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## Some Miocene Fish Otoliths from the Yakuoji Formation, Tsu, Mie Prefecture

Fumio Ohe\* and Yoshio Araki\*\*

### Abstract

From the Miocene Yakuoji Formation in the western part of Tsu City, many deep sea fish otoliths were found. They belong to the families Myctophidae, Notacanthidae and Coryphaenoididae, and described as new to science are *Diaphus angulatus*, *D. hataii*, *Lampanyctus kuboensis*, *Hygophum rotundum*, *Notacanthus circulus*, and *Coelorhynchus yakuojiensis*, whereas the unidentified species belong to the genera *Diaphus* and *Notoscopelus*.

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### MATERIALS AND GEOLOGY

The materials upon which this study is based were collected from the Yakuoji Formation exposed in a cliff situated at about 100 meters north of Kubo-cho, Tsu City. The formation at the exposure consists of black siltstone and it yielded 120 specimens of fish otoliths and other kinds of fossils such as of Foraminifera, Mollusca, fragments of plants, fish scales and also concretions mostly of cobble-size. The otoliths although somewhat weathered still retain perfectness of their forms and also the details of sculpture. In general the fish otoliths can be readily distinguished from other kinds of fossils by their characteristic external forms, sculptures and growth lines.

The fossil locality mentioned above was included by Araki (1960) in the Yakuoji Formation of his Isshi Group (marine, Miocene). In Araki's report, the thickness of the formation was stated to be about 180 meters and to consist of two parts of Upper and Lower. (Table 1).

The upper part consists of the alternations of sandstone and siltstone, intercalated with conglomerate bearing chert pebbles, and the whole is tuffaceous and estimated to be 120 meters in thickness. The lower part consists of the alternations of siltstone and sandstone like the upper part, but the alternations are more or less rhythmic at places, being 5-10 meters in thickness, of flysch type and with thick black siltstone intercalated at several horizons. The locality of the fossil otoliths is considered to occupy the upper part of the lower division of the Yakuoji Formation.

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Table 1. Stratigraphic sequence of the western Tsu area (Y. Araki, 1960).

Age	Group	Formation	General lithological characteristics	Thickness in meters	Characteristic fossils
Pliocene	Agé	Toshima	Tanaka Member, Alternation of sandstone and siltstone intercalating thin conglomerate beds of chert, and several lignite beds	190	<i>Anodonta</i> <i>Cristaria</i> <i>Viviparus</i>
		Koyama Conglomerate	Pebble to cobble size gravels of chert, quartz-porphry, sandstone and siltstone —unconformity and fault—	90	None
Early Miocene	Isshi	Yakuoji	Upper part. Alternation of sandstone and siltstone	120	<i>Macoma tokyoensis</i> , <i>Turritella</i>
			Lower part. Alternation of siltstone and sandstone with flysch-like deposits	60	<i>Fulgoraria yanagidaniensis</i> , Otoliths, Foraminifera
		Chaya Sandstone	Massive sandstone intercalating siltstone layers to form an alternation of sandstone and siltstone	60	<i>Calliostoma myonchomensis</i>
		Kaisekizan	Mitsugano Member: Alternation of tuffaceous siltstone and sandstone	100	<i>Periploma mitsuganoense</i> <i>Euspira meisensis</i>
			Agodani Member: Dark muddy sandstone	150	<i>Acila yanagawensis</i> , <i>Glycymeris cishhuenensis</i> , <i>Periploma yokoyamai</i>
		Furutaike Sandstone	Arkosic sandstone	150	<i>Meretrix</i> , <i>Dosinia</i> Bryozoa, Plant
Kongobo	Alternation of conglomerate and sandstone —unconformity and fault—	150	<i>Mizuhopecten</i> <i>Pitar itoi</i>		
Pre-Tertiary basement of granite gneiss, biotite gneiss, granite (so-called Ryoke complex)					

## DESCRIPTION

Order Myctophida

Family Myctophidae

Genus *Diaphus* Eigenmann & Eigenmann, 1891*Diaphus angulatus* Ohe and Araki, n. sp.

Pl. 49, figs. 1, 2

Holotype: cat. no.\* 698-1, right sagitta, OL\*\*: 5.5 mm, OH\*\*: 4.6 mm, OL/OH: 1.20

Otolith subquadrate in shape, length 1.20 times height. Dorsal margin nearly straight, ventral margin broadly rounded, denticulated, posterior margin an obtuse angle, projecting ventrally as denticle. Otolith rather thick. Outer surface rather smooth, with

\* Catalogue number of specimen(s) in the collection of the Department of Geology, Faculty of Education, Mie University.

\*\* OL: Otolith length, OH: Otolith height.

five annual concentric rings. Inner surface with transverse valley extending to margin. Two posterior sulcus and one anterior colliculums. Lower sulcus crescent shaped, upper one elliptical, much larger than lower; their surface flat and confront each other with deep and narrow fossa.

*Remarks:*— Only one specimen was found from the Yakuoji Formation. The features of this specimen refer it to the genus *Diaphus*. In the form and size, it resembles the sagitta of *Diaphus* sp. found in the stomach contents of *Stenella longirostris* and *S. graffmani* by Fitch and Brownell (1968, p. 2568, fig. 2F). The posterior margin of the otolith is straight and thus it differs from *Diaphus hataii* n. sp.

*Diaphus hataii* Ohe and Araki, n. sp.

Pl. 49, figs. 3, 4

Holotype: cat. no. 698-4-1, right sagitta, OL: 1.80 mm, OH: 1.40 mm, OL/OH: 1.28

Otolith roundly oval in shape. Rostrum a little longer than antiostrum, roundly denticle-like in shape. Seven denticles on ventral margin, and none on dorsal. Ventral and dorsal areas of inner face without sculpture. Inner face flat. Sulcus oval-shaped, surrounded by hairpin-shaped trench. Outer face more or less rough, annual rings obscure and with seven weak grooves on ventral margin. The length range is 1.8–2.3 mm and height is 1.2–1.3 mm; the average length being about 1.24 times height.

Table 2. The lengths of some specimens.

Number of specimen	Standard length in mm.	Height in mm.	OL/OH
698-4-10	2.10	1.75	1.20
18	2.05	1.65	1.22
22	2.00	1.60	1.25
1 (Holotype)	1.80	1.40	1.28
31	1.80	1.45	1.28
32	2.20	1.70	1.29
45	2.12	1.70	1.24
59	2.25	1.78	1.26
67	2.11	1.75	1.21
79	2.34	2.01	1.16
98	2.25	1.70	1.32
Average length	ca. 2.09	ca. 1.68	ca. 1.24

*Remarks:*— This species is the most common type of otolith found from the Yakuoji Formation at Kubo. Its sagitta is of the genus *Diaphus* (family Myctophidae, so-called Hadakaiwashi in Japanese).

The configuration and form of this species more or less resemble the descriptions of *Myctophum spinatum* Aoki and *M. vastus* Aoki from a Pleistocene Jizodo Formation, Boso in Japan (Aoki, 1968, Sci. Rep., Tokyo Kyoiku Daigaku, Sec. C, v. 11, no. 104, p. 24–25), and also *Diaphus* sp. of the Bowden Formation, Jamaica, *Myctophum* sp. from the Round Mountain Silt, and also *Myctophum nitidulum* Garman from the Pleistocene and Pliocene of California (Fitch, Contr. Sci., no. 173, p. 8). Further *Diaphus* #1 and *Dipahus* #2 found in stomachs of three *Kogia simus* captured off Taiji, Japan [Fitch and Brownell 1968, Jour. Fish. Res. Bd. Canada 25 (12), p. 2565] are also similar to the present new species in superficial features.

The difference between the sagitta of some species of the genera *Diaphus* and *Myctophum* is not distinct, though in detail the outline of anterior ostium which is composed of antiostrum and rostrum, is straight in the former while in the latter there is a deep cleft. Since this species resembles most closely the former genus it is referred to it. This new species is named in honor of Professor Kotora Hatai of the Institute of Geology and Paleontology, Tohoku University, in recognition of his deep interest in fish otoliths.

*Diaphus* sp. indet.  
Pl. 49, figs. 5, 6

Specimen: cat. no. 698-5c, left sagitta, OL: 3.37 mm, OH: 2.9 mm, OL/OH: 1.15

This specimen is nearly circular in shape, and both ends barely protrude both posteriorly and anteriorly. Rostrum with shallow cleft. Sulcus long, wide and with three colliculums, anterior end straight. Outer face more or less irregular, with six or seven grooves that do not reach focus area.

*Remarks:*—Although this specimen resembles *Notacanthus circulus* n. sp. in form and length, the arrangements of the colliculums, shape of rostrum, and the pattern of inner-face are different. Fishes having circular shaped otolith are known in the genera of lantern fishes, namely, *Hygophum* sp., *Diogenichthys latesnatus* Garman, *Diaphus* sp., *Lampanyctus* sp., of the family Myctophidae and *Notacanthus* sp. of the family Notacanthidae.

Genus *Lampanyctus* Bonaparte, 1840  
*Lampanyctus kuboensis* Ohe and Araki, n. sp.  
Pl. 49, figs. 7, 8

Holotype: cat. no. 698-2-1, left sagitta, OL: 4.90 mm, OH: 2.48 mm, OL/OH: 1.97

Otolith elongate antero-posteriorly, length 1.90–1.97 times height. Ventral margin broadly bow-shaped, dorsal margin smooth and flat. Ventral margin with 11 shallow denticles. Sulcus parallel with ventral margin, occupies nearly three fourths length. Sulcus with three colliculums. Outer face more or less rough with strong wrinkles.

*Remarks:*—This species from Kubo is next to *Diaphus hatavi* n. sp. in frequency of occurrence. This species resembles very closely the sagitta of some forms of the family Sphyraenidae, Mugiliformes (for instance, *Sphyrana dubia* Bleeker or *S. piscatorum* Cadenat from the Gulf of Guinea, described by W. Schmidt), though the arrangement and form of the colliculums of the sulcus of the Holotype fits the genus *Lampadena* and is similar to *Lampanyctus parvicauda* Parr reported by Fitch and Brownell, (1968: fig. 2E). In addition to this species, there are two or three specimens which seem to represent a different species or variety (Pl. 49, figs. 9, 10, 11) and also a specimen that is somewhat like yet distinguishable from *Notoscopelus resplendes* (Richardson).

This otolith is named after its type locality, Kubo, Katada, Tsu City.

Genus *Hygophum* (Taning) Bolin, 1939  
*Hygophum rotundum* Ohe and Araki, n. sp.  
Pl. 49, figs. 12, 13

Holotype: cat. no. 698-3-1, right sagitta, OL: 3.27 mm, OH: 2.97 mm, OL/OH: 1.10

Otolith with margin oval-shaped, smooth except at posterior margin, inner face flat. Posterior margin straight with many small denticles. Anterior margin with three clefts. Vertical cross-section of inner face half moon to meniscus shaped. Ventral area of inner

face with many ripple-shaped sculptures. Outer face with about 20 grooves which reach base of center dome.

*Remarks:*—This species belongs to the Recent genus *Hygophum* of the family Myctophidae. (Fitch and Brownell 1968, p. 2565, fig. 1E). The sulcus of this species is identical with the characters of lantern fish which belong to the family Myctophidae.

Genus *Notoscopelus* Gunther, 1864

*Notoscopelus* ? sp.

Pl. 49, figs. 14, 15

Specimen: cat. no. 698-10-1, left sagitta, OL: 4.35 mm, OH: 2.70 mm, OL/OH: 1.61

Otoliths elongated oval in shape. Its dorsal margin irregular. Ventral margin with many small irregular denticles. Both lateral extremities rounded. Excisure flat. Outer margin, with small incision. Growth valley touches center area. Several weak grooves extending from dorsal and ventral margins to center area. Inner face of sulcus with three flat colliculums.

*Remarks:*—Although not perfectly preserved this specimen may be a species of the genus *Notoscopelus* of the family Myctophidae judging from the outline and retained features. If perfect it may represent a new species.

Order Notacanthina

Family Notacanthidae

Genus *Notacanthus* Bloch, 1787

*Notacanthus circulus* Ohe and Araki, n. sp.

Pl. 49, figs. 16, 17

Holotype: cat. no. 698-5b, left sagitta, OL: 2.9 mm, OH: 2.54 mm, OL/OH: 1.14

Otolith nearly circular in shape, its margin almost smooth. Ventral margin with many small and obscure denticles. Sulcus peapod-shaped, anterior end straight and not clefted. Inner face flat, outer face with rather convex surface. Ridges like annual rings and seven or eight weak grooves running toward focus on outer face.

*Remarks:*—This species is common in the Yakuoji Formation. The sagitta represents a species similar to but distinct from *Notacanthus phasganorus* Goode, (Werner Schmidt, 1968, p. 11, fig. 17).

Order Coryphaenoidina

Family Coryphaenoididae

Genus *Coelorhynchus* Giorna, 1803

*Coelorhynchus yakuojiensis* Ohe and Araki, n. sp.

Pl. 49, figs. 18, 19

Holotype: cat. no. 698-6-1, left sagitta, OL: 4.05 mm, OH: 2.60 mm, OL/OH: 1.56

Otolith somewhat spindle-shaped with posterior end expanded. Ventral and dorsal margins smooth. Small denticles on both margins, narrow. Antiostrum, excisure and rostrum obscure. Outer face with four grooves running from dorsal margin to focus area. Grooves not touching focus point. Two or three vague grooves extending inward from ventral margin. Focus area swells gradually outside toward center. Inner face flat. Sulcus, thin, convex, horizontal, occupying greater part of otolith, not touching anterior or posterior margins. Sulcus conical in three dimensions, with five or six deep and pit hollows in a row. Dorsal area sunken shallowly.

*Remarks:* - This fossil otolith is identified with the genus *Coelorhynchus* of the family Coryphaenoididae. (Fitch 1966, 1970, Playa del Rey, p. 20, fig. 2E; Werner Schmidt 1968, fig. 45, p. 21, Gulf of Guinea). The outer face of the present new species differs from *C. scaphopsis* (Gilbert) and *C. coelorhynchus* (Risso) described by the above two students. The species name *yakuojiensis* is taken from the Yakuoji Formation.

#### CONCLUSION

(1) The species of otoliths from the locality of Kubo are mostly the sagitta of lantern fishes. They are *Diaphus angulatus* n. sp., *D. hataii* n. sp., *D.* sp., *Lamphanyctus kuboensis* n. sp., *Hygophum rotundum* n. sp., *Notoscopelus* ? sp. of the family Myctophidae and *Coelorhynchus yakuojiensis*, n. sp. of family Coryphaenoididae besides a few of unknown positions.

(2) In general the otoliths are 1.8-5.5 mm in their lengths, oval with white or light amber color and rather well preserved.

(3) The remains of other fish-parts except the otolith of lantern fishes, consist of many *Sardinops* (Clupeidae) scales and cycloid scale of two or three species (probably, they may all belong to the Myctophidae.)

(4) The Yakuoji Formation shows many different kinds of sedimentary structures and has yielded fossils such as Mollusca as, *Limopsis* sp., *Pectunculina* sp., *Macoma tokyoensis*, *Cancellaria* cf. *endoi*, *Fulgoraria hirasei yanagidaniensis* and *Ancistrolepis trochoideus miensis*.

Of the fossils mentioned above, *Fulgoraria* and *Ancistrolepis* are considered to be forms of deep water whereas the others are generally known to occur in shallow water. The flysch type sediments are in good agreement with the characteristic features of the deep water molluscs, but are not in harmony with such bivalves as *Macoma*, *Limopsis* and *Pectunculina* which may live in either deep or shallow water.

(5) Comparing the otoliths from the Kubo locality with the Myctophidae habits of the Pacific Ocean (T.S. Rass and others 1967), of the Japan Sea and the adjacent sea (Lindberg and Legeza, 1965; Matsubara, 1963; Fitch and Brownell, 1968), it is suggested that the Yakuoji Formation was deposited in an environment of more or less deep water, probably at 200-500 meters. The mezobenthos or mezopelagic depth near the continental shelf of the Yakuoji fauna is shown in Table 3.

Table 3. The fish fauna of the Yakuoji Formation.

Species of Yakuoji Formation	Habits of nearest living species
Family Myctophidae	
<i>Disphus angulatus</i> n. sp.	200-700 meters in depth
<i>D. hataii</i> n. sp.	190 species of Myctophidae: 130 in the Pacific Ocean, 60 in the Atlantic Ocean.
<i>D.</i> sp.	
<i>Lamphanyctus kuboensis</i> n. sp.	
<i>Hygophum rotundum</i> n. sp.	
<i>Notoscopelus</i> sp.	
Family Notacanthidae	
<i>Notacanthus circulus</i> n. sp.	500-2000 meters in depth, 16 species: 8, 1, 7.
Family Coryphaenoididae	
<i>Coelorhynchus yakuojiensis</i> n. sp.	100 (500)-500 (2000) meters in depth, 300 species: 200-206, 25, 76-82.

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Plate 49

- Figs. 1, 2, *Diaphus angulatus* Ohe and Araki, n. sp.,  $\times 6$ , right sagitta. fig. 1, outer face; fig. 2, inner face.
- Figs. 20, 21, Sketch of Figs. 1, 2.
- Figs. 3, 4, *Diaphus hataii* Ohe and Araki, n. sp.,  $\times 9$ , right sagitta. fig. 3, inner face; fig. 4, outer face.
- Figs. 5, 6, *Diaphus* sp. indet.,  $\times 5$ , left sagitta. fig. 5, inner face; fig. 6, outer face.
- Figs. 22, 23, Sketch of Figs. 5, 6.
- Figs. 7, 8, *Lampanyctus kuboensis* Ohe and Araki, n. sp.,  $\times 5$ , left sagitta. fig. 7, inner face; fig. 8, outer face.
- Figs. 24, 25, Sketch of Figs. 7, 8.
- Figs. 9-11, Different species or variety of *Lampanyctus kuboensis*.
- Figs. 12, 13, *Hygophum rotundum* Ohe and Araki, n. sp.,  $\times 3$ , right sagitta. fig. 12, inner face; fig. 13, outer face.
- Figs. 26, 27, Sketch of Figs. 12, 13.
- Figs. 14, 15, *Notoscopelus?* sp.,  $\times 5$ , left sagitta. fig. 14, inner face; fig. 15, outer face.
- Figs. 28, 29, Sketch of Figs. 14, 15.
- Figs. 16, 17, *Notacanthus circulus* Ohe and Araki, n. sp.,  $\times 5$ , left sagitta. fig. 16, inner face; fig. 17, outer face.
- Figs. 30, 31, Sketch of Figs. 16, 17.
- Figs. 18, 19, *Coelorhynchus yakuojiensis* Ohe and Araki, n. sp.,  $\times 5$ , fig. 18, inner face; fig. 19, outer face, left sagitta.
- Figs. 32, 33, Sketch of Figs. 18, 19.

