PALAEOWORLD Editorial Office
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PALAEOWORLD online submission:
http://ees.elsevier.com/palwor/

PALAEOWORLD full-text (Volume 15 – ) available at:
http://www.sciencedirect.com/science/journal/1871174X

# ELASMOBRANCHS FROM THE LOWER TERTIARY OF THE WESTERN TARIM BASIN , CHINA, AND THEIR BIOSTRATIGRAPHIC SIGNIFICANCE*

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**Abstract**: A regional elasmobranch fauna, the Tarim fish fauna, is examined in this paper. The composition of this fauna is comparable to a certain extent with the late Eocene eastern North Atlantic elasmobranch fauna of the Paris Basin. A comprehensive study of the stratigraphic distribution of the genera and species in the Tarim fish fauna indicates that the fish-bearing Wulagen Formation must include deposits formed mainly in the late Eocene and part of the lower Oligocene, and that the Qimugen Formation is basically early Eocene in age. An ecological explanation of this fish fauna suggests that a warm subtropical shallow Tarim Sea still existed by late Eocene and early Oligocene time. The paleozoogeographic interpretation of the taxa shared by both the Tarim fauna and the Paris Basin fauna also suggests that there might have been a wide communication between the Tarim Sea and the eastern part of the North Atlantic Ocean, or that the Tarim Sea was the east extension of the early eastern North Atlantic.

**Keywords**: Elasmobranch, fish, Lower Tertiary, biostratigraphy, Tarim Basin

## INTRODUCTION

The Tarim Basin, the largest interior basin in China, is located in southwestern Xinjiang Uygur Zizhiqu, northwestern China. It is bounded by two main geosynclinal foldbelts, the Tian Shan Mountains on the north and the Kunlun Shan and Altun Shan Mountains on the south.

Although a comprehensive investigation concentrating on the exploration for petroleum of the Tarim Basin was made during the last two decades (e.g., Yi and Jiang, 1980; Hu, 1981; Kang, 1981; Lu, 1981; Hao *et al.*, 1982; Zhang, 1982; Yang, 1983; Yang *et al.*, 1983; Lee, 1985), it was not until 1982 that Hao and her colleagues published a paper dealing with the Late Cretaceous and Tertiary strata and the foraminifera collected from the western Tarim Basin. However, no report has so far been made on fossil vertebrates from this area.

Fossil elasmobranch teeth from the Early Tertiary deposits of the western Tarim Basin were first found by Wang Yu-zhen in 1978 when she and her colleagues made geological investigations in Wuqia County, Kashi District (Fig. 1). They were first sent to Prof. Liu H'sian-t'ing in 1979.

In 1987, a program was drawn up in the Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences (IVPP), to make a detailed study of the fossil elasmobranchs from the western Tarim Basin, northwestern China. This program was then assigned as part of the 7th Five-

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Year Plan of the Chinese Academy of Sciences. Under the auspices of this program, I went to southwestern Xinjiang in the autumn of 1987 with the investigation team from Nanjing Institute of Geology and Paleontology, working there for three months. During that field season, more than five fossil localities were visited in Wuqia County (Fig. 1), and a large collection of fossil elasmobranch teeth was made from following sites: The Collection Spot of Phosphate Concretions, about 1km to the southeast of the county city of Wuqia; the North Limb of Wulagen Syncline; Tuzitao, and Kuliuwusu. The tooth-bearing strata are referred to two formations of the Kashi Group, the Wulagen Formation and Qimugen Formation.

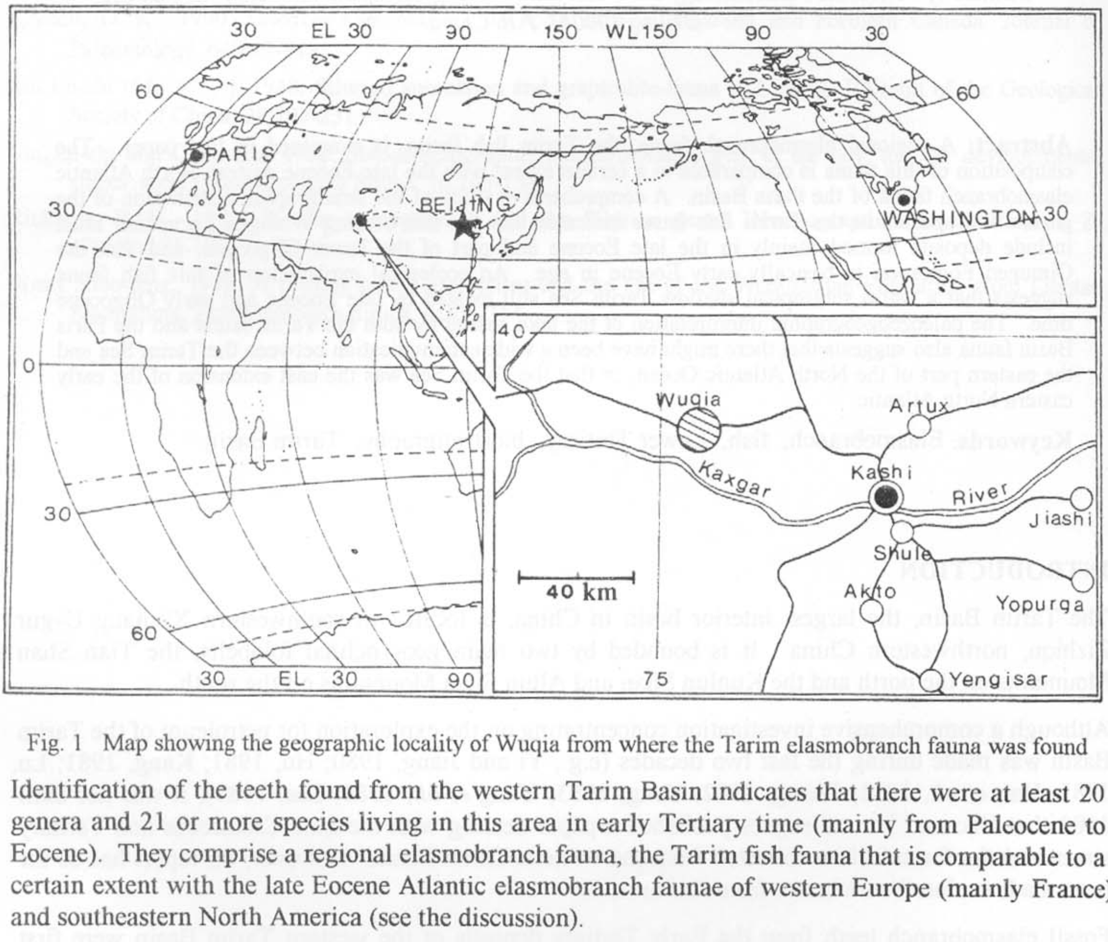


Fig. 1 Map showing the geographic locality of Wuqia from where the Tarim elasmobranch fauna was found

Identification of the teeth found from the western Tarim Basin indicates that there were at least 20 genera and 21 or more species living in this area in early Tertiary time (mainly from Paleocene to Eocene). They comprise a regional elasmobranch fauna, the Tarim fish fauna that is comparable to a certain extent with the late Eocene Atlantic elasmobranch faunae of western Europe (mainly France) and southeastern North America (see the discussion).

This paper is a preliminary report of the study of the fossil elasmobranchs from the western Tarim Basin and their biostratigraphic significance. I expect, by publishing this paper, to provide petroleum geologists and stratigraphers working in the Tarim Basin, as well as the international colleagues, with valuable information.

## MATERIAL AND METHODS

The fossil elasmobranch teeth discussed in this paper can be referred to two groups, sharks and rays. Most of them were collected from the Wulagen Formation, Kashi Group. All the specimens studied here were collected by myself during the field season in 1987, and disposed in the IVPP. The loosely cemented and weathered matrix with teeth was first immersed in water, which could usually be macerated within 24 hours. The teeth were separated from the matrix by washing the macerated rock under running water. The separated teeth were then dried indoors before they were examined.

All of the teeth were examined under WILD M7A or WILD M3 binocular stereomicroscopes. For the smaller teeth, I used a 2.0X accessory lens on the objective and enlarged them up to 60X or 100X so that I could see all of the characters. Some of the large teeth were first outlined by using a projection drawing tube. Pictures were taken with the JSM T-200 scanning electron microscope. The line illustrations were drawn by using "taedtler Marsmatic700" universal pen system.

The terminology of the description mainly follows Applegate (1965) and Cappetta (1987). The systematic classification of the teeth used in this paper follows Cappetta (1987). In order to avoid confusion of subclass and superorder, I use "-morpha" in stead of "-morphii" as the suffix of superorders in this paper.

Paleozoogeographic relationships among Eocene elasmobranch faunae are analysed cladistically using MacClade 3.04 (Maddison and Maddison, 1992), and PAUP 3.1.1 (Swofford, 1993).

## SYSTEMATIC PALEONTOLOGY

Subclass ELASMOBRANCHII
Superorder GALEOMORPHA
Order HETERODONTIFORMES
Family HETERODONTIDAE Gray 1851
Genus *HETERODONTUS* Blainville 1816

***Heterodontus maisierensis*** Herman 1977
(Fig. 2A-B)

Material: Two anterior (most likely symphysial) teeth, IVPP8951-1 (complete) and -2 (incomplete).

Locality: Collection Spot of Phosphate Concretions, County City of Wuqia; the North Limb of Wulagen Syncline.

Occurrence: Wulagen Formation, Kashi Group.

Age: Late Eocene.

Remarks: In general aspects, IVPP8951-1 most resembles the tooth of *Heterodontus maisierensis* (Herman, 1977, pl. 3, fig. 2). Although Herman gave only a short diagnosis for *H. maisierensis*, the characters shown by the picture of his specimen are comparable to the tooth discussed here, both having a low crown with the main cusp flanked by a pair of lateral cusplets on each side, a short and wide "V"-shaped root. Judging from the picture, a lingual furrow seems also present on Herman's specimen. It is true that the specimen referred in this paper is much smaller than Herman's, but this slight difference should not be emphasized in the taxonomy. It is also true that the tooth illustrated in this paper is almost identical to the tooth illustrated by Case (1980, pl. 4, fig. 9). Case placed that tooth in the species *Odontaspis acutissima*, but it seems to me that his description did not cover that tooth at all. Applegate (1965) noticed the wide variation in the posterior teeth that are easy to be confused in sharks. Unfortunately, I have only one complete specimen at present, just as Herman had only one tooth when he named the species. It seems wise at this time to place this specimen in the species *Heterodontus maisierensis* until I get more material from the fossil localities.

According to Herman the first appearance of this species might be in the early Late Cretaceous (Turonian or Coniacian). Its discovery in northwestern China extends the range of this species from early Late Cretaceous to Eocene and expands its geographic distribution from western Europe (Belgium) to East Asia.

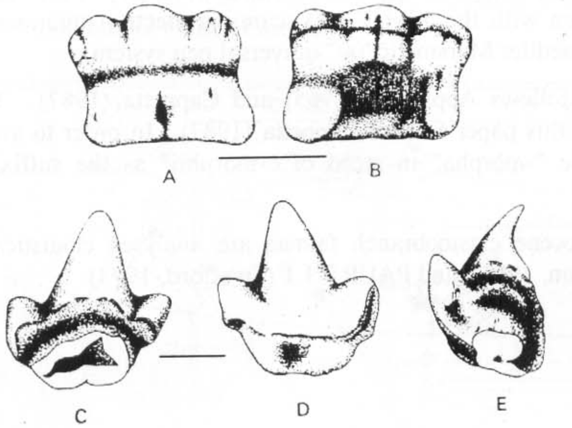


Fig. 2 A-B, *Heterodontus maisierensis*, IVPP8951-1. **A**, lingual view; **B**, labial view. Scale bar equals 1mm. **C-E**, *inglymostoma minutum*, IVPP8952. **C**, lingual view; **D**, labial view; **E**, distal view. Scale bar equals 0.5mm

Order ORECTOLOBIFORMES
Family GINGLYMOSTOMATIDAE Gill 1862
Genus *GINGLYMOSTOMA* Müler et Henle 1837

***Ginglymostoma minutum*** (Forir 1887)
(Fig. 2C-E)

Material: One nearly complete anterior tooth, IVPP8952

Locality: Collection Spot of Phosphate Concretions, County City of Wuqia.

Occurrence: Wulagen Formation, Kashi Group.

Age: Late Eocene.

Remarks: The evidence by which I have identified this tooth as *Ginglymostoma minutum* includes the subheart-shaped basal face of the root, the lingually bent crown (the main cusp) and the divergent lateral cusplets broadly joined to the base of the main cusp. A combination of these characters makes this tooth strongly resemble that shown by Herman as *G. minutum* (1977, pl. 6, fig. 7c).

Before IVPP8952 was discovered, *Ginglymostoma minutum* had mainly been known from Maestrichtian deposits (Upper Cretaceous) in Belgium and Holland of western Europe, and in Morocco, northwestern Africa (Herman, 1977; Cappetta, 1987). Its discovery in the western Tarim Basin indicates that this species had a wide distribution both stratigraphically and geographically.

Family RHINCODONTIDAE Garman 1913
Genus *EORHINCODON* gen. nov.

Type Species: *Eorhincodon tianshanensis* gen. et sp. nov.

Diagnosis: An Eocene whale shark having small teeth with crown consisting of only one main cusp strongly bending lingually. Lingual face of crown convex and rounded; labial face of crown flat or slightly convex, apron formed by rounded basal extension of this face not descending to basal level of root; root bulky and longer than crown in height, and forming angle slightly larger than 90° with crown; upper portion of root contracted to form distinct lingual furrow; lingual face of root convex with strong lingual protuberance not covered by enameloid, nutritive groove extending up to middle level of this side; labial face of root also convex with labial protuberance smaller than that on lingual side; basal face of root subpolyaulacorhized with three labio-lingually extended grooves not communicating with each other.

***Eorhincodon tianshanensis*** gen. et sp. nov.

(Figs. 3 and 9A, )

Diagnosis: As for genus. Length of root about 3/5 of total height of tooth, apron on labial face extending to 1/3 of upper part of root.

Holotype: IVPP8953, one complete tooth possibly from anterior portion of the jaws.

Etymology: The generic name is a combination of "Eocene" with "*Rhincodon*", meaning that this is a whale shark that lived in the Eocene. The specific name is derived from "Tian Shan Mountains" where the holotype was found.

Type Locality: Collection Spot of Phosphate Concretions, County City of Wuqia.

Horizon: Wulagen Formation, Kashi Group.

Age: Late Eocene.

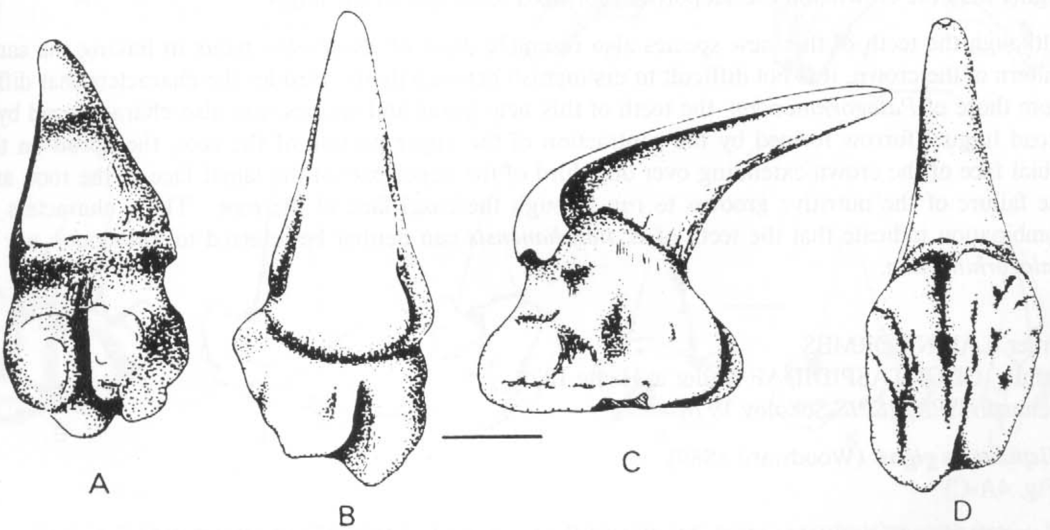


Fig. 3 *Eorhincodon tianshanensis* gen. et sp. nov., holotype
**A**, lingual view; **B**, labial view; **C**, mesial view; **D**, basal view. Scale bar equals 0.5mm

Description: The complete holotype. It is a small tooth with a total height of 1.6 mm (0.7 mm for the crown and 0.9 mm for the root).

The crown is subconical and strongly bent lingually. There are no lateral cusplets flanking the main cusp. The lingual face of the crown is strongly convex, forming a rounded lingual side that does not extend to form a so-called uvula at the base (Fig. 3A). The labial face of crown is almost flat and has a basal expansion to form a distinct apron, which extends basally up to 1/3 of the upper part of the root. Both the mesial and the distal cutting edges are blunt and not serrated (Fig. 3B-C).

The root is robust with a base broader than that of the crown. The upper part of the root is contracted, forming a broad and distinct lingual furrow (neck zone). The lingual face of the root is especially convex and characterized by a strongly developed lingual protuberance, which is not covered by enameloid. The main nutritive groove extends upward to about half the length of the lingual side (Fig. 3A). The labial face of the root is narrower than the lingual face and also convex, with a labial protuberance which is not as strong as that on the lingual face. The mesial and distal faces are somewhat flatter than both the lingual and the labial faces. The basal face of the root is subpolyaulachorized. This face is somewhat rounded and suboval in shape. Three labio-lingually extending nutritive grooves are present on this face, which do not communicate with each other. Of these, the groove extending to the lingual face of the root is the largest and divides the basal face of the root into two main parts; while the groove from labial side of the root does not extend to the lingual face of the root or vice versa (Fig.3D).

Comparison: Two genera are currently placed in the family Rhincodontidae, *Rhincodon* Smith, 1829 and *Palaeorhincodon* Herman, 1977. The former has one Recent species, *R. typus* Smith, 1829 (Bigelow and Schroeder, 1948; Nelson, 1994), and a questionable fossil species, *R. miocaenicus* (Antunes and Jonet, 1970), which was referred to *Megascyliorhinus* Cappetta and Ward 1977 (Cappetta, 1987). The later is a fossil genus found in the lower-middle Eocene of Europe and northern and western Africa.

The teeth of *Eorhincodon tianshanenensis* gen. et sp. nov. are definitely rhincodontid but different from those of *Palaeorhincodon* in having the cusp of the crown not flanked by lateral cusplets, the root higher than the crown and the subpolyaulacorhized basal face of the root.

Although the teeth of this new species also resemble those of *Rhincodon typus* in having the same pattern of the crown, it is not difficult to distinguish between them. Besides the characters that differ from those of *Palaeorhincodon*, the teeth of this new genus and species are also characterized by a broad lingual furrow formed by the contraction of the upper portion of the root, the apron on the labial face of the crown extending over one third of the upper part of the labial face of the root, and the failure of the nutritive grooves to run through the basal face of the root. These characters in combination indicate that the teeth of *E. tianshanensis* can neither be referred to *Rhincodon* nor to *Palaeorhincodon*.

Order LAMNIFORMES
Family ODONTASPIDIDAE Müler et Henle 1839
Genus *HISPIDASPIS* Sokolov 1978

***Hispidaspis gigas*** (Woodward 1889)
(Fig. 4A-C)

Material: Nine incomplete anterior teeth and three incomplete lateral teeth, IVPP8954-1 to -12.

Locality: Mainly from Tuzitao; also from the North Limb of Wulagen Syncline; Kuliuwusu; Gaijitake Hill, Kuzigongsu, Wuqia County.

Occurrence: Qimugen Formation (mainly lower Eocene), Wulagen Formation (upper Eocene), Kashi Group.

Age: Eocene.

Remarks: The features that allow me to identify these teeth as belonging to *Hispidaspis gigas* are the high, mesially sigmoid cusp, the distal and the mesial cutting edges reaching almost to the base of the crown, and the small lateral cusplets having their own contact with the root or only slightly joined with the main cusp at the very base of the crown.

*Hispidaspis gigas* has been found in the Upper Cretaceous of England, northern France (Leriche, 1902), Belgium (Leriche, 1926) and Russia (Sokolov, 1978). It is the first time for this species to be known in China. The teeth belonging to this species occur in both the Qimugen Formation and the Wulagen Formation. This indicates that *Hispidaspis gigas* existed through the Late Cretaceous and at least the Eocene.

Genus *STRIATOLAMIA* Glükman 1964

***Striatolamia macrota*** (Agassiz 1843)
(Fig. 4D-F)

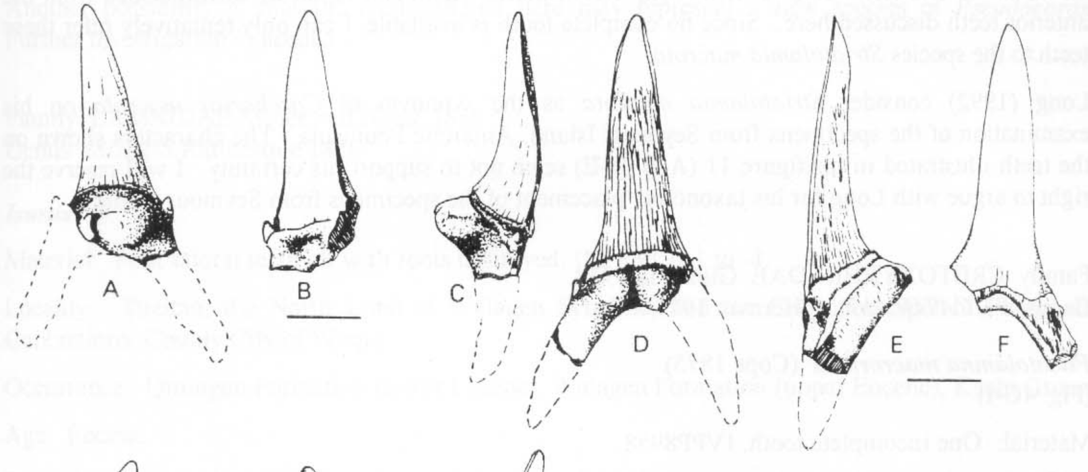


Fig. 4. **A-C,** *Hispidaspis gigas*, IVPP8954-1. **A,** lingual view; **B,** labial view; **C,** mesial view. Scale bar equals 6mm. **D-F,** *Striatolamia macrota*, IVPP8955-1. **D,** lingual view; **E,** mesial view; **F,** labial view. Scale bar equals 6mm. **G-I,** *Plicatolamna macrorhiza*, IVPP8958. **G,** lingual view; **H,** labial view; **I,** mesial view. Scale bar equals 0.6mm. **J-L,** *Pseudocorax* sp., IVPP8959-1. **J,** lingual view; **K,** labial view; **L,** mesial view. Scale bar equals 1mm.

Material: Five incomplete teeth, of which three are anterior (IVPP8955 -1 to -3), two lateral (IVPP8955 -4 to -5).

Locality: Same as those teeth referred to *Hispidaspis gigas*.

Occurrence: Qimugen Formation (mainly lower Eocene), Wulagen Formation (upper Eocene).

Age: Eocene.

Remarks: At the first glance, the anterior teeth seem to resemble those of *Mitsukurina lineata* and of *Scapanorhynchus lewisii* (Davis, 1887) in having a high and slender cusp with a striated lingual face. In detail, however, these teeth are different from the above two species in at least two characters. Firstly, all the striations on these teeth fail to reach the apex of the main cusp, whereas the striations in the above two species occupy almost the whole height of the main cusp (Cappetta, 1987). Secondly, the very reduced lateral cusplets flanking the main cusp are definitely present on these teeth; however, they may be lost on the anterior teeth of the above two species. In addition, a mesial crown tongue can be seen on the remainder root of these teeth. This means that I might see both the distal and the mesial crown tongues on the labial face of the root if the root were complete. These two crown tongues seem absent from *Mitsukurina lineata* and *Scapanorhyinchus lewisii* (see Cappetta, 1987, fig. 81A-C and fig. 82B-D).

Williamson et al. (1993) recently reported a selachian fauna from the "Middle" Cretaceous of Arizona. The anterior teeth of their *Scapanorhyinchus raphiodon* is hardly distinguished from the anterior teeth discussed here. Since no complete tooth is available, I can only tentatively refer these teeth to the species *Striatolamia macrota*.

Long (1992) consider *Striatolamia macrota* as the synonym of *Carcharias macrota* on his examination of the specimens from Seymour Island, Antarctic Peninsula. The characters shown on the teeth illustrated in his figure 11 (A-B, D-E) seem not to support his certainty. I will reserve the right to argue with Long for his taxonomic placement of the specimens from Seymour Island.

Family CRETOXYRHINIDAE Glükman 1958
Genus *PLICATOLAMNA* Herman 1977

***Plicatolamna macrorhiza*** (Cope 1875)
(Fig. 4G-I)

Material: One incomplete tooth, IVPP8958.

Locality: Collection Spot of Phosphate Concretions, County City of Wuqia.

Occurrence: Wulagen Formation.

Age: Late Eocene.

Remarks: Although the root of IVPP8958 is incomplete, the characters shown by the well preserved crown suggest that it is a cretoxyrhinid tooth, particularly resembling those of *Plicatolamna macrorhiza* (Herman, 1977, pl. 8, fig. 3a-d).

According to Herman, *Plicatolamna macrorhiza* is a species that mainly confined in Late Cretaceous time. Apart from in France and Belgium, the teeth of this species have also been known in the Niobrara Chalk, Kansas. Its discovery from the western Tarim Basin not only significantly extends the geological record of this species, but also greatly expands its geographic range. This seems questionable. Since only one specimen is available to me, I reserve the right to reexamine these questions in the future when I get larger, better preserved samples.

Family ANACORACIDAE Casier 1947
Genus *PSEUDOCORAX* Priem 1897

***Pseudocorax*** sp.
(Fig. 4J-L)

Material: Two teeth with incomplete root, IVPP8959-1 to -2.

Locality: Collection Spot of Phosphate Concretions, County City of Wuqia; North Limb of Wulagen Syncline, Wuqia County.

Occurrence: Wulagen Formation, Kashi Group.

Age: Late Eocene.
Remarks: Morphologically, species placed in *Pseudocorax* vary widely one from another. All of them have so far been found in the Upper Cretaceous of western Europe, North America and North Africa. It is difficult to compare the teeth of IVPP8959 with those of previously described species.

In overall features observable under the microscope, I see a similarity between IVPP8959 and those of *Pseudocorax laevis* (Leriche, 1906); the latter has been known from the Upper Cretaceous of France (Cappetta, 1987), Belgium (Leriche, 1906, Herman, 1977), England (Woodward, 1911) and U.S.A. (Applegate, 1970); however, the evidence is insufficient to refer IVPP8959 to that species. Another possibility is that the teeth studied here may represent a new species of *Pseudocorax*. Further investigation is needed.

Family LAMNIDAE Müler and Henle 1838
Genus *ISURUS* Rafinesque 1810

***Isurus*** sp.

Material: Four lateral teeth all with roots destroyed, IVPP8956-1 to -4.

Locality: Tuzitao; the North Limb of Wulagen Syncline; and the Collection Spot of Phosphate Concretions, County City of Wuqia.

Occurrence: Qimugen Formation (lower Eocene), Wulagen Formation (upper Eocene), Kashi Group.

Age: Eocene.

Remarks: It is evident that these incomplete antero-lateral teeth are adapted for a cutting-clutching function. I am rather confident in identifying them as those of *Isurus*. In fact, these teeth are comparable to those of *Isurus oxyrhinchus* Rafinesque 1910 (Bigelow and Schroeder, 1948; Cappetta, 1987) in the main characters of the crown. However, since the evidence from the root of these teeth is not enough, I temporarily refer them to *Isurus* sp.

Genus *ARCHAEOLAMNA* gen. nov.

Type Species: *Archaeolamna apophysata* gen. et sp. nov.

Diagnosis: Lamnid shark having small teeth with developed root as long as main cusp in height; main cusp hemiconical with convex lingual face and slightly convex or flat labial face; smooth enameloid of labial face of crown gradually merged into labial face of root; boundary between crown and root indistinct in labial view; two small lateral cusplets symmetrically flanking main cusp at very base of crown; base of lateral cusplets extending to form both mesial and distal crown tongues on labial face of root lobes; root robust with its width equal to its height; lingual face of root convex, forming strong lingual protuberance; labial face of root lingually concave, forming an arched labial depression.

***Archaeolamna apophysata*** gen. et sp. nov.
(Figs. 5 and 9B)

Diagnosis: As for genus.

Holotype: IVPP8957, one complete tooth.
Etymology: The generic name is derived from the combination of a feminine Greek prefix "archae-", meaning "ancient" or "original", with "*Lamna*", for its similarity to the porbeagle shark. The specific name is derived from "apophysatus", a Latin adjective, in reference to its lingually swollen root.

Type Locality: Collection Spot of Phosphate Concretions, County City of Wuqia.

Horizon: Wulagen Formation, Kashi Group.

Age: Late Eocene.

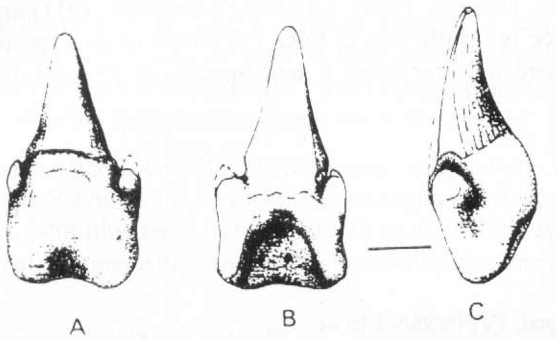

Fig. 5 *Archaeolamna apophysata* gen. et sp. nov., holotype. **A**, lingual view; **B**, labial view; **C**, profile. Scale bar equals 1mm

Description: The holotype is complete and well-preserved. It is possibly a symphysial tooth, as it shows a symmetrical outline. The main cusp of this tooth is hemiconical in occlusal view. The lingual face of the main cusp (Fig. 5A) is convex with a rounded surface. The labial face of the main cusp is also slightly convex; it joins with the lingual face to form blunt mesial and distal cutting edges. These two faces of the main cusp are covered by thick and smooth enameloid that merges gradually into the labial face of the root, leaving no distinct boundary between the crown and the root in labial view. The blunt mesial and distal cutting edges of the main cusp describe a rounded and blunt apex at the tip of the cusp.

There is only one small lateral cusplet on each side of the main cusp. These two small cusplets symmetrically flank the main cusp at the very base of the crown. The base of each of the cusplets extends to the labial face of the root to form mesial and distal crown tongues on their respective root lobes (Fig. 5B).

The root is developed with a length equal to the height of the main cusp. The lingual face of the root is convex, forming a moderately strong lingual protuberance. The labial face of the root is strongly lingually concave at the lower middle portion to form an arched labial depression (Fig. 5B). At the base of this arched concavity are two foramina for blood vessels. A basal view of the root shows that it is of holaulacorhized type although both the mesial and the distal root lobes are undeveloped.

Comparison: In general shape, IVPP8957 seems similar to those of *Plicatolamna borodini* described by Cappetta and Case (1975), particularly to the tooth illustrated in their plate 3, figure 4. However, the root pattern of this tooth keeps me from placing it into that species.

In some aspects, such as the number of the lateral cusplets and the proportion of the root length to the height of the main cusp, IVPP8957 is also comparable to teeth of *Protolamna sokolovi* (Cappetta, 1980). However, the features identifying this new tooth as *P. sokolovi* are not enough. In fact this new tooth is rather different from those of *P. sokolovi* in having no lingual furrow and no distinct boundary between the crown and root in labial view. It is especially characterized by an arched labial concavity at the lower part of the labial face of the root, and by gradual merging of the enameloid on the labial face of the main cusp into the labial face of the root. These characters suggest that IVPP8957 may represent a new genus and species which is here named *Archaeolamna apophysata* and is tentatively placed in the family Lamnidae.

Order CARCHARHINIFORMES
Family CARCHARHINIDAE Jordan and Evermann 1896
Genus *ABDOUNIA* Cappetta 1980

***Abdounia kashiensis*** sp. nov.
(Figs. 6A-C and Fig. 9C)

Diagnosis: *Abdounia* characterized by small teeth with sharp triangular cusp bent to rear; one mesial lateral cusplet present but small; distal lateral cusplet absent; mesial cutting edge convex; both mesial and distal cutting edges moderately sharp with no serrations; lingual face of cusp convex; labial face of cusp moderately convex with its base slightly overhanging labial face of root; root broader than crown, with its length one quarter total height; lingual face of root convex, forming pronounced lingual protuberance; lingual furrow between crown and root present; labial face of root lingually concave; basal face of root flat with a thickness equal to one quarter its length.

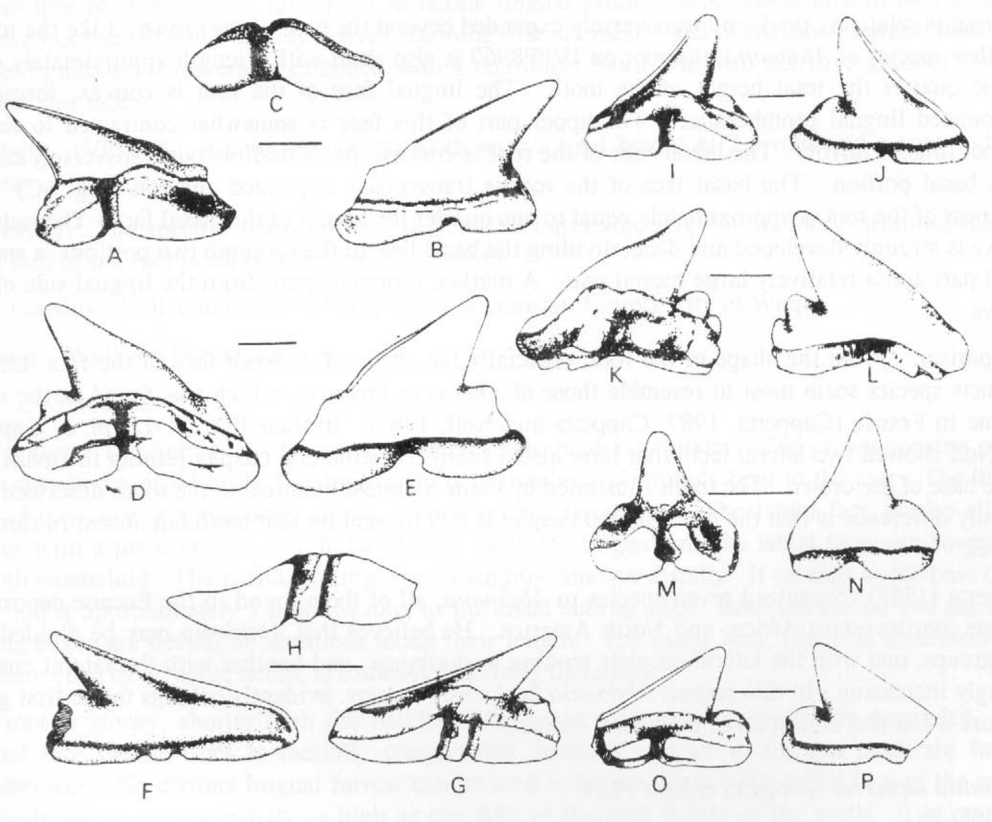


Fig. 6 **A-C**, *Abdounia kashiensis* sp. nov., holotype.
**A**, lingual view; **B**, labial view; **C**, basal view. Scale bar equals 1mm. **D-E**, *Abdounia lapierrei*, IVPP8971. **D**, lingual view; **E**, labial view. Scale bar equals 1mm. **F-H**, *Rhizoprionodon bisulcatus* sp. nov., holotype. **F**, labial view; **G**, lingual view; **H**, basal view. Scale bar equals 2mm. **I-J**, *Scoliodon* sp., aff. *S. ganntourensis*, IVPP8963-7. **I**, lingualview; **J**, labial view. Scale bar equals 1mm. **K-L**, *Eogaleus bolcensis*, IVPP8961-1. **K**, lingual view; **L**, labial view. Scale bar equals 1mm. **M-P**, *Sphyrna zygaena*. **M-N**, anterior tooth. **M**, lingual view; **N**, labial view, based on IVPP8964-1. **O-P**, lateral tooth. **O**, lingual view, **P**, labial view, on IVPP8964-3. Scale bars equal 1mm.

Holotype: IVPP8960, a complete lateral tooth.

Etymology: The specific name is derived from "Kashi", implying that this is a species first found from the Kashi District.

Type Locality: Collection Spot of Phosphate Concretions, County City of Wuqia.

Occurrence: Wulagen Formation, Kashi Group.

Description: The well-preserved holotype is a small lateral tooth with a total height of 2.5mm. The cusp is developed as a sharp triangle in its shape and broad at its base. It leans posteriorly and is described by a convex mesial cutting edge and a basally concave distal cutting edge. Both the mesial and the distal cutting edges are moderately sharp and devoid of serrations. Although the distal lateral cusplets are absent or barely developed, a very small mesial lateral cusplet is still present, joining with the main cusp at the base of the crown. The lingual face of the crown is convex, forming a rounded surface that has a curved basal line. The labial face of the crown is also moderately convex with a more or less straight basal line and a rather flat base that slightly overhangs the labial face of the root. The enameloid covering the cusp is thick and smooth everywhere on the crown.

The root is relatively thick and transversely expanded beyond the base of the crown. Like the root in all other species of *Abdounia*, the root on IVPP8960 is also short with a length approximately equal to one quarter the total height of the tooth. The lingual face of the root is convex, forming a pronounced lingual protuberance. The upper part of this face is somewhat contracted to form a distinct lingual furrow. The labial face of the root is concave in its midline but transversely convex at its basal portion. The basal face of the root is transversely expanded and flat (Fig. 6C). The thickness of the root is approximately equal to one quarter the length of this basal face. The nutritive groove is strongly developed and deep, dividing the basal face of the root into two portions: a smaller distal part and a relatively large mesial part. A marked foramen opens from the lingual side of this groove.

Comparison: From the shape of the root, especially the shape of its basal face of the root, teeth of this new species seem most to resemble those of *Abdounia lapierrei,* which was found in the upper Eocene in France (Cappetta, 1987; Cappetta and Nolf, 1981). In their figs. 11-12, pl. 2, Cappetta and Nolf showed two lateral teeth that have also a small mesial lateral cusplet joining the main cusp at the base of the crown. The tooth illustrated by them is almost identical to the tooth described here; the only difference is that the distal lateral cusplet is still present on that tooth but absent in this new species.

Cappetta (1987) recognized seven species in *Abdounia*, all of them found in the Eocene deposits of Europe, northwestern Africa, and North America. He believes that *Abdounia* may be divided into two groups, one with the lateral cusplets tending to disappear, and another with the lateral cusplets strongly increasing. In this respect *Abdounia kashiensis* sp. nov. evidently belongs to the first group because it has lost almost all of the lateral cusplets.

***Abdounia lapierrei*** Cappetta et Nolf 1981
(Fig. 6D-E)

Material: One complete lateral tooth, IVPP8971.

Locality: North Limb of Wulagen Syncline, Wuqia County.

Occurrence: Wulagen Formation, Kashi Group.

Age: Late Eocene.

Remarks: This tooth differs from the above new species of *A. kashiensis* in having a very small distal lateral cusplet. Morphologically, it is hardly distinguishable from the teeth of *A. lapierrei* (Cappetta and Nolf, 1981, figs. 1 and 2, pl. 2). I am rather confident to identify this tooth as one of the individual of *A. lapierrei.*

*A. lapierrei* first appears in the upper Eocene of Paris Basin. Its discovery from the late Eocene Wulagen Formation of the western Tarim Basin provides me with important information on the relationship between the two selachian faunae.

Genus *RHIZOPRIONODON* Whitley 1929

***Rhizoprionodon bisulcatus*** sp. nov.
(Fig. 6F-H)

Diagnosis: *Rhizoprionodon* different from other species in having teeth moderate in size with a cusp strongly bent to rear and a distinct distal heel; mesial cutting edge broad and extending to base of cusp; lingual face of cusp moderately convex with a curved basal line; labial face of cusp slightly convex with a basal line somewhat straight; root robust and broader than cusp in lingual view; lingual face of root convex, forming a moderate lingual protuberance; labial face of root centrally concave but mesially and distally convex, forming distinct mesial and distal labial bulges; basal face of root broad and transversely extended with a rectilinear basal line; two nutritive grooves running through this face.

Holotype: IVPP8962, a complete lateral tooth with a total height of 2.9 mm and a root width of 5.2 mm.

Etymology: The specific name is derived from the Latin adjective "*bisulcatus*", meaning that the basal face of the root is cut by two nutritive grooves.

Type Locality: Collection Spot of Phosphate Concretions, County City of Wuqia.

Horizon: Wulagen Formation.

Age: Late Eocene.

Description: The holotype is a complete lateral tooth, moderate in size. The crown consists of one main cusp and a distal heel. The main cusp is triangular and strongly bent to the rear. The lingual face of this cusp is moderately convex with a curved basal line. The labial face is also slightly convex with a more or less straight basal line. Both the lingual and the labial faces are covered by smooth enameloid. The mesial cutting edge is slightly concave distally. It extends to the base of the cusp and is approximately 3 times as long as the distal cutting edge. Both the mesial and the distal cutting edges are devoid of serrations along their length. The distal heel, which is separated from the main cusp by an acute notch, is somewhat laterally flattened.

The root is stocky, shorter than the height of the main cusp and mesio-distally expanded. The lingual face of this root is mesially concave but centrally convex to form a moderate lingual protuberance. No distinct lingual furrow can be seen in lingual view. The labial face of the root is relatively lower, approximately as high as one fifth of the total height of the tooth. It is concave centrally, but mesially and distally convex, forming distinct mesial and distal bulges. The basal face of the root is flat and narrower mesially than distally, with a rectilinear basal line. This face is cut by two nutritive grooves that fail to extend to the upper part of the lingual face of the root. Of the two nutritive grooves, the one closer to the mesial edge runs through the midline of the basal face. Each of the grooves has a deep foramen opening on the lingual half of the base.

Comparison: The new species represented by IVPP8962 is characterized by its root that has a basal face cut by two shallow nutritive grooves. Judging from the crown, the teeth of this new species are rather similar to those of *Rhizoprionodon fischeuri* (Joleaud, 1912), which have been known from the middle and upper Miocene in western Europe (Cappetta, 1970; Antunes and Jonet, 1970; and Leriche, 1926), and the lateral teeth of *Rhizoprionodon* sp. (Case and West, 1991), which have been found in the upper Eocene of central western Pakistan. These resemblances may imply that there is a close relationship among these species.

Just as Cappetta (1987) and Case and Cappetta (1990) noticed, the teeth of *Rhizoprionodon* are morphologically similar to those of the Recent *Scoliodon* and *Loxodon*. From my observations, however, I found that the teeth of *Rhizoprionodon* have a distinctive character: the basal line of the root is rather straight in comparison with that of *Scoliodon* and *Loxodon*. Using this character, one may be able to distinguish the teeth of *Rhizoprionodon* from those of *Scoliodon* and *Loxodon*.

Genus *SCOLIODON* Müler and Henle 1837

***Scoliodon*** **sp., aff.** ***S. gannióurensis*** **Arambourg 1952**
(Fig. 6I-J)

Material: Six incomplete (IVPP8963-1 to -6) and four complete (IVPP8963-7 to -10) lateral teeth.

Locality: Collection Spot of Phosphate Concretions, County City of Wuqia; North Limb of Wulagen Syncline, Wuqia County.

Occurrence: Wulagen Formation.

Age: Late Eocene.

Remarks: These teeth seem rather similar to those of *Rhizoprionodon fischeuri* Joleaud, 1927, in the shape. However, their root is less transversely expanded than that of *R. fischeuri*. The basal face of the root of these teeth is somewhat curved; and the distal cutting edge of the main cusp of these teeth is not prominent. These characters indicate that these teeth do not pertain to *R. fischeuri*.

Judging from the available details, these teeth most closely resemble those of *Scoliodon* aff. *ganntourensis* Cappetta and Nolf (1981). They are almost identical to the teeth illustrated by Cappetta and Nolf (pl. 1, figs. 9—18).

Teeth of *Scoliodon, Rhizoprionodon,* and *Sphyrna* are very similar in morphology. Cappetta (1987) has also emphasized the close morphological similarity among the teeth of *Scoliodon, Loxodon* and *Rhizoprionodon*. This similarity increases the difficulty of identifying teeth belonging to these genera, and it may imply a close relationship among them.

*Scoliodon* is a Recent genus distributed in all oceans. *S. ganntourensis* (Arambourg, 1952) is the only fossil species of this genus. It was first found in the Lutetian (lower middle Eocene) of the Ganntour Basin, Morocco. In 1981, Cappetta and Nolf referred 47 teeth from Ronquerolles (upper Eocene of Paris Basin) to their *S.* aff. *ganntourensis,* believing that the teeth of this species were expected to be found in the upper Eocene of England and Belgium. The discovery of *S.* sp., aff. *S. ganntourensis* in the Wulagen Formation of the western Tarim Basin indicates that marine deposits of this formation were formed mainly in late Eocene time.

Genus *EOGALEUS* Cappetta 1975

***Eogaleus bolcensis*** **Cappetta 1975**
(Fig. 6K-L)

Material: Four lateral teeth, one of which (Fig. 6K-L) is nearly complete, IVPP8961-1 to -4.

Locality: Collection Spot of Phosphate Concretions, County City of Wuqia.

Occurrence: Wulagen Formation, Kashi Group.

Age: Late Eocene.

Remarks: In fact, these teeth are comparable to the lower lateral teeth of *E. bolcensis* (Cappetta, 1975b, 1987), which have been found in the lower Eocene of Monte Bolca, Italy.

Applegate (1978) considered *E. bolcensis* to be a synonym of *Galeothinus cuvieri*. Cappetta does not agree with Applegate because he believes that the teeth of *Eogaleus* are very different from those of *Galeothinus* in size and morphology. Although the teeth discussed here are much smaller than the teeth described by Cappetta (1975b), they morphologically support Cappetta's opinion, which states that *E. bolcensis* is a valid name.

Family SPHYRNIDAE Gill 1872
Genus *SPHYRNA* Rafinesque 1810

***Sphyrna zygaena*** (Linnaeus 1758)
(Fig. 6M-P)

Material: At least 29 teeth from anterior and lateral series, IVPP8964-1 to -29.

Locality: Collection Spot of Phosphate Concretions, County City of Wuqia; North Limb of Wulagen Syncline, Wuqia County.

Occurrence: Wulagen Formation, Kashi Group.

Age: Late Eocene.

Remarks: The teeth illustrated in Fig. 6M-P closely resemble those of the Recent *Sphyrna zygaena*. The anterior teeth are particularly comparable to the lower anterior teeth of *S. zygaena*. According to Bigelow and Schroeder (1948), the teeth from adult individuals of this species may be serrated along the cutting edges of the main cusp, but the teeth from the young are smooth-edged. The cutting edges of the teeth in my collection are devoid of serrations. This may indicate that all of these teeth are from young individuals.

Fossil teeth of *S. zygaena* have been found in the lower Miocene of North Carolina, U. S. A. (Case, 1980), the Miocene of Portugal (Antunes and Jonet, 1970) and southern France (Cappetta, 1970), and from the lower Pleistocene of Japan (Uyeno and Matsushima, 1974). It is the first time for this species to be found in the upper Eocene of the western Tarim Basin, China. However, the Recent range of this species extends to almost all of the oceans, mainly in warm coastal waters.

Superorder BATOMORPHA
Order RAJIFORMES
Family PLATYRHINIDAE Jordan 1923
Genus *PLATYRHINA* Müler and Henle 1831

***Platyrhina*** **sp.**
(Fig. 7A-B)
Material: At least 18 lateral teeth, IVPP8965-1 to -18.

Locality: Collection Spot of Phosphate Concretions, County City of Wuqia; North Limb of Wulagen Syncline, Wuqia County.

Occurrence: Wulagen Formation, Kashi Group.

Age: Late Eocene.

Remarks: The evidence on which I refer these lateral teeth to the genus *Platyrhina* is mainly from the observation of the teeth of the Recent *Platyrhina sinensis* Lacépéde, 1803. The occlusal view of all of these teeth shows a distinct transverse crest. The lingual face of the crown is uneven with a long median lingual uvula and two short lingual marginal uvulae. The root of these teeth is almost

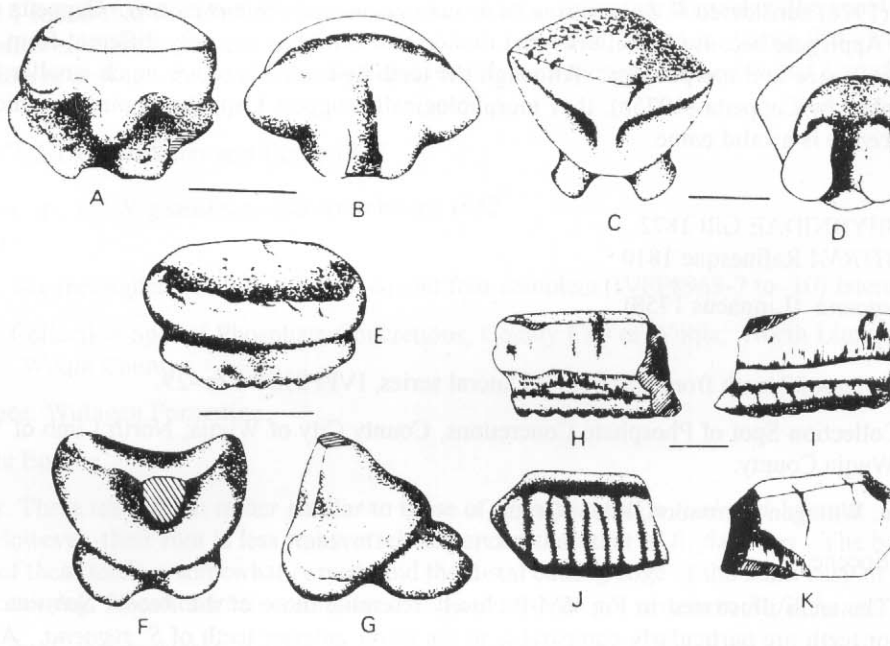


Fig. 7 **A-B,** *Platyrhina* sp., IVPP8965-1. **A,** lingual view; **B,** basal view. Scale bar equals 0.5mm. **C-D,** *Dasyatis* sp., IVPP8966-2. **C,** lingual view; **D,** basal view. Scale bar equals 0.5mm. **E,** *Coupatezia woutersi*, IVPP8967-1, occlusal view. **F-G,** *Jacquhermania duponti*, IVPP8968-1. **F,** occlusal view; **G,** profile. Scale bar for E-G equals 0.5mm. **H-K,** *Myliobatis* sp., IVPP8969-1. **H,** labial view; **I,** lingual view; **J,** basal view; **K,** occlusal view. Scale bar equals 2mm

as high as the crown and consists of two lobes in same size; a pair of large foramina are present on its margino-lingual faces.

Cappetta (1987) noticed that the teeth of the Recent *Platyrhina* are sexually dimorphic. This kind of sexual dimorphism is also shown on the 18 teeth collected from the western Tarim Basin, of which 14 may be identified as the teeth from male individuals. Provisionally these teeth are considered to be *P.* sp.; they possibly represent a new fossil species of *Platyrhina*. Cappetta and Nolf (1981) named a new species of *Rhinobatos* (*R. steurbauti*) on the specimens from the upper Eocene of Paris Basin. The teeth used to define that species are very similar to the teeth identified here as *P.* sp. I doubt that those teeth may be referred to *Platyrhina* rather than to *Rhinobatos*.

Valid fossil species of *Platyrhina* are *P. egertoni* Zigno, 1876 and *P. bolcensis* Moulin, 1860, both of them were named on the poor-preserved skeleton and found in the lower Eocene of Monte Bolca, Italy. However, the Recent platyrhinids "frequent coastal waters of tropical and subtropical regions" (Cappetta, 1987) of the West Pacific. The discovery of *P.* sp. from the western Tarim Basin may be significant for studying the historical biogeography of platyrhinids.

Order MYLIOBATIFORMES
Family DASYATIDAE Jordan 1888
Genus *DASYATIS* Rafinesque 1810

***Dasyatis*** sp.
(Fig. 7C-D)

Material: 20 small teeth, IVPP8966-1 to -20.

Locality: Collection Spot of Phosphate Concretions, County City of Wuqia; North Limb of Wulagen Syncline; Kuliuwusu, Wuqia County.

Occurrence: Wulagen Formation, Kashi Group.

Age: Late Eocene.

Remarks: These teeth resemble those of *D. cavernosa* Probst, 1877 (Case, 1980). The crowns consist of a subrhomboid labial face and a triangular lingual face on which a median lingual ridge is developed. The occlusal view shows a clear transverse crest extending between the two lateral marginal angles, which separates the lingual face from the labial face. The root is bilobate with a deep nutritive groove. For the sake of prudence, I tentatively consider the teeth from the western Tarim Basin to be *Dasyatis* sp.

It should be noticed that *D. cavernosa* was first known in the lower Miocene of southwestern Germany, and later in the early Miocene Trent Marl Formation (Aquitanian) of north Carolina. In total, *Dasyatis* may contain 20 or more species including both fossil and Recent (Cappetta, 1987). The previously described 18 fossil species of this genus distribute over the Europe, North America, and Africa, occurring in the Upper Cretaceous (e.g. *D. schaefferi* Cappetta, 1975a), and varying morphologically one from another. The fragments of caudal spine of *Dasyatis* species have also been found in the Eocene coastal deposits of the Bohai Sea (Chang and Chow, 1986).

Genus *COUPATEZIA* Cappetta 1982

***Coupatezia woutersi*** **Cappetta 1982**
(Fig. 7E)

Material: At least three teeth, IVPP8967-1 to -3.

Locality: Collection Spot of Phosphate Concretions, County City of Wuqia; North Limb of Wulagen Syncline, Wuqia County.

Occurrence: Wulagen Formation, Kashi Group.

Age: Late Eocene.

Remarks: *C. woutersi* (Cappetta, 1982) used to be referred to female *Raja duponti* Winkler, 1874, by Leriche (1905, 1906), and is characterized by having a lower crown with kidney-shaped labial face bearing vermiculated enameloid. Cappetta (1982) first included this species in Dasyatidae and later (1987) considered it to be "Dasyatoidea incertae familiae". According to my observation, I prefer Cappetta's original classification to his later uncertainty because *Coupatezia* possesses a typical dasyatid tooth root. Besides *C. woutersi, Coupatezia* may also contain *C. fallax* (=*Dasyatis fallax* Arambourg, 1952), which is rather different from the teeth in my collection.

*C. woutersi* has been known only in the middle Eocene of Brussels, Belgium. Its discovery in the late Eocene Wulagen Formation of the western Tarim Basin imply: (1) it had a wider distribution both geologically and zoogeographically; (2) the Tarim Sea and the early eastern North Atlantic Ocean were connected with each other during late Eocene time.

Family GYMNURIDAE Fowler 1934
Genus *JACQUHERMANIA* Cappetta 1982

***Jacquhermania duponti*** **(Winkler 1874) Cappetta 1982**
(Fig. 7F-G)

Material: Four teeth; IVPP8968-1 to -4.

Locality: Collection Spot of Phosphate Concretions, County City of Wuqia; North Limb of Wulagen Syncline, Wuqia County.

Occurrence: Wulagen Formation, Kashi Group.

Age: Late Eocene.

Remarks: The anterior teeth may be slightly different from the lateral teeth in *Jacquhermania duponti*, the former with a narrower or mesio-distally compressed crown, and the later with a relatively broader crown and robust root. However, all the crown of the teeth are subsemiconical in shape and bending mesially, with a flat or slightly concave labial face and a convex or peach-shaped lingual face. The root is cut by a deep and broad nutritive groove into two lobes equal in size.

*Jacquhermania* is a monospecific genus. Winkler (1874) initially misidentified it as *Cestracion duponti*. Leriche (1905, 1906) referred it to male individual of *Raja duponti*. Cappetta (1982) renamed this species after his reviewing the previously description. He found that the teeth of *Jacquhermania* closely resemble those of the Recent *Gymnura*, and then adjusted the taxonomic position of this species. In 1987, I examined the teeth of the Recent *Gymnura* and compared them with those of *Jacquhermania* when I visited in Shanghai Fisheries University. My conclusion is the same as that Cappetta arrived.

*J. duponti* was first known in the middle Eocene of Brussels, Belgium, and later in the upper Eocene of the Paris Basin (Cappetta and Nolf, 1981; new name, Cappetta, 1987). It may imply same information on biostratigraphy and paleozoogeography as *Coupatezia woutersi* does.

Family MYLIOBATIDAE Bonaparte 1838
Genus *MYLIOBATIS* Cuvier 1838

***Myliobatis*** sp.
(Fig. 7H-K)

Material: At least 40 incomplete median or lateral teeth, IVPP8969-1 to -40.

Locality Collection Spot of Phosphate Concretions, County City of Wuqia; North Limb of Wulagen Syncline; Tuzitao; and Kuliuwusu, Wuqia County.

Occurrence: Wulagen Formation, Kashi Group.

Age: Late Eocene.

Remarks: All of these teeth possess a high crown, which has a flat occlusal face, and a polyaulacorhized root. They can be definitely referred to the genus *Myliobatis*.

*Myliobatis* first appears in the Paleocene (e.g. *M. nzadinensis* and *M. sulcidens*, Dartevelle and Casier, 1943), and abounds in the Recent warm oceans. According to the literature, about 150 fossil species have been included in this genus (Cappetta, 1987). I believe that most of them need to be reexamined. Any attempt to refer the teeth from the western Tarim Basin to certain named species will be difficult before the reexamination is made.

Family RHOMBODONTIDAE Cappetta 1987
Genus *PLANODENS* gen. nov.

Type Species: *Planodens wuqicus* gen. et sp. nov.

Diagnosis: Rhombodontid different from *Rhombodus* and *Pucabatis* in following characters: teeth small, crown flat and rhomboid, occlusal face even and typical rhombus with two opposite lateral angles larger than 90°, labial visor small, lingual visor large and overhanging lingual face of root, root holaulacorhized and not lower than crown, basal face rhomboid and diagonally (labiao-lingually) cut by nutritive groove into two lobes equal in size, nutritive groove broad and perpendicular to line between two lateral angles of crown.

***Planodens wuqicus*** gen. et sp. nov.
(Fig. 8)

Diagnosis: As for genus.

Holotype: IVPP8970-1, a complete tooth.

Etymology: The generic name is derived from the combination of Latin "planus", meaning "flat", and "dens", meaning "tooth", implying that the teeth of this new genus and species has a lower and flat crown. The specific name is derived from the type locality "Wuqia".

Type Locality: Collection Spot of Phosphate Concretions, County City of Wuqia.

Horizon: Wulagen Formation, Kashi Group.

Age: Late Eocene.

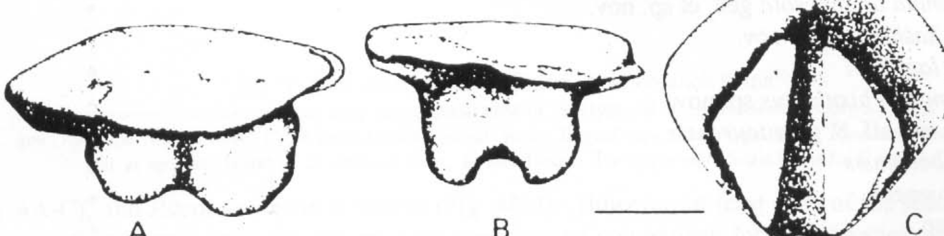


Fig. 8 *Planodens wuqicus* gen. et sp. nov., holotype
**A**, occlusal view; **B**, labial view, **C**, basal view. Scale bar equals 0.4mm

Description: Besides the holotype, I have another 15 small teeth collected from the Collection Spot of Phosphate Concretions, the North Limb of Wulagen Syncline, and Kuliuwusu of Wuqia County. All of these teeth are small and low in height.

The crown is rhomboid and flat, not higher than root. The occlusal face is typical rhombus and flat or slightly convex with two opposite lateral angles larger than 90°. The line between the two lateral angles is perpendicular to the direction in which the nutritive groove extends. The margino-labial faces are concave, forming an inlaying area for the lingual visor of the successive teeth. Labial visor is small, slightly overhanging the labial face of the root. The lingual face is narrow and overhangs the lingual face of the root. Lingual visor is large and extremely overhangs the root.

The root is holaulacorhized and almost as high as the crown. Both labial and lingual faces are steep. The basal face is also rhomboid but much smaller than the occlusal face of the crown; it is diagonally (labiao-lingually) cut by the nutritive groove into two triangular and equal-sized lobes. The nutritive groove is broad and labiao-lingually extends; no large foramen is seen in this groove.

Comparison: Rhombodontidae contain two valid genera: *Rhombodus* (Dame, 1881) and *Pucabatis* (Cappetta, 1975a). Both of them differ from the new genus in having: (1) a high and robust crown, (2) no large lingual visor, (3) a cross section of the nutritive groove in the shape of a capital omega, and (4) marked vertical wrinkles on both the margino-labial and the margino-lingual faces (*Pucabatis* has an occlusal face bearing five ridges). Stratigraphically, *Rhombodus* appears in the Upper Cretaceous of North and South America, Africa, Europe, and Near East (Dames, 1881; Arambourg, 1952; Cappetta and Case, 1975); *Pucabatis* occurs in the Late Cretaceous El Molino Formation of Toro-Toro, Bolivia (Cappetta, 1975a). All of these evidences are incomparable to the new genus *Planodens*.

Table 1 Composition and occurrence of the Tarim elasmobranch fauna in the western Tarim Basin

| species | Qimugen Formation (Early Eocene) | Wulagen Formation (Late Eocene) |
|---|---|---|
| *Heterodontus maisierensis* | | * |
| *Ginglymostoma minutum* | | * |
| *Eorhincodon tianshanensis* gen. et sp. nov. | | * |
| *Hispidaspis gigas* | * | * |
| *Striatolamia macrota* | * | * |
| *Plicatolamna macrorhiza* | | * |
| *Pseudocorax* sp. | | * |
| *Isurus* sp. | * | * |
| *Archaeolamna apophysata* gen. et sp. nov. | | * |
| *Abdounia kashiensis* sp. nov. | | * |
| *Abdounia lapierrei* | | * |
| *Rhizoprionodon bisulcatus* sp. nov. | | * |
| *Scoliodon* sp., aff. *S. ganntourensis* | | * |
| *Eogaleus bolcensis* | | * |
| *Sphyrna zygaena* | | * |
| *Plasyatis* sp. | | * |
| *Dasyatis* sp. | | * |
| *Coupatezia woutersi* | | * |
| *Jacquhermania duponti* | | * |
| *Myliobatis* sp. | | * |
| *Planodens wuqicus* gen. et sp. nov. | | * |

## DISCUSSION AND CONCLUSIONS

### 1 Composition of Tarim Elasmobranch Fauna and Its Bearing on Biostratigraphy

Table 1 shows the composition and occurrence of the species of the Tarim elasmobranch fauna. Among the faunal assemblage, *Eorhincodon tianshanensis* (Figs.3 and 9A), *Archaeolamna apophysata* (Figs. 5 and 9B), *Abdounia kashiensis* (Figs. 6A-C and 9C), *Rhizoprionodon bisulcatus* (Fig. 6F-H), and *Planodens wuqicus* (Figs. 8 and 9D-E) are new taxa that have not been described elsewhere. In addition, I have not found any tooth that may be referred to squaliform, squatiniform, pristiophoriform and topediniform species. This indicates that the Tarim elasmobranch fauna is rather provincial.

It should be noticed that the Tarim elasmobranch fauna contains some Late Cretaceous species, such as *Heterodontus maisierensis* (Fig. 2A-B), *Ginglymostoma minutum* (Fig. 2C-E), *Hispidaspis gigas*

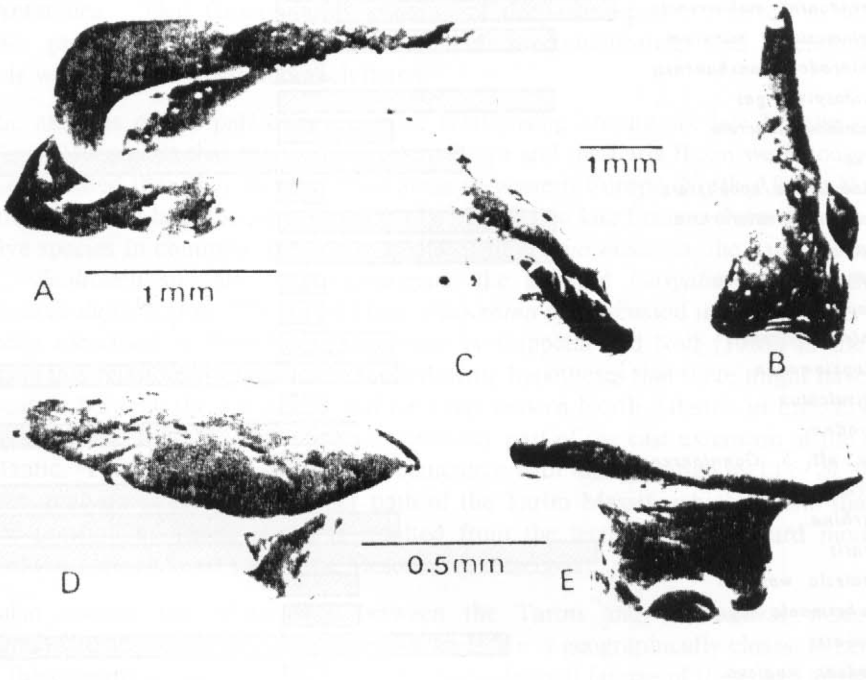


Fig. 9 Four new species in Tarim elasmobranch fauna.
A, *Eorhincodon tianshanensis* gen. et sp. nov., mesial view of holotype. B, *Archaeolamna apophysata* gen. et sp. nov., holotype, lingual view. C, *Abdounia kashiensis* sp. nov., lingual view of holotype. D-E, *Planodens wuqicus* gen. et sp. nov., holotype. D, occlusal view; E, labial view. The upper-right Scale bar is for C and B.

(Fig. 4A-C), and *Plicatolamna macrorhiza* (Fig. 4G-I). However, at least 60% of the species of this fauna are first known from the Eocene (see remarks and comparison for each species and Fig. 10). Species such as *Abdounia lapierrei* (Fig. 6D-E), *Scoliodon* sp., aff. *S. ganntourensis* (Fig. 6I-J), and *Sphyrna zygaena* (Fig. 6M-P) have not been found in deposits older than late Eocene. In terms of the explanation of biostratigraphic distributions for all species in the Tarim elasmobranch fauna (Fig. 10), I believe that this is mainly a late Eocene fish fauna. It might have existed until the early Oligocene, and therefore the fish-bearing Wulagen Formation was formed mainly in the late Eocene; it may contain part of the lower Oligocene. This conclusion is different from those arrived at mainly on the basis of the explanation of fossil foraminifera (Fig. 11).

As for the age of Qimugen Formation, there have been two opinions (see Fig. 11). In this paper I tentatively readjust its geological age to the early Eocene because it contains the teeth of *Striatolamia macrota* (Fig. 4D-F), which is an odontaspidid species found so far in the Eocene deposits of the Paris Basin, France. Further investigation in this formation needs to be made.

## 2 Paleozoogeographic Interpretation of the Tarim Elasmobranch Fauna

The comparison of the Tarim elasmobranch fauna with those late Eocene selachian faunae in western Europe, North Africa, central western Pakistan and North America is summarized in Table 2. In my opinion, the Paris Basin fauna may be representative of the late Eocene eastern North

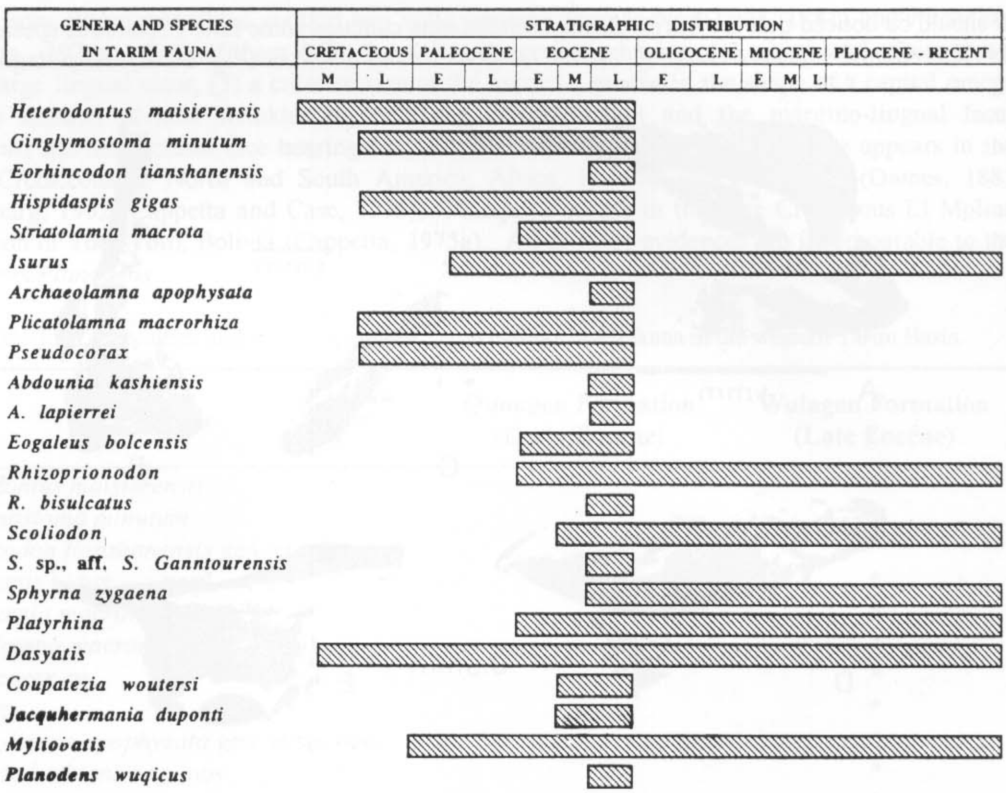


Fig. 10 Stratigraphic distribution of the species in Tarim elasmobranch fauna, refer to the remarks and comparison for each species

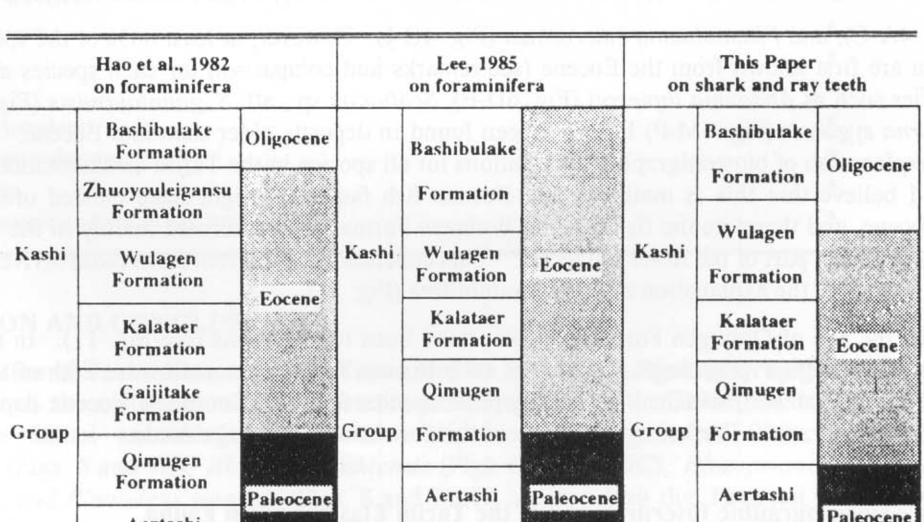


Fig 11 Showing the relationship between the Wulagen Formation and its overlying and underlying strata

Atlantic elasmobranch fauna, which is most comparable to the Tarim elasmobranch fauna at both the generic and specific levels although this comparison is limited to certain taxa.Long (1992) recently reported another possible late Eocene selachian fauna occurs in the La Meseta Formation of Seymour Island, Antarctica. That fauna mainly consists of deep sea species referred to hexanchiforms, squliforms, pristiophoriforms, squatiniforms, and orectolobiforms, and therefore is hardly comparable with the Tarim elasmobranch fauna.

A cladistic analysis of the paleozoogeographic relationship among six late Eocene elasmobranch faunae (Fig. 12) suggests that the western Tarim Basin and the Paris Basin were zoogeographically more closely related than they were to other areas in western Europe, North Africa, North America, and Antarctica during late Eocene time (Fig. 13). These two late Eocene elasmobranch faunae have at least five species in common, the odontaspidid *Striatolamia macrota*, the carcharhinid *Abdounia lapierrei*, *Scoliodon* sp., aff. *S. ganntourensis*, the dasyatid *Dasyatis* sp., and the gymnurid *Jacquhermania duponti* (Fig. 12). In addition, *Platyrhina* sp. discussed in this paper is probably the same species identified as *Rhinobatos steurbauti* by Cappetta and Nolf (1981) in the Paris Basin fauna. From this relationship I am led to the following hypotheses that there might have been a wide communication between the Tarim Sea and the early eastern North Atlantic in Late Eocene or even early Oligocene, and that the Tarim Sea was probably part of the east extension of the early eastern North Atlantic. This hypothesis seems to be coincident with that proposed by Li *et al.* (1989) on the basis of the analysis of the polar wander path of the Tarim Massif, which asserts that the Recent geographic position of Tarim Basin is resulted from the tectonically eastward motion (at least 2000km) of the Tarim Massif since Late Mesozoic (Cretaceous).

I have also noticed the relationship between the Tarim and the central western Pakistan elasmobranch faunae. Although the western Tarim Basin is geographically closest to central western Pakistan, there seems no similarity between the elasmobranch faunae of these two areas. A possible hypothesis for this relationship could be that a barrier had formed between the Indian Ocean and the Tarim Sea before late Eocene. That barrier blocked the communication between the Indian Ocean and the Tarim Sea and hence prevented the exchange of the fish faunae between these two regions.

### 3 Paleoecological Explanation of the Tarim Elasmobranch Fauna

Of the 21 species in the Tarim elasmobranch fauna, 10 have Recent relatives. *Heterodontus maisierensis* (Fig. 2A-B) has its Recent relatives living in the tropical and temperate waters of the Indian and Pacific oceans (Bigelow and Schroeder, 1948; Migdalski and Fichter, 1983; Nelson, 1994). The Recent relatives of *Ginglymostoma minutum* (Fig. 2C-E) inhabit the tropical Atlantic and Indo-Pacific. The Recent species of *Isurus* are cosmopolitan in their distributions. They can be found in both warm and temperate waters of all oceans. *Scoliodon* sp., aff. *S. ganntourensis* (Fig. 6I-J) has Recent relatives distributed in the tropical and temperate waters of all oceans, mainly in coastal shallow seas. *Rhizoprionodon bisulcatus* sp. nov. (Fig. 6F-H) has its Recent sister-species mainly inhabiting the warm Atlantic. *Sphyrna zygaena* (Fig. 6M-P) is itself a Recent species that can be found in the warm coastal waters of all oceans. Its Recent sister-species are either cosmopolitan (*S. mokarran*) or regional in distribution (*S. lewini* and *S. tudes*), mainly in warm coastal or shallow waters.

Although the habitat of the Recent species of *Dasyatis* (Fig. 7C-D) may range from the pelagic open sea (*D. violacea*) to fresh water streams and lakes (Thailand: *D. sephen* and *D. bleekeri*), they inhabit mainly the warm shallow waters of the Atlantic, Pacific [including the South and North China Sea, Yellow Sea, and Bohai Sea (Zhu, 1960)], and Indian oceans, buried in sand or soft sediment (Migdalski and Fichter, 1983). The Recent relatives of *Myliobatis* sp. (also see Shen, 1993) (Fig. 7H-K) are also cosmopolitan in warm seas.

Table 2 Comparison of the late Eocene elasmobranch faunae of the western Tarim Basin, the Paris Basin, the Fayum Depression, central western Pakistan, and georgia (USA). (*)=new taxa

| **Tarim fauna** (This Paper) | **Paris Basin fauna** (Cappetta &Nolf, 1981) (Cappetta, 1987, new name) | **Fayum Depression fauna** (Case &Cappetta, 1990) | **West Pakistan fauna** (Case &West, 1991) | **Georgia fauna** (Case, 1981) (Cappetta, 1987, new name) |
|---|---|---|---|---|
| *Heterodontus maisierensis* | *Heterodontus cf. vincenti* | | | *Heterodontus pineti* |
| | | | | *Nebrius obliquum* |
| | | | *Nebrius obliquum* | |
| *Ginglymostoma minutum* | | | | |
| *Eorhincodon tianshanensis* (*) | | | | |
| | | | | *Chacharias acutissima* |
| *Hispidaspis gigas* | *Odontaspis* sp., aff. *S. winkleri* | | | |
| | | | | *C. cuspidata* |
| *Striatolamia macrota* | *Striatolamia macrota* | | | |
| *Plicatolamna macrorhiza* | | *Cretolamna twiggsensis* | *Cretolamna twiggsensis* | *Cretolamna twiggsensis* |
| | | *Carcharocles cf. sokolowi* | | *Carcharocles auriculatus* |
| | | *Alopias* sp., aff. *A alabamensis* | | |
| *Pseudocorax* sp. | | | | |
| *Isurus* sp. | | *Isurus praecursor* | | *Isurus praecursor* |
| *Archaeolamna apophysata* (*) | | | | |
| | *Scyliorhinus gilberti* | | | *Scyliorhinus distans* |
| | *Galeorhinus sp.* | | | |
| *Abdounia kashiensis* (*) | | *Hemipristis curvatus* | | *Hemipristis curvatus* |
| *Abdounia lapierrei* | *Abdounia lapierrei* | *Abdounia* sp. | | *Abdounia enniskilleni* |
| *Rhizoprionodon bisulcatus* (*) | | *Rhizoprionodon* sp. | *Rhizoprionodon* sp. | *Rhizoprionodon* sp. |
| *Scoliodon* sp., aff. *S. ganntourensis* | *Scoliodon* sp., aff. *S. ganntourensis* | | | |
| *Eogaleus bolcensis* | | *Physogaleus* sp., aff. *P. terrius* | | |
| | | *Carcharhinus frequens* | *Carcharhinus* sp. | *Galeorhinus galeus* |
| | | *Galeocerdo latidens* | *Galeocerdo latidens* | *Galeocerdo clarkensis* |
| | | *Misrichthys stromeri* | *Negaprion eurybathrodon* | *Negaprion eurybathrodon* |
| *Sphyrna zygaena* | | | | |
| | | *Odontorhytis pappenheimi* | *Odontorhytis pappenheimi* | |
| | | | | *Squatina prima* |
| | | *Anoxypristis* sp., aff. *A. mucrodens* | | |
| | | *Pristis lathami* | | *Pristis lathami* |
| *Platyrhina* sp. | | *Propristis schweinfurthi* | | *Propristis schweinfurthi* |
| | *Rhinobatos steurbauti* | | | *Rhinobatos* cf. *casieri* |
| *Dasyatis* sp. | *Dasyatis* sp. | | *Dasyatis charlisae* | *Dasyatis borodini* |
| *Coupatezia woutersi* | | | | |
| *Jacquhermania duponti* | *Jacquhermania duponti* | | | |
| | | | *Rhinoptera* sp. | *Rhinoptera daviesi* |
| *Myliobatis* sp. | *Myliobatis* sp. | *Myliobatis* sp. | *Myliobatis* sp. | *Myliobatis* sp. |
| | *Aetobatus irregularis* | *Aetobatus* cf. *irregularis* | | *Aetobatis* sp. |
| *Planodens wuqicus* (*) | | | | |

| | | Tarim Fauna | Paris Basin Fauna | Fayum Depression Fauna | Western Pakistan Fauna | Georgia Fauna | Seymour Island Fauna |
|---|---|---|---|---|---|---|---|
| 1 | *Myliobatis* sp. | * | * | * | * | * | □ |
| 2 | *Dasyatis* | * | * | □ | * | * | □ |
| 3 | *D.* sp. | * | * | □ | □ | □ | □ |
| 4 | *D. chalisae* | □ | □ | □ | * | □ | □ |
| 5 | *D. borodini* | □ | □ | □ | □ | * | □ |
| 6 | *Rhizoprionodon* | * | □ | * | * | * | □ |
| 7 | *Rh.* sp. | □ | □ | * | * | * | □ |
| 8 | *Abdounia* | * | * | * | □ | * | □ |
| 9 | *A. lapierrei* | * | * | □ | □ | □ | □ |
| 10 | *Heterodontus* | * | * | □ | □ | * | □ |
| 11 | *H. maisierensis* | * | □ | □ | □ | □ | □ |
| 12 | *H.* cf. *vincenti* | □ | * | □ | □ | □ | □ |
| 13 | *H. pineti* | □ | □ | □ | □ | * | □ |
| 14 | *Striatolamia macrota* | * | * | □ | □ | □ | □ |
| 15 | *Scoliodon* | * | * | □ | □ | □ | * |
| 16 | *Sc.* sp., aff. *S. ganntourensis* | * | * | □ | □ | □ | □ |
| 17 | *Sc.* sp. | □ | □ | □ | □ | □ | * |
| 18 | *Jacquhermania duponti* | * | * | □ | □ | □ | □ |
| 19 | *Sphyna zygaena* | * | □ | □ | □ | * | □ |
| 20 | *Squalus woodburnei* | □ | □ | □ | □ | □ | * |
| 21 | *Sp. weltoni* | □ | □ | □ | □ | □ | * |
| 22 | *Squatina* | □ | □ | □ | □ | * | * |
| 23 | *S. prima* | □ | □ | □ | □ | * | □ |
| 24 | *S.* sp. | □ | □ | □ | □ | □ | * |
| 25 | *Pristis lathami* | □ | □ | * | □ | * | □ |
| 26 | *Aetobatus* | □ | * | * | □ | * | □ |
| 27 | *Ae. irregularis* | □ | * | □ | □ | □ | □ |
| 28 | *Ae.* cf. *irregularis* | □ | □ | * | □ | □ | □ |
| 29 | *Rhinobatos* | ? | * | □ | □ | * | □ |
| 30 | *Rhi. steurbauti* | □ | * | □ | □ | □ | □ |
| 31 | *Rhi.* cf. *casieri* | □ | □ | □ | □ | * | □ |
| 32 | *Carcharhinus* | □ | □ | * | * | □ | □ |
| 33 | *C. frequens* | □ | □ | * | □ | □ | □ |
| 34 | *C.* sp. | □ | □ | □ | * | □ | □ |
| 35 | *Cretolamna twiggsensis* | □ | □ | * | * | * | □ |
| 36 | *Galeocerdo* | □ | □ | * | * | * | □ |
| 37 | *G. latidens* | □ | □ | * | * | □ | □ |
| 38 | *G. clarkensis* | □ | □ | □ | □ | * | □ |
| 39 | *Odontorhytis pappenheimi* | □ | □ | * | * | □ | □ |
| 40 | *Isurus praecursor* | □ | □ | * | □ | * | □ |

* Present ? Unknown □ Absent

Fig. 12 Representatives of the genera and species occurred in the six late Eocene elasmobranch faunae

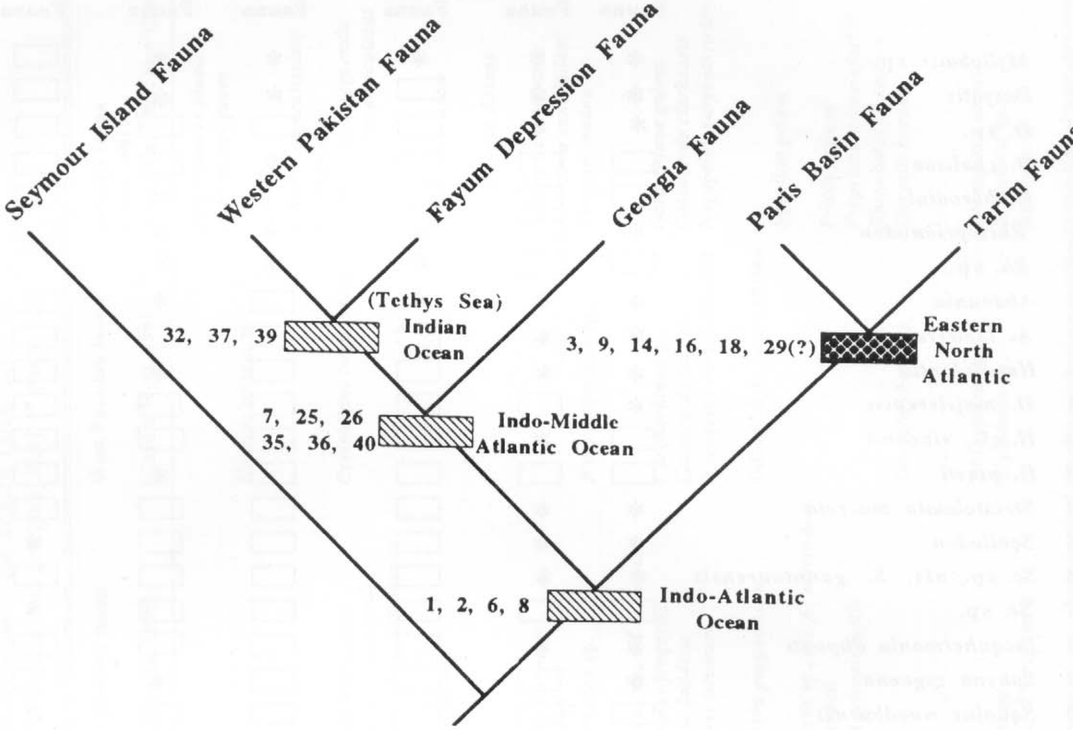


Fig.13 Geogram (Fox, 1992, pers. comm.) derived from Fig. 12, showing the possible paleozoogeographic relationships among the six late Eocene elasmobranch faunae. Taxa represented by the number are listed in Fig. 12

As the closest Recent relative of *Eorhincodon tianshanensis* gen. et sp. nov. (Figs.3 and 9A), *Rhincodon typus* "roams the tropical seas of the world" (Migdalski and Fichter, 1983). And so do the Recent relatives of *Platyrhina* sp. (Fig. 7A-B) (Cappetta, 1987).

All these Recent clues, including the absence of pelagic squaliforms, pristiophoriforms, and topediniforms in the Tarim elasmobranch fauna, suggest that the Tarim Sea was a warm subtropical shallow sea.

Considering the tooth patterns developed in the Tarim elasmobranch fauna, I can arrive at similar conclusion about the paleoecology of the Tarim Sea.

*Ginglymostoma minutum* developed a clutching dentition. The teeth of *Hispidaspis gigas* (Fig. 4A-C), *Striatolamia macrota* (Fig. 4D-F), *Archaeolamna apophysata* gen. et sp. nov. (Figs. 5 and 12B), *Plicatolamna macrorhiza* (Fig. 4G-I) and *Pseudocorax* sp. (Fig. 4J-L) belong to tearing type. *Abdounia kashiensis* sp. nov. (Fig. 6A-C, Fig. 9C), *A. lapierrei* (Fig. 6D-E), *Eogaleus bolcensis* (Fig. 6K-L), *Rhizoprionodon bisulcatus* sp. nov., *Scoliodon* sp., aff. *S. ganntourensis*, and *Sphyrna zygaena* possessed a cutting-clutching dentition. *Platyrhina* sp., *Dasyatis* sp. and *Coupatezia woutersi* (Fig. 7E) were equipped with a set of crushing teeth that denote a benthic life style.

*Myliobatis* sp. and *Planodens wuqicus* gen. et sp. nov. (Figs. 8 and 9D-E) had a grinding dentition. The teeth of *Heterodontus maisierensis* can be referred to the clutching-grinding type.

The above tooth patterns represent all of the tooth types that can be identified from Recent selachian fishes (Meng and Zhu, 1984), strongly suggesting that the Tarim Sea was productive, rich in animal food. As a general rule, sea water abundant in animal food is here considered to be warm coastal to temperate shallow sea.

## 4 Conclusions

1) Tarim elasmobranch fauna is mainly a late Eocene fish fauna with Cretaceous relicts and more modern genera and even recent species. The Wulagen Formation bearing this fish fauna was formed mainly in the late Eocene; it may contain some deposits formed in the early Oligocene.

2) The age of Qimugen Formation should be readjusted to early Eocene because it contains the Eocene species *Striatolamia macrota*.

3) Tarim elasmobranch fauna is most comparable to the eastern North Atlantic selachian fauna of the Paris Basin. This may imply that there was a wide communication between the waters of the Tarim Sea and those of the early eastern North Atlantic during the late Eocene, that is, the Tarim Sea was probably the east extension of the early eastern North Atlantic.

4) The Tarim Sea was a warm subtropical productive shallow sea, being abundant in animal food.

## ACKNOWLEDGEMENTS

I am most grateful to Dr. Mark V. H. Wilson, my supervisor to doctorate, Professor of Biology, University of Alberta, for his financial support, his permission to use equipment to complete writing this manuscript, and his valuable comments on this project; and to Dr. Richard C. Fox, Professor of Geology and Biology, University of Alberta, Canada, for his valuable and constructive suggestions on the earlier versions of this paper.

Dr. Chang Mee-mann, former Director of the IVPP, is the key supporter and instructor of this project. This study has also been encouraged by Profs. Chang Guo-rui and Wang Jun-qing, former Chairmen of the Department of Paleoichthyology of the IVPP. I have benefited a lot from their encouragement and suggestions.

My most sincere gratitude is extended to Prof. Meng Qing-wen, ex-president of Shanghai Fisheries University, for introduction to the knowledge of chondrichthyes; to Dr. John Maisey, American Museum of Natural History, for his valuable comments and suggestions on the earlier version of this paper; to Mr. Zhang Wen-ding for taking the pictures under the scanning electron microscope.

I also greatly appreciate the following persons and institutions for their assistance on this project: Financial support for collecting and preliminary examination of the specimens studied in this paper was provided by both the research grant for the Research Group of Devonian Fishes and the Director's Fund of the Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences. The investigation team from Nanjing Institute of Geology and Paleontology offered much help including a vehicle during the field season in 1987. Drs. Ye Chun-hui and Chen Pei-ji took care of me when I was ill and confined in the hospital. Mr. Wang Yu-zhen, senior engineer of the Geological Survey Bureau of Xinjiang Uygur Zizhiqu, discovered the first specimens and the fossil localities, and provided me with information about the geology and stratigraphy of those localities.

Thanks also go to Mr. David J. Ward and Mr. Gerard R. Case for their good-will to the author.

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