tail fin. Isolated *Phareodus* scales are common throughout the lacustrine deposits of the Green River Formation (see figure II.32b). Maximum length of *Phareodus* is about 76 cm (30 inches) in total length for the large species, *P. encaustus;* the average size for *P. testis* is about half that. Juvenile specimens (less than 7.5 cm or 3 inches in total length) are slightly more common at F-2 than at F-1. On large specimens of *Phareodus*, the long, flexible pectoral fin is about 1/3 the fish's standard length (see figure II.31), with the first ray much thicker and longer than the other rays, though the jointed part of the first ray is often broken off, giving the fin a shorter appearance. The many sharp teeth in the mouth of *Phareodus* attest to a probable carnivorous habit. Percoid spines from *Mioplosus* and *Priscacara* often found in the stomachs of *Phareodus* provide evidence of a piscivorous diet.

The osteoglossids are represented today by four genera, all restricted to the tropical and semitropical fresh water regions of South America, central Africa, Southeast Asia, and northern Australia. The extant genus *Osteoglossum*, commonly called "Arawana," is sold in tropical fish and pet shops.

Phareodus also occurs in the overlying Bridger Formation. *Phareodus* is currently placed within the family Osteoglossidae, though Tanner (1920) cites D.S. Jordan as proposing the family Phareodontidae, separating *Phareodus* from the rest of the osteoglossids. The genus *Phareodus* is known from Eocene fossil deposits in North America and Australia.

GENERIC ETYMOLOGY

Phareodus: phare—to have, *odus*—tooth.

NOMENCLATURE, SPECIFIC INFORMATION, REPOSITORIES, AND SUGGESTED REFERENCES

Other generic names used in the literature for Green River *Phareodus* include *Phareodon*, a misspelling by Cope (1873), and *Osteoglossum* and *Dapedoglossus* (both used by Cope). *Phareodus* was found to be generically different from the living osteoglossid *Osteoglossum*, and *Dapedoglossus* was invalidated by Leidy's prior (1873) usage of *Phareodus*. Specimens of *Phareodus* are fairly common and can be found in most major public repositories.

There appear to be only two valid, described species of *Phareodus* in the Green River Formation, *P. encaustus* and *P. testis*. Cope (1884) synonymized his *P. sericeus* with Leidy's *P. acutus*, leaving 4 described species: *P. encaustus* (holotype AMNH 2793, illustrated in Cope, 1884, plate VI, figure 1, scales only); *P. acutus* (holotype USNM 2178, illustrated in Leidy, 1873, plate XXXII, figures 47-51, consisting of 5 jaw fragments); *P. testis* (holotype USNM 4014, illustrated in Cope, 1884, plate VII, figure 1); and *P. aequipinnis* (syntypes AMNH 2473, illustrated in Cope, 1884, plate VII, figure 3, and USNM 4003, figure II.35a). Thorpe (1938) erected *P. brevicaudatus* (syntypes YPM 1418 and YPM 1636, figure II.36).

Phareodus encaustus, *P. acutus* and *P. aequipinnis* are found here to be synonymous, and *P. testis* (holotype USNM 4014, from F-1) is found to have enough features differentiating it from *P. encaustus* to warrant specific separation. *Phareodus brevicaudatus* is found to be synonymous in part with both *P. encaustus* and *P. testis* (syntype YPM 1636 with *P. encaustus*, syntype YPM 1418 with *P. testis*).

Phareodus encaustus (Cope 1871) was described on the basis of a series of scales (holotype AMNH 2793, from locality G-3) that Cope (1884, page 70) estimated belonged to a fish "3 or 4 feet in length." Since Cope's description, several large complete *Phareodus* (such as SMMP 75.19.1) have been found which have the same large scales and are assigned here to that species. The complete specimens show that Cope overestimated the size of *P. encaustus* on the basis of his scales. SMMP 75.19.1, which is 60 cm (two feet) in total length, has nicely preserved scales which are nearly equal in size (32 mm along the vertical axis) to those of the holotype for *P. encaustus* (AMNH 2793), which are up to 35 mm along the vertical axis. *Phareodus acutus* Leidy 1873 was described on the basis of 5 jaw fragments (all numbered USNM 2178) from the Bridger Formation. These fragments belong to an individual about 46-56 cm (18-22 inches) in total length and are too large to be from *P. testis*. Since they differ in no way from the teeth of *P. encaustus* and more complete specimens of *P. encaustus* have been observed from the Bridger Formation, *P. acutus* is here synonymized with *P. encaustus*.

Phareodus aequipinnis was described by Cope (1878) on the basis of two juvenile specimens, syntypes USNM 4003 and ANMH 2473, apparently from F-1, the larger of which has a standard length of about 70 mm (3 inches). Characters used to define this species were a shorter pectoral fin, the vertebral count, and the median fin ray count. Upon examination of several juvenile *P. encaustus* and *P. testis* specimens (SMMP 78.8.8, 78.9.23, 78.9.24, and others), it was determined here that the proportional length of the pelvic fin in *Phareodus* is a function of maturity rather than a specific character. Juvenile *Phareodus* ususally have a pectoral fin length of 1/5 to 1/4 the standard length, increasing with age to over 1/3 the standard length in very large specimens. Thus, the short pectoral fin on USNM 4003 (about 4 cm or 1½ inches standard length) is probably due to the young age of the individual, and on AMNH 2473 (about 7 cm or 3 inches standard length) in part to the young age of the individual and in part because the tip of the fin is missing. Since vertebral counts and median fin ray counts of *P. aequipinnis* fall well within normal meristic limits for a species when grouped with *P. encaustus* and no other features could be observed to separate it from that species, *P. aequipinnis* is here synonymized with *P. encaustus*.

Phareodus brevicaudatus was described by Thorpe (1938) on the basis of two specimens, syntypes YPM 1636 and YPM 1418. Characters used to define this species were: "first rays of dorsal and of anal fin are in a vertical line, whereas, in [the] preceeding species, the first dorsal is over the sixth anal. The outline is more elongated or more fusiform than the other" [sic]. It was found here that the outline of YPM 1418 was identical to that of USNM 4014, the type for *P. testis* (as Thorpe would have realized if he had examined the type specimens of *Phareodus* in his review). As for the position of the median fins, insertion of the fins relative to each other and to the vertebral column is the same for YPM 1418, YPM 1636, *P. testis* (including the holotype), and all *P. encaustus* specimens observed. Thorpe (1938, page 289) also counted only 20 caudal vertebra (less than known for *P. encaustus* or *P. testis*), but his count was found to be low when the specimens were re-examined here. The actual counts are 25 for YPM 1418 and 24 for YPM 1636 (radiographs support these counts). Thus, there do not appear to be grounds for specific separation of *P. brevicaudatus*. In fact, the two syntypes are different from each other: YPM 1418 is synonymized here with *P. testis*, and YPM 1636 with *P. encaustus*.

Phareodus had a broad, massive dorsocranium (see figure II.35); consequently, there is a great deal of variation in skull outline and articulation in fossil specimens due to lateral compression during fossilization. In some large *Phareodus*, the broad, massive skull became twisted enough to distort the entire body outline. Thus, some *P. encaustus* and *P. testis* have body outlines somewhat different from those shown in figure II.36. The two species of *Phareodus* recognized here, *P. encaustus* and *P. testis*, occur in nearly equal abundance at F-1 and F-2.* The relative abundances of these species in the other Green River deposits and in the overlying Bridger Formation is unknown.

Phareodus has a forked tail, unlike all Recent osteoglossids, which have a convexly rounded tail fin margin.

Care must be taken when counting median fin rays in *Phareodus* (and many other Green River fish), for the large rays occasionally split into two lateral halves, giving the false appearance of a higher ray count. The base of each ray and the segmented ends should be examined very closely to prevent errors in meristic data.

Both Cope's and Thorpe's type specimens were F-1 specimens, except for *P. encaustus* AMNH 2793, from G-3.

PHAREODUS ENCAUSTUS (Cope 1871)

= *Osteoglossum encaustum*, Cope, 1871; *Phareodus acutus* Leidy 1873; *Phareodon acutus* Cope 1873; *Phareodon sericeus*

*About 55% *P. encaustus*, 45% *P. testis* (based on 36 specimens excavated at F-1), and about the same ratio at F-2.

Cope 1873; *Dapedoglossus encaustus* Cope 1877; *Dapedoglossus aequipinnis* Cope 1878; *Phareodus encaustus* Thorpe 1938; *Phareodus aequipinnis* Thorpe 1938; and *Phareodus brevicaudatus* Thorpe 1938 — syntype YPM 1636.

Phareodus encaustus is the larger of the two Green River species recognized here. It is known to occur in all three Green River lakes and in the overlying Bridger Formation. The following information is based on SMMP 75.19.1 (figure II.36g); SMMP 78.9.23 (figure II.32a); UW 12304 (illustrated in McGrew and Casilliano, 1975, figure 21); UW 12308 (illustrated in Hager, 1970, figure 32(6)); LG 6.1 (figure II.31 and figure II.33a); YPM 1636 (one of the syntypes for *P. brevicaudatus* Thorpe; illustrated in figure II.36f); AMNH 2996; AMNH 2473 (one of the syntypes for *P. aequipinnis*; illustrated in Cope, 1884, plate VII, figure 3); and USNM 4003 (one of the syntypes for *P. aequipinnis*; illustrated in Cope, 1884, plate VII, figure 2).

Fin Rays: Pectoral 7-8 (n=5), usually 8 (some of the smaller rays are often missing). The first ray is unbranched and is the longest ray, with the distal half well segmented. Length of this ray is from about 1/5 to over 1/3 of the standard length, shortest in juvenile specimens (such as USNM 4003 and SMMP 78.9.24). In mature adults, the long ray is usually about 2/9 - 3/9 of the standard length, though it is often missing part or all of the segmented end, giving it a shorter appearance. Pelvic 6-7 (n=5), first ray unbranched; Anal 22 to 24 major (n=7, $\overline{X}$=23.28, SD=.95), usually 24. The first major ray is an unbranched ray about equal in length to the first branched ray. All of the major rays but the first are branched. The last major ray is often doubled. The major anal rays are preceded by usually 3 or 4 short accessory rays of which the first 2 or 3 are unsegmented. The last accessory ray is the longest one (about a third to half the length of the first major ray). The fin margin is convexly rounded in outline. Dorsal 20 or 21 major (n=7, $\overline{X}$=20.57, SD=.53). The first major ray is an unbranched ray about equal in length to the first branched ray. All of the major rays but the first are branched. The last major ray is often doubled. The major dorsal rays are preceded by usually 2 to 4 short accessory rays, of which the first 1 to 3 are unsegmented. The last accessory ray is the longest one (about a third to half the length of the first major ray). The fin margin is convexly rounded in outline. The dorsal fin is shorter in both maximum fin ray length and base length than the anal fin. Caudal usually 1,7,8,1 (n=6), but can vary (1,7,7,1 (n=1), 1,8,7,1 (n=1)), very slightly forked, with convexly rounded lobes.

Pterygiophores: Anal 23-25 (n=5, $\overline{X}$=24.00, SD=.71), usually 24; Dorsal 19-22 (n=6, $\overline{X}$=20.80, SD=.84), usually 20-21 (n=5).

Vertebrae: Caudal 24-29 (n=8, $\overline{X}$=26.00, SD=1.58), usually 26-27 (n=5); Precaudal (3 PD) 21-25 (n=6, $\overline{X}$=23.40, SD=1.21); Total 47-52 (n=5, $\overline{X}$=49.40, SD=.71). The predorsal vertebrae are usually covered by the opercle. Radiographs of the specimens were used to get complete vertebral counts.

Scales: Cycloid; large (up to 35 mm in height), oval in shape (see figure II.35c) with rather large cells. Scales are more numerous than in *P. testis*, but in the largest individuals are significantly larger than in that species. Well preserved on

YPM 1636, SMMP 75.19.1, and SMMP 78.8.24, the scales number about 31-34 along (and just above) the vertebral column (n=3). Scale rows above vertebral column at anterior end of dorsal fin about 5 (n=3); scale rows below vertebral column at anterior end of anal fin about 6 (n=3); Predorsal scale rows about 20 (n-3).

Dimensions: Maximum size about 75 cm (30 inches); maximum body depth about 33-47 percent of the standard length (n=7), 27-39 percent of the total length (n=5), the least on very small juveniles (such as SMMP 78.9.24 and USNM 4003); in mature individuals, usually about 38-47 percent of the standard length (n=5). Head length usually about 31-33 percent of the standard length (n=5), 25-29 percent of the total length (n=4), but sometimes with the opercle out of place on a disarticulated specimen, giving the appearance of a slightly longer head. Body outline is different from that of *P. testis* (see figure II.36).

Other Specific Characters: Belly not as keeled as in *P. testis*, often giving the appearance of a lower pectoral fin insertion (see figure II.36). There appear to be more teeth in the jaws of *P. encaustus* than in *P. testis*, and the maximum width-to-height ratio of the opercle is slightly smaller in *P. encaustus* than in *P. testis* (see figure II.33). Width-to-height ratio of infraorbital 3 (see figure II.34c) appears to be larger in *P. encaustus* than in *P. testis*.

PHAREODUS TESTIS (Cope, 1877)

= *Dapedoglossus testis* Cope 1877; and *Phareodus brevicaudatus* Thorp 1938 — syntype YPM 1418.

Little is known about the distribution of *P. testis*, other than that it is not uncommon in Fossil Lake deposits and may also occur rarely in Lake Gosiute. Further collecting of osteoglossids from Gosiute and Uinta is needed to determine its distribution. The following information is based on specimens USNM 4014 (the holotype, figure II.36c); USNM 4007 (illustrated in Cope, 1884, plate VIII, figure 1); USNM 2380; AMNH 802; AMNH 754; AMNH 9850 (figure II.36d); AMNH 5821; SMMP 78.9.36 (figure II.34a); YPM 1418 (one of the syntypes for *P. brevicaudatus*; illustrated in Thorpe, 1938, figure 4); SMMP 78.9.23 (figure II.36a); and SDMNH 18725 (figure II.34b).

Fin Rays: Pectoral usually 7 (n=5), the first ray unbranched and the longest ray, with the distal half well segmented. Length of this ray is from about 1/5 to over 1/3 of the standard length and is shortest in juvenile specimens (such as SMMP 78.9.23). In mature adults, the long ray is usually about 1/3 or more of the standard length, though it is often missing part or all of the segmented end, giving it a shorter appearance. Pelvic 6-7 (n=6), first ray unbranched; Anal 26 or 27 major (n=9, $\overline{X}$=26.22, SD=.44). The first major ray is an unbranched ray about equal in length to the first branched ray. All of the major rays but the first are branched. The last major ray is often doubled. The major anal rays are preceded by usually two accessory rays of which the first is unsegmented. The last accessory ray is the longest one (about a third to half the length of the first major ray). The fin margin is convexly rounded in outline. Dorsal 17 to 19 major (n=9, $\overline{X}$=18.13, SD=.83). The first major ray is an unbranched ray about equal in length to the first branched ray. All of the major rays but the first are branched. The last major ray is often doubled. The major dorsal rays are preceded by usually 3 or 4 short accessory rays of which the first is unsegmented. The last accessory ray is the longest one (about a third to half the length of the first major ray). The fin margin is convexly rounded in outline. The dorsal fin is shorter in both maximum fin ray length and base length than the anal fin. Caudal usually 1,7,8,1 (n=8), very slightly forked, with convexly rounded lobes.

Pterygiophores: Anal 26-28 (n=9, $\overline{X}$=26.66, SD=.71), usually 26-27 (n=7); Dorsal 18-19 (n=8, $\overline{X}$=18.50, SD=.53).

Vertebrae: Caudal 24-27 (n=9, $\overline{X}$=25.56, SD=1.01); Precaudal (3 PD) 21-23 (n=6, $\overline{X}$=22.33, SD=.82); Total 45-50 (n=5, $\overline{X}$=48.40, SD=1.12). The predorsal vertebrae are often covered by the opercle. Radiographs of the specimens were used to get complete vertebral counts.

Scales: Cycloid; large (up to about 20 mm in height), oval in shape (see figure II.35a), with rather large cells. Scales less numerous and relatively larger than in *P. encaustus*. Well preserved on USNM 4014, USNM 2380, YPM 1418, SDMNH 18725, and SMMP 78.9.36, the scales number about 23-26 along (and just above) the vertebral column (n=5). Scale rows above the vertebral column at anterior end of dorsal fin about 3-4 (n=6); scale rows below vertebral column at anterior end of anal fin about 6 (n=4); predorsal scale rows 14-16 (n=6), usually 14-15 (n=5).

Dimensions: Maximum size about 38 cm (15 inches) total length; maximum body depth about 36-52 percent of the standard length (n=9), 31-43 percent of the total length (n=9), the least on very small juveniles (such as SMMP 78.9.23). In mature individuals it is usually about 43-52 percent of the standard length (n=8), 36-43 percent of the total length (n=8). Head length usually about 26-32 percent of the standard length (n-8), 20-27 percent of the total length (n=8). Body outline is different from that of *P. encaustus* (see figure II.36).

Other Specific Characters: Belly deeper keeled, often giving the appearance of a higher pectoral fin insertion than in *P. encaustus* (see figure II.36). There appear to be fewer teeth in the jaws of *P. testis* than in *P. encaustus*, and the maximum width to height ratio of the opercle is slightly larger in *P. testis* than in *P. encaustus* (see figure II.33). The width-to-height ratio of infraorbital 3 appears to be smaller in *P. testis* than in *P. encaustus* (infraorbital 3 not as deep in *P. encaustus* as in *P. testis*). As in *P. encaustus*, there are 11 branchiostegals.

Table II.3. Diagnostic characters distinguishing the two species of Green River *Phareodus.* (Refer also to "other specific characters" section for both species.)

	P. encaustus	*P. testis*
Major anal fin rays*	22-24, usually 23-24 (if the last ray is doubled, it counts as one ray).	26-27 (if the last ray is doubled, it counts as one ray).
Anal pterygiophores	23-25, usually 24	26-28, usually 26-27
Major dorsal fin rays*	20-21 (if the last ray is doubled, it counts as one ray).	usually 17-19 (if the last ray is doubled, it counts as one ray). Specimens (not listed here) have been rarely observed by the author with 20.
Dorsal fin pterygiophores	20-22, usually 20-21	usually 18-19
Body outline	See figure II.36	
Predorsal scale rows**	about 20	about 15
Teeth in maxilla and dentary	more than in *P. testis* (see figures II.33a, b); maxilla usually with $\geqslant 30$†	less than in *P. encaustus* (see figures II.33a, b); maxilla usually with $\leqslant 24$

*See glossary for definition of "major fin rays."

**Counted here as the number of scales along the dorsal margin of the body between the posterior end of the skull and the insertion of the first dorsal fin ray.

†The maxillary teeth are difficult to count if the smaller posterior teeth are broken or covered by the dentary.

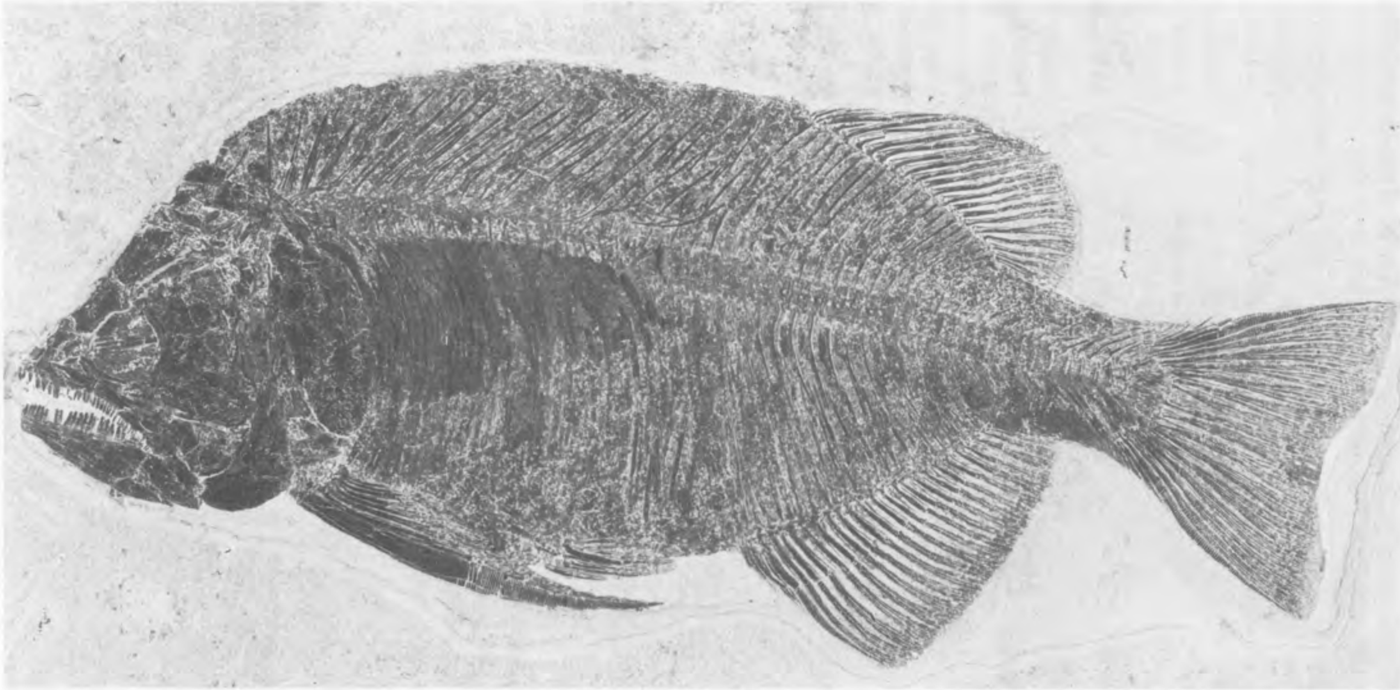


Figure II.31. Large *Phareodus encaustus* (LG 6.1) with an exceptionally well-articulated skull. Total length 57 cm (about 22 inches). Note the large teeth and long pectoral fin characteristic of this genus. From Locality F-1.

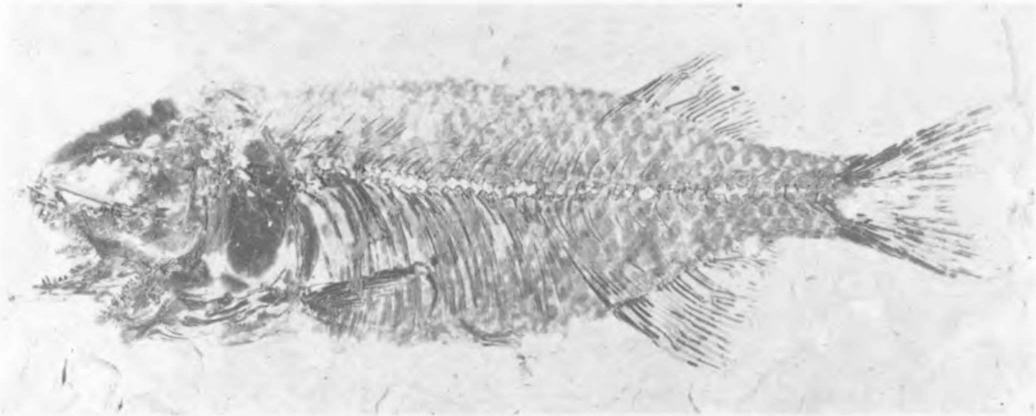


Figure II.32a. A juvenile *P. encaustus* (SMMP 78.9.24) from F-2. Total length 74 mm (about 3 inches).

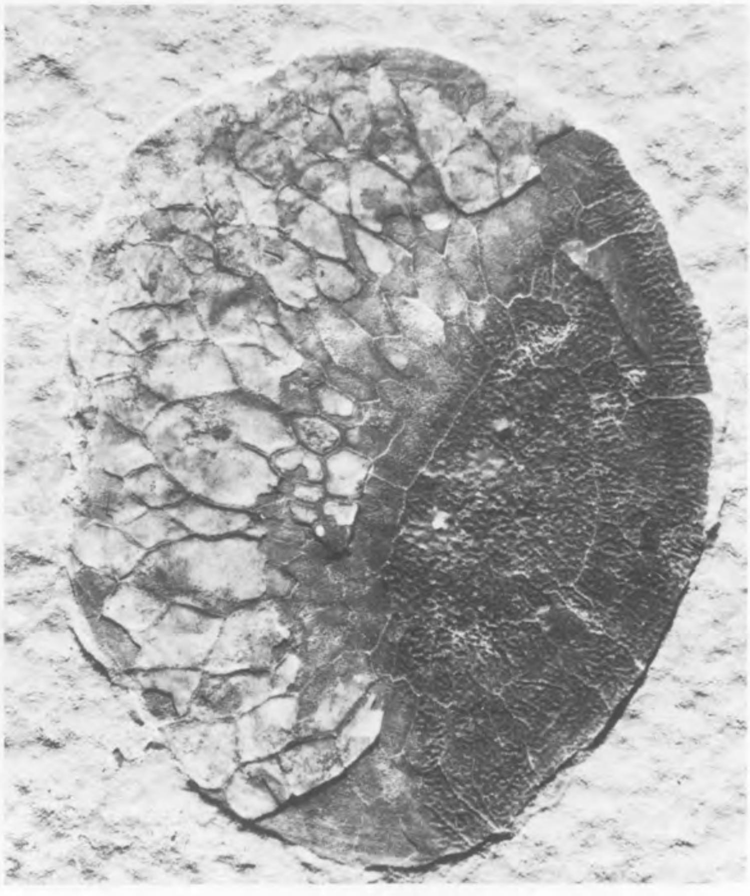
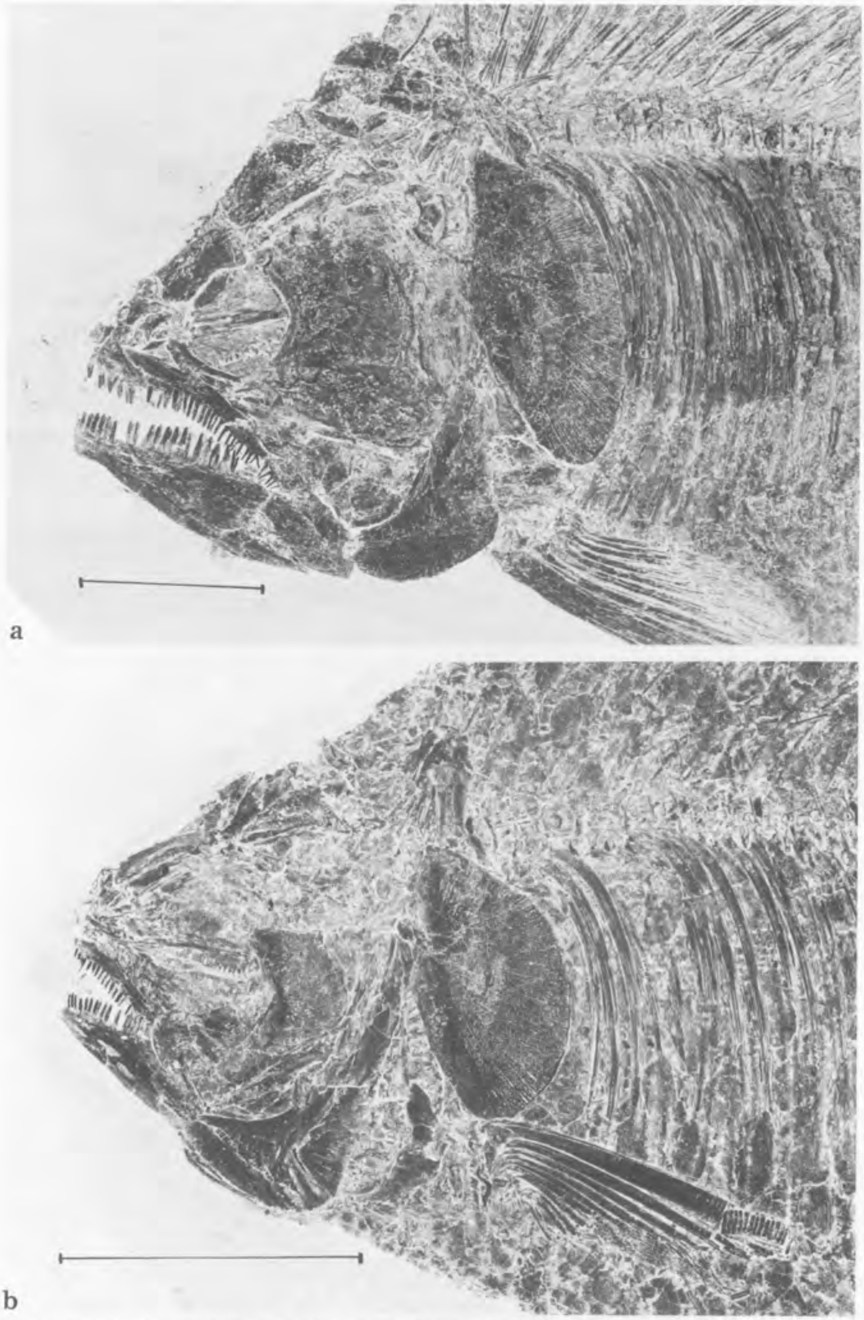


Figure II.32b. Scale from *Phareodus* sp. (probably *P. encaustus*), uncatalogued SMMP specimen. Height of scale is about 3 cm.



a

b

Figure II.33. Comparison of the adult skills of (a) *Phareodus encaustus* (LG 6.1), scale 5 cm, and (b) *Phareodus testis* (BMNH P.61230), scale 5 cm (the posterior circumorbitals are shifted out of place on this specimen). Note the fewer teeth in the jaws, and the wider opercle, of *P. testis.*

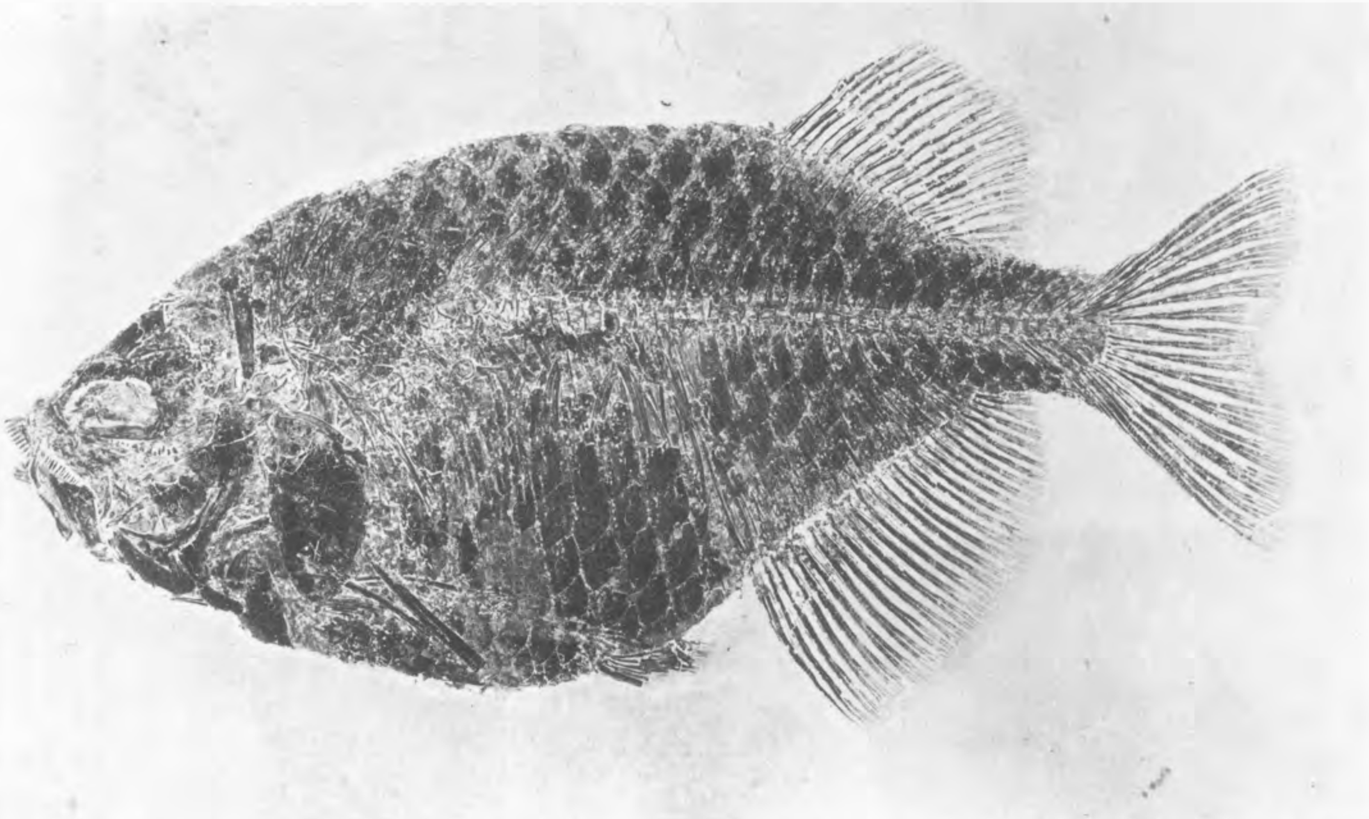


Figure II.34a. *Phareodus testis* (SMMP 78.9.36) from locality F-1, showing the large oval scales characteristic of the genus. The lower jaw is pushed out of place relative to the upper jaw in this specimen. The segmented part of the pectoral fin of *Phareodus* is often found broken, as in this specimen, especially in *P. testis* and small *P. encaustus* specimens. Total length 27 cm (about 11 inches).

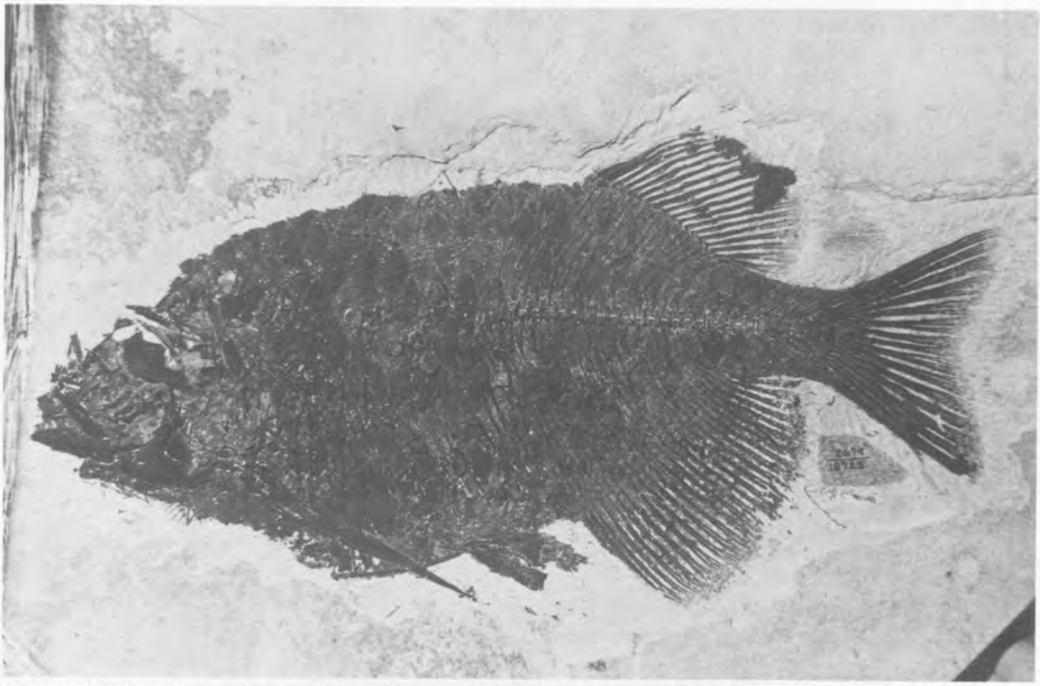


Figure II.34b. *Phareodus testis* (SDNHM 18725) from locality F-1. Total length 33 cm (about 13 inches). Photo courtesy of Fred Schramm, San Diego Museum of Natural History.

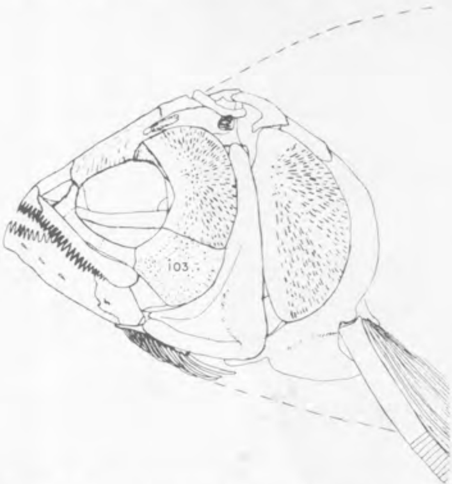


Figure II.34c. Restored line drawing of the skull of *P. testis*, adult specimen, drawn mostly from AMNH 754. Infraorbital 3 is labeled io3. The amount of posterior jaw overlap was probably not as great in the inflated skull.

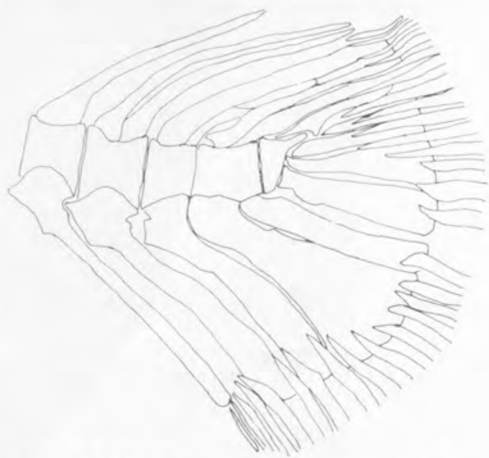


Figure II.34d. Restored line drawing of the caudal skeleton of *P. testis*. After Taverne, 1978.

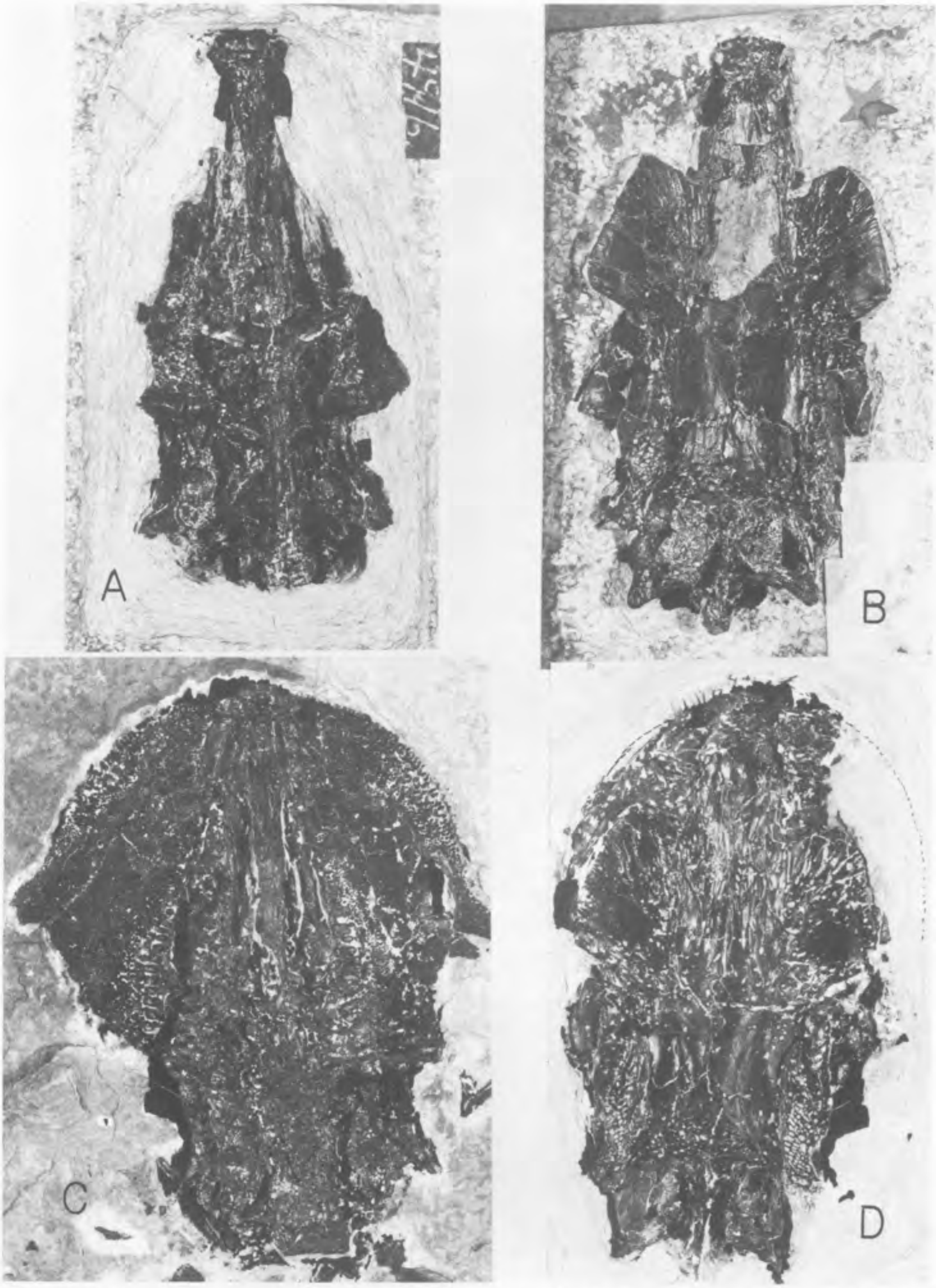


Figure II.35 *Phareodus encaustus*, two dorsocraniums, both 9 cm (3½ inches) in length. These probably belonged to individuals of about 46 cm (18 inches) total length. (A, B) dorsal and palatal views of USNM 4916. (C, D) dorsal and palatal views of USNM 18563 which has upper jaw attached. Anterior ends point up. Taverne (1978) considered USNM 4916 to be *P. testis*, as it was originally identified on the accompanying label.

a

b

c

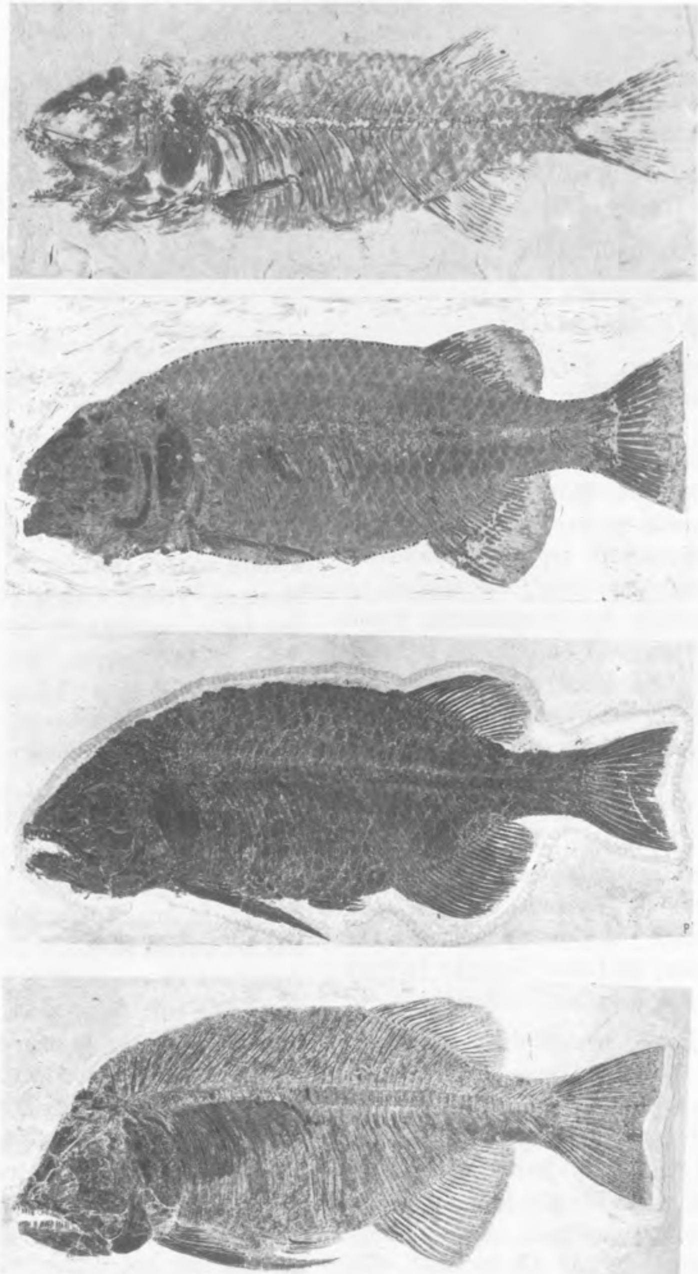
d

Figure II.36. Body outline comparison of *P. testis* (a-d) with *P. encaustus* (e-h). Note larger scales and deeper keeled belly in *P. testis.* (a) *P. testis* (SMMP 78.9.23) from F-2; juvenile, total length 53 mm (about 2 inches). (b) *P. testis* (SMMP 78.9.36) from F-1; total length 27 cm (11 inches). (c) *P. testis* (holotype, USNM 4014) from F-1; total length 30 cm (1 foot). (d) *P. testis* (AMNH 9850) from F-1; total length about 25 cm (10 inches). (e) *P. encaustus* (SMMP 78.9.24) from e

f

g

h



F-2; juvenile, total length 74 mm (about 3 inches). (f) *P. encaustus* (YPM 1636) from F-1; total length about 17 cm (6 inches). (g) *P. encaustus* (SMMP 75.19.1) from F-1; total length 60 cm (about 2 feet). Preparation by Richard W. Jackson. (h) *P. encaustus* (LG 6.1); from F-1; total length 57 cm (about 22 inches).

Genera: *Knightia* Jordan 1907
Gosiutichthys Grande 1982

Species: *K. eocaena* Jordan 1907 — Figures II.37, II.40, II.41, II.49a
K. alta (Leidy 1873) — Figures II.38, II.39

Species: *G. parvus* Grande 1982 — Figures II.42a, II.42b

GENERAL INFORMATION

There are two genera of clupeids (herring) described from the Green River Formation: *Knightia* and the smaller *Gosiutichthys.* These two genera are some of the most common complete vertebrate fossils in the world. In 1978 alone, an estimated twenty thousand complete specimens were excavated in Wyoming, mostly by commercial fossil quarries and amateur collectors, primarily from the G-1 (and similar quarries near G-1), F-2, F-1, and G-4 localities (figure computed on the basis of commercial quarry records). Although *Knightia* is widespread throughout the Green River Formation, and is very common in most areas where it occurs, *Gosiutichthys* is known only from Middle Eocene deposits within the Laney Member, in Lake Gosiute (where it, too, is very common).

In Fossil Lake, where they reach the largest size, *Knightia* have a maximum length of about 25 cm (10 inches) and an average length about half that (at localities F-1 and F-2). In Gosiute locality G-4, maximum length of *Knightia* is about 18 cm (7 inches), and average length is about 10 cm (4 inches). The maximum known size of *Gosiutichthys* is about 8 cm (3 inches); but they rarely exceed 5 cm (2 inches) in total length.

Knightia, a schooling fish, frequently occures in mass mortality layers composed of millions of individuals overlapping and randomly arranged in a horizontal plane (see figure II.41). These mass mortality zones of *Knightia* can be as dense as several hundred fish per square meter (see figure in Schaeffer and Mangus, 1965, pages 20 and 21). There are two particularly good exposures of these death layers, one of which is at the base of the 18-inch-layer on Fossil Ridge and in Fossil Butte National Monument, composed of large *Knightia eocaena* (averaging 13-15 cm or 5-6 inches in total length) as shown in figure II.41. *Gosiutichthys*, where it occurs (see above), is even more frequently found in mass mortalities. The author has observed slabs of *Gosiutichthys* with densities of over 2000 per square meter. Theories on these mass kills range from stratified water turnovers to poisons in the water produced by forms of blue-green algae. Modern fresh water herring (*Alosa pseudoharengus*, the alewife, in Lake Ontario) are known to have mass die-offs, usually in the summer (Scott and Crossman, 1973). These mass mortalities are attributed mainly to the fishes' inability to acclimate to rapidly rising or fluctuating temperatures. It is possible that, similarly, the tropical summer heat occasionally produced temperatures lethal to *Knightia* and *Gosiutichthys* in the shallow regions of the Eocene Green River lakes.

Knightia and *Gosiutichthys* have several morphological differences (described and discussed in Grande, 1982b) and are currently classified within different subfamilies (*Knightia* in Pellonulinae, *Gosiutichthys* in Clupeinae).

Knightia and *Gosiutichthys* seem to have been primary to secondary consumers, probably feeding on algae, diatoms, ostracods, insects, and, rarely, smaller fish. A low position on the food chain is probably one reason for their abundance in the Eocene fish populations. *Knightia* and *Gosiutichthys* were very important links in the Green River lake system's food chain, with most of the larger fishes including them in their diet. *Knightia* and *Gosiutichthys* have been found fossilized in the mouths or stomachs of *Diplomystus*, *Lepisosteus*, *Amphiplaga*, *Mioplosus*, *Phareodus*, *Amia*, and *Astephus*.

Though sensitive to fluctuating temperatures, herrings such as *Knightia* and *Gosiutichthys* are not indicative of any particular climatic conditions. Modern herring have a wide range of optimum temperatures — from warmest tropical waters to very cold northern waters, depending on the species.

KNIGHTIA Jordan

GENERIC ETYMOLOGY

Knightia: named in honor of the paleontologist Wilbur Clinton Knight.

NOMENCLATURE, SPECIFIC INFORMATION, REPOSITORIES, AND SUGGESTED REFERENCES

The first described fish from the Green River Formation was *Clupea humilis* Leidy 1856, which was changed to *Diplomystus humilis* by Cope in 1877. Cope described several species of *Diplomystus* (1877; 1884) and divided all of the species into two main sections. Jordan (1907) recognized the difference between these sections and broke off the *D. humilis* — *D. alta* section into a new genus, *Knightia*.

Jordan (1907) found the name *Clupea humilis* Leidy 1856 to be a junior homonym of *Clupea humilis* von Meyer 1848, so he substituted the name *Knightia eocaena*.

Tanner's (1925) *K. copei* (an F-1 specimen) is synonymous with *K. alta*. The holotype for *K. copei* (UU.11) is lost, and this decision is based on photographs. Tanner described the single incomplete specimen (lost holotype UU.11, illustrated in Tanner, 1925, plate III, figure 6) as having a greater caudal peduncle depth and more dorsal rays (15) than *K. alta*. Tanner probably included accessory rays or counted split rays (lepidotrichia) as two rays in his dorsal count. Careful examination shows his specimen to have 11 principle dorsal rays, as do *K. eocaena* and *K. alta*. Leidy (1856) also mistakenly discribed *K. eocaena* (under the name of *Clupea humilis*) as having 15 dorsal rays, but later (1873) revised this to 13, and Cope ultimately (1884) found the count to be I,11. Caudal peduncle depth (as a specific character for *K. copei*) is no greater on Tanner's specimen than on several of Cope's (1884) figured specimens of *K. alta*. No characters were found to distinguish UU.11 from *K. alta*.

The genera *Knightia* and *Gosiutichthys* are discussed in detail in Grande, 1982b.

KNIGHTIA EOCAENA Jordan 1907

= *Clupea humilis* Leidy 1856; *Clupea pusilla* Cope 1870; *Diplomystus humilis* Cope 1877*, and *Knightia humilis* Grande (1980; first printing of this paper).

Knightia eocaena is the most common species of *Knightia* in Fossil Lake (F-1 and F-2).

The following information is based on USNM 87 (holotype, missing; illustrated in Leidy, 1873, plate XVII, figure 1); USNM 4022 (illustrated in Cope, 1884, plate X, figure 4); UMVP 1180-B; UMVP 1180-E; UMVP 6591; SMMP 64,2.37; SMMP 2-A-2569; SMMP 43-2019; SMMP 1058.1; SMMP 2-A-2570; SMMP 2-A-2571; SMMP 2-A-2573; SMMP 78.9.9; SMMP 78.9.10; and AMNH 10481 (figure II.37).

Fin Rays: Pectoral (11-14) (n=9); Pelvic 6-8, usually 7, with the first ray unbranched (n=10); Anal 13 or 14 major (n=12, $\overline{X}$=13.67, SD=.49), usually 14. The first major ray is unbranched and is the longest anal ray. It is followed by 12 or 13 branched rays. The last anal ray is often doubled. The major anal rays are preceded by two accessory rays, the first of which is very small and unsegmented. The last (second) accessory ray is segmented near the distal end and is about half to two-thirds the length of the first major ray (the segmented tip is sometimes broken off, giving it a slightly shorter appearance). Dorsal 11 or 12 major (n=12, $\overline{X}$=11.16, SD=.39), usually 11. The first major ray is unbranched and is the longest dorsal ray. It is followed by 10 or 11, usually 11, branched rays. The last dorsal ray is often doubled. The major dorsal rays are preceded by two accessory rays, the first of which is very small and unsegmented. The last (second) accessory ray is segmented near the distal end and is about half to two-thirds the length of the first major ray (the segmented tip is sometimes broken off, giving it a slightly shorter appearance). Caudal, usually 1,9,8,1, forded (n=16).

Pterygiophores: Anal 12-15, usually 14 (n=13, $\overline{X}$=13.77, SD=.44); Dorsal 11-12, usually 12 (n=11, $\overline{X}$=11.83, SD=.39).

Vertebrae: Caudal about 13-15 (n=15, $\overline{X}$=14.33, SD=.82); Precaudal (2 PD) 21-24 (n=14, $\overline{X}$=23, SD=1.48); Total 36-38 (n=9), usually 37 (n=7). Neither Cope nor Leidy included predorsal vertebrae in their counts.

Scales: Cycloid. Scale rows along vertebral column about 34-35 (SMMP 78.9.9); scale rows above vertebral column at anterior end of dorsal fin about 3-4; scale rows below vertebral column at greatest body depth about 5-7 (n=2).

Dimensions: Based on Leidy's (1873) type specimens and Cope's (1884) referred specimens, *K. eocaena* is defined here as those specimens with a standard-length-to-body-depth ratio of greater than 3 (body depth is less than one third the standard length).

Knightia eocaena attains its largest size in the Fossil Lake quarries (F-1 and F-2), where it reaches a total length of 25 cm (10 inches). Maximum body depth about 25-31 percent of the standard length (n=18), about 20-25 percent of the total length (n=16); head length about 27-33 percent of the standard length (n=17), about 21-25 percent of

*Also referred to as *Lithichthys pusillus* in Cope, 1871a. Cope (1884) synonymized this species with "*Diplomystus humilus.*"

the total length (n=16).

Other Information: At least one row of tiny conical teeth on the maxilla and dentary (n=5) (neither Cope nor Leidy made mention of any teeth in their descriptions of *Knightia*). 10-12 (usually 11) dorsal scutes between the skull and dorsal fin (n=8). AMNH 10481 (figure II.37) has some possible pigmentation preservation in the skin. There was apparently a line of pigmentation spots running the entire length of the fish along the dorsal edge of the body. A lighter band of spots runs laterally along the side of the fish's body, approximately at the same level as the vertebral column as seen from the side.

For a more detailed description based on a larger study sample see Grande, 1982b.

KNIGHTIA ALTA (Leidy 1873)

= *Clupea alta* Leidy 1873; *Diplomystus altus* Cope 1877; and *Knightia copei* Tanner 1925.

Whereas *K. eocaena* is the most common species of *Knightia* in Fossil Lake, *K. alta* is the most common *Knightia* species in Lake Gosiute (G-1, G-2, G-3 and G-4).

The following information is based on USNM 86 (holotype, missing; illustrated in Leidy, 1873, plate XVII, figure 2); AMNH 2688 (illustrated in Cope, 1884, plate IX, figure 9); AMNH 2686 (illustrated in Cope, 1884, plate IX, figure 11); USNM 4019 (illustrated in Cope, 1884, plate X, figure 5); SMMP 78.9.12 (figure II.39); UMVP 6593 (two complete individuals on a slab); UMVP 6592; SMMP 64.2.22; SMMP 64.2.36; SMMP 64.2.51; and AMNH 10479 (figure II.38).

Fin Rays: Pectoral 12-14 (n=5); Pelvic 6-7, usually 7, the first ray unbranched (n=4); Anal 13 to 15 major (n=7, $\overline{X}$=13.57, SD=.79). The first major ray is unbranched and is the longest anal ray. It is followed by 12 to 14 branched rays. The last anal ray is often doubled. The major anal rays are preceded by two accessory rays, the first of which is very small and unsegmented. The last (second) accessory ray is segmented near the distal end and is about half to two-thirds the length of the first major ray (the segmented tip is sometimes broken off, giving it a slightly shorter appearance). Dorsal 11 major (n=8). The first major ray is unbranched and is the longest dorsal ray. It is followed by 10 branched rays. The last anal ray is often doubled. The major dorsal rays are preceded by two accessory rays, the first of which is very small and unsegmented. The last (second) accessory ray is segmented near the distal end and is about half to two-thirds the length of the first major ray (the segmented tip is sometimes broken off, giving it a slightly shorter appearance). Caudal 1,9,8,1 or 1,8,8,1, (n=7), usually 1,9,8,1.

Pterygiophores: Anal 13-15 (n=8), $\overline{X}$=13.71, SD=.95), usually 13-14; Dorsal 11-12 (n=9, $\overline{X}$=11.11, SD=.33), usually 11.

Vertebrae: Caudal 12-14 (n=9, $\overline{X}$=12.83, SD=.71); Precaudal (2 PD) 22-25 (n=7, $\overline{X}$=23.86, SD=.69); Total 36-38 (n=4). Neither Cope nor Leidy included predorsal vertebrae in their counts.

Scales: Cycloid. Scale rows along vertebral column about 34 (n=2); scale rows above vertebral column at anterior end of dorsal fin about 3-4 (n=4); scale rows below vertebral column at greatest body depth about 7 or 8 (n=2).

Dimensions: Based on Leidy's (1873) type specimens and Cope's (1884) referred specimens, *K. alta* is defined as those specimens with a standard-length-to-body-depth-ratio of 3 or less (body depth is greater than or equal to one-third of the standard length). Maximum size for *K. alta* about 15 cm (6 inches) total length; maximum body depth about 34-35 percent of the standard length (n=9), 27-36 percent of the total length (n=9); head length about 26-34 percent of the standard length (n=9), 20-27 percent of the total length (n=9).

Other Information: There are many small pointed teeth on the maxilla and dentary. There are 10-12 (usually 11) dorsal scutes between the skull and dorsal fin (n=6); preservation of these dorsal scutes is often poor, especially on F-1 specimens.

For a more detailed description based on a larger study sample see Grande, 1982b.

GOSIUTICHTHYS Grande

GENERIC ETYMOLOGY

Gosiutichthys: gosiut, referring to the Eocene lake which the type species inhabited; *ichthys* — a fish (from Greek). The gender is masculine.

NOMENCLATURE, SPECIFIC INFORMATION, REPOSITORIES, AND SUGGESTED REFERENCES

In the first printing of this paper (1980), what was thought to be a new species of *Knightia* was referred to as *Knightia* cf. *alta*. Subsequent study of this species (Grande, 1982b) showed it to have several characters indicating that it was not in *Knightia* or any other previously known genus, so a new genus, *Gosiutichthys*, was erected for the new species.

GOSIUTICHTHYS PARVUS Grande 1982

The following information is based on SMMP 78.9.10, 78.9.11, and 78.9.13.

Fin Rays: Pectoral 11-12 (n=3); Pelvic 6 or 7 (n=3), the first ray unbranched; Anal 10-12 major (n=5, $\overline{X}$=11.20, SD=.84). The first major ray is unbranched, about the same length as the first branched ray, and followed by 9-12 branched rays. The last anal ray is often doubled. The major anal rays are preceded by one or two accessory rays. If two accessory rays are present, the first is extremely small and unsegmented, and the last (second) is segmented at its distal end and is about half the length of the first major ray. If only one accessory ray is present, it is segmented at its distal end and is about half the length of the first major ray. If only one accessory ray is present, it is segmented at its distal end and is about half the length of the first major ray. Dorsal 9 or 10 major (n=5, $\overline{X}$=9.40, SD=.55). The first major ray is unbranched and is the longest dorsal ray. It is followed by 8 or 9 branched rays. The last dorsal ray is often doubled. The major dorsal rays are preceded by two accessory rays, the first of which is extremely small and unsegmented. The last (second) accessory ray is segmented near the distal end and is about half to two-thirds the length of the first major ray. Caudal 1,9,8,1 (n=3) or 1,8,8,1 (n=2).

Pterygiophores: Anal 11-13 (n=5, $\overline{X}$= 12.40, SD=.89), usually 13 (n=3); Dorsal 10-11 (n=5).

Vertebrae: Caudal 13-14 (n=5), $\overline{X}$=13.20, SD=.44); Precaudal (2 PD) 22 (n=5); Total 35-36 (n=3).

Dimensions: About the same as for *K. alta* except for size. Although only the five specimens listed here were studied closely, several hundred specimens were examined briefly, and the maximum size for this species appears to be about 70 mm (2¾ inches). Specimens over 50 mm (2 inches) are very rare.

Other Information: There are many small pointed teeth on the maxilla and dentary. There are 10 or 11 dorsal scutes between the skull and dorsal fin (n=2), often poorly preserved. SMMP 78.9.13 (figure II.42) shows preservation of color pattern (pigmentation) on the skin and fins. The strongest band of pigmentation runs longitudinally along the sides of the body just below the vertebral column from skull to tail. There is also a dorsally located band of pigmentation like that of *K. eocaena*, though not as prominent.

For counts and measurements based on a much larger study sample, see Grande, 1982b.

Table II.4. Easily observable characters distinguishing the two species of Green River *Knightia* from *Gosiutichthys*. The *K. eocaena* — *K. alta* groups are not well defined, and several intermediate forms exist, but *Gosiutichthys* is relatively easy to distinguish. For additional information see Grande, 1982b.

Character	*Knightia eocaena*	*Knightia alta*	*Gosiutichthys parvus*
Body depth divided by standard length	less than 1/3 the standard length	greater than or equal to 1/3 the standard length	about the same as for *K. alta*
Major anal fin rays	13-15, usually 14	13-15, usually 14	9-12, usually 11
Anal pterygiophores	13-15, usually 14	13-16, usually 13-14	10-13, usually 12
Maximum size	about 25 cm (10 inches)	about 15 cm (6 inches)	about 8 cm (3 inches)
Average size	about 13-15 cm (5-6 inches)	about 10 cm (4 inches)	about 3.8 cm (1½ inches)
Where found in the Eocene Green River lake deposits	Fossil Lake, Lake Gosiute, and Lake Uinta	Fossil Lake, Lake Gosiute, and Lake Uinta	Lake Gosiute at G-1 and in the nearby "Little Colorado Desert"

Genus: *Diplomystus* Cope 1877

Species: *D. dentatus* Cope 1877

Figures II.43-II.45, II.49b

GENERAL INFORMATION

There are two clupeomorph families represented in the Green River Formation: the Clupeidae (herrings) and the Ellimmichthyidae (an archaic group of herring-like fishes known only as fossils). Earlier workers (Cope 1877; Schaeffer, 1947; Grande, 1980 [first printing of this paper]; and others) propsed that *Diplomystus* was closely related to *Knightia*, but this was subsequently shown (Grande, 1982a and 1982b) to be false. *Knightia* is more closely related to several hundred species of herring and herring-like fishes than it is to *Diplomystus*. *Diplomystus* is not even a member of the herring and herring-like fish order, Clupeiformes, although it belongs in the superorder Clupeomorpha. *Diplomystus* is discussed in detail in Grande, 1982a.

Diplomystus is extremely common in Fossil Lake but uncommon in Lake Gosiute and Lake Uinta deposits. *Diplomystus* has a maximum length of about 65 cm (26 inches) in the F-1 and F-2 localities, and about half that in the Lake Gosiute and Lake Uinta deposits. The vast majority of *Diplomystus* specimens found in Fossil Lake are *Knightia* size (about 8 to 15 cm or 3 to 6 inches in total length), but even large specimens exceeding 38 cm (15 inches) in total length are fairly common, especially at F-1. Early juvenile stages of *Diplomystus* are common in the F-1 quarries (figure II.47), and one embryonic *Diplomystus* still in the egg (figure II.46) is known. Since developmental states of *Diplomystus* between the youngest fully ossified individuals and individuals still in the egg are abundant at F-1, it can be shown that the egg in figure II.46 is a *Diplomystus* egg by back-tracing the development of the fish. *Diplomystus* eggs are the largest known clupeomorph eggs. Eggs of extant clupeomorph species have a maximum size of about 2 mm, and the *Diplomystus* egg is about six times that size. The large size may be due in part to compression of the egg during and after burial. "Advanced" juveniles with fully ossified skeletons, such as in figure II.48, are quite common in both the F-1 and F-2 quarries.

Diplomystus has the body form, size, and upturned mouth typical of a surface feeder, and fed on smaller surface-dwelling fish such as *Knightia*. Several specimens of *Diplomystus* have been found with *Knightia* fossilized in their stomachs and mouths (see figure II.45).

Diplomystus is also known from Cretaceous (about 80 million years before present) marine deposits of South America.

GENERIC ETYMOLOGY

Diplomystus: diplo — double, *mystus* — hidden or recessed, The gender is masculine.

NOMENCLATURE, SPECIFIC INFORMATION, REPOSITORIES, AND SUGGESTED REFERENCES

DIPLOMYSTUS Cope 1877

When Cope erected the genus *Diplomystus* (1877, page 808) he designated *D. dentatus* as the type species and described 2 additional species, *D. analis* and *D. pectorosus*. He also placed *Clupea theta* (Cope, 1874) in this genus. *Diplomystus humilis* and *D. altus* were removed by Jordan (1907) and put into the genus *Knightia* (see *K. Eocaena* and *K. alta*), leaving 4 remaining species of Green River *Diplomystus: D. dentatus, D. analis, D. pectorosus*, and *D. theta*. These 4 species are reduced to 2 here, though it is very possible that all 4 species are synonymous.

Diplomystus theta was described on the basis of a partial specimen missing the posterior part of the body, and Cope (1884, page 77) admitted that "further investigation may show that the *D. analis* is identical with this species." Unfortunately, he never published an illustration of the specimen, gave only a brief description (with no sound specific characters), and the type specimen has since been lost. Because *D. theta* was found at a different geographic and stratigraphic horizon than the other described *Diplomystus* species and because the author was unable to examine the holotype, the trivial name will be retained here, in the hope that the type specimen may be found and examined.

Diplomystus dentatus, D. analis and *D. pectorosus* were all found to be synonymous by the author and are all referred to the type species *D. dentatus*. Cope separated these three F-1 type specimens on the basis of meristic variation well within that of a single species. Upon examination of the type material, some of Cope's counts were found to be questionable. For USNM 4020 (syntype for *D. pectorosus* Cope) I counted 42 major anal rays (Cope counted 44), and for USNM 4005 (the other syntype for *D. pectorosus* Cope) I counted 10 major dorsal rays (Cope counted 8 or 9). The median fins on the syntypes for *D. pectorosus* Cope are not well preserved. Since Cope's descriptions, which were based on only a few specimens, thousands of additional specimens have been found, and intermediate forms are common. No additional (nonmeristic) characteristics were observed on the type specimens to warrant specific separation. The type specimens seen here were all F-1 specimens.

For additional descriptive information see Cope (1874; 1877; 1884).

DIPLOMYSTUS DENTATUS Cope 1877

= *Diplomystus analis* Cope 1877; *Diplomystus pectorosus* Cope 1877.

The following information is based on AMNH 2477 (holotype of *D. dentatus;* illustrated in Cope, 1884, plate X, figure 1); USNM 4005 (holotype of *D. analis;* illustrated in Cope, 1884, plate VIII, figure 3); USNM 4004 (figured specimen of *D. analis;* illustrated in Cope, 1884, plate VII, figure 4); USNM 4020 (holotype of *D. pectorosus;* illustrated in Cope, 1884, plate X, figure 3); AMNH 790; UW 6393; AMNH 9851; UMVP 1187; UMVP 6593; UMVP 3959; SMMP 78.9.14 - 78.9.15; SMMP 78.2.1; SMMP 2-A-2574; and BMNH P.61231 (figure II.43).

Fin Rays: Pectoral 12-16 (n=9), the first and longest ray unbranched; Pelvic usually 6-7 (n=11), the first ray unbranched; Anal 36 to 42 major (n=15, $\overline{X}$=39.00, SD=1.62). Though large, this variation in number of anal fin rays is similar to that of some species of modern herrings. For example, *Dorsoma cepedianum* (the gizzard shad) has a range of 27 to 34 anal rays (Scott and Crossman, 1973, page 133). The first major ray is unbranched, usually with part of the segmented tip broken off, giving it a shorter appearance. When the first major ray is complete, it is of about the same length as the first branched ray. It is followed by 35 to 41 branched rays, the last of which is often doubled. The major anal rays are preceded by one or two small accessory rays, the first of which is unsegmented and very small. If present, the second accessory ray is about half the length of the first major ray and is segmented at its distal end. Dorsal 11 or 12 major (n=14, $\overline{X}$=11.43, SD=.51), not including USNM 4005 (a syntype for *D. pectorosus* Cope) which appears to have only 10 major rays. This specimen has a damaged dorsal fin, and the low count may be due to lack of preservation. The first major ray is unbranched and when complete is of about the same length as the first branched ray (it is often broken at its distal end, giving it a shorter appearance). The unbranched major dorsal ray is followed by 10 or 11 branched rays, the last of which is often doubled. The major dorsal rays are preceded by one or two small accessory rays. Caudal usually 1,9,8,1 (n=15), forked, the lower lobe slightly longer than the upper.

Pterygiophores: Anal 35-42 (n=15, $\overline{X}$=38.87, SD=1.96), usually 38-41 (n=12); Dorsal 10-13 (n=14, $\overline{X}$=12.00, SD=.78), usually 12-13 (n=12).

Vertebrae: Caudal 22-24 (n=14, $\overline{X}$=23.14, SD=.53); Precaudal (2 PD) 18-21 (n=14, $\overline{X}$=19.62, SD=.87); Total 41-44 (n=9).

Scales: Cycloid; much smaller (proportionately) than in *Knightia*. About 82-90 scales along the vertebral column (n=1); about 16-20 scale rows above the vertebral column at the anterior end of the dorsal fin; 24-30 scale rows below the vertebral column at greatest body depth (n=2).

Dimensions: Can reach a total length of up to 65 cm (26 inches), though the majority of specimens from all of the localities are less than 21 cm (8 inches) in total length. Maximum body depth 33-42 percent of the standard length (n=16), 27-35 percent of the total length (n=15); head length 27-32 percent of the standard length (n=16), 20-25 percent of the total length.

?DIPLOMYSTUS THETA (Cope 1874)

= *Clupea theta* Cope 1874.

The holotype for this species is missing. Cope (1884, page 77) said it was quite possibly synonymous with *D. analis* (= *D. dentatus* here); but without the type specimen, or even a published illustration of the specimen, it is impossible to review the species, so the name will be retained here.

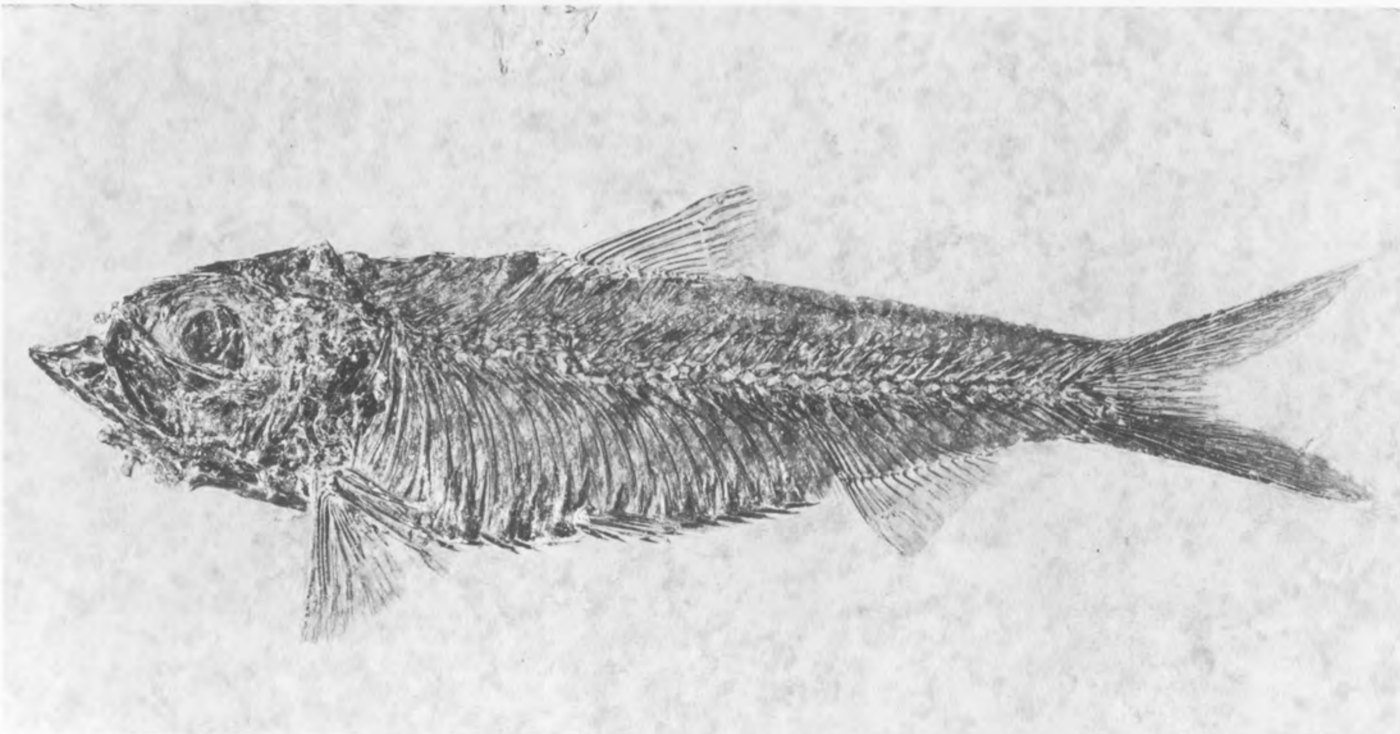


Figure II.37 A specimen of *K. eocaena* (AMNH 10481) from Fossil Lake. Total length about 10 cm (4 inches).

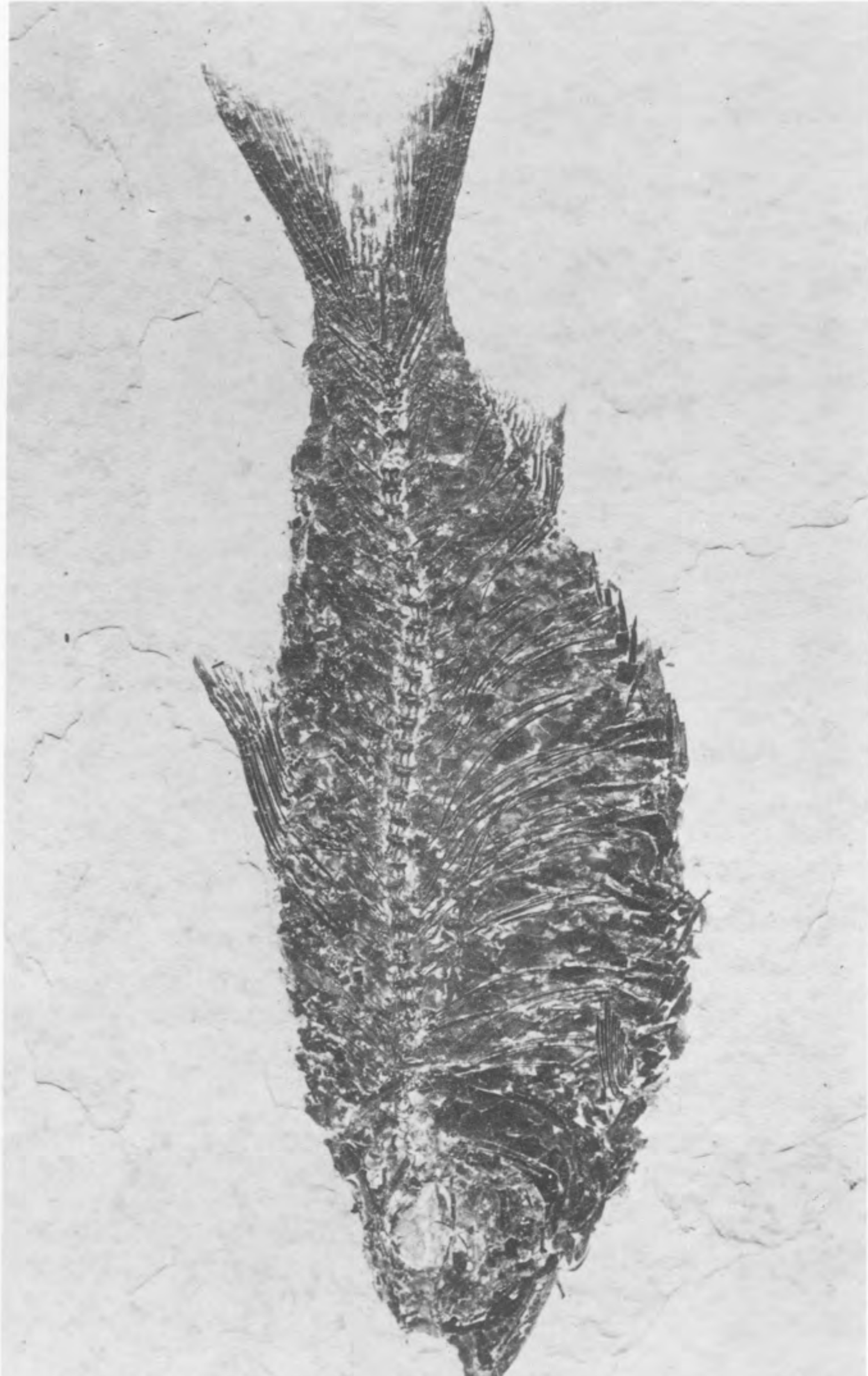


Figure II.38. A specimen of *K. alta* (AMNH 10479) from F-1. Total length about 10 cm (4 inches).

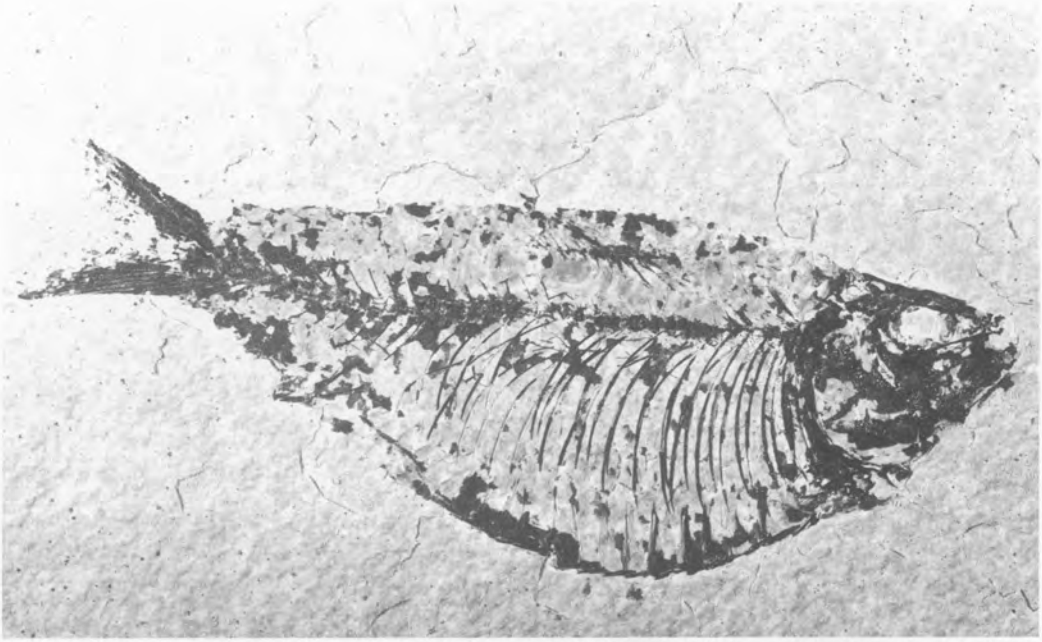


Figure II.39. A particularly deep-bodied *K. alta* (SMMP 78.9.12) from F-2. Total length about 12.5 cm (5 inches). Note the distorted dorsal body margin which has been pushed out above the dorsal fin margin.

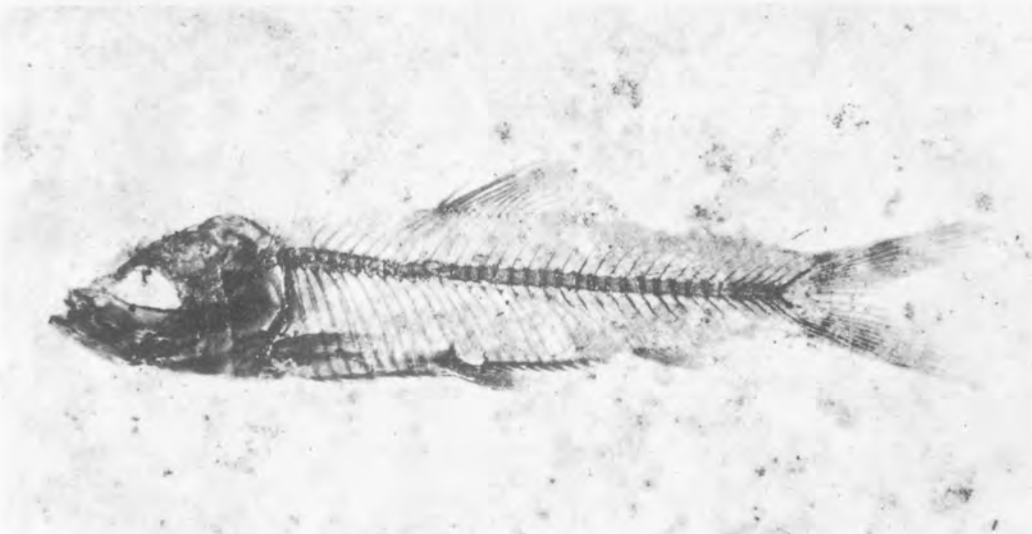


Figure II.40. A juvenile *Knightia eocaena* (SMMP 78.9.17) from F-1. Total length about 24 mm (15/16 inch). Note the fully ossified skeleton. *Diplomystus* of this length (figure II.48) do not yet have fully ossified skeletons and can thus be differentiated from *Knightia* even in the very young juvenile stage of development.

Figure II.41. A slab from the *Knightia eocaena* mass mortality layer of F-1 (SMMP 83.2.7). Average total length of the fish is about 13 cm (5 inches). Preparation by Richard W. Jackson.

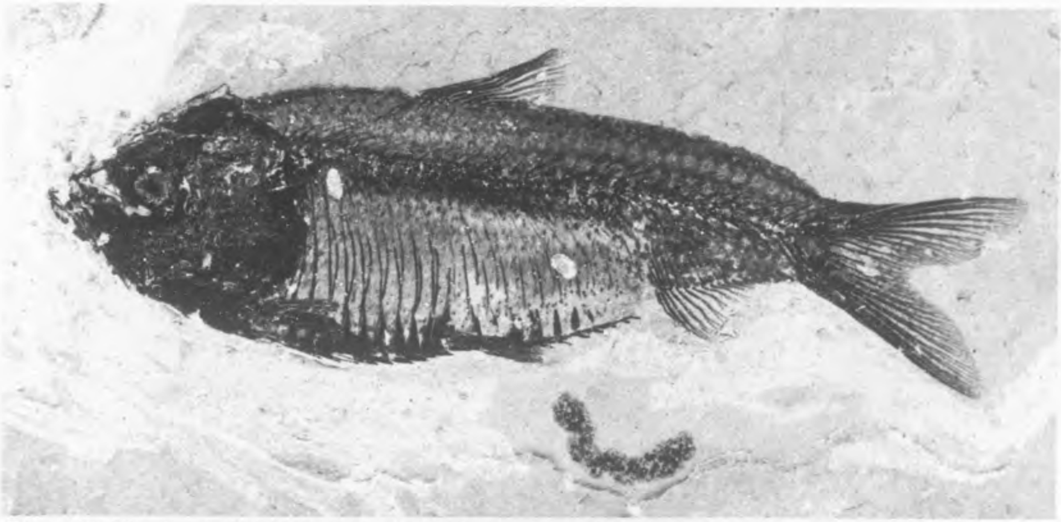


Figure II.42a. An individual of *Gosiutichthys parvus* (SMMP 78.9.13) from the "Little Colorado Desert" near G-1 showing preservation of skin pigmentation: note the lateral line of small dots running just below the vertebrae. Total length 36 mm (about 1-3/8 inches).

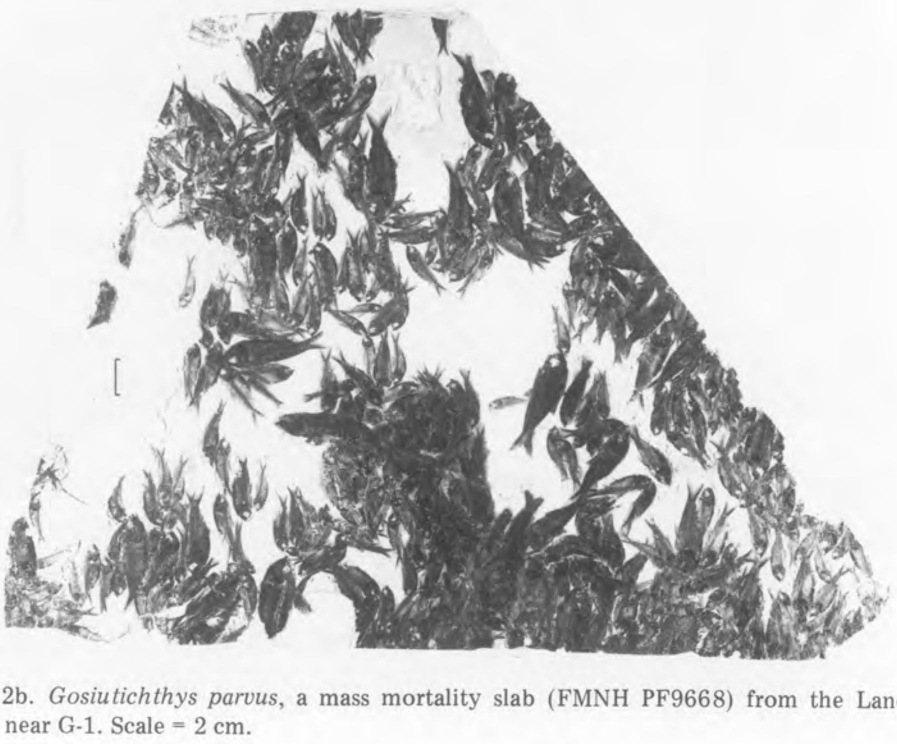


Figure II.42b. *Gosiutichthys parvus*, a mass mortality slab (FMNH PF9668) from the Laney Member near G-1. Scale = 2 cm.

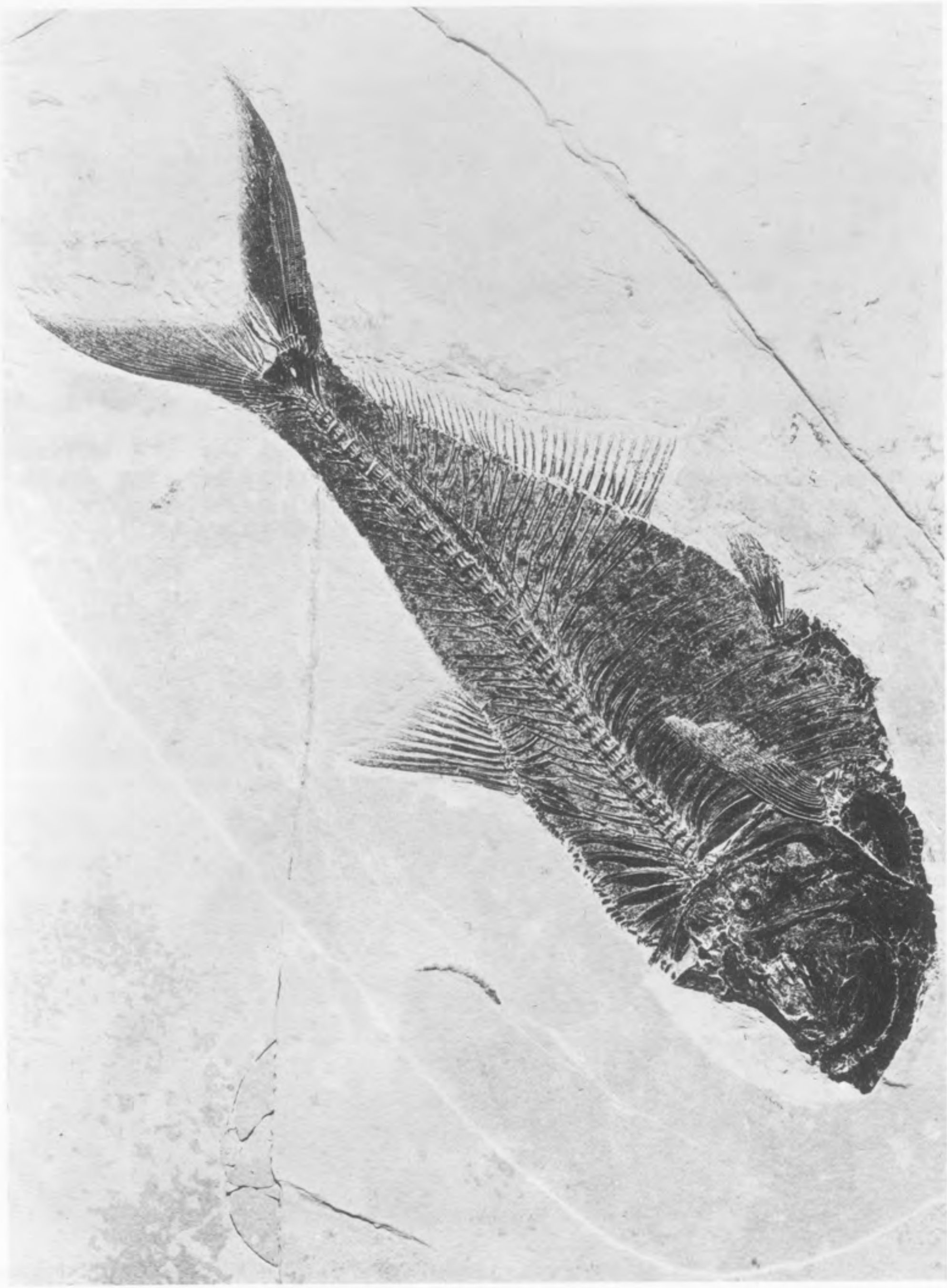


Figure II.43. A large specimen of *Diplomystus dentatus* (BMNH P.61231) from F-1. Total length about 48 cm (19 inches).

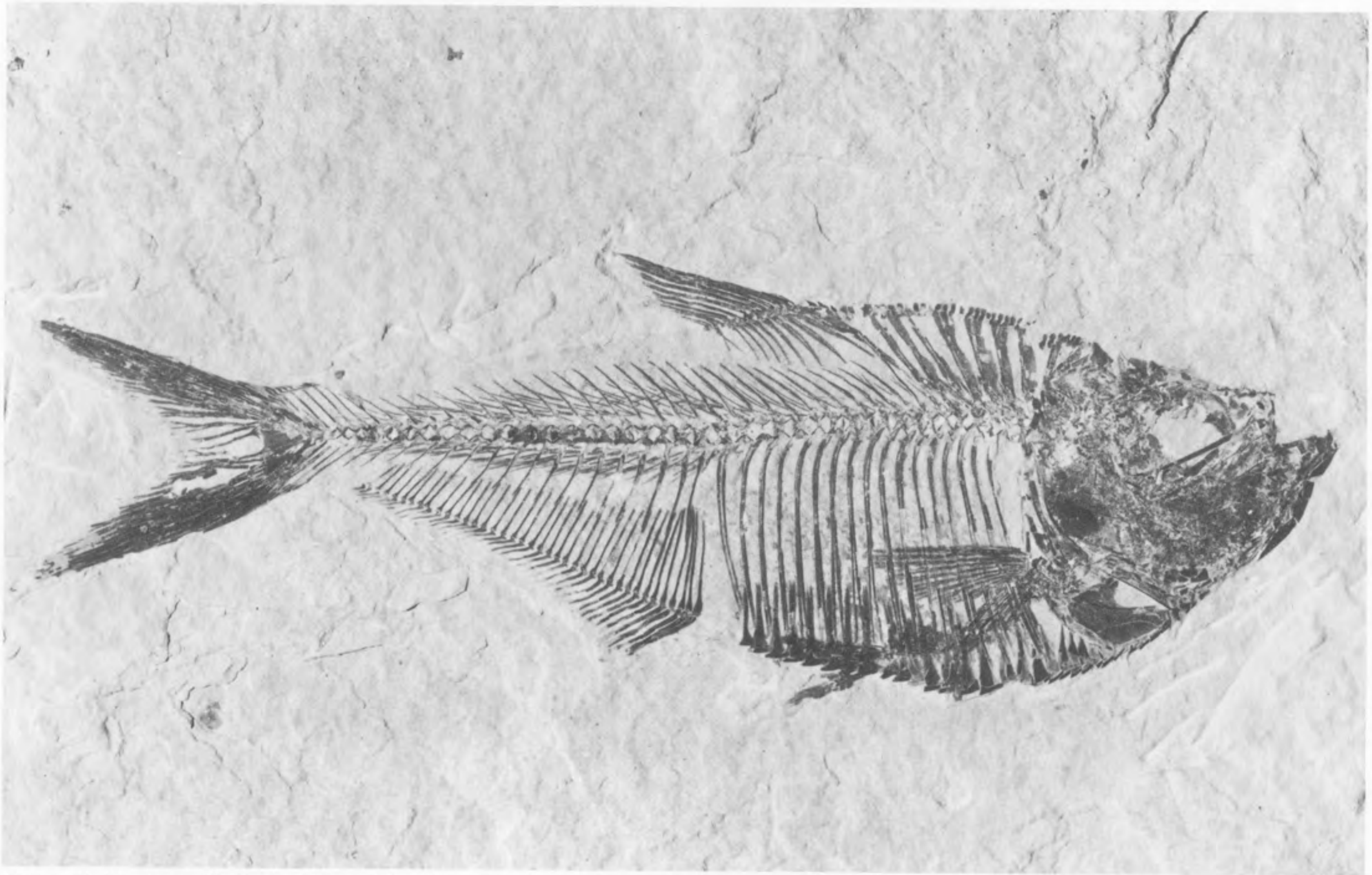


Figure II.44. A small *D. dentatus* without scales showing the bone structure (SMMP 78.9.14), from F-2. Total length about 8.5 cm ($3\frac{1}{3}$ inches).

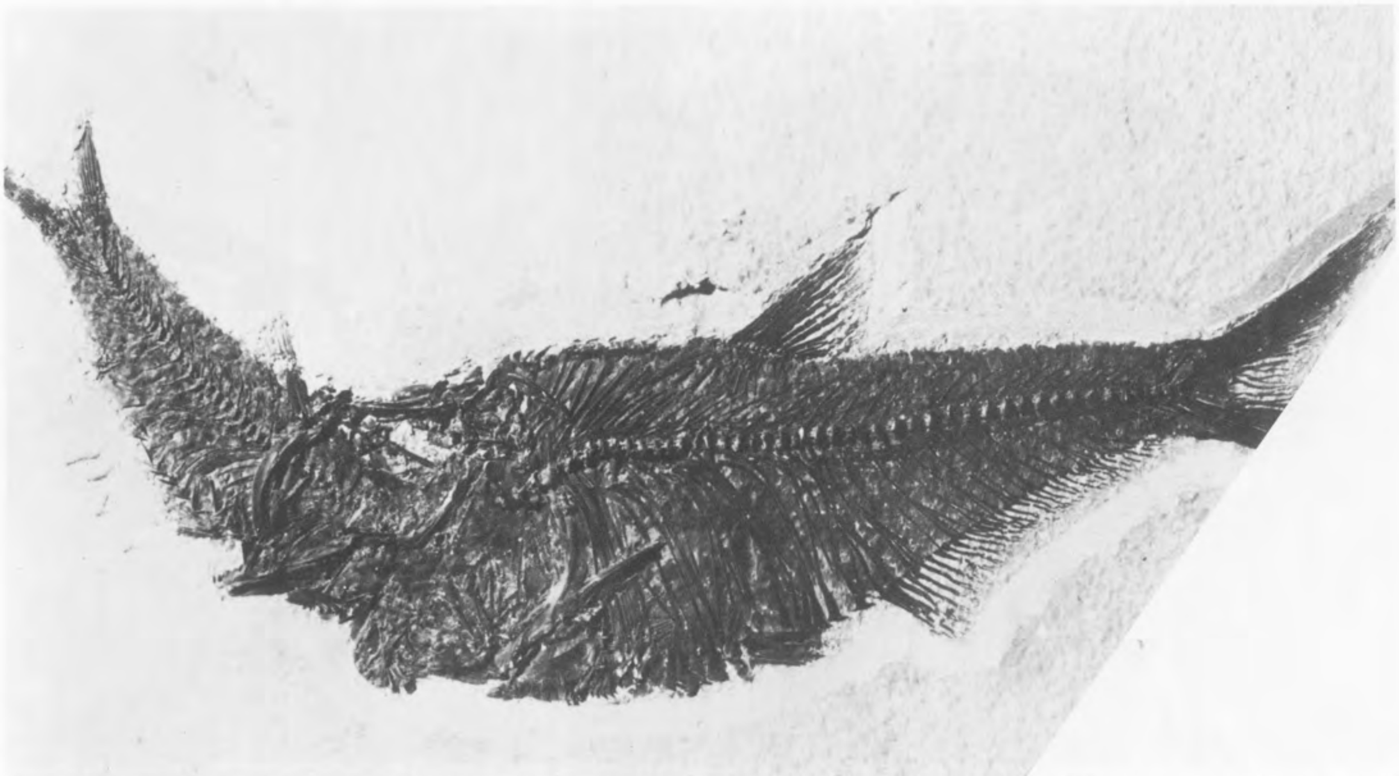


Figure II.45. A *D. dentatus* with a *Knightia eocaena* over half of its own length in its mouth from F-1, attesting to the voracity of *Diplomystus*. Many specimens of *Diplomystus* have been found with *Knightia* specimens (some still fully articulated) in their stomachs. Total length of *Diplomystus* about 20 cm (8 inches). Photo with the permission of Carl Ulrich.

Figure II.46. A *Diplomystus* still in the egg, from F-1 (an uncatalogued University of Wyoming specimen). Longest diameter of egg about 12 mm (about ½ inch).

Figure II.47. A very young *Diplomystus* with a yet unossified skeleton (SMMP 78.9.18), from F-1. Total length about 24 mm (15/16 of an inch).

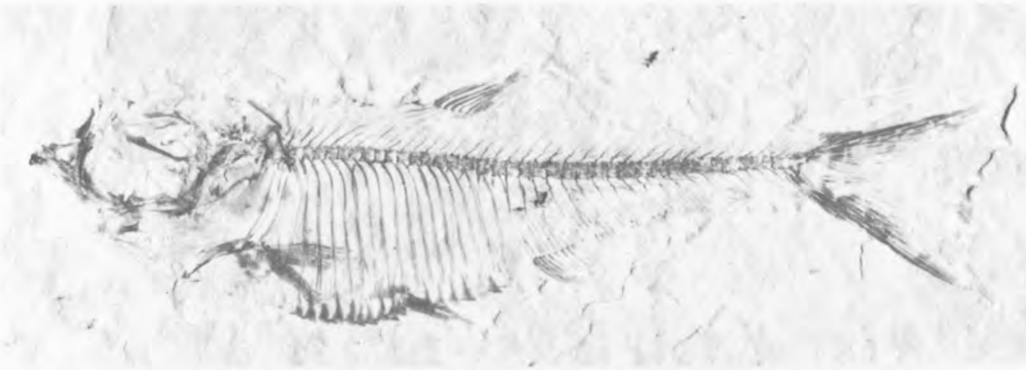


Figure II.48. A young *Diplomystus* with a fully ossified skeleton (SMMP 78.9.19) from F-2. Length 38 mm (about 1½ inches).

Figure II.49a. Scale from *Knightia eocaena* (SMMP 78.9.9). Length of longest diameter is 5 mm (3/16 inch), and total length of the fish it was taken from is 12.5 cm (about 5 inches).

Figure II.49b. Scale from *Diplomystus dentatus* (SMMP 78.9.38 – scale only). Size of scale equal to that of II.49a, but total length of the fish it was taken from is about 41 cm (16 inches), so the scale is proportionately much smaller. Scale taken from a large exploded uncataloged *Diplomystus* in the collection of the U.S. National Park Service, Fossil Butte National Monument, Kemmerer, Wyoming.

Genus: *Notogoneus* Cope 1885

Species: *N. osculus* Cope 1885

Figures II.50-II.53

GENERAL INFORMATION

Notogoneus is a member of the family Gonorynchidae, whose living representatives in the Indo-Pacific area are sometimes referred to as the "sand fish." *Notogoneus* is fairly uncommon in the F-1 quarries and extremely rare in the F-2 quarries.* The only species of *Notogoneus* in the Green River Formation has a maximum total length of about 91 cm (3 ft.) and average total length of about 46 cm (18 inches). Young *Notogoneus* are notably absent from the F-1 and F-2 quarries, where it is extremely rare to find *Notogoneus* smaller than 25 cm (10 inches) in total length. The smallest specimen known to the author in a public repository is USNM 6037, which has a total length of about 15 cm (slightly less than 6 inches; illustrated in Eastman, 1917, plate 15, figure 2).† It is possible that young *Notogoneus* were born and spent the early part of their lives in the river and channel enviornments connected to Fossil Lake. *Notogoneus* can be found in channel facies deposits of the overlying and adjacent Bridger Formation.

The scales of *Notogoneus* are quite distinctive, with a fringe of relatively long spines along the posterior border (figure II.53). There are no teeth in the jaws or on the pterygoid or hyoid bones; with its ventrally located mouth parts, it was probably a bottom feeder on plant material and decaying organisms. Its scarcity may be due to the frequent thermal stratification of Fossil Lake, possibly making bottom waters uninhabitable for this fish much of the time. It may have migrated into the lake to feed only during the season of the annual turnover when the bottom waters were nontoxic.

Living gonorhynchids, sometimes re-referred to as "sand fish," are in the genus *Gonorynchus*, which are near-shore marine fishes of the Indo-Pacific. Fossil gonorynchids are known from North America (Upper Cretaceous - Eocene), S.W. Asia (Upper Cretaceous - Recent), Europe (Upper Cretaceous - Oligocene), and Australia (Oligocene-Recent).

GENERIC ETYMOLOGY

Notogoneus: noto — from the south, *goneus* — a father.

NOMENCLATURE, SPECIFIC INFORMATION, REPOSITORIES, AND SUGGESTED REFERENCES

*Known from F-2 only by one incomplete specimen and a patch of scales.

†While this manuscript was in press, an unusually small *Notogoneus* was found at F-1 with a total length of 31 mm (1¼ inches), see plate (added in proof) on page 333.

There is but a single species of *Notogoneus* described from the Green River Formation. Whitfield (1890) described *Protocatostomus constablei*, which is identical with *Notogoneus osculus*. The following information is based on the holotype, AMNH 2503 (illustrated in Cope, 1886, figure 4); AMNH 1340; AMNH 3900 (type for *Protocatostomus constablei*, illustrated in Whitefield, 1890, plate 4); SMMP 76.18.1 (figure II.51); UW 6390 (illustrated in McGrew and Casilliano, 1975, figure 22), UW 12307 (illustrated in Hager, 1970, figure 32.3); UMVP 6513; USNM 2422; USNM 11737; and USNM 6037, all from F-1.

NOTOGONEUS OSCULUS Cope 1885

= *Protocatostomus constablei* Whitfield 1890.

Fin Rays: Pectoral 9-10 (n=6) (pectorals usually incomplete or damaged); Pelvic 9-10 (n=3); Anal 8 or 9 major (n=8, $\overline{X}$=8.50, SD=.53). The first major ray is unbranched and is the longest anal ray (when still intact). It is followed by 7 or 8 branched rays, the last of which is often doubled. The segmented distal end of the first major ray is very thin and delicate, often broken off at about half its length, giving it a much shorter appearance. The major rays are preceded by one or two very small unsegmented accessory rays. Dorsal 13-15 major (n=8), $\overline{X}$=13.74, SD=.76). The posteriormost dorsal rays are often very difficult to see in *Notogoneus* because they are very small and are often completely covered by thick, dense scales. Specimens should be very closely examined (under a microscope, if possible) if accurate dorsal fin ray counts are desired. The first major dorsal ray is unbranched, and is slightly shorter than the first branched ray. The last dorsal ray is often doubled. The major dorsal rays are preceded by two accessory rays, the first of which is very short and unsegmented, and the second of which is about one-fourth to one-third the length of the first major ray and segmented at its distal end. The distal end of the second accessory ray is often broken off. The second accessory ray is often missing completely. Caudal 1,9,8,1 (n=7). Caudal fin slightly forked with rounded margin.

Pterygiophores: Dorsal 14-15 (n=5, $\overline{X}$=14.17, SD=.41); Anal 8-9 (n=6, $\overline{X}$=8.80, SD=.41)

Vertebrae: Caudal 14-15 (n=7, $\overline{X}$=14.43, SD=.40); Precaudal (2 PD) 35-37 (n=7, $\overline{X}$=36.17, SD=.75); Total 51=52 (n=6).

Scales: Small, Strongly ctenoid (see figure II.53). Predorsal 48-53 (n=2); rows above vertebral column at anterior end of dorsal fin 10-12 (n=2); rows below vertebral column at anterior end of dorsal fin 13-14 (n=2). The entire head is covered with scales. Scales are very similar to those of *Gonorynchus gonorynchus*.

Dimensions: Maximum body depth about 17-20 percent of the total length (n=7), about 18-25 percent of the standard length (n=8); head length about 21-22 percent of the total length (n=7), about 25-27 percent of the standard length (n=8).

Other Information: Branchiostegals 3-4, very broad (n=4). The first rib is a large blade-like structure, much wider than any of the following ribs. Unlike *Gonorynchus*, *Notogoneus* has no dental apparatus on the hyoid or pterygoid.

Figure II.50. *Notogoneus osculus* (BMNH P.61232) form locality F-1. Total length about 33 cm (13 inches).

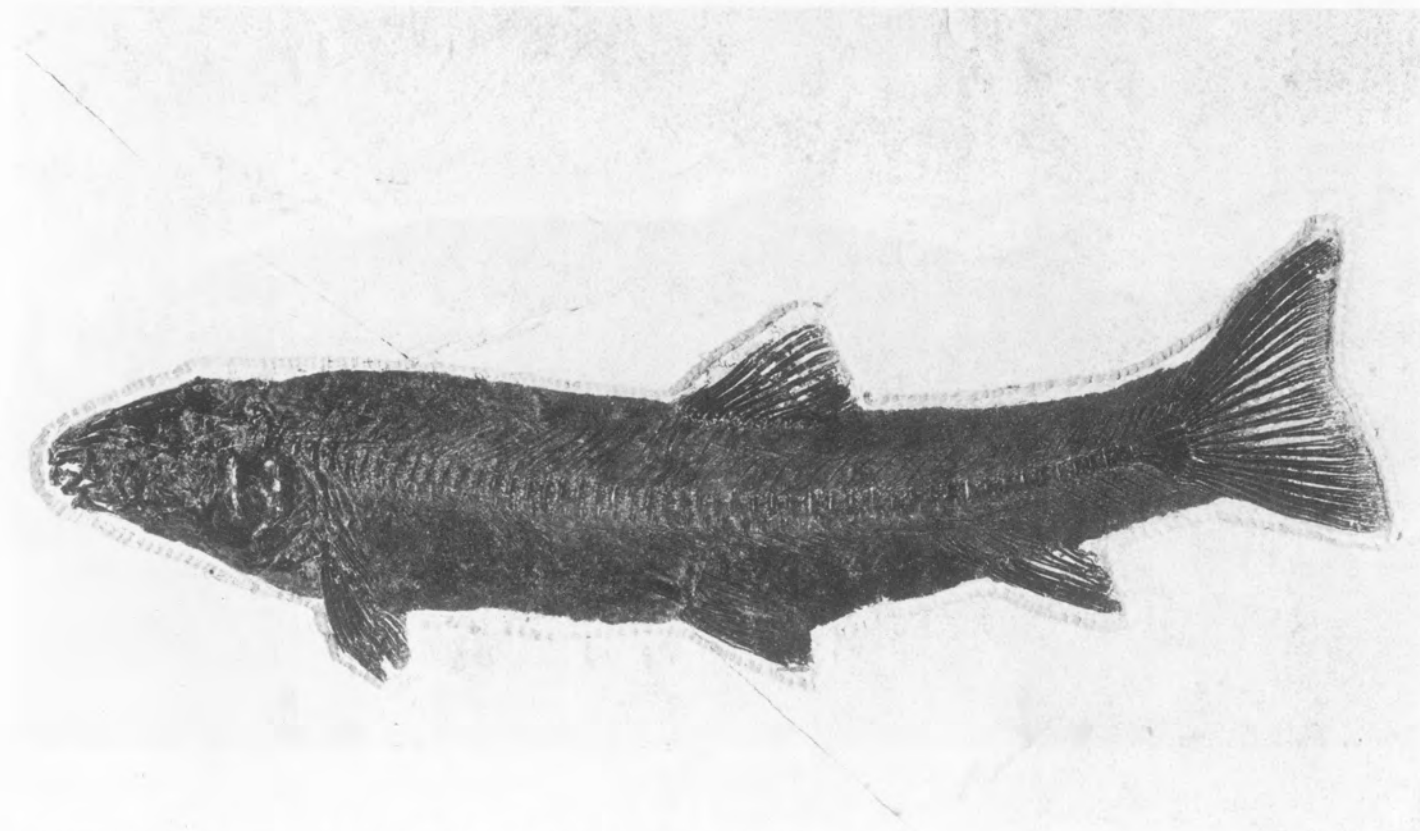


Figure II.51. *Notogoneus osculus* (SMMP 76.18.1) from locality F-1. Total length about 56 cm (22 inches). Preparation by Richard W. Jackson.

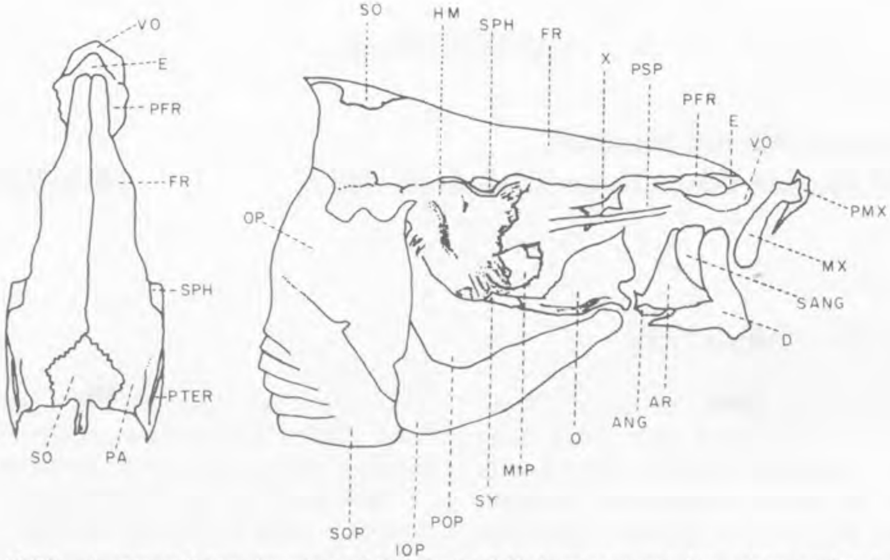


Figure II.52. A restored line drawing of the skull of *Notogoneus osculus,* scales omitted. Taken from Eastman (1917, page 289). (A) dorsal and (B) lateral views of cranium. ANG, angular; AR, articular; D, dentary; E, ethmoid; FR, frontal; HM, hyomandibular; PFR, prefrontal; PMX, premaxilla; POP, preoperculum; PSP, parasphenoid; PTER, pterotic; Q, quadrate; SANG, surangular; SO, supraoccipital; SOP, suboperculum; SPH, sphenotic; SY, symplectic; VO, vomer; X, cheek-plate.

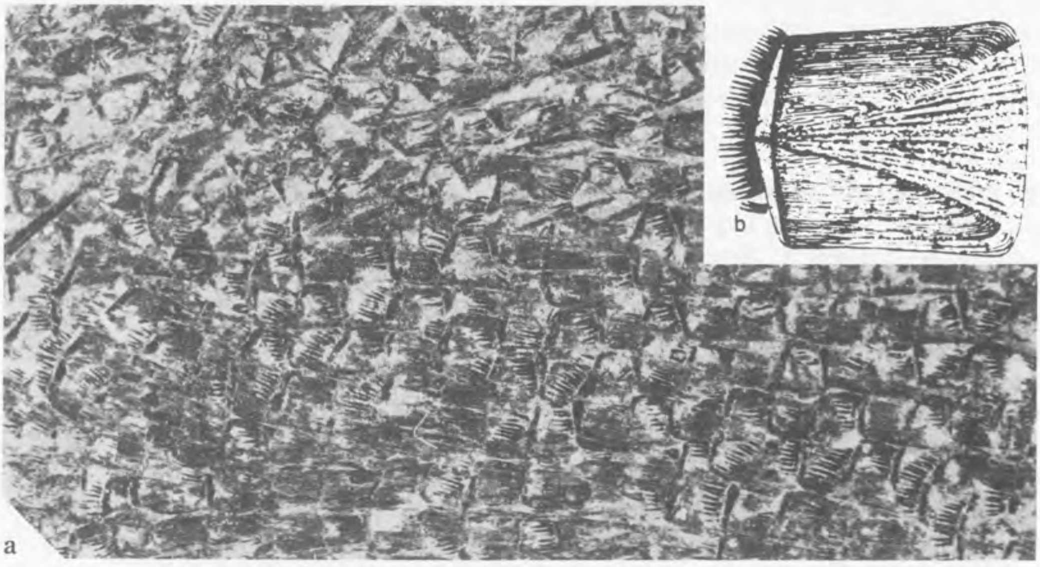


Figure II.53. (a) Scales of *Notogoneus* showing the fringe of spines along the posterior borders. Fish is facing right. (b) Enlarged drawing of a single scale from *Notogoneus* (AMNH 3900); the length of the scale is about 6.5 mm (¼ inch) and the total length of the fish it is from is about 55 cm (22 inches). Taken from Whitfield, 1890.

Genus: *Amyzon* Cope 1872 (the sucker)

Species: *A. gosiutensis* Grande, Eastman, and Cavender 1982 — Figures II.54-II.59

GENERAL INFORMATION

In the Green River Formation, *Amyzon* has been reported only from Lake Gosiute deposits within the Laney Member. It is most common at localities G-1 and G-2 and is found frequently associated with the catfish *Astephus antiquus* (see figure II.59). Specimens of *Amyzon* are fairly abundant, though complete specimens are scarce. They have a maximum total length of about 30 cm (12 inches) and an average total length of about 20 cm (8 inches). *Amyzon* is easy to recognize in the Green River Formation by its distinctively shaped dorsal fin (see figures II.54, II.55, and II.58). The fin arrangement and shapes closely resemble those of the living sucker *Ictiobus cyprinellus* (the "Bigmouth Buffalo"). *Amyzon* in the Green River Formation is one of the first known occurrences of a sucker in North America south of the Canadian border. That they occur in the early Middle Eocene Laney Member deposits but don't appear to be present in the late Early Eocene Fossil Butte Member deposits may indicate that suckers did not migrate to central North America until the Middle Eocene.

Amyzon had no teeth in its jaws, and thick, fleshy lips on its extensible mouth enabled it to suck food from the bottom of the lake. It had teeth on its pharyngeal arch (gill arch) in a comb-like row, which it probably used to crush various invertebrates and possibly small fish. Its diet probably consisted mostly of insects, plant material, and decaying organisms on the bottom. Suckers are, and apparently always have been, freshwater fish.

Today, suckers can be found living in fresh waters in China, northeast Siberia, and North America. Fossil suckers are known from East Asia (Eocene-Recent) and from North America (Paleocene-Recent).

GENERIC ETYMOLOGY

Amyzon: a — from, *myzon* — to suck.

NOMENCLATURE, SPECIFIC INFORMATION, REPOSITORIES, AND SUGGESTED REFERENCES

Specific description will be omitted here. For type description see Grande, Eastman, and Cavender, 1982.

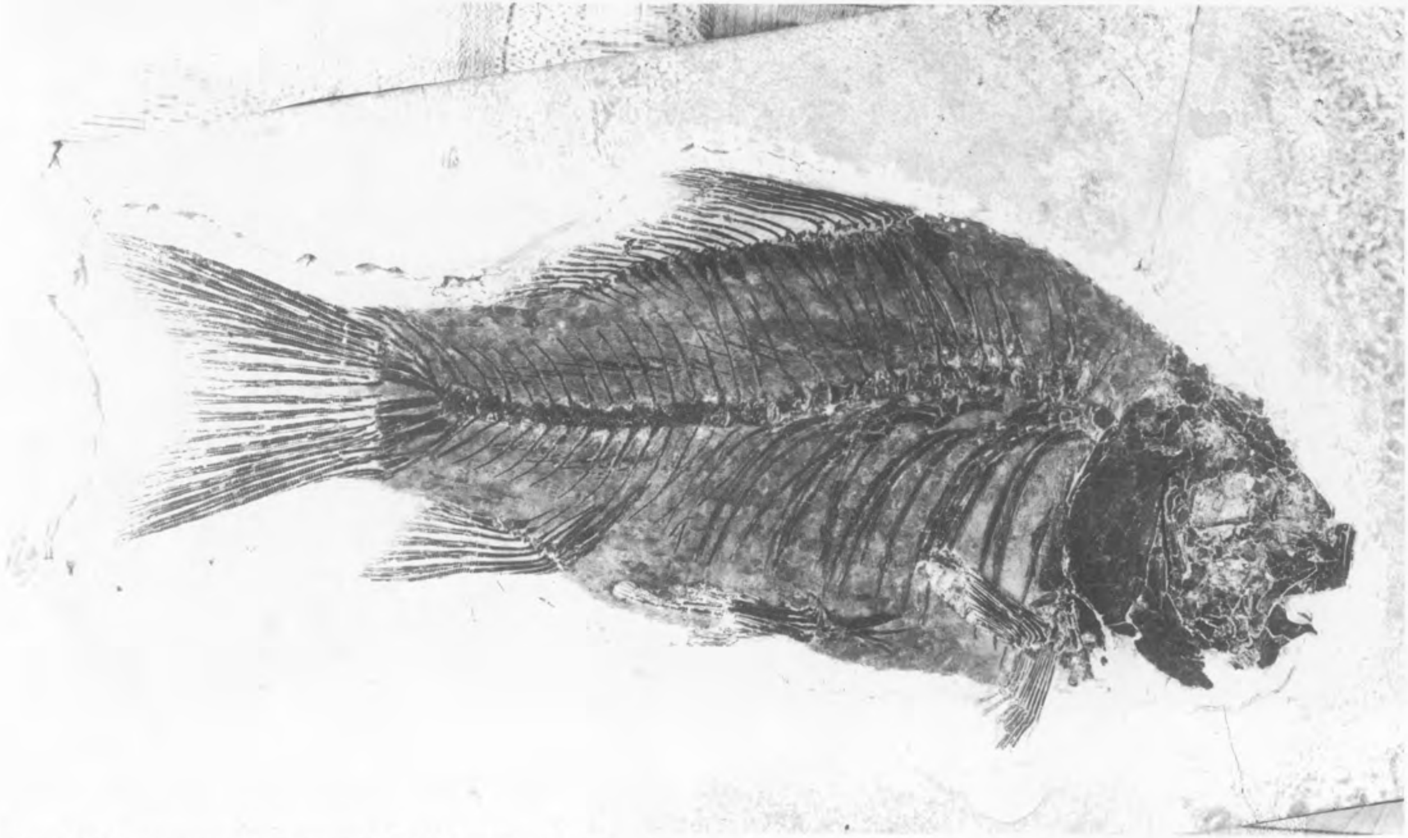


Figure II.54. *Amyzon gosiutensis* (AMNH 10460), from locality G-1. Length about 25 cm (10 inches).

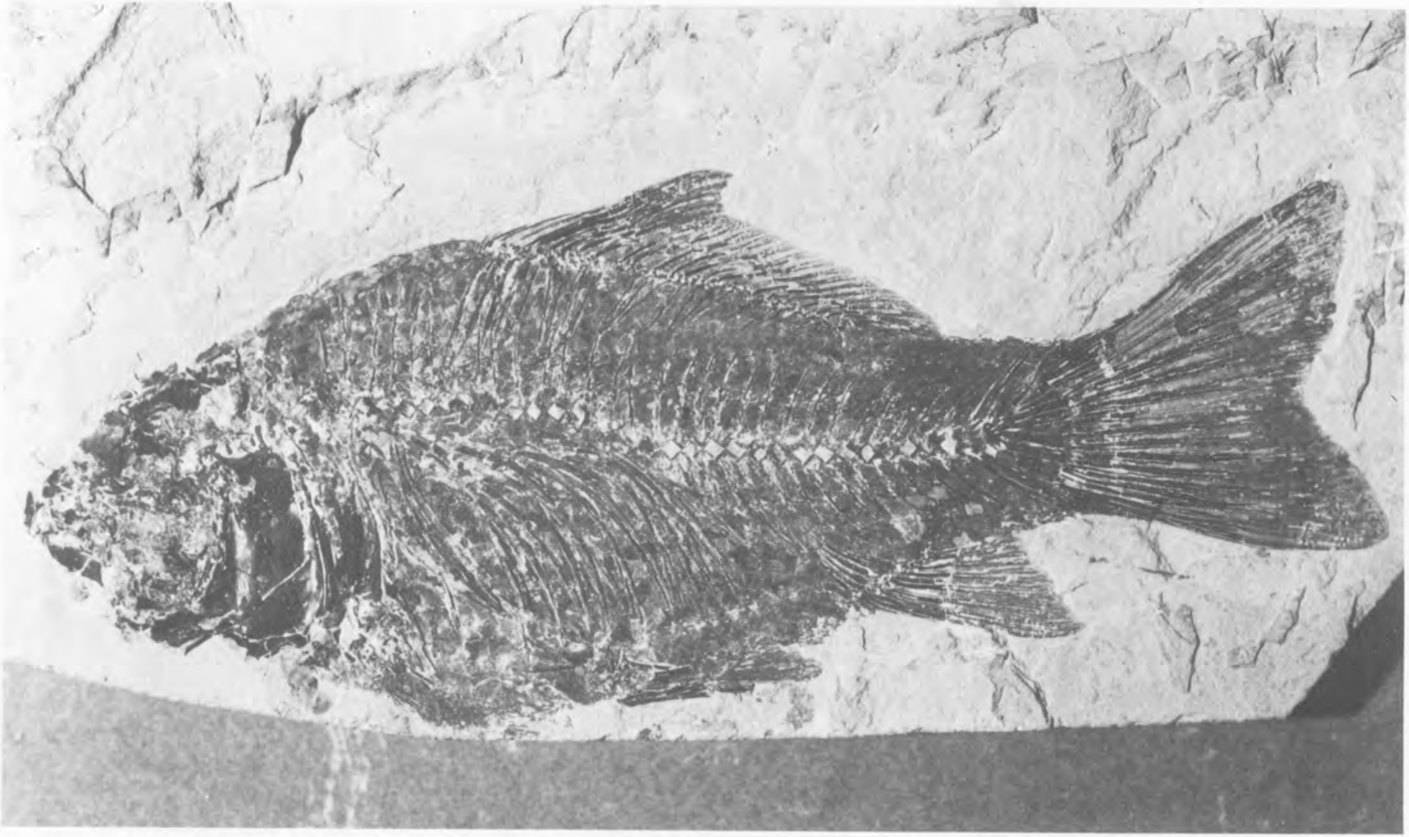


Figure II.55. *Amyzon gosiutensis* (SMMP 78.4.2) from locality G-1, missing the lower jaw, but showing the dorsal fin shape characteristic of this fish. Total length about 22.5 cm (9 inches).

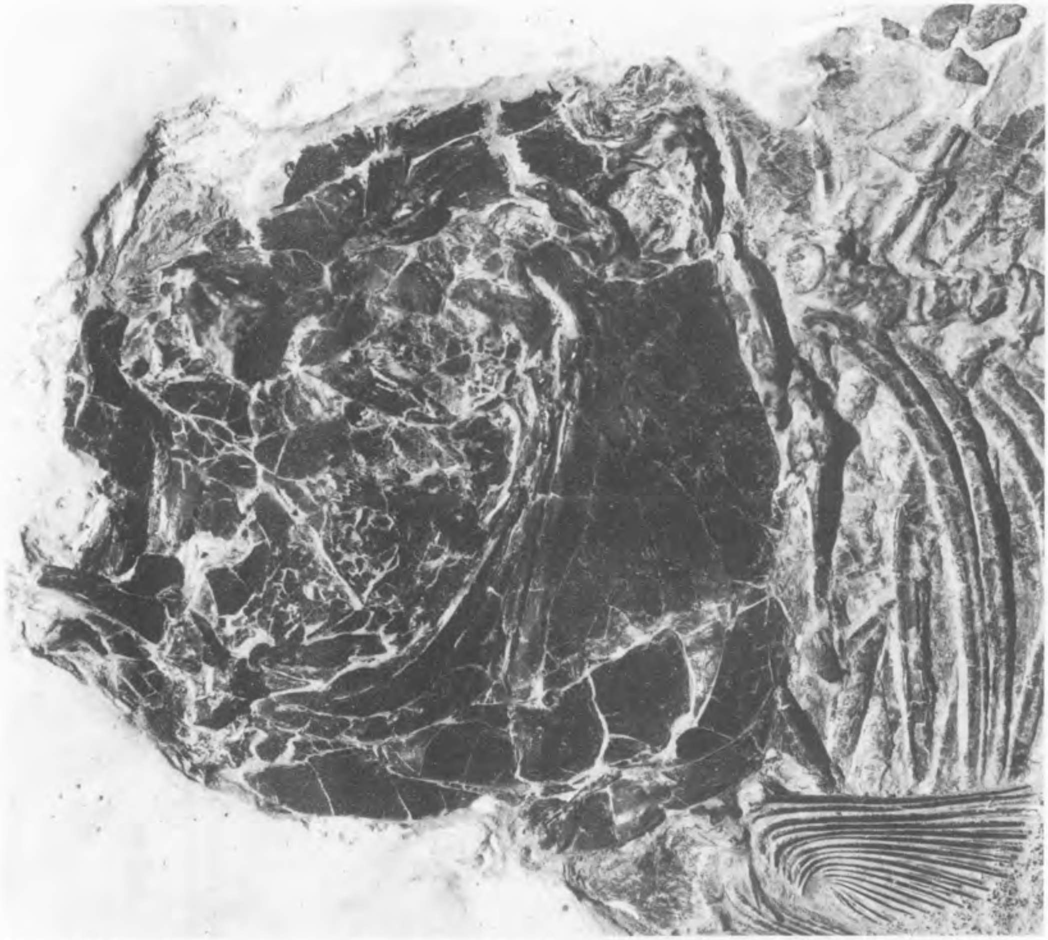


Figure II.56. *Amyzon gosiutensis* (UW 11578) from locality G-2 (in the upper light brown dolomitic shale zone). Skull length about 5.8 cm (2¼ inches). Preparation by the author.

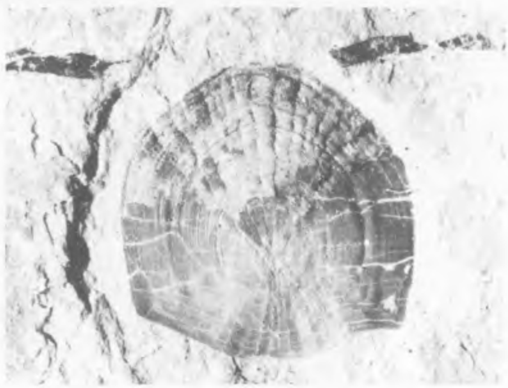


Figure II.57. Isolated flank scale of *Amyzon gosiutensis* from G-1 (UMVP 6507). Length of scale is 7.5 mm.

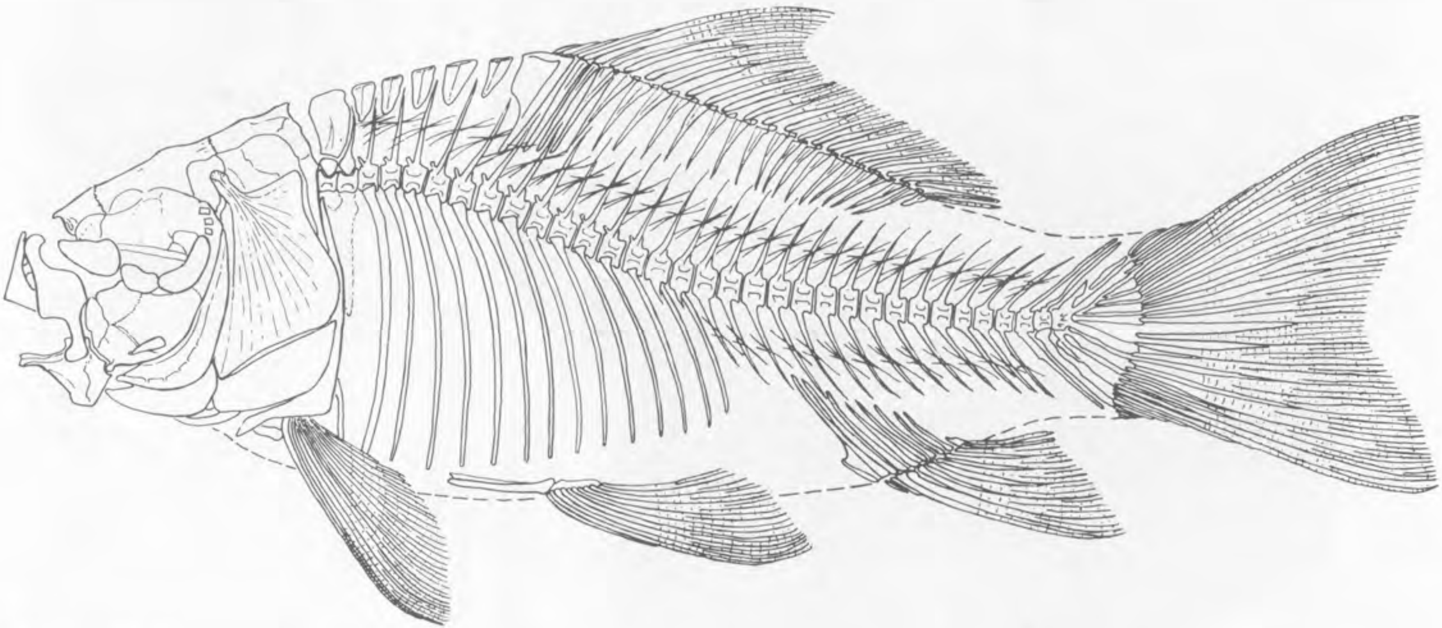


Figure II.58. Restored line drawing of *Amyzon gosiutensis* from the Laney Member of the Green River Formation, scales omitted. This represents an adult fish about the size of the specimens in figures II.54 through II.56. Taken from Grande, Eastman and Cavender, 1982.

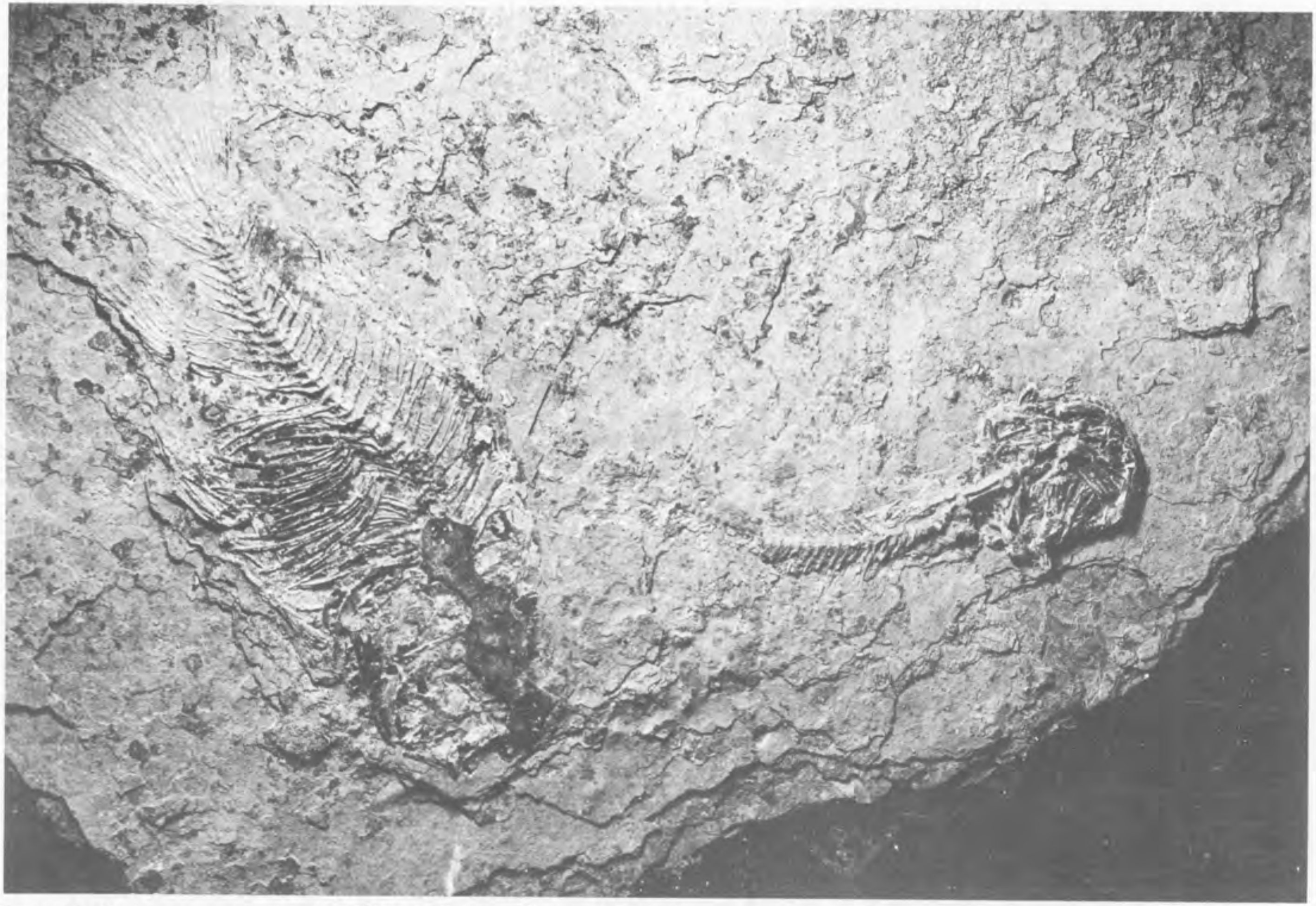


Figure II.59. *Amyzon gosiutensis* (UW 11578 from Figure II.56 before removal and preparation) on slab with *Astephus antiquus* (a catfish), from locality G-2 (in the upper light brown dolomitic shale zone). Total length of sucker is about 25 cm (10 inches). Photograph courtesy of Paul Buchheim.

Genera: *Astephus* Cope 1873
Hypsidoris Lundberg and Case 1970 (the catfish)

Species: *A. antiquus* (Leidy 1873) Figures II.60-II.62
H. farsonensis Lundberg and Case 1970 Figures II.63-II.65
H. sp Figure 11.66

GENERAL INFORMATION

Catfish so far reported from the Green River Formation include one species each of the genera *Astephus* and *Hypsidoris*. Both are members of the Family Ictaluridae. The easiest way to distinguish *Hypsidoris* from *Astephus* is by counting anal fin rays; *H. farsonensis* has about 15 to 17 and *A. antiquus* has about 26. *Hypsidoris* also usually has a much longer pectoral spine (see figure II.64). At least one other species of catfish from the Green River Formation is being described by John G. Lundberg (personal communication). The overlying Bridger Formation contains the genus *Rhineastes* (see Lundberg, 1975), which is a member of the Family Ariidae; but, so far, no ariid catfish have been discovered in the Green River Formation. The overlying Bridger Formation includes two other described species of *Astephus* (*A. calvus* and *A. resimus*). Catfish are exceedingly rare (only a few specimens known) in Fossil Lake localities F-1 and F-2, scarce in Gosiute localities G-1 and G-3, and more abundant at localities G-4 and G-2. Locality G-2 contains one mass mortality layer of catfish (*Astephus antiquus*), having density of about 3 per square meter. *Hypsidoris* is the rarer of the two described Green River catfish and is known only from localities G-1 and G-4. *Astephus* is known from all the Green River catfish localities. In the Green River Formation, *Astephus* has a maximum total length of about 30 cm (12 inches), though it rarely exceeds 18 cm (7 inches) and is usually about 15 to 18 cm (6-7 inches). *Hypsidoris* probably has approximately the same size range, though there have not been enough specimens reported to be sure. Green River catfish are easily recognized by their stout dorsal and pectoral spines which are serrated or toothed on one edge, scaleless bodies, and broad skulls. They also have whisker-like barbels (figure II.60), a weberian apparatus, and an adipose fin (figure II.61), but these features are only rarely preserved.

Mouth structure indicates that the diet of Green River catfish was probably similar to that of living ictalurids: smaller fish, crayfish, mollusks, and plant material (Eddy and Underhill, 1974). *Astephus* and *Hypsidoris*, like their living counterparts, were probably bottom feeders. One possible reason for their scarcity in Fossil Lake could be a preference for river and stream habitats connected to the lake.

Ictalurid catfish are known from Paleocene to Recent time (Lundberg, 1975). The Green River forms are the earliest known nearly complete ictalurids. Most or all of the fragmentary Paleocene material is questionable in its assignment to the Ictaluridae. Fossil catfish fragments erroneously reported from Cretaceous deposits of Montana were found to be sturgeon elements (Acipenseridae) by Estes (1964, page 21).

Today, living ictalurid catfish are restricted to fresh waters of North America (southern Canada to Guatemala) and are represented by 5 genera and 11 species.

GENERIC ETYMOLOGY

Astephus: having a crown.
Hypsidoris: hypsi — lofty or high, *doris* — dagger, in reference to the long pectoral and dorsal spines; gender feminine.

NOMENCLATURE, SPECIFIC INFORMATION, REPOSITORIES, AND SUGGESTED REFERENCES

Other generic names that have been used (in the literature) for *Astephus* are *Pimelodus* (Leidy), *Rhineastes* (Cope) and *Ameiurus* (Eastman). The earliest described specimens of *Astephus antiquus* are described from the Bridger Formation (Leidy, 1873) on the basis of a pectoral spine and a dentary bone (USNM 2179). The earliest description of a nearly complete specimen (USNM 8122) from the Green River Formation is by Eastman (1917, page 292). *Ictalurus* was erroneously reported from the Green River Formation by Schaeffer and Mangus (1965, page 20).

ASTEPHUS ANTIQUUS (Leidy 1873)

= *Pimelodus antiquus* Leidy 1873; *Rineastes arcuatus* Cope 1873; and *Ameiurus primaevus* Eastman 1917.

This species of catfish is known from all three Green River Lake deposits. The following information is based on Lundberg's (1975) review of *Astephus antiquus* (he used several nearly complete Green River specimens including AMNH 6387; USNM 8122; AMNH 6388; AMNH 9499; and YPM 844) and on UMVP 6514 (an anterior half of a fish) and SMMP 78.9.3 (missing the tail and anterior end of the skull).

Fin Rays: Pectoral about I,8-9, usually I,9; Pelvic about 8-10; Anal 23-26, the anteriormost rays very small, anal fin margin rounded; Dorsal II,5-6, the first spine very small; Caudal 1,7,8,1, forked with pointed lobes.

Pterygiophores: Dorsal about 7, plus a supraneural and a neural spine support; Anal usually 22-24.

Vertebrae: Caudal usually 24-25; Precaudal usually 17-18, 5 vertebrae involved in weberian complex.

Other Information: The rib on the 5th vertebra (last vertebra involved in the weberian apparatus) is well developed (unlike *Hypsidoris*). The length of the dorsal and pectoral spines is less than 1/5 of the standard length.

For more detailed description see Eastman (1917) and Lundberg (1970, 1975) (Eastman's anal ray count is low in that paper due to damage to the specimen he described, USNM 8122.)

HYPSIDORIS FARSONENSIS
Lundberg and Case 1970

This species of Green River catfish is known only from deposits of Eocene Lake Gosiute. The following information is based on the holotype (PU 20570 a and b, re-examined by the author) and the type description (Lundberg and Case, 1970). Other specimens that are in public repositories are AMNH 6888 (a complete ventral side); UMMP V 57142 (skull); and UMMP V 97672 (a latex peel of an anterior partial specimen).

Fin Rays: Pectoral about I,9; Pelvic 6-7; Anal about 15-17, the first few rays small and crowded, anal fin margin rounded; Dorsal II,6-7, the first spine very small; Caudal 1,7,8,1, forked, with upper and lower lobes subequal and slightly rounded.

Pterygiophores: Dorsal about 6, plus a supraneural and a neural spine helping to support the dorsal fin; Anal about 14.

Vertebrae: Caudal about 21-23; Precaudal 19-20, 5 vertebrae involved in weberian complex.

Other Information: Rib on the 5th vertebra reduced and weak. Length of the dorsal and pectoral spines more than 1/5 the standard length, though on specimens from G-4 this feature is often not completely preserved on the fossils, giving them the appearance of having shorter spines (for example, compare the relative spine lengths of figure II.63 with those of its counterpart slab, figure II.64).

For further study and more detailed description see Lundberg and Case (1970) and Lundberg (1970, 1975).

Table II.5 Diagnostic characters distinguishing the two described Green River catfish.

	Astephus antiquus	*Hypsidoris farsonensis*
Number of anal rays	23-26 (usually 25-26)	usually 15-17
Number of anal pterygiophores	usually 22-24	about 14
Number of pelvic rays	8-10	6-7
Rib on the 5th vertebra (last vertebra of weberian complex)	well developed	poorly developed
Length of dorsal and pectoral spines	less than 1/5 the standard length	greater than 1/5 the standard length

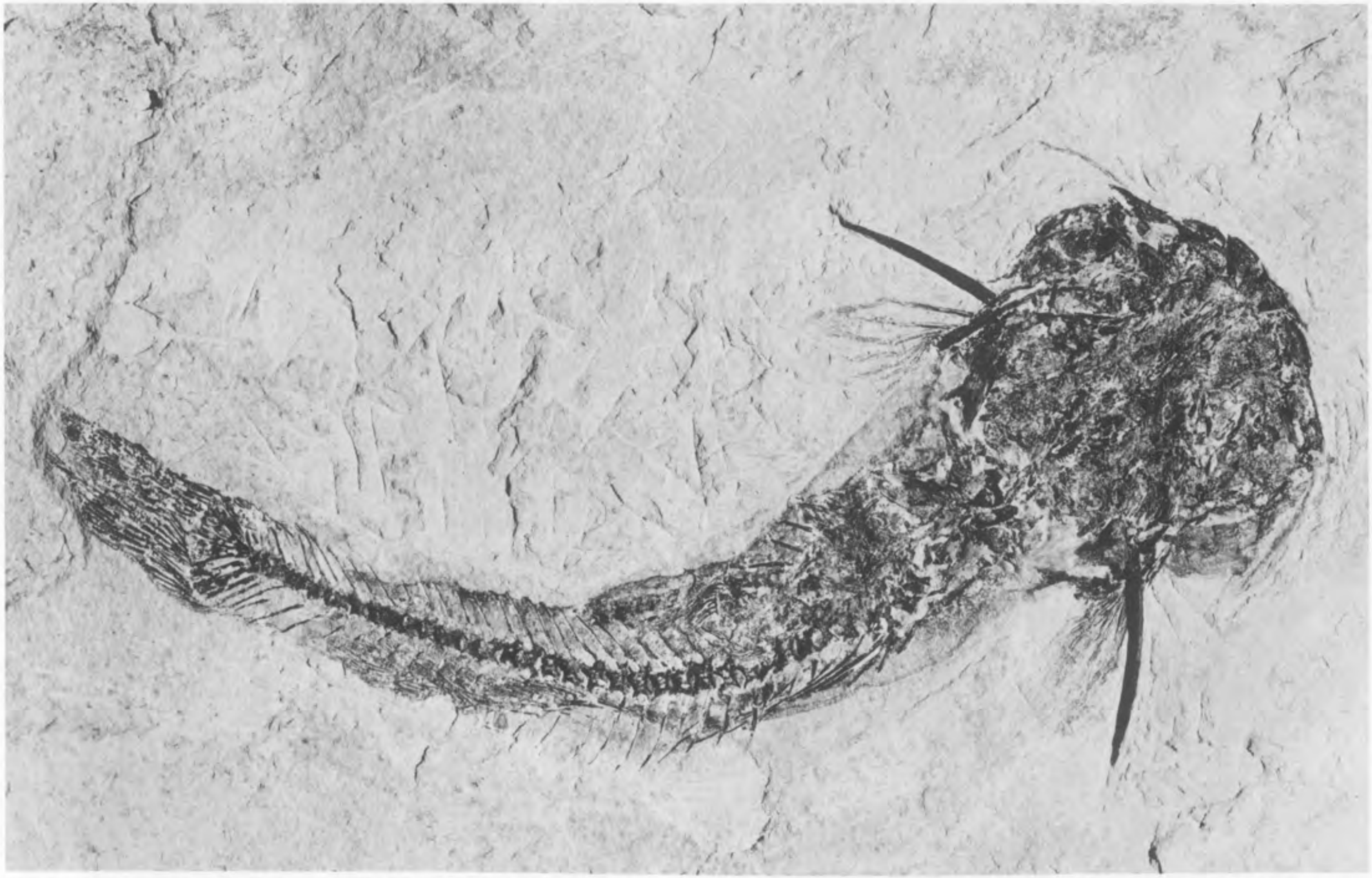


Figure II.60. *Astephus antiquus* (BMNH P.61233) showing preservation of skin and barbels, from locality G-1. Total axial length 19 cm (7¼ inches).

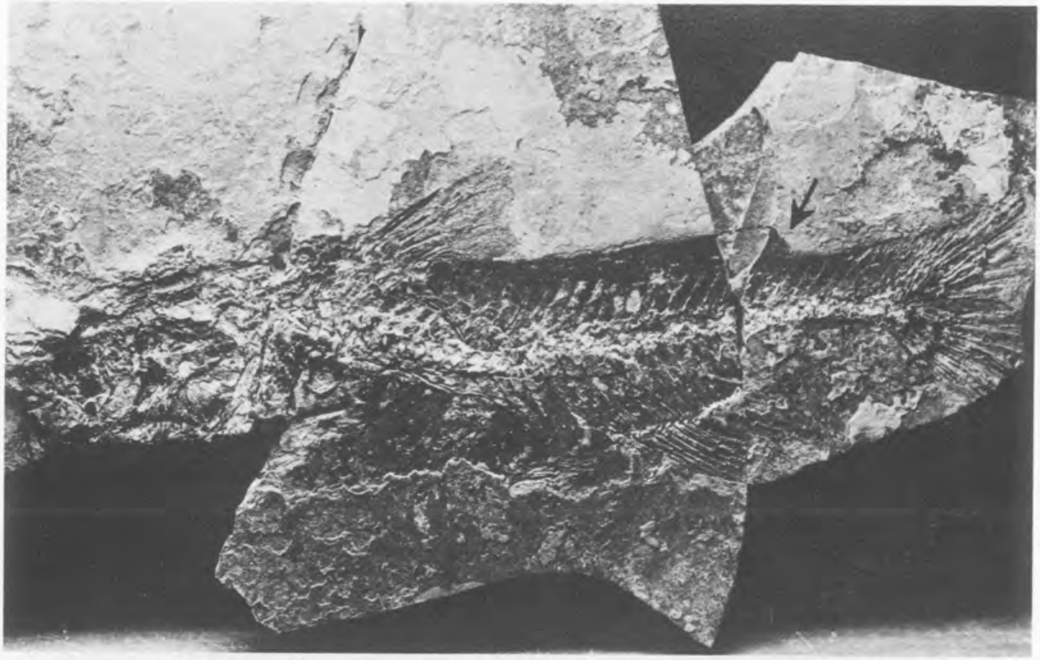


Figure II.61. *Astephus antiquus* (uncataloged University of Wyoming specimen) showing adipose fin (indicated by arrow) from locality G-2. Length about 22 cm (9 inches). Photograph courtesy of Paul Buchheim.

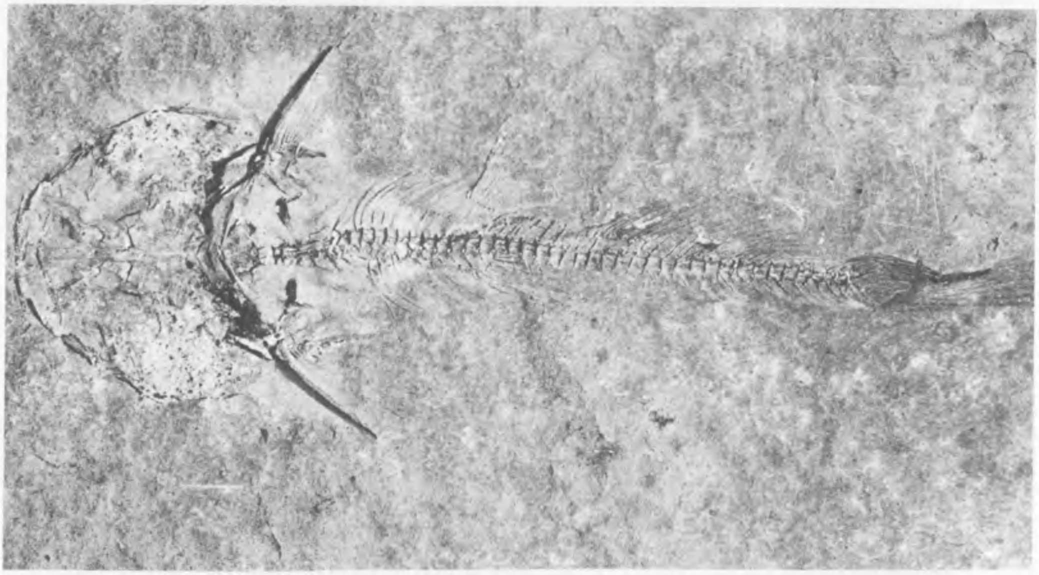


Figure II.62. *Astephus antiquus* (BMNH P.61234) juvenile from locality G-4. Total length 4½ cm (1¾ inches).

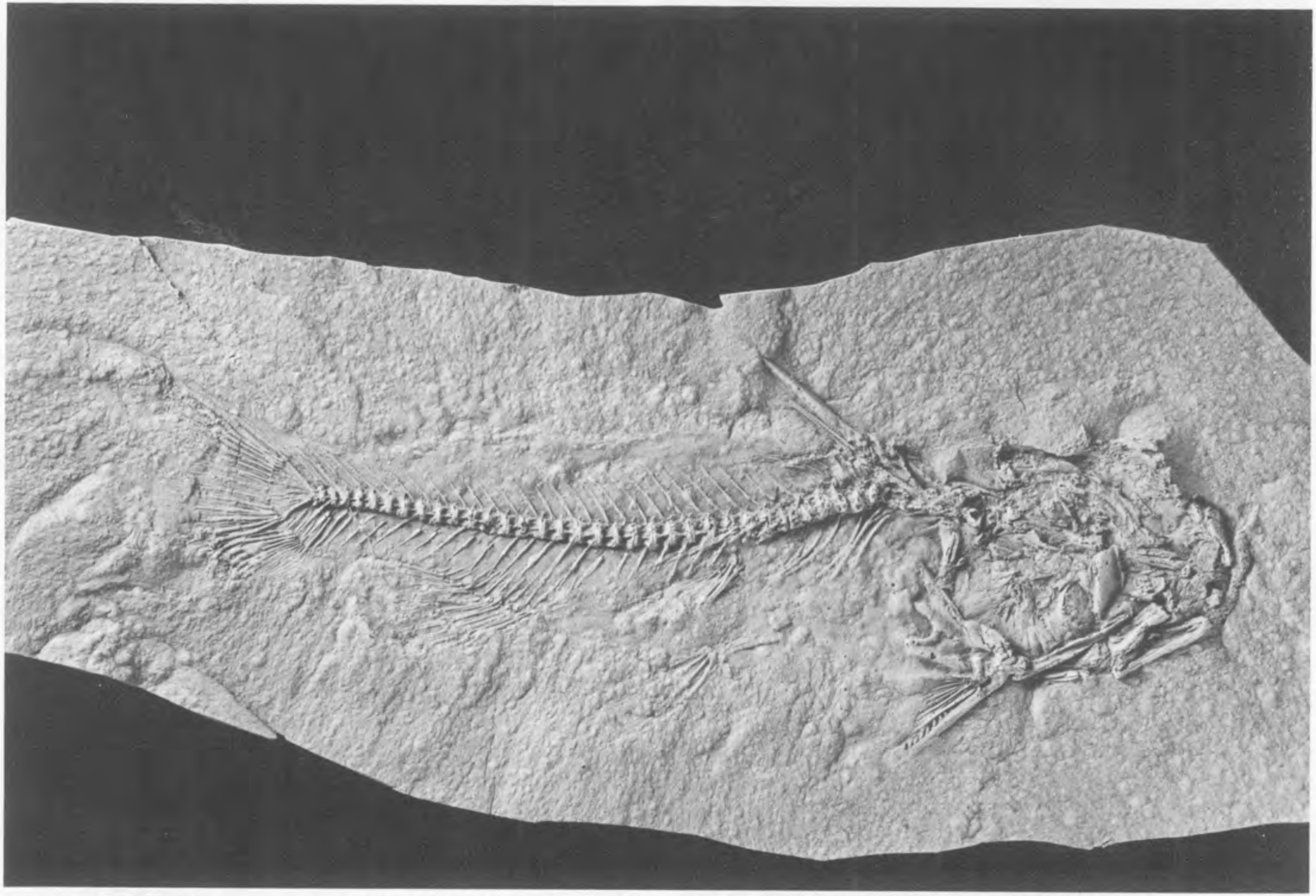


Figure II.63. *Hypsidoris farsonensis* (PU 20570b) holotype, total length about 20.5 cm (8 inches). This is a positive latex cast from a typically negative G-4 specimen. Photo courtesy of UMMP and Ms. Karna Steelquist.

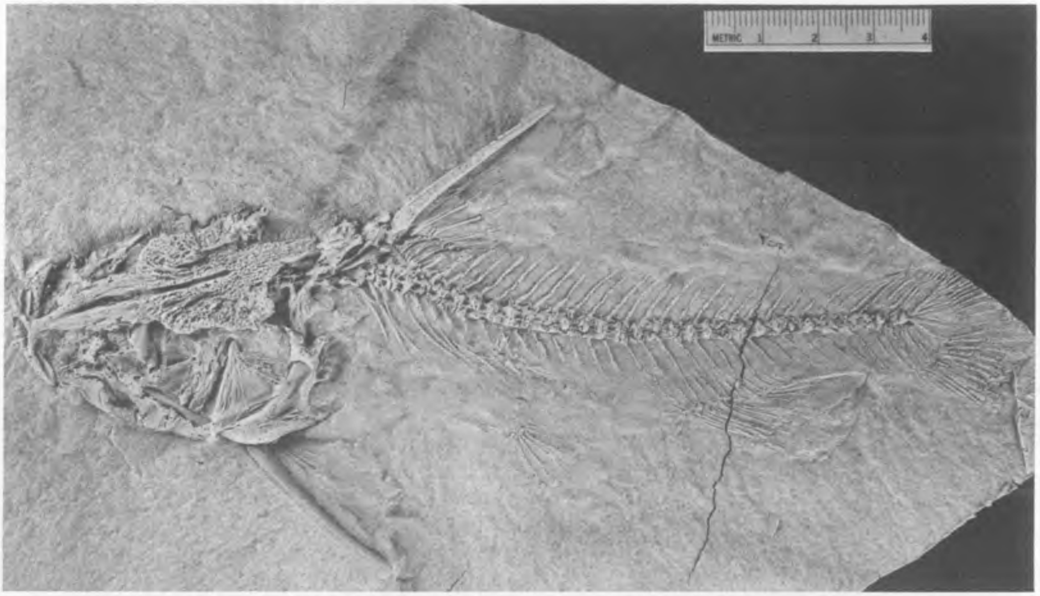


Figure II.64. *Hypsidoris farsonensis* (PU 20570a) holotype, counterpart to the specimen in figure II.63. This is also a latex cast from a typically negative G-4 specimen. Photo courtesy of UMMP and Mrs. Karna Steelquist.

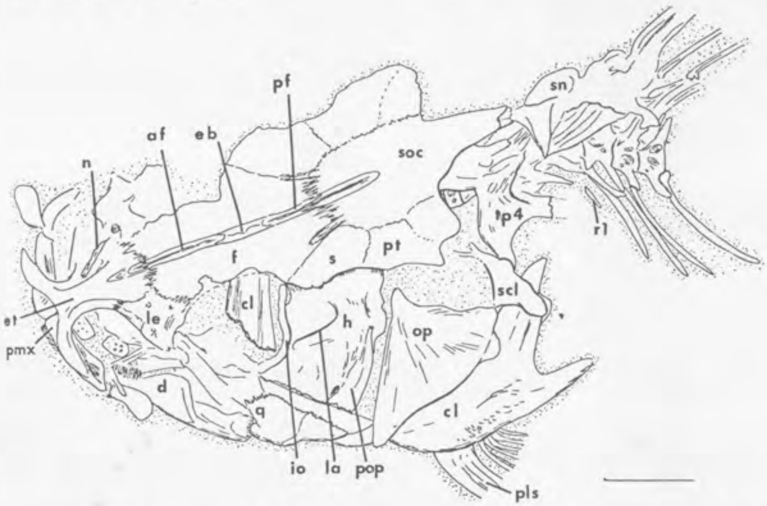


Figure II.65. *Hypsidoris farsonensis*, a line drawing of the skull of PU 20570a, the holotype. Scale 1 cm; cl, cleithrum; d, dentary; eb, epiphyseal bar; et, supraethmoid; f, frontal; h. hyomandibular; io, infraorbitals; la, levator arcus palatini crest on hyomandibular; le, lateral ethmoid; n, nasal; op, opercle; pf, posterior fontanelle; pmx, premaxilla; pop, preopercle; pt, pterotic; pls, pectoral spine; q, quadrate; r1, first rib; s, sphenotic; scl, supracleithrum; sn, supraneural; soc, supraoccipital; tp4, expanded transverse process of fourth vertebra. From Lundberg and Case (1970).

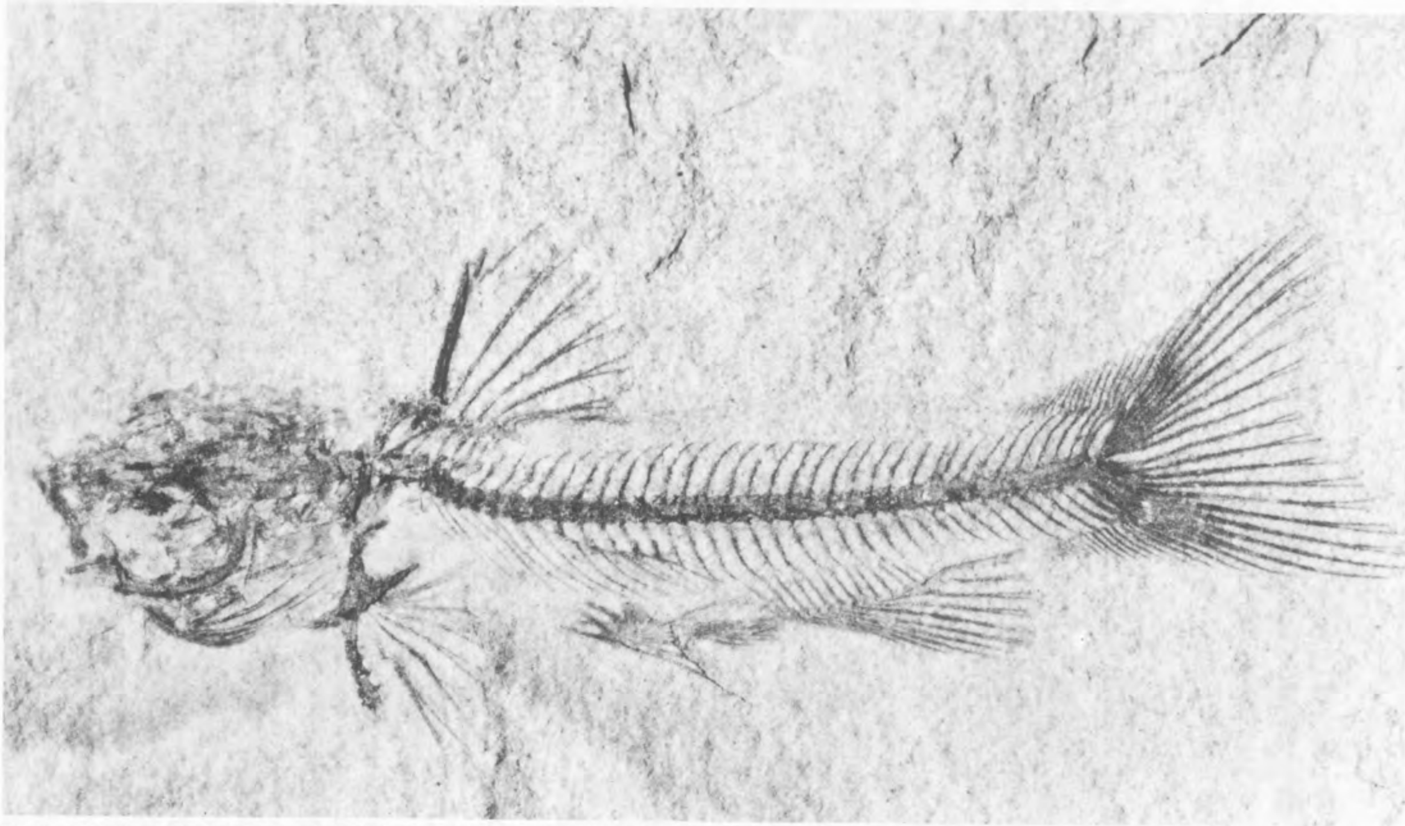


Figure II.66. *Hypsidoris* sp. (SMMP 78.9.6) from locality G-4. Juvenile 3.9 cm (1½ inches) in total length. This specimen shows all the characteristics of *H. farsonensis*, but has a much shorter pectoral spine (about 1/8 the total lengty) and may represent a new species (new taxon will not be named in this paper). Counterpart to this specimen is FMNH PF9642.

Genera: *Amphiplaga* Cope 1877 (the trout perch)
Erismatopterus Cope 1871

Species: *A. brachyptera* Cope 1877 — Figures II.67-II.71
E. levatus (Cope 1870) — Figures II.70, II.72-II.76

GENERAL INFORMATION

The trout perch are so called because they are morphologically intermediate in many ways between trout (or salmon) and the perches. They resemble trout somewhat in appearance, though quite small. They are represented in the Green River Formation by two described genera, each with one valid species.

Amphiplaga has been reported only from the Fossil Lake deposits and is most common at locality F-2 where it makes up about 1 percent of the fossil fish population. *Amphiplaga* is best distinguished from *Erismatopterus* by its dorsal fin, which has three hard spines (the first of which is very small) followed by 9 or 10 soft rays. *Erismatopterus* usually has two hard spines followed by 6 or 7 soft rays. *Amphiplaga* is also larger, with a maximum total length of about 15 cm (6 inches) and a usual total length of about 10 cm (4 inches). Both *Erismatopterus* and *Amphiplaga* are frequently found with their gill filaments well preserved (see figures II.70a and b). *Amphiplaga* and *Erismatopterus*, like living percopsids, were equipped to feed mainly on insects and insect larvae, and may also have fed on the ostracods found in abundance where *Amphiplaga* and *Erismatopterus* are found.

Both Green River trout perch (particularly the smaller *Erismatopterus*) are occasionally misidentified as *Knightia*, but they are easy to distinguish, since the well-developed abdominal scutes present in *Knightia* are absent in the trout perch.

Erismatopteris is known only from Lake Gosiute and Lake Uinta deposits. It is uncommon except in some mass-mortality zones at localities G-1, G-2, and G-3 (see figure II.74), where it is found in vast numbers. Living trout perch such as *Percopsis* are very temperature sensitive and often have summer mass mortalities during unusually warm periods (Eddy and Underhill, 1974). It is reasonable that in shallow Lake Gosiute, water temperature could have periodically risen to a level lethal to *Erismatopterus*. *Erismatopterus* is smaller in average size than *Amphiplaga*, with a maximum total length of about 12.5 cm (5 inches) and an average total length of about 5 cm (2 inches). The jaw teeth of *Erismatopterus* are proportionately smaller than those of *Amphiplaga*. Unlike *Amphiplaga*, but like the modern trout perch *Percopsis*, *Erismatopteris* had hundreds of tiny black spots of pigmentation covering its body (see figure II.75) and dark marks along the midline of the back and sides. This pigmentation is rarely preserved except at locality G-1 outside of the *Eristmatopteris* mass mortality zone.

True trout perch possess an adipose fin; though these are not preserved on

Erismatopterus or *Amphiplaga*, both fish show small disturbances in the dorsal body margin between the dorsal fin and the caudal fin on specimens with well-preserved scales. This disturbance on an otherwise smooth upper body margin very possibly indicates the position of a decomposed adipose fin.

Erismatopterus and *Amphiplaga* are more closely related to each other than to any living percopsid, and Jordan (1905) proposed that a new family (Erismatopteridae) be erected for them; but Rosen and Patterson (1969) found insufficient grounds for familial separation from the Percopsidae.

Today, living percopsids are restricted to fresh waters in North America and are represented by one genus, *Percopsis*, with two species. Fossil percopsids are known only from North America (Eocene-Recent). The fact that *Amphiplaga* only occurs in the late Early Eocene Fossil Lake sediments and *Erismatopterus* occurs only in Middle Eocene deposits of Lakes Gosiute and Uinta remotely suggests that *Amphiplaga* was ancestral to *Erismatopterus*.

GENERIC ETYMOLOGY

Amphiplaga: Unknown; one possible etymology is *amph* — ambiguous, *plaga* — wound, referring to the headless nature of the holotype.

Erismatopterus: erisma — cause of dispute, *top* — place, *ter* — wonder; possibly referring to the early trouble Cope had in classifying this fish; gender masculine.

NOMENCLATURE, SPECIFIC INFORMATION, REPOSITORIES, AND SUGGESTED REFERENCES

The earliest description of *Amphiplaga* in the Green River Formation is by Cope (1877, page 388). The holotype (USNM 3966) consists of a headless fish (illustrated in Cope, 1884, plate 7, figure 5) from locality F-2. Rosen and Patterson (1969, page 394) found *Erismatopterus endlichi* (Cope, 1877) to be a synonym of *Amphiplaga brachyptera*. The earliest description of *Erismatopterus* is under the genus *Cyprinodon* (Cope, 1870), which was later changed by Cope (1871) to *Erismatopterus* when he found it to be a percopsid (trout perch) rather than a cyprinodontid (killifish), as he had first thought. Rosen and Patterson (1969) found *E. rickseckeri* to be a synonym of *E. levatus*. The syntype specimens for *E. levatus* (AMNH 2526) consist of two headless fish on a single slab.

AMPHIPLAGA BRACHYPTERA Cope 1877

= *Erismatopterus endlichi* Cope 1877.

The following specific data combine the data presented in Rosen and Patterson (1969) and data on additional specimens examined by the author. Specimens, most of which are nearly complete, used by Rosen and Patterson are USNM 3996 (holotype); USNM 4011 (Cope, 1884, plate 7, figure 5); USNM 3997 (holotype of *Erismatopterus endlichi*, Cope, 1884, plate 12, figure 5); USNM 18133; USNM 19878; and USNM 19882. Additional specimens examined by the author include SMMP 78.9.1 (two complete individuals on one slab);

UMVP 6515; BMNH P.61235 (figure II.67); BMNH P.61236 (figure II.68); and FMNH PF9643 (figure II.69). The "n" values given after meristic values do not include those specimens used by Rosen and Patterson.

Fin Rays: Pectoral usually 14-15 (n=3); Pelvic usually 8 soft rays, all branched, and a splint (n=3); Anal usually III,7, with the last double ray counting as one ray (n=3); Dorsal usually III,9, with the last double ray counting as one ray (n=6); Caudal 1,8,8,1, forked (n=4).

Pterygiophores: Dorsal usually 11-12 (n=5); Anal 7-8 (n=4).

Vertebrae: Caudal 16-17 (n=6); Precaudal (2 PD) 13-14 (n=5); Total 29-31 (n=3).

Scales: Ctenoid; illustrated in figure II.69b. Above lateral line 9 (n=2); below lateral line 9-10 (n=2). Scales cover opercle and subopercle (n=1).

Dimensions: Maximum body depth about 20-27 percent of the standard length (n=6), about 17-23 percent of the total length (n=6); head length about 29-35 percent of the standard length (n=6), about 22-28 percent of the total length (n=6).

Other Information: Teeth in premaxilla and dentary proportionately larger than in *Erismatopterus* (also possibly larger than in *Percopsis*), and the pharyngeal teeth large and conspicuous. Endopterygoid and ectopterygoid without teeth as in *Percopsis*. Palatine toothed. This fish is known only from Fossil Lake deposits, and nearly all specimens are from locality F-2.

For a more detailed description see Rosen and Patterson (1969).

ERISMATOPTERUS LEVATUS (Cope 1870)

= *Cyprinodon levatus* Cope 1870; and *Erismatopterus rickseckeri* Cope 1871.

The following specific data combine data presented by Rosen and Patterson (1969) and data on additional specimens examined by the author. Specimens used by Rosen and Patterson are AMNH 2526 (the syntypes); AMNH 2696 (illustrated in Cope, 1884, plate 9, figure 7); AMNH 2800 (two fishes on a slab, syntypes of *E. rickseckeri*, one figured by Cope, 1884, plate 6, figure 2); and AMNH 3993-3999. Additional specimens examined include UMVP 6517; SMMP 78.9.2 (figure II.70a); BMNH P.61238 (figure II.72); BMNH P.61239 (figure II.73); and SMMP 83.2.8, containing nine relatively complete individuals (figure II.74). As with *Amphiplaga*, the "n" values are only for these additional specimens examined here.

Fin Rays: Pectoral usually 14-16 (n=6); Pelvic 6-7 soft rays, the first unbranched, plus a splint (n=7); Anal usually II,7, with the last double ray counting as one ray (n=7); Dorsal II,6-8, usually II,7, counting the last double ray as one (n=6); Caudal 1,8,8,1, forked (n=8).

Pterygiophores: Dorsal 7-9, usually 8 (n=7); Anal 7-8 (n=3).

Vertebrae: Caudal 15-17, usually 15-16 (n=5); Precaudal 13-14 (n=4); Total usually 29-30 (n=4).

Scales: Ctenoid; appear to be relatively larger than those of *Amphiplaga* but similar in shape (visible on UMVP 6517); 7-8 rows of scales above and below the vertebral column at the posterior end of the dorsal fin.

Dimensions: Maximum body depth about 23-28 percent of the standard length (n=10), 23-25 percent of the total length (n=9); head length about 28-32 percent of the standard length (n=10), 19-22 percent of the total length (n=9).

Other Information: Teeth in premaxilla and dentary proportionately smaller, and pharyngeal dentition more feebly developed, than in *Amphiplaga.* Endopterygoid and ectopterygoid without teeth. Palatine teeth not visible. *Erismatopterus* is not known from Fossil Lake deposits.

For a more detailed description see Rosen and Patterson (1969).

Table II.6 Diagnostic characters distinguishing the two described Green River trout perch.

	Amphiplaga brachyptera	*Erismatopterus levatus*
Dorsal fin rays (the last double ray counts as one ray)	usually III, 9	usually II, 6-7
Dorsal pterygiophores	usually 11-12	7-9, usually 8
Anal fin rays (the last double ray counts as one ray)	usually III, 7	usually II, 7

Figure II.67. *Amphiplaga brachyptera* (BMNH P.61235) from locality F-2. Total length 11 cm (about 4¼ inches).

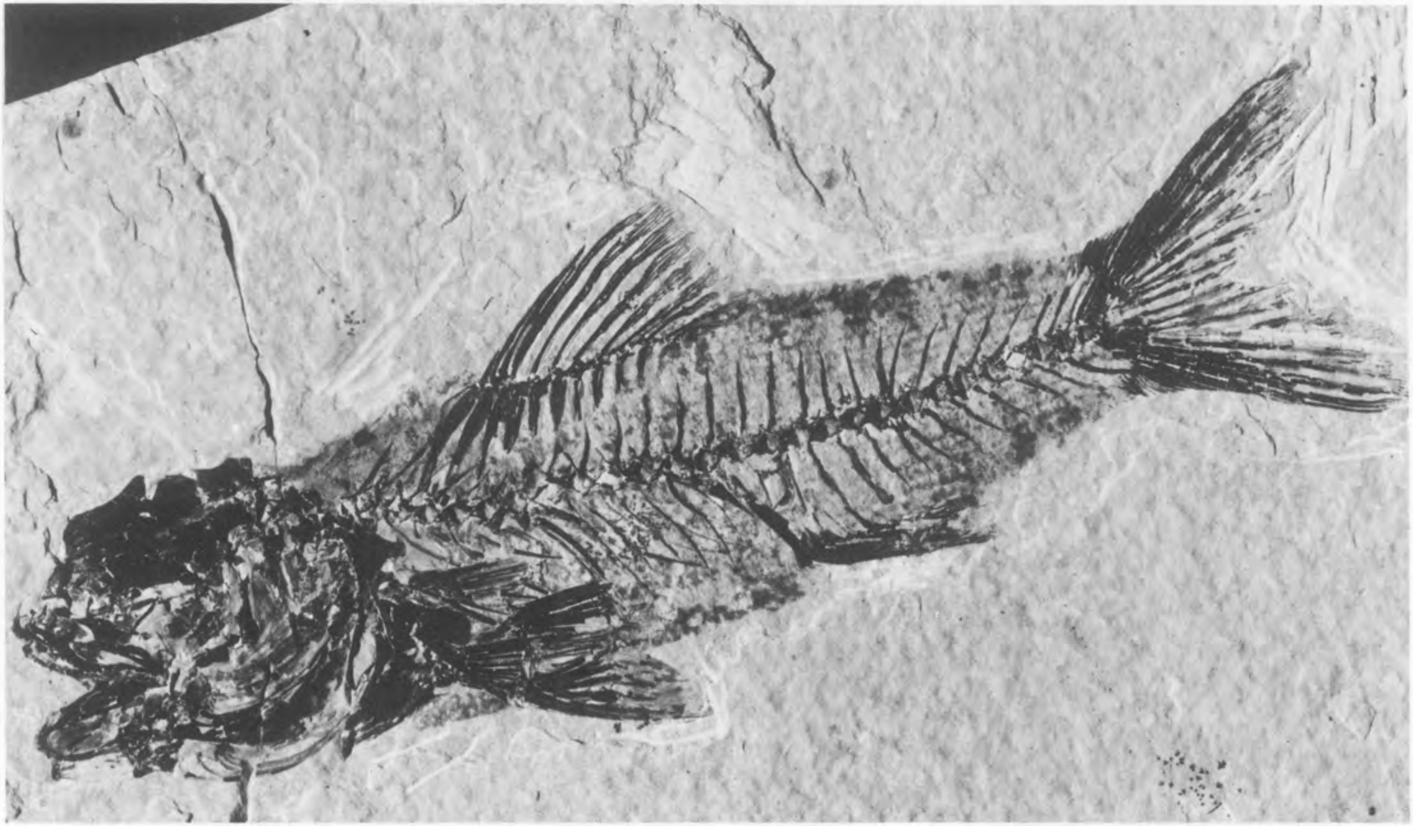


Figure II.68 *Amphiplaga brachyptera* (BMNH P.61236) from locality F-2. Total length 11 cm (about 4¼ inches). Entire dorsocranium is exposed on this specimen.

Figure II.69a. Juvenile *Amphiplaga brachyptera* (FMNH PF9643) from locality F-2. Total length about 5 cm (2 inches).

Figure II.69b. *Amphiplaga brachyptera* (USNM 4011) from F-2. Enlarged sections of the caudal peduncle below and behind dorsal fin to show ctenoid scales. From Rosen and Patterson, 1969.

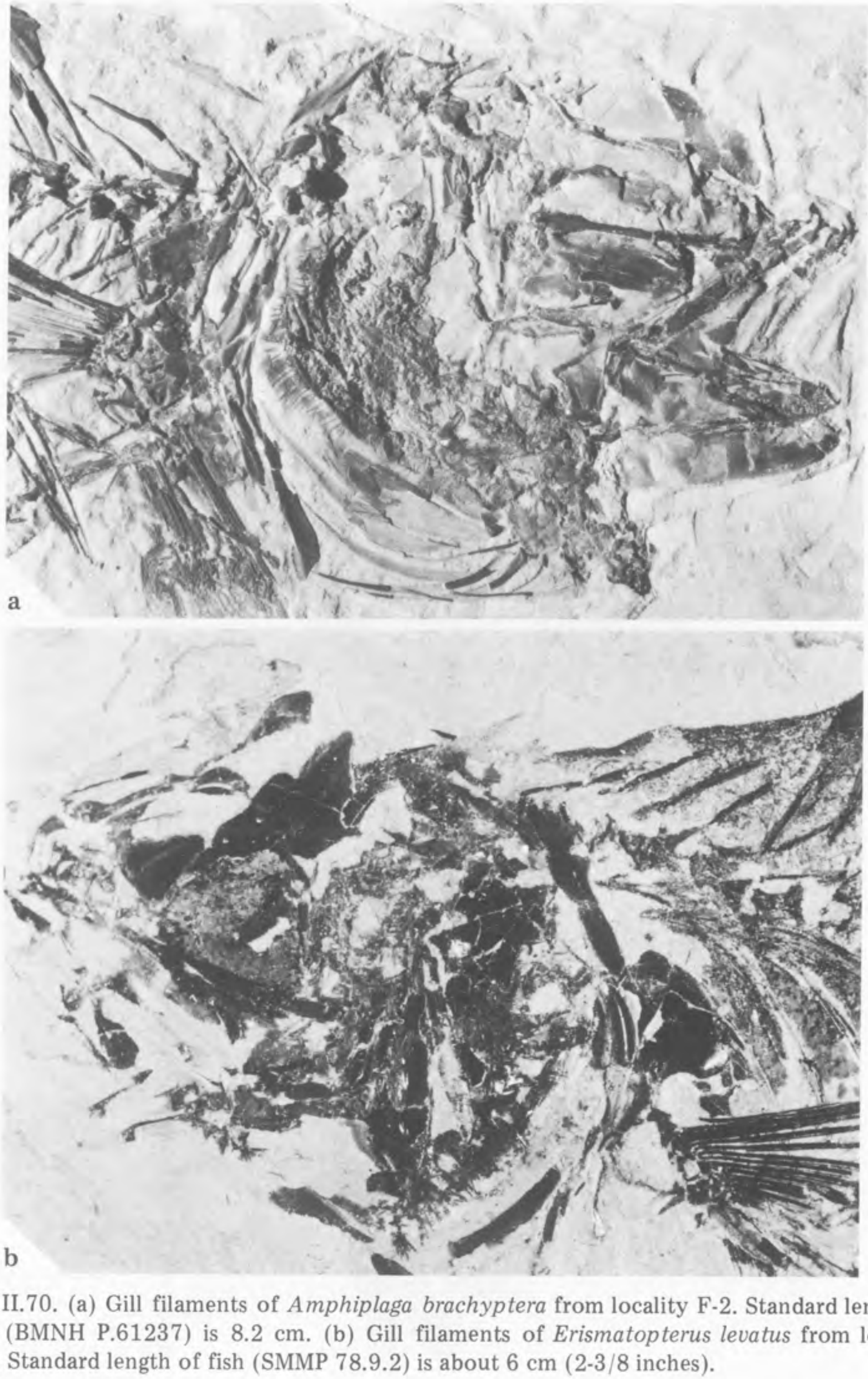


Figure II.70. (a) Gill filaments of *Amphiplaga brachyptera* from locality F-2. Standard length of fish (BMNH P.61237) is 8.2 cm. (b) Gill filaments of *Erismatopterus levatus* from locality G-1. Standard length of fish (SMMP 78.9.2) is about 6 cm (2-3/8 inches).

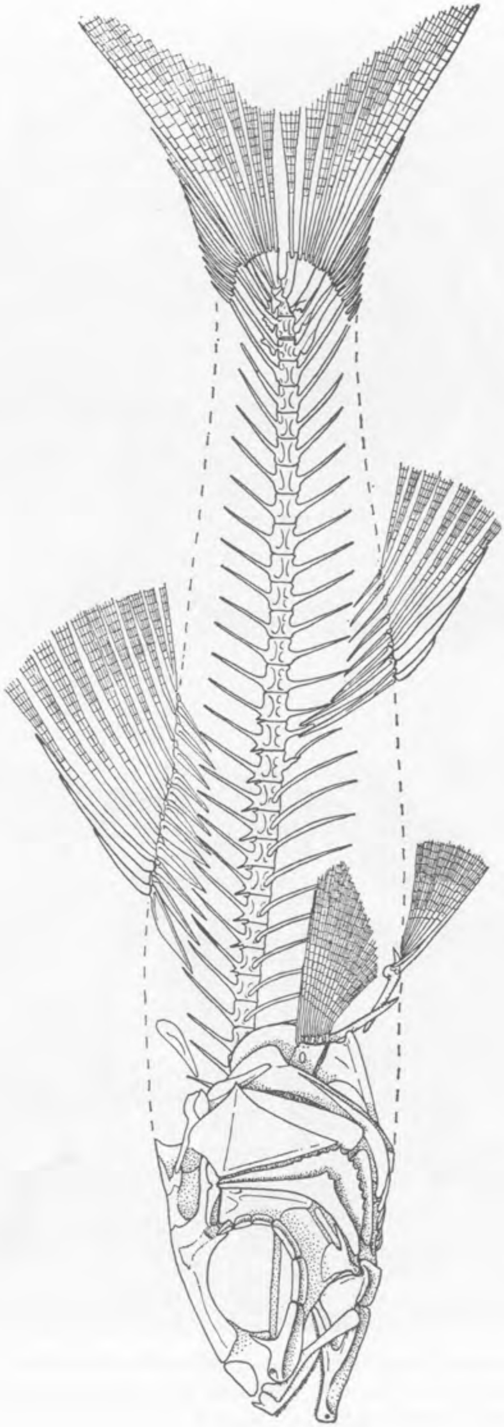


Figure II.71. Restored line drawing of *Amphiplaga brachyptera*, scales omitted. From Rosen and Patterson (1969).

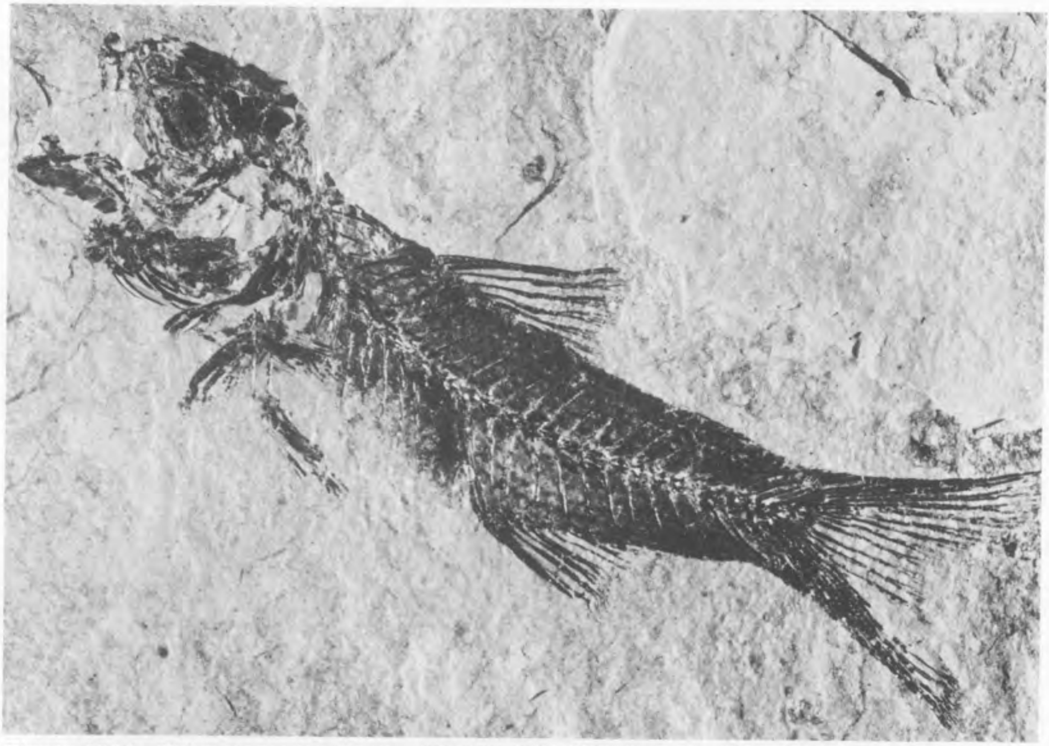


Figure II.72. *Erismatopterus levatus* (BMNH P.61238) from locality G-1. Total length about 6 cm (2-3/8 inches).

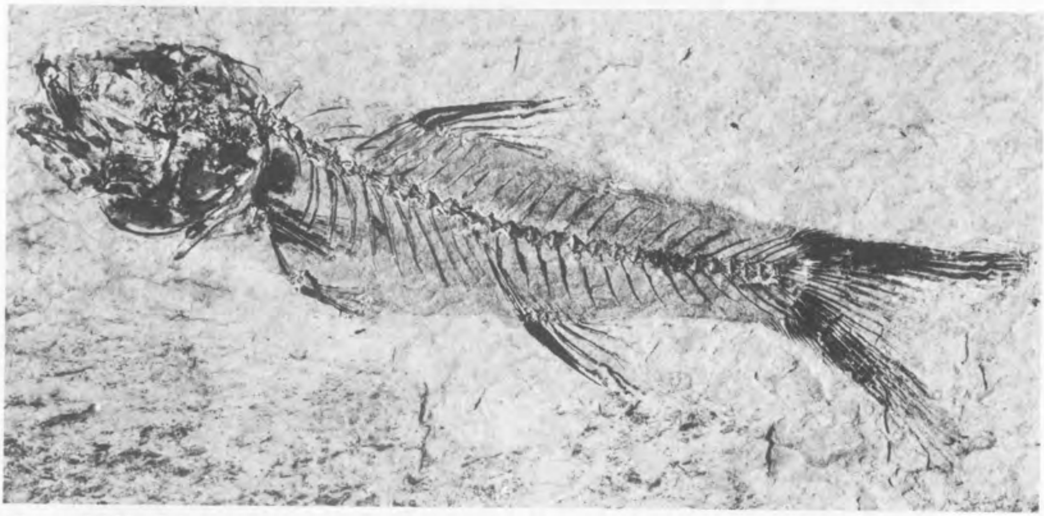


Figure II.73. *Erismatopterus levatus* juvenile? (BMNH P.61239) from locality G-1. Total length about 4.7 cm (1¾ inches).

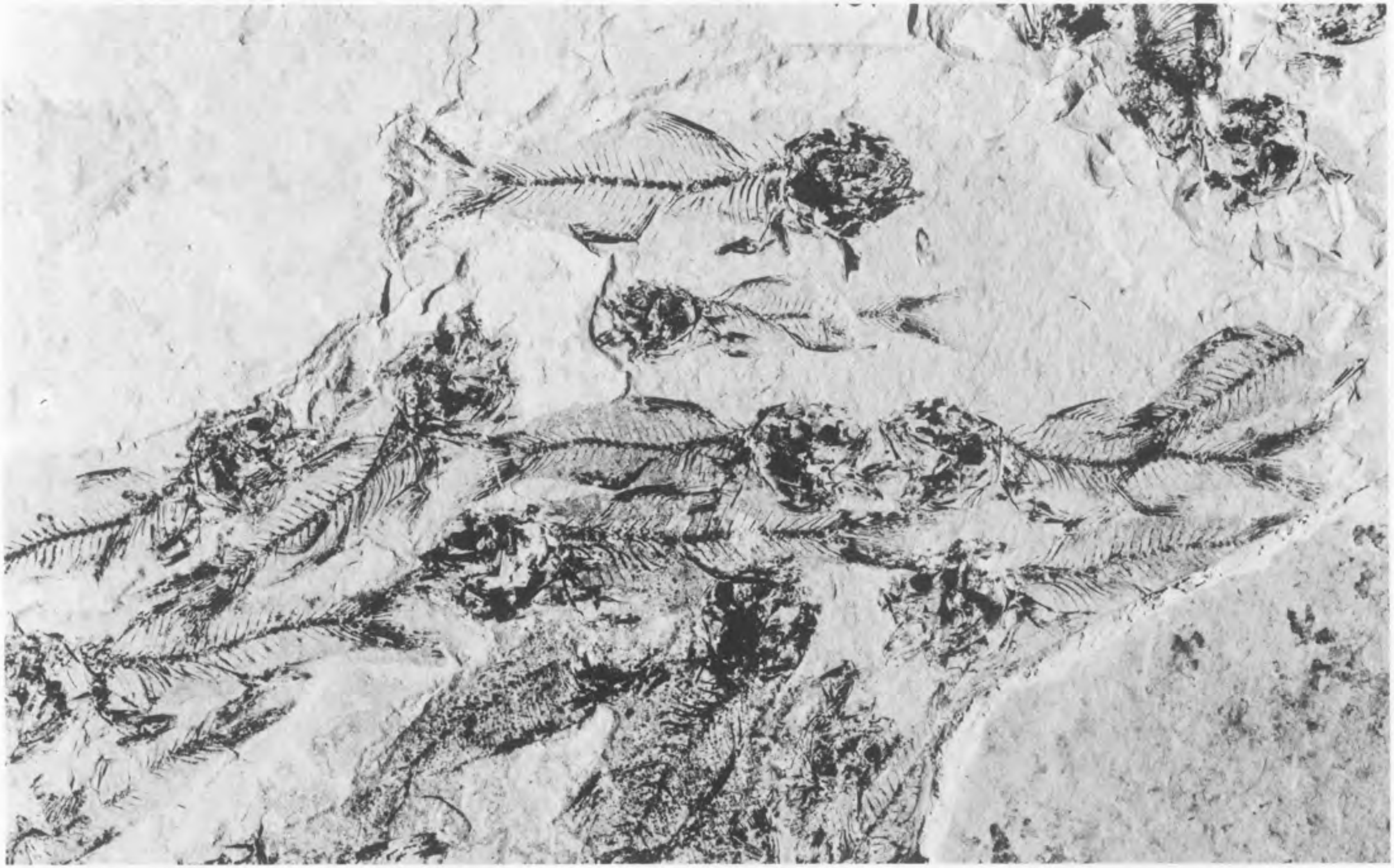


Figure II.74. *Erismatopterus levatus* (SMMP 83.2.8) mass mortality layer from locality G-1. Average total length of fish is about 5 cm (2 inches).

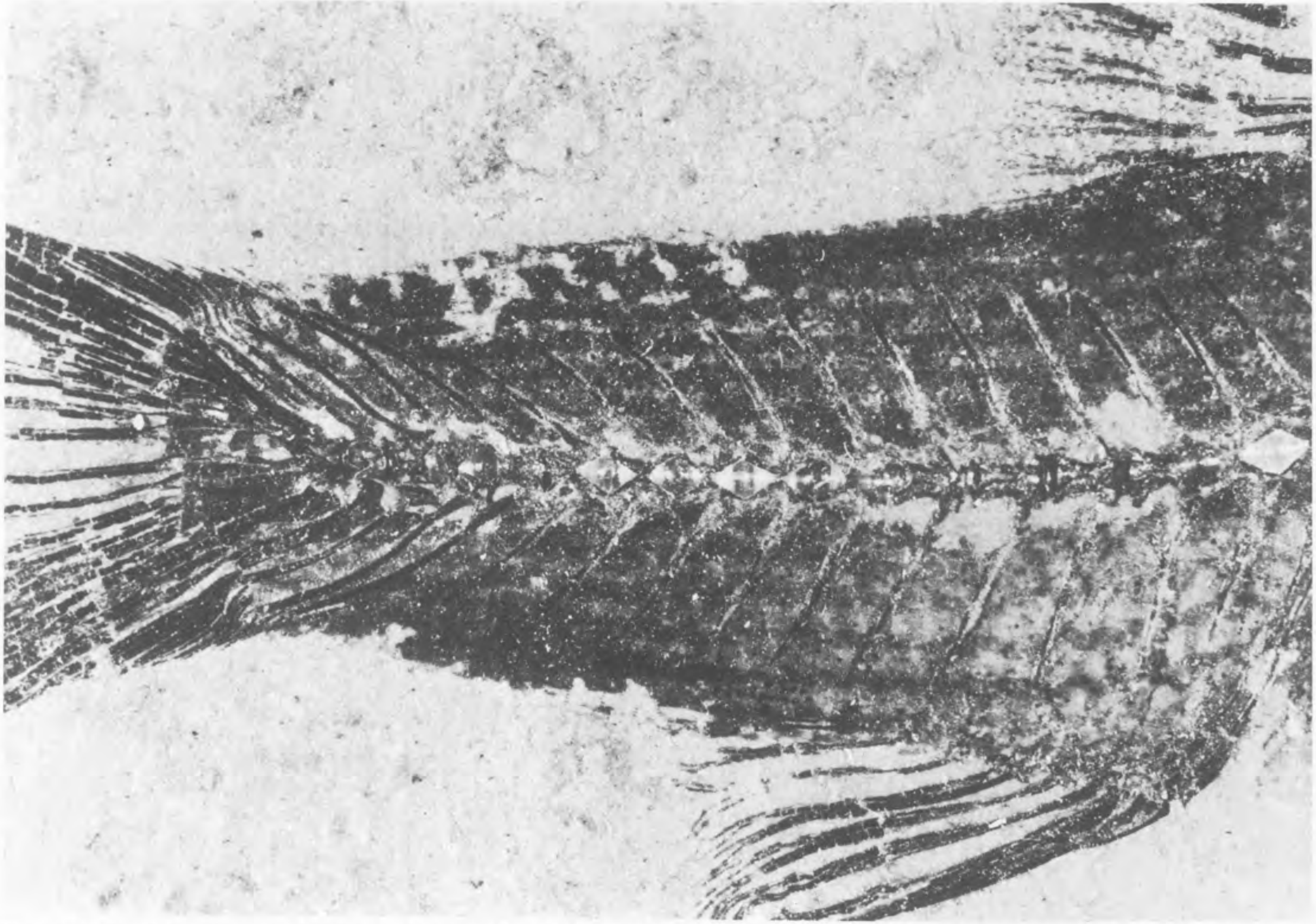


Figure II.75. *Erismatopterus levatus*, a close-up of part of figure II.72 showing the black pigmentation spots on fins and body similar to those of the living trout perch *Percopsis*.

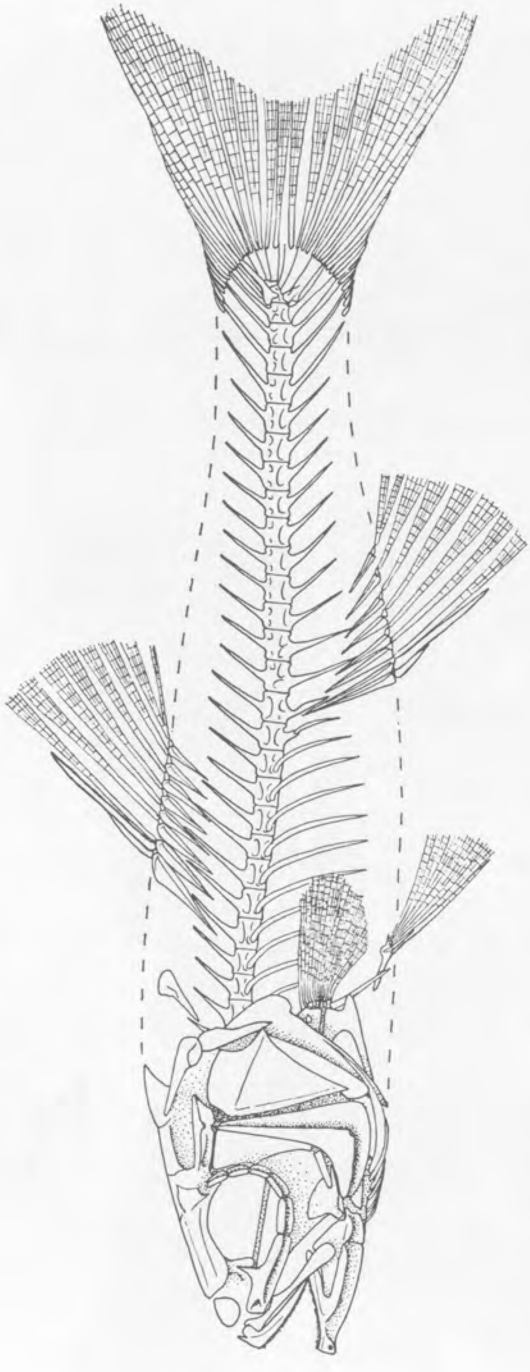


Figure II.76. Restored line drawing of *Erismatopterus levatus*, scales omitted. From Rosen and Patterson (1969).

Genus: *Asineops* Cope 1870

Species: *A. squamifrons* Cope 1870

Figures II.77-II.81

GENERAL INFORMATION

Asineops is known from the Green River Formation by one valid species, *Asineops squamifrons* (Cope, 1870). *Asineops* can be recognized by its hard dorsal spines (much like those of *Priscacara*) which number 8 to 10 (usually 9). Unlike that of *Priscacara*, the caudal fin of *Asineops* has only 14 principle rays, 12 of which are unbranched, and the posterior edge of the caudal fin rounded. *Asineops* has a broad, scale-covered head, and its relatively large mouth is filled with numerous, very tiny teeth (often not well preserved).

Asineops inhabited all three Green River lakes, but is abundant only in Lake Gosiute deposits (G-1, G-2, G-3, G-4, and other Laney Member deposits). It is fairly uncommon in Lake Uinta deposits, where it is known from U-2, U-4, and near U-3, and is extremely rare in Fossil Lake deposits F-1 and F-2, where it is occasionally mistaken for *Priscacara* or *Amia* by commerical collectors. As with most genera of Green River fish, *Asineops* specimens found in Fossil Lake deposits are considerably larger in average size than those of Lake Gosiute. Those from Fossil Lake deposits show a maximum total length of about 31 cm (12 inches; see figure II.79) and an average length of 20 or 22 cm (8 or 9 inches) (based on USNM 4045, UW 11240, and a specimen in a private collection). Specimens from Lake Gosiute deposits have a maximum length of about 18 cm (7 inches) and an average length of 13 cm (5 inches) (based on several dozen specimens discovered by amateur collectors and Cope's type specimens).

Asineops is the only member of a family of uncertain origin, possibly related to *Percopsiformes* (trout perches, pirate perches, and cave fishes), *Polymixiformes* (beard fishes and a few extinct families), or *Perciformes* (the largest order of fishes, including the perches, 146 other living families, and many fossil families). Rosen and Patterson (1969) concluded that there was no available evidence suggesting to which of the three orders *Asineops* belongs, so they left *Asineops* in the *Asineopidae*, a family *incertae sedis* (of uncertain origin). *Asineops* is not known to occur outside of the Green River and Bridger Formations.

GENERIC ETYMOLOGY

Asineops: asin — donkey, *ops* — face; probably aluding to the long head of Asineops; gender masculine.

NOMENCLATURE, SPECIFIC INFORMATION, REPOSITORIES, AND SUGGESTED REFERENCES

Only one species, *A. squamifrons*, is recognized here. *Asineops pauciradiatus*

(Cope, 1877), known from a single damaged specimen (USNM 4045), has a toothed bone, possibly the endopterygoid, which is toothless in *A. squamifrons.* However, it is not certain whether this single specimen represents a second species or whether it is only a large specimen of *A. squamifrons* (Rosen and Patterson, 1969). Cope (1871) named another species, *A. viridensis,* which he later (1884) found to be a synonym of *A. squamifrons.*

ASINEOPS SQUAMIFRONS Cope 1870

= *Asineops viridensis* Cope 1870; and possibly *Asineops pauciradiatus* Cope 1877.

The following specific data is a combination of data presented by Rosen and Patterson (1969) and data from additional specimens examined here. The "n" values given here represent only the number of additional specimens examined by the author. Specimens used by Rosen and Patterson are USNM 4009 (the holotype, illustrated in Cope, 1884, plate 9, figure 5, a headless fish); USNM 11109, 11111, 11112, 19678, 19681, and 19873; AMNH 781G, 2530, 2691, and 3992; and MCZ 2837. Additional specimens examined by the author include AMNH 2542 from locality G-3 (illustrated in Cope, 1884, plate 11, figure 1); SMMP 77.1.1 (figure II.78); SMMP 78.9.4; UW 11240 (figure II.79); FMNH PF9644, the specimen in figure II.77; and the specimen in figure II.80.

Fin Rays: Pectoral 15-17, usually 17 (n=5); Pelvic 7-8, the first unbranched (n=3); Anal II-III,8-11, usually II,8-9, last ray double (n=6); Dorsal VII-X, 11-12, usually IX,11 (n=5), last ray double; Caudal 1,6,6,1, with rounded posterior margin (n=6).

Pterygiophores: Dorsal 18-20, usually 19-20; Anal 10-13.

Vertebrae: Caudal 13-15, usually 14-15 (n=6); Precaudal 12-14, difficult to count anteriorly where they are covered by the skull bones (n=2).

Scales: Cycloid, illustrated in Rosen and Patterson, 1969, plate 67. Lateral line clearly visible on specimen SMMP 77.1.1 (figure II.79). Scales above lateral line about 4, below lateral line about 11; scales along lateral line 31-32; cheek scales 11-12. Scales cover nearly the entire skull.

Dimensions: Maximum body depth about 24-34 percent of the total length (n=5), about 31-45 percent of the standard length (n=5). Juvenile specimens of less than two inches in total length often have a greater relative body depth than do larger specimens.

Other Information: Branchiostegals number 6 (n=3). Basihyal broadest anteriorly where it bears a small patch of rounded teeth; lower pharyngeals covered with long, pointed teeth, larger anteriorly; ectopterygoid and palatine toothed; premaxilla and dentary with a row of small teeth. If additional Fossil Lake specimens are found to have 10 dorsal spines and three anal spines (like the unique specimen in figure II.80), this may be found to be specifically different from *A. squamifrons.*

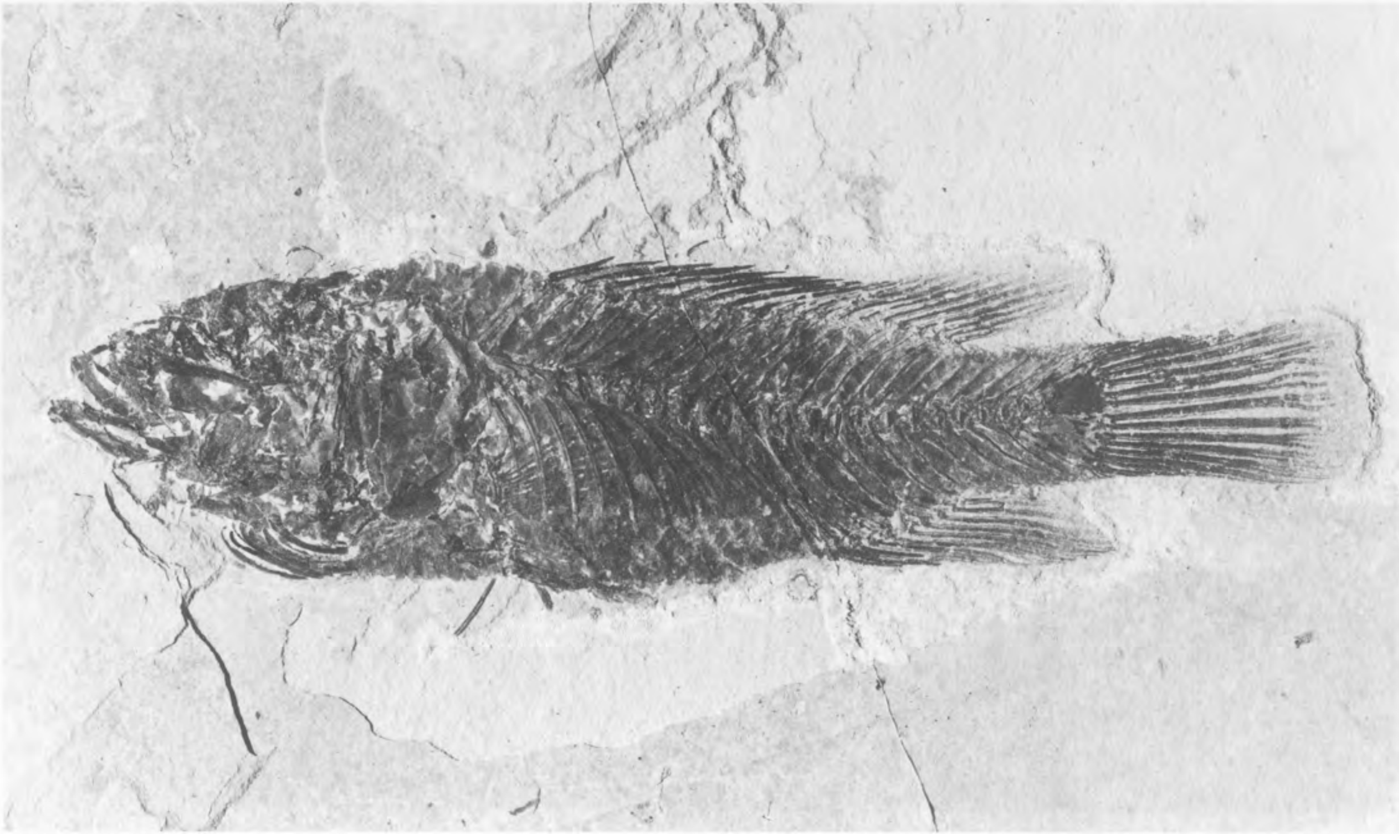


Figure II.77. *Asineops squamifrons* (BMNH P.61240) from locality G-1. Total length 7.9 cm (about 3 inches). Counterpart FMNH PF9644

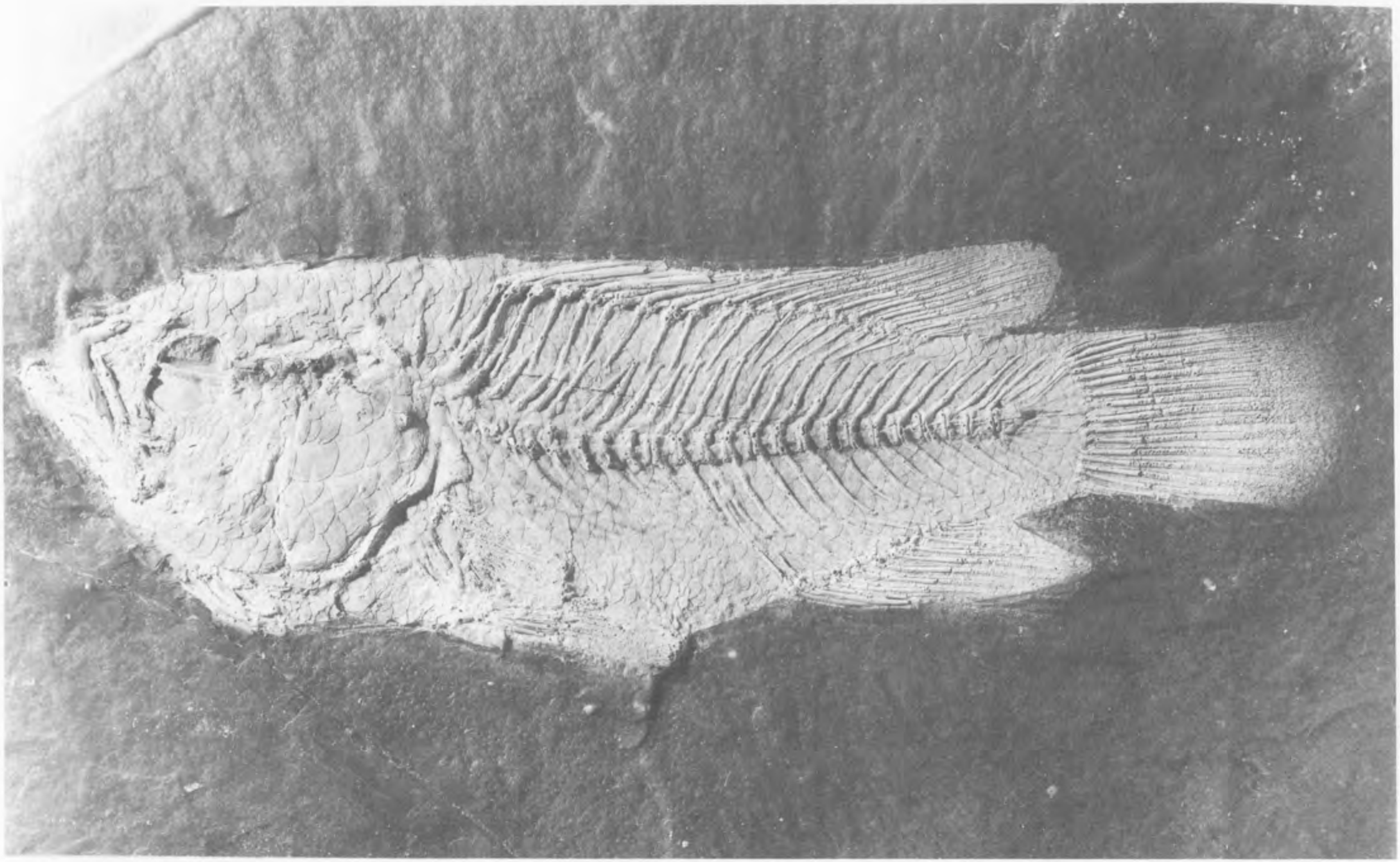


Figure II.78. *Asineops squamifrons* (SMMP 77.1.1, a latex peel) from locality G-4. Note the well preserved scales and lateral line. Total length about 16 cm (6¼ inches).

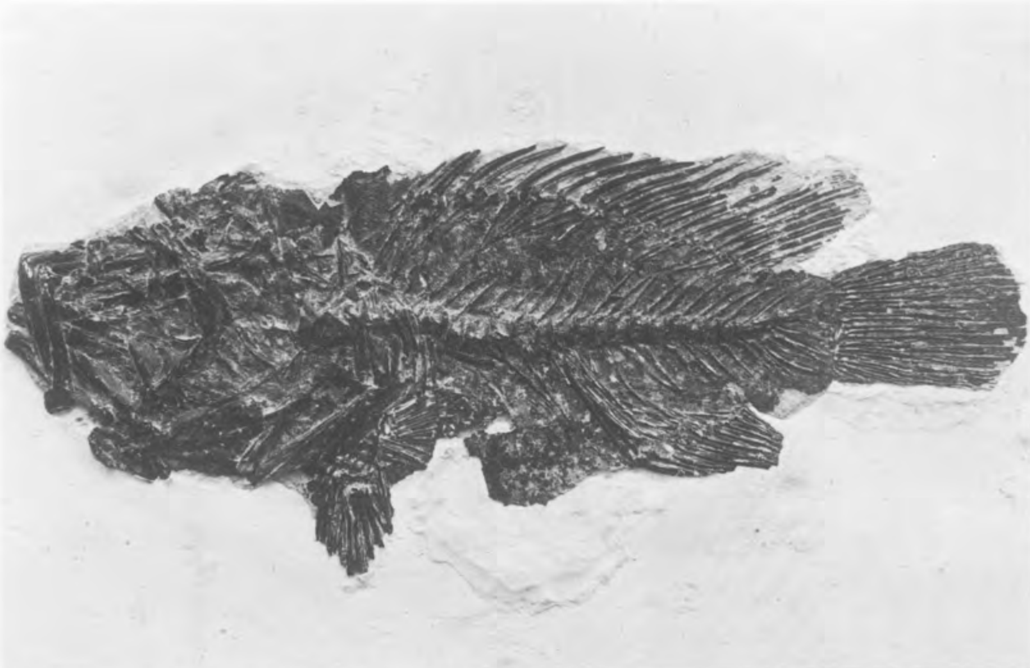


Figure II.79. The largest known specimen of *Asineops squamifrons.* Total length 31 cm (12 inches), from locality F-1 (UW 11240).

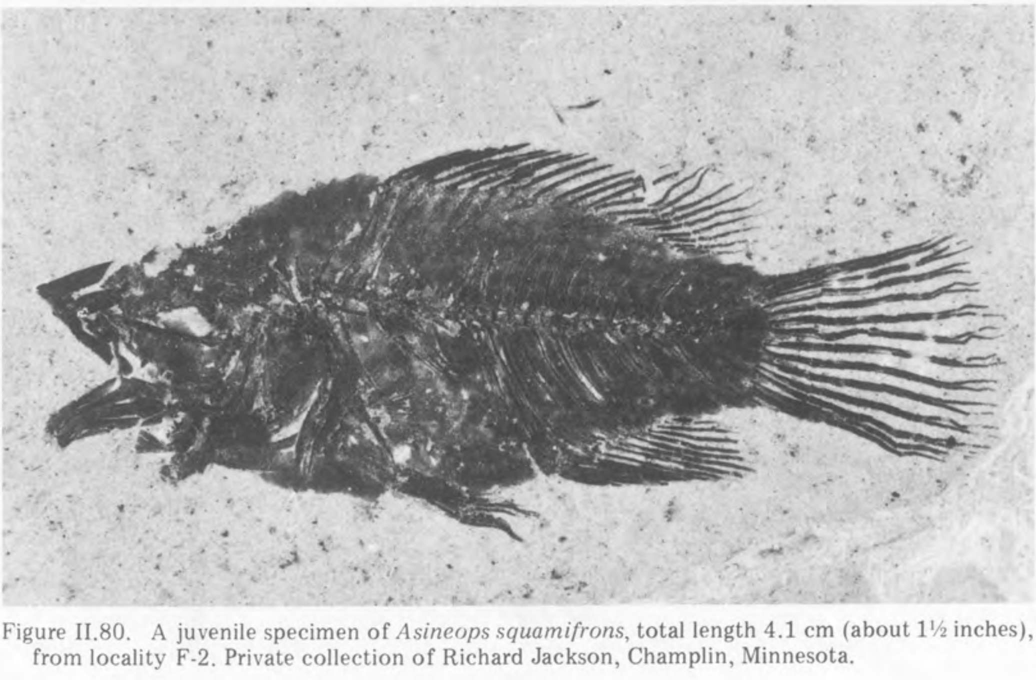


Figure II.80. A juvenile specimen of *Asineops squamifrons*, total length 4.1 cm (about 1½ inches), from locality F-2. Private collection of Richard Jackson, Champlin, Minnesota.

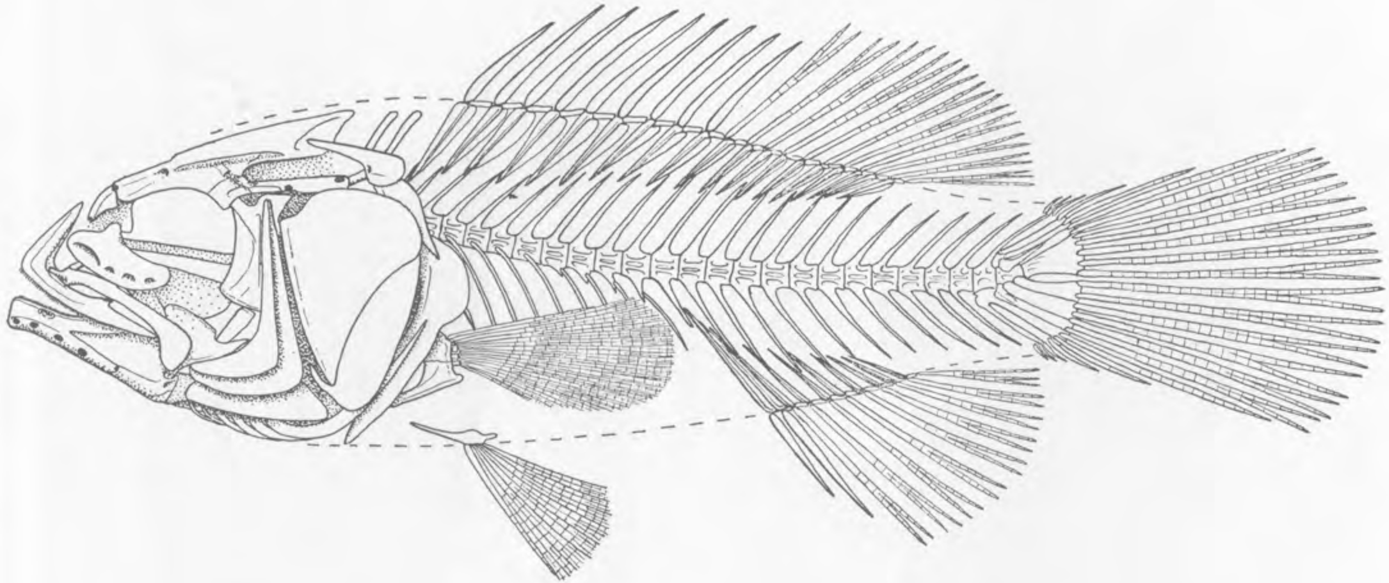


Figure II.81. Restored line drawing of *Asineops squamifrons*, scales omitted. From Rosen and Patterson (1969).

Genus: *Mioplosus* Cope 1877

Species: *M. labracoides* Cope 1877 — Figures II.82-87

?M. sauvagenus Cope 1884

GENERAL INFORMATION

Mioplosus is a fairly common fish in the Fossil Lake deposits, but very rare in Lake Gosiute and Lake Uinta deposits. All of Cope's type specimens for *Mioplosus* were collected at his "Twin Creek" locality, and are F-1 specimens. *Mioplosus* was a perch-like fish with a strongly built, long body, similar in appearance to the living perch, *Perca*. In the Green River Formation, it is easily recognized by its two dorsal fins, its large fan-shaped tail, and its second dorsal fin and anal fin which are subequal in size and positioned opposite each other. *Mioplosus* is known from Eocene Lakes Gosiute and Uinta mostly by fragments which indicate an average size smaller than those specimens found in Fossil Lake. Specimens from Fossil Lake deposits range in size from 2 cm or about ¾ inch in total length for very young juveniles such as shown in figure II.83b to a maximum total length of about 51 cm (20 inches), though they rarely exceed 41 cm (16 inches) in length, and average about 20-30 cm (8-12 inches) in total length. Like living perches today, *Mioplosus* probably occupied the shore areas and the middle and upper lake zones. *Mioplosus*, as indicated by its many pointed teeth, and by numerous specimens such as the one shown in figure II.84 (see also the Fossil Lake specimen on the front cover), was a voracious predator, taking fish up to half its own length. Unlike the herring, trout perch, and *Priscacara* of Fossil Lake, *Mioplosus* is not found fossilized in groups within the mass-mortality zones; thus, it was probably a solitary predator as an adult.

Today, living percids can be found in fresh waters over most of the Northern Hemisphere. Fossil percids are known from North America (Eocene-Recent), Asia (late Tertiary-Recent), Europe (Eocene-Recent) and New Zealand (Miocene).

GENERIC ETYMOLOGY

Mioplosus: Unknown; one possible etymology is *mio* — Miocene, *plosus* — near. When Cope erected the genus, the Miocene was the recognized time epoch after the Eocene.

NOMENCLATURE, SPECIFIC INFORMATION, REPOSITORIES, AND SUGGESTED REFERENCES

Cope (1877a; 1884) described 5 species of *Mioplosus: M. abbreviatus* (holotype AMNH 2463, figure II.87a); *M. labracoides* (cotypes USNM 4010, figure II.87b, and AMNH 2457, illustrated in Cope, 1884, plate XII, figure 1); *M. longus* (holotype USNM 3995, illustrated in Cope, 1884, plate XII, figure 2);

M. sauvagenus (holotype missing; no illustration of this species ever published); and *M. beani* (holotype USNM 3994, illustrated in Cope 1884, plate XII, figure 3). Cope (1884, page 88) designated *M. labracoides* the type species for the genus.

After examining the type specimens for the first four species, and several additional specimens, the author could find no good specific characters to separate the four species. All of Cope's type specimens appear to be F-1 specimens. Cope used body depth and meristic features to separate the species. The meristic variations are all well within the normal range of a single species of percid, and intermediate forms of all meristic combinations are common. The body depth, though variable, does not correlate with any meristic variables and is often dependent on the state of preservation (how badly compressed the fish is), especially in fish like *Mioplosus*, *Notogoneus*, *Priscacara*, etc., which have no abdominal scutes or other abdominal structural supports. Examples of such body depth distortion as the body outline extending beyond the dorsal fin are common in the Green River Formation (see, for example, the dorsal fin on the *Knightia* in figure II.39). Also, body depth in modern percids is quite variable. Body depth for the yellow perch, *Perca flavecens*, is 16 to 28 percent of the total length (Scott and Crossman, 1973, page 761). No additional features were observed on the type specimens to warrant specific separation.

Mioplosus sauvagenus will be retained here because the type could not be studied. With the absence of a published illustration, the loss of the holotype is indeed unfortunate.

MIOPLOSUS LABRACOIDES Cope 1877

= *Mioplosus abbreviatus* Cope, 1877a; *Mioplosus longus* Cope, 1877a; and *Mioplosus beani* Cope, 1877a.

The following information is based on AMNH 2457 (syntype, illustrated in Cope, 1884, plate XII, figure 1); AMNH 2460 (illustrated in McGrew and Casilliano, 1975, figure 23); AMNH 2463 (figure II.87a); AMNH 6898; USNM 4010 (syntype, figure II.87b); USNM 3994 (illustrated in Cope, 1884, plate XII, figure 2); UW 6394; PU 14705 (figure II.85); SMMP 75.26.1; SMMP 2141.3; BMNH P.61241 (figure II.82b), and SMMP 78.9.28 (figure II.83a).

Fin Rays: Pectoral 13-16 (n=6), rarely all preserved; Pelvic usually I,5-6 (n=7); Anal II,11-13 (for the soft rays n=13, $\overline{X}$=12.08, SD=.49), usually II,12. The last ray is often doubled, and the first spine is very small. Dorsal, two fins slightly connected at the base, VIII-IX and I-II,11-13 (8 or 9 hard spines in the first dorsal fin and 1 or 2 hard spines followed by 11 to 13 soft rays in the second dorsal fin). Usually the fin ray count is IX and I,11-12 (n=14, $\overline{X}$=11.77, SD=.60). The last two spines of the first dorsal fin are very small. The last ray of the second dorsal fin is often doubled. Caudal usually 1,8,7,1 (n=10), very slightly forked.

Pterygiophores: Anal usually 12-13 (n=14, $\overline{X}$=12.43, SD=.51); Dorsal 19-22 (n=13, $\overline{X}$=20.46, SD=.97), usually 20-21 (n=9).

Vertebrae: Caudal 15-16 (n=12, $\overline{X}$=15.91, SD=.29), usually 16 (n=11); Precaudal (2 PD) 11-12 (n=11, $\overline{X}$=11.91, SD=.30); Total 27-28. The predorsal vertebrae are usually covered by superficial skull elements, and x-ray techniques should be used to obtain accurate counts.

Scales: Ctenoid. Between the two dorsal fins, about 6-8 scale rows above the vertebral column and 10-13 below the vertebral column (n=2).

Dimensions: Body depth variable, about 23-33 percent of standard length (n=10), 19-27 percent of total length, though specimens with even greater body depth than in study sample have been observed; head length about 29-34 percent of the standard length (n=9), 24-27 percent of the total length.

Other Features: Branchiostegal rays 7 or 8; teeth strong, pointed slightly inward; mouth opens slightly upward; anterior profile of the head ranges from rounded to slightly pointed at the anterior end of the jaw, probably a factor of preservation.

?MIOPLOSUS SAUVAGENUS Cope 1884

The holotype for this species is missing and no illustration of the specimen was ever published, so it is impossible to review the specimen. Therefore, the name is retained here as a *nomen dubium.*

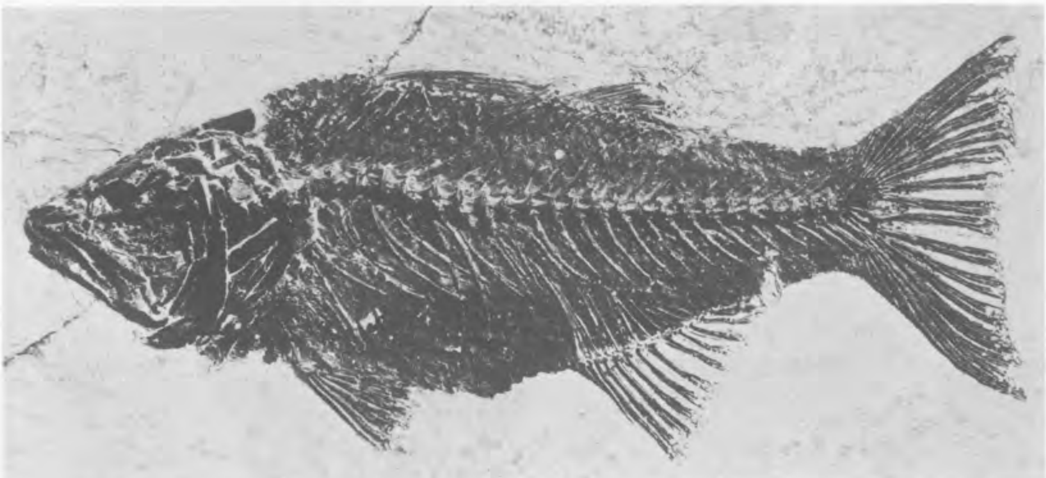


Figure II.82a. *Mioplosus labracoides* (AMNH 2972) from F-1. Total length 277 mm (about 11 inches). The body depth of *M. labracoides* is quite variable (compare the relative body depth of this specimen with that of the specimen shown in figure II.83a).

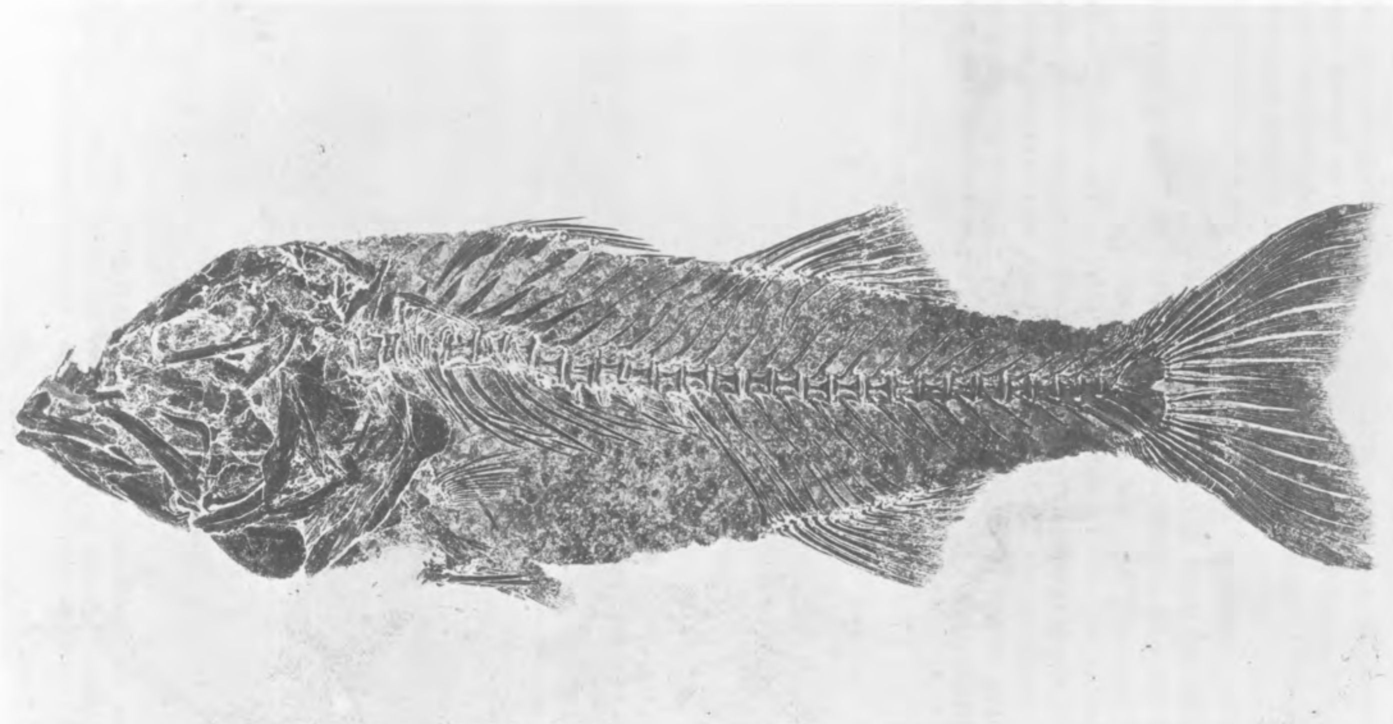


Figure II.82b. A large *Mioplosus labracoides* (BMNH P.61241) from F-1. Total length 42 cm (about 16½ inches).

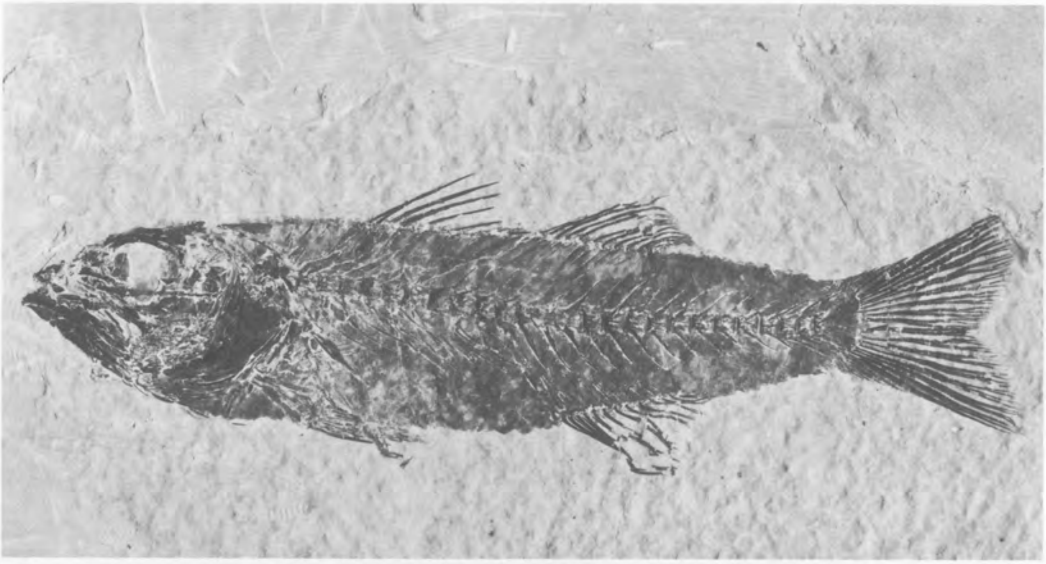


Figure II.83a. A small *M. labracoides* (SMMP 78.9.28) from F-2. Total length 10 cm (about 4 inches).

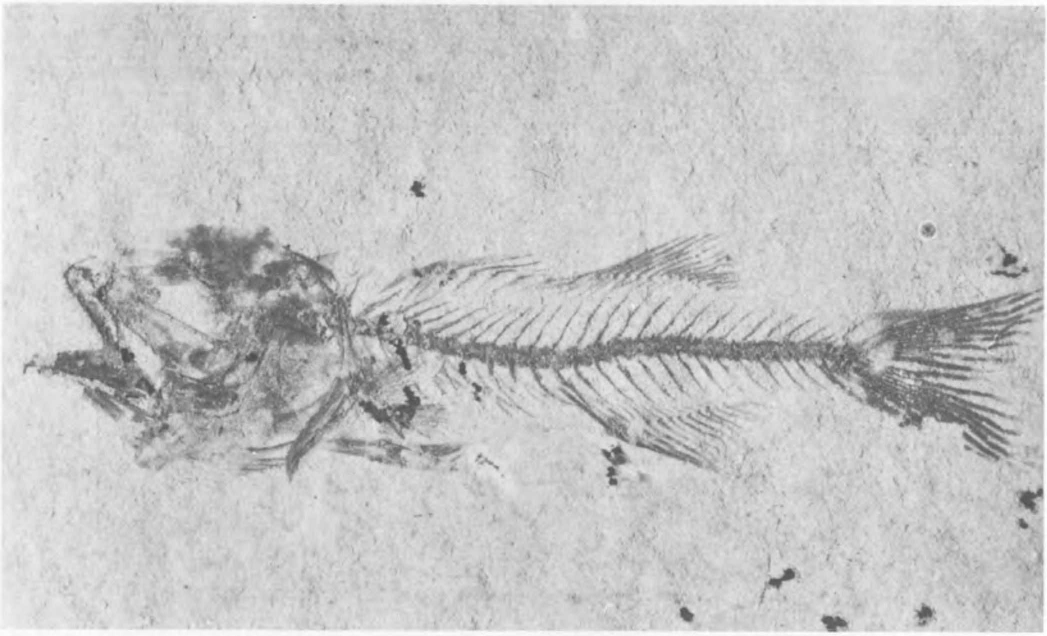


Figure II.83b. A very young juvenile *Mioplosus* sp. (SMMP 78.9.28) from F-2; the vertebrae are not yet fully ossified. Total length about 2 cm (about ¾ inch).

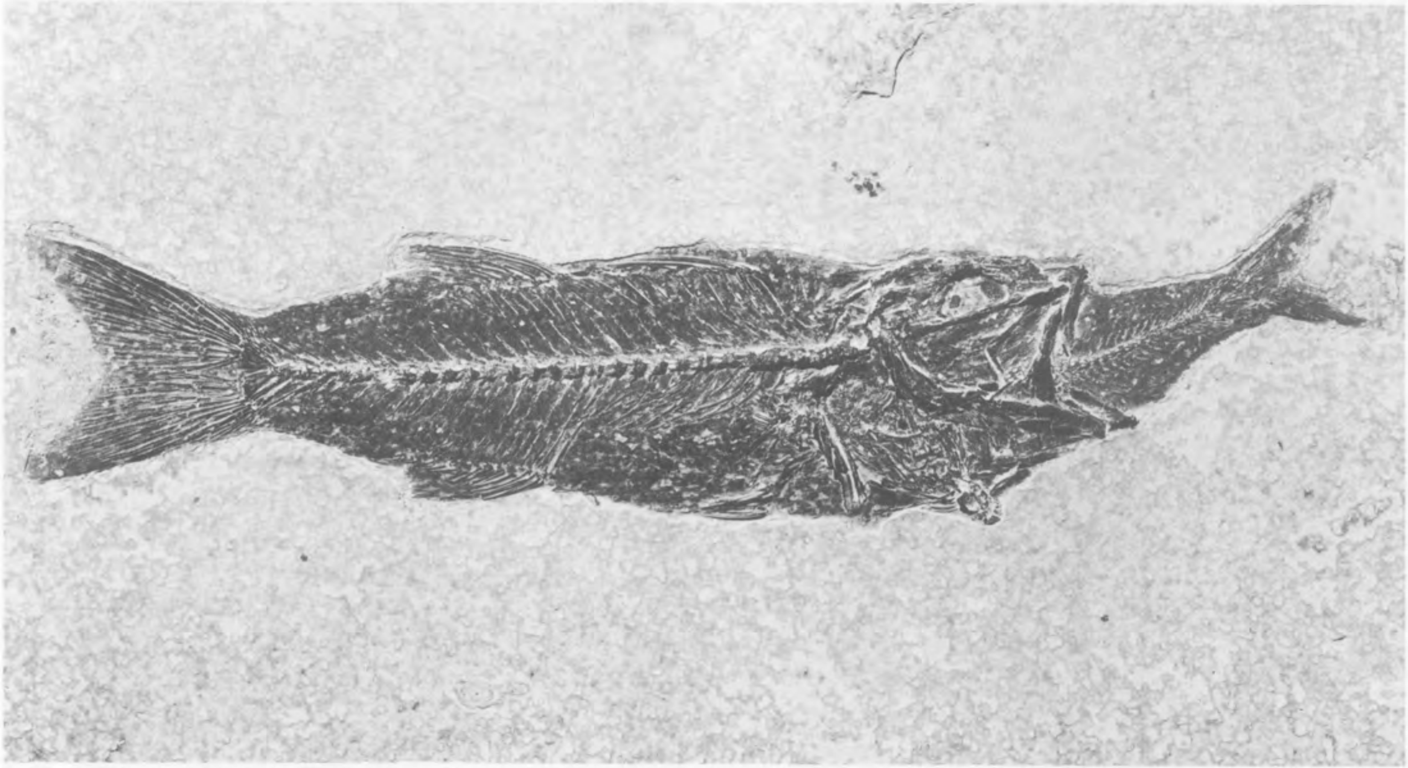


Figure II.84. A specimen of *Mioplosus labracoides* (PU 14705) which appears to have choked to death on a *Knightia eocaena* over half its own length, from F-1. Specimen is 166 mm (6½ inches) from tail tip to tail tip. Photo courtesy of Don Baird and Willard Starks, Princeton University. This specimen is discussed briefly in Jepsen (1967).

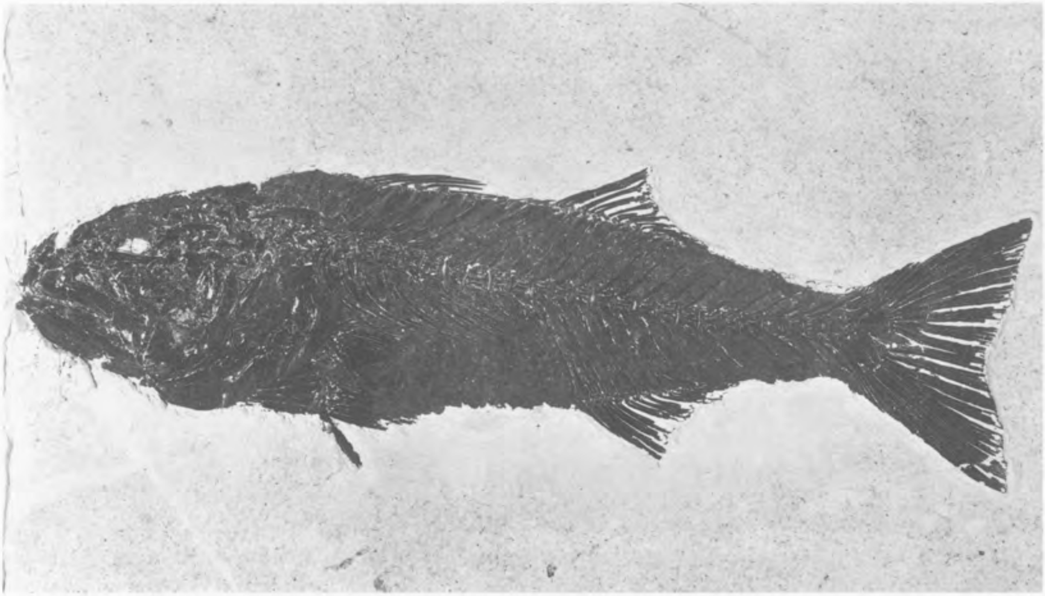


Figure II.85. *Mioplosus labracoides* (SMMP 75.26.1) from F-1. Total length is about 37 cm (14½ inches). Preparation by Richard W. Jackson.

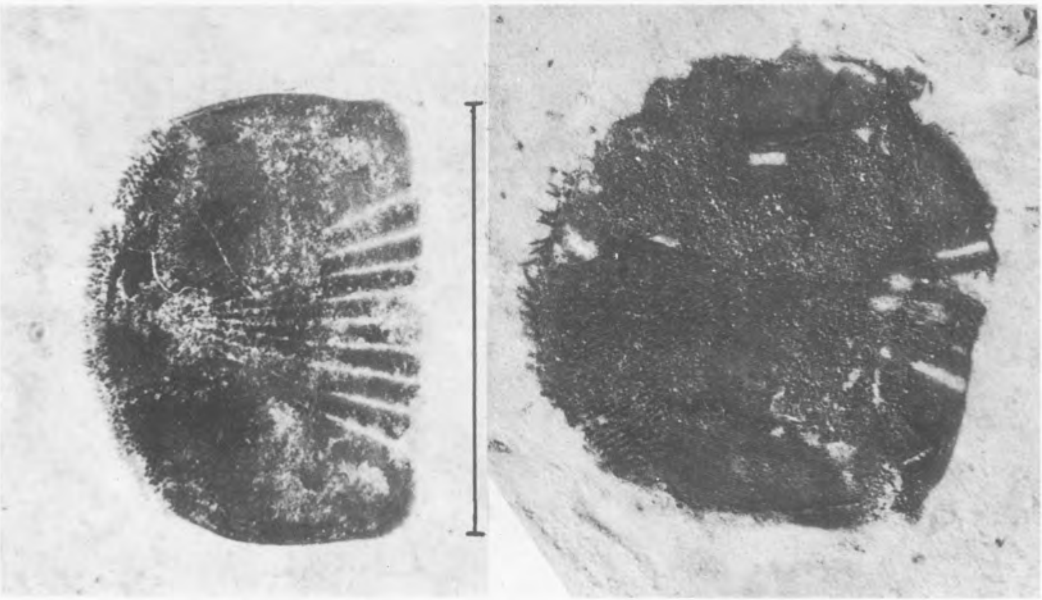


Figure II.86. Scales from *Mioplosus labracoides* (SMMP 78.9.22) from F-1; scale bar is about 5 mm.

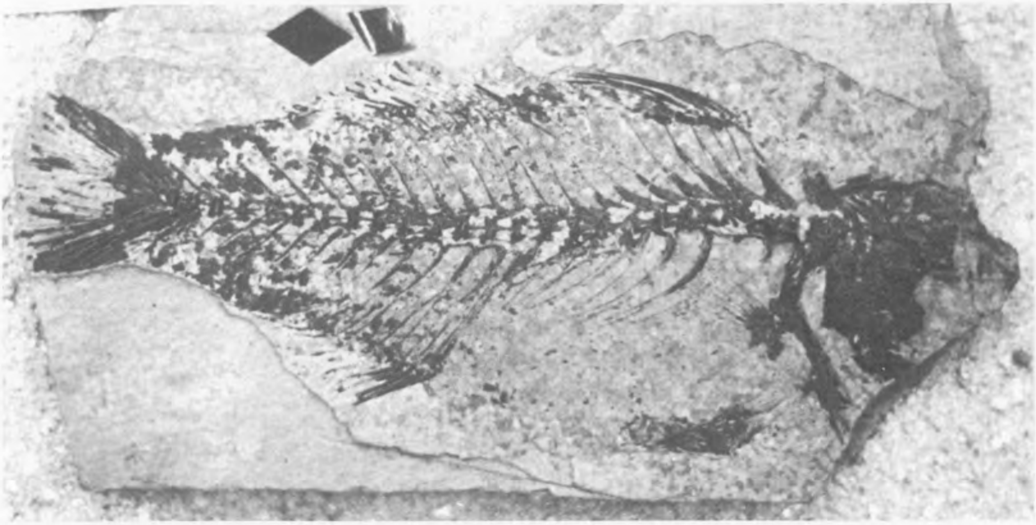


Figure II.87a. The type specimen for *M. abbreviatus*, Cope 1877 (= *M. labracoides* here) (AMNH 2463).

Figure II.87b. A syntype for *M. labracoides* (Cope 1877) which has no previously published illustration (USNM 4010).

Genus: *Priscacara* Cope 1877

Species: *P. serrata* Cope 1877 Figures II.88-II.90

P. liops Cope 1877 Figures II.91, II.92, II.94

? ? (other species currently being reviewed by Ted Cavender)

GENERAL INFORMATION

Priscacara is a common fish in the Fossil Lake quarries and fairly rare in the Gosiute and Uinta quarries. It is much more common in locality F-1 than in F-2 (see tables II.8, II.9, and II.10). *Priscacara* is easily identified by its deep, oval, sunfish-like body and its stout dorsal and anal spines which may have protected it from being swallowed from behind by the more voracious fish in the Green River lakes. Its size is highly variable. *Priscacara* is known in the Green River Formation from specimens 2 cm (7/8 inch) to 38 cm (15 inches) in total length (see figure II.89), though most of the specimens are 10-15 cm (4-6 inches) in total length. *Priscacara liops*, the most common species of the genus, is extremely common at F-1 and is smaller than *P. serrata*. The smallest known priscacarid is AMNH 9857, from F-1, 9 mm (1/3 inch) long. *Priscacara*, like *Knightia*, appears to have been a schooling fish. It occurs in at least one mass mortality zone (nearly all *P. liops*) near the middle of the 18-inch layer (locality F-1), at an average density of about 2 or 3 per square meter (occasionally as high as 8 to 10 per square meter). *Priscacara serrata* has massive pharyngeal bones covered with obtuse grinding teeth (see figure II.90), and probably fed mainly on snails and crustaceans. That *Priscacara* spines are occasionally found in large *Phareodus* specimens indicates that it was preyed upon by that genus. *Priscacara* is known only from Eocene deposits, and occurs in fresh water deposits as far north as Horsefly, British Columbia (Wilson, 1977).

GENERIC ETYMOLOGY

Priscacara: prisca — primitive, *cara* — head.

NOMENCLATURE, SPECIFIC INFORMATION, REPOSITORIES, AND SUGGESTED REFERENCES

Since Dr. Ted Cavender of Ohio State University is presently reviewing the priscacarids (personal communication), a specific review is omitted here. The number of valid species will have to be reduced from the nine described Green River species. A table of distinguishing characters for two valid species is given in this paper because these two species, *Priscacara liops* and *Priscacara serrata*, make up the majority of the Green River forms. Jordan (1923) erected the new genus *Cockerellites* for those species with 13 or 14 soft dorsal rays and thin pelvic spine (which includes *P. liops*). Because no other described characters separate

Cockerellites from *Priscacara*, only *Priscacara* will be recognized here. The other described Green River species, several of which appear to be invalid (synonyms), include *P. clivosa* (holotype USNM 4041, illustrated in Cope, 1884, plate XIII, figure 3); *P. pealei* (syntypes USNM 4037 and 4008, illustrated in Cope, 1884, plate XIV, figure 4 and plate VIII, figure 4, respectively); *P. cypha* (holotype USNM 4042, illustrated in Cope, 1884, plate XIII, figure 2); *P. dartonae* (holotype USNM 2381, illustrated in Eastman, 1917, plate 23); *P. hypsacantha* (holotype AMNH 2453; illustrated in Cope, 1886, figure 6); *P. oxyprion* (holotype USNM 4039, illustrated in Cope, 1884. plate XIV, figure 5, mistakenly labeled "*Priscacara serrata*" in plate caption); and *P. testudinaria* (holotype AMNH 2444, illustrated in Cope, 1884, plate I, figure 7).

All Cope's type specimens for Green River *Priscacara* species are from F-1 except AMNH 2453 (*P. hypsacantha*) — which is from F-2, and AMNH 2444 (*P. testudinaria*) — which is from the "Manti beds" of Lake Uinta.

For additional information see Cope (1877; 1878; 1884; 1886).

PRISCACARA SERRATA Cope 1877

P. serrata is the type species for the genus *Priscacara*. The following information is based on AMNH 2442 (the holotype, illustrated in Cope, 1884, plate XIII, figure 1); AMNH 9856; AMNH 2962; UW 5649 (illustrated in McGrew and Casilliano, 1975, figure 29); SMMP 2.A.2572; SMMP 2141.2; SMMP 78.9.27; UMVP 6590; and SMMP 78.9.37.

Fin Rays: Pectoral about 15 (n=3); Pelvic I,5-6 (n=3), the first soft ray unbranched, and the spine usually thicker than in *P. liops*; Anal III,8-9 (soft rays n=8, $\overline{X}$=8.12, SD=.35), usually III,8, the last ray often doubled; Dorsal usually X,9-11 with the last ray often doubled (soft rays n=8, $\overline{X}$=10.25, SD=.71), the first soft ray unbranched. Specimens of *P. serrata* rarely occur with 11 hard spines instead of 10. Caudal usually 1,8,7,1 (n=8), fin margin sometimes slightly rounded convexly but usually nearly a straight line. The median fin margins are also convexly rounded, but more so than the caudal fin.

Pterygiophores: Anal, 9-11 (n=7, $\overline{X}$=9.86, SD=.69); Dorsal, 19-20 (n=6, $\overline{X}$=19.83, SD=.41).

Vertebrae: Caudal usually 15 (n=8); Precaudal (2 PD) 10-12 (n=7, $\overline{X}$=11, SD=.58). Cope (1884) did not count predorsal vertebrae in his *Priscacara* descriptions.

Scales: Ctenoid. There are about 20-23 rows of abdominal scale rows below the vertebral column at greatest body depth (n=2); the operculum is scaled (n=2).

Dimensions: Maximum total length 38 cm (15 inches), *P. serrata* specimens usually much larger in average size than *P. liops*. Maximum body depth variable, 42-59 percent of the standard length (n=7), 32-45 percent of the total length (n=5); head length about 30-36 percent of the standard length (n=7), usually 34-36 percent (n=6), 23-27 percent of the total length.

Other Information: *Priscacara serrata* displays massive superior and inferior pharyngeal bones covered with obtuse grinding teeth (see figure II.90); these are well preserved on UW 5649 and SMMP 2.A.2572. The posterior margin of the preopercle is strongly serrated.

PRISCACARA LIOPS Cope 1877

Priscacara liops is the most common species of *Priscacara* in the Green River Formation; at F-1 it outnumbers *P. serrata* by over 3 to 1.

The following information is based on USNM 4044 (the holotype, illustrated in Cope, 1884, plate XIV, figure 3); USNM 4043 (illustrated in Cope, 1884, plate XIV, figure 2); AMNH 4579; AMNH 772G; AMNH 2586; SMMP 66.43.1, UW 13417 (illustrated in McGrew and Casilliano, 1975, figure 24); the specimen in figure II.91; and FMNH PF9645 (figure II.92).

Fin Rays: Pectoral about 12-15, rarely all preserved (n=3); Pelvic I,5-6 (n=5), the first soft ray unbranched, the spine usually thinner than in *P. serrata;* Anal III,10-12 (soft rays n=9, $\overline{X}$=10.55, SD=.72), the first ray usually unbranched and the last ray often doubled; Dorsal usually X,12-13, (soft rays n=9, $\overline{X}$=12.22, SD=.44), with the first soft ray unbranched and the last ray often doubled. Specimens of *P. liops* rarely occur with 11 hard spines instead of 10. Caudal usually 1,8,7,1 (n=9), fin margin slightly convexly rounded. The median fin margins are also convexly rounded, more so than the caudal fin.

Pterygiophores: Anal 12-14 (n=8, $\overline{X}$=12.63, SD=.74); Dorsal usually 21-22 (n=9, $\overline{X}$=21.22, SD=.44).

Vertebrae: Caudal 14-15 (n=8); Precaudal (2 PD) 10-11 (n=6).

Scales: Ctenoid. There are about 16-20 rows of abdominal scale rows below the vertebral column at the greatest body depth (n=3); the operculum is scaled (n=6). The scales appear to be proportionately larger than in *P. serrata*.

Dimensions: Maximum total length about 15 cm (6 inches). Maximum body depth variable, 46-57 percent of the standard length (n=9), 37-43 percent of the total length (n=8); head length about 35-39 percent of the standard length, 26-31 percent of the total length.

Other Information: *Priscacara liops* usually has a very finely serrated to nearly smooth posterior margin on the preopercle.

Table II.7 Diagnostic characters distinguishing *Priscacara serrata* and *P. liops.*

	P. serrata	*P. liops*
Dorsal fin rays	usually X, 9 or 10 (last ray doubled)	usually X, 12 or 13 (last ray doubled)
Dorsal pterygiophores	usually 19-20	usually 21-22
Anal fin rays	usually III, 8 or 9 (last ray doubled)	usually III, 10-12 (last ray doubled)
Anal pterygiophores	usually 9-11	usually 12-14
Posterior margin of the preopercle	strongly serrated (see fig. II.88b)	finely serrated to smooth (see fig. II.91)
Pelvic fin spine	usually stout, as thick as the dorsal spines	usually thinner than in *P. serrata*

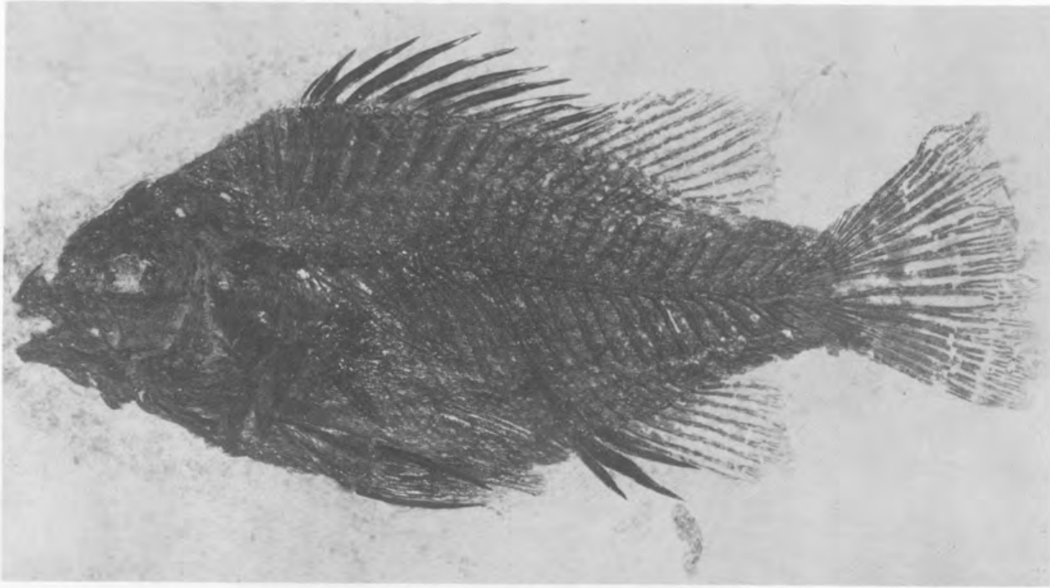


Figure II.88a. *Priscacara serrata* (SMMP 78.9.27) from F-1. Total length about 15 cm (6 inches). Preparation by Ronald Mjos.

Figure II.88b. Skull of *Priscacara serrata* (BMNH P.61242) from F-1 showing the strongly serrated preopercle characteristic of this species. Photography by Guido Dingerkus.

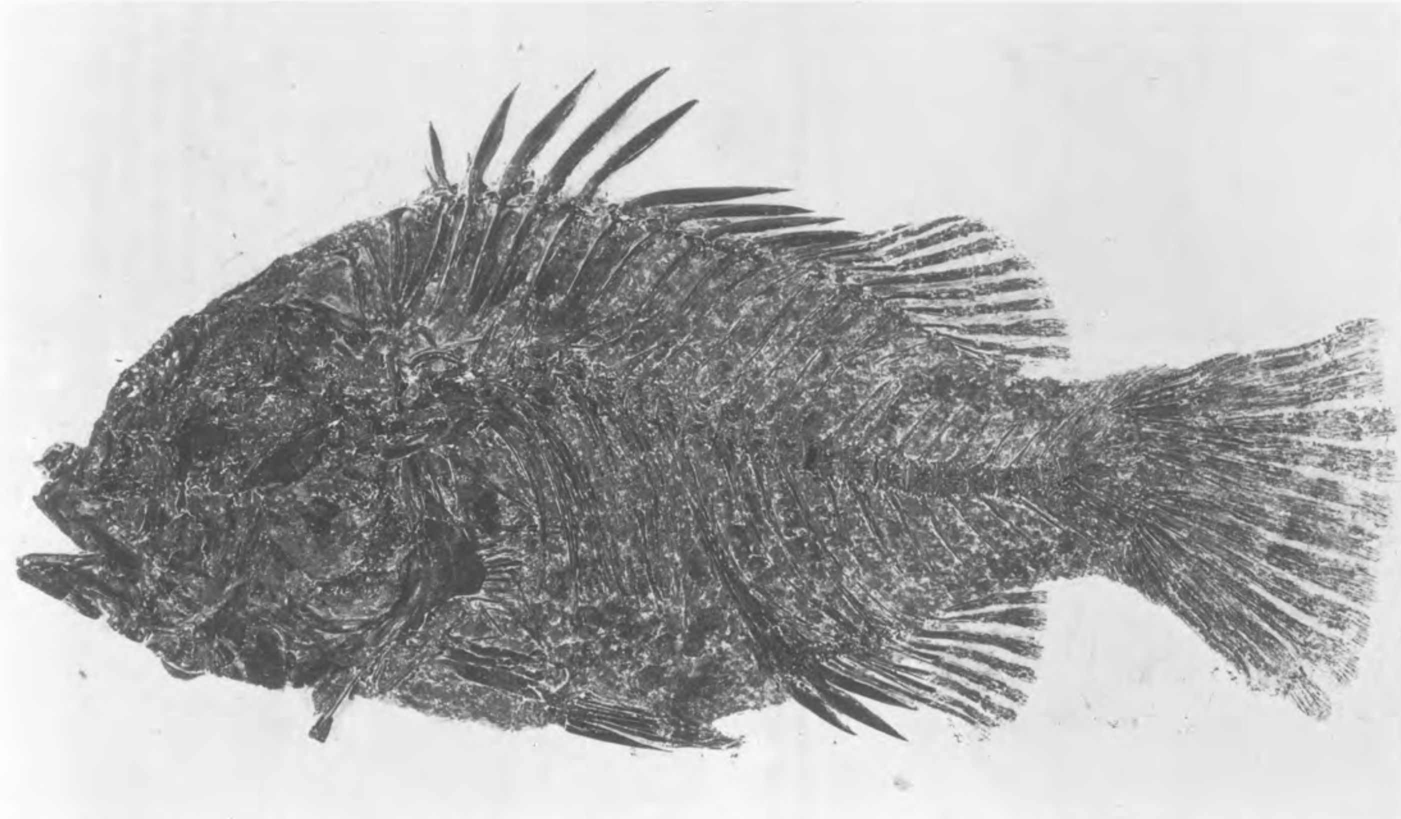


Figure II.89. Extremely large specimen of *Priscacara serrata* (SMMP 78.9.37) from F-1. Total length 39 cm (15 inches).

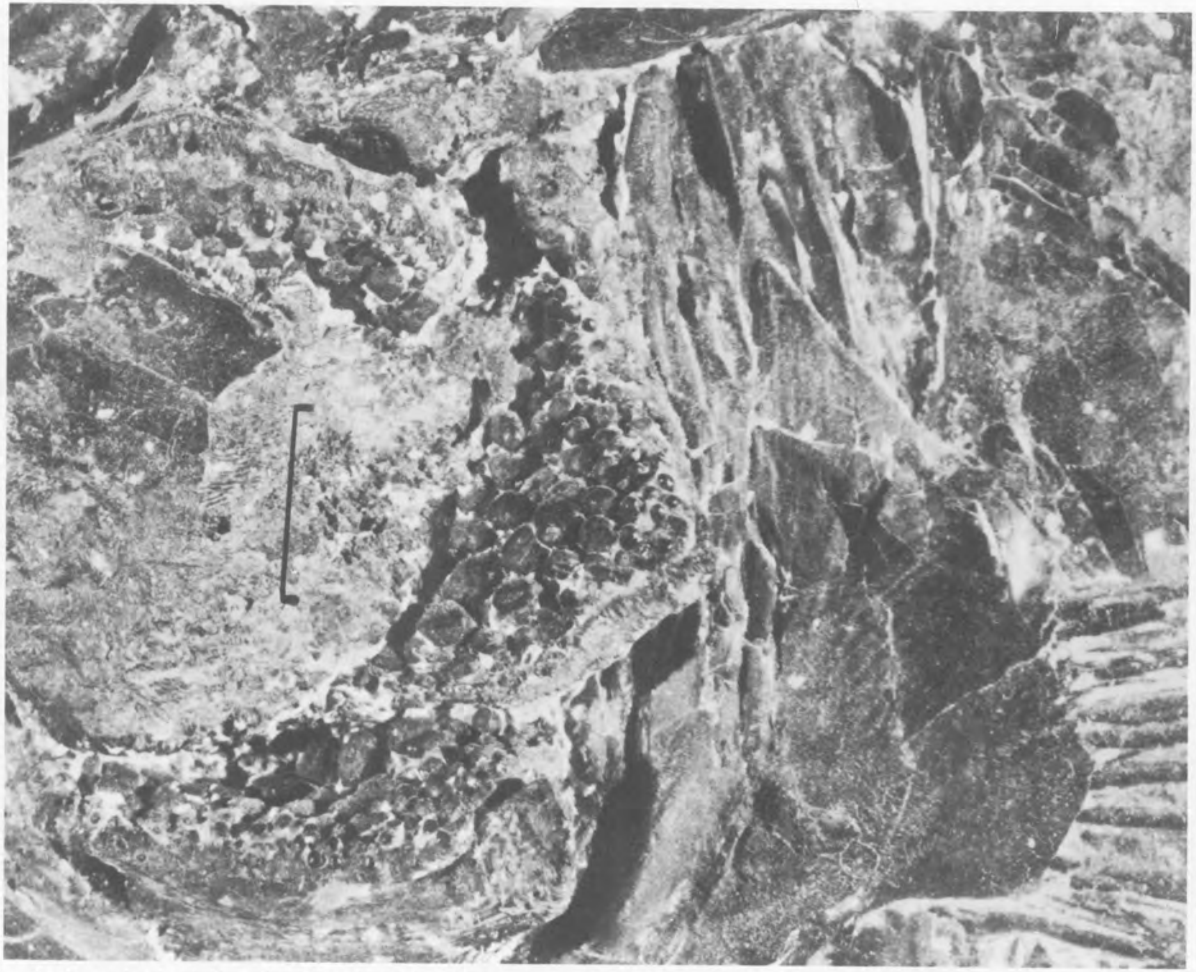


Figure II.90. A closer look at the pharyngeal teeth of the specimen in figure II.89. These are commonly well preserved in specimens of *P. serrata.* Scale 1 cm. Preparation by Mr. William Boundy.

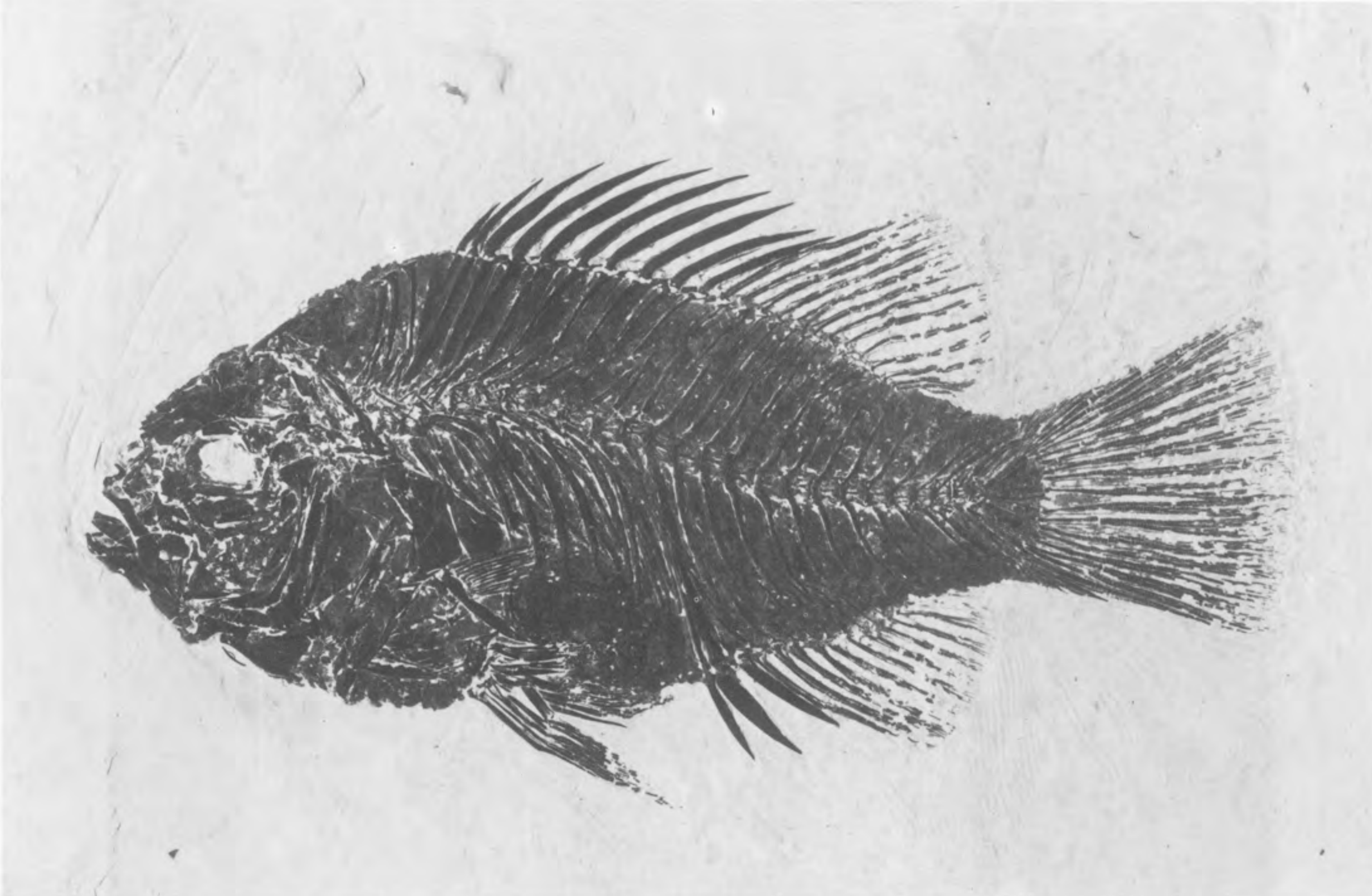


Figure II.91. *Priscacara liops* from F-1. Total length about 13 cm (5 inches). Note the thin spine of the pelvic fin. In the study collection of the Bell Museum, University of Minnesota.

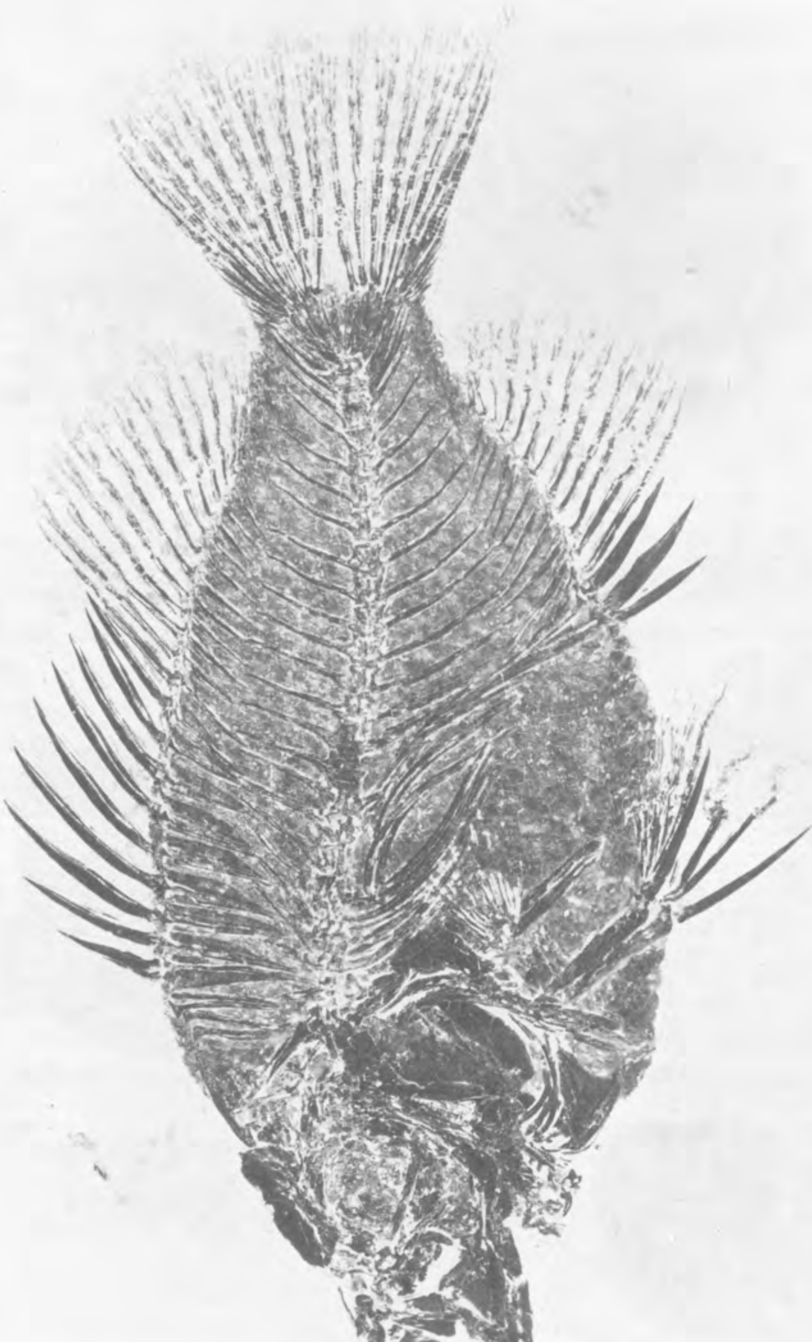


Figure II.92. *Priscacara liops* (FMNH PF9645) from the F-1 *Priscacara* mass mortality layer. Total length 11 cm (about 4¼ inches).

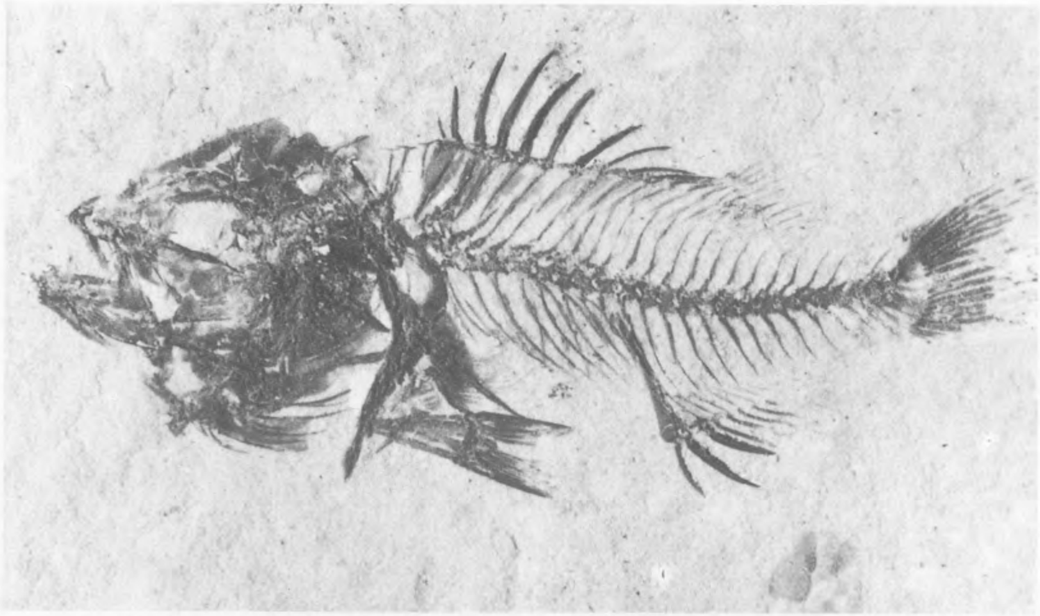


Figure II.93. Very young juvenile *Priscacara* sp. (SMMP 78.9.20) from F-2. Total length about 20 mm (1 inch).

Figure II.94. Isolated scales from *P. liops*; F-1 specimen. The length of the larger scale is 4 mm (slightly larger than 1/8 inch). The scale is from a fish about 13 cm (5 inches) in total length.

There are at least two other genera of fish present in the Green River Formation. Ted Cavender (personal communication) is describing a new percoid from F-2 (see figures II.95a,b), similar to *Priscacara* but much more enlongated and with 8 or 9 dorsal spines, long spines on the preopercle, and several other special characters. Referred to as "new percoid genus A" in tables II.8-12, this species is probably generically different from *Priscacara* but a member of the same family, Priscacaridae.

Also, dermal denticles from sturgeon (family Acipenseridae) have been found by amateur collectors. The author is studying a possible new genus of stingray from F-1 and F-2, and Dr. John G. Lundberg has a new genus of Green River catfish (personal communication).

Moore (1933, page 179, figure 79) mistakenly reported *Zebrasoma* (a marine perciform) from the Green River Formation. This is a caption misprint, and the specimen he illustrates (AMNH 7483) is actually from Tertiary marine deposits in the West Indies (personal communication, Bobb Schaeffer).

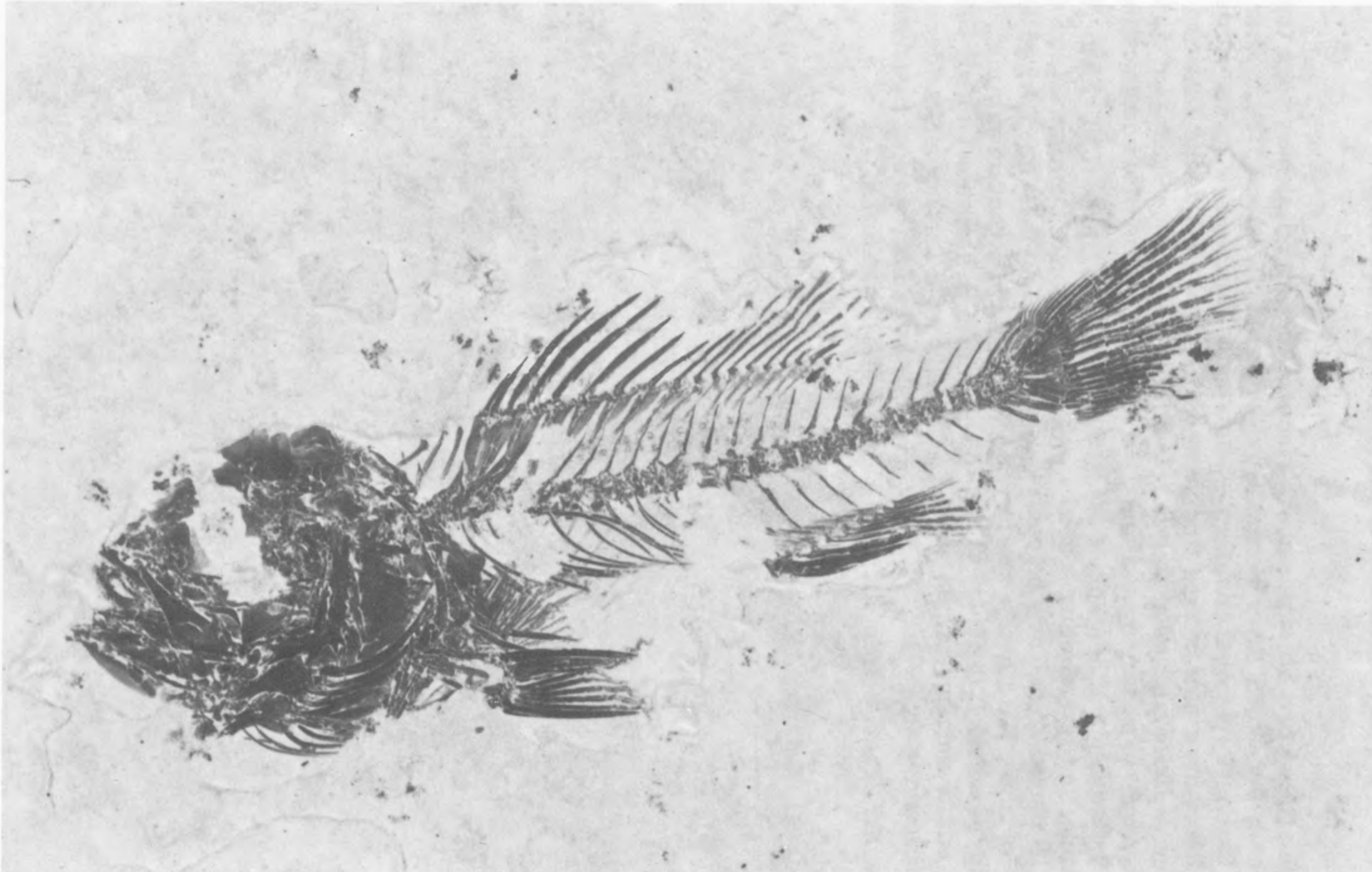


Figure II.95a. New percoid genus A (SMMP 78.9.29) from F-2, currently being described by Ted Cavender. Total length about 47 mm (1¾ inches).

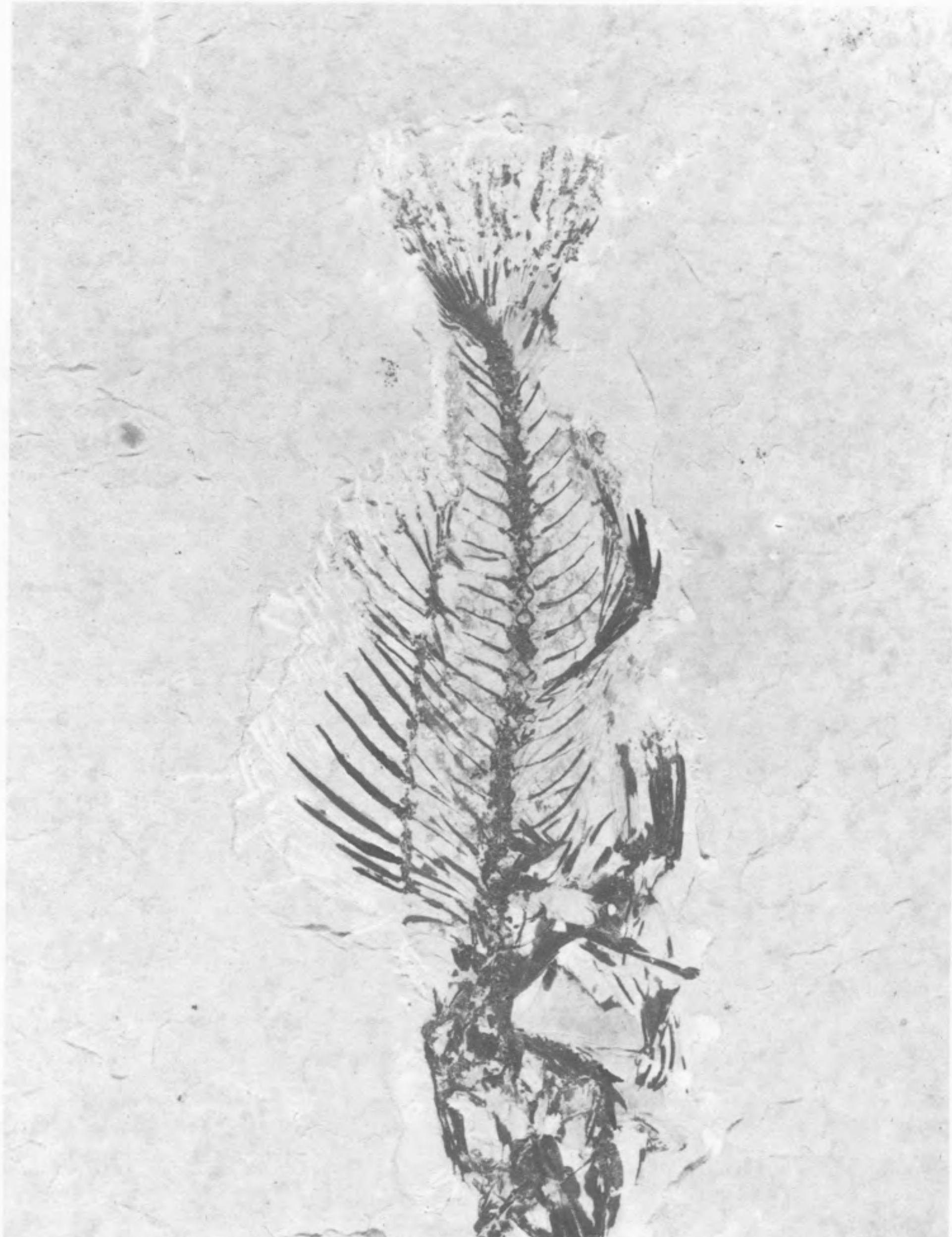


Figure II.95b. New percoid species A (FMNH PF9877) from F-2. Total length about 9 cm ($3\frac{1}{2}$ inches), about maximum size for this species.

Fish coprolites (fossilized fecal material) are extremely common in the Green River Formation, particularly at locality F-1. Several varieties occur, but the small rope-shaped coprolites are the most common (figure II.94). These rope-shaped specimens appear to contain no bones, scales, or shell fragments; small herring are a likely source, since small herring such as *Knightia* are the most common fish, and fed primarily on non-vertebrate material. Drop-shaped coprolites of various sizes containing fish bones are occasionally found, obviously of carnivorous origin (see figure II.97). According to Edwards (1976), apatite is the major mineral of which the F-1 coprolites are composed. The fossilization of delicate coprolites such as the rope-shaped variety is rare in the fossil record and serves further to emphasize the unusual nature of the depositional environment and fossil preservation within the Green River Formation. Buchheim (1977, page 198) reported abundant apatitic fish coprolites which he identified as belonging to *Astephus*. These were found in the catfish mass-mortality layer of G-2. For further information see Edwards (1976) and Buchheim and Surdam (1977).

Figure II.96. Coprolites (SMMP 78.9.7) from F-1. The longest rope-shaped specimen is 3.5 cm (about 1³/₈ inches). These are extremely common in the F-1 beds.

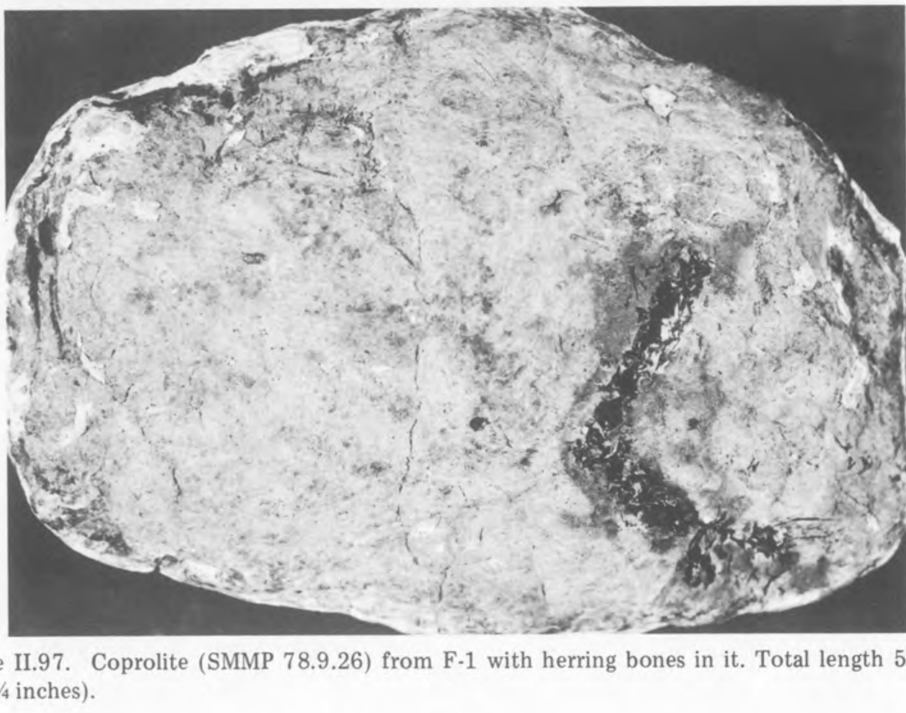
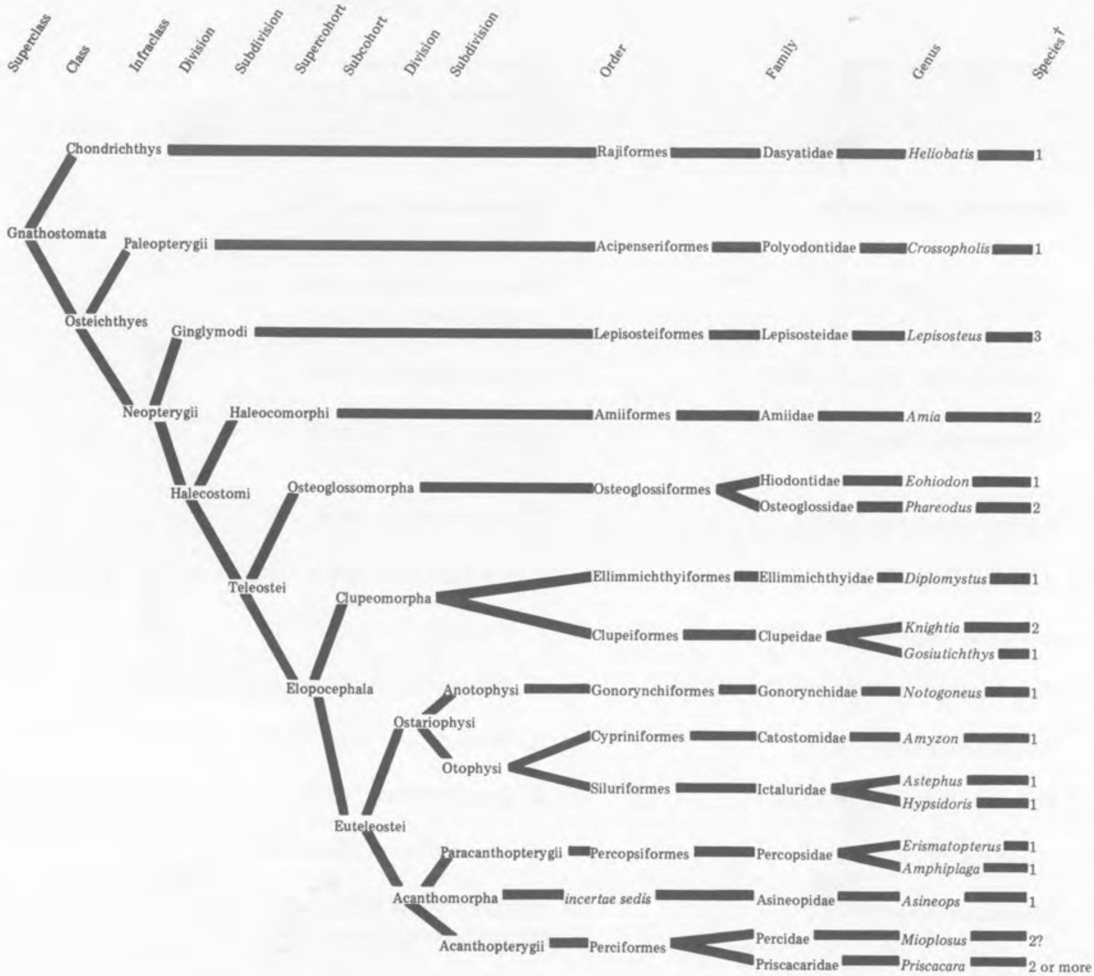


Figure II.97. Coprolite (SMMP 78.9.26) from F-1 with herring bones in it. Total length 56 mm (2¼ inches).

CLASSIFICATION OF THE GREEN RIVER FISH COMMUNITY

Figures II.98 and II.99 show a classification of all the described Green River fish found valid in this paper. Patterson and Rosen's (1977) classification system is used.



†Number of valid described Green River species recognized here

Figure II.98. Classification diagram of all the described Green River fish recognized as valid in this paper. Paleopterygii = Chondrostei

Genus	Described Green River species recognized in this paper as valid
Heliobatis Marsh 1877	*H. radians* Marsh 1877
Crossopholis Cope 1883	*C. magnicaudatus* Cope 1883
Lepisosteus Lacépéde 1803	*L. simplex* (Cope 1873) *L. atrox* (Leidy 1873) *L. cuneatus* (Cope 1877)
Amia Linnaeus 1766	*A. uintaensis* (Leidy 1873) *A. fragosa* (Jordan 1927)
Eohiodon Cavender 1966	*E. falcatus* Grande 1979
Phareodus Leidy 1873	*P. encaustus* (Cope 1871) *P. testis* (Cope 1877)
Knightia Jordan 1907	*K. eocaena* Jordan 1907 *K. alta* (Leidy 1873)
Gosiutichthys Grande 1982	*G. parvus* Grande 1982
Diplomystus Cope 1877	*D. dentatus* Cope 1877 ?*D. theta* (Cope 1874)
Notogoneus Cope 1885	*N. osculus* Cope 1885
Amyzon Cope 1872	*A. gosiutensis* Grande, Eastman, & Cavender 1982
Astephus Cope 1873	*A. antiquus* (Leidy 1873)
Hypsidoris Lundberg and Case 1976	*H. farsonensis* Lundberg and Case 1976
Amphiplaga Cope 1877	*A. brachyptera* Cope 1877
Erismatopterus Cope 1871	*E. levatus* (Cope 1870)
Asineops Cope 1870	*A. squamifrons* Cope 1870
Mioplosus Cope 1877	*M. labracoides* Cope 1877 ?*M. sauvagenus* Cope 1884
Priscacara Cope 1877	*P. serrata* Cope 1877 *P. liops* Cope 1877 (Other *Priscacara* species are currently being reviewed by Ted Cavender.)

Figure II.99. All of the described Green River fish genera and species (with their authors) recognized as valid in this paper.

FOSSIL LAKE

F-1: Fish population samples were counted at two different F-1 localities. One sample of 1049 fish (shown in table II.8) was counted from the R.W. Jackson quarry during August and September 1978. The Jackson quarry is in sec. 16, T21N, R117W, Lincoln County (Kemmerer 15-minute quadrangle), about 9 miles west of Kemmerer, Wyoming. This sample was counted as each individual specimen was discovered and represents a random count, though it is slightly prejudiced (perhaps by 5 percent) against small fish genera (*Priscacara*, *Knightia*, and small *Diplomystus*) because the larger fish are more visible than smaller specimens while covered with matrix. (Unlike the F-2 quarries, F-1 specimens do not normally split out exposed, but are usually found covered with a thin layer of matrix which must be scratched off — see Appendix I).

The second sample, of 386 fish (shown in table II.9), was taken by Dr. Paul O.

Table II.8. The relative abundance of described fish genera at F-1 (at the "Jackson quarry," 1978).

Genus	Common Name	Number Observed	Percent of Sample Population
Heliobatis	stingray	*	*
Crossopholis	paddlefish	*	*
Lepisosteus	gar	*	*
Amia	bowfin	1	.1%
Eohiodon	mooneye	*	*
Phareodus	—	21	2.0%
Knightia	herring	309	29.5%
Gosiutichthys	herring	none	
Diplomystus	herring	416	39.6%
Notogoneus	—	23	2.2
Amyzon	sucker	none	
Astephus	catfish	*	*
Hypsidoris	catfish	none	
Erismatopterus	trout perch	none	
Amphiplaga	trout perch	*	
Asineops	—	*	*
Mioplosus	perch	43	4.1%
Priscacara	—	236	22.5%
new percoid genus A	—	*	
TOTAL		1049	100.0%

*Known to occur at this locality, but none excavated in study sample.

McGrew from the C.J. Ulrich 1963-1964 quarry site (on Fossil Ridge, about 2½ km or 1½ miles west of the Jackson quarry) for a study on the taphonomy of Green River fish (see McGrew, 1975). He excavated a large block of F-1 which he later split into thin slabs and X-rayed. Dr. McGrew kindly lent the author about 500 radiographs, from which the sample in table II.9 was counted.† The X-rayed sample revealed only fish greater than 5 cm (2 inches) in total length. Given the different methods used for counting for the two F-1 sites and the relatively small sample sizes, the generic proportions do not vary significantly between the two areas except among the herring. The Jackson 1978 quarry appears to contain more small *Knightia* sized *Diplomystus* (8-15 cm or 3-6 inches in total length) and fewer *Knightia* than the Ulrich 1963-1964 quarry. This is due in part to the presence of a dense *Knightia* mass mortality horizon (see figure II.41) at the Ulrich 1963-1964 site, which is absent at the Jackson site.

Table II.9. The relative abundance of described fish genera at F-1 (at the "Ulrich quarry," 1963-1964).

Genus	Common Name	Number Observed	Percent of Sample Population
Heliobatis	stingray	*	*
Crossopholis	paddlefish	*	*
Lepisosteus	gar	*	*
Amia	bowfin	*	*
Eohiodon	mooneye	*	*
Phareodus	—	2	.5%
Knightia	herring	155	40.2%
Gosiutichthys	herring	none	
Diplomystus	herring	105	27.2%
Notogoneus	—	1	.3%
Amyzon	sucker	none	
Astephus	catfish	*	*
Hypsidoris	catfish	none	
Erismatopterus	trout perch	none	
Amphiplaga	trout perch	*	
Asineops	—	*	*
Mioplosus	perch	9	2.3%
Priscacara	—	114	29.5%
new percoid genus A	—	*	
TOTAL		386	100.0%

*Known to occur at this locality, but none excavated in study sample.

†Among these radiographs there was duplication due to overlapping x-rays and multiple x-rays of the same slab: many specimens were shown more than once. Counting such specimens only once for table II.9 was difficult, so sampling error in this table may be higher than in other tables.

Both F-1 localities contain abundant plant fossils (mostly terrestrial plant leaves) and occasional insect (mostly *Plecia pealei* Scudder) and molluscan (mostly *Viviparus sp.*) fossils. The plant, insect, and molluscan fossils are much more common in the thin oil shale unit underlying the 18-inch layer. F-1 molluscs are found preserved in a relatively uncompressed state ("in the round"). *Plecia pealei* (a march fly) makes up about 90 percent of the insect fauna. Birds, bats, turtles, and crocodilians (and one known snake) are found on rare occasions at F-1 localities, but the crayfish and shrimp found at F-2 are notably absent here. Very young juvenile specimens of *Diplomystus* (figure II.48) are much more common here than at F-2, though juvenile specimens with fully ossified vertebrae occur at approximately the same frequencey as at F-2.

F-2: Table II.10 shows the fish fauna of F-2 (the split-fish layer) based on fish counted from the J.E. Tynsky quarry during the summers of 1976 and 1977. This sample represents a random count of 5232 fish, though only complete or nearly complete fish were enumerated. Only fish that were "split out" and completely exposed were counted, so no size bias is present here. Insect and plant

Table II.10. The relative abundance of described fish genera at F-2 (at the "J.E. Tynsky quarry," 1976-1977). Slightly revised from Grande (1979, table 3), after four very young juvenile specimens originally counted as *Mioplosus* sp. were later discovered to be new percoid genus A., and *Xiphotrygon acutidens* was found to be a junior synonym of *Heliobatis radians*.

Genus	Common Name	Number Observed	Percent of Sample Population
Heliobatis	stingray	3	.06%
Crossopholis	paddlefish	1	.02%
Lepisosteus	gar	2	.04%
Amia	bowfin	1	.02%
Eohiodon	mooneye	2	.04%
Phareodus	—	285	5.45%
Knightia	herring	3187	60.91%
Gosiutichthys	herring	none	
Diplomystus	herring	1436	27.45%
Notogoneus	—	1 (partial)	.02%
Amyzon	sucker	none	
Astephus	catfish	1 (partial)	.02%
Hypsidoris	catfish	none	
Erismatopterus	trout perch	none	
Amphiplaga	trout perch	56	1.06%
Asineops	—	1	.02%
Mioplosus	perch	129	2.46%
Priscacara	—	123	2.35%
new percoid genus A	—	4	08%
TOTAL		5232	100.00%

fossils are extremely rare here, in contrast to F-1; and whereas *Viviparus sp.* is the dominant F-1 snail, *Goniobasis sp.* is the dominant F-2 snail. Birds, bats, turtles, and crocodilians have been found here, and crayfish and shrimp occur occasionally. Extremely small juvenile specimens of *Priscacara* (see figure II.92), *Mioplosus* (see figure II.83), and *Phareodus* (see figure II.34) are more common here than at F-1. The most obvious differences between the fish faunas of F-1 and F-2 are the significantly greater numbers of *Priscacara* and *Notogoneus* at F-1 and of *Amphiplaga* and *Knightia* at F-2. Based on additional unpublished data, *Heliobatis* (the sting ray) is more common at F-2 than at F-1. The F-2 community may have been closer to the shore of Eocene Fossil Lake than the F-1 community (Paul McGrew, personal communication); this hypothesis may explain the appearance of crayfish, shrimp, and more sting rays, and the absence of varves, at F-2.

GOSIUTE LAKE

G-1: Table II.11 shows the fish fauna of G-1 at the Fontenelle Reservoir based on fish counted from local amateur collectors' quarries during the summers of 1976 through 1978. This sample represents a random population count of 497 fish which were all "split out" and exposed in the field, resulting in a sample unbiased with respect to fish size. Insect and plant fossils are extremely common here, as are ostracods. Unlike the F-1 quarries, G-1 has as its most common insect the mosquite *Culex* sp., which occurs in extensive mass mortalities of adult, pupae, and larval forms and makes up over 98 percent of the insect fauna studied here. Birds, turtles, and crocodilians are found only rarely, and crayfish and shrimp appear to be absent. The average size of all fish except the catfish is relatively smaller than of specimens of the same genera occurring in Fossil Lake, probably because of the very shallow depth of Eocene Lake Gosiute at G-1. Shallow areas of lakes generally provide habitat and serve as nursery grounds for juvenile fishes.

Similar Laney Member exposures near Fontenelle in the "Little Colorado Desert" contain a similar fish fauna with a much higher proportion of clupeids (mostly *Gosiutichthys*).

G-2: Population data for this locality are based on only a few specimens, most of which were collected by Dr. Paul Buchheim. *Astephus*, *Hypsidoris*, *Erismatopterus*, *Amyzon*, *Knightia* and *Lepisosteus* are all present at this locality, and other genera may be found with further collecting. This locality contains mass mortality layers of both *Erismatopterus* (over 100 per square meter in places) and *Astephus* (about 3 per square meter; Paul Buchheim, personal communication).

G-3: Cope (1871) reported that the fish fauna included *Asineops*, *Erismatopterus*, *Knightia*, and *Phareodus*. Since then, pieces of *Astephus*, *Lepisosteus*, and *Amia* have been collected from this locality. Population data for this locality are based on only a few specimens.

G-4: The Farson beds have been heavily collected by amateur collectors for decades. The G-4 fish fauna includes *Knightia*, *Diplomystus*, *Asineops*, *Lepisosteus*, *Amia*, *Astephus*, and *Hypsidoris*, with *Knightia* making up over 75 percent of the population. The *Knightia* are larger here than at G-1, averaging about 10-13 cm (4-5 inches) in length. Insects and leaves occur, like the fish, as external molds or impressions. Birds, crocodilians, and a frog are also known from this locality.

LAKE UINTA

Very little is known about the fish fauna of Eocene Lake Uinta. Cope reported *Priscacara* and *Lepisosteus* from Green River deposits near Manti, Utah ("Manti Shales"; Cope, 1884, pages 55, 99). Baer (1969, page 29) illustrated two Green River fish from near Provo, Utah, which he identified as *Priscacara* and *Knightia* but which are actually *Phareodus* and probably *Erismatopterus*. Both localities are probably in the Parachute Creek member of the Green River Formation or at least of equivalent age (personal communications, Wade Miller and J.L. Baer). *Amia*, *Knightia*, *Diplomystus*, *Asineops*, *Astephus*, and *Mioplosus* have also been found in Lake Uinta deposits. Several marginal deltaic or stream deposits such as U-1 appear to contain only gar (*Lepisosteus cuneatus*),

Table II.11. The relative abundance of described fish genera at G-1.

Genus	Common Name	Number Observed	Percent of Sample Population
Heliobatis	stingray	none	
Crossopholis	paddlefish	none	
Lepisosteus	gar	*	*
Amia	bowfin	*	*
Eohiodon	mooneye	none	
Phareodus	—	*	*
Knightia and *Gosiutichthys***	herring	487	98.0%
Diplomystus	herring	*	*
Notogoneus	—	none	
Amyzon	sucker	3	.6%
Astephus	catfish	1	.2%
Hypsidoris	catfish	*	*
Erismatopterus	trout perch	4	.8%
Amphiplaga	trout perch	none	
Asineops	—	2	.4%
Mioplosus	perch	none	
Priscacara	—	*	*
new percoid genus A	—	*?	
TOTAL		497	100.0%

*Known to occur at this locality, but none excavated in study sample.

**Nearly all of these were actually *Gosiutichthys*, a fish described (Grande, 1982b) after the first edition of this bulletin had been printed. This genus was found only at G-1 and similar Laney Member beds north of Fontenelle Reservoir.

which occur in large numbers (see figure II.17). Turtles, crocodilians, lizards, bats, birds, and a frog are known from U-2, U-3, U-4, and several other localities, and a titanothere was reported by Parker (1970) near the U-3 horizon in Summit County, Utah. Of the three Green River lakes, Lake Uinta's fish population is by far the least studied or understood.

THE GREEN RIVER LAKE SYSTEM

A summary of the relative abundance of fish genera in the three Green River lakes, based on the localities listed in this paper, is given in table II.12. The "other" category for Lake Uinta deposits is an estimate based on a limited number of specimens and will be revised with further research.

The Green River Formation represents one of the earliest fresh water lake systems of North America which supported a modern (teleost) fish fauna. Primary (strictly fresh water) fish families include the Polyodontidae (*Crossopholis*), Amiidae (*Amia*), Ictaluridae (*Astephus* and *Hypsidoris*), Hiodontidae (*Eohiodon*), and Catostomidae (*Amyzon*). Marine derivatives include the Dasyatidae (*Heliobatis*), Clupeidae (*Gosiutichthys* and *Knightia*), Gonorynchidae (*Notogoneus*), and some percoids (*Mioplosus*, *Priscacara*, and an undescribed genus currently being described by Ted Cavender). The Percopsidae (*Amphiplaga* and *Erismatopterus*), Asineopidae (*Asineops*), Lepisostidae (*Lepisosteus*), Ellimmichthyidae (*Diplomystus*) and Osteoglossidae (*Phareodus*) are of uncertain derivation. Some of the marine derivatives such as *Heliobatis* may have entered the Eocene lake system in the early Flagstaff stages through connections with the sea. *Lepisosteus*, *Amia*, and a polyodontid are known in North American fresh water deposits as early as the Cretaceous, so their presence in the Green River Lake system is not surprising. The origin of most of the other members of the Green River fish fauna is poorly understood, primarily because of the extreme rarity of Paleocene fresh water fish deposits in North America. Currently, Mark Wilson (personal communication) is studying Paleocene teleosts of Alberta and Saskatchewan, and the author is studying some Paleocene teleost deposits of North Dakota.

The known specific richness of the

Table II.12. A summary of the relative abundance of fish genera in the three Eocene Green River lakes, based on the localities listed in this paper. Several thousands of additional specimens, together with those samples used in tables II.8 through II.11, were examined for construction of this table.

—	not known to occur at this locality
*	known by disarticulated pieces only
ER — Extremely Rare	only known by a few specimens
R — Rare	less than 1% of the total fish population
U — Uncommon	between 1 and 5% of total fish population
C — Common	between 5 and 25% of total fish population
VC — Very Common	between 25 and 50% of total fish population
EC — Extremely Common	greater than 50% of total fish population

RELATIVE ABUNDANCE								
Genus	Fossil Lake Deposits of late Early Eocene age		Lake Gosiute Deposits of early Middle Eocene age				Lake Uinta Deposits of early Middle Eocene age	
	F-1	F-2	G-1	G-2	G-3	G-4	U-1	Other
Heliobatis (stingray)	R	R	–	–	–	–	–	–
Crossopholis (paddle fish)	ER	ER	–	–	–	–	–	–
Lepisosteus (gar)	R	R	ER	*	*	ER	EC	C-VC
Amia (bowfin)	ER	ER	ER	*	*	ER	*	*
Knightia (herring)	VC	EC	EC	U	EC	EC	–	C-VC
Gosiutichthys (herring)	–	–	EC	–	–	–	–	–
Diplomystus (herring-like)	VC	VC	R	ER	ER	R	–	R-U
Eohiodon (Eocene mooneye)	ER	R	–	–	–	–	–	–
Phareodus (osteoglossid)	U	C	ER	ER	ER	–	–	U
Notogoneus (gonorynchid)	U	*	–	–	–	–	–	–
Amyzon (sucker)	–	–	R	R	ER	ER	–	–
Astephus (catfish)	ER	ER	R	U	ER	R-U	*	ER-R
Hypsidoris (catfish)	–	–	ER	ER	–	R	–	–
Erismatopterus (trout perch)	–	–	R	EC	C	–	–	U
Amphiplaga (trout perch)	ER	U	–	–	–	–	–	–
Asineops (uncertain derivation)	ER	ER	R	R-U	U	R-U	–	R
Mioplosus (perch-like)	U	U	–	–	–	–	–	ER
Priscacara (percoid)	C-VC	U	ER	ER	ER	–	–	ER
new percoid genus A	*	R	*?	–	–	–	–	–

Green River fish fauna, even at its highest (in the upper half of the Fossil Lake sediments [F-1 and F-2] with at least 22 species of fish), was considerably lower than that of modern lakes of similar longevity. African Lakes Malawi and Tanganyika (very large, deep lakes with durations of more than two million years) contain about 234 and 184 fish species, respectively (Lowe-McConnel, 1975, page 279). Not all Green River fossil species are described, and differences between the criteria used in specific separation of extant species and of fossil species probably also contribute to the relatively low number of fossil species. But the magnitude of the difference in specific richness between the Green River lakes and the African lakes is much too great to be attributed merely to yet undescribed fossil species or differences in specific criteria. The relatively low specific richness of the fish fauna inhabiting the Green River lake system is likely the result of a highly fluctuating environment, where conditions were never stable long enough for teleost radiation to occur as explosively as it did in the African lakes.

Geochemical and sedimentological data indicate a fluctuating environment. Fluctuations of depth or salinity or both, based on geological data for Lake Gosiute, are discussed by Smith (1969), Wolfbauer (1971), Eugster and Surdam (1973), Surdam and Wolfbauer (1975), and Buchheim (1978); for Lake Uinta by Baer (1969); and for Fossil Lake by Eugster (paper in progress). Frequent volcanic disturbances, as indicated by ash beds from ¼ to 2 inches thick scattered throughout the sediments of Fossil Lake (Oriel and Tracey, 1970), may have altered the water chemistry periodically. The duration of the F-2 unit is unknown, but duration of the F-1 unit of Fossil Lake and the adjacent thin oil shale units (which appears to represent a period of relative stability) is estimated to be only 4 to 5 thousand years.

TROPHIC ADAPTATIONS

The trophic adaptations of the Green River fish genera are summarized in table II.13. *Heliobatis* had flat crushing surfaces on its teeth and, like most extant dasyatides, probably fed on mollusks and decapods. *Crossopholis* was clearly a plankton strainer, much like the extant *Polyodon*. *Lepisosteus*, *Amia*, and *Phareodus* were the largest predators of the lake, followed closely by *Mioplosus*. Though *Mioplosus* was not as well armed with teeth as *Lepisosteus*, *Amia*, and *Phareodus*, it had adequate teeth to catch and hold fish up to half its own length. Specimens of *Mioplosus* with fish (usually *Knightia*) preserved in their stomachs or mouths are not rare. The two species of Green River *Amia* may have had slightly different feeding habits: Boreske (1974) found *Amia uintaensis*' sharp palatal teeth to indicate a more predaceous (fish-eating) habit than *A. fragosa's*.

The palatal teeth of *A. fragosa* (thick, short, and styliform) were more adapted to crushing, so it may have fed on molluscs and crustaceans. *Diplomystus*, with its upturned mouth parts, probably fed near the surface, with a planktivorous diet as a juvenile and a more predaceous diet as an adult. Several large *Diplomystus* specimens have been found with one to several adult sized *Knightia* (10 cm or 9 inches total length) in their stomachs. *Diplomystus* was armed only with small teeth, and probably relied mostly on suction feeding. With its large jaws and buccal cavity, an adult *Diplomystus* could have generated enough siphon action to capture adult *Knightia*. *Eohiodon* had large pointed teeth on the dentary, maxilla, premaxilla, and palatine, as does the modern *Hiodon*. The teeth were larger than in *Hiodon*, but *Eohiodon* was smaller in average size than *Hiodon*. *Eohiodon* probably had a diet similar to that of *Hiodon* but, because of its smaller size, needed larger teeth to

Table II.13. Trophic adaptations of the Green River fish genera.

	Major predator	*Predator of small fish*	*Predator of insects*	*Predator of decapods*	*Molluscivore*	*Zooplanktivore*	*Herbivore (algae or plant eater)*
Heliobatis				X	X		
Crossopholis						X	
Lepisosteus	X						
Amia	X			X	X		
Eohiodon		X	X				
Phareodus	X						
Knightia						X	X
Gosiutichthys						X	X
Diplomystus		X				X	
Notogoneus							X
Amyzon		X	X				
Astephus		X	X		X		
Hypsidoris		X	X		X		
Erismatopterus			X			X	?
Amphiplaga		?	X				
Asineops		?	X				
Mioplosus	X	X		X			
Priscacara			X		X	X	X

catch and consume the same prey. *Knightia* and *Gosiutichthys* were probable herbivore-planktivores at the bottom of the fish fauna's tropic system, and were food fish for predators. *Notogoneus*, with its ventrully placed mouth parts and toothless jaws, pterygoid, and hyoid bones, was probably a suction feeding herbivore, feeding on the bottom of the lake. It may have also fed on dead and decaying organisms on the lake bottom. *Amyzon gosiutensis* had heavy pharyngeal bones with teeth more conical than those of modern suckers (such as *Ictiobus*). It is speculated (Grande, Eastman, and Cavender, 1982) that the Green River *Amyzon* was an opportunistic feeder on a variety of benthic and nektonic organisms, including insects, insect larvae, crustaceans, and small fish (*Gosiutichthys* and *Knightia*). *Astephus* and *Hypsidoris* had villiform vomerine teeth which extant North American ictalurid catfish lack, but it is reasonable to assume that the dietary habits of the Green River catfish were similar to those of modern ictalurids. *Amphiplaga* had teeth in the premaxilla, dentary, palatine and upper and lower pharyngeals and none on the endopterygoid and ectopterygoid, much like *Percopsis*, and its dietary habits were probably similar. The teeth in the jaws of *Amphiplaga* were slightly bigger than those in *Percopsis*'; *Amphiplaga* probably included very small *Knightia* in its diet (one specimen of *Amphiplaga* in a private collection has a small *Knightia* lodged in its mouth). *Percopsis* is known to have occasionally eaten small fish (Scott and Crossman, 1973, page 681). *Erismatopterus* was a smaller fish than *Amphiplaga*, and had much smaller teeth in its jaws and pharyngeals. Palatine teeth were not visible on any specimens examined. Its diet was probably less predaceous than that of *Amphiplaga*, consisting mostly of insects, plankton, and possibly algae. *Erismatopterus* was also probably an important food fish for predators in Lakes Gosiute and Uinta. *Asineops* had a small patch of rounded teeth on the anterior end of the basihyal, and small, long, pointed teeth in the dentary, premaxilla, and covering the lower pharyngeals. It probably fed mostly on insects, insect larave, and possibly small fish. *Priscacara serrata* had massive upper and lower pharyngeal bones covered with obtuse grinding teeth probably used to grind up molluscs and insects. *Priscacara liops* was not as large in average size as *P. serrata*, and did not exhibit such massive pharyngeals. *P. liops* may have occupied more of a planktivore-herbivore-insectivore niche. *P. liops* may have been an important food fish for *Phareodus*; several specimens have been found in the stomachs of large *Phareodus*.

COMPARISON WITH OTHER MIDDLE EOCENE NORTH AMERICAN LACUSTRINE FISH FAUNAS

The known apparent specific richness of the Green River fish community was highest during deposition of F-1 and F-2 (late Early Eocene) in Fossil Lake, with at least 22 species of fish belonging to 14 different families making it the most diverse Eocene North American lacustrine fish fauna known. Wilson (1977; 1978c; 1979) has examined Middle Eocene lacustrine fish faunas of British Columbia and Washington State; these faunas are compared with the Green River faunas in Table II.14.

Fauna WA in Table II.14 is from the Middle Eocene Klondike Mountain Formation near Republic, Washington (see Wilson, 1978c), and fauna WB is from various Middle Eocene fresh water deposits between Princeton and Horsefly, British Columbia (see Wilson, 1977). Fauna WB is based on 240 fish and 275 scales, fauna WA on only a few specimens. In spite of the difference in sample sizes, some faunal differences are obvious. The most obvious difference is the absence of herring in Washington and British Columbia.

Amyzon brevipinne, a small sucker (standard length between 2 and 5 cm or 1-2 inches), is common in the British Columbia lakes and probably, like *Knightia* in the Green River Formation, was the main food item for predators of the northern lakes. There are no small suckers known from the Green River Formation, the only known sucker being *Amyzon gosiutensis*, which reaches a standard length of 30 cm (1 foot). Though young *Amyzon gosiutensis* were probably preyed upon by predator fish, they were probably too rare in proportion to *Knightia* to be a very important food source for the predators.

The predominant fish both in number (well over half of all fish, according

Table II.14. A comparison of specific richness between some Green River lacustrine deposits and some other Middle Eocene North American lacustrine deposits. Location of fauna WA and WB given in text. Numbers of species include some undescribed species.

	Number of Known Species				
	late Early Eocene Fossil Lake (F-1 & F-2)	Middle Eocene Lake Gosiute (G-1,G-2, G-3 & G-4)	Middle Eocene Lake Uinta deposits	Middle Eocene lacustrine fish fauna WA, Washington State	Middle Eocene lacustrine fish fauna WB, British Columbia
Dasyatidae	2	none	none	none	none
Polyodontidae	1	none	none	none	none
Lepisosteidae	2	1	1	none	none
Amiidae	2	1	1	1	1
Hiodontidae	1	none	none	1	1-2
Osteoglossidae	2	1 (or 2?)	1 (or 2?)	none	none
Ellimmichthyidae	1	1	1	none	none
Clupeidae	2	3	2	none	none
Salmonidae	none	none	none	1	1
Gonorynchidae	1	none	none	none	none
Catostomidae	none	1	none	1	3
Ictaluridae	1	4	1	none	none
Percopsidae	1	1	1	2	1
Asineopidae	1	1	1	none	none
Percidae	$\geqslant 1$	1	1	none	none
Priscacaridae	$\geqslant 3$	2	2	none	1

to Wilson, 1977) and in specific diversity in the British Columbia deposits are catostomids and hiodontids, two families which are relatively rare in the Green River localities studied. Salmonids, which are present in both the Washington and British Columbian sites, are absent in the Green River Formation. Because of the relatively small sample size of the British Columbia and Washington sites, the apparent absence of some of the rare Green River species from these sites is not very significant. The occurrence of the genera *Amia*, *Amyzon*, *Eohiodon*, and *Priscacara* in both the Green River deposits and the northern deposits suggests the possibility of a brief connection between the Green River lake system and the northern Eocene lakes, possibly through stream piracy or possibly because both lake systems were connected to a common source at one time.

The catostomids are most diverse in the northern Eocene Lakes, with 3 species. They are known only by one rare species in the Middle Eocene phase of the Green River Formation (in Lake Gosiute only). Suckers are absent from the late Early Eocene Green River deposits (such as F-1 and F-2). The predominance of suckers in the northern lakes and of herring in the Green River Lake system could have been due to the ecological requirements of the species. The climate of the northern Eocene lakes was perhaps slightly cooler than that of the Green River Lake system due to their latitudinal difference.

COMPARISON WITH MODERN LAKE ICHTHYOFAUNAS

Barbour and Brown (1974) compared the diversity of fish species among 67 extant lakes and three seas with respect to their surface areas. Because the surface areas of the three Green River lakes can be estimated for specific points in time, we can compare their diversity of fish species relative to surface area to that of the modern lakes examined by Barbour and Brown. Table II.15 shows the number of fish species and the sur-

Table II.15. The number of fish species and surface areas for the three Green River lakes at specific points in time. For illustration of these surface areas, see figure I.1.

	Number of Species	Estimated Surface Area (km^2)
Fossil Lake (during the late Early Eocene)	22	100
Lake Gosiute (during the early Middle Eocene)	15	4400
Lake Uinta (during the early Middle Eocene)	11	4600

Table II.16. The number of fish species and surface areas for 67 modern lakes and 3 modern seas. From Barbour and Brown (1974).

	Number of Species	Surface Area (km^2)
AFRICA:		
1. Albert	46	5,346.0
2. Bangweulu	68	2,072.0
3. Chad	93	17,500.0
4. Chilwa	13	673.0
5. Edward	53	2,150.0
6. Kivu	17	2,370.0
7. Malawi	245	28,490.0
8. Mweru	88	4,413.0
9. Nabugabo	24	28.5
10. Rudolf	37	9,065.0
11. Rukwa	22	3,302.0
12. Tana	18	3,626.0
13. Tanganyika	214	32,893.0
14. Victoria	177	69,484.0
CANADA:		
15. Athabasca	21	7,154.0
16. Big Trout (Ontario)	24	616.0
17. Great Bear	12	31,153.0
18. Great Slave	26	27,195.0
19. Keller	13	406.0
20. Kootenay	19	399.0
21. La Ronge	19	1,425.0
22. Opeongo	22	60.0
GREAT BRITAIN:		
23. Loch Lomond	15	71.0
24. Windermere	9	15.0
GUATEMALA:		
25. Petén	23	98.0
26. Yzabal	48	684.0
ITALY:		
27. Maggiore	21	212.0
JAPAN:		
28. Biwa	46	676.0
MEXICO:		
29. Chapala	14	1,080.0
30. Pátzcuaro	7	111.0
31. Zirahuén	5	8.0
NICARAGUA-COSTA RICA:		
32. Nicaragua	40	8,264.0
PERU-BOLIVIA:		
33. Titicaca	18	9,065.0
PHILIPPINE ISLANDS:		
34. Lanao	20	357.0
SOVIET UNION:		
35. Aral Sea	17	64,500.0
36. Baikal	50	31,500.0
37. Balkhash	5	18,500.0
38. Beloe (Vologda reg.)	22	1,125.0
39. Black Sea	156	423,488.0
40. Caspian Sea	74	436,000.0
41. Gusinoe	13	165.0
42. Issyk Kul	11	6,206.0
43. Ladoga	48	18,400.0
44. Leprindo	14	24.0
45. Onega	28	10,340.0
46. Pestovo	17	2.0
47. Sea of Azov	17	38,000.0
48. Seliger	21	221.0
49. Taimyr	13	4,650.0
50. Teletskoe	14	231.0
UNITED STATES:		
51. Black (N.C.)	10	5.2
52. Canandaigua	37	41.0
53. Cayuga	60	171.0
54. Erie	113	25,719.0
55. Huron	99	59,596.0
56. Jones (N.C.)	13	0.8
57. Keuka	30	44.0
58. Michigan	114	58,016.0
59. Ontario	112	19,477.0
60. Otisco	17	10.0
61. Owasco	10	85.0
62. Salters (N.C.)	14	1.3
63. Seneca	39	174.0
64. Singletary (N.C.)	14	2.6
65. Skaneateles	14	54.0
66. Superior	67	82,414.0
67. Waccamaw	36	36.0
68. Walnut (Michigan)	30	0.8
69. White (N.C.)	19	5.2
YUGOSLAVIA-ROMANIA:		
70. Ohrid	17	347.0

face areas for the three Green River lakes at specific points in time. Figure II.100 then compares the diversity of fish species (relative to lake surface area) in the Green River lakes to that in modern lakes and seas. Using the species-area regression line of Barbour and Brown for the 70 modern ichthyofaunas (line RL in figure II.100), Fossil Lake plots right on the regression line and both Lake Gosiute and Lake Uinta are well below it. Likely reasons for Lakes Gosiute and Uinta plotting well below the regression line could include the shallow nature of Lakes Gosiute and Uinta which gave rise to fluctuations in water temperature, shoreline, and salinity. Fossil Lake, a considerably deeper lake, would have been less susceptible to these fluctuations and would have offered a more stable environment for a larger number of species (at least during deposition of F-1 and F-2). Also, Fossil Lake during deposition of F-1 and F-2 had a flora possibly indicating a moister climate than the Early-Middle Eocene deposits of Lakes Uinta and Gosiute (H.D. MacGinitie, personal communication). Mean annual rainfall is an environmental factor which can affect the number of fish species in lakes (Barbour and Brown, 1974).

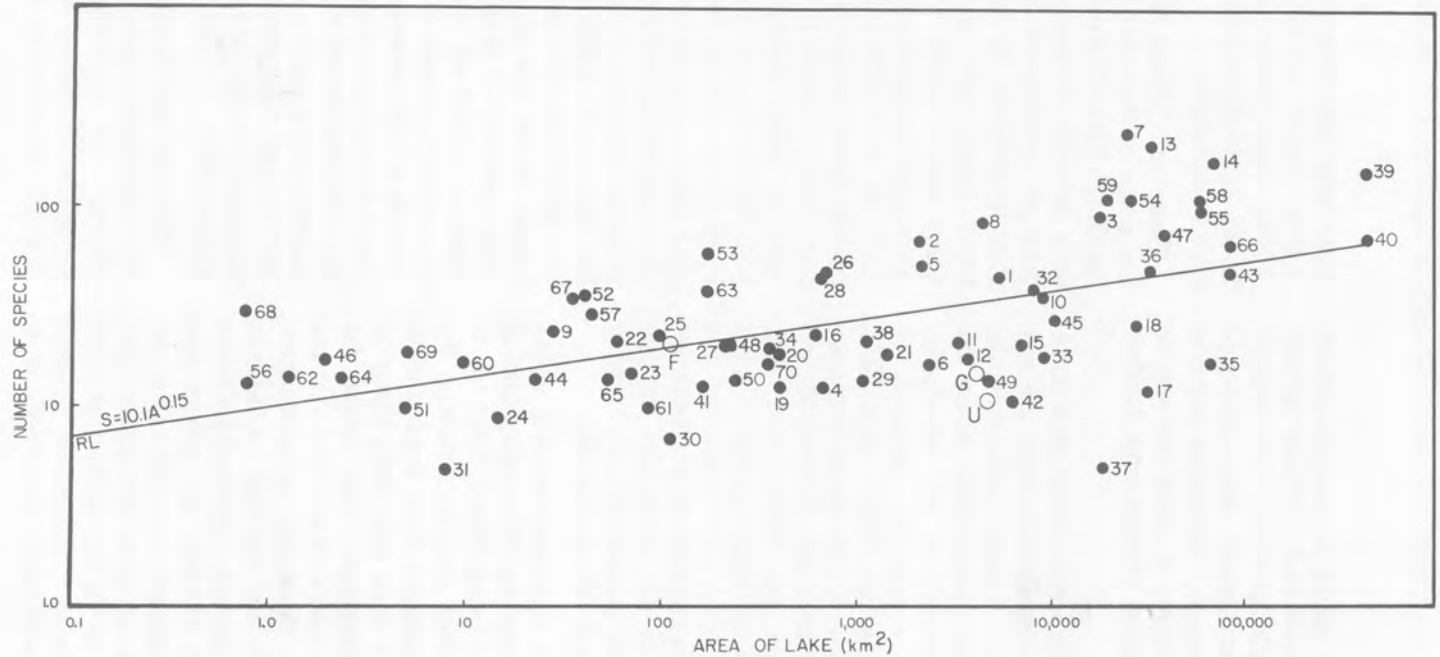


Figure II.100. The relationship of number of fish species to surface area for 70 modern lakes and seas, and the three Eocene Green River lakes at specific points in time. The data for the 70 modern ichthyofaunas are taken from Barbour and Brown (1974). The data used for plotting the three Green River lakes are shown in Table II.15. The regression line was computed for the 70 modern ichthyofaunas only. The 70 modern basins are numbered as in Table II.16. For the three Green River lakes; F = Fossil Lake (during the late Early Eocene); G = Lake Gosiute (during the early Middle Eocene); and U = Lake Uinta (during the early Middle Eocene).

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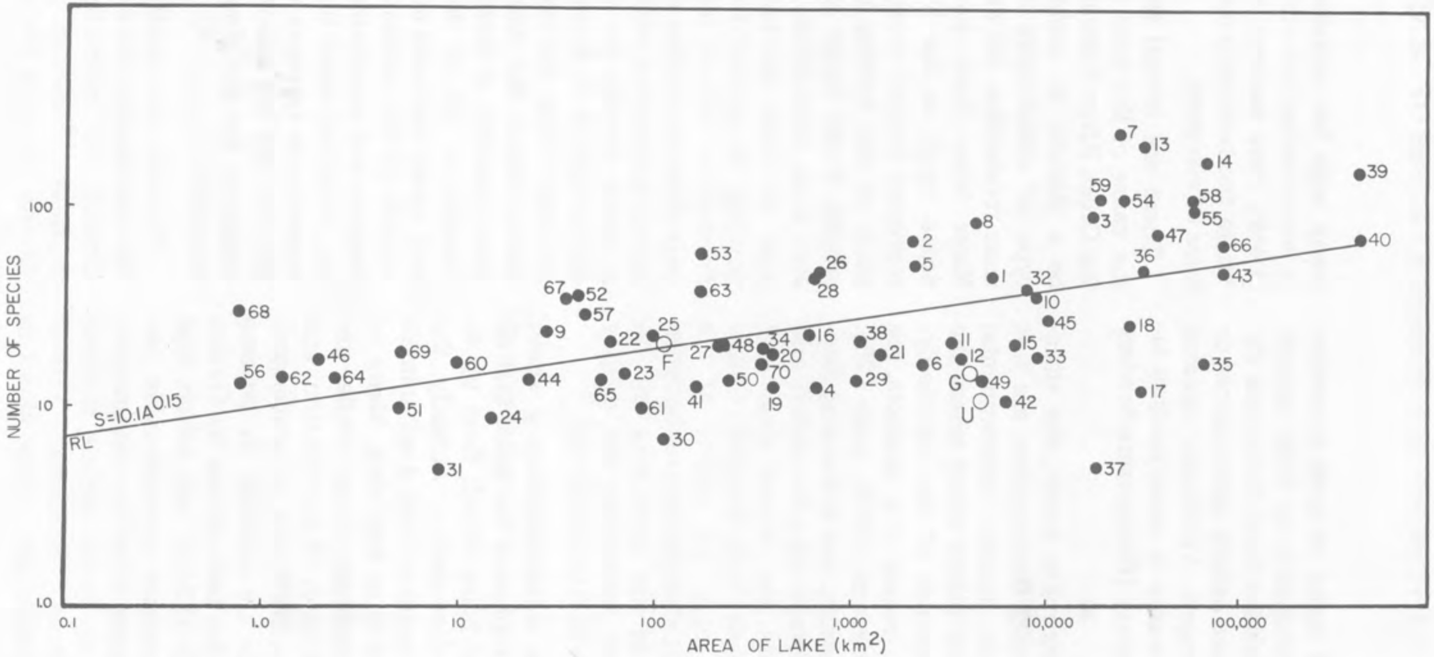

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The lives of many or most lacustrine animals are terminated by their capture by other animals for food; those that die in other ways are usually eaten sooner or later by scavengers. Vertebrate remains are therefore scarce in most modern lacustrine sediments (Brongersma-Sanders 1957).

Where catastrophes occur, the situation is different. Catastrophes are not rare in modern aquatic environments; there are several places today where the killing of thousands of fish repeatedly, even annually, occurs (for example, see Scott and Crossman, 1973, page 126). Besides vertebrates, the scavenging benthonic invertebrates are often killed, and will repopulate the whole area only after a relatively long interval. Consequently, not only the extent of the catastrophe but also the interval between catastrophies in the same area are important factors controlling the density of fish remains in lake sediments.

A common misunderstanding about aquatic catastrophies is the belief that all the fish, after being killed, float up to the surface before sinking. Actually, the catastrophe produces both dead animals that float and ones that sink. Many of the dead vertebrates float while distended by the gases of putrifaction, and are subject to the attack of scavengers. These animals are unlikely to become fossilized. It has been shown by Gunter (1941), Smith (1949), and others that many fish, possibly a considerable percentage of those killed by catastrophe, do not come up to the surface, but sink to the bottom. Baughman (1947) discusses a catastrophe where about as many large fish remained on the bottom as were washed up on shore, and Smith (1949) cites modern examples of bays where the bottom is covered with a solid mass of carcasses.

There are several theories to explain the cause of the mass mortalities within the Green River Formation, and it would be a mistake to assume that the same type of catastrophe caused all of the mass mortalities. All three Eocene Green River lakes have mortality horizons. Some (such as the U-1 gar mortality) represent limited mortalities and others (such as the herring mortalities at F-1 around Fossil Ridge and at G-1) represent mass mortalities. Some of the reasons for mass mortalities which could possibly be applied to the Green River Formation include lethal temperatures near shore or sudden changes in temperature; underwater earthquakes resulting in death directly by shock waves or by the release of H_2S and/or other poisonour gases when the earthquake occurs in places where the sediment contains a great quantity of these gases; temporary changes in pH of the inflowing tributary water; increases in salinity; and large schools of fish swimming into the hypolimnion and succumbing to H_2S poisoning, stratified water turnover, or noxious waterbloom (massive algal blooms). The last two are the reasons most frequently suggested for the *Knightia* mass mortalities of F-1.

Plankton are usually beneficial to the fish community, for all primary fish feed directly or indirectly on these tiny organisms. However, under certain conditions, one or a few species of plankton multiply with abnormal rapidity. The discoloration of the water caused by such rapid multiplication or by swarming of microscopic organisms is called waterbloom (Brongersma-Sanders, 1957). Blue-green algae, which are known from the Green River Formation (see MONERA in Part V), can cause such a waterbloom. A very strong poison is generated in the water during blue-green algal waterblooms (Fitch *et al*, 1934; Shelbusky, 1951). Komarovsky (1951) describes heavy mortalities in recent fish ponds in the Jordan Valley of Israel caused by waterbloom of blue-green algae. McGrew (1975) suggests that normally minor annual blooms of blue-green algae caused limited mortalities throughout F-1, and that an occasional "superbloom" or waterbloom was responsible for the mass mortality layers. This blue-green algae theory is also desirable because blue-green algae extract CO_2 from the water and are known to cause precipitation of $CaCO_3$ thereby, which would facilitate the burial of the specimens and prevent decomposition.

Stratified water turnover, if responsible for the mortalities of F-1, would also precipitate $CaCO_3$ and aid in preservation of fossil fish. To understand the stratification of Fossil Lake, we review some basic principles of limnology. In subtropical areas (figure II.101a) during the coldest part of the year, the water temperature of a lake is basically homogenous. The wind blowing across the water's surface is sufficient to set up a slow circulation throughout the lake, and oxygenated surface waters are carried to all parts of the lake. With the arrival of summer the surface water warms up, and as it warms its density and viscosity decrease until a distinct upper layer of relatively warm, light, less viscous water (figure II.101b) known as the epilimnion is established. This layer rests on a deeper, colder, denser body of water known as the hypolimnion. There is a relatively thin transitional zone, or thermocline, between the two layers. Now the wind blowing across the lake sets in motion only the epilimnion, whose light, warm water flows easily and resists being pushed down into and mixed with the hypolimnion. This surface layer acts as a seal, for the oxygenated surface water is not carried below the thermocline into the hypolimnion. In the hypolimnion the respiration of organisms and the decay of organic matter continue to use up the dissolved oxygen and increase the dissolved carbon dioxide. The stagnation continues until all the oxygen is used up, and then the hypolimnion becomes progressively charged with hydrogen sulfide, lethal to most organisms. The stratification of the lake remains for a considerable part of

Figure II.101. A. Schematic cross section of a subtropical lake during the cold season, showing complete circulation. B. Schematic cross section of a subtropical lake during the summer, stratified into a hypolimnion (lower layer) and an epilimnion (upper layer), with the thermocline (between the two dashed lines) in between. After Bradley, 1948.

the year, until annual turnover (Bradley, 1948). Similarly, since the paleoclimate of Fossil Lake was probably subtropical, and sedimentological and structural geological evidence suggests that Fossil Lake was a deep-basinal lake, it was probably also stratified with annual turnovers, at least during the deposition of F-1. During the stratified periods of summer the anoxic, possibly H_2S-rich hypolimnion would protect dead animal and plant remains on the lake bottom from decomposition. The annual turnover of the lake might cause limited mortalities, and would also cause precipitation of $CaCO_3$ to facilitate burial of specimens. Carbonate precipitation occurs as follows: During periods of stratification in modern lakes, carbonates that precipitate from the surface waters by warming and photosynthesis fall into the hypolimnion. The hypolimnion is acidic because of its high content of carbon dioxide and hydrogen sulfide; therefore when the sinking carbonate precipitate reaches this level, it goes back into solution until the annual overturn. During the overturn the complete circulation of the waters raises the pH value of the hypolimnion by dissipation of the hydrogen sulfide and excess carbon dioxide, and also by mixing with the more alkaline surface water. At that time, the bulk of the normal carbonates is precipitated. The occurrence of probable varves in the F-1 sediments suggests a stratified lake, since the stratification of the lake would protect the brown organic-rich layers from bioturbation, and the deposition of carbonate during the annual turnover would produce the light carbonate layers (see figure I.3). During the stratified seasons, the anoxic hypolimnion would also protect dead animals on the lake bottom from decomposition by most scavengers and bacteria. A protection such as this would be needed to produce the high percentage of well articulated fish at F-1. McGrew (1975), in a quantitative study of the percentage of well articulated fossil fish from F-1, found that over 50 percent of the fossil fish recovered from that locality are essentially perfectly articulated.

Lakes Gosiute and Uinta, both shallower than Fossil Lake, had mortalities that could have been caused by catastrophies different from those that occurred during F-1 deposition. The known fish mortality horizons within Lakes Gosiute and Uinta occurred more than a million years after the events in F-1, so there is no chance of their all being the result of a single regional event. Lake Gosiute is known to have had many periods of high salinity (McGrew and Casilliano, 1975), and Gunter (1947) has shown that annual periods of excess salinity in Texas lagoons cause annual limited mortalities. Some of the mortality layers of Lake Gosiute could be the result of such increases in salinity. Lake Gosiute also had more regions of shallow water than did Fossil Lake. Because the water level of Lake Gosiute fluctuated, large ponds of shallow-water-dwelling fish could have been periodically cut off from the rest of the lake, to eventually succumb to water stagnation and become buried with the following transgression of the lake. For example, plant and insect horizons between some of the fish layers at G-1 probably indicate a series of transgressive-regressive events.

The shallow region of Lake Gosiute, like modern shallow lake regions, probably served as a habitat for millions of small fish. Since these shallow regions would be more susceptible to rapid temperature changes than deeper regions of the lake, abnormally hot spells during the Middle Eocene could have caused the mass mortalities of many of these small fish in the shallows, and produced mortality horizons such as the *Gosiutichthys* mass mortality layers of G-1. Other causes, such as waterbloom or stratified water turnover, are also possible explanations for mortality in Lake Gosiute; but since Gosiute was a shallower lake, stratification would probably not be as likely a factor as it was in Fossil Lake.

The only reported mass mortality horizons in Lake Uinta are several very local, limited mortalities of gar (*Lepisosteus*). The fact that only gar are found in these mortalities may indicate that water conditions in these areas became lethal gradually rather than as a catastrophic event. Lake Uinta's lagoonal nature and fluctuating water level (see Part I) were probably conducive to the formation of shallow streams and ponds during dry periods. As these ephemeral bodies of water evaporated away and stagnated, trapped fish would die, the least hardy first, until only the hardiest fish such as the gar were left. Gars possess a highly vascular gas bladder with an open passage to the throat, and they can use the gas bladder as a lung to supplement their gill respiration. Their ability to breath air enables them to live in stagnant water unfit for any other fishes except bowfins (*Amia*). Gar have been known to survive very well in water totally depleted of oxygen (Eddy and Underhill, 1974, page 132). The fact that many of these Lake Uinta mortalities are exclusively gar may indicate cutoff stagnating streams or ponds where all other species died before the gar mortality occurred and were decomposed or eaten by scavengers and predators, including the gar. Then the gar themselves eventually succumbed to lethal temperatures or toxins, since the evaporating body of water would eventually become small enough to change temperature, salinity, or toxicity rapidly. U-1 contained a small channel-shaped deposit of sandstone (including the block shown in figure II.17a, and similar blocks at FMNH, AMNH, and BYU), together containing several dozen gar. Nearly all gar were oriented in the same direction or 180° to it, indicating that a current probably flowed before and during burial of the specimens, and that this stream probably never completely dried up before burial of the gar, since the stranded gar would have flipped around if still alive (gar can live several hours out of water) or curled up if they were dead and exposed to drying. According to J.C. Underhill (personal communication), when gar habitats completely dry up, the dead gar often curl as they dry.

Whatever the causes of the catastrophic and limited mortalities of the Green River Lake system were, it is clear that, like their different histories and environments, the reasons for mortalities were different in each lake. Even within a single Green River lake, different causes could have been responsible for different mortality horizons.

PART III

VERTEBRATES OTHER THAN FISH IN THE GREEN RIVER FORMATON

INTRODUCTION TO PART III

Part III is a brief presentation of vertebrates other than fish that have been found in the Green River Formation. Rather than a review such as was given in Part II, Part III is basically a pictorial atlas with faunal lists, some repository listings and suggested references, and very little descriptive text.

AMPHIBIANS

The frogs illustrated here are the first known complete amphibians from the Green River Formation (Cope (1884, page 100) reported a vertebral column and part of a cranium of a frog, probably from G-3). The complete pelobatid frog illustrated as figure III.1a, from G-4, is currently being described by the author. It is probably a new species of the genus *Eopelobates*. Figure III.1b shows a frog, possibly also *Eopelobates*, from U-2 with the typical type of skin preservation from that locality. Pieces of salamanders have been found by amateur collectors at F-2, G-1, and possibly U-2, but this material is as yet undescribed. The extreme rarity of amphibian material in Fossil Lake may be a result of the deep basinal structure of the lake. The swamp or marsh areas which would be occasional habitats for amphibians were much more common in Lakes Gosiute and Uinta. Several pieces of amphibians have also been found at the "Powder Wash" locality from Eocene Lake Uinta (see section on Mammals for information about this locality), and these are currently being studied.

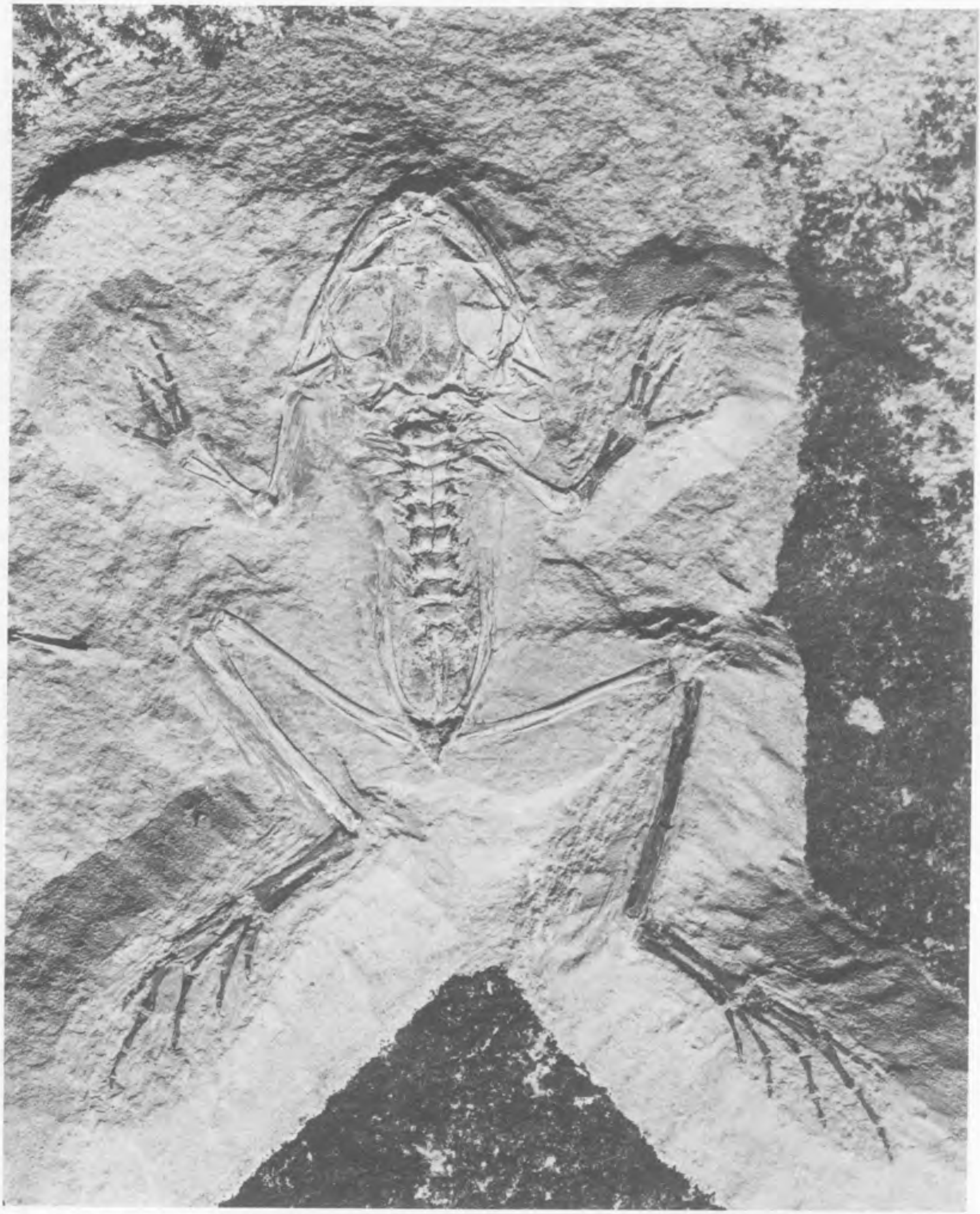


Figure III.1a. A complete articulated frog, possibly *Eopelobates* sp., from G-4 (latex peel SMMP 78.8.29, original BHI-GR 123). Total length, measured in a vertical line from the anterior tip of the skull to the posterior end of the hind foot, is about 6 cm (2 1/3 inches).

Figure III.1b. The nearly complete skin impression of a frog from U-2, with the leaf *Acer lesquereuxi*. About the same size as the specimen in Figure III.1a. Large slab in the collection of Catherine M. Grande, small counterpart in the collection of BMNH.

Turtles: Turtles are not as abundant in the Green River deposits as they are in the overlying and adjacent Bridger Formation. In the Green River Formation they are more common in Lake Gosiute and Lake Uinta deposits then in Fossil Lake. Complete articulated specimens are extremely rare.

The most common turtle in the Green River Formation is *Trionyx* (see figures III.2a and III.2b), with at least 3 known complete articulated specimens (one from F-1, one from F-2, and one from G-1), several skulls (mostly from F-1), and many shells and shell fragments. *Trionyx* is a soft shelled aquatic turtle which still lives today, usually in shallow water near shore in lakes or rivers. Trionychid turtles date back to the Jurassic, and from Late Cretaceous to Recent are fairly common fossil forms. Modern trionychid turtles are found today in Africa, Asia, Malaysia, and North America.

Another turtle which occurs in the Green River Formation is *Echmatemys* (figure III.3a), an Eocene pond turtle. This genus has been reported from Lake Uinta (Baer 1969, page 29) and has been found at Fossil Lake (the F-2 specimen illustrated in figure III.3a). Shell fragments probably from this genus have also been recovered from Lake Gosiute deposits. Though extremely rare in the Green River Formation, *Echmatemys* is fairly abundant in the overlying Bridger and Uinta Formations. The genus is restricted to Early Tertiary deposits in North America.

An undescribed snapping turtle (family Chelydridae) known from F-2 is illustrated in figure III.3b. The illustrated specimen and one additional specimen, also a juvenile in a private collection, are the only relatively complete chelydridid turtles known from the Green River Formation.

Dr. E.S. Gaffney (personal communication) has identified a complete skull of a baenid turtle from F-1 (in a private collection). The family Baenidae is an extinct group whose known age range is Early Cretaceous to Late Eocene.

Cope (1884) described several turtles from various Tertiary formations; but from the Green River Formation proper, he reported only emydids based on fragmentary material (1884, pages 129, 132-135).

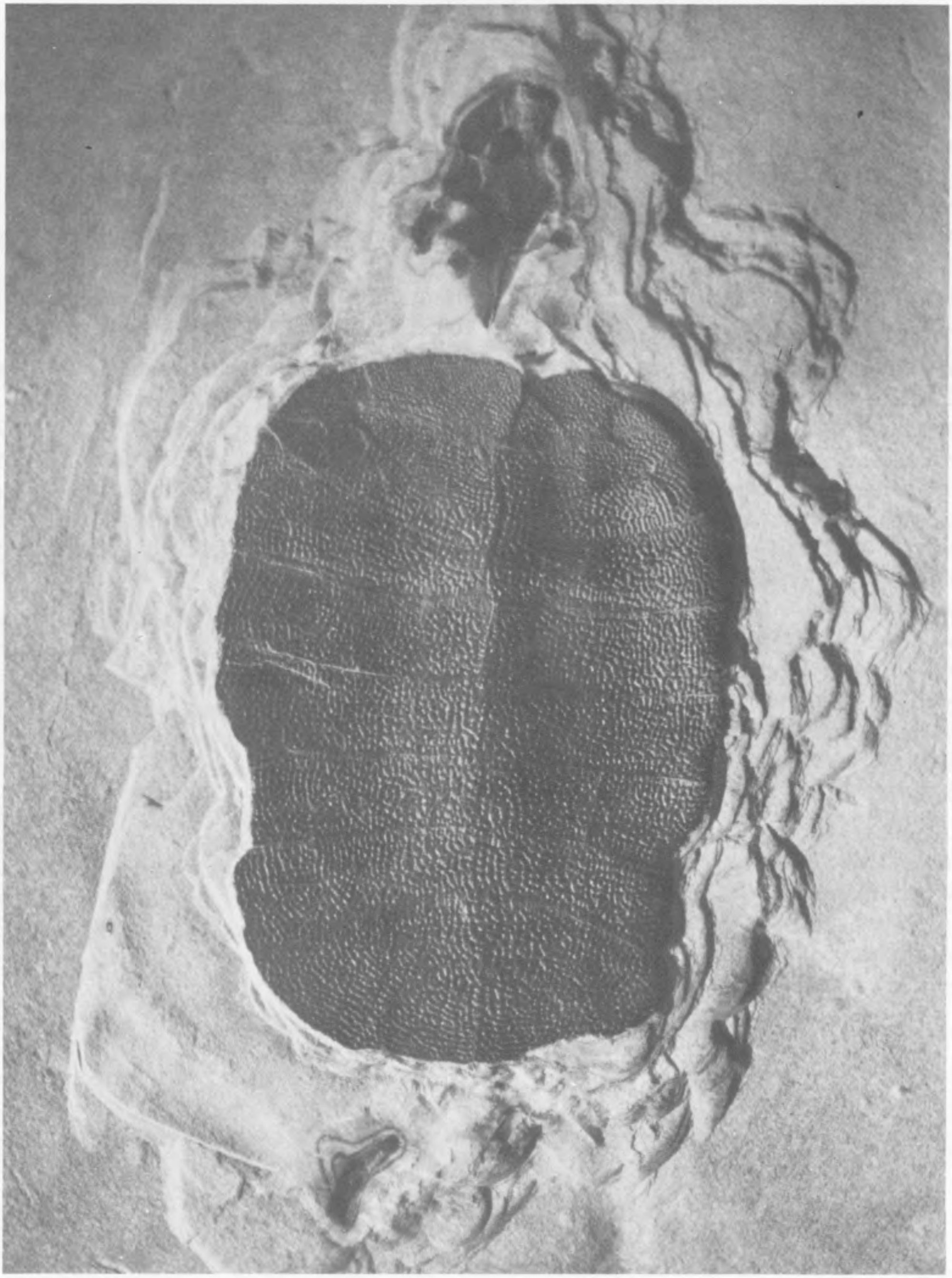


Figure III.2a. Dorsal side of a complete softshelled turtle, *Trionyx* sp. from F-1. Total length about 60 cm (2 feet).

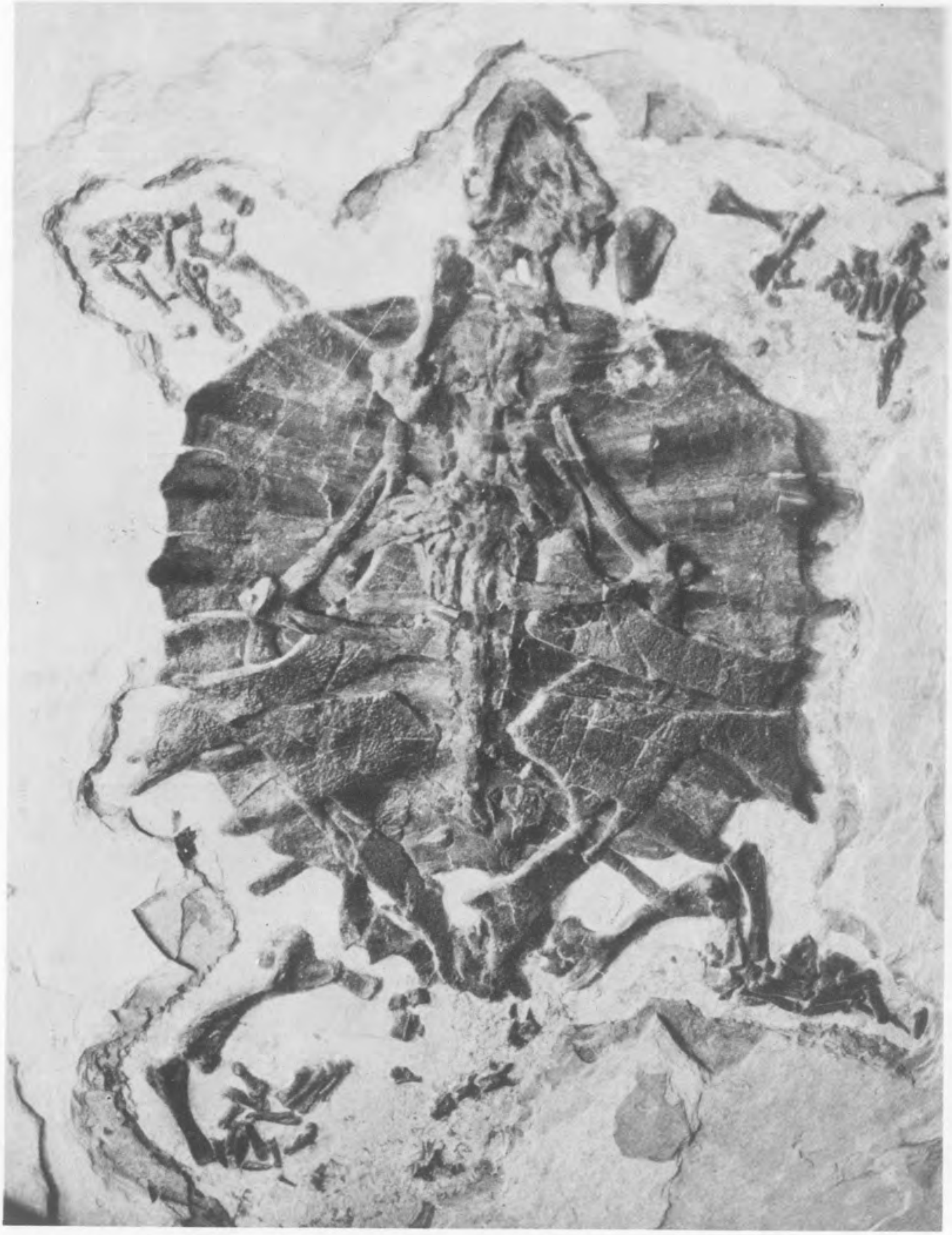


Figure III.2b. Ventral view of the same specimen. (Private collection of Mr. Robert Lynch; photos courtesy of Carl and Shirley Ulrich.)

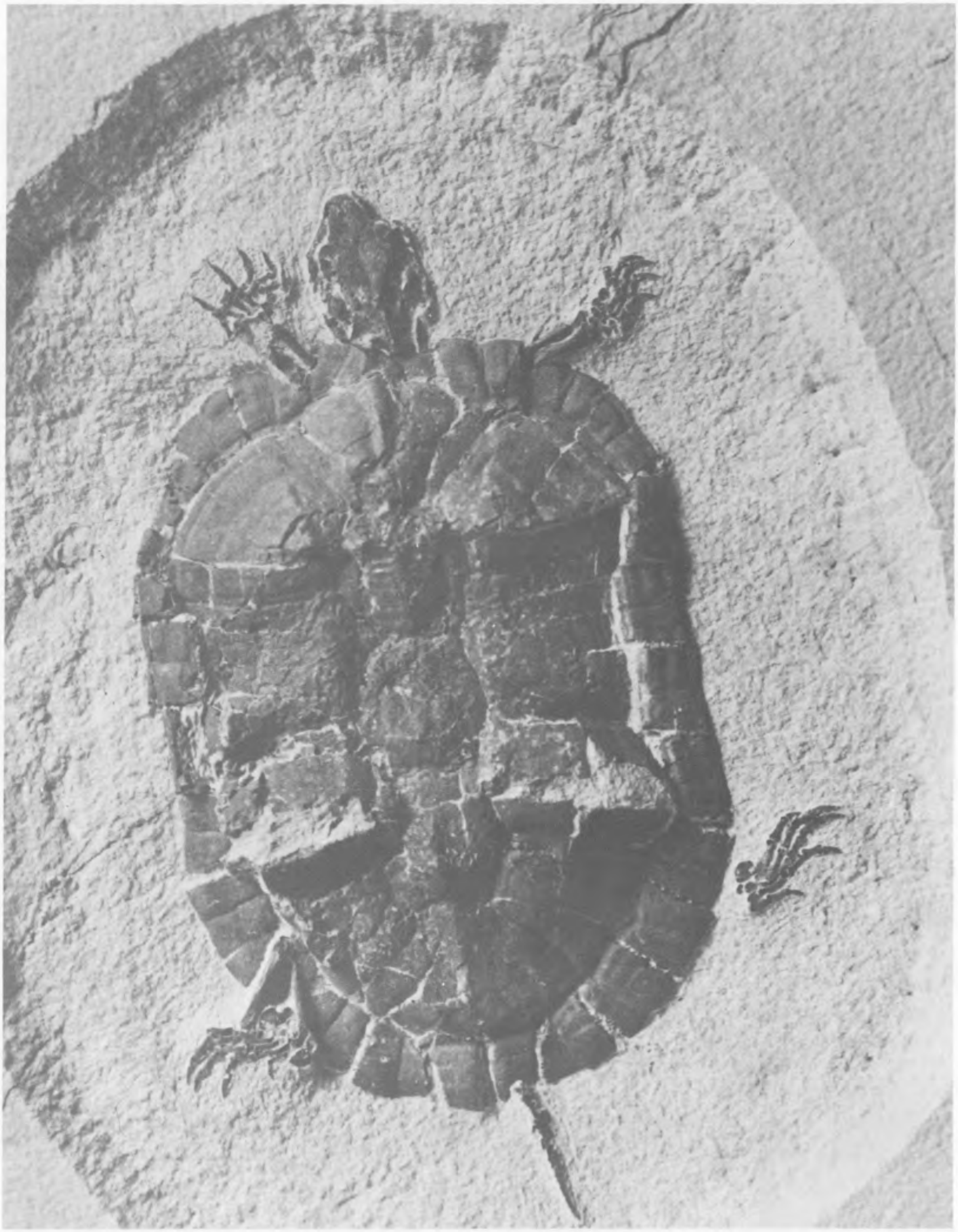


Figure III.3a. Dorsal view of a complete hardshelled turtle, *Echmatemys* sp. from F-2. Total length about 20 cm (8 inches). Tyrrell Museum of Paleontology, Drumheller, Alberta.

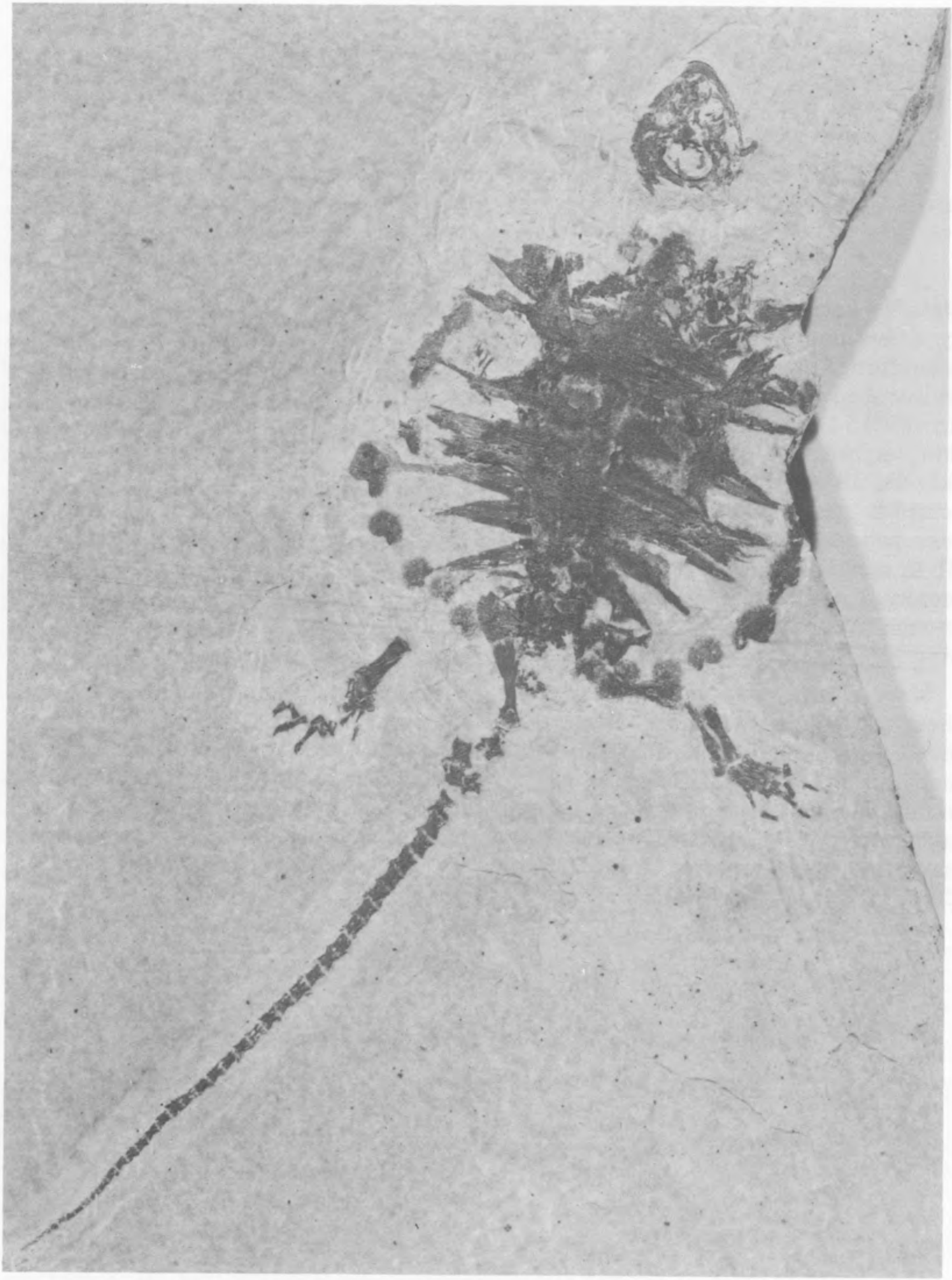


Figure III.3b. Ventral view of a nearly complete snapping turtle (family Chelydridae) from F-2. Total length about 15 cm (6 inches). Private collection of James E. and Carolyn Tynsky.

Both lizards and snakes are extremely rare in the Green River Formation.

Lizards (Lacertilia): Lizards are known by a few undescribed articulated specimens from Fossil Lake (such as the large undescribed specimen [Varanidae?] in figure III.11a) and Lake Gosiute and by skin impressions from Lake Uinta (Stokes, 1978). Recently, several nearly complete lizard skin impressions have been found at U-2 and U-4 (see figures III.4a and III.4b). These have no bones preserved, yet preservation is detailed enough that individual scales can be observed.

Since lizards are terrestrial animals, their scarcity in the Green River sediments, particularly Fossil Lake sediments, is not surprising. Lizard bones are more abundant in the overlying Bridger and nearby Wasatch Formations. Lizard trackways were reported from U-5 by Curry (1957; see figure III.5).

Snakes (Serpentes): Fossil snakes have only one described species, *Boavus idelmani*, represented by a single specimen. The holotype of *Boavus idelmani* is a beautifully complete articulated specimen (see figure III.6) from F-1. The history of this specimen is somewhat obscure. Originally discovered by Lee Craig sometime before 1912 (see "Historical Background of Amateur Collection of Green River Fossils" in Part I of this paper), its last known location was during the late 1930's, in the possession of a wealthy collector from New York named Edward S. Weinberg. Its present location is unknown. The American Museum of Natural History in New York has some excellent epoxy casts of the specimen, and Gilmore (1938) described the specimen in some detail. *Boavus idelmani* was a boa constrictor (family Boidae), a type of snake now confined to tropical or subtropical regions. Since most snakes are not aquatic, their rarity in the Green River lacustrine deposits is not surprising.

Figure III.4a. Skin impression of a nearly complete unidentified lizard from U-2 on a slab with a sycamore leaf (*Platanus wyomingensis*) (BHI-GR 45). Total length of lizard about 10 cm (4 inches).

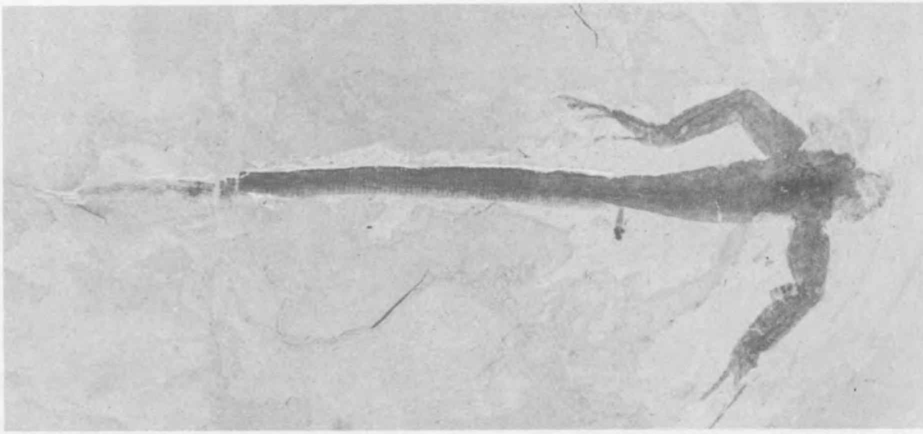


Figure III.4b. Skin impression of the hindquarters and tail of a lizard from U-4 (BHI-GR 102). Total length is about 12 cm (5 inches).

Figure III.5. A lizard trackway (SMMP 78.9.50) from U-5. Courtesy of Mr. H.D. Curry.

Figure III.6. *Boavus idelmani*, a fossil boa constrictor from F-1. Axial length about 96 cm (38 inches). This is the holotype, illustrated by Gilmore (1938).

Alligators and Crocodiles: The most common crocodilian fossils in the Green River Formation are teeth, scutes and coprolites (see figures III.7a and b and III.8), which have been found at nearly all vertebrate fossil bearing lacustrine outcrops of the Green River Formation.

Complete articulated specimens are much more rare. Langston and Rose (1978) described a very small fairly complete yearling crocodile from U-2 (see figure III.9). Other known nearly complete crocodilians from the Green River Formation include a part and counterpart of an alligator from G-1 (the better side illustrated in figure III.10); an uncataloged UW specimen (headless specimen from F-2); and a complete 43-cm (17-inch) skull from F-1 (UW 20531). The ASC specimen (figure III.10) may be *Alligator* sp. (Dr. Wann Langston, personal communication). There are also some nearly complete crocodilians from near G-1 in various private collections.

Crocodile skulls of the genus *Leidyosuchus* have been found in deposits near Wamsutter, Wyoming (see figure II.12; description in Mook, 1959). Crocodilians are more common in the overlying Bridger Formation.

The only crocodilian reported by Cope from the Green River Formation (1884, page 154-156) was *Crocodilus acer* from the "Manti beds" of Utah.

The presence of crocodilians in the Green River Formation is further evidence of a warm temperate to subtropical environment. It is interesting to note that alligators are apparently much more common than crocodiles in the Green River Formation, as crocodiles are usually more common than alligators in Early Tertiary crocodilian fossil deposits.

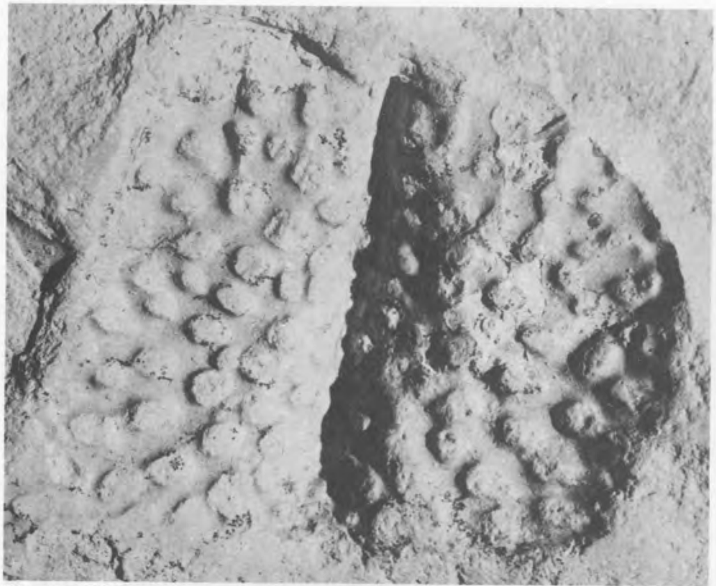


Figure III.7a. A crocodilian (probably alligator) midline scute from G-1 (external mold) (SMMP 78.9.30). Maximum width about 3 cm (1 inch).

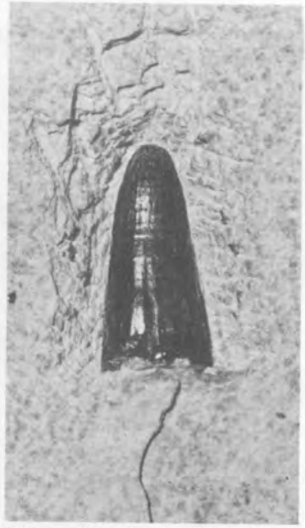


Figure III.7b. A crocodilian tooth from F-1 (private collection, Rick Jackson). Height 30 mm (about 1 inch).

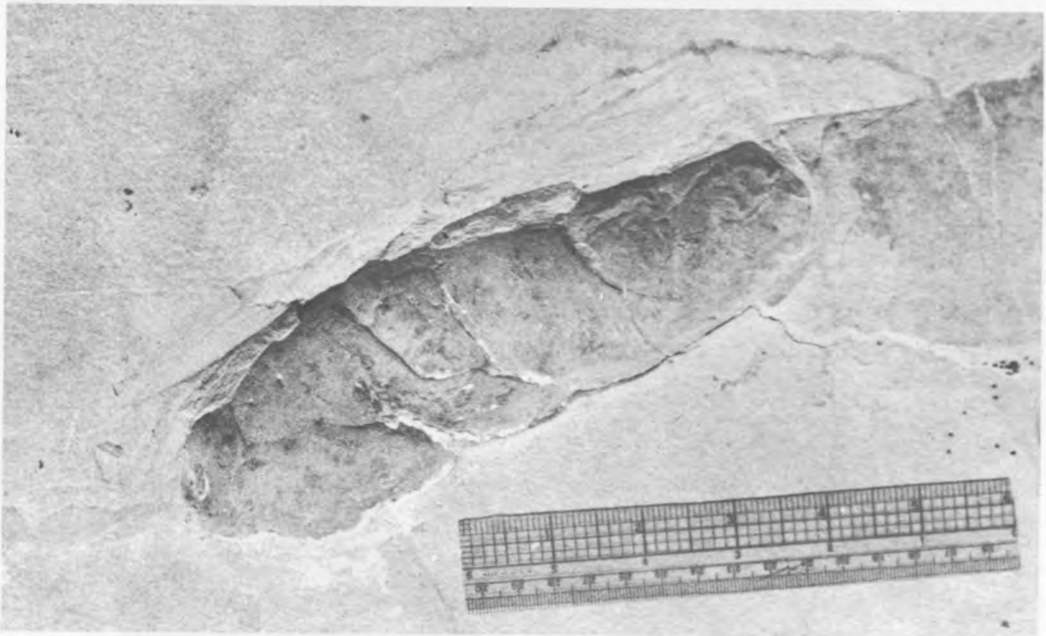


Figure III.8. A coprolite (FBNM 2) of probable crocodilian origin, so identified because of its large size. Length 20 cm (7½ inches). Photo courtesy of Roger Martin, Superintendent, Fossil Butte National Monument.

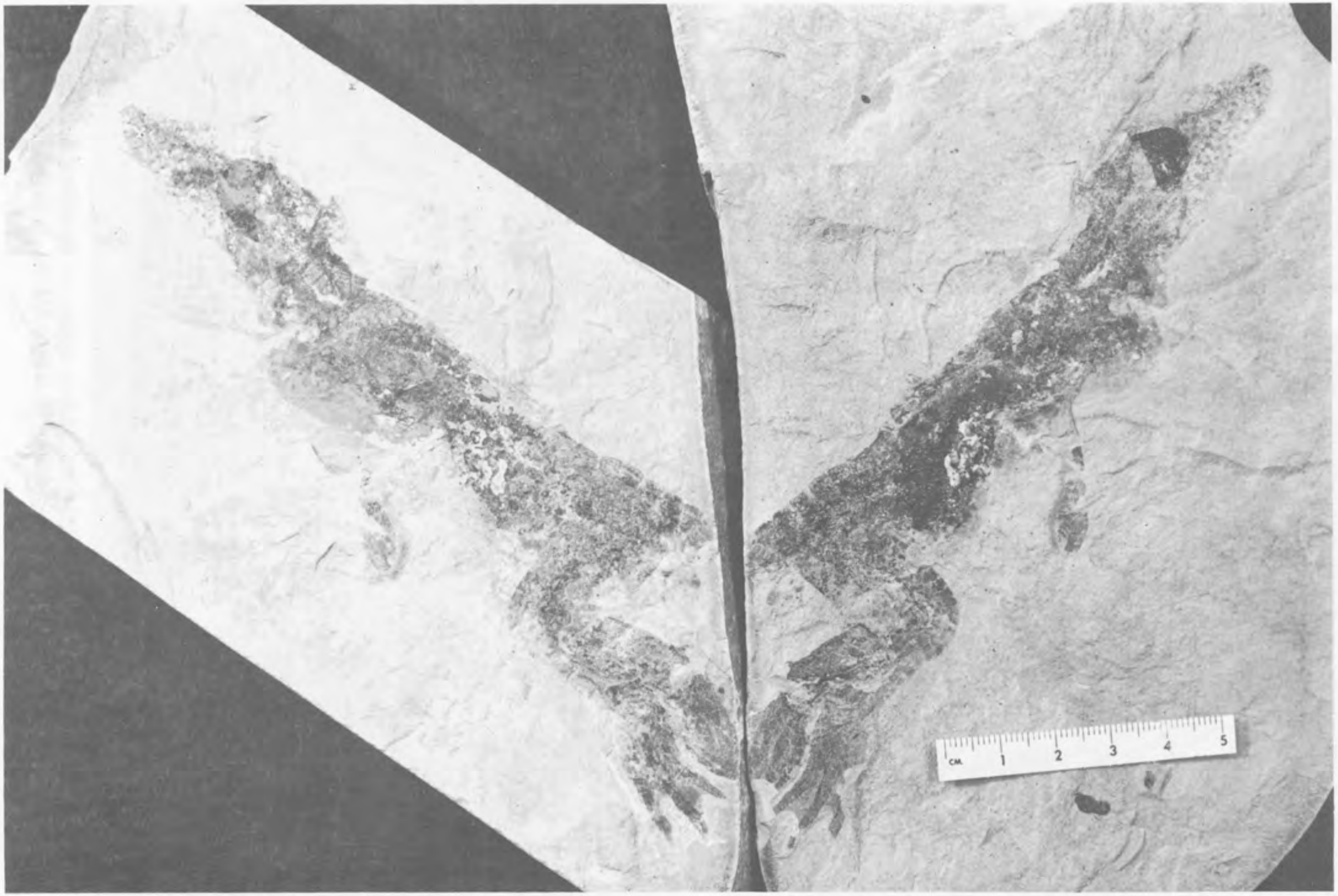


Figure III.9. Fairly complete yearling crocodilian from U-2 (from Langston and Rose, 1978). Total length of specimen on right about 18 cm (about 7 inches). These specimens are counterparts to each other. Note that the webbing and scalation between the toes of the hind foot are preserved. Most of the bones are missing, which is the normal type of preservation of vertebrate fossils from this locality. (Photo courtesy of the Society of Economic Paleontologists, and Langston and Rose).

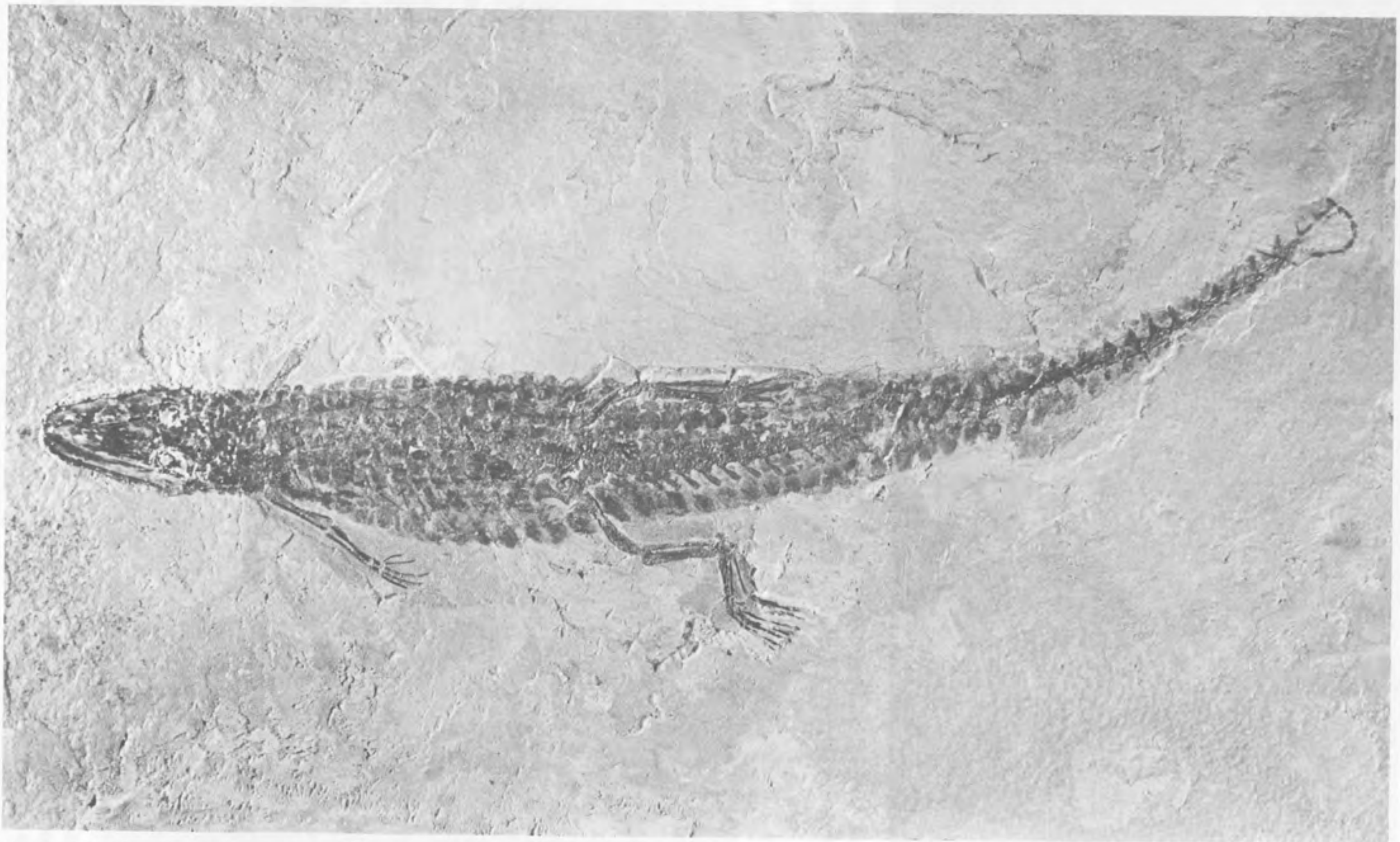


Figure III.10. Nearly complete alligator (ASC V-849) from G-1, possibly *Alligator* n. sp. Total length about 75 cm (30 inches). (Photo courtesy of Michael W. Haeger).

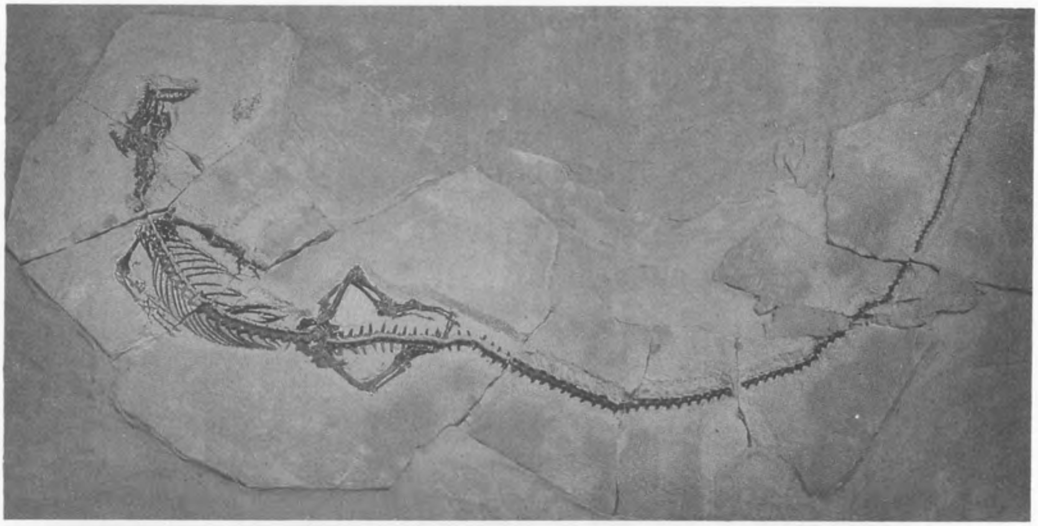


Figure III.11a. A large lizard from Fossil Lake deposits near Warfield Springs; possibly a varanid. Total length 1.32 m (52 inches). BHI specimen. Photograph courtesy BHI.

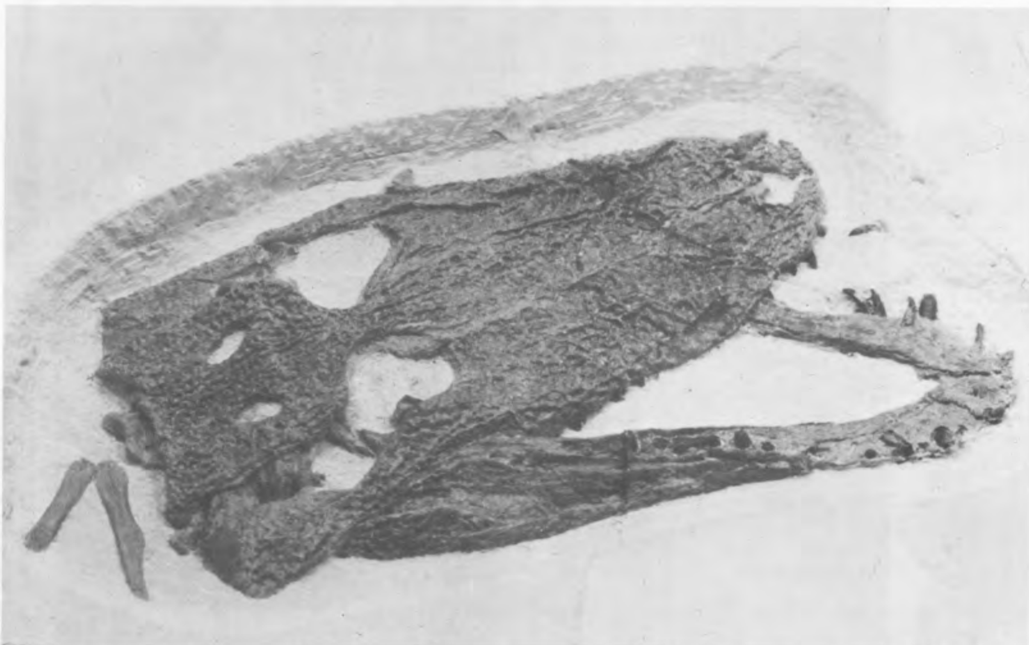
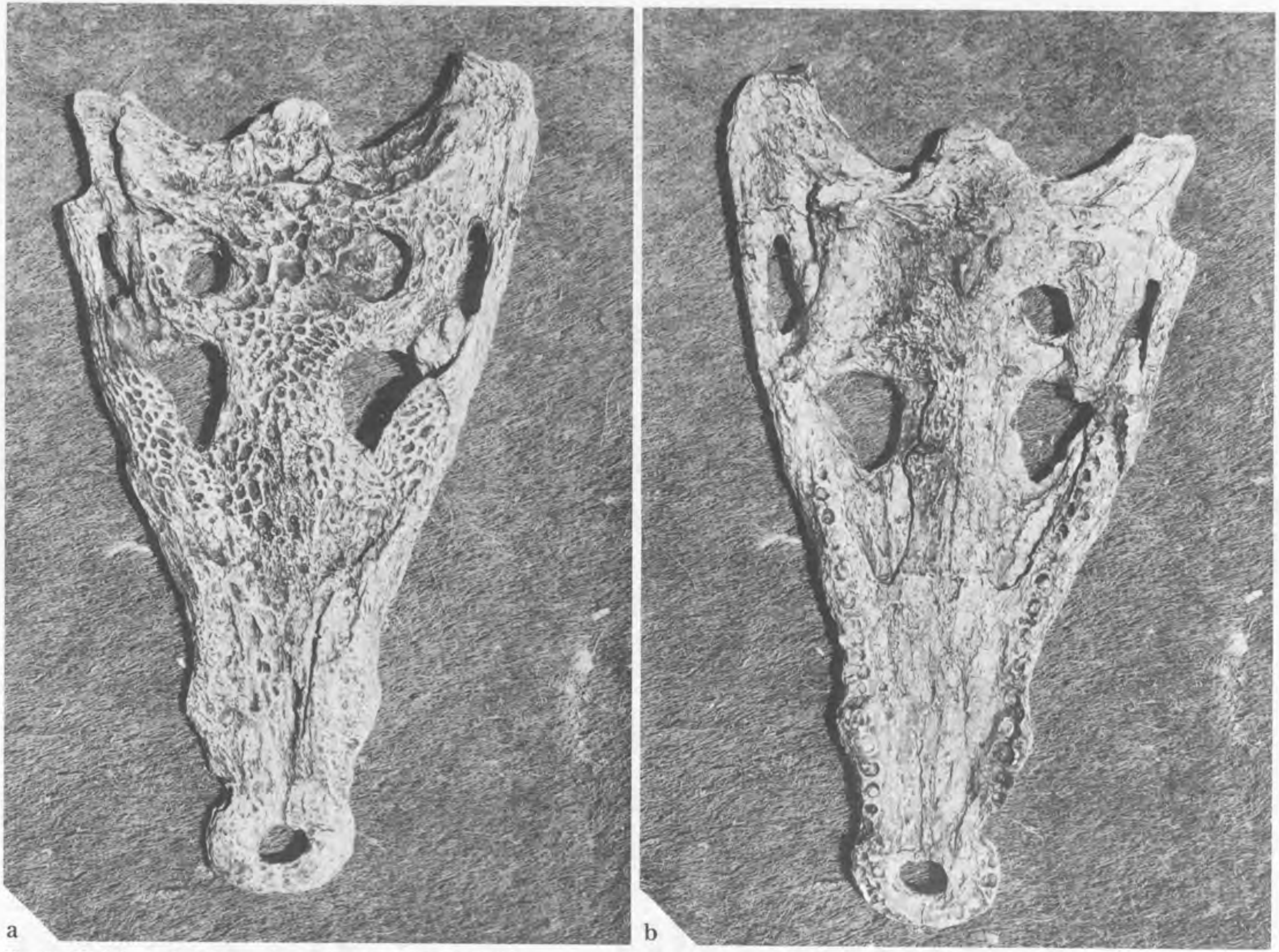


Figure III.11b. Large alligator skull (possibly *Alligator* n. sp. according to Dr. Wann Langston, personal communication) from G-1. Skull length is about 25 cm (10 inches). (Private collection in Rock Springs, Wyoming; photo courtesy of Black Hills Institute.)



a b

Figure III.12. a. *Leidyosuchus wilsoni* (AMNH 7637), a crocodile skull from the Green River Formation (Laney Member?) near Wamsutter, Wyoming (Lake Gosiute sediments), dorsal view. b. Palatal view of same skull, Total length is 33 cm (13 inches).

The Green River Formation has produced more complete or nearly complete articulated fossil birds than any other pre-Pleistocene locality in North America. Many of these birds were nonaquatic; they fell into the lake, somehow, and were covered with sediment and fossilized in the same way the fish were. Feathers (figure II.13) are much more abundant than skeletons, and are most abundant at F-1 and G-1. Legs, feet, and skulls are more abundant than complete specimens and have been found at nearly all vertebrate-bearing deposits within the Green River Formation. Bird tracks are very common at U-3 and U-5 (Curry, 1957; Erickson, 1967; Moussa, 1968) and some trackways even show "dabble" patterns left from the bill of a bird (very possibly *Presbyornis*) probing for food (see figures III.14a and III.14b). A bird's nest with eggs was found at F-2, but the whereabouts of this specimen is unknown.

Pelecaniformes: *Limnofregata azygosternon* (figures III.15a and III.15b) is the earliest known occurrence of a frigate bird (family Fregatidae). Modern frigate birds are confined to tropical oceans and breed exclusively on islands, whereas *Limnofregata* probably occupied a niche somewhat similar to that of modern gulls of the genus *Larus* (Olson 1977). *Limnofregata* was probably a predator and scavenger on the multitudes of *Knightia* and small *Diplomystus* found in the Green River lakes. The holotype (USNM 22753), an F-1 specimen, was originally discovered by Carl Ulrich.

Galliformes: *Gallinuloides wyomingensis* (figure III.16) is an Eocene galliform represented by an excellent articulated specimen (MCZ 1598) from F-1. The specimen was purchased from David Haddenham in 1899, but was probably originally discovered by Robert Craig. Somewhat smaller than the North American ruffed grouse (*Bonasa umbellus*), it had a powerfully developed pectoral arch and wing (Shufeldt, 1915). *Gallinuloides* was described by Eastman (1900b), Lucas (1900), and Shufeldt (1915). Figure III.22 shows an undescribed galliform (possibly *Gallinuloides* sp.) from F-2.

Anseriformes*: *Presbyornis* is a relatively abundant bird in the Green River Formation. It was a long-legged shorebird with a duck-like head. This is probably the bird that made most of the large trackways at U-3 (figures III.13 and III.14). An unprepared skull is shown in figure III.17, and much of the postcranial skeleton is illustrated and described by Feduccia and McGrew (1974). The unprepared skull shown in figure III.17 is illustrated in a fully prepared state in Olsen and Feduccia (in press). The majority of the *Presbyornis* fossil bones come from Lake Gosiute sediments just below the oil shales of the Laney Member of the Green River Formation, S½ sec. 24, T25N, R102W, Sweetwater County, Wyoming. Several hundred bones have been discovered at this locality, and McGrew and Feduccia (1973) and Feduccia and McGrew (1974) have speculated that this was a shoreline nesting site for a colony of these birds. This site was originally discovered by Faroy Simnacher, a graduate student at the University of Wyoming at the time. Wetmore (1926) named two birds, *Nautilornis avus* and *N. proavitus*, which he thought were alcid birds, but Feduccia and McGrew (1974) found them to be synonymous with *Presbyornis*. Suggested references are Wetmore, 1926; McGrew and Fedduccia, 1973; Feduccia and McGrew, 1974; and Feduccia, 1978.

Coraciiformes*: Primobucconids were small perching birds that are known from the Green River Formation by four described species and two described genera. These birds have been found at F-1, F-2, G-1, and several other localities in the Green River Formation. There are also several species known from the overlying Bridger Formation. The Green River types are *Primobucco mcgrewi* (holotype — right wing UW 3255 from F-1, illustrated in Brodkorb, 1970, figure 1); *Primobucco olsoni* (holotype — two slabs containing a nearly complete skeleton, Geological Survey of Alabama #217, illustrated in Feduccia and Martin, 1976, figures 3 and 4); *Neanis shucherti* (holotype — partial skeleton YPM 1233, illustrated in Shufeldt, 1913, figure 10); and *Neanis kistneri* (holotype — nearly complete skeleton UW 3196, illustrated in Feduccia, 1973, plate 1). There is also an undescribed primobucconid (uncataloged USNM specimen) from F-2, shown in figure III.18. Feduccia and Martin (1976) propose, in view of the relative abundance of fossil primobucconids in the Eocene, that they were probably the typical "perching" birds of the early Tertiary of North America; it was not until the mid-Tertiary that passerines took over in North America as the predominant "perching" group.

*Classification by Olson and Feduccia, 1980.

Other Green River Birds: Undescribed, nearly complete articulated birds from the Green River Formation include members of the Coraciiformes (kingfishers and allies), illustrated in figure III.19; Gruiformes (cranes, rails and allies), illustrated in figures III.21 and III.23; and several other groups. Descriptions are in progress by Olson, Feduccia, and others (Storrs Olson, personal communication).

Figure III.13. Fossil feather from F-1 (uncataloged National Park Service specimen, Fossil Butte National Monument, Kemmerer, Wyoming). Length is about 5 cm (2 inches).

Figure III.14a. Trackway of a large wading bird (BYU B20), probably *Presbyornis*, from U-3. Total length of slab is about 65 cm (25 inches). Photo courtesy of Mr. Bruce Erickson and SMMP.

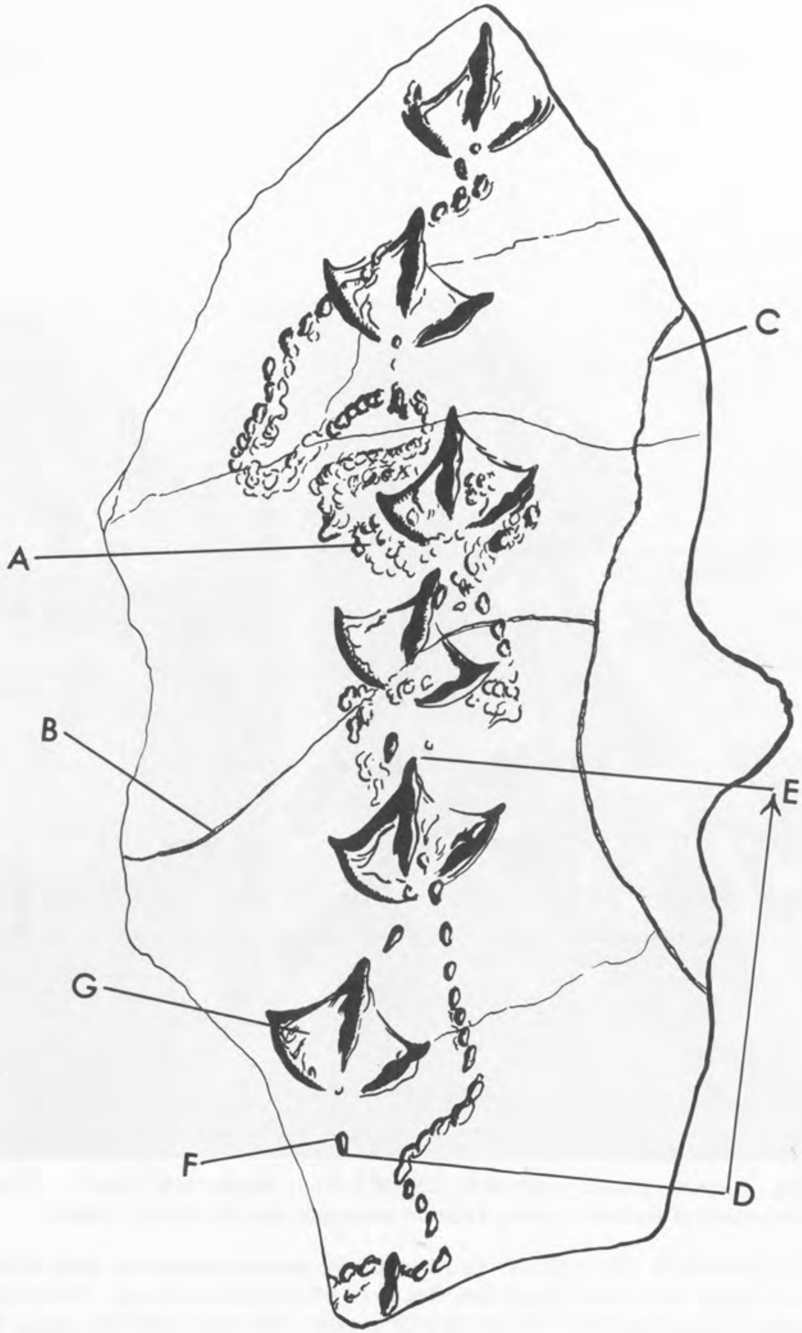


Figure III.14b. Line drawing of the slab in figure III.14a with an explanation of features, from Erickson, 1967. (A) Interrupted "dabble" pattern, (B and C) mud cracks, (D and E) stride, (F) hallux (hind toe), (G) webbed portion of left foot.

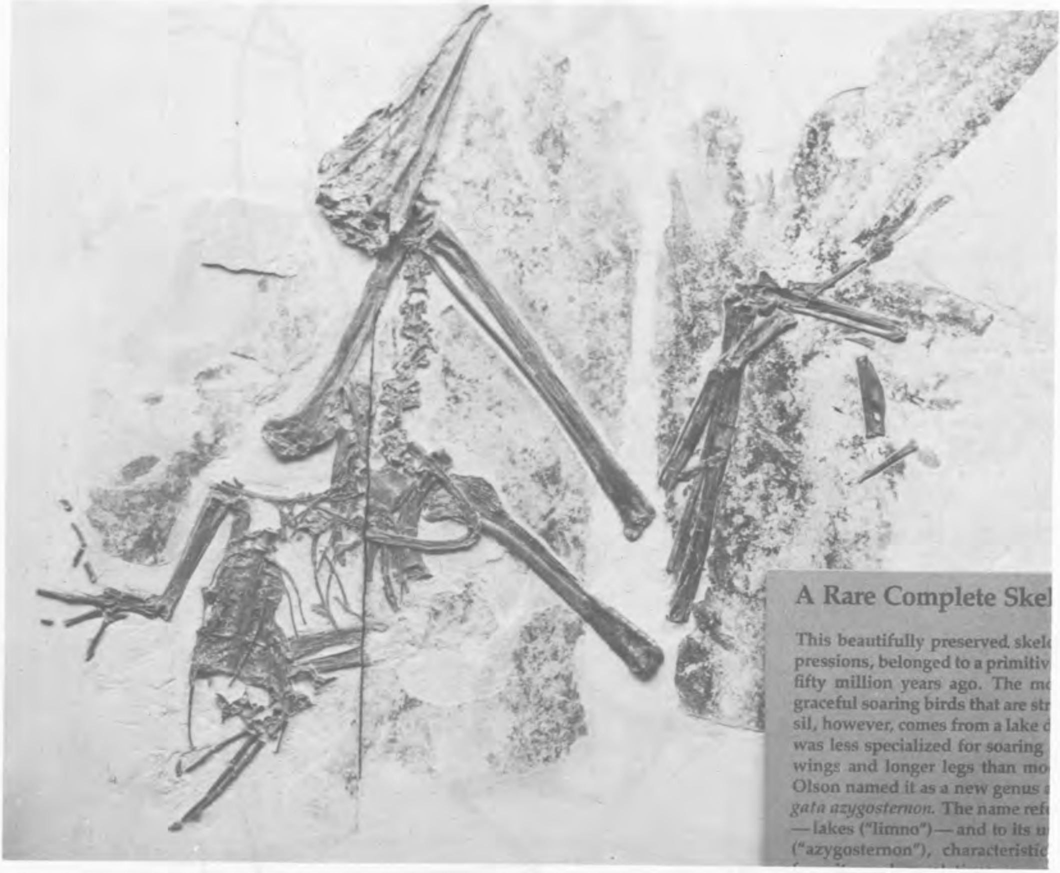


Figure III.15a. *Limnofregata azygosternon* (USNM 22753), frigate bird from F-1. Scale = 5 cm. Note preservation of feathers in wing. Caption accompanying this display reads:

A RARE COMPLETE SKELETON. This beautifully preserved skeleton, with feather impressions, belonged to a primitive frigatebird that lived fifty million years ago. The modern frigatebirds are graceful soaring birds that are strictly oceanic. The fossil, however, comes from a lake deposit in Wyoming. It was less specialized for soaring flight and had shorter wings and longer legs than modern frigatebirds. Dr. Olson named it as a new genus and species, *Limnofregata azygosternon*. The name refers to the bird's habitat — lakes ("limno") — and to its unfused pectoral girdle ("azygosternon"), characteristics that distinguish it from its modern relatives.

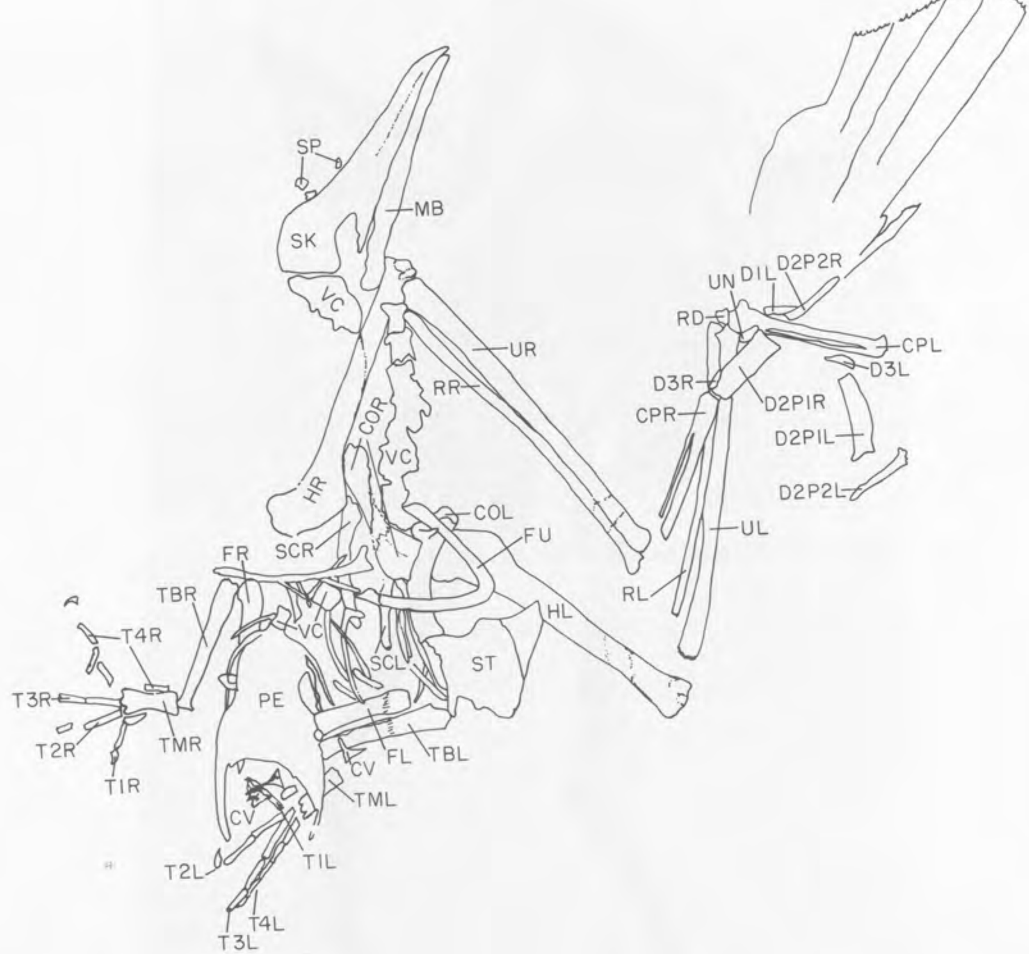


Figure III.15b. Line drawing of the specimen from figure III.15a identifying various parts. (Abbreviations ending with L indicate the element is from the left side, while R indicates the right side. CO = coracoid; CP = carpometacarpus; CV = caudal vertebra; D1 = first digit; D2P1 = second digit first phalanx; D2P2 = second digit second phalanx; D3 = third digit; F = femur; FU = furcula; H = humerus; MB = mandible; PE = pelvis; R = radius; RD = radiale; SC = scapula; SK = skull ; SP = sclerotic plates; ST = sternum; TB = tibiotarsus; TM = tarsometatarsus; T1 = first toe; T2 = second toe; T3 = third toe, T4 = fourth toe; U = ulna, UN = ulnare, VC = vertebral column.) From Olson, 1977.

Figure III.16. *Gallinuloides wyomingensis* (MCZ 1598), a galliform from F-1. Length from wing-tip to clawtip is about 25 cm (10 inches).

Figure III.17. *Presbyornis* sp. (USNM 299846), skull from the southern shore of Eocene Lake Gosiute. This ducklike skull belonged to a long legged wading bird, probably the bird that made the trackway in figure III.13. Skull length is about 7 cm (3 inches). Photograph by Victor E. Krantz, courtesy of Storrs Olson and the Smithsonian Insitution.

Figure III.18. Undescribed primobucconid? (USNM 299821) missing the legs. Total length about 5 cm (2 inches). From F-2. Photo courtesy of Mr. James E. Tynsky.

Figure III.19. Undescribed kingfisher-like bird (order Coraciiformes) (BHI-GR 207) from F-2. Total length is about 15 cm (6 inches).

Figure III.20. Undescribed swift-like bird (Aegialornithidae) from Lake Gosiute sediments, Tipton Tongue of Green River Formation, N½NW¼ sec. 6, T23N, R104W, Sweetwater County, Wyoming. Lenth is about 10 cm (4 inches). Private collection in Farson, Wyoming; photo courtesy of Frank Kistner. Peel of specimen in collection of USNM.

Figure III.21. Undescribed gruiform? from F-2. Total height is about 25 cm (10 inches). Now in a private collection in Arezzo, Italy.

Figure III.22. *Gallinuloides* sp., a galliform from F-2. Height of bird is about 25 cm (10 inches). In a private collection in Arezzo, Italy; photo courtesy of Mrs. Carolyn Tynsky.

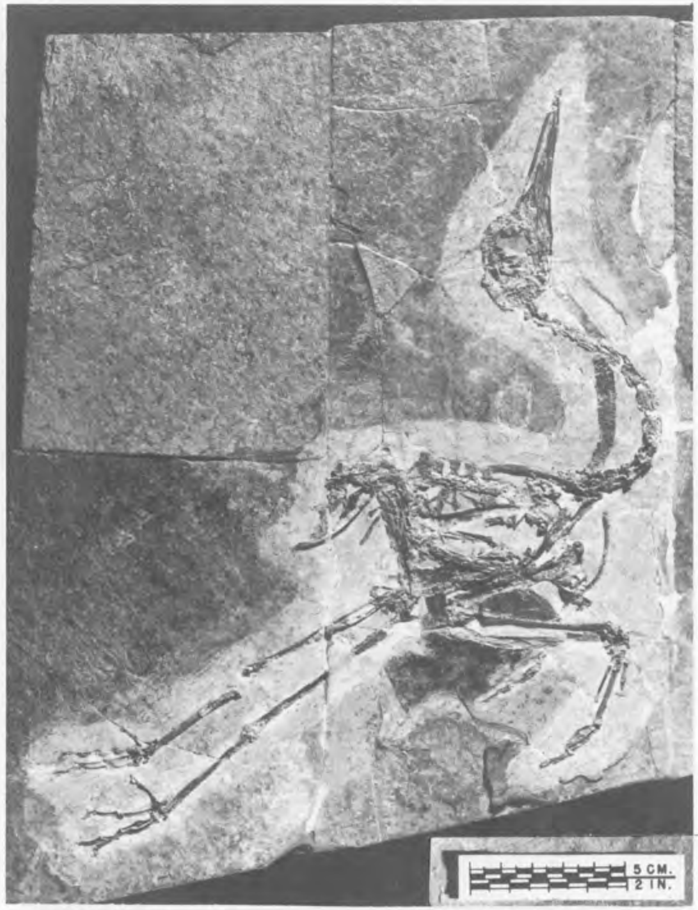


Figure III.23. Undescribed gruiform (order Gruiformes; USNM 336377) from Eocene Fossil Lake. Length from tip of foot to tip of beak is about 28 cm (11 inches). A description of this bird is currently in preparation by Dr. Storrs Olson. Photo courtesy of Dr. Storrs Olson.

Order	Family	Genus	Described Green River species
Pelicaniformes	Fregatidae	*Limnofregata*	*L. azygosternon* Olson 1977
Galliformes	Gallinuloididae	*Gallinuloides*	*G. wyomingensis* Eastman 1900
Anseriformes	Presbyornithidae	*Presbyornis*	*P. pervetus* Wetman 1926
Coraciiformes	Primobucconidae	*Primobucco*	*P. mcgrewi* Broadkorb 1970
			P. olsoni Feduccia & Martin 1976
		Neanis	*N. schucherti* (Shufeldt 1913)
			N. kistneri (Feduccia 1973)

Figure III.24. Classification of described Green River Birds.

Complete mammalian fossils from the Green River Formation are extremely rare, and consist only of bats. Most of the Green River mammalian fauna is known from teeth and bone fragments. Fossil mammal localities which produce identifiable fragments are not common. Mammal trackways are occasionally found at U-3 and U-5 (see figure III.27).

Bats (order Chiroptera): A few bat specimens occur in the Green River Formation, including one described species, *Icaronycteris index*. The holotype (PU 18150, figure III.25) is a beautifully articulated complete skeleton from F-1 discovered in the early 1930's. Other bat specimens include UW 2244 (a nearly complete skeleton from F-1) and several partial skeletons at the University of Wyoming and Princeton University from F-1. One specimen (part and counterpart of a complete bat, in private collections) is known from U-2 (see figure III.26) and probably represents an undescribed species. *Icaronycteris* was described in detail by Jepson (1966).

Other Mammals: Other Green River mammal faunas reported include a small but diagnostic fauna in the Tipton Tongue in sec. 30, T25N, R101W in the Green River Basin which indicates a Lostcabinian age (late Early Eocene). This Eocene Lake Gosiute fauna contains *Cynodontomys*, *Hyracotherium*, and *Lambdotherium* (McGrew and Roehler, 1960).

Table III.1. Mammalian faunal list from Simnacher (1970).

- Class Mammalia
  - Order Marsupialia
    - Family Didelphidae
      - *Peratherium knighti*
      - *Peratherium innominatum*
  - Order Insectivora
    - Family Adapisorididae
      - *Talpavus nitidus*
  - Order Primates
    - Family Adaphidae
      - *Notharctus* sp.
    - Family Anaptomorphidae
      - *Uintasorex parvulus*
    - Family Microsyopsidae
      - *Microsyops elegans*
    - Family Omomyidae
      - *Washakius insignis*
  - Order Rodentia
    - Family Paramyidae
      - *Thisbemys* sp.
  - Order Carnivora
    - Family Miacidae
      - *Vulpavus profectus*
  - Order Condylarthra
    - Family Hyopsodontidae
      - *Hyopsodus miniscululus*

Simnacher (1970, page 54) reported several mammals (listed in table III.1) from the Parnell Creek Area, sec. 24, T25N, R102W, Sweetwater Co., Wyoming, which, according to Dr. Paul O. McGrew (personal communication), are from a shoreline phase of the Wilkins Peak Member (Eocene Lake Gosiute). These specimens are reposited at the University of Wyoming, Laramie.

Kay (1957) reported several mammals (listed in table III.2) from a "sandy deltaic facies [of the Green River Formation] along the basin side of Raven Ridge in the eastern end of the Uinta Basin," sec. 8, T75N, R25E, Uintah Co.,

Table III.2. Mammalian faunal list from Kay (1957).

ORDER *Genus, species*
MARSUPIALIA
Peratherium innominatum
INSECTIVORA
Nyctitherium sp.
CARNIVORA
Viverravus eucristadens
V. minutus
Miacis gracilis
Sinopa minor
CONDYLARTHRA
Hyopsodus vicarius
H. miniscululs
TILLODONTIA
Tellotherium?
RODENTIA
Paramys sp.
Sciuravus sp.
PRIMATES
Tetonius sp.
Notharctus matthewi
Onomys pucillus

Utah. This is sometimes referred to as the "Powder Wash" locality (Dawson 1968; Burke, 1969; and others) and is in the Douglas Creek Member of the Green River Formation (Burke, 1969). A collection (some of which remains undescribed) of thousands of fragments of reptiles, mammals, and birds from this locality is reposited at the Carnegie Museum, Pittsburgh, Pennsylvania. Gazin (1958) described the primates from this fauna, which include *Uintasorex pravulus* Matthew, *Utahia kayi* Gazin, *Uintalacus nettingi* Gazin, *Omomys lloydi* Gazin, and cf. *Utahia kayi* Gazin. Dawson (1958) described the rodents, which include *Paramys* cf. *P. delicatus* Leidy, *Pseudotomus* cf. *P. robustus* (Marsh), *Microparamys minutus* (Wilson), *Sciuravus eucristadens* (Burke), *Sciuravid* sp., and *Pauromys* sp.; she also noted the occurrence of some larger mammals (*Orohippus* and *Hyrachyus*). Krishtalka (1976) described an insectivore [*Nyctitherium serotinum* (Marsh)], and Burke (1969) described an antiacodont [*Antiacodon pygmaeus* (Cope)], from this Eocene Lake Uinta fauna.

Parker (1970) reported a titanothere from the Parachute Creek(?) Member of the Green River Formation (Lake Uinta sediments) near U-3. Only a humerus and a portion of an atlas vertebra were found, and he identified them as possibly belonging to the genus *Mesartirhinus*. Dr. Jim Jensen, of Brigham Young University, Provo, Utah (personal communication), discovered a large (unidentified) perissodactyl at U-1.

Rich and Collinson (1973) reported *Vulpavus australis* from the Flagstaff Member of the Lake Uinta deposits.

Mammal tracks and trackways: Very rarely, mammalian trackways are found at U-3 and U-5. Curry (1957, page 45) illustrates a large, short-legged, three-toed mammal track from U-5 (his figure 8), about 13 cm (5 inches) in width, which he suggests belonged to one of the Eocene perissodactyls ancestral to modern tapirs. Moussa (1968) illustrates some smaller mammal tracks from U-3 (see figure III.27). According to Clayton Ray of the U.S. National Museum (Moussa 1968, page 1435), "It appears that the tracks were made either by a small, three-toed horse, or perhaps a tapiroid, although it would be difficult to identify them with a specific genus. However, on the assumption that one or the other of the above categories is correct, the genera *Orohippus* and *Helaletes*, respectively, are suggested."

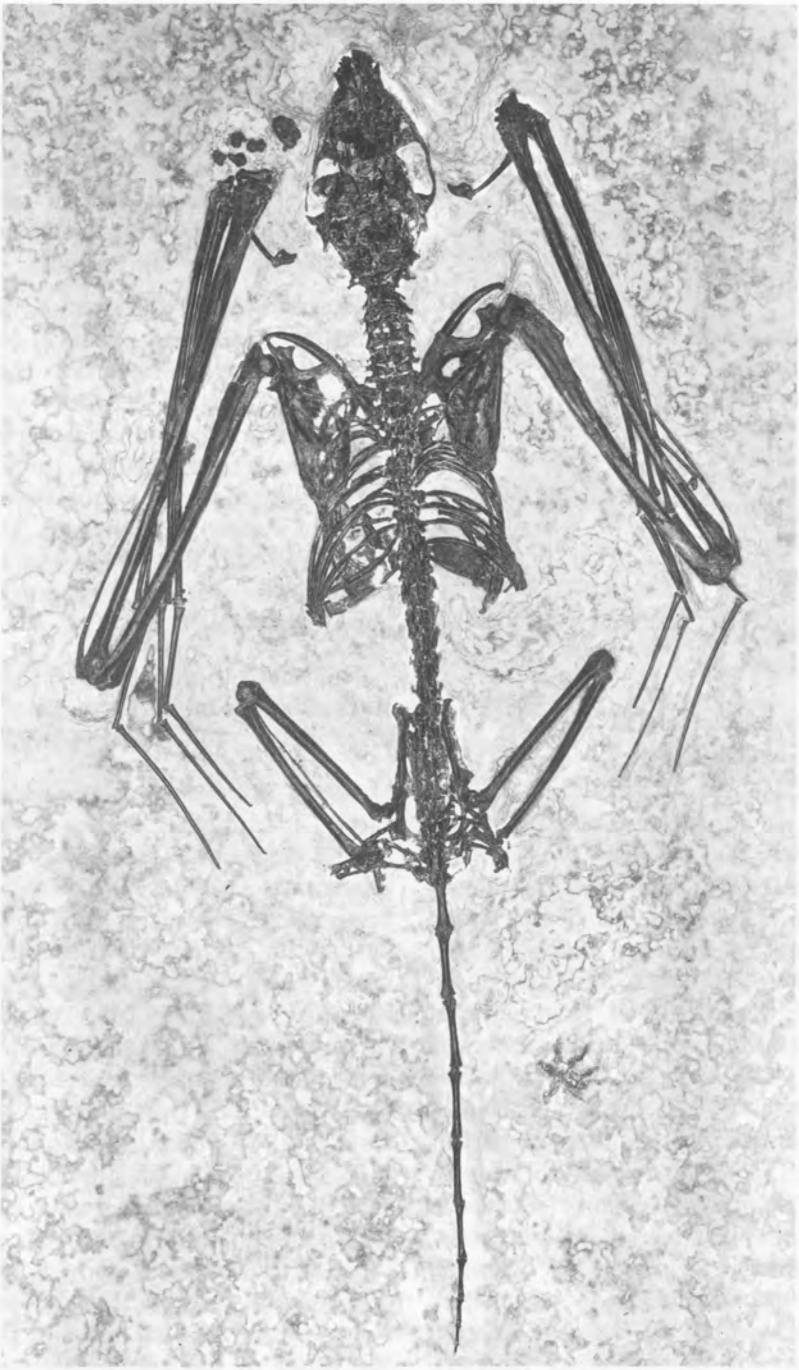


Figure III.25. *Icaronycteris index* (PU 18150 — holotype), a complete bat from F-1. About 13 cm (5 inches) long. Photo courtesy of Willard Starks, Princeton University.

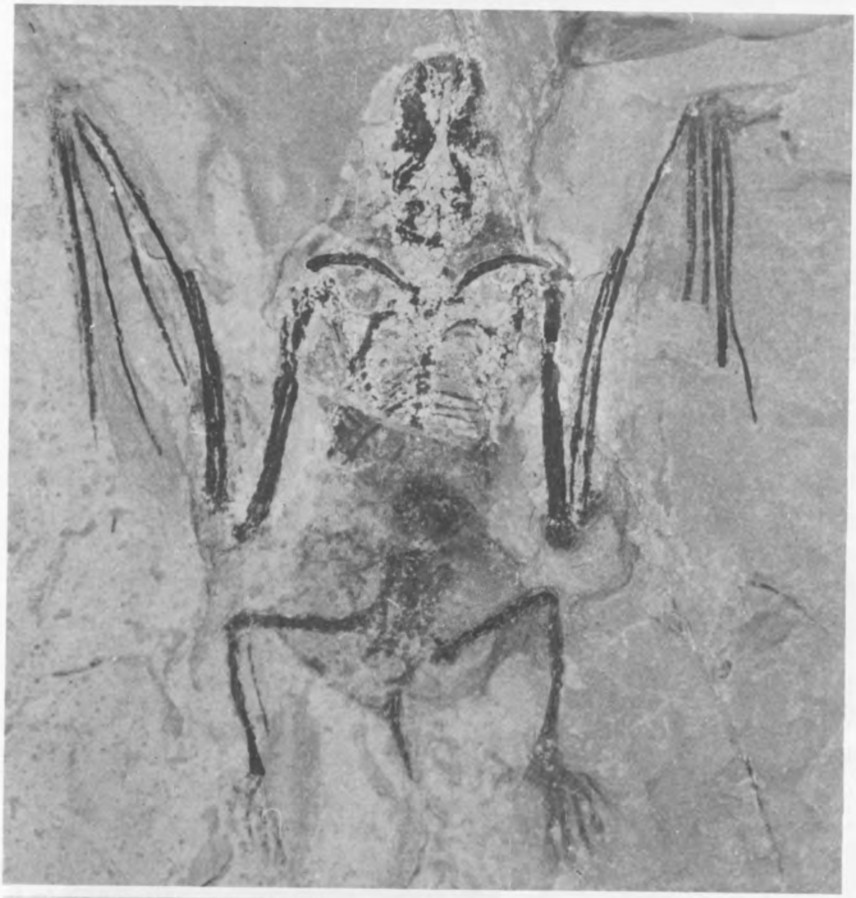


Figure III.26. Unidentified bat from U-2 (in the private collection of Mr. Tom Maloney). Note the preserved skin in some areas and poorly preserved bone, typical of vertebrate fossil preservation at U-2 and U-4. Total length is about 10 cm (4 inches).

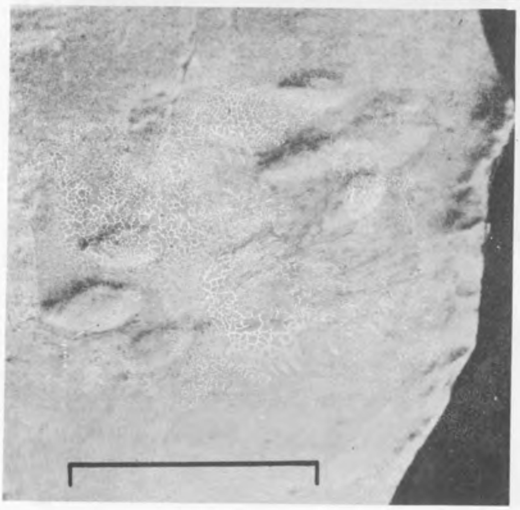


Figure III.27. Three-toed mammal tracks from U-3 (from Moussa, 1968). Bar scale is 5 cm.

Figure III.28a. Artist's conception of some of the North American Eocene mammals, many of which inhabited the shores of the Green River Lakes. Painting by J.H. Matternes (courtesy U.S. National Museum). Also shown are *Echmatemys* and *Crocodilis*.

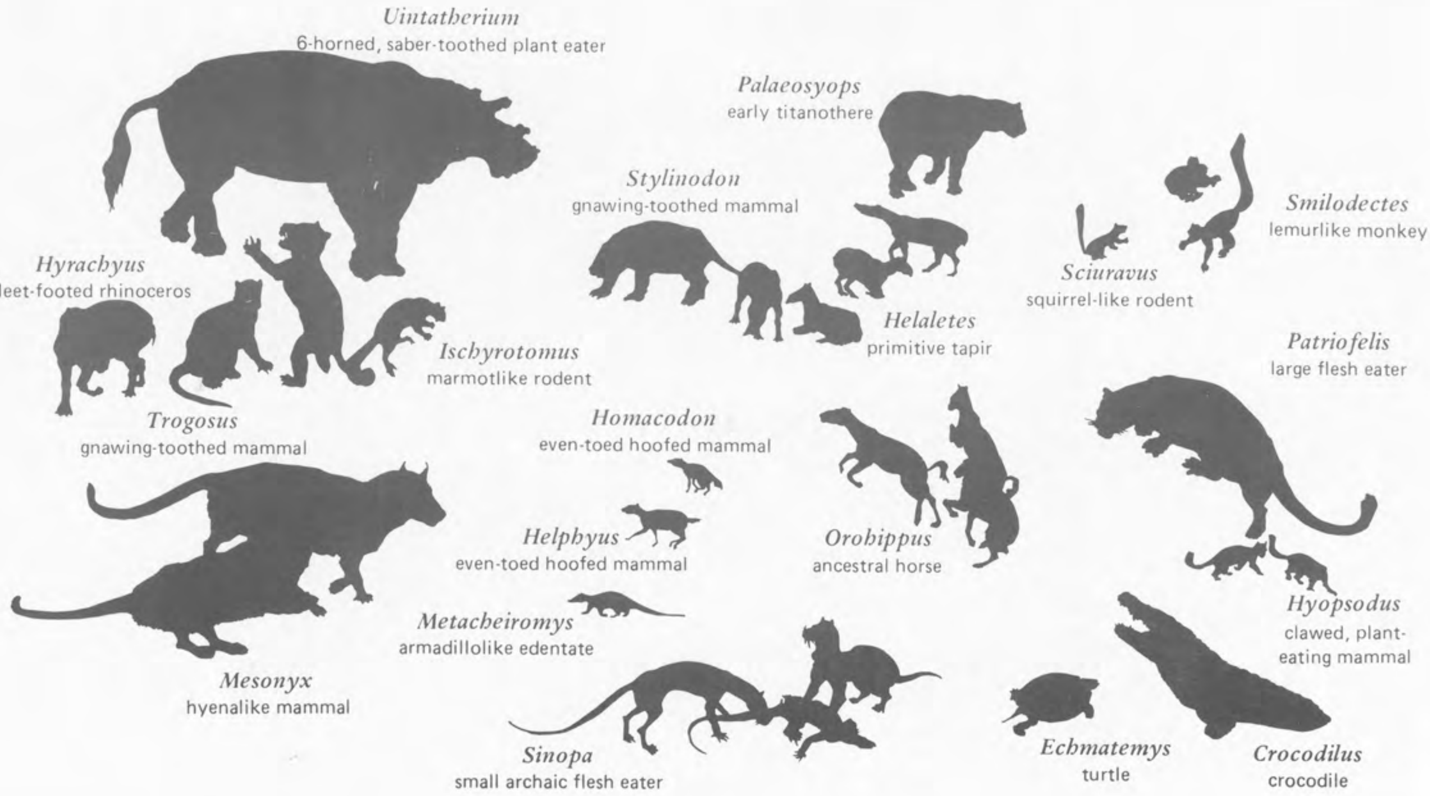


Figure III.28b. Identification key to the animals shown in figure III.28a (courtesy of the Smithsonian Institution).

PART IV

INVERTEBRATE FOSSILS OF THE GREEN RIVER FORMATION

INTRODUCTION TO PART IV

Part IV, a brief presentation of the invertebrate fauna of the Green River Formation, includes a pictorial atlas with faunal lists, a partial listing of repositories, selected references, and supplementary descriptive information.

Arthropods (mostly insects and ostracodes, with a few branchiopods, malacostracans and arachnids) make up the largest part of the Green River invertebrate fauna. Nematode trails are also fairly common in some parts of the Green River Formation (at localities U-3 and U-5). The rest of the invertebrate fauna consists mainly of mollusks (gastropods and bivalves).

PORIFERA

Sponge spicules have been reported from Lake Uinta by Bear (1969).

NEMATODA

Fossil roundworm trails were reported by Moussa (1970) from U-3, and are illustrated in figure IV.15. Curry (1957, figure 6) illustrates these trails from U-5.

MOLLUSCA

Gastropoda and Bivalvia: Snails and clams were common in all three lakes of the Green River Formation. Little is known about the molluscan faunas of Fossil Lake and Lake Uinta because most research on Green River molluscan faunas has been done in sediments of Lake Gosiute. A classification and list of mollusks from Lake Gosiute, including references for fossil descriptions and locality data, are given in figure IV.1 and table IV.1 (based mostly on Hanley, 1974a).

Figures IV.6-IV.8 illustrate most of the mollusks known from the Green River Formation. Although not all of the specimens illustrated in figures IV.6-IV.8 are from the Green River Formation (some are common in the Wasatch Formation), all of the species illustrated in those figures are known to occur in the Green River Formation (personal communication, Dr. John Hanley, U.S.G.S., Denver).

Table IV.1. List of selected references for descriptions of mollusks that occur in the Green River Formation and stratigraphic distribution (based on Hanely, 1974). Reference Key: A = Baker, 1945; B = Hall, 1845; C = Hanley, 1974; D = LaRocque, 1960; E = Meek, 1860; F = Meek, 1872; G = Meek, 1876; H = Meek and Hayden, 1856a; I = Meek and Hayden, 1856b; J = Russell, 1931; K = White, 1877; L = White, 1883; M = White, 1879; N = White, 1880. Stratigraphic Key: lu = Luman Tongue, t = Tipton Shale Member, f = Fontenelle Tongue, w = Wilkins Peak Member, l = Laney Member. "?" indicates questionable occurrence of that species in that stratigraphic unit.

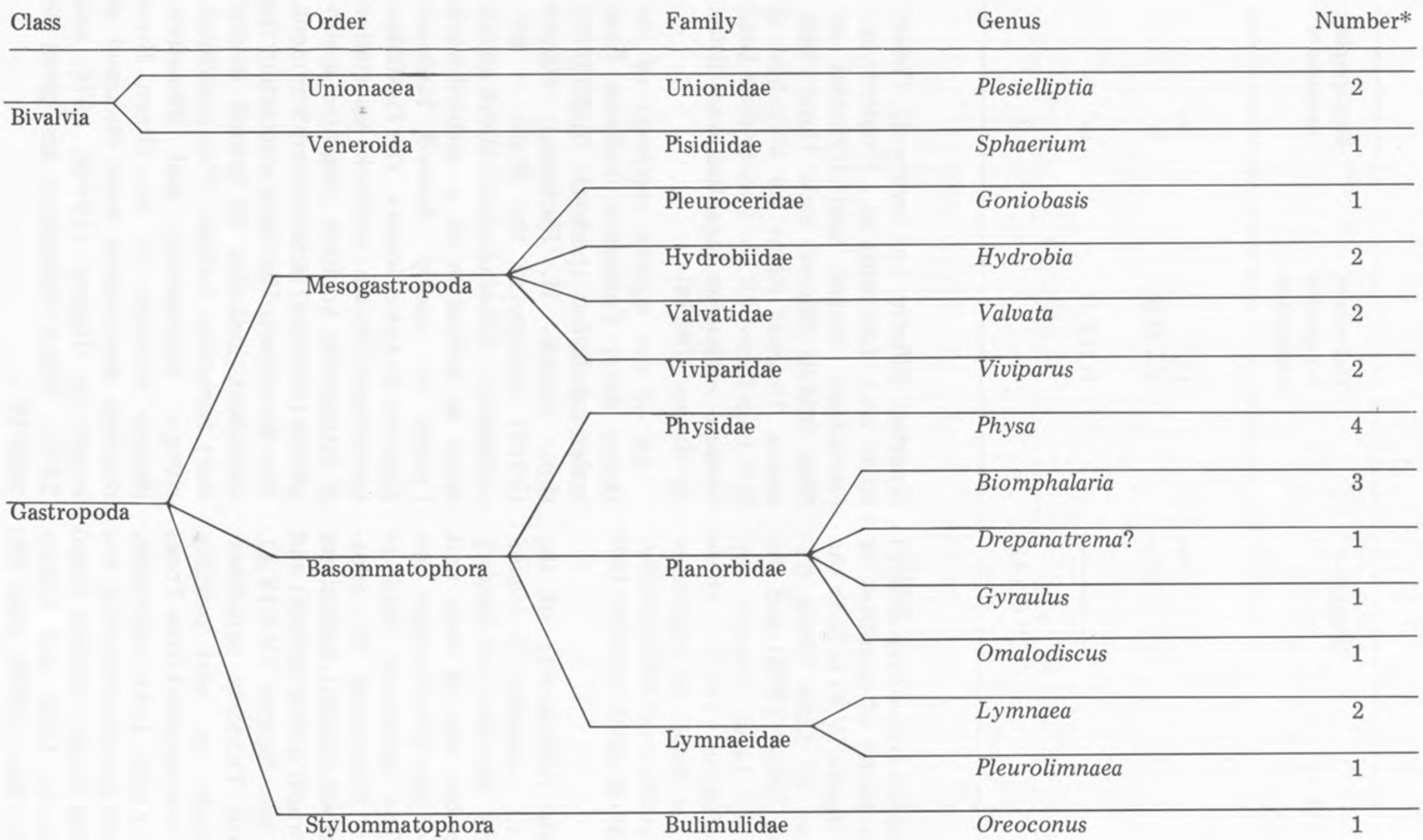
Genus Species that occur in the Green River Formation	Illustrated	References for specific description	Stratigraphic occurrence
Plesielliptio			
P. priscus	IV.6(1-4)	C,H,I,G,J	lu?, t?
P.. n. sp. A	IV.7(1-4)	C	lu
Sphaerium			
S. sp.	IV.6(5)	C	lu,la
Goniobasis			
G. tenera	IV.7(5-11)	B,C,K,D	lu,t,f,w,la
Hydrobia			
H. aff. *H. utaensis*	IV.6(6)	C	lu,t,f,w,la
H. sp. A	————	C	t
Valvata			
V. subumbilicata	————	C,H,I,G,	lu,la
V. cf. *V. filosa*	IV.6(7-8)	C	lu,t,la
Viviparus			
V. trochiformis	IV.7(12-13)	C,D,H,I,D	lu,t,f,la
V. paludinaeformis	————	B,D,C	lu?,f
Physa			
P. bridgerensis	IV.8(4-5)	C,D,F,J,K	lu?,f,la
P. longiuscula?	IV.8(6-7)	I,G,C	lu
P. pleromatis	IV.8(2-3)	J,K,D,C	lu,t,f
P. sp. A	————	C	la
Biomphalaria			
B. aequalis	IV.8(8-10)	N,C	lu,la
B. storchi	IV.8(11-13)	J,C	lu,f?,la?
B. pseudoammonius	————	E,C	f,la
Drepanotrema			
D.? sp.	————	A,C	la
Gyraulus			
G. militaris	————	N,C	lu
Omalodiscus			
O. cirrus	IV.8(1)	L,M,C	lu

Genus Species that occur in the Green River Formation	Illustrated	References for specific description	Stratigraphic occurrence
Lymnaea			
L. sp. B	————	C	lu
L. similis	————	E,C,G,K	la
Pleurolimnaea			
P. tenuicosta	————	H,G,C,D	lu?
Oreoconus			
O. n. sp. A	IV.6(9-12)	C	?

Gastropods (mostly *Goniobasis tenera*) are found as the nuclei of oncolites, or "algal biscuits," (figure IV.4) in both the Flagstaff Member of Lake Uinta (reported by Weiss, 1969; 1970) and the Laney Member of Lake Gosiute (reported by Wolfbauer, 1972). These oncolites were the result of successive algal layers encrusting snail shells; today, they weather out as small nodules (see figure IV.4).

Internal molds (steinkerns) of the snail *Viviparus* sp. (possibly *V. trochiformis*) are fairly abundant at locality F-1, typically in the thin oil shale unit at the bottom of the 18-inch layer (see figure IV.2). The dominant snail at locality F-2 is *Goniobasis* sp. (possibly an undescribed species), sometimes preserved with whorl nodes (spines) and radular teeth (see figures IV.3-IV.4). *Physa pleromatis*, *Viviparus paludinaeformis*, *Plesielliptio* sp., and possibly *Oreoconus* sp. were reported from Fossil Butte Member Fossil Lake sediments, and *Biomphalaria pseudoammonius* was reported from the Angelo Member Fossil Lake sediments, by Oriel and Tracey (1970, page 32). Baer (1969, page 66) reported *Elliptio* sp. (probably *Plesielliptio* sp.), *Lampsilis* sp., *Viviparus* sp., *Goniobasis tenera*, and *Gyraulus* sp. from Middle Eocene Lake Uinta sediments. Unionid clams are abundant at U-3 (see figure IV.5). Ninety-four Lake Gosiute molluscan localities were listed by Hanley (1974a).

All of the aquatic mollusks of the Green River Formation indicate fresh water conditions (personal communication, Joseph H. Hartman). Hanley (1976) interpreted the *Physa — Biomphalaria — Omalodiscus* mollusk association as indicative of a ponded-water habitat in poorly drained lowlands adjacent to Lake Gosiute. The Pisidiidae-*Goniobasis*-*Valvata* mollusk association is interpreted to have inhabited a sublittoral (offshore) lacustrine environment. The *Goniobasis*-*Viviparus* association is a consistent indicator of littoral (shoreline) lacustrine habitat. The paleosynecology, taphonomy, and lithostratigraphic relations of the Green River mollusk associations were discussed at length by Hanley (1974a; 1976; and 1977). Other references are given in table IV.1.



*Number of described species that occur in the Green River Formation

Figure IV.1. Classification of Green River mollusks (from Hanley, 1974).

Figure IV.2. A steinkern (internal mold) of *Viviparus* sp. from F-1 on a slab with *Diplomystus dentatus*, (SMMP 78.9.32). Length of gastropod is 20 mm (about ¾ inch).

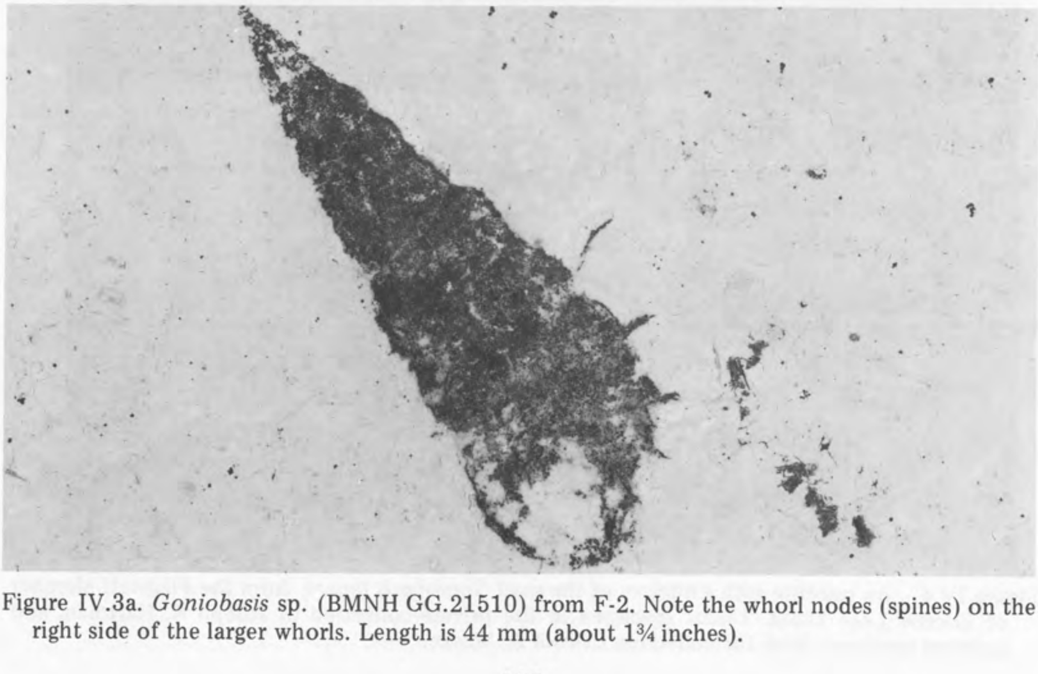


Figure IV.3a. *Goniobasis* sp. (BMNH GG.21510) from F-2. Note the whorl nodes (spines) on the right side of the larger whorls. Length is 44 mm (about 1¾ inches).

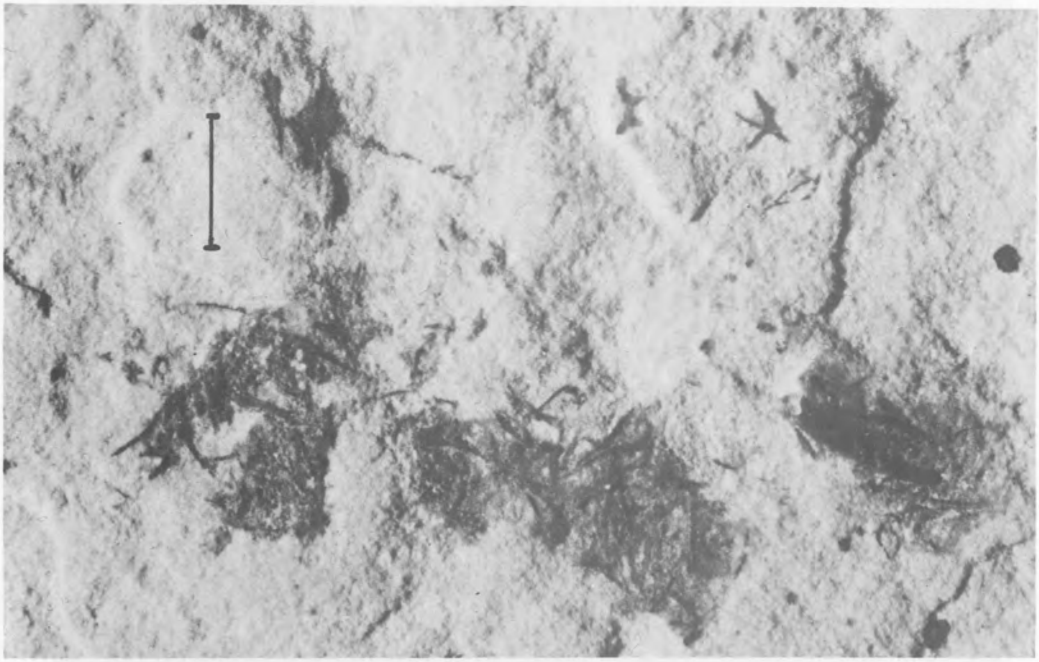


Figure IV.3b. Enlargement of the radular teeth shown to the lower right of the specimen in figure IV.3a. Scale is 1 mm.

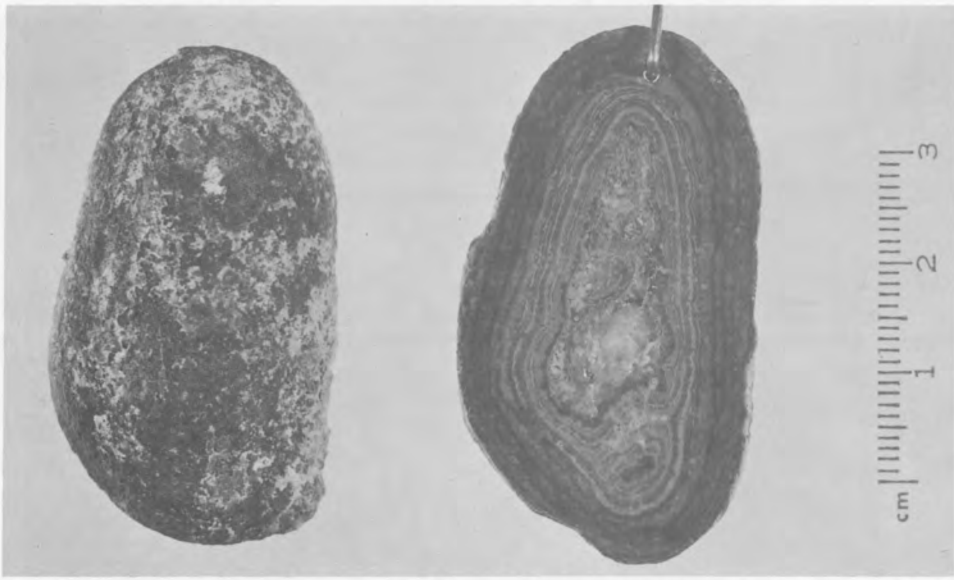


Figure IV.4. An oncolite with a nucleus of the snail *Goniobasis tenera*, from the Flagstaff Member of Eocene Lake Uinta. Uncut specimen in the private collection of Joseph H. Hartman, and polished specimen from the collection of Jodi A. Milske.

Figure IV.5. A group of clams from the Family Unionidae (BMNH LL.18785), from U-3. Scale = 2 cm.

Figure IV.6. Mollusks found in the Green River Formation. 1-4—*Plesielliptio priscus* (Meek and Hayden): (1-2) Interior and exterior of right valve with straight ventral margin, hypotype USNM 209988, main body of Wasatch Formation, Sweetwater County, Wyoming, X0.75. (3) Interior of right valve with prominent trigonal cardinal tooth, hypotype USNM 209989, main body of Wasatch Formation, Sweetwater County, Wyoming, X1.5. (4) Dorsal margin of right valve with prominent double-looped juvenile umbonal sculpture and posteroventrally radiating costae, hypotype USNM 209993, main body of Wasatch Formation, Sweetwater County, Wyoming, X5. (5) Pisidiidae: *Sphaerium* sp. Exterior, USNM 210027, Douglas Creek Member of Green River Formation, Rio Blanco County, Colorado, X9. (6) *Hydrobia* aff. *H. utahensis* White. Apertural view, USNM 210049, Niland Tongue of Wasatch Formation, Sweetwater County, Wyoming, X20. 7-8—*Valvata* cf. *V. filosa* Whiteaves. (7) apical view, USNM 210064, Niland Tongue of Wasatch Formation, Sweetwater County, Wyoming, X15. (8) apertural view, USNM 210061, Niland Tongue of Wasatch Formation, Sweetwater County, Wyoming, X15. 9-12—*Oreoconus* n. sp. A. (9) apertural view of immature specimen. USNM 210134, main body of Wasatch Formation, Sweetwater County, Wyoming, X2. (10-12) profile, abapertural, and apertural views of mature specimen, UMMZ 232201, Pass Peak Formation of Dorr (1969), Hoback Basin, Sublette County, Wyoming, X1.75. From Hanley, 1976. Photo courtesy of John Hanley.

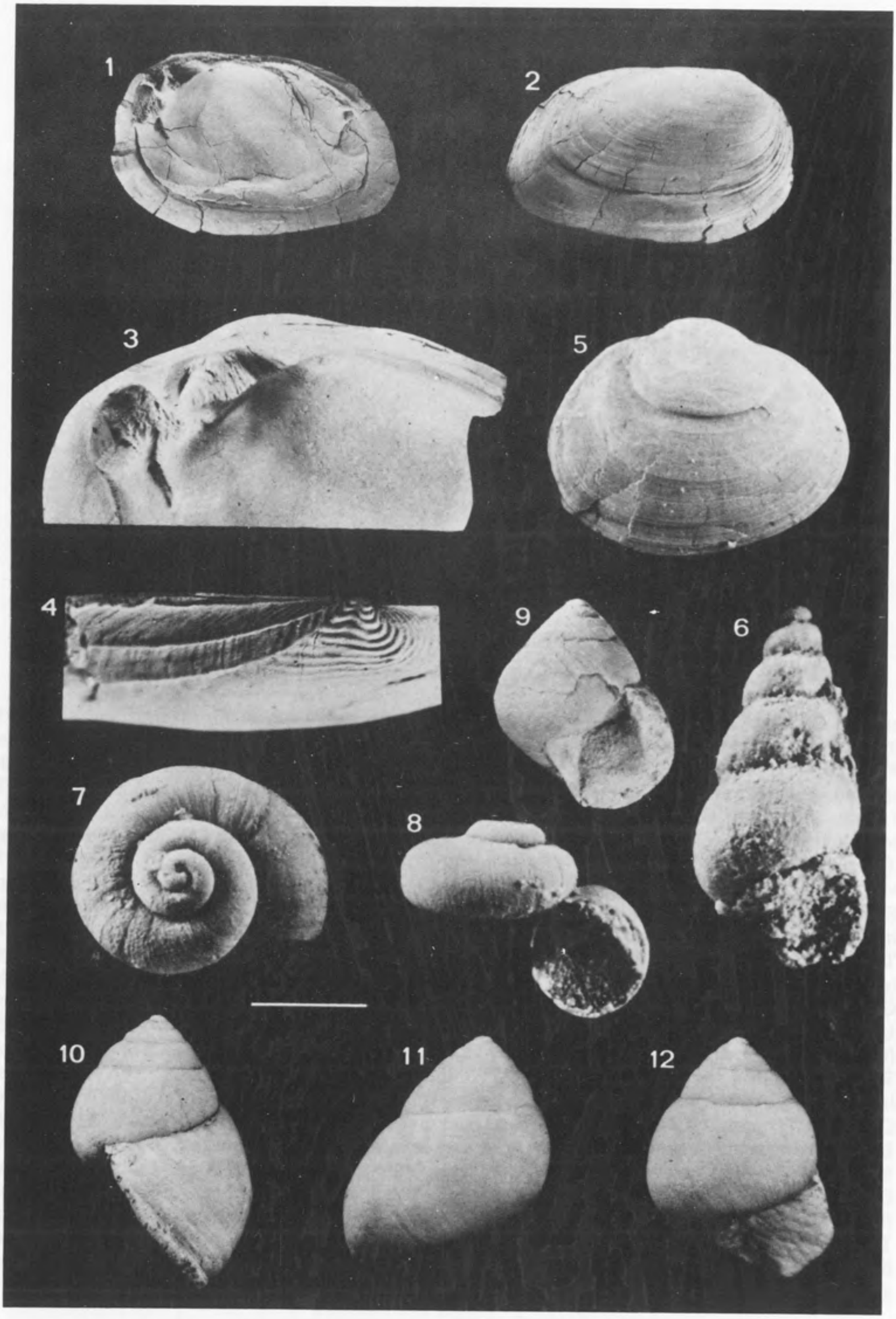

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Figure IV.7. Mollusks found in the Green River Formation. 1-4—*Plesielliptio* n. sp. A. (1) interior of right valve with lamellar cardinal tooth. USNM 210014, Luman Tongue of Green River Formation, Sweetwater County, Wyoming, X1.25. (2) dorsal margin of left valve with double looped juvenile umbonal sculpture intersected obliquely by growth lines, USNM 210017, Luman Tongue of Green River Formation, Sweetwater County, Wyoming, X6. (3) exterior of left valve with convex ventral margin and incomplete posterior shell tip, USNM 210000, Luman Tongue of Green River Formation, Sweetwater County, Wyoming, X0.75. (4) interior of left valve with lamellar cardinal teeth, USNM 210000, Luman Tongue of Green River Formation, Sweetwater County, Wyoming, X1.25. 5-11—*Goniobasis tenera* (Hall). (5) apertural view of mature specimen with incomplete juvenile whorls, hypotype USNM 210035, Fontenelle Tongue of Green River Formation, Lincoln County, Wyoming, X2. (6) abapertural view, spire incomplete, hypotype USNM 210039, Fontenelle Tongue of Green River Formation, Lincoln County, Wyoming, X2. (7) profile view, aperture and juvenile whorls incomplete, hypotype USNM 210032, Niland Tongue of Wasatch Formation, Sweetwater County, Wyoming, X2. (8) abapertural view, spire incomplete, hypotype USNM 210036, Luman Tongue of Green River Formation, Sweetwater County, Wyoming, X2. (9) abapertural view, juvenile whorls incomplete, hypotype USNM 210038, Luman Tongue of Green River Formation, Sweetwater County, Wyoming, X2. (10) abapertural view, spire incomplete, hypotype USNM 210040, Luman Tongue of Green River Formation, Sweetwater County, Wyoming, X2. (11) apertural view, aperture and juvenile whorls incomplete, hypotype USNM 210034, Luman Tongue of Green River Formation, Sweetwater County, Wyoming, X2. 12-13—*Viviparus trochiformis* (Meek and Hayden). (12) apertural view of mature specimen, hypotype USNM 210071, Niland Tongue of Wasatch Formation, Sweetwater County, Wyoming, X2. (13) abapertural view of immature specimen, hypotype USNM 210077, Luman Tongue of Green River Formation. Sweetwater County, Wyoming, X3. From Hanley, 1976. Photo courtesy of John Hanley.

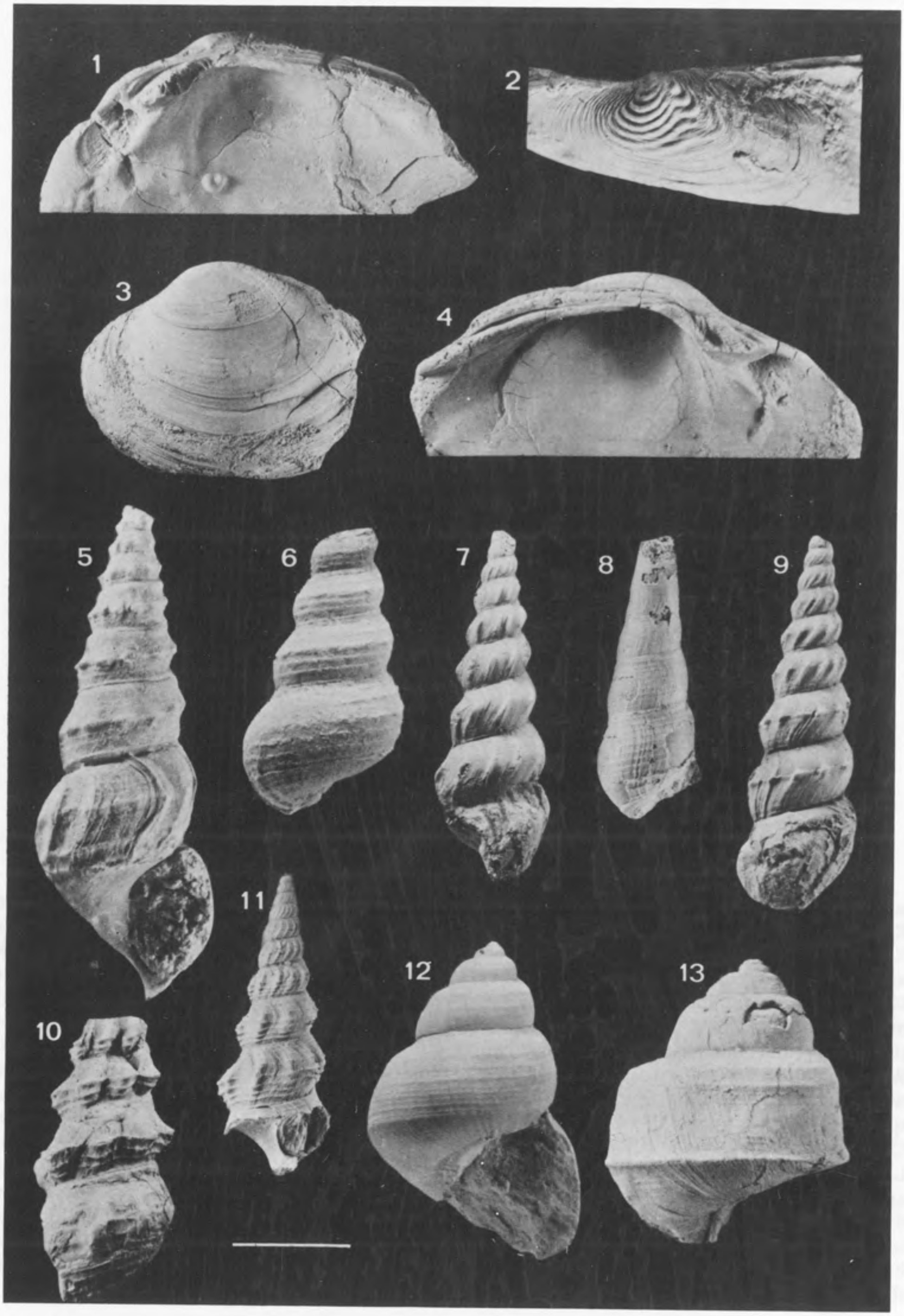
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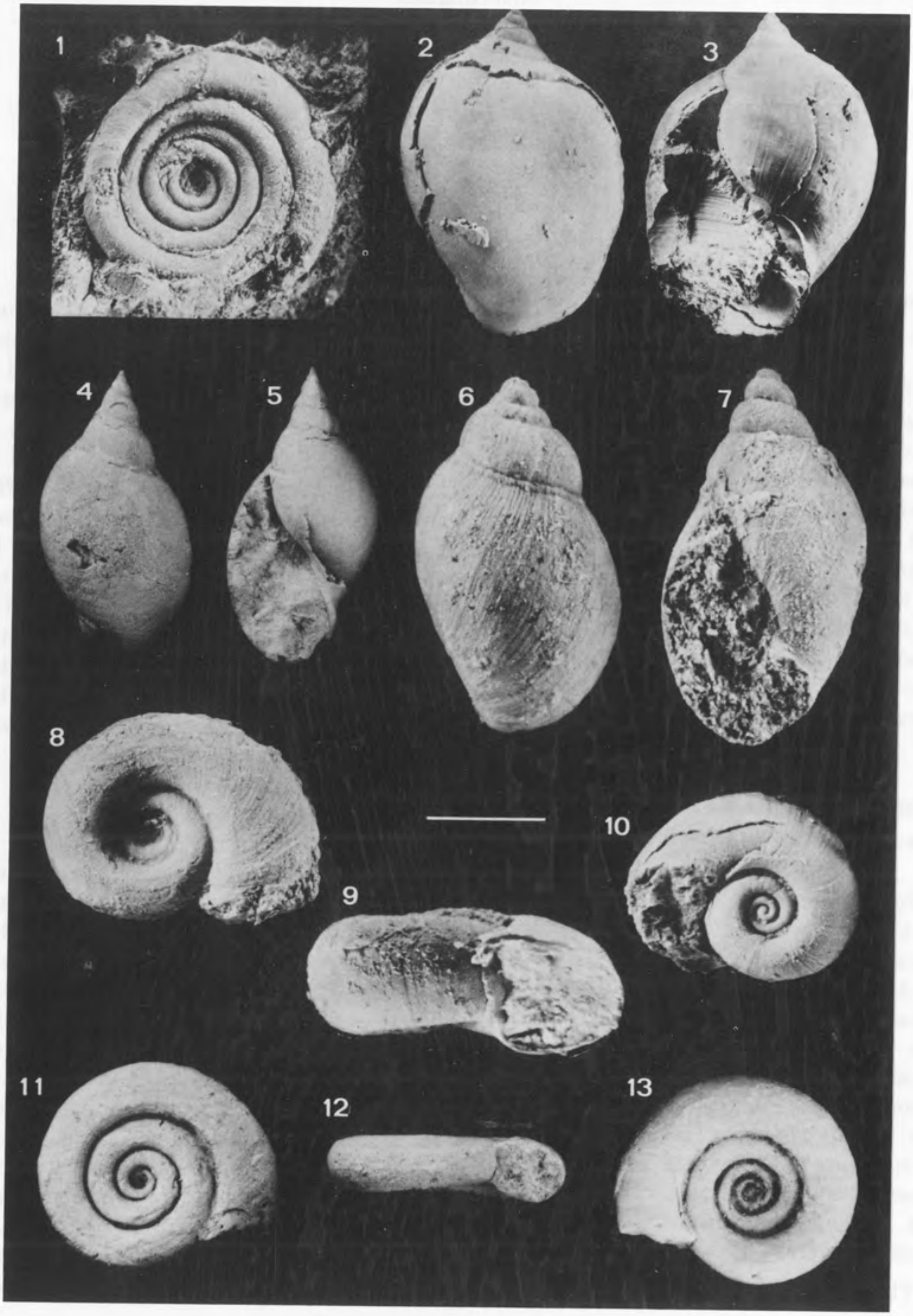
Figure IV.8. Mollusks found in the Green River Formation. (1) *Omalodiscus cirrus* (White). Right side, USNM 210121, main body of Wasatch Formation, Sweetwater County, Wyoming, X6. (2-3) *Physa pleromatis* White. Abapertural and apertural views, hypotype USNM 210094, main body of Wasatch Formation, Sweetwater County, Wyoming, X2. (4-5) *Physa bridgerensis* Meek. Abapertural and apertural views, hypotype USNM 210082, main body of Wasatch Formation, Sweetwater County, Wyoming, X1.75. 6-7—*Physa longiuscula?* (Meek and Hayden) (6) abapertural view, USNM 210088, main body of Wasatch Formation, Sweetwater County, Wyoming, X10. (7) apertural view, USNM 210086, main body of Wasatch Formation, Sweetwater County, Wyoming, X12. 8-10—*Biomphalaria aequalis* (White). (8) right side of mature specimen, hypotype USNM 210115, Laney Member of Green River Formation, Sweetwater County, Wyoming, X7. (9) apertural view of immature specimen, hypotype USNM 210116, Laney Member of Green River Formation, Sweetwater County, Wyoming, X12. (10) left side, aperture incomplete, hypotype USNM 210231, Laney Member of Green River Formation, Sweetwater County, Wyoming, X10. (11-13) *Biomphalaria storchi* (Russell). Right side, apertural view, and left side of mature specimen, hypotype USNM 210120, main body of Wasatch Formation, Sweetwater County, Wyoming, X3. From Hanley, 1976. Photo courtesy of John Hanley.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ANNELIDA

Possible annelid wormtrails have been found in Fossil Lake sediments (Paul Buchheim, personal communication).

ARTHROPODA

Subphylum: CHELICERATA

Class: ARACHNIDA (Spiders and mites)

Described arachnids from the Green River Formation include spiders (order Araneae) and ticks and mites (order Acarina). Green River mites (Family Chelytidae; see figure IV.9) are described and illustrated by Bradley (1931), ticks by Scudder (1890a), and a spider of the Family Linyphiidae ("sheet-web spider") by Cockerell (1925a, page 13; illustrated plate 1, figure 8). Spiders are extremely rare in the Green River Formation (see figure IV.10).

Subphylum: CRUSTACEA

Class: BRANCHIOPODA

Paul Buchheim (1978) reported the first occurrence of clam shrimp in the Green River Formation (see figure IV.11a). This specimen is obviously a conchostracan (clam shrimp) with only the bivalved shells preserved. Clam shrimp shells are easily distinguished from molluscan bivalves by their chitinous composition. (This can be tested with dilute HCl, which will completely dissolve the calcareous molluscan shells but leave the chitinous clam shrimp shells intact.)

The Green River form shown in figure IV.11a is probably of the genus *Cyzicus*, which is first known in the Devonian and survives today. *Cyzicus* is found in both fresh and brackish water deposits. Figure IV.11b shows the orientation of the shell to the body of the animal in the living *C. morsei.* Clam shrimp differ from ostracodes mainly in the body being not entirely enclosed in the bivalved shell, the shell sculpture, and the lack of a dorsal hinge in the shell. The Green River clam shrimp are from the Laney Member (Lake Gosiute sediments); several specimens are reposited in the Buchheim thesis collection at the University of Wyoming in Laramie.

Class: OSTRACODA

An ostracod is a tiny crustacean whose body is entirely enclosed in a dorsally hinged bivalve shell (see figure IV.12b). The sculpture or design on the outer surface of the shell is highly variable. These shells are commonly used as index fossils. Swain (1964) illustrates and describes many species of Green River ostracods. Ostracods are microfossils; in order to identify them, a microscope or a good handlens is needed. Figure IV.12a shows *Hemicyprinotus watsonensis* from G-1 (identified by Dr. F.M. Swain). This species occurs in vast numbers at that locality. Baer (1969, page

67) reported *Hemicyprinotus*, *Heterocypris*, *Procyprois*, *Potamocypris*, *Pseudoeucypris*, and *Cypridea* from Middle Eocene lacustrine phases of Lake Uinta, and *Procyprois* and *Hemicyprinotus* from Middle Eocene transition and deltaic phases of Lake Uinta. Oriel and Tracey (1970, page 32) reported *Hemicyprinotus watsonensis*, *Procyprois ravenridgensis*, and *Pseudocypris* sp. from the Fossil Butte and Angelo members of Fossil Lake sediments.

Suggested references are Swain, 1949; 1956; 1964.

Class: MALACOSTRACA

Malacostracans known from the Green River Formation are of two decapod taxa, *Procambarus primaevus* (Packard 1880), an astacid crayfish illustrated in figure IV.14, and *Bechleja rostrata* Feldmann, Grande and McCoy 1981, a palaemonid prawn illustrated in figure IV.13. Packard (1880, 1881a, 1881b) described "*Cambarus*" *primaevus* from Fossil Lake deposits (probably F-2). He failed to designate a holotype; and the referred specimens he used (illustrated 1881a, page 833) are lost. Feldmann et al. (1981) designated a neotype for "*C.*" *primaevus*, and assigned the species to the genus *Procambarus*.

Decapods from the Green River Formation are known almost exclusively from F-2 (mostly from the J.E. Tynsky 1971-1979 quarry). They occur there at about one to two times the frequency of the stingray, *Heliobatis* (see table II.10). Fossil fresh-water decapod species are very rare, known in North America only by the Green River forms and one other species, *Pacifastacus chenoderma* (Cope) (see Feldmann and Grande, in prep.) from the Miocene Payette Formation of Idaho and Oregon.

Probable molt parts of the Green River decapods occur occasionally, but not as often as nearly complete individuals. The decapods are sometimes found with ostracodes in their intestinal tract area, indicating that they may have fed on them at least occasionally. The modern bowfin *Amia calva* includes palaemonid prawns in its diet (Scott and Crossman, 1973, page 115), and, therefore, the Green River *Amia* species may have fed on the Green River palaemonids.

Extant palaemonid prawns are known from North America, South America, and Europe, and the genus *Bechleja* is known only from the late Oligocene or early Miocene of Czechoslovakia. For further information see Feldmann, Grande, Birkhimer, Hannibal and McCoy (1981).

Figure IV.9. The anterior half of a predaceous mite belonging to the Chelytidae, from Eocene Lake Uinta sediments of the Parachute Creek Member, x 325. Taken from Bradley, 1931.

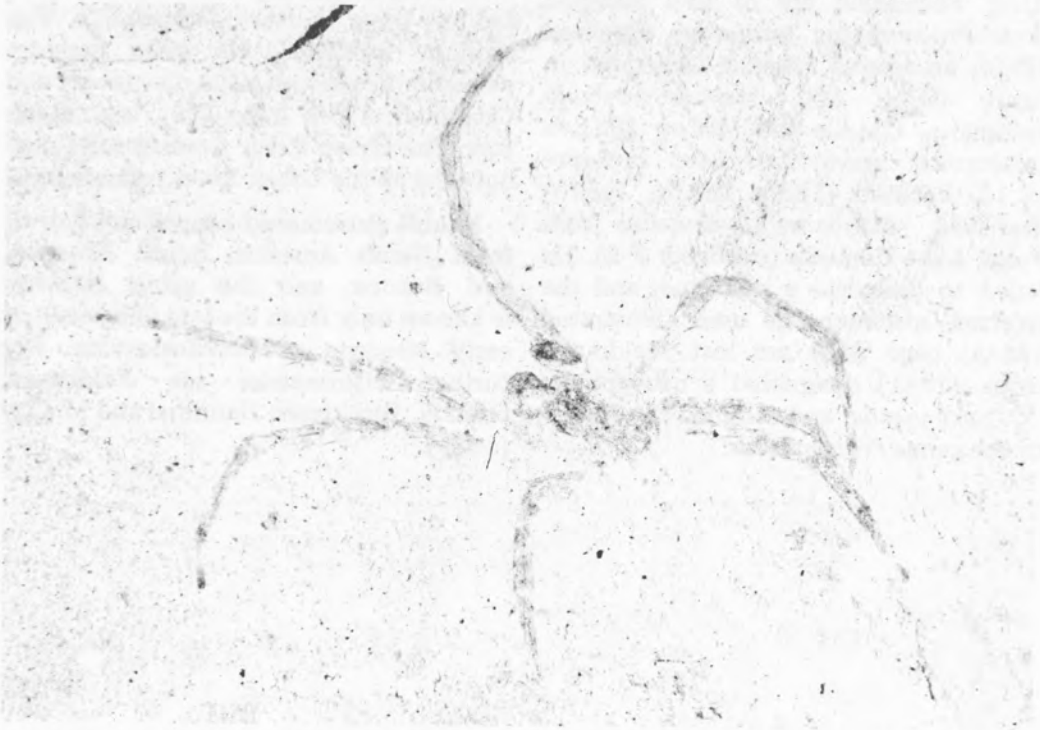

Figure IV.10. An undescribed spider from U-2 (BHI-GR 144). Length from farthest leg-tip to leg-tip 21 mm (about ¾ inches) ♂.

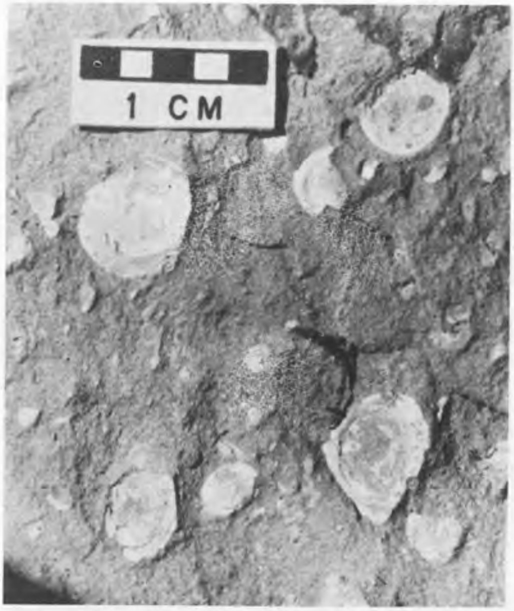

Figure IV.11a. Clamshrimp valves of the genus *Cyzicus* (uncataloged UW specimens) from the Laney Member of the Green River Formation (near G-3). Photo courtesy of Paul Buchheim.

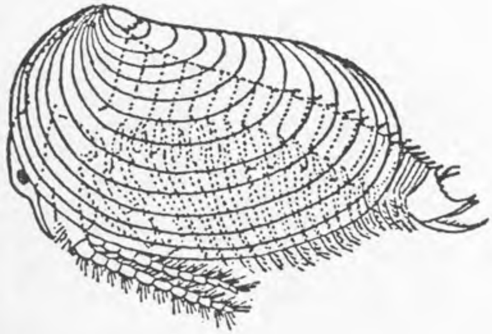

Figure IV.11b. A line drawing of the extant *Cyzicus morsei* showing the complete animal inside the valves (in dotted outline). Total length of this adult is about 1 cm (½ inch). Taken (with permission) from Moore, Lalicker, and Fischer, 1952.

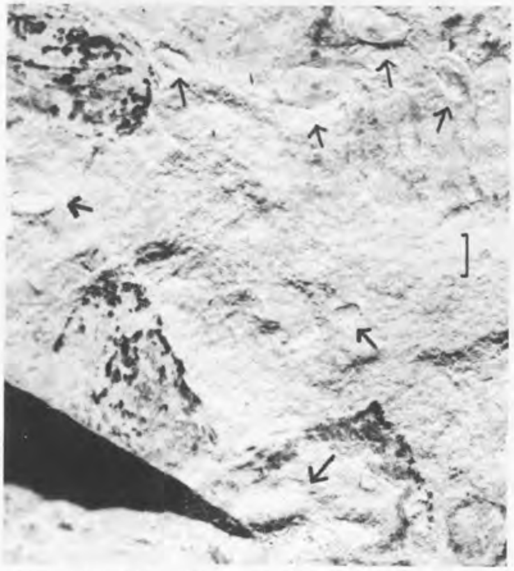

Figure IV.12a. The ostracod *Hemicyprinotus watsonensis* from G-1. Scale is 1 mm.

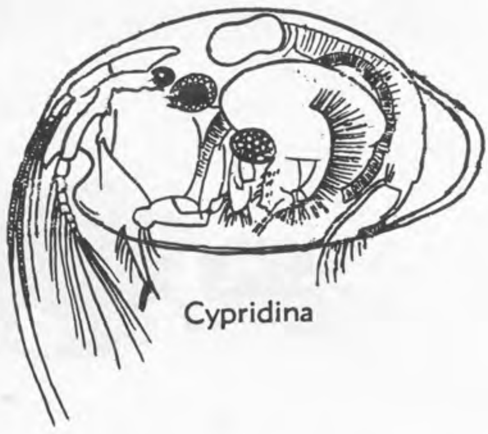

Figure IV.12b. A line drawing of the internal anatomy of *Cypridina*, an extant ostracod. Taken (with permission) from Moore, Lalicker, and Fischer, 1952.

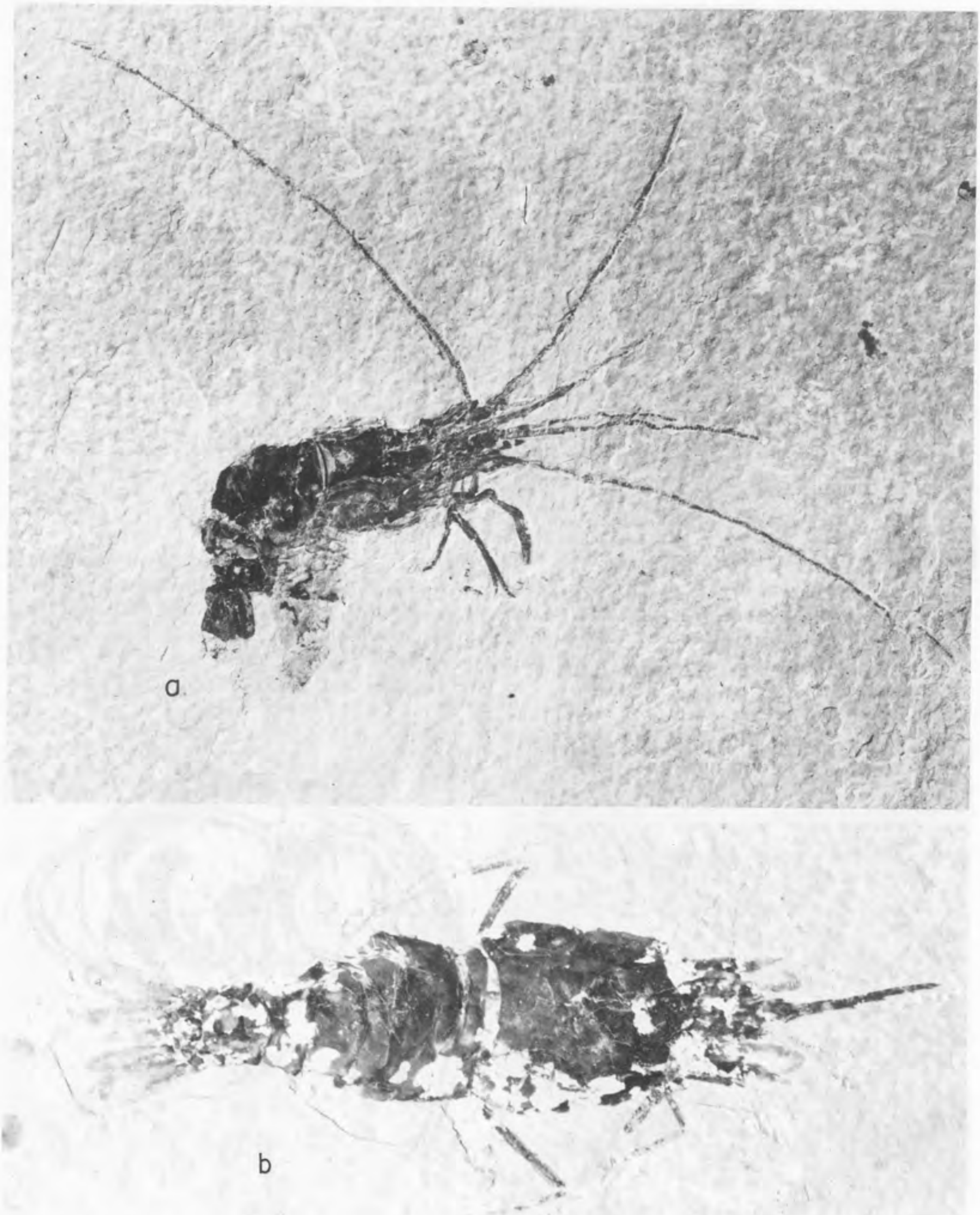

Figure IV.13. Prawns (*Bechleja rostrata*) from F-2. a. Lateral view (BHI-GR 86). Total axial length (not including antennae) is about 50 mm (2 inches). b. Dorsal view (BMNH In. 63226). Total length (not including antennae) is about 83 mm (3¼ inches).

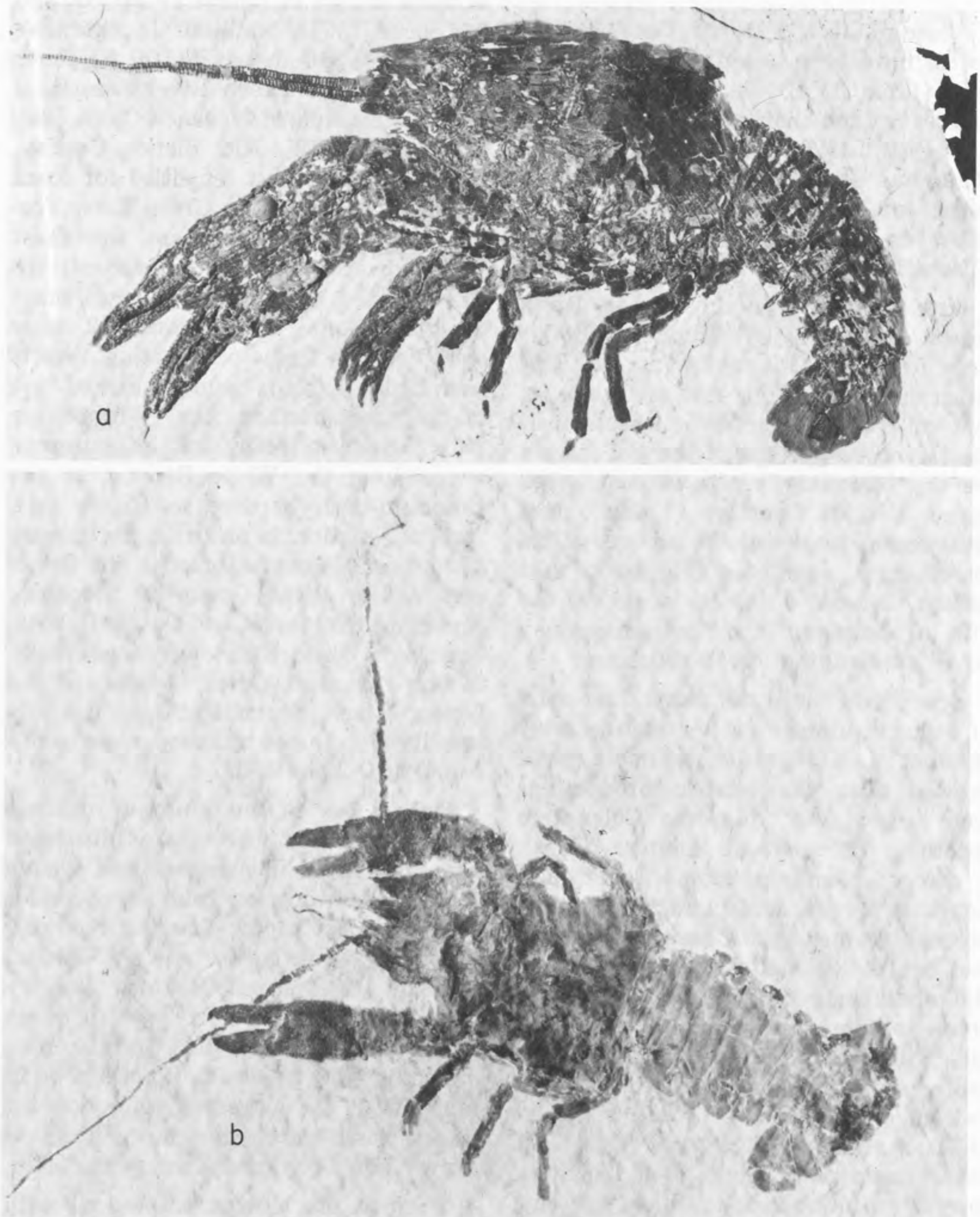

Figure IV.14 Crayfish, *Procambarus primaevus* (Packard), from F-2. a. Lateral view (BMNH In. 63227). Total axial length from claw tip to posterior end of telson is 9 cm (3½ inches). b. Dorsal view (SMMP 78.9.41). Total length (not including antennae) is about 5½ cm (2 inches).

Subphylum: INSECTA

About 300 species of Green River insects have been described. References here (table IV.2) will be given for families rather than genera or species: table IV.2 lists 14 orders and 90 families of insects found in the Green River Formation. Much of the information below on Green River insects is after Wilson (1978a).

Most of the Wyoming Green River insects described by Scudder (1890a) were found at G-3, a few at F-1. The insect fauna of F-1 is not as diverse as that of other Green River insect localities; over 80 percent of the F-1 insects are the bibionid fly, *Plecia pealei* (see figure IV.29). Scudder (1890a, page 585) found that over 96 percent of his insects from, near, or at F-1 were of that species. Most F-1 insects occur in the thin oil shale unit (the "bottom capping layer") underlying the 18-inch layer.

Scudder (1890b) tabulated the results of a single summer's collecting of Laney Member Lake Gosiute sediments and showed that the relative proportions were about 63 percent Coleoptera (beetles), 22 percent Diptera (flies), 9 percent Hemiptera-Homoptera (bugs, hoppers, aphids, and plant lice), and 3 percent Hymenoptera (sawflies, wasps, and ants). Cockerell (1921a) also noted the abundance of Coleoptera, Diptera, Hymenoptera, and Homoptera (especially Fulgoridae). Mosquitoes and mosquito pupae and larvae (*Culex?* sp.) are extremely common in some zones at G-1 (see figures IV.27 and IV.28). At the Farson, Wyoming, G-4 localities, insects are preserved, in much the same way as the fish, as external molds; consequently, only the larger specimens are easily spotted in the field.

In Lake Uinta, dipterous larvae such as those shown in figures IV.30, 32, and 34 occur by the millions in extensive beds about 340 meters (1100 ft) above the base of the Green River Formation on the west side of Piceance Creek (sec. 11, T1N, R97W, Rio Blanco County, Colorado). The best localities for fossil adult insects from the Green River Formation (where insects are the most dense, diverse, and best preserved) are U-2 and U-4, also excellent fossil plant localities. Some plants from U-2 show chew marks from plant-eating insects (see figure IV.16). Scudder named one of his insect horizons the "White River Beds" because many of its outcrops were along the White River near the Colorado-Utah border (see figure I.4). This designation is unfortunate because of its possible confusion with the Oligocene White River Group of Colorado, Wyoming, Nebraska, and South Dakota. Scudder's White River Beds are actually in the Parachute Creek Member of the Green River Formation, and include locality U-4. Insect trails are occasionally found at U-3 and U-5.

Only a few of the hundreds of kinds of Green River insects are illustrated here. For more illustrations and a large specific identification guide, see Scudder (1890a). Most of the Scudder type collection is reposited in the U.S. National Museum of Natural History. Bradley (1931) illustrates several types of insect larvae. A systematic list of references including all type descriptions is given in table IV.2. A suggested reference for insect classification and morphology is Borror, De Long, and Triplehorn, 1976.

There is much work to be done with the Green River insects. Many forms remain undescribed, and the fauna is in need of review. It would also be useful to compare the early Middle Eocene Green River insect fauna (G-1, G-3, G-4, U-2, and U-4) with a more detailed study of the late Early Eocene Green River insect fauna of F-1.

Table IV.2. A systematic list of insect families containing genera described from the Green River Formation. Reference Key: Bradley 1924 (a), 1931 (b), 1974 (c); Carpenter 1928 (d), 1955 (e); Cockerell 1908a (f), 1908b (g), 1909a (h), 1909b (i), 1916a (j), 1921a (k), 1921b (l), 1921c (m), 1925a (n), 1925c (o), 1933 (p); Cockerell and Le Veque 1931 (q); Durden and Rose 1978 (r); Forbes 1931 (s); Hull 1945 (t), 1949 (u); Scudder 1890a (v), 1890b (w), 1892 (x), 1893 (y), 1894 (z). Mostly modified after Wilson (1978a).

Order Family	(Common Name)	References
Odonata (dragonflies and damselflies)		
Chlorocyphidae	(damselflies)	n
Calopterygidae	(damselflies)	h,j,k,v
Libellulidae	(common skimmers (dragonfly))	l
Blattodea (Cockroaches or roaches)		
Blattidae	(cockroaches)	v
Orthoptera (grasshoppers, crickets, and kin)		
Gryllidae	(crickets)	l,w
Acrididae	(short-horned grasshoppers)	i,v
Ephemeroptera (Mayflies)		
Baetidae	(mayflies)	v
Epehmeridae	(mayflies)	v
Psocoptera (Psocids)		
Psocidae	(psocids)	v
Hemiptera (Bugs)		
Reduviidae	(assassin bugs)	v
Coreidae	(leaf-footed bugs)	h,v,w
Saldidae	(shore bugs)	v
Lygaeidae	(seed bugs)	v,w
Cydnidae	(burrower bugs)	v,h
Pentatomidae	(stink bugs)	v
Gerridae	(water striders)	v
Gelastocoridae	(toad bugs)	v
Homoptera (Hoppers, Cicadas, Aphids, and kin)		
Cixiidae	(planthoppers)	v
Delphacidae	(planthoppers)	n,v

Order Family	(Common Name)	References
Fulgoridae	(planthoppers)	h,k
Ricaniidae	(planthoppers)	v
Flatidae	(planthoppers)	k,v
Cercopidae	(froghoppers, spittlebugs)	k,v,w
Cicadellidae	(leafhoppers)	k,n,v
Aphididae	(aphids and plant lice)	v?
Pemphigidae	(woolly and gall making aphids)	w
Thysanoptera (Thrips)		
Aeolothripidae	(broad winged or banded thrips)	v
Coleoptera (Beetles)		
Carabidae	(ground beetles)	f,k,l,n,v
Cicindelidae	(tiger beetles)	k?
Dytiscidae	(predaceous diving beetles)	v
Hydrophilidae	(water scavenger beetles)	v
Staphylinidae	(rove beetles)	v
Scarabeidae	(Scarab beetles)	v
Nosodendridae	(wounded-tree beetles)	v
Elateridae	(click beetles)	v,g
Anobiidae	(death watch beetles)	v (anobium)
Ptinidae	(spider beetles)	v,x
Nitidulidae	(sap beetles)	v
Cucujidae	(flat bark beetles)	v
Cryptophagidae	(silken fungus beetles)	v
Erotylidae	(pleasing fungus beetles)	v
Melandryidae	(false darkling beetles)	n
Mordellidae	(tumbling flower beetles)	n
Rhipiphoridae	(wedge-shaped beetles)	v
Cerambycidae	(long-horned beetles)	n
Bruchidae	(seed beetles)	v
Chrysomelidae	(leaf beetles)	v,k
Anthribidae	(fungus weevils)	v,x,y
Attelabidae	(leaf-rolling beetles)	v,x,y
Curculionidae (=Rhynchitidae)	(snout beetles)	v,i,l,x,y
Scolytidae	(bark, engraver and ambrosia beetles)	v,x,y
Mecoptera (Scorpionflies)		
Bittacidae	(hangflies)	d
Diptera (Flies)		
Tipulidae	(crane flies)	v,g,k,n,z
Culicidae	(mosquitoes)	v,k
Chironomidae	(midges)	v,b
Bibionidae	(March flies)	v,h,j,k,n

Order Family	(Common Name)	References
Cecidomyiidae	(gall gnats)	v
Sciaridae	(dark-winged fungus gnats)	v
Mycetophilidae	(fungus gnats)	v,l,n
Tabanidae	(horse and deer flies)	b
Stratiomyidae	(soldier flies)	v,b
Acroceridae	(small-headed flies)	v
Asilidae	(robber flies)	k
Empididae	(dance flies)	k
Dolichopodidae	(long-legged flies)	v
Platypezidae	(flat-footed flies)	v
Syrphidae	(hover or flower flies)	k,n,q,t,u,v
Conopidae	(thick-headed flies)	v
Tephritidae	(fruit flies)	n
Sciomyzidae	(marsh flies)	v
Heleomyzidae	(helamyzid flies)	v
Anthomyiidae	(anthomyiid flies)	k
Eophlebomyiidae	(tsetse flies)	n,o
Muscidae	(muscid flies)	v
Tachinidae	(tachinid flies)	v
Oestridae	(warble and bot flies)	b
Trichoptera (Caddisflies)		
Hydropsychidae	(net-spinning caddis flies)	v
Hydroptilidae	(micro-caddis flies)	k
Limnephilidae	(northern caddis flies)	k,v
Sericostomatidae	(sericostomatids)	a,c
Lepidoptera (Butterflies and Moths)		
Yponomeutidae	(ermine moths)	p,q,s
Thyrididae	(window-winged moths)	p
Papilionidae	(swallowtails)	r
Lycaenidae	(gossamer-winged butterflies)	r
Hymenoptera (Sawflies, Ants, Wasps, Bees, and kin)		
Tenthredinidae	(common sawflies)	v
Ichneumonidae	(ichneumonid wasps)	k,q,v
Braconidae	(braconid wasps)	v
Chalcididae	(chalcidid wasps)	v
Sphecidae	(sphecid wasps)	v
Formicidae	(ants)	m,v

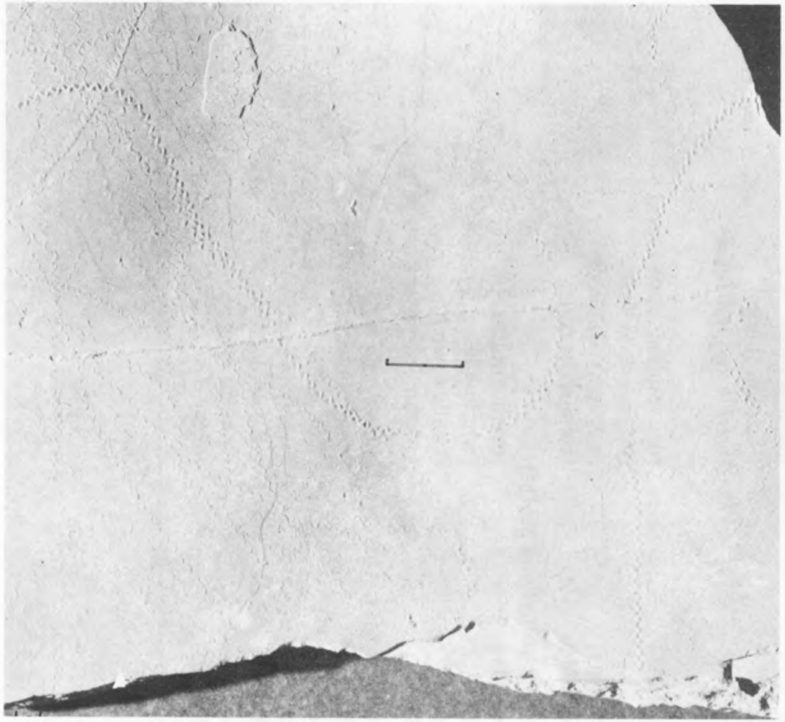

Figure IV.15. Fossil nematode trails from U-3 (SMMP 78.9.42). Scale is 1 cm.

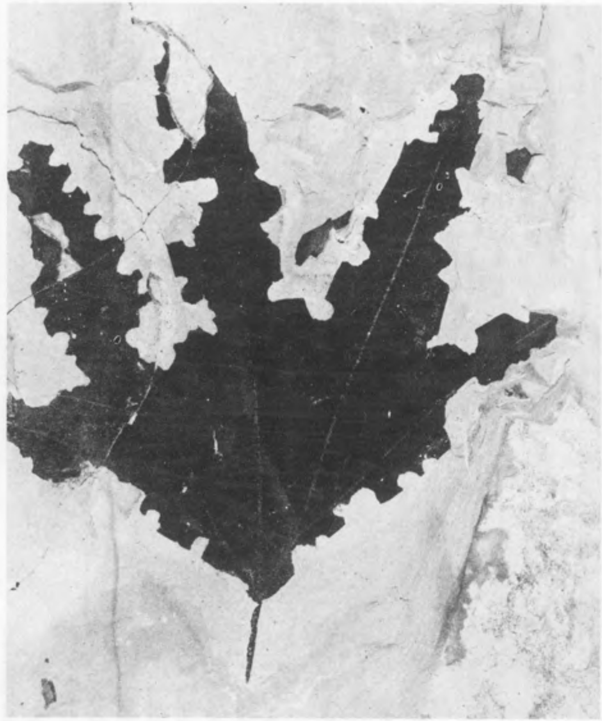

Figure IV.16. Sycamore leaf (*Platanus wyomingensis*) from U-2 (BHI-GR 142) with chew marks from an adult insect or insects. Length is about 15 cm (6 inches).

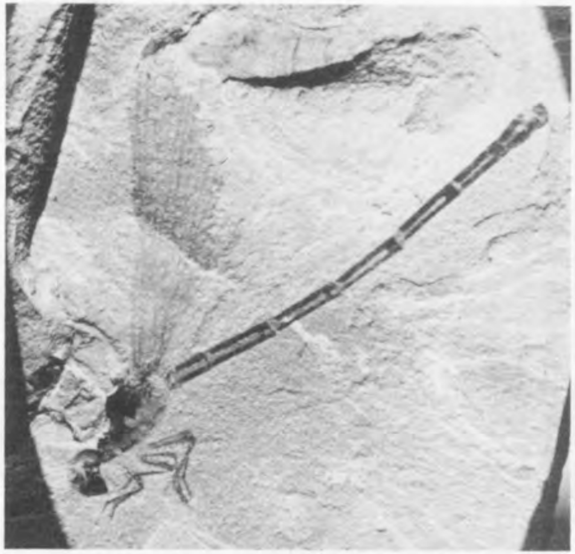

Figure IV.17. Damselfly from U-2, lateral view. Length is 35 mm (about 1½ inches). Private collection, photo courtesy of Allen Graffham and Harold Denison.

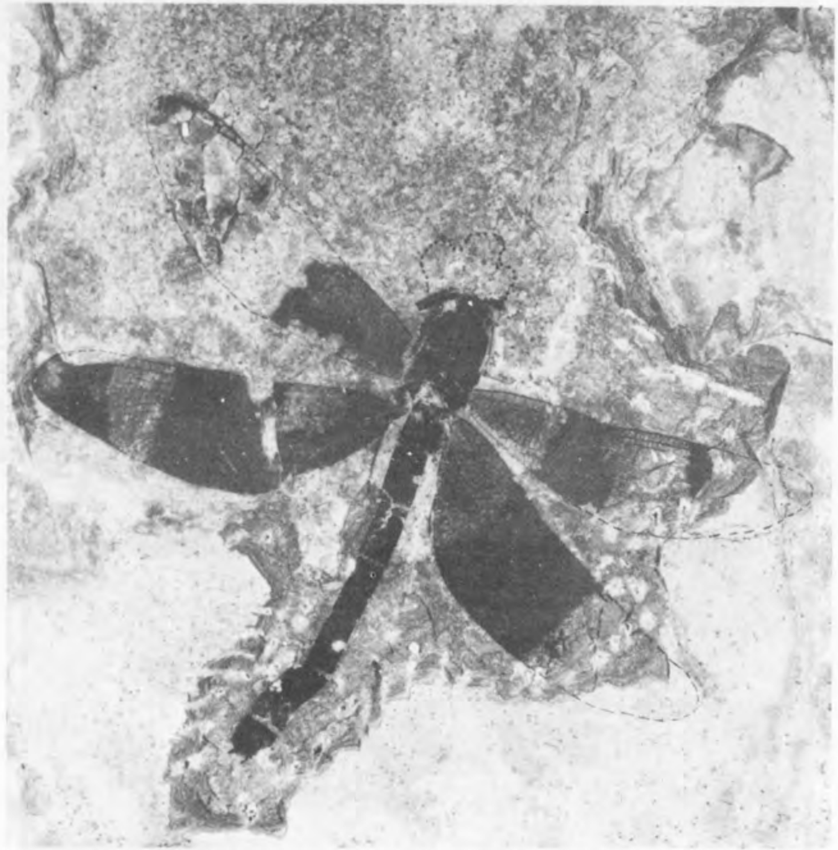

Figure IV.18. Dragonfly (family Libellulidae) from U-2 (BHI-GR 106), dorsal view showing color pattern of wings. Length is about 5 cm (2 inches).

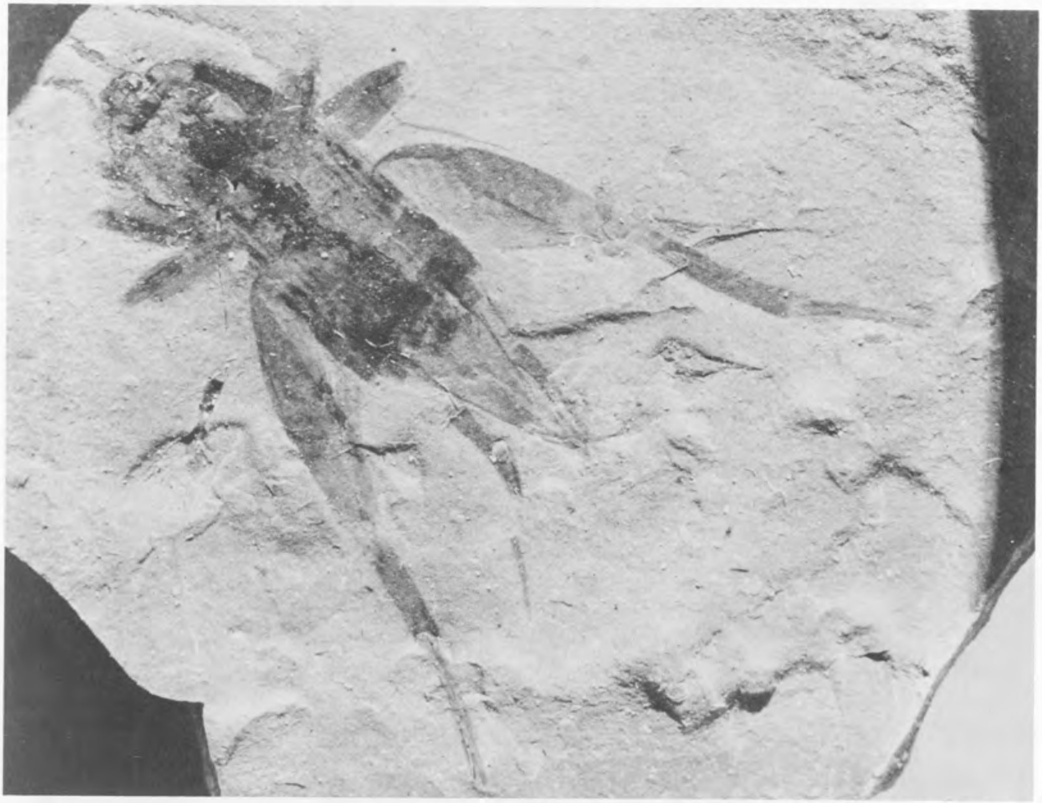

Figure IV.19. *Pronemobius smithii*, a cricket (family Gryllidae) from U-2. Body length is 2 cm (¾ inch). Private collection, photo courtesy of Allen Graffham and Harold Denison.

Figure IV.20. *Telmatrechus parallelus*, a water strider (family Gerridae) from G-1. Length is 2 cm (¾ inch). Private collection of Mr. and Mrs. James Rogers of LaBarge, Wyoming.

Figure IV.21. A planthopper (family Fulgoridae) from F-1 (BMNH In.64612). Length is 1 cm (about ½ inch).

Figure IV.22. *Eugnamptus* sp., a snout beetle (family Curculionidae) from F-1 (BMNH In.64613). Length is 9 mm (3/8 inch).

Figure IV.23. Scarab beetle (family Scarabeidae) from U-2. Length is 22 mm (7/8 inch). Private collection, photo courtesy of Allen Graffham and Harold Denison.

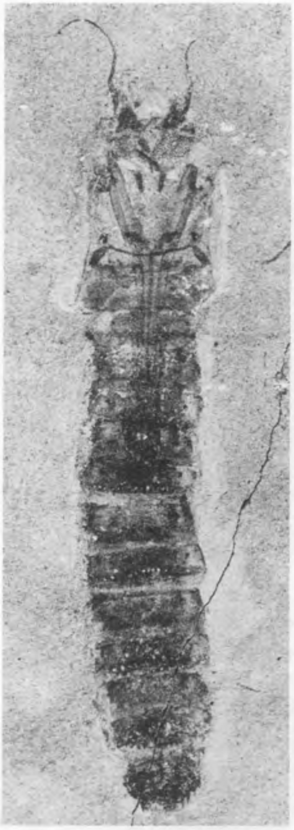

Figure IV.24. Ventral side of a cranefly pupa (family Tipulidae) from G-1 (BMNH In.64614). Length is 25 mm (1 inch). Adult head and thoracic structures are visible.

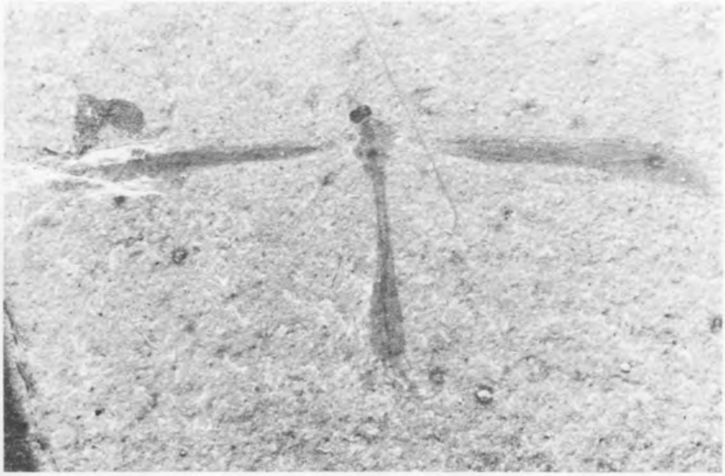

Figure IV.25. *Pronophlebia rediviva*, a cranefly (family Tipulidae) from U-2. Length is 25 mm (1 inch). Private collection, photo courtesy of Allen Graffham and Harold Denison.

Figure IV.26. Cranefly (family Tipulidae) from U-2 (FMNH PE39254). Length is 20 mm (3/4 inch). Tipulid flies are common at most Green River insect localities.

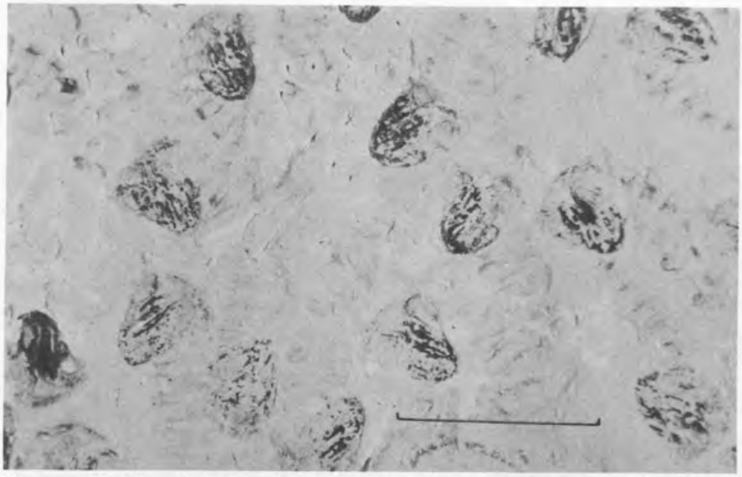

Figure IV.27. *Culex* sp?, mosquito larvae and pupae (family Culicidae) from G-1 (BMNH In.64615). Scale = 1 cm.

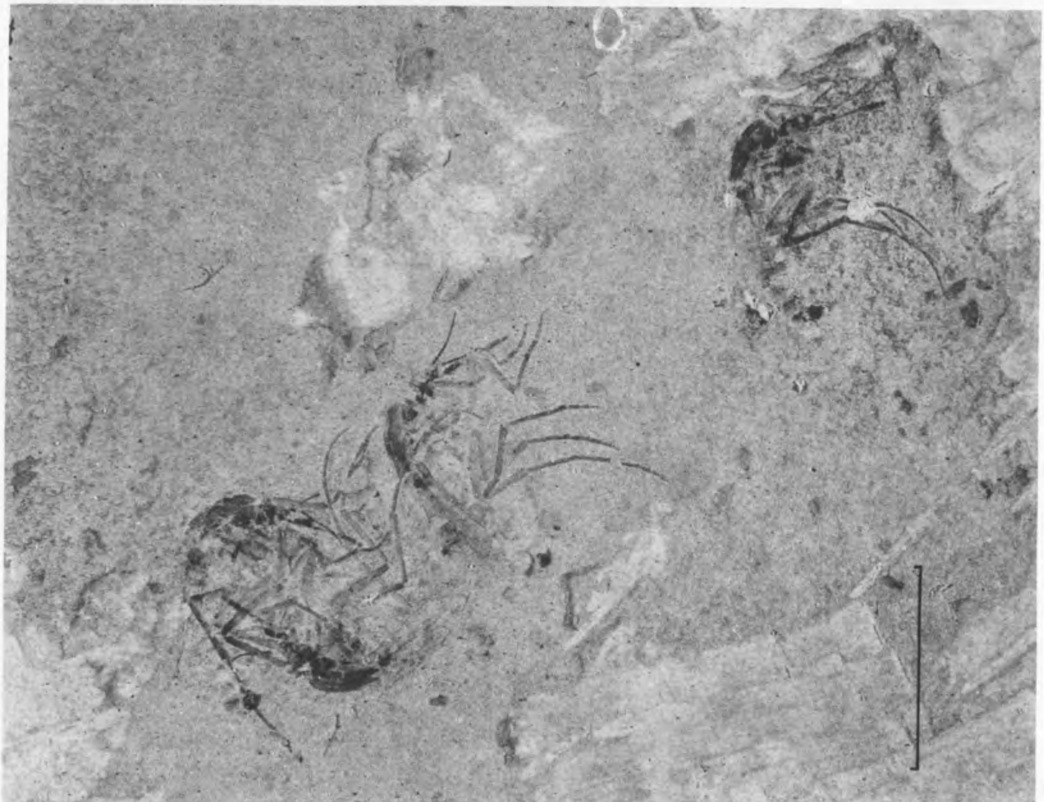

Figure IV.28. *Culex* sp., mosquito adults (family Culicidae) from a G-1 mass mortality layer of mosquito adults, pupae, and larvae containing millions of these insects (BMNH In.64616). Scale = 5 mm.

Figure IV.29. *Plecia pealei*, a march fly (family Bibionidae) from F-1. This is the most common insect from Eocene Fossil Lake. Body length is 11 mm (about ½ inch).

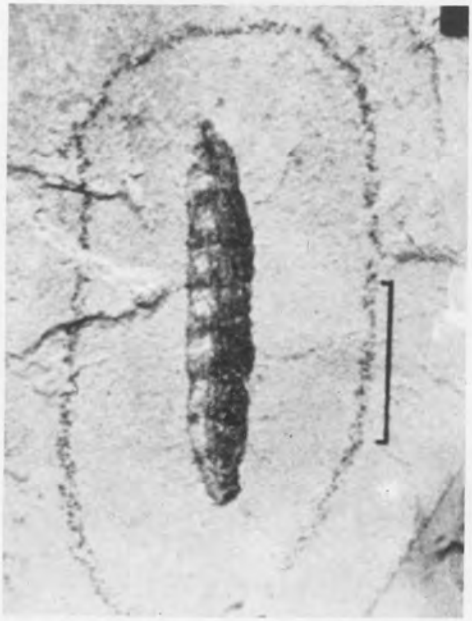

Figure IV.30. Horsefly larva (family Tabanidae) from Eocene Lake Uinta sediments of the Parachute Creek Member. Scale = 1 cm. Taken from Bradley, 1931.

Figure IV.31. Robber fly (family Asilidae) from G-3 (uncatalogued UW specimen). Axial length of body 19 mm (¾ inch).

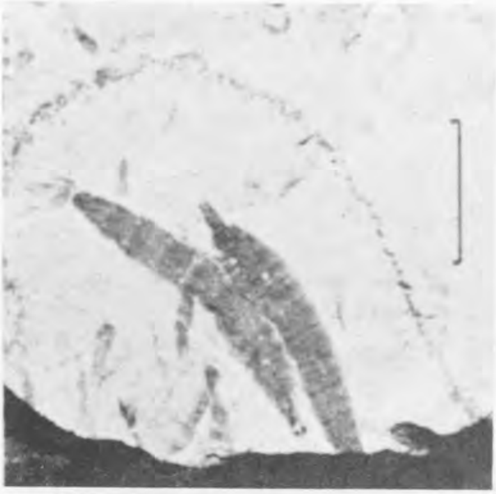

Figure IV.32. Hover fly larvae (family Syrphidae), from Eocene Lake Uinta sediments of the Parachute Creek Member. Scale = 1 cm. Taken from Bradley, 1931.

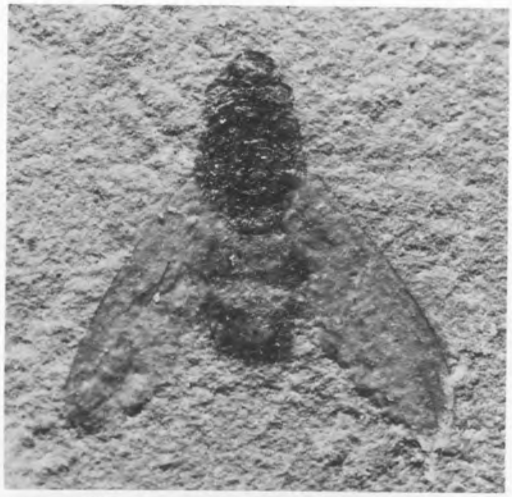

Figure IV.33. Adult hover fly (family Syrphidae) from U-2. Body length is 12 mm (½ inch). Private collection, photo courtesy of Allen Graffham and Harold Denison.

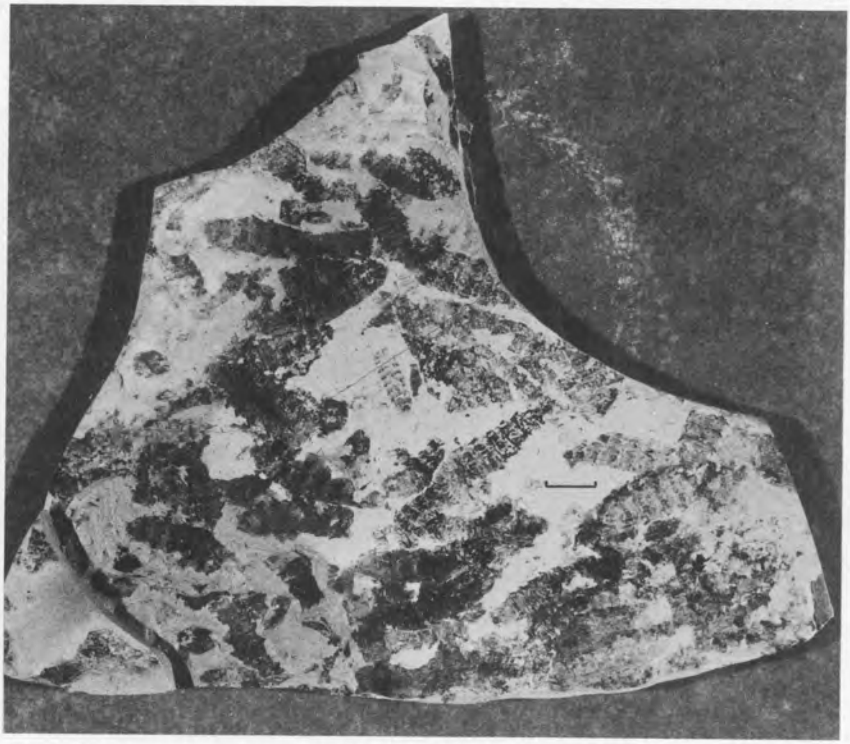

Figure IV.34. *Lithophypoderma* sp., (BMNH In.64617), bot fly larvae (family Oestridae) from Eocene Lake Uinta sediments of the Parachute Creek Member. Scale = 1 cm.

Figure IV.35. Unidentified moth from U-2. Body length is about 1 cm (½ inch). Private collection, photo courtesy of Allen Graffham and Harold Denison.

Figure IV.36. Ermine moth (family Yponomeutidae) from U-2. Body length is about 1 cm (½ inch). Private collection, photo courtesy of Allen Graffham and Harold Denison.

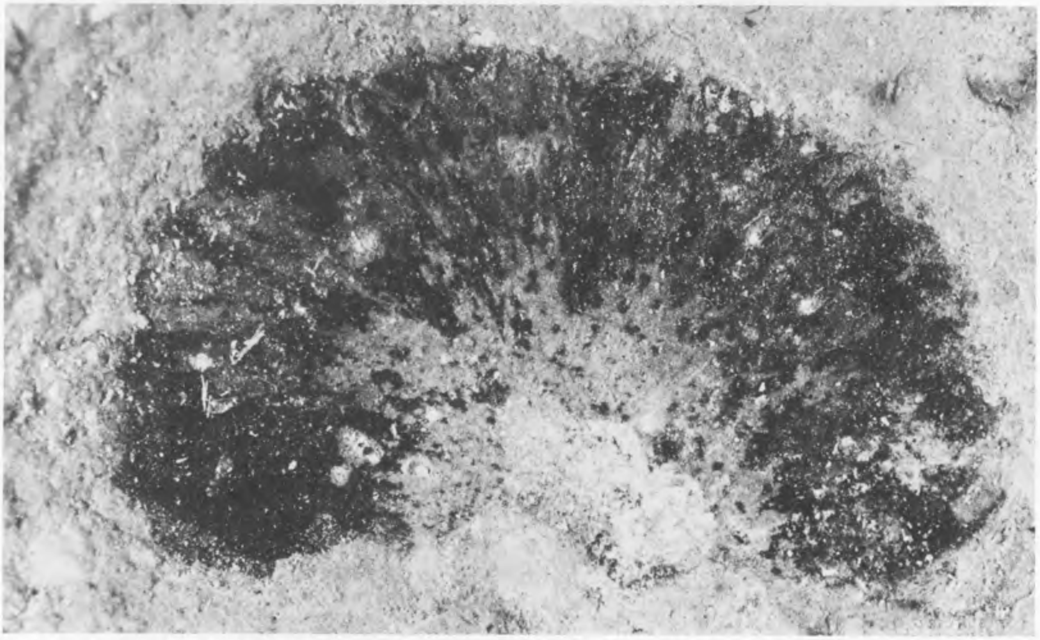

Figure IV.37. Unidentified caterpillar? from U-2 (BHI-GR 167). Axial length is 21 mm (about 1 inch).

Figure IV.38. *Praepapilio colorado* (family Papilionidae), a swallowtail butterfly from U-2 with some color pattern still preserved. Wing span is about 8 cm (3 inches). Hugh Rose Collection, Amherst, New Hampshire; photo courtesy of Christopher Durden.

Figure IV.39. *Liometopum* sp., an ant (family Formicidae) from G-1. Body length is about 1½ cm (½ inch). Private collection of James E. Tynsky, Rock Springs, Wyoming.

Figure IV.28. *Praepapilio colorado* (family Papilionidae), a swallowtail butterfly from U-2 with some color pattern still preserved. Wing span is about 8 cm (3 inches). Hugh Rose Collection, Amherst, New Hampshire; photo courtesy of Constance Darden.

Figure IV.29. *Lasius?* sp., an ant (family Formicidae) from U-1. Body length is about 1½ cm (½ inch). Private collection of James E. Tynsky, Rock Springs, Wyoming.

PART V

GREEN RIVER FOSSILS FROM KINGDOMS OTHER THAN ANIMALIA

INTRODUCTION TO PART V

Parts II through IV examine the animal kingdom (Animalia). Part V lists and illustrates some members of the other four kingdoms of living organisms, all present as fossils in the Green River Formation. Fossil members of the Kingdoms Monera, Protista, and Fungi are all exceedingly small, and need to be magnified 200 to 1200 times to be clearly visible. These microfossils are normally examined in thin sections under a microscope. The most common non-animal fossils from the Green River Formation are plants (Kingdom Plantae). Because of the space constraints of this paper, and because MacGinitie (1969) recently published a fine, well illustrated review of the Green River flora of Eocene Lake Uinta, the flora will not be covered in detail here. MacGinitie's monograph is strongly recommended to accompany this paper as a field guide for identification of Green River macrofossils.

MONERA

The kingdom Monera contains the simplest and least highly organized kinds of life. This group of single-celled organisms consists of bacteria and blue-green algae, which differ from all other life in that they have no well-differentiated nucleus within the cell. Both bacteria (figure V.1) and blue-green algae (Bradley, 1931, plate 19, figures 8-10) are known from the Green River Formation. Blue-green algae commonly make dome-like structures called stromatolites; such structures are common at some Green River localities, especially in Eocene Lake Gosiute and Lake Uinta sediments (see figure V.2). Since blue-green algae need light, stromatolites indicate fairly shallow conditions of low turbidity (clear water). Bradley (1928) describes, discusses, and illustrates several types of stromatolites from the Green River Formation. (See Surdam and Wray (1976) for additional references on Green River stromatolites.)

PROTISTA

The kingdom Protista contains single-celled organisms, each with a well-differentiated nucleus surrounded by a nuclear membrane. Two groups of protistans, the flagellates and sarcodines, are known from the Green River Formation and are described and illustrated by Bradley (1931). The green algae (see figure V.3) are classed by different authors as members of either the Protista or the Plantae, because they possess characters of both groups.

FUNGI

The kindgom Fungi (see figure V.4), which contains the molds, is represented in the Green River Formation by several forms, some of which are illustrated and described by Bradley (1931;1964;1967) and Lesquereux (1878).

PLANTAE

The fossil flora of the Green River Formation is extensive and contains all sizes of specimens, from microscopic pollen (described and illustrated by Bradley, 1931; Wodehouse, 1932 and 1933; Ames 1959) to 2-meter (7-foot) palm fronds (see figures V.9 and V.5).

MacGinitie's (1969) review of the Green River flora is an excellent identification guide for the early Middle Eocene plant localities such as U-2, U-4, and G-1, and includes 149 photographs of leaves, branches, seeds, and flowers. Table V.1 is a systematic list of families and species described from the upper Parachute Creek Member of the Green River Formation (Eocene Lake Uinta sediments), which includes localities U-2 and U-4. All species listed in table V.1 are described and illustrated by MacGinitie. MacGinitie (1969, page 30) found that the eight most abundant species in all of the Parachute Creek localities he studies were (in descending order of abundance) *Mimosites coloradensis*, *Zelkova nervosa* (Keaki tree),

Table V.1. A systematic list of the megafloral species found in the Parachute Creek Member of the Green River Formation (Eocene Lake Uinta sediments). After MacGinitie, 1969.

Family Genus, species	(Common Name)
Schizaeaceae	
Lygodium kaulfussii	(climbing fern)
Pteridaceae	
Acrostichum hesperium	————
Aspleniaceae	
Asplenium delicatula	(spleenwort)
Asplenium serraforme	(spleenwort)
Salviniaceae	
Azolla berryi	————
Isoetaceae	
Isoëtites horridus	————

Family Genus, species	(Common Name)
Equisetaceae	
Equisetum winchesteri	(horsetail)
Pinaceae	
Pinus balli	(pine)
Pinus florissanti	(pine)
Taxodiaceae	
Sequoia cf. *affinis*	(redwood)
Typhaceae	
Typha lesquereuxi	(cattail)
Sparganiaceae	
Sparganium antiquum	(burweed)
Sparganium eocenicum	(burweed)
Potamogetonaceae	
Potamogeton rubus	________
Salicaceae	
Populus cinnamomoides	(poplar)
Populus wilmattae	(poplar)
Salix cockerelli	(willow)
Salix longiacummata	(willow)
Juglandaceae	
Engelhardtia uintaensis	________
Pterocarya roanensis	(wing nut)
Fagaceae	
Quercus cuneatus	(oak)
Quercus petros	(oak)
Ulmaceae	
Celtis mccoshii	(hackberry)
Zelkova nervosa	(keaki tree)
Proteaceae	
Lomatia lineatulus	________
Aristolochiaceae	
Aristolochia mortua	________
Berberidaceae	
Mahonia eocenica	(Oregon grape)
Menispermaceae	
Menispermites limaciodes	(moon seed)
Lauraceae	
Beilschmiedia eocenica	________
Lindera allardi	________
Ocotea coloradensis	________
Persea coriacea	________
Hammamelicaceae	
Distylium eocenica	________
Liquidambar callarche	________

Family Genus species	(Common Name)
Platanaceae	
Platanus wyomingensis	(sycamore)
Rosaceae	
Prunus stewarti	(rose)
Rosa hilliae	(rose)
Vauquelinia comptonifolia	(rose)
Leguminosae	
Caesalpinites falcata	____________
Caesalpinia pecorae	____________
Erythrina roanensis	____________
Gymnocladus hesperia	____________
Leguminosites lesquereuxiana	____________
Leguminosites regularis	____________
Mimosites coloradensis	____________
Swartzia wardelli	____________
Rutaceae	
Ptelea cassioides	(hop tree)
Simarubaceae	
Ailanthus lesquereuxi	(tree of heaven)
Burseraceae	
Bursera inaequalateralis	____________
Meliaceae	
Cedrela trainii	____________
Euphorbiaceae	
Aleurites glandulosa	____________
Anacardaceae	
Anacardites schinoloxus	____________
Astronium truncatum	____________
Rhus nigricans	(sumac)
Toxicodendron winchesteri	(bald cypress)
Celastraceae	
Celastrus winchesteri	____________
Aceraceae	
Acer lesquereuxi	(maple)
Dipteronia insignis	____________
Sapindaceae	
Allophylus flexifolia	____________
Athyana balli	____________
Cardiospermum coloradensis	(balloon vine)
Koelreuteria viridifluminis	(goldenrain tree)
Sapindus dentoni	(soapberry)
Thouinia eocenica	____________
Rhamnaceae	
Berchemiopsis paucidentata	____________

Family Genus, species	(Common Name)
Tiliaceae	
Triumfetta ovata	________
Malvaceae	
Hibiscus roanensis	(hibiscus)
Bombacaceae	
Ochroma murata	________
Sterculiaceae?	
Sterculia coloradensis	________
Myrtaceae	
Eugenia americana	________
Araliaceae	
Araliophyllum quina	________
Oreopanax elongatum	________
Symplocaceae	
Symplocos exilis	________
Styracaceae	
Styrax transversa	________
Oleaceae	
Osmanthus praemissa	________
Apocynaceae	
Apocynospermum coloradensis	________
Incertae sedis	
Carpites newberryana	________

Rhus nigricans (Sumac), *Platanus wyomingensis* (sycamore), *Cardiospermum coloradensis* (balloon vine), *Allophylus flexifolia*, *Populus cinnamomoides* (poplar), and *Leguminosites lesquereuxiana*. At his Wardell Ranch locality, he found 73 species of plant megafossils; 75 percent of the flora belonged to the 8 most common species (1969, page 30).

There are no comprehensive megafloral lists available for localities in Lake Gosiute or Fossil Lake. Brown (1934) listed species from the Green River deposits of Wyoming, but did not define localities. MacGinitie (1969, page 23) states that Brown's 1934 list of "species from the Gosiute Lake, Wyoming" is not actually a floral list from Lake Gosiute, but a list from both Lake Gosiute and Fossil Lake, and contains plants not only from different localities (including F-1, G-3 and others), but of different geologic ages as well (late Early Eocene to early Middle Eocene). Lesquereux (1878; 1883) listed fossil plants from "Green River Station," but, according to Dr. H.D. MacGinitie (personal communication), these too are probably from mixed localities and horizons. Several additional fossil plant species, including palms and other families not included in the list in table V.1, are described from other Green River localities by Brown (1928; 1934; 1936), Knowlton (1923), and Lesquereux (1873; 1878; 1883), but most of these species are in need of taxonomic revision, and others should be dropped. Much work is needed on the Lake Gosiute and Fossil Lake floras.

Locality G-1 contains numerous plant fossils, with *Platanus* sp. and *Equisetum* sp. particularly prevalent. A detailed floristic study of various localities and horizons in Lake Gosiute sediments would be very useful to compare with MacGinitie's data from Lake Uinta. Buchheim (1978, illustration only, plate 1, figure 3) reported the first lily pad from the Green River Formation from the Laney Member near G-3 (see figure V.7).

A few species of plants from Eocene Fossil Lake (probably F-1) are described and illustrated by Brown (1936). They include *Quercus castaneopsis* (oak), *Rhus longepetiolata* (sumac), *Acer lesquereuxi* (maple), *Sterculia coloradensis*, *Porana speirii*, and *Aleurites glandulosa* (=*Ficus mississippiensis*). Additional plants observed at F-1 include *Sabalites* sp. (palm; illustrated in figure V.5), *Typha* sp. (cattail; illustrated in figure V.6), *Pinus* sp. (figures V.9-11), *Populus cinnamomoides*, *Populus wilmattae* (poplar; illustrated in figure V.21), *Zelkova nervosa* (Keaki tree), *Prunus* sp. (rose), *Mimosites* sp., *Swartzia wardelli* (illustrated in figure V.14), *Bursera* sp., *Astronium truncatum* (a tropical flower; illustrated in figure V.12), *Rhus nigricans* (sumac; illustrated in figure V.15), and *Sapindus* sp. (soapberry; illustrated in figure V.20). Seeds from *Ailanthus* sp. (tree of heaven; illustrated in figure V.13) are very common at F-1.

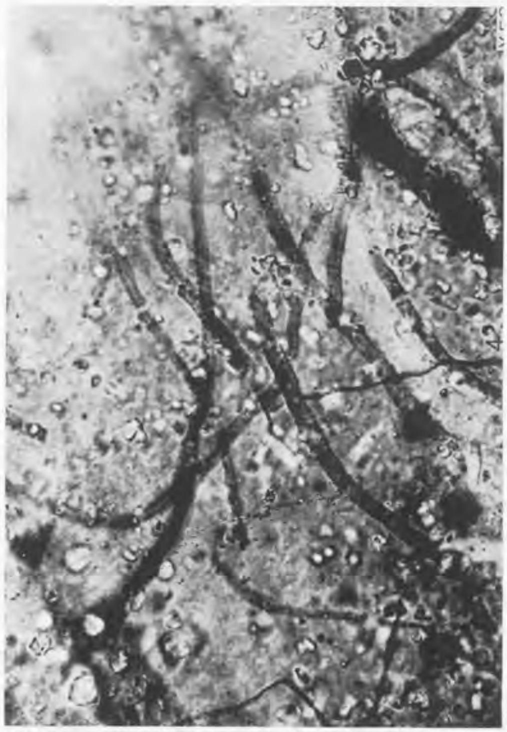

Figure V.1. Trichobacteria? (Monera), greatly enlarged, taken from Bradley, 1931. From Eocene Lake Uinta (Parachute Creek Member). [x260]

Figure V.2. Stromatolite from Eocene Lake Gosiute (Laney Member). Scale is 1 cm. Note the dome-like elements of the surface.

Figure V.3. *Eoglobella longipes*, a single alga-thallus (Protista or Plantae, depending on classification system used). Taken from Bradley, 1931. From Eocene Lake Uinta (Parachute Creek Member). [x400]

Figure V.4. Spores (Fungi), greatly enlarged, resembling ascospores or conidia. If the latter, they may be of a living genus like *Didymella*. From Eocene Lake Uinta (Parachute Creek Member). From Bradley, 1931. [x625]

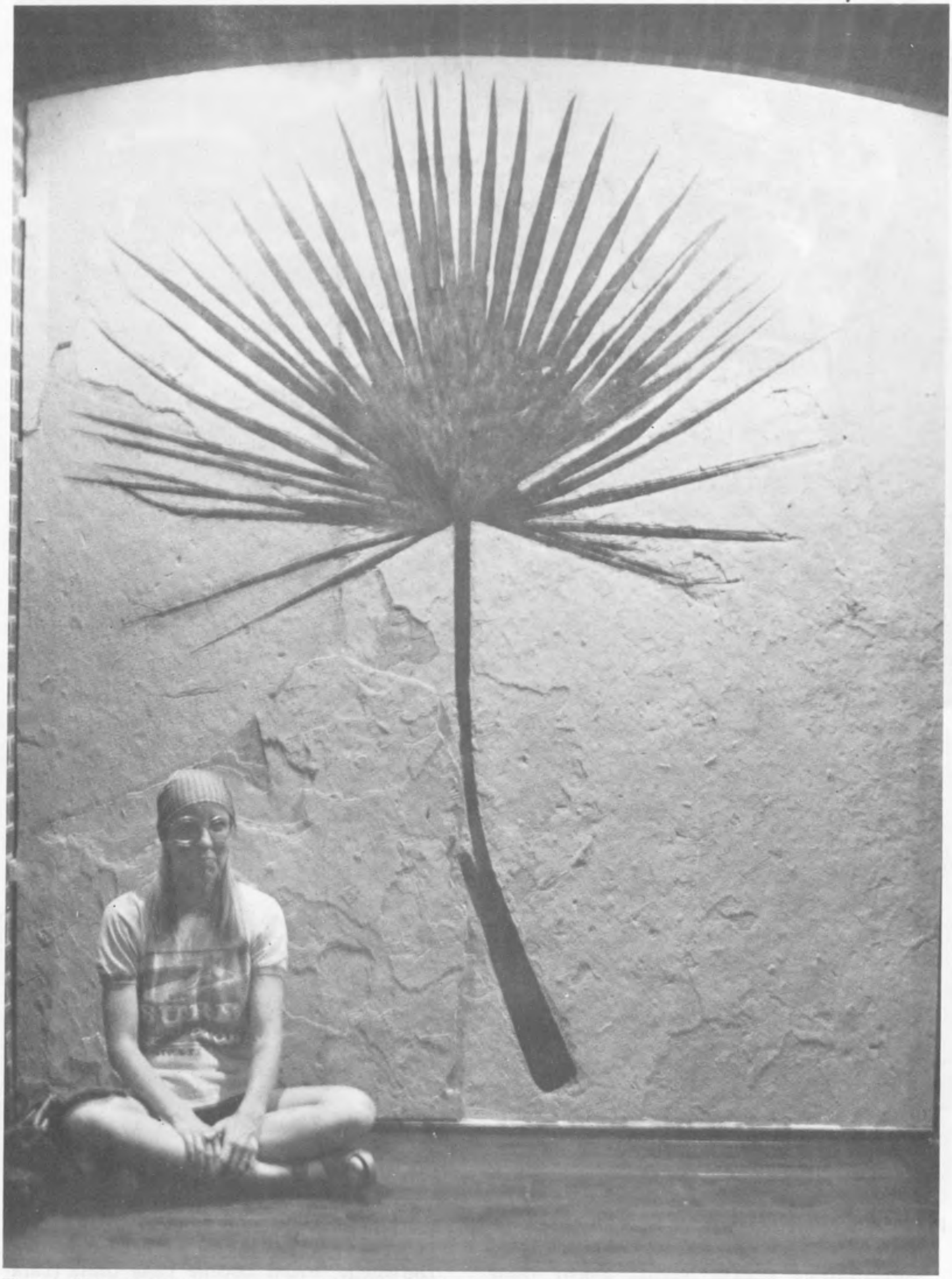

Figure V.5. *Sabalites* sp., a remarkably well preserved palm frond from F-1, about 2 meters (7 feet) long. On exhibit at Little America Restaurant, Salt Lake City, Utah.

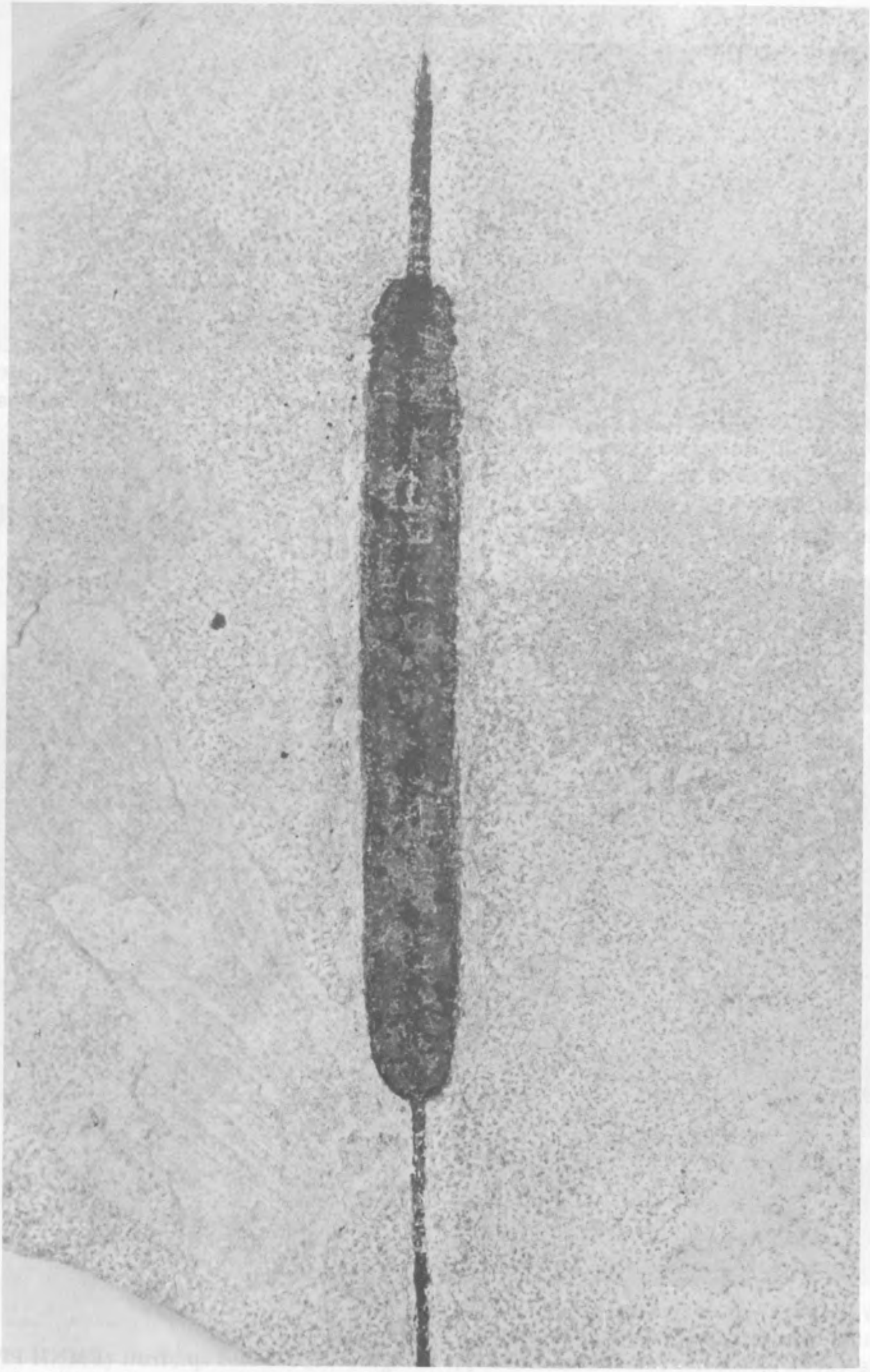

Figure V.6. *Typha* sp., a cattail from F-1 (FMNH PP33654). Length of head is 18 cm (7 inches).

Figure V.7. *Nelumbo* sp., a lilypad (uncataloged UW specimen) from the Laney Member of the Green River Formation. Scale is 2 cm. Photograph courtesy of Paul Buchheim.

Figure V.8. *Equisetum winchesteri*, horsetail (FMNH PP33656), from G-1. Scale is 1 cm.

Figure V.9. *Pinus* sp. (pine tree), pollen greatly magnified, from Lake Uinta sediments (Parachute Creek Member). Taken from Bradley, 1931. [x210]

Figure V.10. *Pinus* sp., fruit (FMNH PP33655) from F-1. Scale is 1 mm.

Figure V.11. *Pinus* sp., needles (BMNH V.62000) from F-1. Scale is 1 cm.

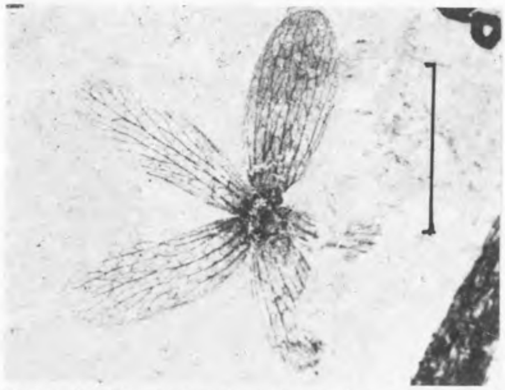

Figure V.12. *Astronium truncatum*, a tropical flower (UC PA20638). Scale is 1 cm. From Eocene Lake Uinta sediments (Parachute Creek Member). Photo courtesy of H.D. MacGinitie.

Figure V.13. *Ailanthus* sp. (tree of heaven), seed-pod from F-1 (BMNH V.62001). Length is about 3½ cm (1-1/3 inches).

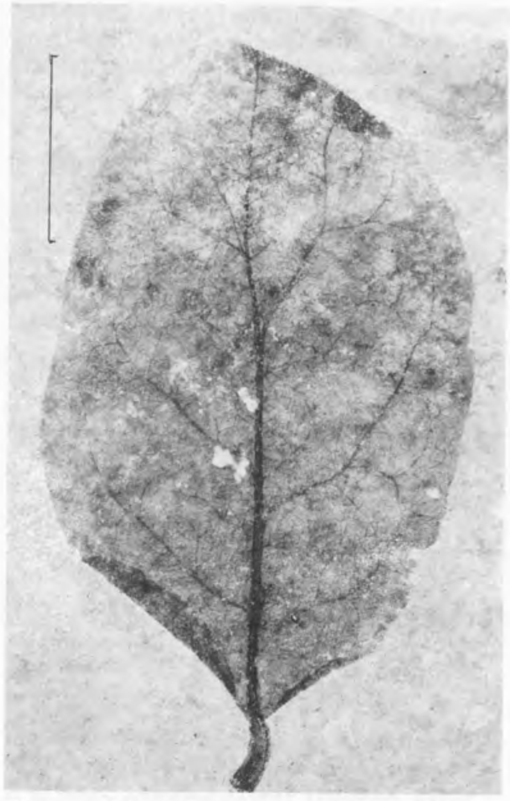

Figure V.14. *Swartzia wardelli*, (BMNH V.62002), from F-1. Scale is 1 cm.

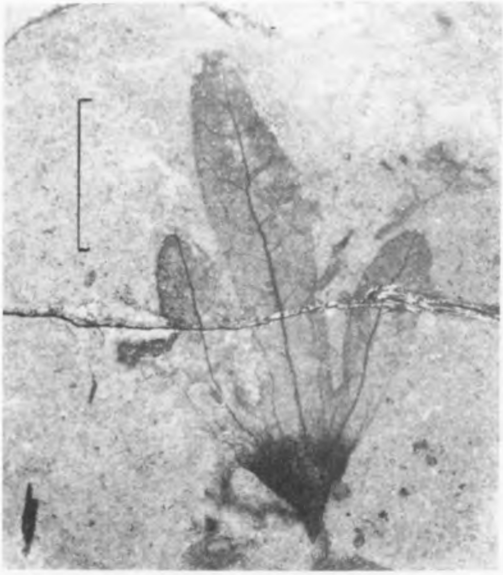

Figure V.15. *Engelhardtia uintaensis*, (UC PA20572) from Eocene Lake Uinta sediments (Parachute Creek Member). Scale is 1 cm. Photo courtesy of H.D. MacGinitie.

Figure V.16. *Rhus nigricans*, (Sumac) from F-1 (Uncataloged FBNM specimen). Scale is 1 cm.

Figure V.17. *Acer lesquereuxi* (Maple) from Eocene Lake Uinta sediments (Parachute Creek Member) (UC PA20564). Scale is 1 cm. Photo courtesy of H.D. MacGinitie.

Figure V.18. Unidentified plant with seeds from U-2 (BHI-GR 36). Scale is 1 cm.

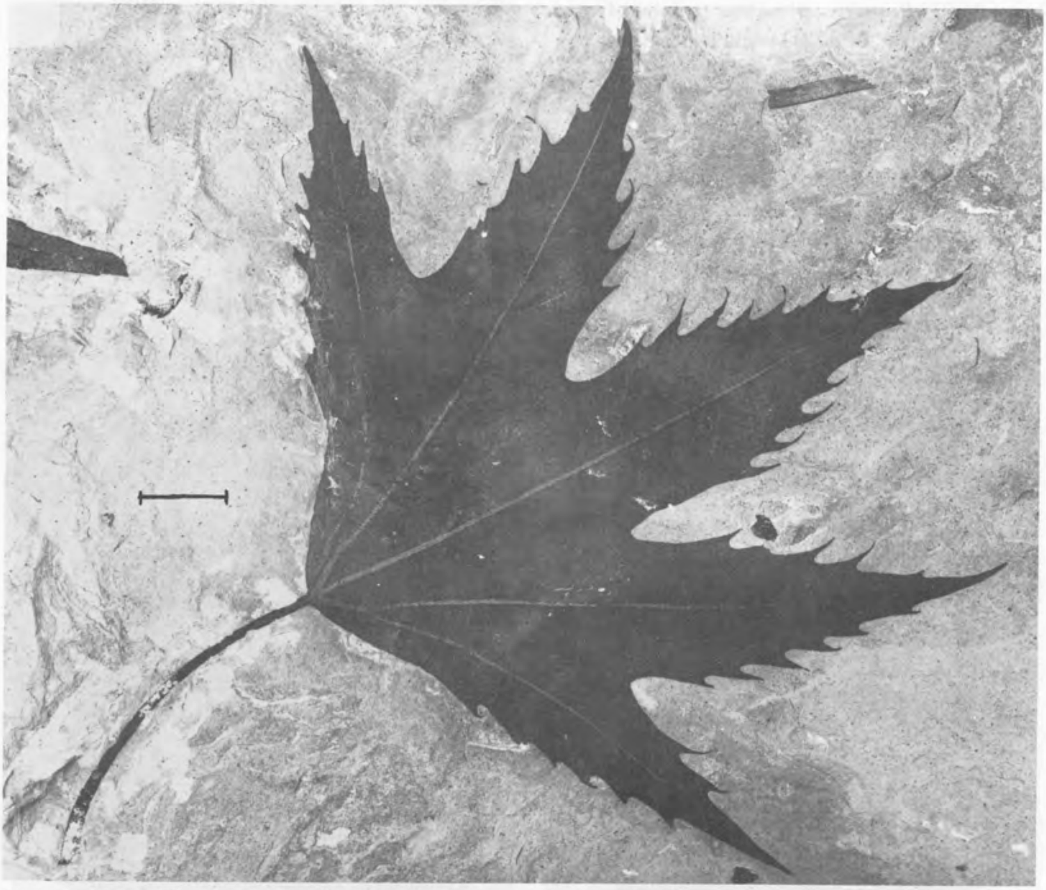

Figure V.19. *Platanus wyomingensis* (Sycamore) from Eocene Lake Uinta sediments (Parachute Creek Member) (UC PA20617). Scale is 1 cm. Photo courtesy of H.D. MacGinitie.

Figure V.20. *Sapindus* sp.? (soapberry) from F-1 (uncataloged FBNM specimen). Scale is 1 cm.

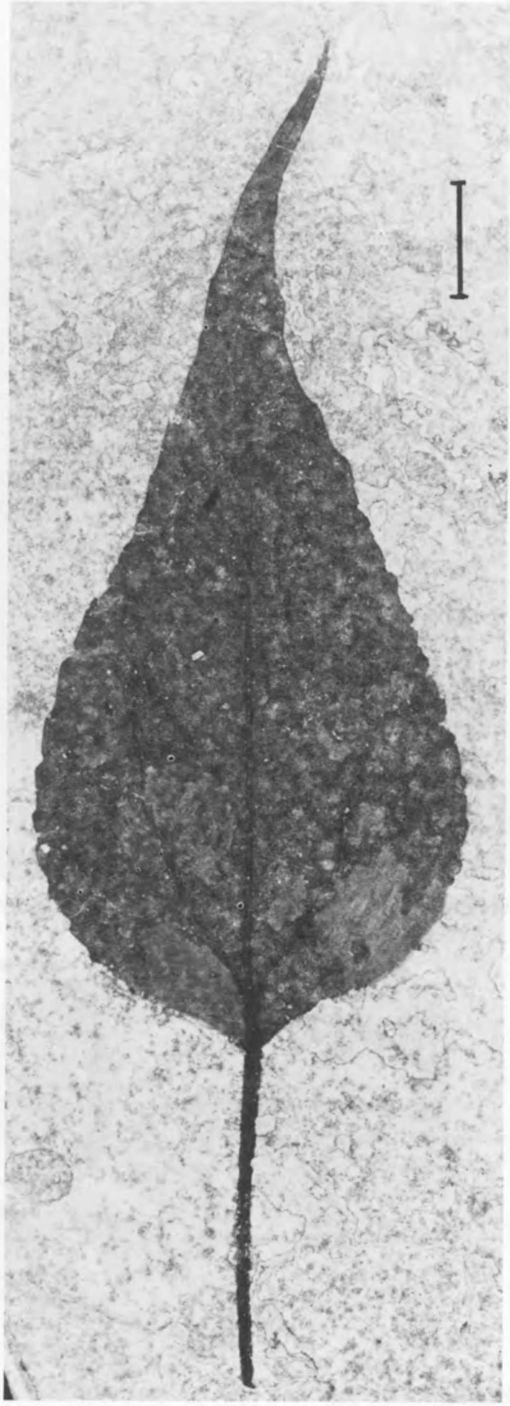

Figure V.21. *Populus wilmattae* (poplar) from F-1 (BMNH V.62003). Scale is 1 cm.

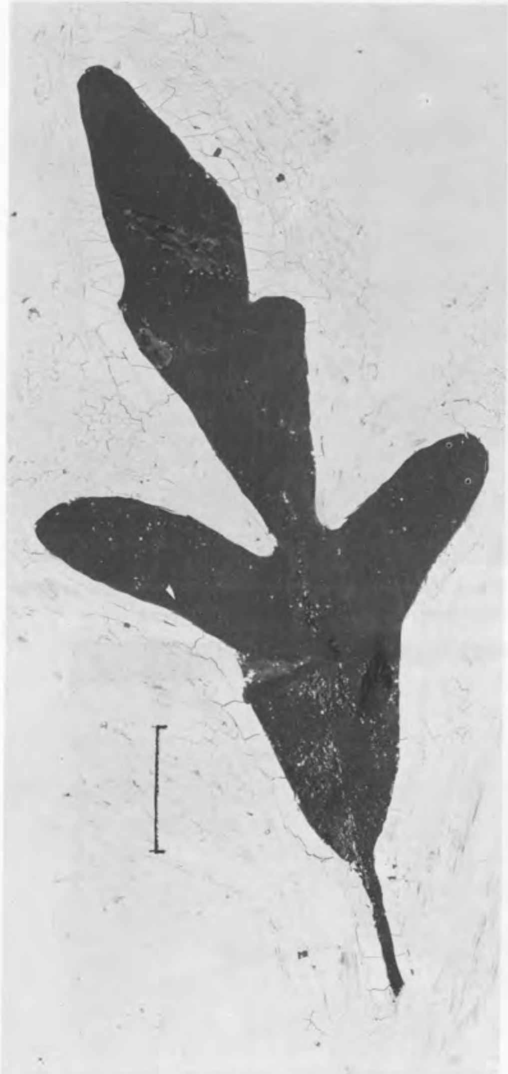

Figure V.22. *Cardiospermum coloradensis* (balloon vine) (UC PA20593) from Eocene Lake Uinta sediments (Parachute Creek Member). Scale is 1 cm. Photo courtesy of H.D. MacGinitie.

Figure V.23. Well preserved flower from F-1. Height of specimen is about 8 cm (3 inches).

APPENDIX I
PREPARATION TECHNIQUES

F-1 specimens: The best way to prepare vertebrate fossils from these quarries is to lightly scratch away the covering matrix with drill bits (or other hardened steel tools) sharpened to needle sharp points (see figure AI.2). Keeping preparation tools extremely sharp will eliminate the need to apply too much pressure, which can damage the specimen. If maximum detail is desired, the work should be done under a binocular microscope or magnifying glass. The limestone dust must constantly be blown off the specimen during preparation; by alternately scratching and blowing, the extremely fine detail of these specimens can be exposed. Unlike F-2 specimens, which often "split out" (a process which usually severely damages the specimen), F-1 specimens are almost always found with a 1-20 mm layer of matrix covering the fossil (see figures AI.2 and AII.5). Removal of this covering matrix can take from 5 to 10 hours on very small specimens and several hundred hours on larger specimens.

If the specimen is deeply buried in the matrix (¼ inch or deeper), the upper covering matrix can be rapidly removed to about 1/8 of an inch above the specimen to save time, since the fish is preserved within the plane of very few varves or even a single varve. Rapid removal of upper matrix is best done with a high speed air powered engraver such as an "Air-scribe"[1] with carbide tips sharpened to needle points. This tool is easy to handle and works quickly, but is expensive. Chiseling or rasping the upper matrix also works, although not as quickly or accurately. Chiseling should be done only on the upper matrix parallel to a varve, so that the resulting surface is flat and the outline of the large bones still shows under the lower matrix (see figure A.3).

F-1 vertebrate specimens of sufficient size (10 cm or greater) can be x-rayed prior to preparation (see figure AI.4) to guide in preparation. An Airbrasive[2] device can be used to prepare the vertebrae on large fish, but should never be used on any other parts of the fish or on the vertebrae of smaller fish. (The entire fish can be prepared with an Airbrasive device if a powder mixture of one part dolomite to four parts sodium carbonate is used, with only 20 to 25 pounds of air pressure. This is practical only on a specimen with a very thin covering of matrix.) Acid etching does not work on the calcium carbonate matrix. Several of Cope's type specimens in the U.S. National Museum (USNM 4008, 4043, and 3995) have been destroyed because of an apparent attempt to etch the specimens in acid.

F-1 specimens often have one side of the skull better articulated than the other (usually the lower side or the side that was buried first is better articulated). If the specimen is prepared from the wrong side, it can be imbedded in casting

[1] Chicago Pneumatic, New York.

[2] S.S. White Industrial Airbrasive.

epoxy or plastic and prepared from the other side (acid etching will work once the prepared side has been embedded in epoxy).

An art gum eraser will aid in removing fine dust film from the skin, scales, and fins of a specimen, but rubbing should be done only with light pressure to avoid damaging delicate bones. The most difficult fish to prepare is *Diplomystus*, which usually has very thin skin and scales, patches of which are often missing. The skin and scales of small *Diplomystus* (less than 10 inches in total length) are nearly always partly or completely missing. Commercially prepared *Diplomystus* and *Mioplosus* sometimes have considerable restoration of the skin (often skillfully done), especially in the posterior half of the body, which can always be detected with the aid of a binocular microscope.

Most of the F-1 specimens have a light buff to grayish white, brownish white, or orangish white, relatively soft matrix. Specimens in a dark grey or bluish grey matrix are from the thin oil shale units (the so called "capping layers") above and below the 18-inch layer. Capping layer specimens are much more difficult to prepare than normal 18-inch layer specimens, and small fish and *Diplomystus* from these layers are nearly impossible to prepare well. An Airbrasive device should be used on these difficult specimens.

Prior to preparation, a large, thin slab should be backed with epoxy and several layers of fiberglass cloth for added strength. The specimen can then be squared and recut with a hand circular saw or radial arm saw equipped with a masonary blade, or a band saw.

Invertebrate and plant fossils from F-1 must usually split out to be found, so very little preparation is needed with these. A protective coating such as a light spray of clear acrylic will help preserve these delicate specimens.

F-2 specimens: Most F-2 specimens "split out" when they are found, damaging the specimen (see figure AI.5). Very large specimens can be epoxied back together and prepared from one side using the "scratch and blow" method described for F-1 specimens. The large *Amia* shown in figures II.20b and II.20c was originally split out and later glued together and prepared. On small or juvenile fish, the specimens sometimes will split perfectly with a complete positive and a complete negative (see the *Mioplosus* positives in figures II.83a and II.83b). Occasionally, a specimen will split with a thin layer of matrix covering the specimen as in F-1 specimens. The beautifully preserved turtle and bird in figures III.3 and III.19) were both found with a matrix covering. As with F-1 specimens, matrix on important specimens should be removed with very sharp tools under a microscope, applying as little pressure as possible.

F-2 specimens do not x-ray as clearly as F-1 specimens, and x-ray techniques will usually work only on the large specimens.

G-1 specimens: The matrix of G-1 specimens is much harder than that of F-1 or F-2 specimens. Most small fish (as *Knightia* and *Erismatopterus*) split out very nicely (see figures II.42 and II.75), and cannot be detected unless they split out. Larger fish (mostly *Astephus* and *Amyzon*) usually split out poorly, often in several pieces, but occasionally do split out with a thin covering of matrix. Again, the "scratch and blow" method should be used; but, because of the harder matrix, it may take 5 to 10 times as long as with F-1 and F-2 specimens. The *Amyzon* in figure II.54 was prepared in this way.

G-2 and G-3: G-2 and G-3 are similar to G-1 specimens; the same techniques should be used.

G-4: The so called "Farson Fish" are some of the best preserved fossils of the Green River Formation when prepared properly. Because the matrix has little or no calcium carbonate in it, the fossil can be completely etched out with acid (a 10 to 20 percent solution of hydrochloric works best) to give an extremely detailed external mold. A latex (rubber) peel can then be made to produce a positive specimen. Figures II.78 and II.24 are latex peels of G-4 specimens. The bone is rarely well preserved in these specimens and is usually partly missing, making the negative mold much more useful than the actual remaining bone material. These specimens often have a white calcite film covering them, easily removed with acid.

U-1 specimens: This material is very difficult to work with. A combination of engraver, airbrasive, and hand tool work must be used to remove the hard sandstone matrix. The specimen in figure II.17a took about 400 hours to prepare.

U-2 and U-4 specimens: Most of these specimens are insects and leaves with few vertebrates, but all known material from these localities splits out. Specimens (especially vertebrates) should be sprayed with a clear acrylic at the excavation site, since bone and other material tends to flake off unless treated. The acrylic can later be removed with acetone.

U-3 specimens: The trackways from this locality need little or no preparation after they are split out. Often, slabs will be stained with black (pyrolusite), red, and/or yellow (iron), making trackways difficult to see. Scrubbing the slab with a nylon brush and a strong hydrochloric acid solution will remove the stain, resulting in a single light grey color in which the tracks will be more visible.

Figure AI.1. A typical unprepared *Priscacara* from F-1. Standard length is about 10 cm (4 inches).

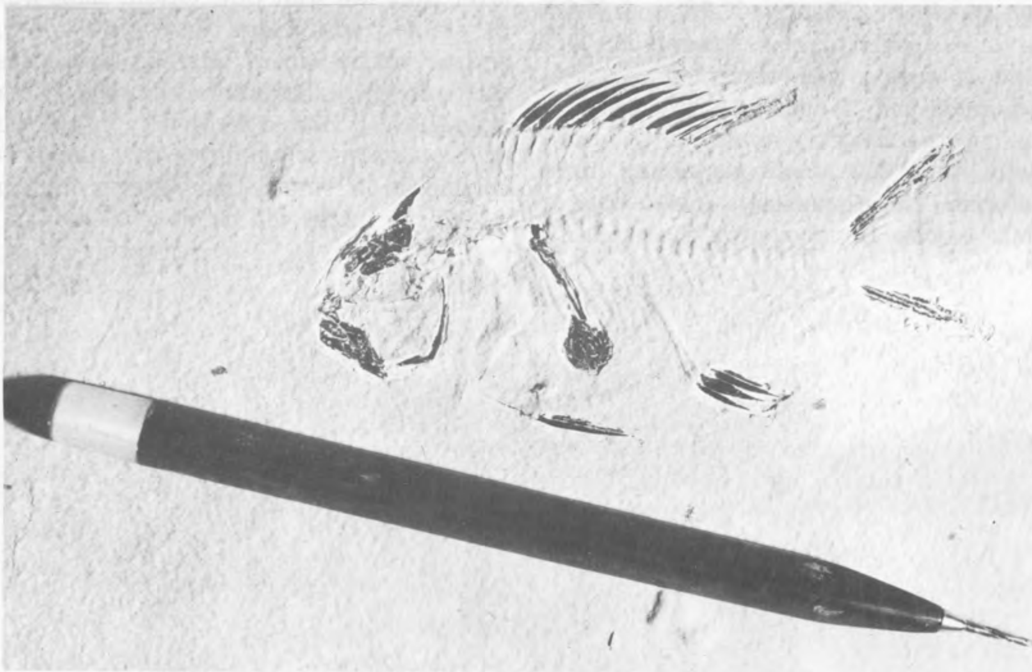

Figure AI.2. The specimen from figure AI.1 after partial preparation, and a needle pointed tool used for preparation.

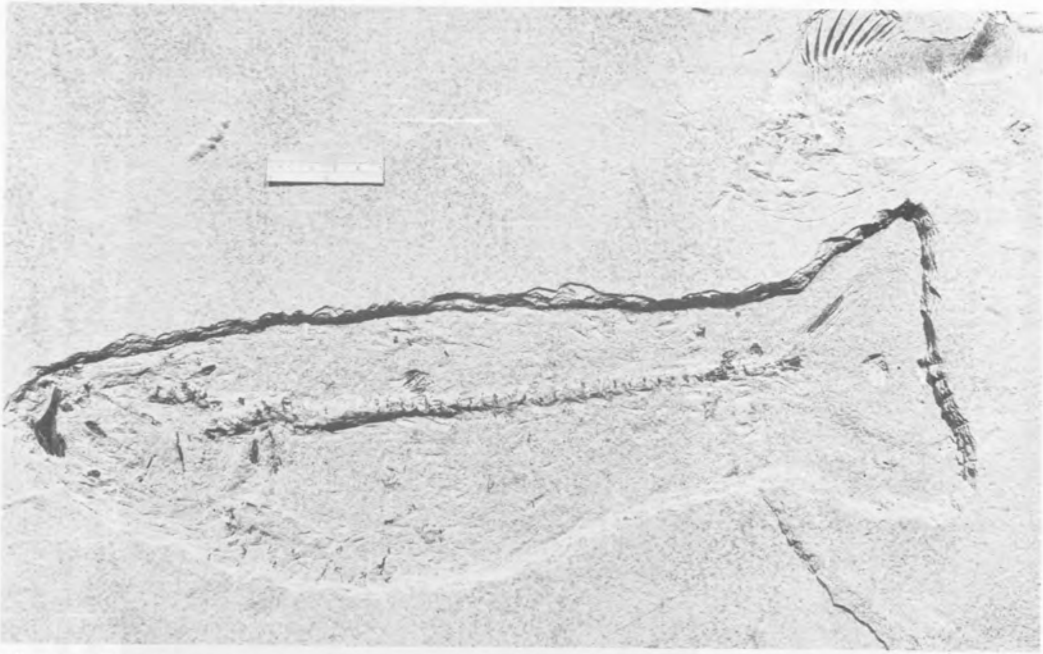

Figure AI.3. F-1 specimens which are covered with a thick layer of matrix can be prepared more quickly if the upper layers are chiseled off to a varve just above the fossil prior to the more careful, detailed removal of the matrix in contact with the fossil. This has been done to the *Diplomystus* shown, which is about 40 cm (16 inches) in total length.

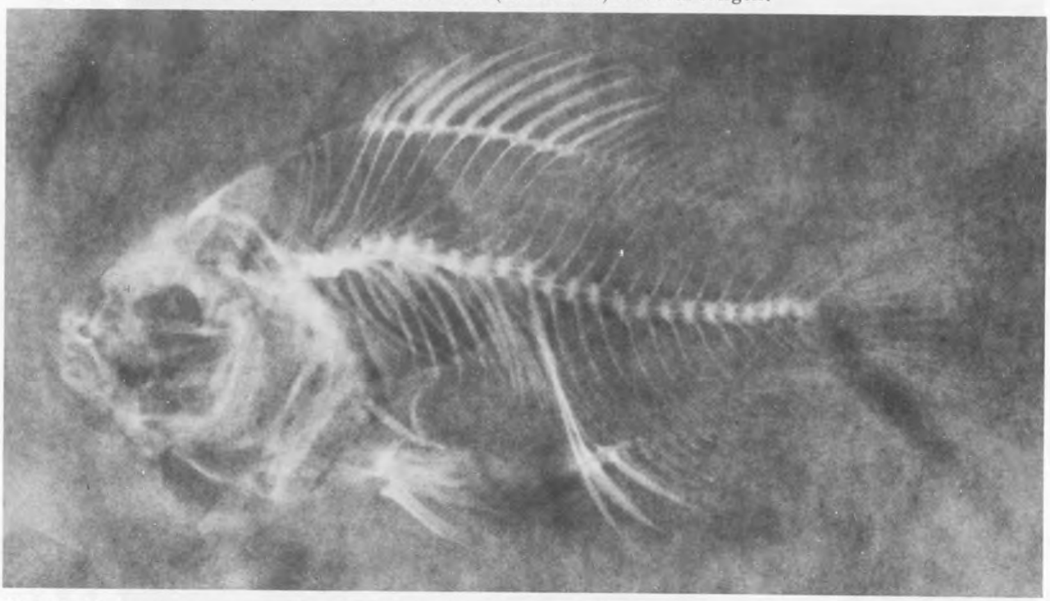

Figure AI.4. An x-ray radiograph of the specimen illustrated in figure II.91 made prior to preparation.

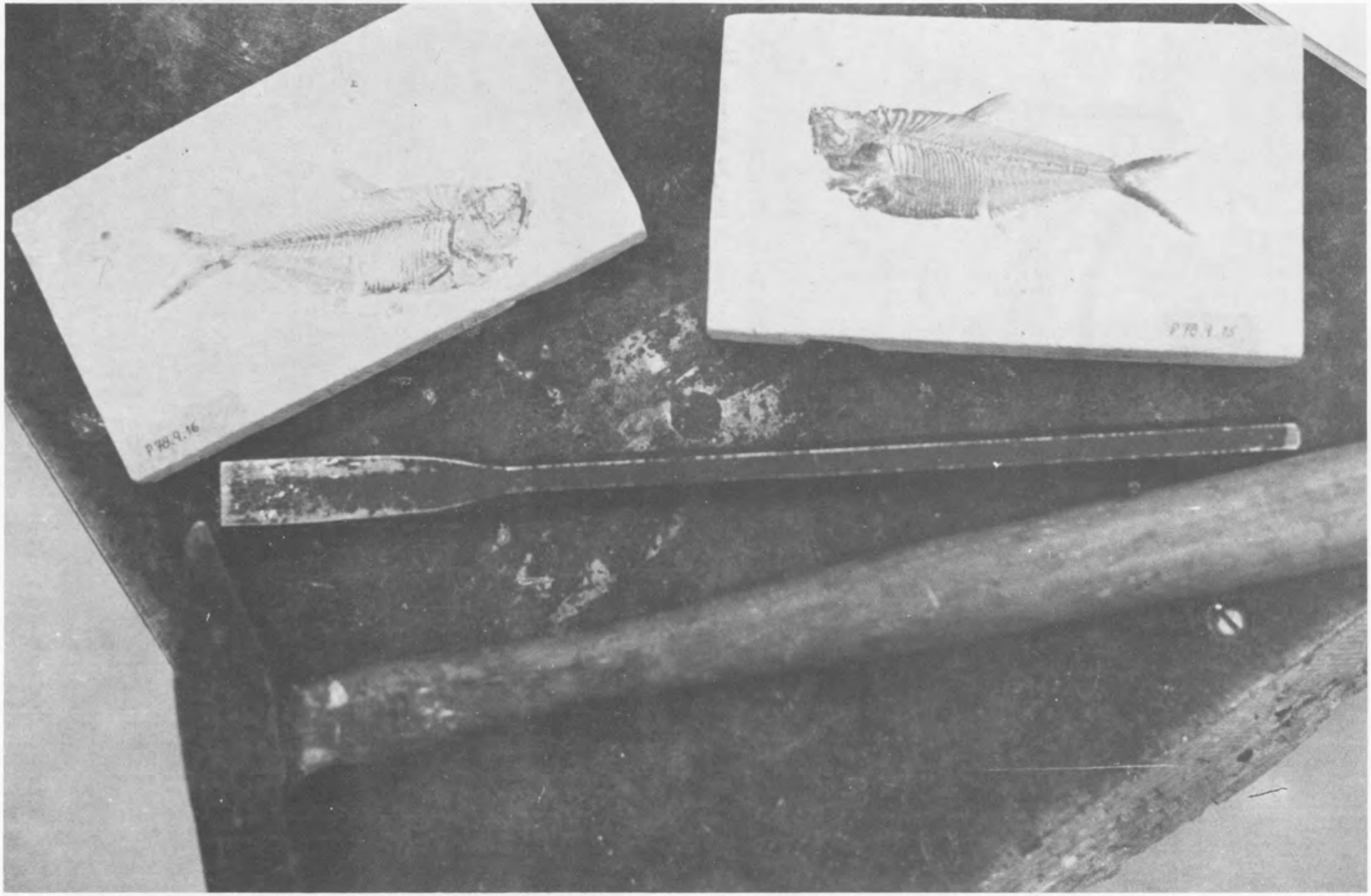

Figure AI.5. A "split fish" from F-2 (SMMP 78.9.16) showing both the positive and negative sides. Vertebrate fossils from F-2 are much harder to see while covered with matrix than those of F-1. Consequently, most F-2 specimens are not discovered until the rock has been split along the plane which contains them. Total length of fish is about 15 cm (6 inches).

APPENDIX II
EXCAVATION TECHNIQUES

F-1: Once the 18-inch layer is located (see figure AII.1), all overburden must be bulldozed off down to about 10-15 cm (4-6 inches) above the thin grey oil shale unit capping the 18-inch layer. If there is not at least 2 meters of overburden before bulldozing, the 18-inch layer is likely to be weathered and too soft to prepare well. The 18-inch layer occurs jointed into blocks (usually rectangular in shape) up to 3 x 10 meters (10 x 35 ft) in surface area, and bulldozing should go far enough back into the butte to uncover entire blocks.

The remaining 10-15 cm of overburden (usually clay and mudstone) is removed by shoveling, or dozing with a very light tractor, down to the hard upper capping layer. This thin grey oil shale unit is usually 5-13 cm (2-5 inches) thick and extremely tough, and must be broken up with sledge hammers before it can be removed with shovels and prybars (see figure AII.3). The 18-inch layer is a lighter color when it has dried out in the sun, easy to distinguish from the darker capping layer. This color change is sometimes better observed by examining the 18-inch layer and capping layer from the side. The blocks closest to the weathered edge of the quarry should be worked first. These should have easily splitting varves. Newly uncovered blocks farther into the Butte may need a year or two to rebound and weather before they will split properly along varves, especially if the overburden removed was 4 meters or more thick.

Once the 18-inch layer is exposed, a properly splitting block should split along varve planes about every 5-15 mm (1/4-5/8 inches) throughout the 18-inch layer, until the lower hard capping layer is reached. Prior to working a block, a trench should be dug around the block to expose the entire 18-inch unit on as many sides of the block as possible (the joints between blocks are often 15 cm (6 inches) or more wide and filled with dirt, clay and rock debris). Then, if a layer becomes difficult to split from one edge, it can be approached from another.

Used to take up the thin layers are flat, spatula-like tools of spring steel with sharpened ends and "potato shovels," also with sharpened ends (see figure AII.2). Once the capping layer is removed, the top of the 18-inch layer is swept free of dust and the surface (see figure AII.4) is inspected closely (by crawling on hands and knees over it) for faint ridges and bumps in the general outline of a fish (see figures AII.5 and AI.1). The smaller fish or the fish with a thick layer of overlying matrix (¼ inch or more) may show only a ridge indicating the vertebral column (see figure AII.5). When a fish is discovered it is marked in chalk, and a hand circular saw with masonary blade is then used to cut outlining grooves around the specimen, ½ inch to 1 inch deep, depending on how large or deep the specimen is (see figure AII.6). Then, the next separating varve layer, usually about ½-¾ inches down, is lifted up all around the specimen until the outlined specimens of the preceeding layer are all that remain of that layer. Then each specimen can be lifted as a plate by sliding thin spatula-like tools made of spring steel and with sharpened edges (see figure AII.2) under the specimen on all sides until it separates cleanly from the underlying layer. The now flat underlying layer is swept off and the process starts again and is repeated about every ½ to ¾ inch down through the 18-inch layer until the bottom capping layer is reached.

The 18-inch layer can be lifted in quite large thin sheets (see figure A.II.7). The bottom side of each sheet must also be inspected for specimens that do not show up on the top side. If a lifted sheet is thicker than ½ inch, it should be resplit into thinner sheets to miss as few specimens as possible.

F-2: The F-2 matrix is not well varved and, though it splits apart in flat surfaces, there are not many pre-split bedding planes to enable the lifting of large thin sheets as in F-1. The F-2 fish layers appear more massive from the edge than does the 18-inch layer (see figure AII.8). As at F-1, a bulldozer must usually push off several meters of overburden consisting of limestone broken up into pieces too small to contain complete fish. Once the 3-meter-thick, massive-looking unit is reached, it should be taken up in layers as thin as possible. There will be many small but very thick blocks encountered, and these can be removed, stood on edge, and split into thin sheets with hammer and chisel.

Other localities: Vertebrate fossils from most Lake Gosiute and Lake Uinta sediments are recovered by splitting the matrix along bedding planes and inspecting the split surfaces for exposed and covered fossils. Vertebrates from U-2 and U-4 should be sprayed with a clear preservative as they tend to crumble when exposed to the air.

NOTE: The localities listed here are all on state, federal, or private land. Permission from the landowner is needed for collecting on private land, and special permits are needed to collect vertebrate fossils from federal or state land.

Figure AII.1. A side view of the 18-inch layer on the weathered face of a butte near Fossil Butte National Monument. This F-1 unit (within the bar scale) is about 50 cm (20 inches) thick here.

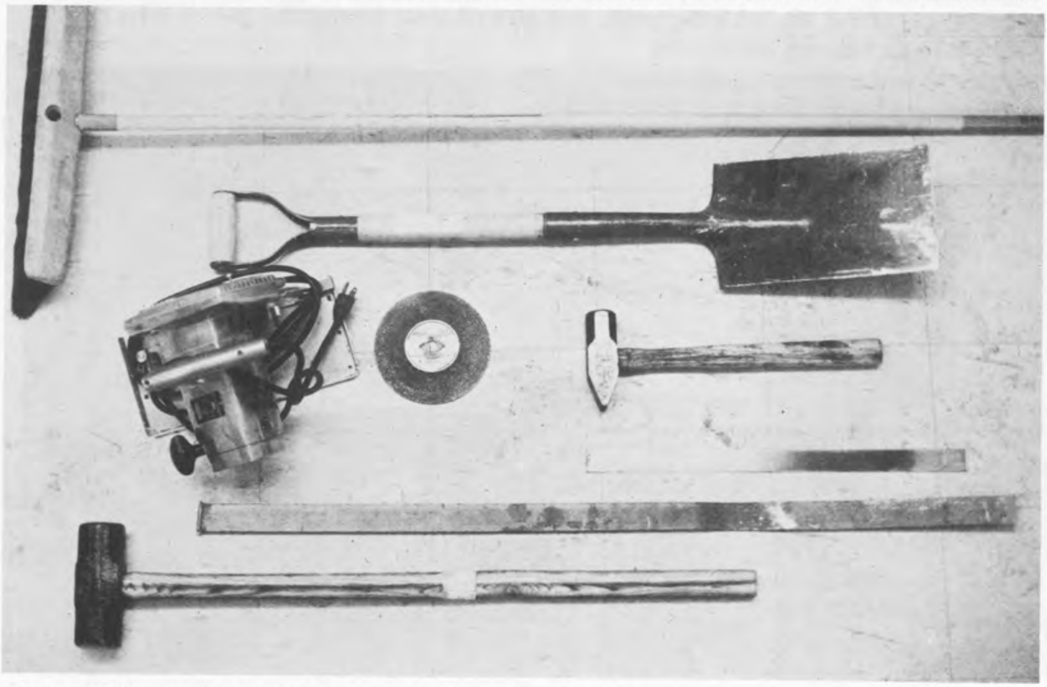

Figure AII.2. Equipment needed for proper removal of F-1 and F-2 specimens includes an electric generator and the cutting, prying, sweeping, and pounding tools shown here.

Figure AII.3. At F-1, the 3-5 inch, tough, dark-gray oil shale capping the 18-inch layer must be removed with hammers and shovels.

Figure AII.4. Once the upper "capping layer" is removed, the surface of the 18-inch layer should be swept clean and examined closely for ridges indicating fossils.

Figure AII.5. In the early morning or late afternoon low-angle sunlight, ridges indicating fish fossils on the clean swept surface of the 18-inch layer are most easily seen. This specimen is a *Notogoneus* with a standard length of about 46 cm (18 inches).

Figure AII.6. After discovery of a specimen in the quarry floor of F-1, grooves are cut around the specimen. Then the rest of the floor layer (about ¼ to ¾ inch thick) is removed with "potato shovels," leaving only the plates with fossils in them, which can then be removed with extremely thin pry-bars of spring steel (knife-edge sharpened hack-saw blades work well for small specimens).

Figure AII.7. A typical F-1 quarry. Very large, thin sheets of F-1 can be lifted without breakage. The sheet stood on edge by the workers is only ¾ inch thick.

Figure AII.8. A typical F-2 quarry. The prime fossil-containing units are much thicker and more massive than at F-1. The bar scale shows the main vertebrate fossil layer, about 2 meters (6½ feet) thick.

APPENDIX III

REPOSITORY KEY

AMNH	American Museum of Natural History, New York, New York.
ANSP	Academy of Natural Science, Philadelphia, Pennsylvania.
ASC	Fryxell Geology Museum, Augustana State College, Rock Island, Illinois.
BHI	Black Hills Institute, Hill City, South Dakota (private museum collection).
BMNH	British Museum (Natural History), London.
BYU	Brigham Young University, Provo, Utah.
DMNH	Denver Museum of Natural History, Denver, Colorado.
FBNM	Fossil Butte National Monument, display collection, Kemmerer, Wyoming.
FMNH	Field Museum of Natural History, Chicago, Illinois.
LG	The author's research collection.
MCZ	Museum of Comparative Zoology, Harvard University, Cambridge, Massachusetts.
PU	Museum of Natural History, Princeton University, Princeton, New Jersey.
SDMNH	San Diego Museum of Natural History, San Diego, California.
SMMP	Science Museum of Minnesota, St. Paul, Minnesota.
UC	Museum of Paleontology, University of California, Berkeley.
UMMP	Museum of Paleontology, University of Michigan, Ann Arbor, Michigan.
UMMZ	Museum of Zoology, University of Michigan, Ann Arbor, Michigan.
UMVP	University of Minnesota vertebrate paleontological collection, Minneapolis, Minnesota.
USNM	National Museum of Natural History (Smithsonian Institution), Washington, D.C.
UU	University of Utah, Salt Lake City, Utah.
UW	Geological Museum, University of Wyoming, Laramie.
YPM	Peabody Museum of Natural History, Yale University, New Haven, Connecticut.

APPENDIX IV

GLOSSARY

abbreviate-heterocercal tail	A relatively primitive type of fish tail found in *Amia* and *Lepisosteus*; see fig. II.2.
abdominal vertebrae	See **precaudal vertebrae**.
accessory rays	Here, those rays of the dorsal and anal fins preceding the major rays (see **major fin rays**). Accessory rays are unbranched, and range in length from less than the width of a centrum to about 2/3 the length of the first major ray. For example, the fish shown in figure II.29 has 5 accessory rays in front of the longest dorsal fin ray. The smallest, most anterior accessory rays are spinelike in some cases.
Actinopterygii	(The ray-finned fishes.) A subclass of fishes (regarded as a class by some authors) which includes all of the extant "bony fishes" except lungfish and coelacanths. Most common extant fishes belong to this group except sharks, skates, and rays.
adnasal	In fishes, a ventro-lateral dermal bone in the nasal region which lies on top of the **ethmoid.** Primitively, bears a lateral line canal.
anal fin	A fin on the ventral mid-line of a fish behind the anus; see fig. II.1a.
antorbital	A bone which is located in front of the **orbital series** in some fishes.

articular — The articular bone is the primary joint of the lower jaw with the quadrate in fishes; see fig. II.1b.

autotrophic organisms — Organisms which can manufacture their own source of energy from inorganic materials. Examples include phototrophic plants and algae which use sunlight, and autotrophic bacteria which use the energy produced from the oxidation of inorganic materials.

barbel — A slender, "whiskerlike" projection extending from the mouth or other regions of the head of some fishes.

base length of dorsal or anal fins — A measure of distance along a fish's back or ventral body surface between insertion of the first and last rays of the dorsal or anal fin.

basioccipital — In fishes, a postero-ventrally located bone of the cranial base. Partly covered ventrally by the parasphenoid, the caudal end of it articulates with the first vertebra.

branched fin rays — Those principal rays of a fish which start as a single element (in lateral view) at the base of the ray and branch or fan out into several thin, segmented elements at the outer end; see fig. II.1a.

branchiostegal rays — In fishes, the long narrow bones that are located in the ventral part of the membrane of the gill cover; see fig. II.1b.

branchiostegals — See **branchiostegal rays**.

caudal fin — The tail fin of a fish.

caudal peduncle — The slender portion of a fish's body between the anus and the tail fin.

caudal vertebrae — In fishes, those vertebrae which bear **hemal spines** or elements of the caudal skeleton; see figs. II.1b and II.1c.

centrum (plural = centra) — The centrum is the massive part of each vertebra that forms around the notochord.

ceratohyal — In fishes, the one or two most massive bones of the **hyoid arch**, between the ventral hypohyal and dorsal interhyal. This element supports the **branchiostegal rays**; see fig. II.1b.

ceratotrichia — The dermal fin rays in stingrays and other elasmobranchs.

cheek scales (number of) — The number of scale rows crossing an imaginary line form the eye of a fish to the posterior margin of the **preopercular** angle.

chondocranium — The part of the skull first formed as cartilage in the embryo of vertebrates. In most vertebrates, some or all of this cartilage is later replaced by bones, but in stingrays, sharks, and kin it remains as cartilage.

circumorbitals — The ring of small bones bordering the ventral and posterior part of the eye socket (see fig. II.1a), and also the dorsal part in primitive forms.

clasper — One of a pair of reproductive organs on the pelvic fins of male sharks, skates, rays, and ratfishes; see fig. II.3.

clastic rocks	Rocks made from fragments of pre-existing rocks by the process of weathering, redeposition, and lithification.
community paleoecology	The study of the relations of fossil animal and plant communities to their surroundings, animate and inanimate.
ctenoid scale	A scale that has growth lines covering the outer surface, and small spines or denticles (teeth), called ctenii, on the posterior margin (see figs. II.9, II.53, II.69b, and II.94 for examples). For more detailed information see Lagler (1947).
cycloid scale	A scale type that has growth lines covering the outer surface, and a smooth (toothless) posterior margin (see figs. II.57, II.49a, II.49b and II.35b for examples). For more detailed information see Lagler (1947).
dermal denticles	See **placoid scales.**
distal end (of a fin ray)	The outer tip.
dorsal	Situated at, or relatively nearer to, the back. Normally directed upwards with reference to gravity. Opposite of ventral.
dorsal vertebrae	See **predorsal vertebrae.**
doubled fin ray	Of the dorsal and anal fins of many fishes, that articulate at the base with a single pterygiophore; often counted as a single ray; see fig. II.1a. The posterior limb of the doubled ray may be branched or unbranched.

ecological niche	The ecologic position that an organism occupies with respect to the rest of the community.
ectopterygoid	(= pterygoid of some authors.) In fishes, the bone is located in the palatoquadrate arch between the palatine, the quadrate, and the entopterygoid, and often tooth-bearing.
endopterygoid	(= mesopterygoid or entopterygoid of various authors.) In fishes, primitively the largest dentigerous bone of the palatoquadrate arch, lying dorsal and medial to the **ectopterygoid**, quadrate, and symplectic.
ethmoid	In fishes, the central element of the nasal region.
entopterygoid	See **endopterygoid**.
etymology	The origin of a word.
eutrophic (with respect to lakes)	Highly productive in terms of organic matter (particularly algae); well supplied with nutrients.
extrascapular	See **supratemporal**.
falcate fin margin	Concave posteriorly in outline; see **median fins** in fig. II.29 for example.
fin margin	The outer or distal edge of a fin.
fin ray	Any of the long bony structures supporting the fin membrane of a fish; see fig. II.1a. Also see **soft rays** and **spines**.

flank scales — Scales taken from the side of a fish, as opposed to scales from the keel, dorsal midline, or head.

fontanelle — A gap in the skeletal covering of the brain.

formation — A mappable lithologic unit; the basic rock-stratigraphic unit in the local classification of rocks, consisting of a body of rock characterized by lithologic homogeneity or distinctive lithologic features.

fusiform — Spindle shaped; rounded, broadest in the middle and tapering toward each end.

ganoid scale — A scale type found in gars and many extinct groups of fishes. It has a shiny smooth surface (due to large amounts of ganoin) and is generally diamond shaped and relatively thick; see fig. II.19a for example. For more detailed information, see Lagler (1947).

gill arches — In fishes include the definitive gill arches (those arches which bear gills) and the jaw arch and hyoid arch (which are phylogenetically derived from gill arches).

gill cover — In fishes, a partly-bony cover which serves to protect the gills, and which takes part in respiration by moving actively. Includes the **opercular series** of bones.

gill filaments — Thread-like structures, functioning in gas exchange, attached to the outside of the gill arches in a fish; see figs. II.70a and II.70b.

gill rakers — Bony structures, rostrally located on the gill arches, which protect the gill filaments from mechanical injury. In plankton-feeders (see fig. II.10), can be used to filter food out of the respiratory water.

gular plate	A hard plate covering the underpart of the chin between the two halves of the lower jaw in some fishes; see fig. II.22.
halecostomes	The group of fishes, Halecostomi, which includes all amiaforms and teleosts; see fig. II.98.
hemal spines	In fishes, the ventral spine which is fused proximally to the hemal arch. The hemal arch forms a canal which contains the caudal blood vessels. The hemal arches attach to the **caudal vertebrae** see fig. II.1a and **caudal vertebrae.**
herbivore	An animal which feeds on algae or plant material.
heterocercal tail	A relatively primitive type of fish tail found in sturgeon and sharks; see fig. II.2.
holotype	The name-bearing type specimen; the original specimen from which the description of a new species is made. Only a single specimen can be designated as the holotype. If the name of a species is based on two or more specimens and no holotype is designated, these specimens are syntypes.
homocercal tail	A relatively advanced type of fish tail, dorso-ventrally symmetrical, found in most teleost fishes; see fig. II.2.
hyoid arch	In fishes, includes the hypohyal, the **cerato-hyal**, and the interhyal; see fig. II.1b. The interhyal, not shown in figure II.1b., connects the posterior end of the ceratohyal with the **hyomandibular** bone.
hyomandibular	In fishes, suspends the **hyoid arch** and **oro-mandibular arch** from the neurocranium; see fig. IIb.

hypotype	A described or figured specimen, published to extend or correct the knowledge of a previously defined species.
ichnofossil	A sedimentary structure such as a track, trail, burrow, tube, boring, or tunnel resulting from the activity of an organism. Syn: *trace fossil*
infraorbitals	In fishes, a group of sensory-canal-bearing **circumorbital** bones starting with the **lacrimal** (=io1) and continuing backward below the **orbit** and then upward to the dermosphenotic or intertemporal (=io6). The number of infraorbitals is often less than 6 because the elements are fused together to varying degrees or lost. (See fig. II.1b.)
interopercle	A fourth bone in the opercular series, present in halecostomes (teleosts and Halecomorphi — see fig. II.98) lying below and medial to the ventral arm of the **preopercle**.
lacrimal	In fishes, the most anterior of the **infraorbital** bones; see fig. II.1b.
lacustrine	Pertaining to a lake.
lagoon	A marginal bay or pond adjacent to a larger body of water, usually separated from the open water by a sandy spit or island.
larval stage of an insect (larva sing., larvae pl.)	The earliest pre-adult form in which an insect hatches from the egg.

lateral line	A longitudinal line of canals on each side of a fish's body, composed of pores opening into sensory organs, or a longitudinal line of sensory pits in the scales.
lepidotrichia	The dermal fin rays in teleosts. These are soft rays that are typically branched and segmented.
lithification	The process of sediment becoming sedimentary rock.
major fin rays	Defined here as the **median fin** rays that reach all the way to the outer fin margins. Usually the major fin rays contain one long unbranched ray followed by a number of branched rays, but in a few species all of the major rays are branched or unbranched. The major fin rays are usually preceded by smaller fin rays, decreasing in size anteriorly, called **accessory rays.** In the caudal fin, the major fin rays = the principal rays, and the accessory rays = the procurrent rays.
maxilla	See **maxillary bone.**
maxillary bone	The more posterior and usually larger of the two bones forming the upper jaw; see fig. II.1b. Equivalent to maxilla. Some authors use maxillary as a noun.
median fins	The **dorsal, anal,** and **caudal** fins.
member	A lithostratigraphic (rock stratigraphic) unit just below **formation** in rank (of equivalent rank with **tongue**); smaller divisions of formations.

meristic features or characters — Numbers of fin-rays, vertebrae, scales, and other features of a fish that are associated with the anter-posterior segmentation of the body.

mesopterygoid — See **endopterygoid**.

metapterygia — See **propterygia**.

metapterygoid — In fishes, joins the anterior edge of the **hyomandibular** with the **endopterygoid**.

neurocranium — In fishes, the portion of the skull which houses the brain, olfactory organ, eyes, and stato-acoustic organs.

nomen dubium — A latin term for an available specific name which cannot be assigned to a definite taxon because of shortcomings in the original diagnosis or the type material.

nomen nudum — A name published without satisfying the conditions of availability (see part III of Mayr, 1969).

opercle — A surficial skull element (bone) which is part of the gill cover in most bony fish, also called an operculum or opercular by various authors. See fig. II.1b.

opercular — See **opercle**.

opercular series — (= opercularia.) In fishes, the series of bones which makes up the gill cover; includes the opercle, the subopercle, the preopercle and the interopercle. This series is incomplete in some species.

operculum — See **opercle**.

orbit	The cavity or depression, in the skull of vertebrates, housing the eyeball.
orbital margin	The inside edge of the **circumorbital** bones of a fish, often circular in shape.
orbital series	See **circumorbitals.**
oromandibular arch	In fishes, the bones which surround the oral opening (**premaxilla, maxilla,** supramaxilla, **pterygoid,** quadrate, **articular** and dentary). It is attached to the **hyoid arch** by the symplectic. (See fig. II.1b.)
ossified	Developed into bone.
osteology	The science dealing with the bones of vertebrates.
palatal (palatine) teeth	The teeth on the roof of a fish's mouth postero-lateral to the **vomer(s)**; the dermopalatine.
palatine bones	The bones arranged on the sides of the upper part of the oral cavity, near the **maxillaries** that bear **palatine teeth**; the autopalatine.
paleoecology	The study of the relationships between fossil organisms and the environments they inhabited.
passerine	A member of the bird group Passeriformes. A perching bird with a large first toe directed back and three other toes directed forward. This group includes about half the known species of birds and most common inland species such as warblers and finches.

parasphenoid — In fishes, a ventral bone in the **neurocranium** which extends from the **vomer** posteriorly to the **basioccipital**. Laterally it covers the basisphenoid and part of the prootic and basioccipital.

pectoral fin — See fig. II.1a. The paired shoulder fins of fishes.

pelvic fin — In primitive fishes, the paired abdominal fins; in more advanced fishes the pelvic fins are found below the **pectoral fins**; see fig. II.1a.

pharyngeal teeth — Teeth in the throat of fishes supported by dorsal and ventral **gill arches** (located on the pharyngobranchials and the ceratobranchials).

phyletic — Pertaining to evolutionary descent.

placoid scale — Sometimes referred to as a "denticle," this is a toothlike scale present in the skin of most sharks and rays, often bearing sharp hooks or outward projecting teeth (see fig. II.7).

playa lake — A relatively shallow, flat-bottomed lake with gently dipping shores. Found in arid regions, this type of lake is prone to dry up periodically.

postcranial — Posterior to the cranium in position.

posttemporal — In fishes, a bone that connects the **neurocranium** and supracleithrum. It lies on the epiotic and pterotic, characteristically forked and bent with the branches of the fork lying on the skull; see fig. II.1b.

prawn A fresh water shrimp.

precaudal vertebrae (= abdominal vertebrae.) In fishes, all vertebrae anterior to the caudal vertebrae; see fig. II.1a. (= dorsal plus **predorsal vertebrae.**)

predorsal vertebrae A term not generally used in ichthyology today. Cope (1884) separated most of his vertebral counts into caudal, dorsal and predorsal vertebrae. The dorsal vertebrae are those vertebrae bearing movably articulated ribs, starting anteriorly with the first centrum bearing a full length rib. Many teleost fishes have two "predorsal" vertebrae (anterior to the dorsal vertebrae and bearing no, or highly reduced, ribs). In fossils, these are often covered by superficial bones of the skull, and are visible only in radiographs.

Cope did not usually count predorsal vertebrae, and so most of his total vertebral counts for Green River fishes are too low. In the vertebral counts given here for teleosts, those anteriormost centra which bear no ribs are designated by "PD" (except for the otophysins). The precaudal vertebrae include all predorsal vertebrae.

premaxillary bone or premaxilla A pair of bones that form the front of the upper jaw in a fish; see fig. II.1b. Some authors use premaxillary as a noun.

preopercle A bone of the **opercular series** of a fish just anterior to the **opercle** that encloses a sensory canal; see fig. II.1b.

preopercular See **preopercle.**

preoperculum See **preopercle**.

primary consumer A member of a food chain that feeds on primary producers (see **primary producers**).

primary producers The bottom members of a food chain; the **autotrophic organisms** of an ecosystem, such as most bacteria and algae.

principal rays The **caudal** fin rays which extend all the way to the posterior fin margin. This count can usually be obtained by counting branched caudal rays and adding two for the two unbranched principal caudal rays; see fig. II.1a.

procurrent rays The short unbranched caudal rays anterior to the **principal caudal rays**; see fig. II.1a.

propterygia (propterygium sing.) In stingrays, the pectoral fin rays are supported by three large cartilages; the propterygia anteriorly, the metapterygia posteriorly, and the mesopterygia in between. The mesopterygia is much smaller than the other two cartilages. The propterygium is equivalent to the anterior axis, and the metapterygium the posterior axis, illustrated in Goodrich, 1958, fig. 160.

pterygoid See **ectopterygoid**.

pterygiophores **Median fin** supports; see fig. II.1a.

pupa (insects) The stage between **larva** and adult of endopterygote insects, during which feeding and locomotion cease and great developmental changes occur.

radiographs	Pictures made from X-rays.
radula	A horny strip with teeth in the mouth of molluscs, usually used for rasping food or burrowing.
ray	See **fin ray**.
regression line	A line, on a graph, that depicts a general statistical relationship between two variables (such as number of fish species to lake surface area in fig. II.100).
rudimentary rays	See **procurrent** and **accessory rays**.
scales along lateral line (number of)	The number of scales along the **lateral line**, or along the position which would normally be occupied by a typical lateral line.
scute	An external bony or horny plate or scale.
secondary consumer	Animals in the food chain of an ecosystem which feed on **primary consumers**.
septomaxilla	In fishes and tetrapods, a dermal bone of the ethmo-vomer block located at the base of the nasal capsule. Some authors use septomaxillary as a noun.
septomaxillary	See **septomaxilla**.
soft rays	The flexible, jointed fin rays of a fish; see fig. II.1a.

specific richness	A relative measurement of number of species. A biota with relatively many species has a relatively high specific richness.
specific separation	Separation into different species.
spines or spiny rays	The non-jointed, usually hard, pointed fin rays of a fish; see fig. II.1a. Spines usually are unpaired structures; no matter how rudimentary or flexible, they are designated by Roman numerals.
splint	In fishes, a splint-like structure parallel to and on the anterior edge of the **pelvic fin** rays. It is not bisymmetrical like a fin ray or spine.
standard length	As used here for fossil fishes, the distance from the most anterior part of a fish's head to the posterior end of the vertebral column.
stratified	Layered or bedded.
stratigraphy	The study of **stratified** rocks, especially their sequence in time, the character of the rocks, and the correlation of beds or layers in different localities.
subopercle	In fishes, a part of the **opercular series** below the **opercle**.
subopercular	See **subopercle**.
suboperculum	See **subopercle**.

supraangular — See **surangular**.

supratemporal or supratemporal bone — In fish, this bone has numerous synonyms (scalebone, tabulare, extrascapula). Dorsally located above the epiotic and pterotic, it covers the attachment of the **posttemporal** to the skull.

surangular — In fishes, part of the primary lower jaw, located directly dorsal to the **articular**. Usually absent in **teleosts**.

syntype — See **holotype**.

taphonomy — The branch of paleoecology concerned with the manner of burial and the origin of fossils.

tectonic — An adjective used to relate a particular geologic structure or phenomenon to natural mountain building activity.

teleost — Common name for a fish that is a member of the Teleostei, a subdivision of Actinopterygii, containing the great majority of extant fishes (over 20,000 species).

thin section (geologic) — Because most minerals are transparent when examined in sufficiently thin slices, they can be identified by their optical properties as viewed under a microscope equipped to transmit polarized light. The standard thickness of such a slice is about .03 mm; it is cemented to a microscope slide.

tongue (geologic) — A lithostratigraphic (rock stratigraphic) unit just below **formation** in rank (of equivalent rank with **member**); differs from a member in that it extends outside of the main body of the formation.

total length	The distance from the most anterior part of a fish's head to the most posterior tip of the **caudal fin**. The measurement is a straight line and not taken over the curve of the body.
type species	See **holotype**.
ventral	Situated at, or relatively nearer to, that side of the animal which is normally directed downwards with reference to gravity. Opposite of **dorsal**.
ventral fin	The **pelvic fin**.
vomer(s)	The median bone or pair of bones in the anterior part of the roof of the mouth behind the **premaxillaries** in fishes.
vomerine teeth	Teeth on the **vomer** of a fish.
Weberian apparatus	See **Weberian ossicles**.
Weberian ossicles	In the order Ostariophysi (which includes the Catfish, suckers, and carps), a chain of small bones derived from ribs and a few of the most anterior vertebrae, which connect the swim bladder to the ear. They function somewhat like the middle ear ossicles of tetrapods.
zooplanktivore	Animals which feed on **zooplankton**.
zooplankton	The animal portion of plankton, which includes copepods, ostracodes, and many other tiny animals.

BIBLIOGRAPHY

The bibliography is divided into two parts, the first a "Bibliography of Paleontology in the Green River Formation" which includes nearly all publications through December 1978 concerned with the paleontology of the Green River Formation. The second part includes additional references cited in this paper. "Bibliography of the Geology of the Green River Formation, Colorado, Utah and Wyoming, to March 1, 1977" by Mullens (1977) is suggested as a bibliography of Green River Geology.

BIBLIOGRAPHY OF PALEONTOLOGY IN THE GREEN RIVER FORMATION

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INDEX OF FISH GENERA AND SPECIES

INDEX B
GENERAL INDEX EXCLUSIVE OF FISH GENERA AND SPECIES
(See also Table of Contents)

Figure added in proof. A very young juvenile *Notogoneus osculus* (FMNH PF9646) from F-1. Total length is 31 mm (1¼ inches). This is the smallest known specimen of this species. See footnote and text on page 103.