Gill rakers of basking sharks (Lamniformes: Cetorhinidae) from the Tertiary of Sakhalin Island, Russia

Жаберные тычинки гигантских акул (Lamniformes: Cetorhinidae) из третичных отложений острова Сахалин, Россия

M.V. Nazarkin

М.В. Назаркин

M.V. Nazarkin, Zoological Institute, Russian Academy of Sciences, 1 Universitetskaya Emb., St Petersburg 199034, Russia. E-mail: m_nazarkin@mail.ru

Isolated gill rakers of basking sharks (Lamniformes: Cetorhinidae) were collected from the upper Oligocene Holmsk Formation and Middle-Upper Miocene Kurasi Formation of the Sakhalin Island. This is the second finding of fossil basking shark remains in Russia. Fossil gill rakers are similar to those in recent representatives of the genus *Cetorhinus*, but differ from the latter by wider and shorter medial processes and higher bases. These features are more typical for basking sharks in the fossil genus *Keasius*. Additional material is needed for the exact taxonomic identification of the Tertiary basking sharks from Sakhalin.

Сообщается о находке отдельных жаберных тычинок гигантских акул (Lamniformes: Cetorhinidae) в верхнее-олигоценовых отложениях холмской свиты и средне-верхне-миоценовых отложениях курасийской свиты острова Сахалин. Это второе обнаружение ископаемых остатков гигантских акул на территории России. Рассматриваемые тычинки напоминают таковые современного рода *Cetorhinus*, но отличаются более короткими и широкими медиальными отростками и более высокими основаниями. Эти признаки более характерны для гигантских акул вымершего рода *Keasius*. Необходимы более многочисленные дополнительные материалы для точной идентификации третичных гигантских акул Сахалина.

Key words: Oligocene, Miocene, Sakhalin, fossil basking shark, Cetorhinidae

Ключевые слова: олигоцен, миоцен, Сахалин, ископаемая гигантская акула, Cetorhinidae

INTRODUCTION

Cetorhinus maximus (Gunnerus, 1765) is the only representative of the basking shark family Cetorhinidae (Lamniformes) in the modern fauna. After whale shark *Rhincodon typus* Smith, 1828, this is the second largest shark attaining up to 12 m in total length (Compagno, 1984, 2002; Hovestadt & Hovestadt-Euler, 2011). This species is widely distributed in cold and warm temperate waters worldwide (Compagno, 2002). One of the most distinctive morphological features of this species is very wide gill openings which almost encircle the head. Basking sharks are pelagic filter-feeders which prey on small planktonic organisms and fish eggs (Compagno, 2002). Their filtering apparatus consists of high and numerous gill rakers (modified dermal denticles with extremely elongated crowns) which are densely placed in two rows along each gill arch (Hovestadt & Hovestadt-Euler, 2011). Number of gill rakers per gill arch is about 1260 (Bigelow & Schroeder, 1948). The jaw teeth are monocuspid, small and numerous (Compagno, 1984; Cappetta, 1987). The gill raker sets are annually shed during the low zooplankton abundance season and, after that, basking sharks presumably feed on benthic organisms using their tiny jaw teeth (Compagno, 2002). Apparently, because of this biological trait, fossilised remains of cetorhinid gill rakers are commonly found on all continents

in deposits from the middle Eocene through Pleistocene, whereas findings of the teeth, vertebrae or skeletons are rather rare. In a detailed review of cetorhinid fossil records, Welton (2013) assigned two species of early and rather primitive cetorhinids in his new extinct genus *Keasius*. One of them, *K. taylori* Welton, 2013, is known only from the late Eocene deposits in Oregon, USA (Welton, 2013). The other, *K. parvus* (Leriche, 1908), is known from numerous localities in Oligocene and Miocene deposits in Europe and North America (Welton, 2013).

A tooth from the Eocene deposits in the Western Siberia is probably the earliest representative of *Cetorhinus* (Malyshkina, 2006). *Cetorhinus* sp. has been also reported from the late Oligocene in Japan (Uyeno et al., 1984) and Mexico (Gonzalez-Barba & Thies, 2000). Early to middle Miocene findings of *Cetorhinus* came from Europe, North and South America, and East Asia (Japan), and were usually identified as *Cetorhinus* sp. or, less often, as *C. maximus* (Welton, 2013). Almost all late Miocene through Pleistocene cethorinids are referred to as *C. maximus*. Remains of this species were found also in Europe, both Americas and East Asia (Japan) (Welton, 2013). The second (extinct) species of this genus – *C. huddlestoni* Welton, 2014 – was recently described from the Middle Miocene of California, USA (Welton, 2014).

All data on fossil basking sharks in East Asia (the north-western Pacific) are from Japan. More than 360 separate gill rakers of *Cetorhinus* sp. were discovered from the lower Oligocene beds on Ainoshima Island (Tomita & Oji, 2010). Remains of *Cetorhinus* sp. are reported also from the upper Oligocene and middle Miocene localities (Uyeno et al., 1984; Itoigawa et al., 1985; Karasawa, 1989; Yabumoto & Uyeno, 1994). *Cetorhinus maximus* remains from Japan were found in deposits of the middle Miocene (Uyeno et al., 1983; Karasawa, 1989) and Pleistocene (Uyeno & Matsushima, 1974).

Recently, two gill rakers of basking shark were found in the deposits of Late Oligocene of the Holmsk Formation and one more – in the deposits of Middle-Late Miocene of the Kurasi Formation on the Sakhalin Island, Russia. These findings are the second known occurrence of fossil cetorhinids in Russia. The structure of gill rakers is similar to that in known *Cetorhinus*. At the same time, there are some differences from the recent *Cetorhinus* that bring the Sakhalin findings together with the extinct *Keasius*. Thus, it seems important to describe these fossils though without either generic or species identification until more representative material on this taxa is available.

Remains of chondrichthyans in both mentioned formations are very rare. Earlier, a single tooth of a thresher shark (Alopiidae) was described from the same locality of the Holmsk Formation (Nazarkin & Malyshkina, 2012) and a single tooth of mako shark (Lamnidae) is known from the same locality of the Kurasi Formation (Nazarkin, 2013).

MATERIALS, METHODS AND LOCALITIES

Specimens are deposited in the paleontological section of ichthyological collection of the Zoological Institute of the Russian Academy of Sciences, St Petersburg (ZIN). Gill raker terminology follows Welton (2013). Measurements are made with calipers to the nearest 0.1 mm. Drawings are made according to digital photos.

The Late Oligocene findings from the Holmsk Formation are represented by the imprints of two separate gill rakers in the matrix with both rakers' bodies themselves preserved in its most part. Specimen ZIN 306p-1 with filament is broken and displaced in the proximal part. In specimen ZIN 306p-2, the medial process is missing. The Middle-Late Miocene fossil raker from the Kurasi Formation (ZIN 307p) is represented as an imprint in matrix; with the bone itself completely lost.

The fossils were found on the coastal cliffs of the Tatar Strait. Fossiliferous beds of the

Holmsk Formation are located about one kilometre south from the settlement of Nevodskoye and three kilometres north from the town of Tomari on the south-western coast of the island (47°47.921′N 142°04.602′E). The outcrop of Kurasi Formation is placed approximately 8 km to the north from the former (47°52.224′N 142°05.813′E), about five kilometres south from the settlement of Penzenskoye at the same district.

The cliffs of both localities exposed laminated clayish aleurolites, superficially similar to each other. The fossiliferous beds of the both sites were formed in comparatively deep marine environments (Savitskyi, 1982; Zhidkova, 1982, 1986). Periods of sedimentation coincided with two largest phases of the Tertiary sea transgression on Sakhalin. During these periods, two strongest phases of the accumulation of siliceous deep-water deposits were noted which were connected with periods of high biomass production of diatoms (Gladenkov et al., 2002). Numerous remains of deep-water fish taxa such as myctophids, bathylagids, macrourids, polymerichthiids, and stomiids were discovered from both localities. The remains of neritic or near-bottom fishes of the families Clupeidae, Gasterosteidae, Sebastidae are less frequent. Structure of both, Late Oligocene and Middle-Late Miocene fish communities are very close at the levels of families and genera of fishes.

SYSTEMATIC PART

Class **CHONDRICHTHYES** Huxley, 1880

Superorder **GALEOMORPHII** Compagno, 1973

Order **LAMNIFORMES** Berg, 1958

Family **CETORHINIDAE** Gill, 1862

Gen. et sp. indet.
(Figs 1, 2)

Material. ZIN 306p 1 and 2, two gill rakers. Coastal cliff of Tatar Strait about one kilometer south of settlement of Nevodskoye, Tomari District, *Sakhalin Province*, **Russia**; Holmsk Formation, Upper Oligocene; coll. M.V. Nazarkin, 2012 and 2013. ZIN 307p, one gill raker. Coastal cliff of Tatar Strait about five kilometers south of settlement of Penzenskoye, Tomari District, *Sakhalin Province*, **Russia**; Kurasi Formation, Middle-Upper Miocene; coll. M.V. Nazarkin, 2014.

Description. Total length of gill rakers from the Holmsk Formation are approximately 56 mm in specimen ZIN 306p-1 and 55.7 mm in specimen ZIN 306p-2; length of the filament exceeds the basal height by 12.5 and 14.7 times, respectively (Fig. 1a, b). The surface of the filament is densely covered with weak longitudinal wrinkles. The central part of the filament is depressed and bordered by two flat ridges which extend from the base joint to halfway to the apex. Curvature of the filament base is weak. The bight is comparatively deep, with intermediate width and of subangular shape (Fig. 2a). The bight in specimen ZIN 306p-1 seems slightly wider than that of specimen ZIN 306p-2. The bight depth of the former specimen is slightly (by 2%) exceeding the basal height; the bight depth of the second specimen makes, probably, about 98% of basal height. Thus, the basal height is medium. The medial process is of medium size, comparatively wide, of a triangle shape, with a slightly concave mesial edge and a rounded apex. The basal protuberance is weakly developed. The basal edge of the base is almost straight. Basal length varies from medium in specimen ZIN 306p-1 to long in specimen ZIN 306p-2. The basal angle is subangular.

Total length of the gill raker from the Kurasi Formation (specimen ZIN 307p) is approximately 100 mm; length of the filament exceeds the basal height by 14.5 times (Fig. 1c). The surface of the filament is densely covered with weak longitudinal wrinkles. The central part of the filament is depressed medially from the base joint to one third of its length. Curvature of the filament base is weak. The bight is of subangular shape, narrow and shallow; its depth

Fig. 1. Gill rakers of basking sharks from Sakhalin Tertiary. Specimens ZIN 306p-1 (**a**) and ZIN 306p-2 (**b**) from Holmsk Formation and ZIN 307p (**c**) from Kurasi Formation. Scale bar: 10 mm.

is about 67% of the base height. The base is very high (Fig. 2b). The medial process is short, comparatively wide, of triangle shape, with a slightly convex mesial edge and a rounded apex. The basal protuberance is weak. The basal edge of the base is straight. Basal length is medium. The basal angle is subangular.

DISCUSSION

Gill rakers of adult individuals of two known cetorhinid genera significantly differ in length. The length of gill rakers of large adults of *C. maximus* may exceed 200 mm (Hovestadt & Hovestadt-Euler, 2011), whereas gill rakers in *Keasius* are

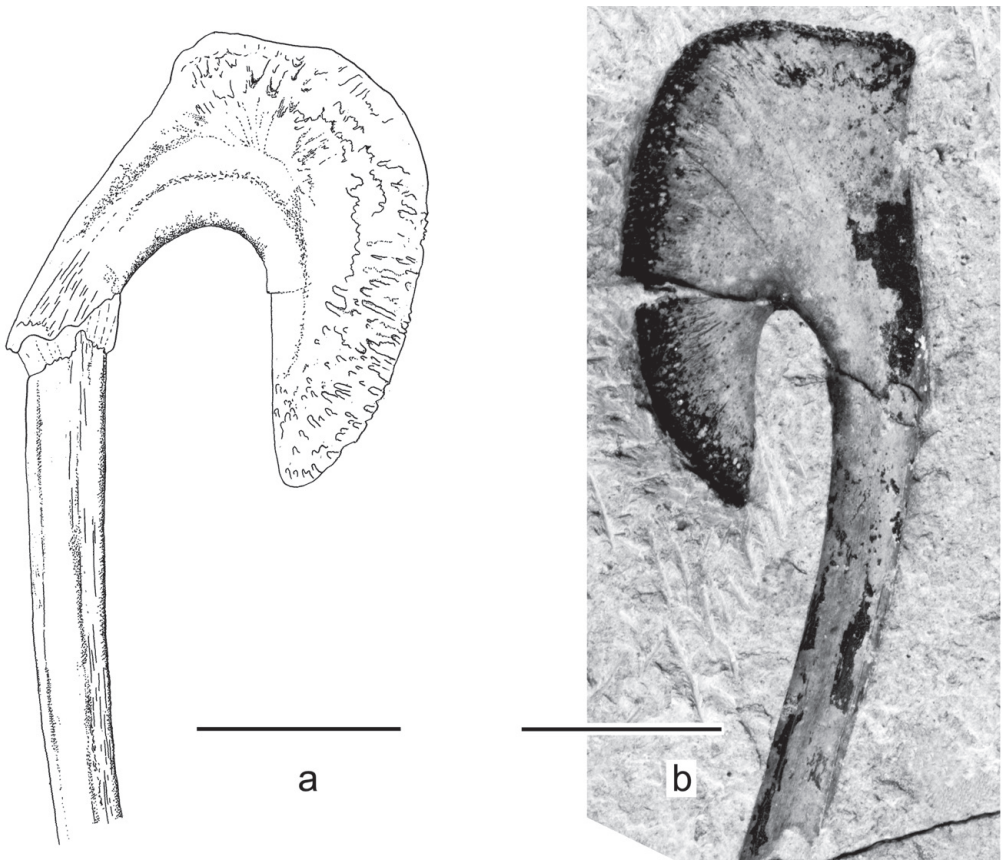

Fig. 2. Proximal parts of fossil gill rakers. Outline drawing of specimen ZIN 306p-1 (**a**) and photo of specimen ZIN 307p (**b**). Scale bar: 5 mm.

shorter, usually less than 60 mm in *K. parvus* (Hovestadt & Hovestadt-Euler, 2011). An estimated length of the largest gill raker of *K. taylori* slightly exceeds 50 mm (Welton, 2013). The gill rakers described here from the Holmsk Formation are comparatively long. While their length is close to that of the largest gill rakers known for *Keasius*, they fall within the range of medium-sized individuals of *Cetorhinus*. Thus, the length of the gill rakers alone cannot be used for generic identification.

The gill rakers from the Holmsk Formation are similar to those in *Keasius* as diagnosed by Welton (2013) in subangular form of the bight, moderately short, broadly triangular medial process, and subangular basal angle of the base. At the same time, all these characters are applicable to some gill rakers in *Cetorhinus* as it appears from their descriptions (Welton, 2013). The latter genus is characterised by an angular to subangular bight, a rounded to subangular basal angle; medial processes of the posteriormost rakers can be short and wide, resembling those in *Keasius*. Nevertheless, the gill rakers in consideration are more similar to those in *Cetorhinus* because they have a lesser basal height (usually exceeding the bight height in *Keasius*), a comparatively long medial process (usually very short and wide in *Keasius*), and a short and blunt basal protuberance (usually pointed in *Keasius*). In addition, specimen ZIN 306p-1 has very similar shape and proportions to those in *C. maximus* illustrated by Welton (2013,

p. 21, fig.12, 2). Because of existing variability in shape and size of the medial process of fossil and recent cetorhinids, more numerous materials are needed for exact genus and species identification of the Oligocene basking shark from Sakhalin.

The specimen ZIN 307p from the Kurasi Formation is considerably similar to gill rakers of the genus *Keasius* in its high base, shallow and narrow bight, and short and wide triangular medial process. At the same time, the basal protuberance of this specimen is only weakly developed corresponding to the features of gill rakers in *Cetorhinus*. The total length of the gill raker considerably exceeds those known for *Keasius* that brings it together with *Cetorhinus*.

Thus, the gill rakers of Tertiary basking sharks from Sakhalin are characterised by the mosaic set of characters shared with both *Keasius* and *Cetorhinus*. More numerous findings of fossil remains, especially jaw teeth, are necessary for exact generic and specific identification of these sharks.

According to the ratio between body size and gill rakers length established for basking sharks (Hovestadt & Hovestadt-Euler, 2011, p. 80, fig. 11), the fossil shark from the Holmsk Formation most probably reached about 4.3 m in total length. The total length of the basking shark from Kurasi Formation, consequently, was approximately 6.8 m.

Recent *C. maximus* is distributed along the Asian Pacific coast from Taiwan to southern Kamchatka (Compagno, 2002). This species is very rare in the northern Sea of Japan and in Primoriye (Novikov et al., 2002). There are no any reliable data on occurrence of this species in the Tartar Strait.

ACKNOWLEDGEMENTS

Author would like to express his sincere thanks to Y. Yabumoto (Kitakiyshu Museum, Japan), T.P. Malyshkina (Zavaritskii Institute of Geology and Geochemistry, Russia), and A.I. Pinchuk (University of Alaska, USA) for their kind help with the literature and to A.I. Pinchuk for his linguistic assistance. Special thanks to B.J. Welton (New Mexico Museum of Natural History and Science, USA) and N.G. Bogutskaya for critical reading of the manuscript and valuable comments. This study was supported by the Russian Foundation for Fundamental Research, grant 14-04-00642a.

REFERENCES

Bigelow H.B. & Schroeder W.C. 1948. Fishes of the Western North Atlantic. *Memoir of the Sears Foundation for Marine Research*, **1**(1): 56–576.

Cappetta H. 1987. Chondrichthyes II: Mesozoic and Cenozoic Elasmobranchii. *In*: **Schultze H.-P.** (Ed.). *Handbook of Paleoichthyology*, **3B**. Stuttgart: Gustav Fischer Verlag. 193 p.

Compagno L.J.V. 1984. Sharks of the World. An annotated and illustrated catalogue of shark species known to date. Part 1 – Hexanchiformes to Lamniformes. *FAO Fisheries Synopsis*. No. 125, **4**(1). Rome: FAO. 249 p.

Compagno L.J.V. 2002. Sharks of the World. An annotated and illustrated catalogue of shark species known to date. 2. Bullhead, mackerel and carpet sharks (Heterodontiformes, Lamniformes and Orectolobiformes), **2**(1). *FAO Species Catalogue for Fishery Purposes*. Rome: FAO. 269 p.

Gladenkov Yu.B., Bazhenova O.K., Grechin V.I., Margulis L.S. & Salnikov B.A. 2002. *Kaynozoy Sahalina i ego neftegazonosnost* [Cenozoic of Sakhalin and its oil-and-gas content]. Moscow: GEOS. 223 p. (In Russian).

Gonzalez-Barba G. & Thies D. 2000. Asociaciones faunisticas de condrictios en el Cenozoico de la Peninsula de Baja California, Mexico. *Profil*, **18**: 1–4.

Hovestadt D.C. & Hovestadt-Euler M. 2011. A partial skeleton of *Cetorhinus parvus* Leriche, 1910 (Chondrichthyes, Cetorhinidae) from the Oligocene of Germany. *Paläontologische Zeitschrift*, **86**: 71–83.

Itoigawa J., Nishimoto H. & Karasawa H. 1985. Miocene fossils of the Mizunami group, central Japan. 3. Elasmobranchs. *Monograph of the Mizunami Fossil Museum*, **5**: 1–89.

Karasawa H. 1989. Late Cenozoic Elasmobranchs from the Hokuriku district, central Japan. *The Science Reports of the Kanazawa University*, **34**(1): 1–57.

Malyshkina T. 2006. *Elasmobranchs of the western margin of the West Siberian Paleogene ba-*

sin. Ekaterinburg: Institute of geology and geochemistry of the Ural Branch of RAS. 224 p.

Nazarkin M.V. 2013. Hooked Mako *Isurus planus* (Agassiz, 1856) from the Miocene of Sakhalin. *Zoosystematica Rossica*, **22**(2): 311–314.

Nazarkin M.V. & Malyshkina T.P. 2012. The first reliable record of selachians from the Neogene deposits of Sakhalin Island. *Zoosystematica Rossica*, **21**(1): 180–184.

Novikov N.P., Sokolovskii A.S., Sokolovskaya T.G. & Yakovlev Yu.M. 2002. *Fishes of Primor'ye*. Vladivostok: Dal'rybvtuz. 550 p. (In Russian).

Savitskyi V.O. 1982. Kurasiiskaya Formation. *In*: **Vereschagin V.N.** (Ed.). *Stratigraphichesky slovar' SSSR. Paleogen, Neogen, Chetvertichnaya sistema* [Stratigraphic dictionary of the USSR. Paleogene, Neogene, Quarter System]: 463. Leningrad: Nedra. (In Russian).

Tomita T. & Oji T. 2010. Habitat reconstruction of Oligocene Elasmobranchs from Yamaga Formation, Ashiya group, Western Japan. *Paleontological Research*, **14**(1): 69–80.

Uyeno T. & Matsushima Y. 1974. Early Pleistocene remains of basking shark, hammerhead shark, and others found in Yokohama, Japan. *Bulletin of the Kanagawa Prefectural Museum, Natural Science*, **7**: 57–66.

Uyeno T., Ono K. & Sakamoto O. 1983. Miocene elasmobranchs from Chichibu basin, Saitama, Japan. *Bulletin of Saitama Museum of Natural History*, **1**: 27–36.

Uyeno T., Yabumoto Y. & Kuga N. 1984. Fossil fishes of Ashiya group – (1); Late Oligocene elasmobranchs from Island of Ainoshima and Kaijima Kitakyushu. *Bulletin of Kitakyushu Museum of Natural History*, **5**: 135–142.

Welton B.J. 2013. A new archaic basking shark (Lamniformes: Cetorhinidae) from the late Eocene of western Oregon, U.S.A., and description of the dentition, gill rakers and vertebrae of the recent basking shark *Cetorhinus maximus* (Gunnerus). *Bulletin of New Mexico Museum of Natural History and Science,* **58**: 1–48.

Welton B.J. 2014. A new fossil basking shark (Lamniformes: Cetorhinidae) from the Middle Miocene Sharktooth Hill bonebed, Kern County, California. *Contributions in Science*, **522**: 29–44.

Yabumoto Y. & Uyeno T. 1994. Late Mesozoic and Cenozoic fish faunas of Japan. *Island Arc*, **3**(4): 255–269.

Zhidkova L.S. 1982. Holmsk Formation. *In*: **Vereschagin V.N.** (Ed.). *Stratigraphichesky slovar' SSSR. Paleogen, Neogen, Chetvertichnaya sistema* [Stratigraphic dictionary of the USSR. Paleogene, Neogene, Quarter System]: 463. Leningrad: Nedra. (In Russian).

Zhidkova L.S. 1986. Sakhalin and Kuril Islands. *In*: *Stratigraphia SSSR. Neogenovaia sistema* [Stratigraphy of the USSR. Neogene system], **2**: 141–175. Moscow: Nedra. (In Russian).

Received July 19, 2014 / Accepted October 2, 2014

Editorial responsibility: N.G. Bogutskaya