

Selachian Fauna from the Upper Miocene Senhata Formation, Boso Peninsula, Central Japan¹⁾

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Abstract Over two thousand selachian (shark) remains from the upper Miocene Senhata Formation of the Boso Peninsula, central Japan are described. This formation contains a diverse selachian fauna belonging to 20 taxa: Hexanchidae gen. et sp. indet., *Dalatias licha*, *Isistius* sp., *Pristiophorus lanceolatus*, *Squatina* sp., *Carcharias* sp., *Carcharodon carcharias*, *Isurus oxyrinchus*, *Isurus hastalis*, *Carcharocles megalodon*, *Parotodus benedeni*, *Galeorhinus* sp., *Hemipristis serra*, *Carcharhinus* sp. A, *Carcharhinus* sp. B, *Carcharhinus* sp. C, *Carcharhinus* sp. D, *Carcharhinus* sp. E, *Sphyrna zygaena* and vertebral centra. The fauna is composed of neritic, epipelagic and bathypelagic elements of both extinct and Recent taxa.

Key words: Boso Peninsula, late Miocene, selachians, Senhata Formation.

The upper Miocene Senhata Formation, distributed in the central part of the Boso Peninsula, yields rich selachian remains, as well as hexacorals, echinoids, decapods, molluscs and marine tetrapods (Tomida, 1989; Karasawa *et al.*, 1992; Kohno, 1992; Kohno and Hirayama, personal communication).

Ishiwara (1921) initially described and figured the selachians from the Neogene of Japan, including the locality at Mt. Nokogiri where the megatooth shark *Carcharocles megalodon* was collected from. The locality at Nokogiri-yama was also noted by Goto (1972). The localities at Fudoiwa and Shiofuki-Tunnel are well known for occurrence of selachian remains (Takahashi, 1954). Uyeno *et al.* (1990) described a specimen of the lamnoid shark *Isurus hastalis*, which contains an almost complete dentition and several vertebral centra from this formation.

Despite the richness of selachian remains, few paleontological studies had been done on them before 1990's. The purpose and scope

of this paper is to present a systematic description of the selachian specimens from the Senhata Formation.

Geological Setting of the Senhata Formation

Specimens were collected from the Neogene strata in Futtsu City and Kyonan-machi, the central part of the Boso Peninsula, central Japan (Figs. 1 and 2). The Neogene series in this area is composed of the Miocene to lower Pliocene Miura Group and the upper Pliocene to Pleistocene Kazusa Group. The geological studies of this area were carried out in detail by Koike (1949), Endo (1969), Mitsunashi *et al.* (1976, 1979), O'hara and Ito (1980) and Fujita and Kodama (1990). The pyroclastic key beds intercalated in these groups were described and correlated by Mitsunashi and Yazaki (1958), Urabe *et al.* (1990), Kanie *et al.* (1991) and Urabe (1992). Furthermore, Suzuki *et al.* (1995) recently summarized the geology and stratigraphy of

¹⁾ Preliminary works leading to this study were presented at the 1994 Annual Meeting of the Palaeontological Society of Japan (Tokyo), the 101st and 102nd Annual Meeting of the Geological Society of Japan (Hokkaido, Hiroshima), the 12th Annual Meeting of the Fossil Research Society of Japan (Osaka) and the 145th Regular Meeting of the Palaeontological Society of Japan (Niigata). This study was also the main part of the master thesis by the senior author submitted to Niigata University in 1995.

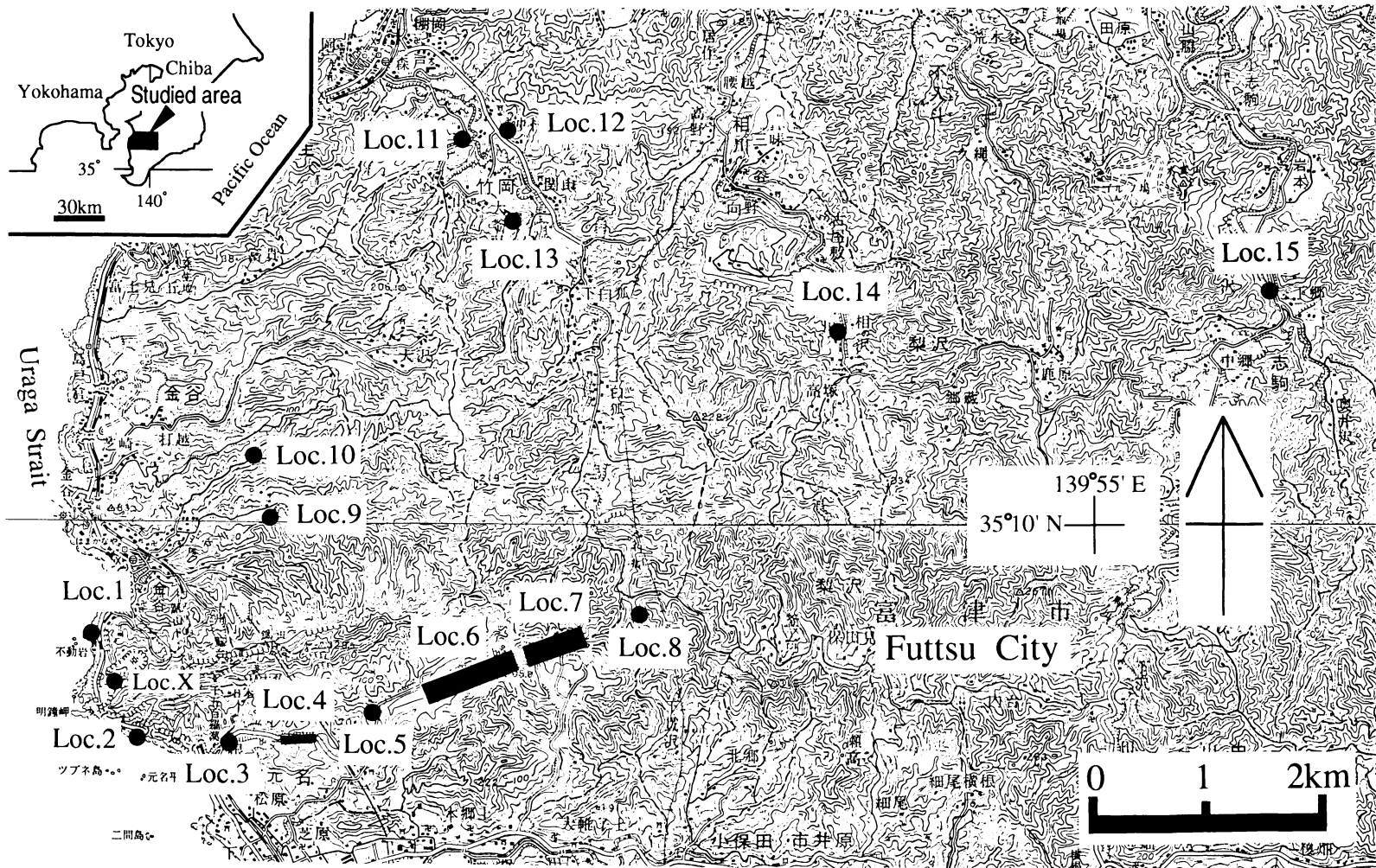


Fig. 1. Study area and localities of selachian remains. Modified from the 1:50000 “Futtsu” and “Nago” topographical maps issued by the Geographical Survey Institute of Japan.

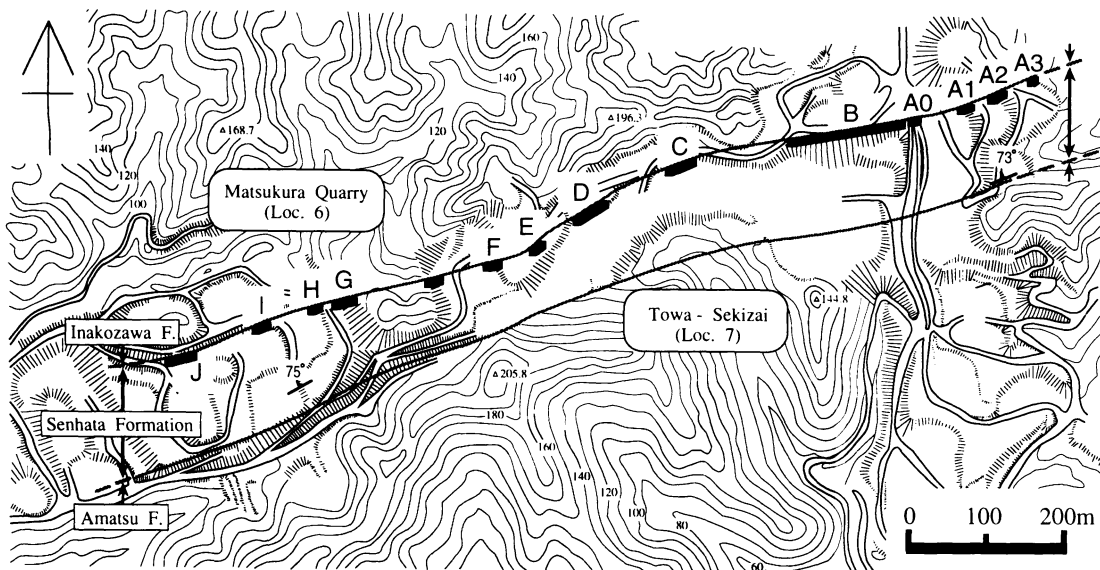


Fig. 2. Geological map and collecting points at the Matsukura Quarry (Loc. 6) and Towa-Sekizai (Loc. 7). Thick lines show the outcrop of the bone-bed.

the Tokyo Bay and adjacent areas including the present study area.

The stratigraphy proposed by Urabe *et al.* (1990) and Suzuki *et al.* (1995) at the central part of the Boso Peninsula is shown in Fig. 3. All materials were obtained from the Senhata Formation of the Miura Group. This formation overlies the Amatsu Formation unconformably in its western part, and conformably in the eastern part, and is conformably overlain by the Inakozawa Formation.

The Senhata Formation is typically exposed at Mt. Nokogiri, Takeoka and Shimo-Byakko area and extends eastwardly up to the Mt. Kiyosumi. It consists of massive fine to medium sandstones with tuff, calcareous sandstones, pebbly sandstone and conglomerate intercalations (Fig. 4). The thickness varies from place to place, ranging from about 1.5 (Loc. 9) to 130 m (Loc. 6 to 7). Abundant marine vertebrate fossils were obtained from the upper pebbly sandstone and conglomerate at the Loc. 6 and 7.

Ishikawa *et al.* (1982) correlated the Senhata Formation to the Blow's N. 17 to N. 18 planktonic foraminiferal zone. Kanie *et al.* (1991) correlated the upper part of the underlying Amatsu Formation to Okada and Bukry's CN9 calcareous nannoplankton zone and the lowest part of the overlying Inako-

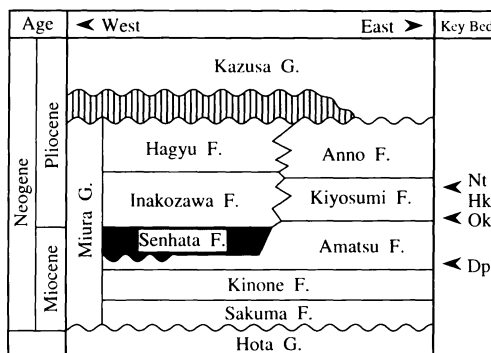


Fig. 3. Stratigraphy in central part of the Boso Peninsula. Simplified from Urabe *et al.* (1990) and Suzuki *et al.* (1995).

zawa Formation to CN10b zone. Furthermore Kasuya (1987) obtained 6.3 ± 0.4 Ma Fission-track age for OK-tuff, which is a well-known pyroclastic key-bed in the lowest part of the Inakozawa Formation. These data indicate that the Senhata Formation was deposited during the late Miocene.

This formation also yields abundant marine bivalve and gastropod molluscs (O'Hara and Ito, 1980; Tomida, 1983, 1989; Tomida and Itoigawa, 1986), isopod crustaceans (Karasawa *et al.*, 1992), selachians, bony fishes, marine turtles, pinnipeds and cetaceans (Uyeno *et al.*, 1990; Kohno, 1992;

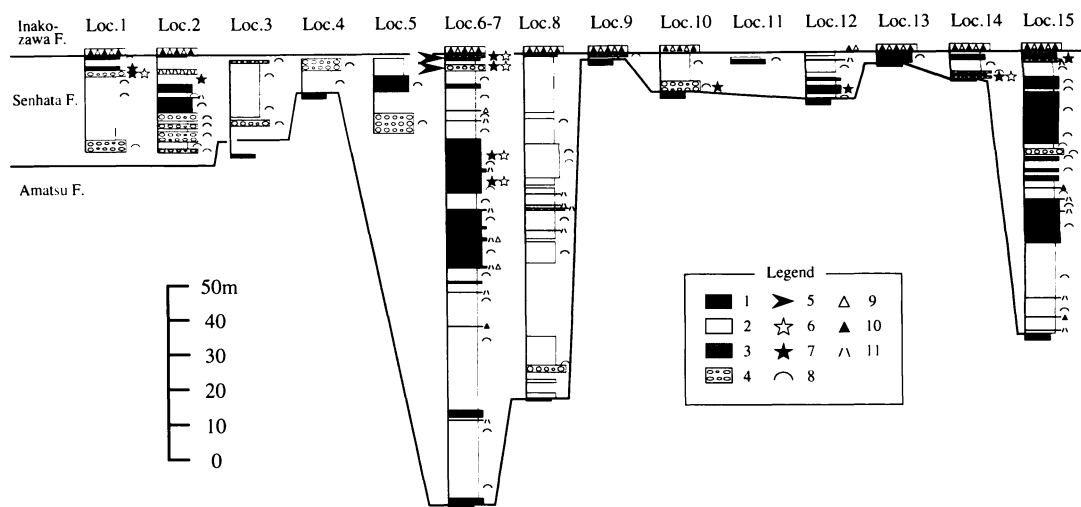


Fig. 4. Columnar sections of the Senhata Formation. 1, mudstone; 2, fine to medium sandstone; 3, medium to coarse sandstone; 4, conglomerate; 5, bone-bed; 6, vertebrates; 7, selachians; 8, molluscs; 9, pumice; 10, scoria; 11, tuff. Loc. 1, Fudojwa; Loc. 2, Shiofuki-Tunnel; Loc. 3, Nemoto; Loc. 4, Motona-Dam; Loc. 5, Nokogiriyama-Dam; Loc. 6, Matsukura-Quarry; Loc. 7, Towa-Sekizai; Loc. 8, upper stream of Byakko River; Loc. 9, tributary of Kanaya River; Loc. 10, main stream of Kanaya River; Loc. 11, Kanayama; Loc. 12, Nakamura; Loc. 13, Okamado-Tunnel; Loc. 14, Ainosawa; Loc. 15, Senhata (type locality of the Senhata Formation). Localities are shown in Figs. 1 and 2.

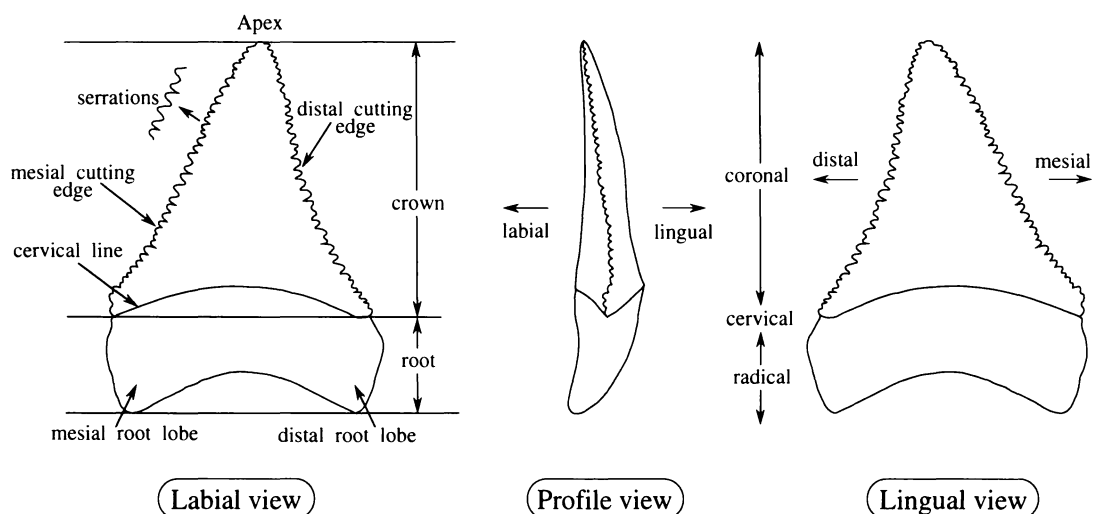


Fig. 5. General terminologies for selachian tooth.

Kohno and Hirayama, personal communication). These fossils are similar to the Zushi fauna (Ozawa and Tomida, 1992) which is considered as tropical to subtropical elements distributed around the southern Japan during the late Miocene to early Pliocene.

Materials and Methods

The specimens have been collected since 1990 by many paleontologists and undergraduate students of Teikyo Heisei University. All specimens are stored in the university. The specimens are represented by detached jaw teeth, rostral teeth and vertebral

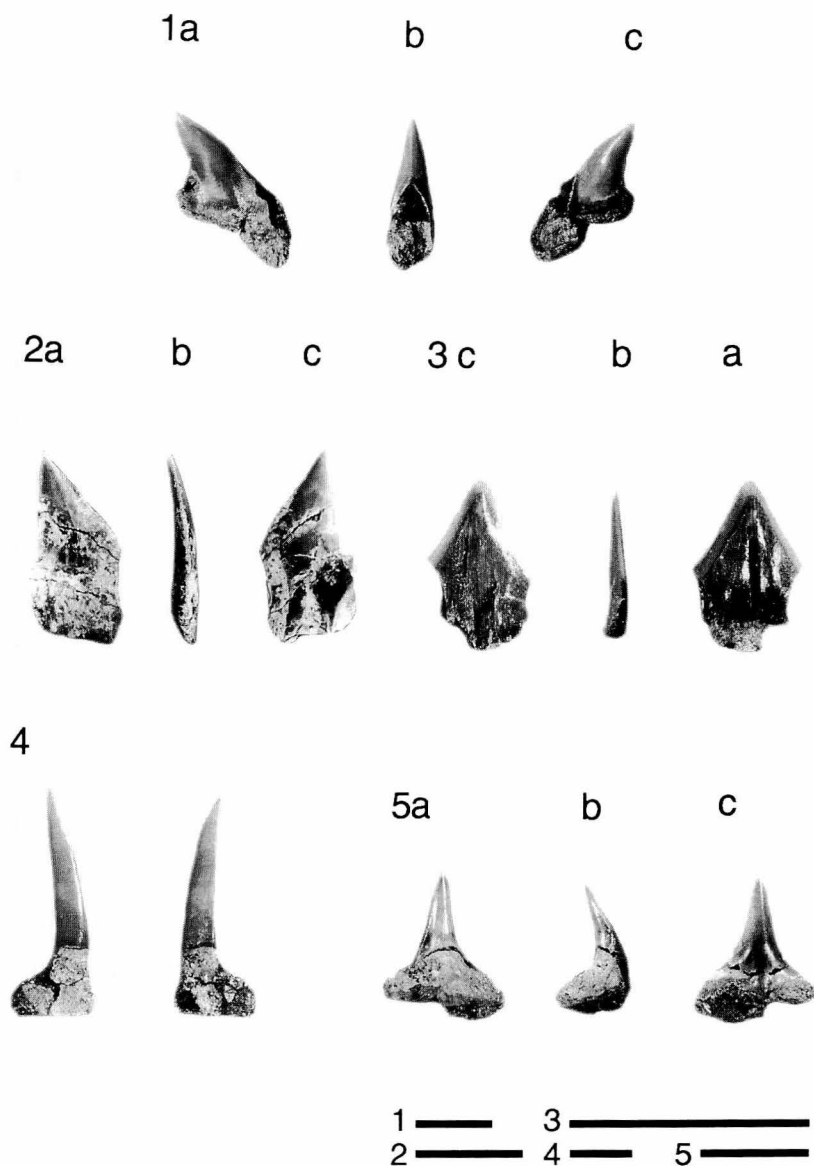


Fig. 6. Hexanchidae (1, THUg 0150), *Dalatias licha* (2, THUg 1104), *Isistius* sp. (3, THUg 0732), *Pristiophorus lanceolatus* (4, THUg 0848), *Squatina* sp. (5, THUg 2447). All bar scales are 5 mm and alphabets show the views of tooth (Figs. 6 to 16). a, lingual view; b, profile view; c, labial view.

centra. The registration numbers of the described specimens are shown in the Appendix.

The tooth terminologies used below are mainly after Applegate (1965), Kuga and Goto (1980), Ishiyama *et al.* (1986), Cappetta (1987a) and Welton and Farish (1993). The basic morphological terms for the selachian tooth are shown in Fig. 5. The systematics of selachians adopted here is based on that of

Cappetta (1987a).

Systematic Description

Class Chondrichthyes
Subclass Elasmobranchii
Cohort Euselachii
Subcohort Neoselachii
Superorder Squalomorphii
Order Hexanchiformes
Suborder Hexanchoidei

Family Hexanchidae Gray, 1851

Diagnosis. This family differs from other families of the suborder Hexanchoidei in having following characters: 1) markedly dignathic heterodonty, 2) upper tooth crown slender and pointed with mesial and distal cusplets, 3) cusplets gradually decrease in size distally (comb like) in the lower tooth. (All diagnosis based on Cappetta (1987a) and Kent (1994).)

Hexanchidae gen. et sp. indet.
(Fig. 6-1)

Material. One incomplete tooth.

Description. Tooth represented by incomplete cone and root; small sized, 8.1 mm in height; cone nearly acute-angled triangle and sigmoid in outline; lingual and labial faces of the crown strongly convex; crown faces smooth; profile view of the crown straight.

Occurrence. Towa-Sekizai, Hota, Kyonan-machi, Chiba Prefecture (Loc. 7-A1).

Order Squaliformes

Family Squalidae

Subfamily Dalatiinae

Genus *Dalatias* Rafinesque, 1810

Type species. *Squalus licha* Bonnaterre, 1788; Recent.

Diagnosis. This genus differs from other genera of the subfamily Dalatiinae in having following characters: 1) upper tooth crown slender, pointed and strongly inclined distally, 2) lower tooth crown regularly triangular with serrated cutting edges, 3) two aprons present on the labial face of the lower tooth.

***Dalatias licha* (Bonnaterre, 1788)**
(Fig. 6-2)

Materials. Eight lower teeth.

Diagnosis. As for the genus, monospecific.

Description. Teeth small sized, up to 11.1 mm in height; crown regular triangle in outline; apex of the cusp slightly inclined distally; lingual and labial faces of the crown flat; margins of the crown straight; cutting edges finely serrated, the serrations being directed upward; two aprons present at the labial face; crown faces smooth; profile view of the crown straight; root labiolingually flat, slightly bilobate.

Discussion. The genus *Dalatias*, in the fossil state, is known from the Cenozoic strata of Japan, France, Italy, New Zealand and U.S.S.R. and assigned to the Recent *D. licha* (Keyes, 1984; Cappetta, 1987a). Owing to its labiolingually flattened crown, serrations directed upward and two aprons, the present specimens agree with Recent species.

Occurrence. Matsukura Quarry, Motona, Kyonan-machi, Chiba Prefecture (Loc. 6-E and 6-F) and Towa-Sekizai (Loc. 7-A0 and 7-B).

Geologic range and distribution. ?Paleocene or Eocene–Recent. Japan (Uyeno and Matsushima, 1975), New Zealand (Keyes, 1984) and West Indies (Casier, 1966). Recent, in the eastern and western Atlantic Ocean, the western Indian Ocean, and the western and central Pacific Ocean (Last and Stevens, 1994).

Genus *Isistius* Gill, 1864

Type species. *Scymnus brasiliensis* Quoy and Gaimard, 1824; Recent.

Diagnosis. This genus differs from other genera of the subfamily Dalatiinae in having following characters: 1) upper tooth crown slender, pointed and strongly inclined distally, 2) lower tooth crown regularly triangular with smooth or weakly serrated cutting edges, 3) poorly marked apron present on labial face of the lower tooth.

***Isistius* sp. indet.**
(Fig. 6-3)

Material. One incomplete tooth.

Description. Tooth very small sized, 3.6 mm in height; crown regular triangle in outline; apex of the cusp erect; lingual and labial faces of the crown flat; margins of the crown straight; cutting edges smooth; crown faces smooth; profile view of the crown straight.

Discussion. The genus *Isistius* is represented by *I. triturator* (Winkler) from the Paleocene to Eocene, *I. triangulus* (Probst) from the Miocene to Pliocene, *I. brasiliensis* (Quoy and Gaimard) and *I. plutodus* Garrick and Springer both Recent species (Cappetta, 1970, 1987a; Compagno, 1984a). The former two fossil species are distinguished from each other by the features of the crown foot, cutting edges and root lobes of the upper teeth (Cappetta, 1970), however, the distinguishing features of latter two Recent spe-

cies is not known in detail. Due to the incomplete nature of the present specimen, the characteristic information needed for identification to the species is lacking.

Occurrence. Matsukura Quarry (Loc. 6-H).

Order Pristiophoriformes

Family Pristiophoridae

Genus *Pristiophorus* Müller and Henle, 1837

Type species. *Pristis cirratus* Latham, 1794; Recent.

Diagnosis. This genus differs from other genera of the family Pristiophoridae in having following characters: 1) medium to large sized rostral tooth long, slender and flat, 2) rostral tooth more or less bent toward the rear, 3) generally surfaces of enameloid cap smooth and cutting edges smooth, 4) peduncle of rostral tooth tall and massive in shape.

***Pristiophorus lanceolatus* (Davis, 1888)**

emend. Keyes, 1982

(Fig. 6-4)

Materials. 203 rostral teeth.

Diagnosis. This species differs from other species of the genus *Pristiophorus* in having following characters: 1) medium to large sized rostral tooth elongate, lanceolate, symmetrical and gradually tapering from the base to the apex, 2) surfaces of enameloid cap smooth.

Description. Rostal teeth small to medium sized, up to 21.5 mm in height; enameloid cap longer, slender and labiolingually compressed; apex of the enameloid cap inclined distally; lingual and labial faces of the enameloid cap flat and smooth; margins of the enameloid cap smooth; crown faces smooth; profile view of the enameloid cap straight; peduncle tall and massive in shape.

Discussion. The genus *Pristiophorous* is known from the Cretaceous to Recent and is represented by several species (Keyes, 1982; Compagno, 1984a; Cappetta, 1987a). Comparing the rostral teeth, these species are distinguished from each other by outline, size and smoothness (Keyes, 1982). Owing to its larger size, gradually tapering enameloid cap from the base to apex and smooth surfaces, the present specimens are identified as *P. lanceolatus*.

Occurrence. Matsukura Quarry (Loc. 6-E, 6-

F, 6-G, 6-H and 6-I), Towa-Sekizai (Loc. 7-A0, 7-A1, 7-A2, 7-B, 7-C and 7-D) and Myougane-Misaki, Futtsu City, Chiba Prefecture (Loc. X; floats derived from Matsukura Quarry or Towa-Sekizai).

Geologic range and distribution. Eocene-upper Pliocene. New Zealand and Australia (Keyes, 1982) and Japan (present study).

Superorder Squatinomorphii

Order Squatinoformes

Family Squatinidae

Genus *Squatina* Duméril, 1806

Type species. *Squalus squatina* Linnaeus, 1758; Recent.

Diagnosis. This genus has following characters: 1) slender and pointed tooth crown with horizontal shoulders, and smooth and complete cutting edges, 2) pronounced apron present on the basal part of the labial face, 3) labiolingually flattened root develops perpendicular to the tooth crown.

***Squatina* sp. indet.**

(Fig. 6-5)

Materials. Two incomplete teeth.

Description. Teeth small sized, up to 7.25 mm in height; crown slender and pointed with horizontal shoulders; apex of the cusp erect; lingual face of the crown convex, labial face of the crown slightly convex; cutting edges smooth and complete; crown faces smooth; profile view of the crown sigmoid; pronounced apron present; root flat and perpendicular to the crown.

Discussion. The *Squatina* species are widely distributed and are known from the Jurassic to Recent (Cappetta, 1987a). The identification of these species based only on their teeth morphology can be difficult (Cappetta, 1987a). And based on teeth with convex labial face of the crown, smooth cutting edges and pronounced apron, the present specimens are identified as belonging to genus *Squatina*.

Occurrence. Matsukura Quarry (Loc. 6-I) and Towa-Sekizai (Loc. 7-B).

Superorder Galeomorphii

Order Lamniformes

Family Odontaspidae

Genus *Carcharias* Rafinesque, 1810

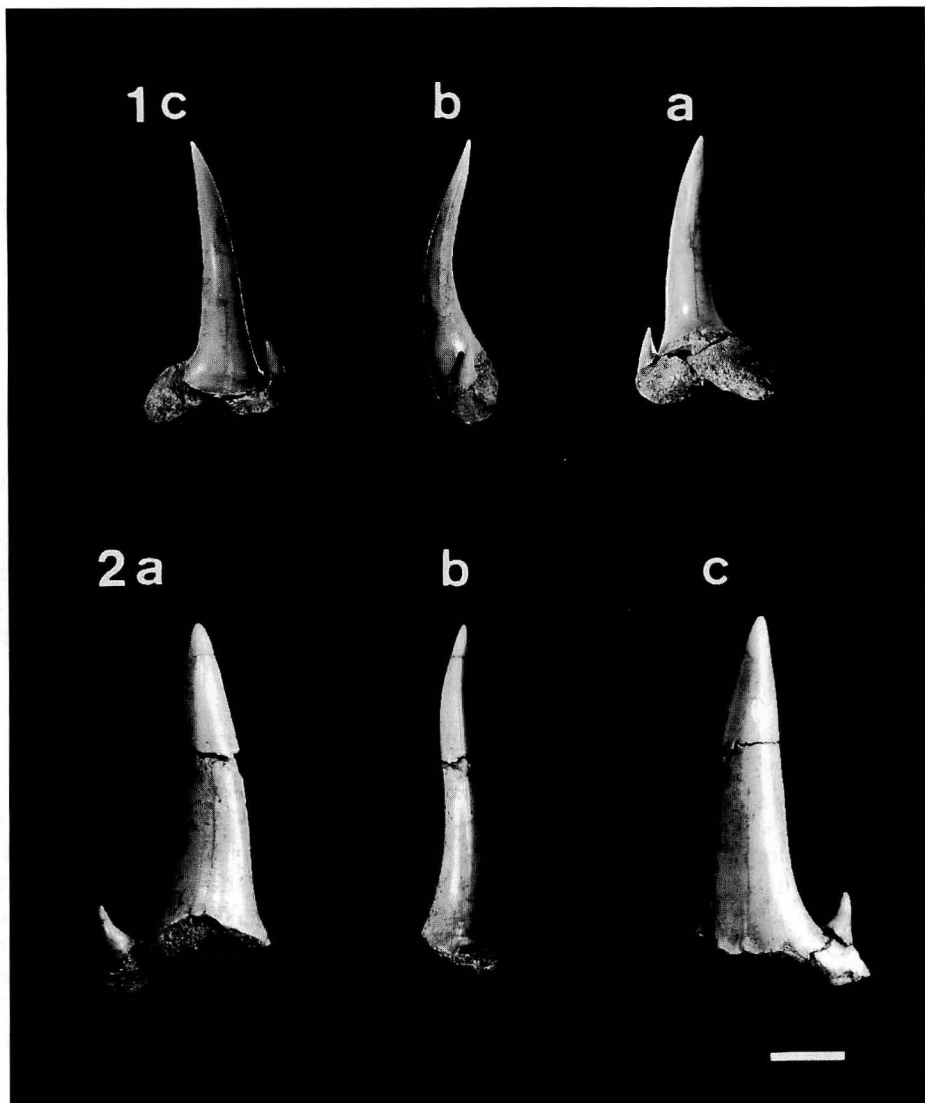


Fig. 7. *Carcharias* sp. (1, THUg1132; 2, THUg 0440).

(*Synodontaspis* White, 1931; *Patodontaspis* White, 1931)

Type species. *Carcharias taurus* Rafinesque, 1810; Recent.

Diagnosis. This genus differs from other genera of the family Odontaspidae in having following characters: 1) three rows of upper anterior teeth, symphyseal teeth absent, 2) medium sized slender and pointed tooth crown with smooth or weak longitudinal striation, 3) generally short and sig-

moid one pair of cusplets present.

***Carcharias* sp. indet.**
(Figs. 7-1, 2)

Materials. 44 teeth.

Description. Teeth medium sized, up to 25.3 mm in height; crown slender, pointed in outline; apex of the cusp inclined distally; lingual face of the crown strongly convex, labial face of the crown slightly convex; cutting edges smooth and nearly complete; crown faces smooth; profile view of the

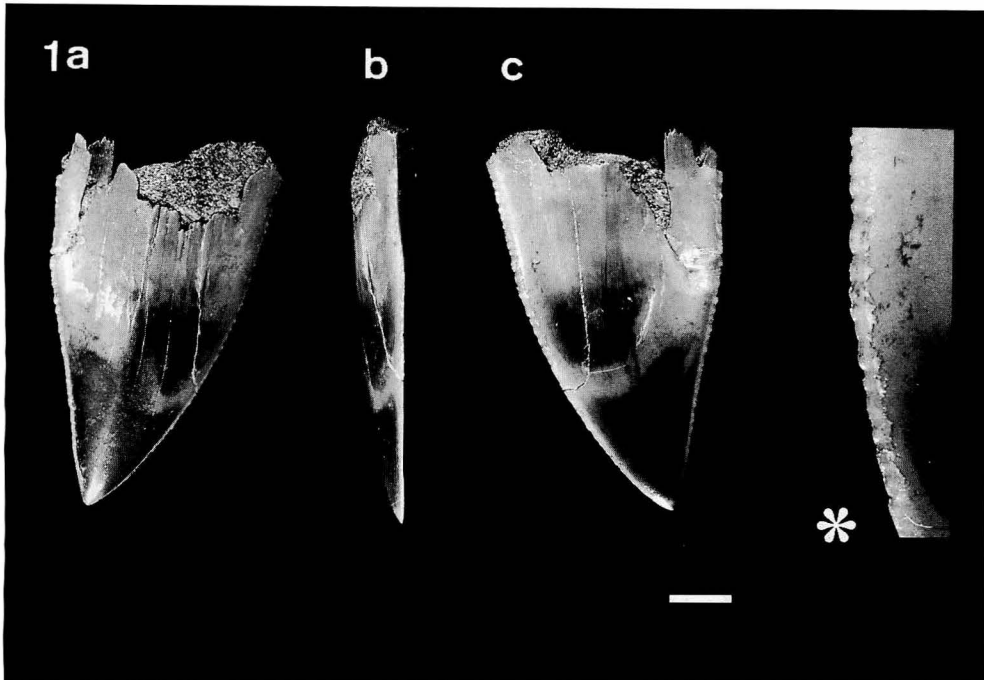


Fig. 8. *Carcharodon carcharias* (1, THUg 0674, * magnification of the cutting edge).

crown sigmoid. As most of the present specimens are worn, cusplets can not be observed, although in the specimen THUg 0440 one long and sigmoid cusplet is present.

Discussion. Although the cusplets and root are not preserved, the present specimens belong to the genus *Carcharias* by its horn like crown with convexed labial face. The genus *Carcharias* is known from the Cretaceous to Recent and is represented by a large number of species (Cappetta, 1987a). But due to the incomplete nature of the present specimens, the characteristic information needed for identification to the species is lacking.

Occurrence. Matsukura Quarry (Loc. 6-E, 6-F, 6-H and 6-I) and Towa-Sekizai (Loc. 7-A0, 7-A1, 7-B, 7-C and 7-D).

Family Lamnidae

Genus *Carcharodon* Müller and Henle, 1838

Type species. *Squalus carcharias* Linnaeus, 1758; Recent.

Diagnosis. This genus differs from other genera of the family Lamnidae in having following characters: 1) medium to large sized and labiolingually flattened tooth crown, 2) serrated cutting edge, 3) cusplets

absent except in juvenile, 4) moderately bilobate root.

Carcharodon carcharias (Linnaeus, 1758) (Fig. 8-1)

Diagnosis. As for the genus, monospecific.

Materials. 14 anterolateral and lateral teeth from both jaws.

Description. Teeth medium to large sized, up to 39.3mm in height.

Upper lateral teeth: crown range from acute-angled to right angled triangle in outline; apex of the cusp inclined distally; lingual face of the crown convex, labial face of the crown flat to slightly convex; mesial margin of the crown nearly straight, distal margin of the crown gently S-shaped; cutting edges weakly or irregularly serrated; crown faces smooth; profile view of the crown straight.

Lower anterolateral tooth: crown acute-angled triangle; both margins of the crown nearly straight.

Discussion. The present specimens are identified as *C. carcharias* by its medium to large sized tooth crown, triangular shape, serrated cutting edges and moderately bilobate

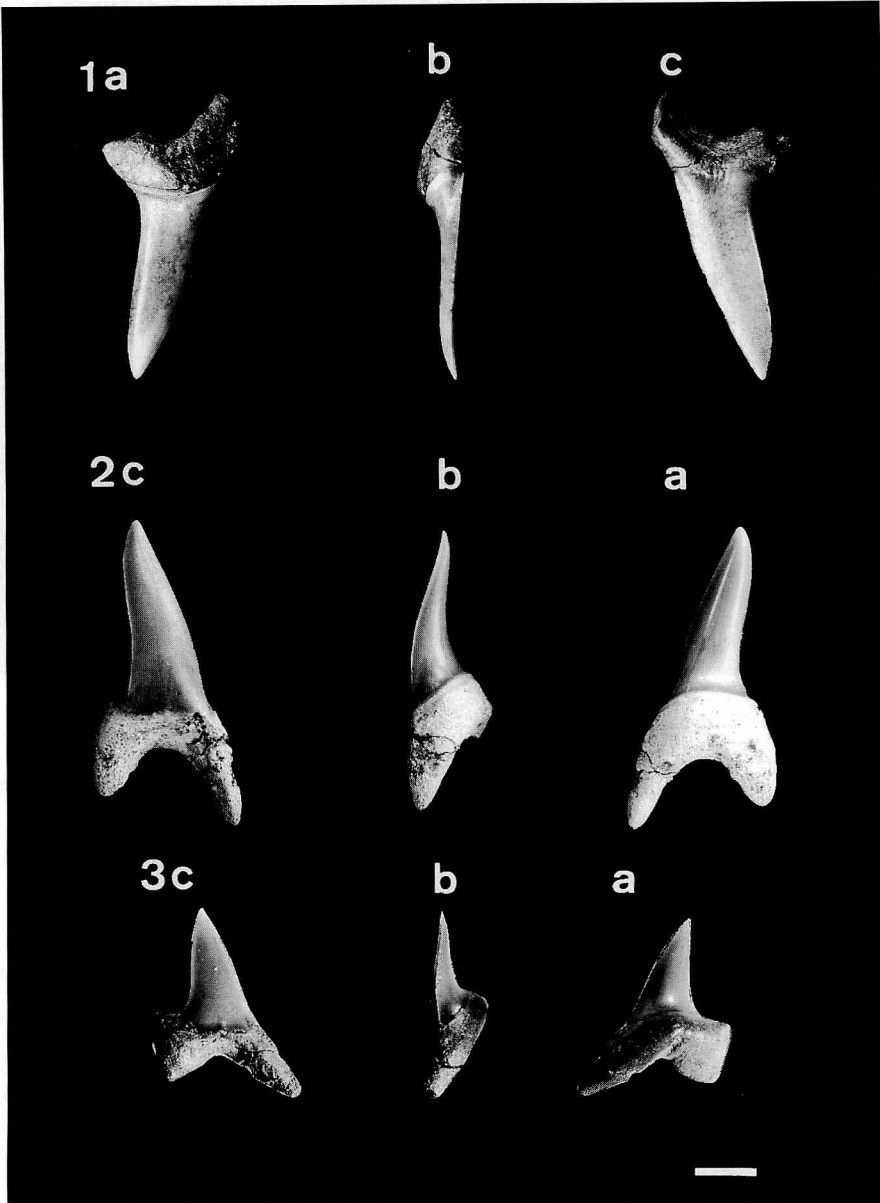


Fig. 9. *Isurus oxyrinchus* (1, THUg 0485; 2, THUg 1293; 3, THUg 1105).

root. The serrations of the specimens THUg 616, 674, 1751, 2884, 2922, 3232 and 3271 are weaker compared with the typical *C. carcharias*. The weakly serrated carcharodont species have been previously named as *Carcharodon escheri* (Agassiz), *Oxyrhina hastalis* (Agassiz) var. *escheri* (Agassiz), *Isurus escheri* (Agassiz) or *Isurus hastalis* (Agassiz) (Agassiz, 1843; Leriche, 1926; Bosch *et al.*, 1975; Mui-zon and Devries, 1985; Cappetta, 1987a). How-

ever, it is quite difficult to clearly separate the present specimens from the former, therefore we identify the presentspecimens as *C. carcharias*.

Occurrence. Matsukura Quarry (Loc. 6-E, 6-F, 6-G, 6-H and 6-I) and Towa-Sekizai (Loc. 7-A2, 7-B, 7-C and 7-D).

Geologic range and distribution. Late Miocene–Recent. Japan (Goto *et al.*, 1993), America (Leriche, 1942), Africa (Davis, 1964) and

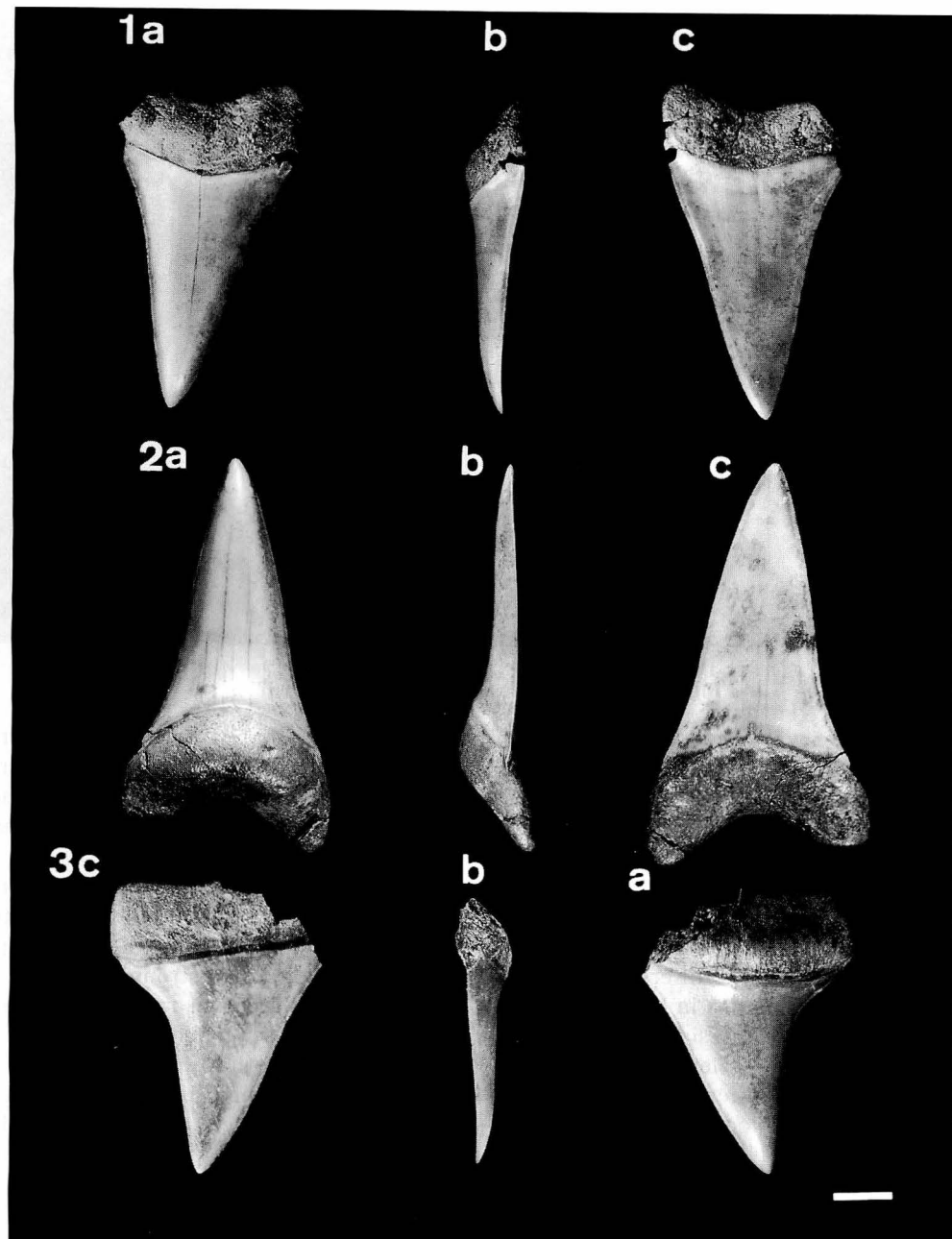


Fig. 10. *Isurus hastalis* (1, THUg 0584; 2, THUg 0568; 3, THUg0256).

Australia (Kemp, 1991). Recent, in anti-tropical in temperate seas (Last and Stevens, 1994).

Genus *Isurus* Rafinesque, 1810
(*Oxyrhina* Agassiz, 1843; *Anotodus* Le-Hon, 1871; *Cosmopolitodus* Glükman, 1964;

Macrorhizodus Glükman, 1964)

Type species. *Isurus oxyrinchus* Rafinesque, 1810; Recent.

Diagnosis. This genus differs from other genera of the family Lamnidae in having following characters: 1) medium to large

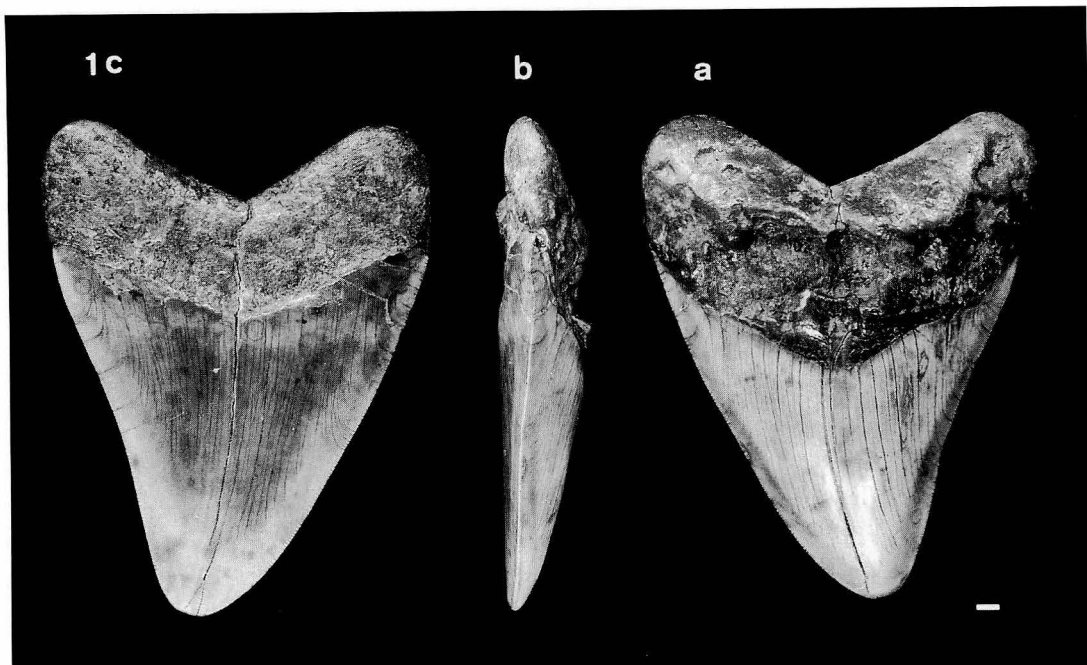


Fig. 11. *Carcharocles megalodon* (1, THUg 0677).

sized tooth crown with smooth cutting edges, 2) cusplets absent, 3) generally root of anterior tooth strongly bilobated.

***Isurus oxyrinchus* Rafinesque, 1810**

(Figs. 9-1, 2, 3)

Materials. 453 anterior and lateral teeth from both jaws.

Diagnosis. This species differs from other species of the genus *Isurus* in having following characters: 1) medium sized tooth crown, 2) anterior tooth crown slender and pointed in outline, 3) root of anterior tooth strongly bilobated, 4) distal smooth cutting edges of the upper and lower anterior tooth crown extended from the apex to the middle part (Kuga, 1985b).

Description. Teeth medium to large sized, up to 26.3mm in height.

Upper anterior teeth: crown slender and pointed in outline (horn like); apex of the cusp inclined distally; lingual face of the crown strongly convex, labial face of the crown flat; mesial margin of the crown nearly straight or slightly convex, distal margin of the crown nearly straight or gentle S-shaped; mesial cutting edge smooth and complete, distal cutting edge smooth but incomplete

(from apex to midway of the crown); crown faces smooth; profile view of the crown nearly straight; root strongly convex and bilobate with lingual protuberance and central groove.

Lower anterior teeth: crown narrower and thicker, root more acute than upper anterior teeth; cutting edges smooth and complete; profile view of crown strongly sigmoid.

Lateral teeth: crown ranging from acute-angled to obtuse-angled triangle in outline depending on tooth row group position; apex of the cusp inclined distally; cutting edges smooth and complete; root compressed and moderately bilobate with shallow central groove.

Discussion. The widely distributed genus *Isurus* is known from Paleocene strata and is represented by two Recent species (Kuga, 1985b; Cappetta, 1987a). Owing to its crown size, slender anterior teeth, incomplete distal cutting edge, the present specimens agree with the Recent *I. oxyrinchus*.

Occurrence. Shiofuki-Tunnel, Kyonan-machi, Chiba Prefecture (Loc. 2), Matsukura Quarry (Loc. 6-E, 6-F, 6-G, 6-H and 6-I), Towa-Sekizai (Loc. 7-A0, 7-A1, 7-A2, 7-B, 7-C and 7-D) and Myougane-Misaki (Loc. X).

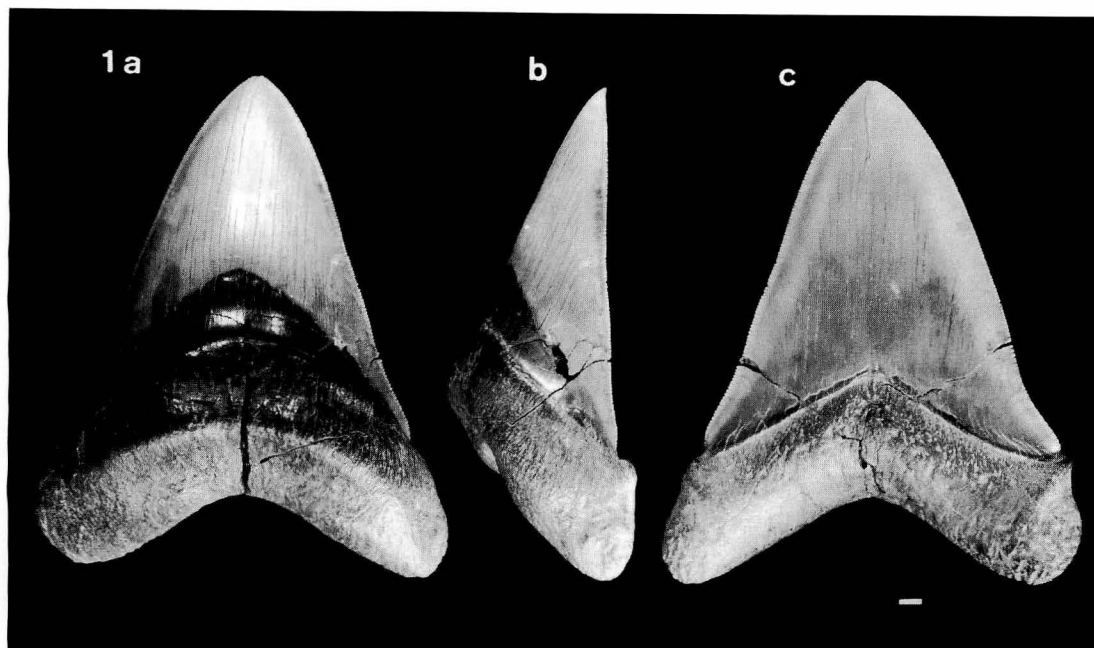


Fig. 12. *Carcharocles megalodon* (1, THUg 0735).

Geologic range and distribution. Middle Miocene–Recent. Japan (Itoigawa *et al.*, 1985), Africa (Antunes, 1978) and Australia (Kemp, 1991). Recent, in tropical and temperate sea of both hemispheres (Last and Stevens, 1994).

***Isurus hastalis* (Agassiz, 1843)**
(Figs. 10-1, 2, 3)

Materials. 501 anterior, anterolateral and lateral teeth from both jaws.

Diagnosis. This species differs from other species of the genus *Isurus* in having following characters: 1) medium to large sized tooth crown with smooth cutting edges, 2) tooth crown thin and triangle in outline, except lower anterior tooth.

Description. Teeth medium to large sized, up to 47.7mm in height.

Upper anterior teeth: crown acute-angled triangle in outline; apex of the cusp erect to slightly inclined distally; lingual face of the crown convex, labial face of the crown flat to slightly convex; mesial margin of the crown nearly straight, distal margin of the crown gently S-shaped; cutting edges smooth; crown faces smooth; profile view of the crown straight; root labiolingually flat, moderately bilobate.

erately bilobate.

Upper lateral teeth: crown range from acute-angled to right angled triangle in outline depending on tooth row group position; apex of the cusp inclined distally; mesial margin of the crown nearly straight, distal margin of the crown gently S-shaped.

Lower anterior and anterolateral teeth: crown acute-angled triangle; mesial margin of the crown nearly straight, distal margin of the crown gently S-shaped; root strongly convex and bilobate with lingual protuberance and central groove; lower teeth narrower and thicker than upper teeth.

Lower lateral teeth: crown ranging from acute-angled to obtuse angle triangle in outline depending on tooth row group position; root flat and bilobate with shallow central groove.

Discussion. The lateral teeth of *I. oxyrinchus* resemble the present species in having triangular crown and smooth cutting edges, however latter has broader crown, perpendicular apex and more abbreviated root lobes.

Occurrence. Fudojiwa, Futtsu City, Chiba Prefecture (Loc. 1), Matsukura Quarry (Loc. 6-E, 6-F, 6-G, 6-H and 6-I), Towa-Sekizai (Loc.

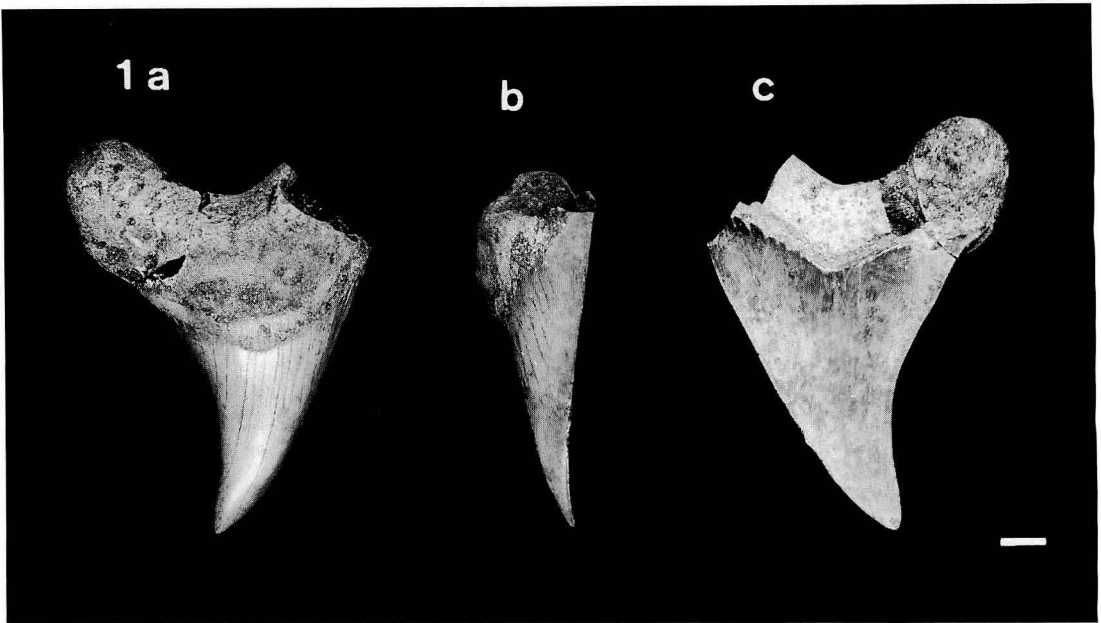


Fig. 13. *Parotodus benedeni* (1, THUg 2314).

7-A0, 7-A1, 7-A2, 7-B, 7-C and 7-D), main stream of Kanaya River, Futtsu City, Chiba Prefecture (Loc. 10), Ainosawa, Futtsu City, Chiba Prefecture (Loc. 14) and Myougane-Misaki (Loc. X).

Geologic range and distribution. Oligocene–upper Miocene. This species is widely distributed in Japan (Itoigawa *et al.*, 1985), Europe (Leriche, 1926), America (Eastman, 1904) and Australia (Kemp, 1991).

Family Otodontidae
Genus *Carcharocles* Jordan
and Hannibal, 1923

(*Procarcharodon* Casier, 1960;

Megaselachus Glükman, 1964;

Carcharodon Müller and Henle, 1838 in part)

Type species. *Carcharodon auriculatus* Blainville, 1818

Diagnosis. This genus differs from other genera of the family Otodontidae in having following characters: 1) large to very large sized tooth crown with serrated cutting edges, 2) cusplets present in primitive species.

***Carcharocles megalodon* (Agassiz, 1843)**

(Figs. 11-1, 12-1)

Materials. 59 anterior and lateral teeth

from both jaws.

Diagnosis. This species differs from other species of the genus *Carcharocles* in having following characters: 1) crown cutting edges serrated regularly, 2) generally cusplets absent.

Description. Teeth large to very large sized, up to 131.5 mm in height.

Upper anterior teeth: crown acute-angled triangle in outline; apex of the cusp nearly erect; lingual face of the crown strongly convex, labial face of the crown flat to slightly convex; mesial margin of the crown nearly straight to slightly convex, distal margin of the crown gently S-shaped; cutting edges coarsely and regularly serrated; crown faces smooth; profile view of the crown strongly sigmoid; neck very broad with strongly convex upward; root strongly convex and bilobate with lingual protuberance.

Upper lateral teeth: crown nearly regular to obtuse-angled triangle in outline; apex of the cusp strongly inclined distally; mesial margin of the crown nearly straight to slightly convex, distal margin of the crown gently S-shaped; cutting edges coarsely and regularly serrated.

Lower teeth: crown and root narrower and thicker than upper teeth; crown acute-angled

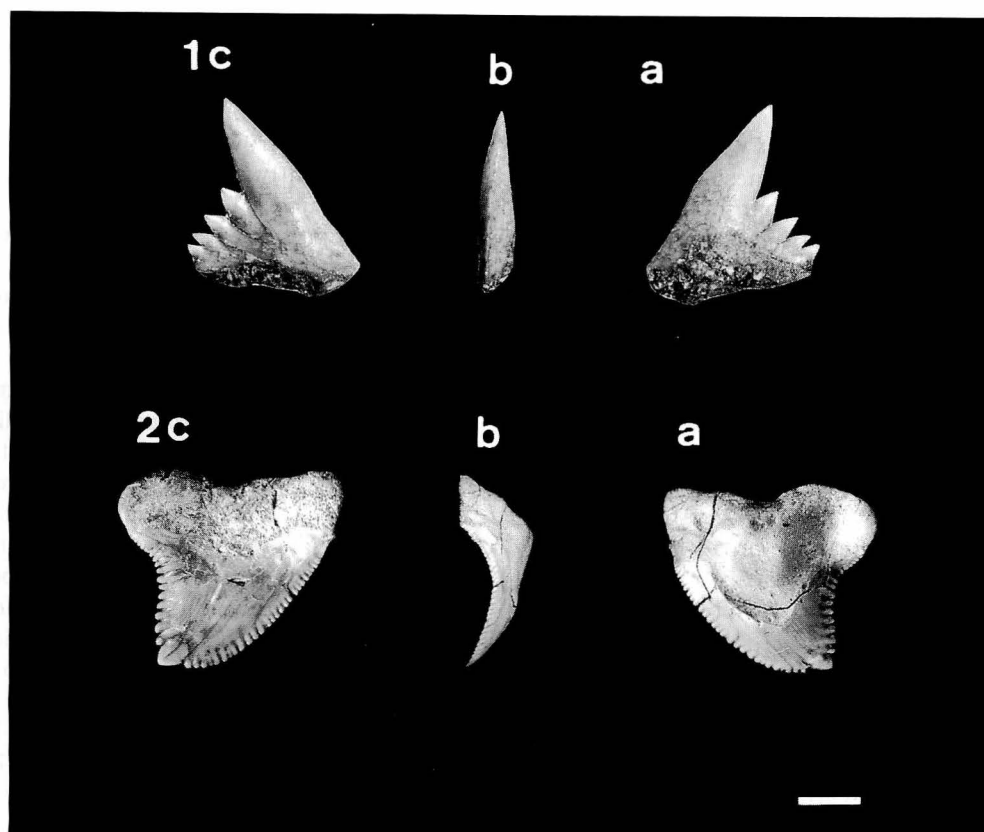


Fig. 14. *Galeorhinus* sp. (1, THUg 0495), *Hemipristis serra* (2, THUg 1729).

triangle in outline; apex of the cusp nearly erect.

Discussion. Many extinct species, subspecies and variations belonging to *Carcharocles* have been previously described from the Cenozoic beds. Yabe and Goto (1996) recently discussed the species belonging to this genus and concluded that only three species, *C. auriculatus* (Blainville), *C. angustidens* (Agassiz) and *C. megalodon* can be considered as valid species of it. Owing to its size, regularly serrated cutting edges and lack of cusplets, the present specimens are identified as *C. megalodon*.

Occurrence. Matsukura Quarry (Loc. 6-E, 6-F 6-G, 6-H and 6-I), Towa-Sekizai (Loc. 7-A1, 7-A2, 7-B, 7-C and 7-D), Ainosawa (Loc. 14) and Myougane-Misaki (Loc. X).

Geologic range and distribution. Lower Miocene–lower Pliocene or ?Pleistocene. This species is widely distributed in Japan (Itoigawa *et al.*, 1985), Europe (Leriche, 1926),

America (Leriche, 1942), Africa (Davis, 1964) and Australia (Kemp, 1991). This species was also reported from Plio-Pleistocene Omma Formation (Matsuura, 1996), however, when considering the state of preservation of the specimen, there is a possibility that this may have been derived from older strata.

Genus *Parotodus* Cappetta, 1980
(Uyenoa Kuga, 1985b)

Type species. *Isurus benedeni* Le-Hon, 1871

Diagnosis. This genus differs from other genera of the family Otodontidae in having following characters: 1) medium sized tooth crown with smooth cutting edges, 2) generally cusplets absent.

***Parotodus benedeni* (Le-Hon, 1871)**
(Fig. 13-1)

Materials. 16 teeth from both jaws.

Diagnosis. As for the genus, monospecific.

Description. Teeth medium to large sized,

up to 36.7 mm in height; upper teeth crown acute-angled triangle in outline; lower teeth crown narrower and erect than upper teeth; apex of the cusp inclined distally; lingual face of the crown strongly convex, labial face of the crown nearly flat; mesial margin of the crown convex, distal margin of the crown strongly concave; cutting edges smooth and complete; crown faces smooth; profile view of the crown strongly sigmoid; neck very broad with strongly convex upward; root strongly convex and bilobate with lingual protuberance.

Discussion. In Japan, this species was previously described as *Isurus moniwaensis* Hatai, Masuda and Noda (Hatai *et al.*, 1974; Katto, *et al.* 1977). However based on its robust crown and root, broad neck, smooth cutting edge and absence of cusplets, it is assigned as junior synonym of *P. benedeni* by Kuga (1985b).

Occurrence. Matsukura Quarry (Loc. 6-F, 6-H and 6-I) and Towa-Sekizai (Loc. 7-A2, 7-B, 7-C and 7-D).

Geologic range and distribution. Lower Eocene (David Ward, personal communication)–lower Pliocene. This species is widely distributed in Japan (Itoigawa *et al.*, 1985), Europe (Leriche, 1926), America (Kent, 1994), Africa (Davis, 1964) and Australia (Kemp, 1991).

Order Carcharhiniformes

Family Triakidae

Tribe Galeorhinini

Genus *Galeorhinus* Blainville, 1816

Type species. *Galeorhinus galeus* Linnaeus, 1758; Recent

Diagnosis. This genus has following characters: 1) slender tooth crown with up to ten distal serrations decreasing in size toward the distal tooth edge, 2) ornamentation on the tooth crown absent, 3) labial face of the tooth crown strongly overhangs the root, 4) thin, broad holaulacorchizid root with well developed narrow and deep central groove.

Galeorhinus sp. indet.

(Fig. 14-1)

Materials. Eight teeth.

Description. Teeth small sized, up to 4.5 mm in height; cusp slender and pointed with

some coarse distal serrations at the basal part; distal serrations decreasing in size toward the distal tooth edge (one to four serrations observed, but not complete); lingual face of the crown convex, labial face of the crown slightly convex; mesial margin of the crown suberect, distal margin of the crown straight; mesial cutting edge smooth; crown faces smooth; profile view of the crown nearly straight; root labiolingually flat, moderately bilobate with central groove.

Discussion. Although the crown foot and root are not preserved, the present specimens belong to genus *Galeorhinus* by its well developed cusp, absence of mesial serrations and suberect mesial margin. The genus *Galeorhinus* is widely distributed and is known from late Cretaceous to Recent and is represented by several species (Cappetta, 1987a). But due to the incomplete nature of the present specimens, the characteristic information needed for identification to the species is lacking.

Occurrence. Matsukura Quarry (Loc. 6-E, 6-F, 6-G and 6-H) and Towa-Sekizai (Loc. 7-B).

Genus *Hemipristis* Agassiz, 1843

Type species. *Hemipristis serra* Agassiz, 1843.

Diagnosis. This genus differ from other genera of the family Hemigaleidae in having following characters: 1) dignathic heterodonty, 2) upper tooth crown acute-angled to regular triangular in outline, 3) cutting edges of the upper tooth crown markedly serrated and coarsen upward, 4) lower tooth crown slender and pointed with some reduced cusplets.

Hemipristis serra Agassiz, 1843

(Fig. 14-2)

Materials. 13 teeth, all from upper jaw.

Diagnosis. This species differs from other species of the genus *Hemipristis* in having following characters: 1) medium to large sized tooth, 2) cutting edges of the upper tooth crown markedly serrated and coarsen upward, 3) distal serrations of the upper tooth bigger than mesial serrations, 4) composed of orthodont-type dentin.

Description. Teeth medium to large sized, up to 25.7mm in height; crown acute-angled

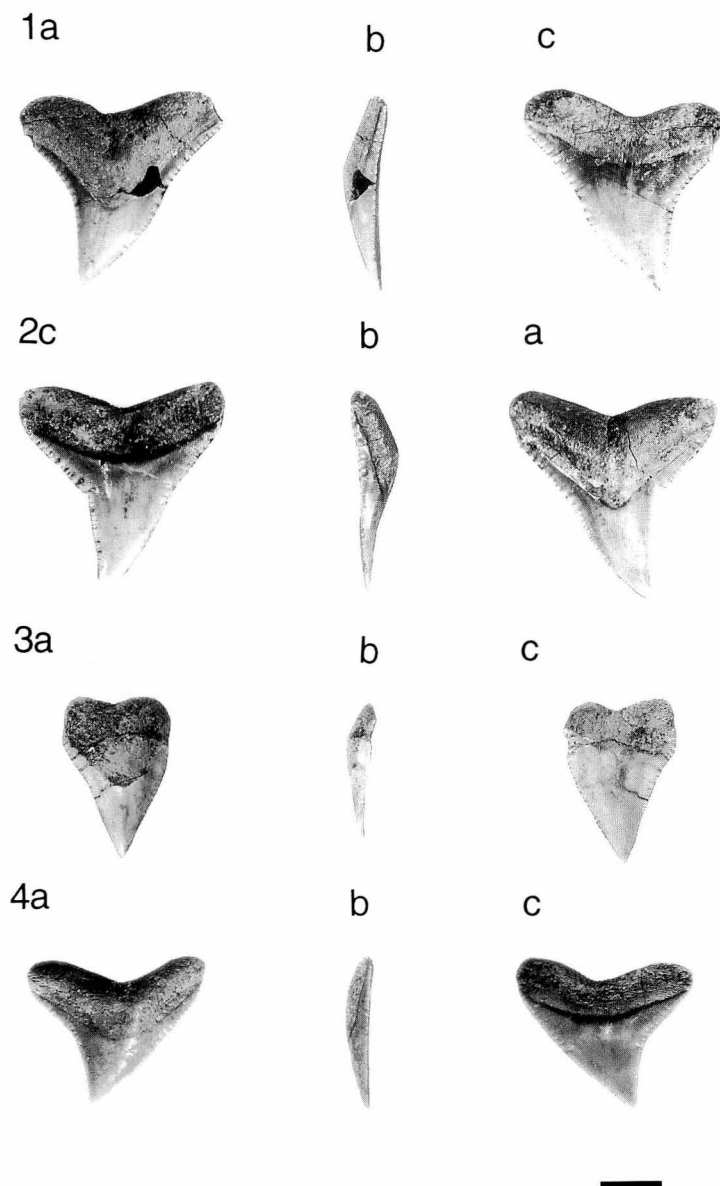


Fig. 15. *Carcharhinus* sp. A (1, THUg 0925), *Carcharhinus* sp. B (2, THUg 1950), *Carcharhinus* sp. C (3, THUg 0252; 4, THUg 1592).

or nearly regular triangle in outline; apex of the cusp inclined distally; lingual face of the crown convex, labial face of the crown nearly flat; mesial margin of the crown range from slightly to moderately convex, distal margin of the crown slightly concave; cutting edges strongly serrated increasing in size toward the apex; distal serrations bigger than mesial serrations; crown faces smooth; profile view of the crown strongly sigmoid; root labiolin-

gually flat and moderately bilobate with central groove.

Discussion. The genus *Hemipristis* is represented by three species: Eocene *H. curvatus*, Miocene to Pleistocene *H. serra* Agassiz and Recent *H. elongatus* (Klunzinger). Although the dentine histology is not examined, from its mesial serrations and crown size, the present specimens are identified as *H. serra*.

Occurrence. Towa-Sekizai (Loc. 7-A0, 7-A1,

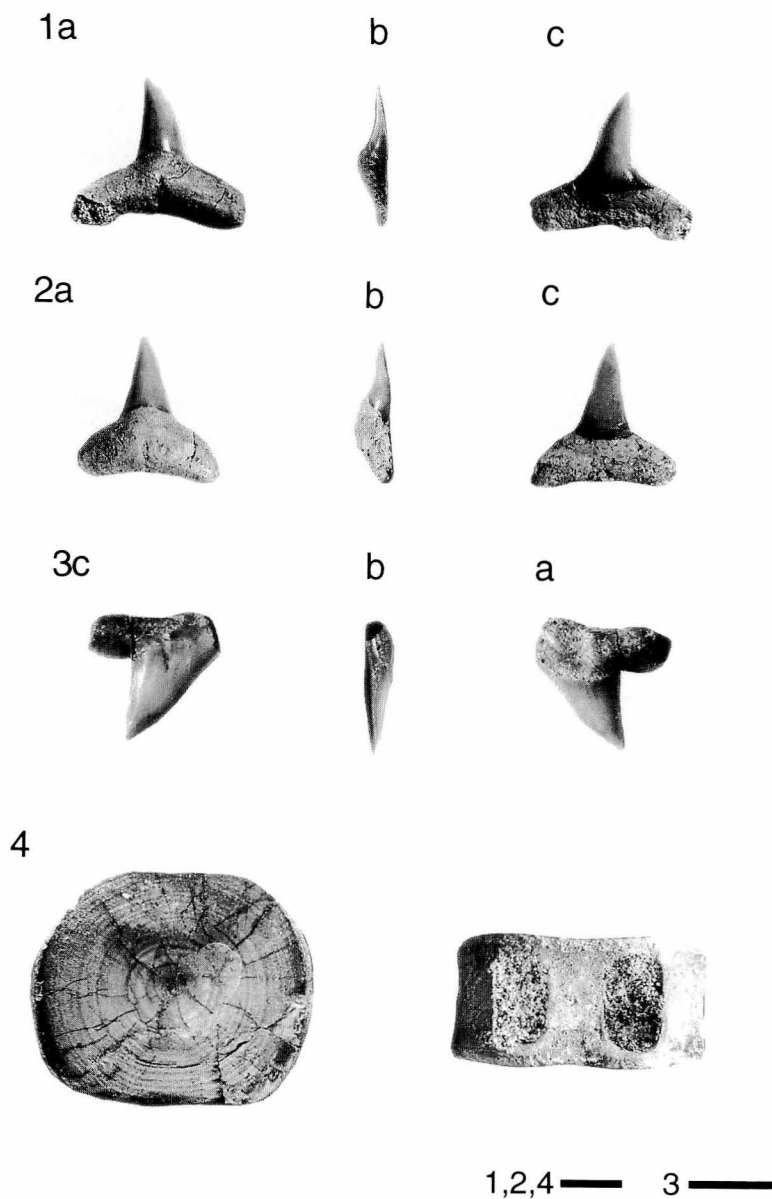


Fig. 16. *Carcharhinus* sp. D (1, THUG 1151), *Carcharhinus* sp. E (2, THUG 0994), *Sphyrna zygaena* (3, THUG 0621), Indetermined vertebral centra of selachians (4, THUG 0724).

7-B, 7-C and 7-D).

Geologic range and distribution. Lower Miocene–Pleistocene. This species is widely distributed in Japan (Itoigawa *et al.*, 1985), Europe (Menesini, 1969), America (Leriche, 1942), Africa (Davis, 1964) and Australia (Kemp, 1991).

Family Carchahrinidae
Genus *Carcharhinus* Blainville, 1816

Type species. *Carcharias melanopterus* Quoy and Gaimard, 1824; Recent.

Diagnosis. This genus differs from other genera of the family Carcharhinidae in having following characters: 1) markedly dignathic heterodonty, 2) up to three symphysial teeth present, 3) tooth crown decreasing in size toward the distal tooth edge and lacks cusplets, 4) generally upper tooth crown serrated from apex to basal part.

***Carcharhinus* sp. A**

(Fig. 15-1)

Materials. 166 teeth, all from upper jaw.

Description. Teeth small to medium sized, up to 20.7mm in height; crown right-angled to obtuse-angled triangle in outline; apex of the cusp range from slightly to strongly inclined distally depending on tooth rowgroup position; lingual face of the crown convex, labial face of the crown nearly flat; mesial margin of the crown convex, distal margin of the crown strongly concave; cutting edges finely, regularly serrated decreasing in size toward the apex; crown faces smooth; profile view of the crown nearly straight; root labiolingually flat, moderately bilobate with central groove.

Discussion. The genus *Carcharhinus* is widely distributed and is known from the Eocene to Recent (Cappetta, 1987a). There are twenty nine species belonging to this genus (Compagno, 1984b). It has been pointed out that the identification of *Carcharhinus* species based solely on teeth morphology can be difficult (Garrick, 1982). Although the *Carcharhinus* specimens from the Senhata Formation can be separated into the upper and lower teeth, the arrangement of each tooth types within the dentition are unsolved. Because of this, we tentatively distinguished the upper teeth as *Carcharhinus* sp. A, sp. B and sp. C; and lower teeth as *Carcharhinus* sp. D and sp. E. The teeth of *Carcharhinus* sp. A are somewhat similar to those of sp. B in shape. But the teeth of *Carcharhinus* sp. A have broader cusp apex and concave margins of the crown without distinct notches.

Occurrence. Matsukura Quarry (Loc. 6-E, 6-F 6-G, 6-H and 6-I) and Towa-Sekizai (Loc. 7-A0, 7-A1, 7-A2, 7-B, 7-C and 7-D).

***Carcharhinus* sp. B**

(Fig. 15-2)

Materials. 96 teeth, all from upper jaw.

Description. Teeth small to medium sized, up to 19.6 mm in height; crown right-angled to obtuse-angled triangle in outline; apex of the cusp more or less inclined distally; lingual face of the crown convex, labial face of the crown nearly flat; mesial margin of the crown convex, distal margin of the crown

concave with distinct notch at the middle part; cutting edges finely, regularly serrated decreasing in size toward the apex; crown faces smooth; profile view of the crown nearly straight; root labiolingually flat, moderately bilobate with central groove.

Discussion. It can be distinguished from *Carcharhinus* sp. A in having narrower cusp apex and distinct notch of the middle part of distal margin of the crown.

Occurrence. Matsukura Quarry (Loc. 6-E, 6-F 6-G, 6-H and 6-I) and Towa-Sekizai (Loc. 7-B, 7-C and 7-D).

***Carcharhinus* sp. C**

(Figs. 15-3, 4)

Materials. 16 teeth, all from upper jaw.

Description. Teeth small to medium sized, up to 16.7 mm in height.

Upper anterolateral teeth: crown acute-angled triangle in outline; apex of the cusp erect; lingual face of the crown convex, labial face of the crown nearly flat; mesial margin of the crown straight, distal margin of the crown slightly concave; cutting edges finely, regularly serrated decreasing in size toward the apex; crown faces smooth; profile view of the crown nearly straight; root labiolingually flat, moderately bilobate with central groove.

Upper lateral teeth: crown regular triangle in outline; apex of the cusp inclined distally; lingual face of the crown convex, labial face of the crown nearly flat; mesial margin of the crown slightly convex, distal margin of the crown strongly concave.

Discussion. The present species can be distinguished from *Carcharhinus* sp. A and sp. B in having more broader crown and nearly straight mesial margin.

Occurrence. Matsukura Quarry (Loc. 6-E, 6-F, 6-H and 6-I) and Towa-Sekizai (Loc. 7-A2, 7-B, 7-C and 7-D).

***Carcharhinus* sp. D**

(Fig. 16-1)

Materials. 40 teeth, all from lower jaw.

Description. Teeth small to medium sized, up to 14.0 mm in height; crown slender and pointed with horizontal shoulders; apex of the cusp inclined distally; lingual face of the crown convex, labial face of the crown nearly flat; cutting edges finely, regularly serrated;

Table 1. List of selachian remains from the Senhata Formation. Localities are shown in Figs. 1 and 2.

Taxa	Localities																		Total
	1	2	6-E	6-F	6-G	6-H	6-I	7-A0	7-A1	7-A2	7-A3	7-B	7-C	7-D	10	12	14	15	
Hexanchidae									1										1
<i>Dalatias licha</i>			1	1				1				5							8
<i>Isistius</i> sp.						1													1
<i>Pristiophorus lanceolatus</i>			9	23	6	18	4	6	16	19		77	3	20				2	203
<i>Squatina</i> sp.							1					1							2
<i>Carcharias</i> sp.			1	3		8	2	1	3			15	2	9					44
<i>Carcharodon carcharias</i>			1	2	2	2	1			1		2	1	2					14
<i>Isurus oxyrinchus</i>		1	26	59	9	35	14	18	31	18		175	22	43				2	453
<i>Isurus hastalis</i>	1		21	92	10	69	15	24	25	26		125	12	78	1		1	1	501
<i>Carcharocles megalodon</i>			2	5	3	6	4		1	2		24	3	7			1	1	59
<i>Parotodus benedeni</i>				3		4	2			1		3	1	2					16
<i>Galeorhinus</i> sp.			2	2	1	2						1							8
<i>Hemipristis serra</i>				1				1	1			7	1	2					13
<i>Carcharhinus</i> sp. A			16	30	1	16	4	1	5	4		46	15	28					166
<i>Carcharhinus</i> sp. B			13	25	4	13	5					20	6	10					96
<i>Carcharhinus</i> sp. C			1	1		3	2			2		4	1	2					16
<i>Carcharhinus</i> sp. D			10	7	1	4	2		2			10	1	2				1	40
<i>Carcharhinus</i> sp. E			8	8		3	5		1	1		11	4	4				1	46
<i>Carcharhinus</i> sp.	1		43	114	14	51	23	17	26	32		182	28	71		1		2	610
<i>Sphyrna zygaena</i>	1		5	6	2	8	1		2			11	3	1					40
Vertebral centra			4	13	1	4	1	1	2	1		13		4					44
Gen. et sp. indet.	1		6	52	2	55	18	21	42	41	1	150	10	39			1	8	447
Total	4	1	169	447	56	302	104	91	158	148	1	882	113	324	1	1	3	3	2828

crown faces smooth; profile view of the crown sigmoid; root strongly bilobate with central groove.

Discussion. The lower teeth of *Carcharhinus* from the Senhata Formation are separated into two types, sp. D and sp. E. The teeth of *Carcharhinus* sp. D are characterized by the serrated cutting edges which extends from the apex to shoulders.

Occurrence. Matsukura Quarry (Loc. 6-E, 6-F, 6-G, 6-H and 6-I), Towa-Sekizai (Loc. 7-A1, 7-B, 7-C and 7-D) and Myougane-Misaki (Loc. X).

***Carcharhinus* sp. E**

(Fig. 16-2)

Materials. 46 teeth, all from lower jaw.

Description. Teeth small to medium sized, up to 13.40 mm in height; crown slender and pointed with horizontal shoulders; apex of the cusp slightly inclined distally; lingual face of the crown convex, labial face of the crown nearly flat; cutting edges finely serrated at the upper one third of the crown;

crown faces smooth; profile view of the crown sigmoid; root strongly bilobate with central groove.

Discussion. The teeth of *Carcharhinus* sp. E have restricted serrated cutting edges at the upper part of the crown and broader crown, which are different from sp. D.

Occurrence. Matsukura Quarry (Loc. 6-E, 6-F, 6-H and 6-I), Towa-Sekizai (Loc. 7-A1, 7-A2, 7-B, 7-C and 7-D) and Senhata, Futtsu City, Chiba Prefecture (Loc. 15).

Family Sphyrinidae

Genus *Sphyrna* Rafinesque, 1810

Type species. *Squalus zygaena* Linnaeus, 1758; Recent.

Diagnosis. This genus differs from other genus of the family Sphyrinidae in having following characters: 1) dignathic heterodonty, 2) distal heel separated from main cusp present, 3) cutting edges smooth or serrated.

Table 2. Bathymetric and climatic range of Recent selachian taxa. Taken from Bigelow and Schroeder (1948), Compagno (1984a, 1984b) and Last and Stevens (1994).

Taxa	Bathymetry				Climate		
	Neritic	Epipelagic	Mesopelagic	Bathypelagic	Tropical	Subtropical	Temperate
<i>Dalatias</i>		+	+	+	+	+	+
<i>Isistius</i>		+	+	+	+	+	
<i>Pristiophorus</i>	+		+		+	+	+
<i>Squatina</i>	+		+		+	+	+
<i>Carcharias</i>	+				+	+	+
<i>Carcharodon</i>	+					+	+
<i>Isurus</i>	+	+			+	+	+
<i>Galeorhinus</i>	+		+				+
<i>Hemipristis</i>	+				+	+	
<i>Carcharhinus</i>	+	+	+		+	+	+
<i>Sphyrna</i>	+		+		+	+	+

***Sphyrna zygaena* (Linnaeus, 1758)**

(Fig. 16-3)

Materials. 40 teeth from both jaws.

Diagnosis. This species differ from other species of the genus *Sphyrna* in having following characters: 1) upper tooth nearly regular triangle in outline, 2) mesial margin of the upper tooth crown convex curved, 3) cutting edges smooth or weakly serrated.

Description. Teeth very small to small sized, up to 8.8mm in height; crown range from obtuse-angled to regular triangle in outline depending on tooth rowgroup position; distal heel separated from cusp by distinct notch; apex of the cusp inclined distally; lingual face of the crown convex, labial face of the crown slightly convex; mesial margin of the crown convex, distal margin of the crown nearly straight or slightly concave; cutting edges smooth and complete; crown faces smooth; profile view of the crown nearly straight; root labiolingually flat, moderately bilobate with central groove.

Discussion. The genus *Sphyrna* is known from the Miocene to Recent and is represented by several species (Leriche, 1942; Cappetta, 1970; Compagno, 1984b). These species are distinguished from each other by their crown outline of upper teeth, curvature of mesial margin of the crown and serrated or smooth cutting edges (Cappetta, 1970; Compagno, 1984b; Last and Stevens, 1994). The present specimens are identified as *S. zygaena*, owing to its triangular crown

of upper teeth and convex curved mesial margin of the crown.

Occurrence. Fudoiwa (Loc. 1), Matsukura Quarry (Loc. 6-E, 6-F 6-G, 6-H and 6-I) and Towa-Sekizai (Loc. 7-A1, 7-B, 7-C and 7-D).

Geologic range and distribution. Miocene–Recent. Japan (Uyeno and Matsushima, 1974) and France (Cappetta, 1987a). Recent, in temperate sea of both hemispheres (Last and Stevens, 1994).

**Indeterminate vertebral centra
of selachians**

(Fig. 16-4)

Materials. 44 vertebral centra.

Description. Up to 39.0 mm in width; both anterolateral surfaces concave end with numerous growth line; paired basidorsal and basiventral foramina present. Most of present specimens are characterized by smooth lateral surfaces.

Occurrence. Matsukura Quarry (Loc. 6-E, 6-F, 6-G, 6-H and 6-I) and Towa-Sekizai (Loc. 7-A0, 7-A1, 7-A2, 7-B and 7-D).

Discussion**1. Faunal composition**

Although only two species, *I. hastalis* and *C. megalodon*, have been previously known from the Senhata Formation (Ishiwara, 1921; Takahashi, 1954; Goto, 1972; Uyeno *et al.*, 1990), present study records 20 taxa of selachian remains represented as detached jaw teeth, rostral teeth and vertebral centra. Table 1 presents a list of number of taxa

found in each localities. The selachian fauna is dominated by *Carcharhinus* spp., *I. hastalis*, *I. oxyrinchus* and *P. lanceolatus*. In addition to these taxa, *C. megalodon*, *Carcharias* sp., *S. zygaena* and vertebral centra are common. Kuga (1985a) mentioned that the selachian records of late Miocene of Japan are poorly known compared with those of middle Miocene and Pliocene. Although approximately ten selachian localities have been previously reported from late Miocene of Japan, taxa recovered from these localities are few, such as *Squalus* sp., *Squatina* sp., *C. carcharias*, *I. hastalis*, *Cetorhinus* sp., *C. megalodon*, *Negaprion kraussi* (Probst), *Carcharhinus* sp. and others (Shikama, 1973; Hatai *et al.*, 1974; Uyeno and Ono, 1982; Uyeno and Oshiro, 1982; Uyeno and Watanabe, 1984; Itoigawa *et al.*, 1985; Goto and Goto, 1987; Karasawa, 1989; Uyeno *et al.*, 1990; Goto *et al.*, 1993; Numano, 1993; Uyeno, 1993; Tanaka and Mori, 1996). In the present study, several taxa such as, *D. licha*, *Isistius* sp., *I. oxyrinchus*, *Galeorhinus* sp. and *S. zygaena* are recorded for the first time from upper Miocene strata in Japan.

The late Miocene selachian fauna is represented by both extinct and Recent taxa (Kuga, 1985a; Cappetta, 1987b). Among the species described in the present study, extinct taxa are *P. lanceolatus*, *I. hastalis*, *C. megalodon*, *P. benedeni* and *H. serra*; and Recent taxa are *D. licha*, *C. carcharias*, *I. oxyrinchus* and *S. zygaena*. The present study provides the most complete selachian faunal composition of the late Miocene in Japan.

2. Paleoenvironment of the Senhata Formation

Table 2 shows the bathymetric and climatic range of Recent selachians related to the taxa from the Senhata Formation, taken mainly from Bigelow and Schroeder (1948), Compagno (1984a, 1984b) and Last and Stevens (1994). Most selachians have wide distributional range, therefore, it is difficult to infer paleoenvironment from their fossil records. However, the selachian assemblage of the Senhata Formation indicates some restrictions in the bathymetric and climatic range. The representative elements are as follows:

Neritic elements: *Carcharias*, *Carcharodon*,

Hemipristis

Neritic to epipelagic elements: *Isurus*

Epipelagic to bathypelagic elements: *Dalatias*, *Isistius*

Neritic to bathypelagic elements: *Pristiophorus*, *Squatina*, *Galeorhinus*, *Sphyrna*

The occurrence of neritic, epipelagic and bathypelagic elements together in this assemblage can best be explained if the Senhata Formation was deposited in the upper continental slope environment. Similarly the occurrence of the *Dalatias* and *Isistius* species which are at present commonly distributed in the mesopelagic to bathypelagic region also denotes such environment. The neritic elements, such as *Carcharias*, *Carcharodon* and *Hemipristis* must have been transported from shallower water. The accumulation of wide variety of selachian species from neritic to bathypelagic element is possible in the upper continental slope. Apart from that, abundant occurrence of *I. oxyrinchus* suggests that this formation was deposited under the influence of oceanic water (Taniuchi, 1979). At the same time *Isistius* and *Hemipristis* species indicate tropical to subtropical environment (Bigelow and Schroeder, 1948; Compagno, 1984a, 1984b; Last and Stevens, 1994).

The Senhata selachian assemblage is found associated with rich molluscan fossils. Tomida (1989) analyzed and concluded that the molluscan assemblages from the Loc. 6 and 7 (in the present paper), are represented by mixture of allochthonous neritic element (200–250 m in depth on continental shelf) and autochthonous hemibathyal to bathyal elements (continental slope or more than 200 m in depth). Karasawa *et al.* (1992) also described autochthonous or semiautochthonous isopod crustacean from Loc. 6, and concluded that this formation was deposited in the upper continental slope. Apart from these some associated fossils, such as molluscan, *Atsuria coxi* Miller, *Hartungia* sp. and baleen whale indicate the influence of oceanic water. Further Ozawa and Tomida (1992) recently proposed to call the marine molluscan fauna of Late Miocene to early Pliocene in central and southwestern Japan, the Zushi Fauna. This fauna is considered to have flourished under the strong influence of the Paleo-

Kuroshio current and corresponding to the Neogene Climatic Optimum 3 of Barron and Baldauf (1990). The molluscan assemblage from the Senhata Formation belongs to this fauna. On the whole, the paleoenvironment of the Senhata Formation inferred from the selachian fauna agrees well with the environment indicated by the associate fossils.

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房総半島に分布する上部中新統千畑層から産出した板鰐類化石群

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千葉県富津市から安房郡鋸南町にかけて分布する上部中新統の三浦層群千畑層は、以前から豊富な板鰐類化石が産出することで知られていたにもかかわらず、その分類の記載は必ずしも充分ではなかった。今回、本層から産出した 2828 点の板鰐類化石を検討した結果、これらは 20 タクサに同定されることが明らかになった。それらは以下のとおりである。

Hexanchidae gen. et sp. indet., *Dalatias licha*, *Isistius* sp., *Pristiophorus lanceolatus*, *Squatina* sp., *Carcharias* sp., *Carcharodon carcharias*, *Isurus oxyrinchus*, *Isurus hastalis*, *Carcharocles megalodon*, *Parotodus benedeni*, *Galeorhinus* sp., *Hemipristis serra*, *Carcharhinus* sp. A, *Carcharhinus* sp. B, *Carcharhinus* sp. C, *Carcharhinus* sp. D, *Carcharhinus* sp. E, *Sphyrna zygaena*, 属種未定の椎体。

千畑層産の板鰐類化石群のうち 5 タクサは本邦上

部中新統から初の産出記録となり、後期中新世の板鰐類相についての新たな資料を提供する。また現生板鰐類の分布域について検討した結果、本層は陸棚斜面上部に堆積したものと推定される。

Appendix

All specimens described here have been stored at the Faculty of Information, Teikyo Heisei University, 2289 Uruido, Ichihara, Japan (THUg). Their registration numbers are as follows.

Hexanchidae gen. et sp. indet.

THUg 0150.

Dalatias licha

Left lower teeth, THUg 1104, 1192, 1766; right lower teeth, THUg 0977, 1072, 2566; lower teeth, THUg 0503, 2591.

Isistius sp.

Lower tooth, THUg 0732.

Pristiophorus lanceolatus

THUg 0110, 0121, 0131, 0132, 0141, 0154, 0170, 0177, 0182, 0184, 0186, 0191, 0229, 0230, 0238, 0277, 0294, 0309, 0344, 0381, 0393, 0399, 0420, 0427, 0429, 0430, 0435, 0449, 0450, 0480, 0506, 0510, 0523, 0528, 0537, 0558, 0575, 0623, 0654, 0659, 0663, 0695, 0710, 0716, 0740, 0789, 0824, 0832, 0835, 0838, 0848, 0863, 0871, 0889, 0892, 0932, 0955, 0960, 0963, 0990, 0999, 1005, 1022, 1031, 1085, 1093, 1118, 1120, 1121, 1127, 1135, 1138, 1156, 1191, 1193, 1205, 1216, 1220, 1244, 1248, 1259, 1274, 1302, 1316, 1335, 1341, 1368, 1384, 1393, 1422, 1495, 1510, 1517, 1518, 1574, 1575, 1600, 1607, 1672, 1675, 1679, 1686, 1696, 1705, 1709, 1714, 1725, 1728, 1730, 1738, 1759, 1788, 1806, 1818, 1819, 1820, 1830, 1832, 1843, 1897, 1926, 1928, 1930, 1937, 2001, 2027, 2076, 2028, 2079, 2090, 2105, 2107, 2116, 2126, 2167, 2184, 2188, 2229, 2293, 2310, 2326, 2328, 2333, 2336, 2347, 2351, 2361, 2395, 2421, 2426, 2438, 2466, 2478, 2494, 2496, 2536, 2613, 2618, 2619, 2634, 2638, 2648, 2683, 2720, 2739, 2742, 2769, 2772, 2780, 2782, 2791, 2845, 2850, 2870, 2890, 2894, 2970, 2980, 2999, 3006, 3010, 3017, 3023, 3029, 3038, 3060, 3070, 3088, 3141, 3154, 3165, 3234, 3238, 3244, 3250, 3280, 3285, 3288, 3289, 3303, 3787, 3790, 3796.

Squatina sp. indet.

THUg2255, 2447.

Carcharias sp. indet.

THUg 0143, 0217, 0241, 0284, 0299, 0304, 0339, 0340, 0384, 0440, 0462, 0723, 0822, 0836, 0877, 1017, 1068, 1099, 1103, 1132, 1236, 1288, 1407,

1479, 1515, 1597, 1716, 1726, 1842, 2111, 2136, 2217, 2233, 2236, 2263, 2277, 2560, 2698, 2919, 2921, 2947, 3051, 3052, 3163.

Carcharodon carcharias

Left upper lateral teeth, THUg 0303, 0616, 0674, 0776, 1751, 2884, 2922, 3232; right upper teeth, THUg1985, 2004, 3271, 3779; upper tooth, THUg 1283; right lower anterolateral tooth, THUg 2435.

Isurus oxyrinchus

Left upper anterior teeth, THUg 0271, 0445, 0451, 0485, 0567, 0688, 0813, 0929, 1273, 1362, 1371, 1387, 1474, 1499, 1527, 1536, 1619, 1710, 1994, 2013, 2029, 2152, 2174, 2248, 2264, 2331, 2349, 2479, 2485, 2531, 2535, 2545, 2555, 2562, 2574, 2663, 2665, 2718, 2763, 2774, 2821, 2907, 2946, 2966, 3004, 3305, 3789, 3792; right upper anterior teeth, THUg 0201, 0251, 0257, 0293, 0354, 0467, 0499, 0605, 0689, 1008, 1163, 1189, 1584, 1629, 1834, 1870, 1966, 1983, 2015, 2043, 2166, 2179, 2389, 2508, 2672, 2711, 2956, 3048, 3155, 3262, 3761, 3766, 3768, 3772; left lower anterior teeth, THUg 0113, 0124, 0221, 0225, 0338, 0412, 0491, 0504, 0518, 0531, 0534, 0541, 0542, 0548, 0672, 0690, 0738, 0757, 0759, 0773, 0796, 0820, 0897, 0922, 0938, 0944, 1153, 1155, 1164, 1179, 1253, 1291, 1612, 1632, 1655, 1817, 1827, 1849, 1892, 1939, 1959, 2058, 2062, 2141, 2209, 2307, 2502, 2523, 2590, 2639, 2650, 2654, 2670, 2730, 2732, 2991, 3020, 3065, 3292, 3296, 3788, 3791; right lower anterior teeth, THUg 0193, 0208, 0302, 0328, 0342, 0366, 0375, 0398, 0564, 0618, 0784, 0797, 0839, 0856, 0908, 0952, 1045, 1058, 1064, 1066, 1148, 1206, 1222, 1264, 1293, 1307, 1337, 1365, 1389, 1398, 1405, 1625, 1740, 2046, 2102, 2114, 2165, 2181, 2191, 2195, 2213, 2297, 2301, 2327, 2400, 2422, 2431, 2468, 2487, 2501, 2674, 2695, 2755, 2786, 2788, 2842, 2895, 2908, 2915, 2925, 2961, 3002, 3012, 3126, 3142, 3175, 3179, 3283; left upper tooth, THUg 1478; lower anterior teeth, THUg 0641, 2065; anterior teeth, THUg 0192, 0232, 0385, 0416, 0536, 0546, 0613, 0627, 0907, 1026, 1052, 1263, 1404, 1667, 1689, 1695, 1715, 1754, 1807, 1816, 1833, 1852, 1942, 2202, 2276, 2428, 2499, 2504, 2544, 2592, 2609, 2642, 2645, 2655, 2673, 2686, 2713, 2721, 2723, 2749, 2750, 2751, 2804, 2918, 2945, 2968, 3035, 3121, 3233, 3239, 3267; lateral teeth, THUg 0146, 0158, 0163, 0164, 0270, 0273, 0280, 0290, 0291, 0301, 0378, 0419, 0422, 0454, 0474, 0549, 0550, 0571, 0578, 0655, 0669, 0682, 0686, 0751, 0764, 0788, 0790, 0804, 0843, 0853, 0883, 0915, 0961, 0969, 0980, 1000, 1037, 1040, 1042, 1071, 1095, 1101, 1105, 1128, 1133, 1212, 1226, 1241, 1243, 1271, 1308, 1315, 1345, 1350, 1388, 1392, 1394, 1414, 1419, 1429, 1455, 1470, 1476, 1484, 1485, 1511,

1512, 1520, 1530, 1571, 1599, 1650, 1722, 1727, 1737, 1739, 1756, 1775, 1791, 1805, 1875, 1893, 1912, 1920, 1931, 1982, 2016, 2045, 2053, 2056, 2084, 2151, 2156, 2170, 2185, 2201, 2228, 2246, 2260, 2266, 2271, 2272, 2299, 2303, 2317, 2397, 2399, 2441, 2450, 2475, 2476, 2488, 2516, 2526, 2528, 2537, 2554, 2563, 2585, 2597, 2607, 2631, 2633, 2646, 2657, 2659, 2667, 2691, 2696, 2717, 2743, 2761, 2766, 2779, 2812, 2826, 2827, 2841, 2866, 2869, 2949, 2959, 2965, 2973, 2976, 2986, 2987, 2988, 3007, 3026, 3030, 3032, 3067, 3069, 3083, 3155, 3160, 3172, 3174, 3246, 3275, 3276, 3295, 3307, 3756, 3771, 3781, 3798, 3804; teeth positions are unknown, THUg 0138, 0173, 0333, 0350, 0389, 0444, 0879, 1070, 1114, 1198, 1427, 1516, 1581, 1700, 2012, 2120, 2177, 2369.

Isurus hastalis

Left upper anterior teeth, THUg 0471, 0584, 0633, 0731, 0748, 0821, 1186, 1282, 1579, 2039, 2530, 2892, 2978, 3181; right upper anterior teeth, THUg 0402, 0589, 0644, 0697, 0762, 1252, 1415, 1721, 1841, 1861, 2008, 2226, 2257, 2282, 2283, 2325, 2577, 2898, 3110, 3302, 3304; left upper lateral teeth, THUg 0194, 0311, 0438, 0443, 0460, 0561, 0572, 0600, 0722, 0730, 0746, 0766, 0772, 0913, 0949, 0964, 1112, 1208, 1255, 1295, 1298, 1513, 1535, 1583, 1606, 1609, 1681, 1882, 1911, 1974, 1978, 2007, 2061, 2132, 2168, 2172, 2198, 2203, 2204, 2210, 2240, 2243, 2289, 2292, 2332, 2354, 2357, 2363, 2396, 2461, 2520, 2525, 2559, 2662, 2669, 2703, 2768, 3009, 3014, 3071, 3111, 3119, 3125, 3167, 3182, 3184, 3254, 3259, 3260; right upper lateral teeth, THUg 0060, 0125, 0133, 0135, 0153, 0161, 0210, 0215, 0234, 0239, 0256, 0295, 0428, 0458, 0463, 0585, 0646, 0660, 0692, 0699, 0702, 0709, 0711, 0777, 0779, 0800, 0805, 0868, 0899, 0904, 0921, 0927, 0933, 0940, 0941, 0943, 1168, 1174, 1204, 1373, 1425, 1463, 1509, 1651, 1684, 1690, 1723, 1813, 1829, 1835, 1868, 1891, 1915, 1975, 1998, 2037, 2087, 2112, 2131, 2145, 2176, 2254, 2261, 2329, 2337, 2366, 2375, 2406, 2412, 2449, 2453, 2483, 2505, 2552, 2587, 2729, 2754, 2758, 2860, 2914, 2983, 3016, 3018, 3063, 3093, 3123, 3145, 3228, 3241, 3242, 3258, 3264, 3759, 3762, 3785; left upper teeth, THUg 0235, 0395, 0466, 0587, 0950, 0951, 1196, 1280, 1352, 1446, 1448, 1460, 1496, 1519, 1627, 1628, 1702, 1814, 1846, 1914, 2180; right upper teeth, THUg 0272, 0442, 0461, 0775, 0902, 1149, 1403, 1784, 1794, 1884, 2038; left lower anterior teeth, THUg 0875, 1831, 2759, 3183, 3286; right lower anterior teeth, THUg 0592, 0886, 0953, 1356, 1616, 1904, 2982, 3146, 3192, 3243, 3274; left lower anterolateral teeth, THUg 0227, 0253, 0320, 0325, 0453, 0568, 0643, 0658, 0771, 0801, 0898, 1223, 1879, 2251, 2621, 2760, 3129; right lower anterolateral

tooth; THUg 0128, 0219, 0321, 0781, 1202, 1311, 1659, 1924, 1979, 2044, 2108, 2125, 2147, 2270, 2274, 2364, 2500, 2595, 2796, 2815, 2867, 2951, 3054, 3092, 3231; left lower lateral teeth, THUg 0162, 0224, 0760, 0878, 1578, 1967, 1995, 2030, 2392, 2433, 2497, 2550, 2744, 2897, 3015, 3149, 3265; right lower lateral teeth, THUg 0172, 0199, 0482, 0509, 0719, 0812, 1256, 1347, 1445, 1493, 2294, 2443, 2470, 2702, 2916, 2979, 3783; upper anterior tooth, THUg 2381; upper lateral teeth, THUg 0147, 0213, 0418, 0533, 1764, 1773, 1886, 1965, 2382, 2430, 3046; upper teeth, THUg 0222, 0312, 0409, 0432, 0459, 0464, 0515, 0580, 0645, 0648, 0671, 0780, 0893, 0903, 0959, 0979, 1056, 1435, 1713, 1824, 2137, 2199, 2200, 2252, 2256, 2265, 2296, 2306, 2334, 2362, 2393, 2454, 2455, 2512, 2629, 2660, 2661, 2664, 2688, 2781, 2857, 2910, 2933, 2936, 2943, 2952, 2972, 2995, 3066, 3075, 3166, 3177, 3236, 3251; lower teeth, THUg 0218, 0441, 0496, 1047, 1183, 1278, 1339, 1757, 1812, 1900, 1940, 2003, 2820; lower anterior teeth, THUg 0755, 0894, 1494, 1800, 1992, 2057, 3180, 3237; lower anterolateral teeth, THUg 0597, 0910, 0930, 1885, 2034, 2572, 3178; lower lateral teeth, THUg 0139, 0212, 0292, 0349, 0436, 0786, 1024, 1199, 1437, 1676, 1941, 2054, 2321, 3245; teeth positions are unknown, THUg 0189, 0196, 0244, 0365, 0407, 0586, 0649, 0720, 0747, 0761, 0763, 0906, 0911, 0920, 0928, 0957, 1012, 1279, 1281, 1456, 1457, 1466, 1477, 1601, 1618, 1694, 1720, 1741, 1780, 1837, 1855, 1860, 1932, 1970, 2064, 2066, 2073, 2128, 2130, 2146, 2192, 2205, 2208, 2320, 2390, 2398, 2410, 2511, 2589, 2604, 2612, 2676, 2693, 2724, 2726, 2728, 2757, 2765, 2799, 2816, 2817, 2836, 2837, 2840, 2941, 2996, 3003, 3080, 3273, 3299, 3770, 3803.

Carcharocles megalodon

Left upper anterior teeth, THUg 0200, 2311; right upper anterior teeth, THUg 0308, 1048; left upper lateral teeth, THUg 0240, 0411; right upper lateral teeth, THUg 0677, 1374; left upper tooth, THUg 1608; upper teeth, THUg 0811, 1025, 1110, 1662, 3282; left lower teeth, THUg 0310, 0735, 1166, 1507, 2268, 2389; right lower teeth, THUg 0223, 0457, 1304; lower teeth, THUg 1502, 1522, 1665; teeth positions are unknown, THUg 0226, 0282, 0837, 0890, 0905, 0991, 1016, 1034, 1084, 1090, 1221, 1306, 1313, 1336, 1354, 1644, 1809, 1850, 2182, 2237, 2290, 2372, 2458, 2469, 2578, 2644, 2685, 2740, 2901, 3152, 3168, 3786.

Parotodus benedeni

Left upper teeth, THUg 0288, 1836, 2234, 2314; right upper teeth, THUg 0383, 0756, 2348, 3757; right lower tooth, THUg 0715; anterior tooth, THUg 3253; lateral tooth, THUg 2704; teeth posi-

tion are unknown, THUg 0276, 0696, 1528, 2127, 3091.

Galeorhinus sp. indet.

THUg 0495, 0996, 1125, 1154, 2288, 2790, 3193.

Hemipristis serra

Left upper teeth, THUg 0144, 0895, 1054, 1706, 1792, 2077, 2298, 2365, 2640, 3780, 3805; right upper tooth, THUg 1729; upper tooth, THUg 2359.

Carcharhinus sp. A

Left upper teeth, THUg 0174, 0211, 0287, 0343, 0357, 0371, 0376, 0386, 0423, 0424, 0487, 0557, 0569, 0622, 0685, 0728, 0733, 0767, 0778, 0803, 0808, 0814, 0817, 0827, 0829, 0834, 0859, 0864, 0925, 1002, 1006, 1009, 1165, 1171, 1203, 1242, 1257, 1395, 1396, 1417, 1451, 1458, 1481, 1489, 1603, 1635, 1647, 1717, 1776, 1811, 1851, 1865, 1899, 1916, 1955, 1984, 2011, 2022, 2042, 2082, 2088, 2091, 2121, 2124, 2148, 2157, 2227, 2281, 2338, 2373, 2417, 2529, 2565, 2576, 2616, 2625, 2716, 2787, 2848, 3106, 3191, 3229, 3235, 3277, 3301, 3784; right upper teeth, THUg 0127, 0171, 0286, 0317, 0322, 0351, 0360, 0361, 0377, 0387, 0425, 0434, 0703, 0704, 0795, 0818, 0881, 0975, 0976, 0987, 1032, 1041, 1083, 1089, 1100, 1147, 1161, 1173, 1182, 1184, 1213, 1272, 1379, 1480, 1596, 1605, 1645, 1658, 1663, 1670, 1671, 1707, 1731, 1743, 1799, 1802, 1889, 2009, 2040, 2041, 2048, 2050, 2074, 2278, 2367, 2378, 2385, 2386, 2387, 2391, 2429, 2495, 2561, 2605, 2635, 2647, 2649, 2684, 2807, 2862, 2950, 3040, 3098, 3113, 3120, 3139, 3162, 3282, 3306, 3802.

Carcharhinus sp. B

Left upper teeth, THUg 0242, 0296, 0331, 0539, 0570, 0594, 0624, 0630, 0954, 1001, 1010, 1055, 1106, 1124, 1141, 1237, 1286, 1297, 1351, 1378, 1486, 1577, 1789, 1790, 1795, 1853, 1880, 1919, 1946, 1990, 1992, 2021, 2028, 2035, 2232, 2489, 2626, 2679, 2806, 2878, 2964, 3077, 3261; right upper teeth, THUg 0243, 0298, 0335, 0353, 0356, 0397, 0602, 0606, 0625, 0676, 0707, 0815, 0833, 0974, 0993, 1015, 1035, 1142, 1181, 1228, 1235, 1332, 1358, 1533, 1573, 1652, 1753, 1777, 1862, 1938, 1948, 1950, 1954, 1962, 2014, 2047, 2094, 2223, 2225, 2279, 2287, 2308, 2313, 2341, 2405, 2463, 2527, 2581, 2727, 2735, 2843, 2920, 3775.

Carcharhinus sp. C

Left upper tooth, THUg 0252, 0635, 0901, 1239, 1592, 2239, 2687, 2927; right upper teeth, THUg 0741, 0752, 1075, 1736, 2249, 2800; upper teeth, THUg 0989, 1786.

Carcharhinus sp. D

Left lower teeth, THUg 0142, 0414, 0739, 0840, 0972, 1096, 1151, 1176, 1190, 1275, 1500, 1698,

1921, 2049, 2492, 2575, 2882, 2885, 2955, 3153; right lower teeth, THUg 0112, 0285, 0345, 0404, 0492, 0631, 0810, 0841, 1004, 1534, 1641, 1661, 2153, 2231, 2238, 2610, 2709, 3279; lower teeth, THUg 0355, 1711.

Carcharhinus sp. E

Left lower teeth, THUg 0488, 0493, 0494, 0547, 0599, 0610, 0687, 0846, 0994, 1007, 1218, 1631, 1968, 1988, 2023, 2100, 2142, 2291, 2344, 2624, 2785, 2852, 2859, 3171, 3278; right lower teeth, THUg 0297, 0359, 0379, 0421, 0634, 0712, 0736, 0962, 1285, 1796, 1869, 1953, 1973, 2019, 3102, 3190, 3269; lower teeth, THUg 1363, 1402, 2018, 2222.

Sphyrna zygaena

Left upper teeth, 0524, 0721, 0726, 0860, 0924,

1069, 1102, 1109, 1589, 1614, 1660, 1750, 1980, 2075, 2104, 2113, 2133, 2134, 2553, 2593, 3124; right upper teeth, THUg 0621, 0629, 0758, 1167, 1305, 1692, 2024, 2377, 3062, 3161; left lower teeth, THUg 0611, 0744, 1397, 1961, 3156; right lower teeth, THUg 0152, 1080, 3109; tooth position is unknown THUg 3195.

Indetermined vertebral centra of selachians

THUg 0203, 0318, 0576, 0582, 0588, 0628, 0724, 0857, 0887, 0967, 1021, 1122, 1123, 1180, 1260, 1261, 1310, 1426, 1439, 1442, 1498, 1801, 1844, 1873, 1934, 1947, 1996, 2068, 2109, 2273, 2490, 2519, 2522, 2678, 2699, 2823, 3056, 3120, 3188, 3200, 3240, 3297, 3774, 3801.