Fossil sperm whales (Cetacea, Physeteridae) from Gunma and Ibaraki prefectures, Japan; with observations on the Miocene fossil sperm whale Scaldicetus shigensis
Hirota and Barnes, 1995

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Abstract: Fossil specimens of sperm whales (members of the odontocete cetacean family Physeteridae) are rare in Japan, and this is true also in other parts of the world. Two physeterid fossils have been previously reported from Middle Miocene age deposits of Gunma and Ibaraki prefectures, Japan, and these specimens are re-identified here as cf. Scaldicetus sp. The morphology of the teeth of these specimens is consistent with the traditional concept of the genus Scaldicetus. However, because the genus Scaldicetus is a form taxon, based solely on isolated teeth, it is not appropriate to assign more completely known fossil sperm whales, several of which have other characters that are distinctive at the generic level, to the genus Scaldicetus. Thus, the Japanese Middle Miocene sperm whale Scaldicetus shigensis Hirota and Barnes, 1995, is here assigned to the new genus Brygmophyseter. We include here additional observations and illustrations of the holotype skeleton of Brygmophyseter shigensis.

Key Words: Cetacea, Physeteridae, Brygmophyseter shigensis, Scaldicetus, Miocene, Haraichi Formation, Urizura Formation, Bessho Formation, Gunma, Ibaraki, Nagano, Japan, tooth

INTRODUCTION

The sperm whales, family Physeteridae, are one of the longest-surviving lineages of the Cetacea (Fordyce and Barnes, 1994). The geochronologically earliest documented fossil physeterid is the late Oligocene Fercceotherium kelloggii Mchedlidze, 1970, from Azerbaijan (see Barnes, 1985:90, for re-identification of this species as a physeterid). The family Physeteridae attained its maximum phylectic diversity during the Miocene. In contrast, only one species of physeterid survives now, and that is the relict taxon Physeter macrocephalus Linnaeus, 1758, the giant sperm whale (for taxonomy see Rice, 1998:82-83).

Members of the family Physeteridae are characterized by having a cranium with profound left-skew asymmetry around the dorsal narial region and a large supracranial basin. The supracranial basin is the depression on the facial region of the cranium that is occupied in life by the spermaceti organ, which is a modification of the odontocete melon that is unique to members of the superfamly Physeteroidea (including the families Physeteridae (giant sperm whales) and Kogiidae (pygmy and dwarf sperm whales)).

The living giant sperm whale, P. macrocephalus, is the largest living member of the cetacean suborder Odontoceti, and adult males of this species can reach approximately 18 m in length (Dawbin, in Barnes, 1988; Jefferson et al., 1993; Rice, 1998). Physeter macrocephalus has 20 to 26 large teeth in each dentary. In contrast, the teeth in its palate are fewer in number, vestigial, and rarely erupt (Whitehead, 2002).

In contrast, many fossil sperm whales have large and fully functional upper teeth in their palates (Fordyce and Barnes, 1994), and this is the primitive character state for the Physeteridae. A low tooth count, as is found in some fossil sperm whales, some of which have as few as only 12 teeth in each dentary, is also a primitive character state for the family, because this is close to number of teeth in primitive archaeocete cetaceans (Hirota and Barnes, 1995; Barnes et al., 2004).

Although many cetacean fossils have been found in Japan, as is the situation in other parts of the world, the fossil record of the family Physeteridae is relatively poor (Oishi and Hasegawa, 1995). The purpose of this paper is to describe two physeterid specimens from Gunma and Ibaraki prefectures in Japan, and to discuss their phylogenetic affinities. The Middle Miocene Scaldicetus shigensis Hirota and Barnes, 1995, is the only
Japanese fossil sperm whale that has previously been identified at the species level, and it is herein assigned to a new genus. Some additional information, measurements, and photographs are provided herein for the holotype of this species.

Institutional abbreviations used in the text are: GMNH, Gunma Museum of Natural History, Tomioka, Gunma Prefecture, Japan; INM, Ibaraki Nature Museum, Bando, Ibaraki Prefecture, Japan; LACM, Department of Vertebrate Paleontology, Natural History Museum of Los Angeles County, Los Angeles, California, U.S.A.; NSM, National Science Museum, Tokyo; SFM, Shiga Fossil Museum, Matsumoto, Nagano Prefecture, Japan; UCMP, University of California Museum of Paleontology, Berkeley, California, U.S.A.; YPM, Yamagata Prefectural Museum, Yamagata, Yamagata Prefecture, Japan.

SYSTEMATIC PALEONTOLOGY
Suborder Odontoceti Flower, 1867
Superfamily Physeteroidea (Gray, 1821) Gill, 1872
Family Physeteridae Gray, 1821
Scalidicetus Du Bus, 1867
cf. Scalidicetus sp.
Figure 1,2

Physeteridae gen. et sp.indet.Hasegawa,Takakuwa, and Nakajima, 2001:33, figs. 3-4, pl. 1.

Referred specimen: GMNH-PV-581; parts of both dentaries, each containing four teeth, and two isolated teeth, all belonging to one individual. Collected in December 1998 by H. Nakajima.

Locality: Annaka, Gunma Prefecture, Japan

Formation and Age: The specimen is from the Haraiuchi Formation, which is part of the Annaka Group, and is late Middle Miocene in age, approximately 11.5 Ma (Odin et al., 1997; Hasegawa et al., 2001).

DESCRIPTION
Mandible (Fig. 2)
The dorsoventral dimension of the left dentary at its broken anterior end is 113 mm, and at the broken posterior end is 124 mm. The lateral surface of the dentary is slightly convex, and there are four mental foramina on the lateral surface in this section of dentary. These foramina are at 45, 85, 174, 211 mm posterior from the broken anterior end of the section of dentary, and they are positioned at 54, 53, 50, 44 mm ventral to the edge of the alveolar row. Each of these foramina opens into an anteriorly-directed sulcus.

The dorsoventral dimension of the right dentary at the preserved anterior broken end is 142 mm, and where it is broken at the posterior end is 147 mm. The medial surface of the right dentary is nearly flat, but the ventral one-third of the dentary has a corrugated area, which is the posterior part of the symphyseal surface. Apparently the mandibular symphysis was unfused, as is typical of sperm whales. The lateral surface of the right dentary is also convex laterally. The ventral edge of the preserved posterior half of the right dentary is nearly straight.

On the left dentary, the first and second teeth from the broken anterior end are separated by an interalveolar septum that is approximately 14 mm thick. Following the second in-situ tooth from the anterior end of the right dentary, there is an empty alveolus that is approximately 37 mm in its anteroposterior diameter. The interalveolar septum between the second tooth and this empty alveolus is approximately 11 mm thick. Interalveolar septa in other parts of the dentary are not
measurable because of distortion of the bone and dislocation of the teeth.

**Teeth (Fig. 1, 2)**

One of the isolated teeth is almost complete (Fig. 1) and, unless otherwise mentioned, the following description is based upon this tooth. The crown of this tooth is conical in shape, and its apex is worn off. The enamel that covers the crown is less than 1 mm thick, and its surface is rugose and wrinkled (Fig. 1E). The greatest height of the enamel crown as preserved is approximately 15 mm. There is no distinct neck on the tooth below the enamel margin, but there is a shallow wear facet on the posterior surface of the tooth immediately below (proximal to) the enamel margin.

The root of the tooth is long and curves posteriorly. It tapers toward its extremity, which is compressed anteroposteriorly. The swelling of the root is most pronounced on its lateral side. There is some shallow longitudinal fluting on the root, which becomes more pronounced toward the extremity of the root.

Measurements of the tooth that is shown in Fig. 1 are: greatest length of the tooth as preserved, 139.6 mm; greatest transverse diameter of the crown at the base of the enamel, 21.8 mm; greatest anteroposterior diameter of the crown at the base of the enamel, 19 mm; greatest transverse diameter of the root, 43.8 mm; greatest anteroposterior diameter of the root, 37 mm.

**cf. Scaldicetus sp.**

Figure 3 and Plate 1


*cf. Scaldicetus sp.* Hasegawa et al., 2006 no.10 :27, fig. 2, pls. 2-6.

Referred Specimen: INM-4-012885; fragment of rostrum, anterior part of dentary, teeth, phalanges, right petroso, and right tympanic bulla; all representing one individual; collected in May 1984 by I. Takahashi.

Locality: Naka (formerly Naka-machi), Ibaraki Prefecture, Japan.

Formation and Age: Urizura Formation, late Middle Miocene to early Late Miocene in age. Koizumi and Terunuma (1985) suggested that based upon diatom biostratigraphy the horizon from which this physeterid fossil was collected can be assigned to the *Denticulus praeidemorpha* zone. Although Koizumi and Terunuma (1985) reported the abundant occurrence of both *D. praeidemorpha* and *D. hustedii* in this formation, these two species do not occur in a single horizon (Yanagisawa and Akiba, 1990, 1998) . The *Denticulus praeidemorpha* Zone (NPD 5B, late Middle Miocene in age(Yanagisawa and Akiba, 1998)), is recognized by the stratigraphic interval ranging from the first occurrence of *D. praeidemorpha* var. *minor* to the last occurrence of *D. praeidemorpha*. The base of the *Thalassiosira yabei* Zone (NPD 5C, latest Middle Miocene to early Late Miocene in age(Yanagisawa and Akiba, 1998) ), is recognized by the stratigraphic interval between the last occurrence of *D. praeidemorpha* and the first appearance of *D. hustedii*. Therefore, the horizon in which the fossil physeterid was found can be regarded as late Middle Miocene to early Late Miocene in age.

**Figure 2** cf. *Scaldicetus sp.* (GMNH-PV-581): partial dentary. Scale bar equals 10 cm.

**DESCRIPTION**

**Teeth (Fig. 3 and Pl. 1B-F)**

At least 37 teeth are preserved with this specimen, 32 of which are isolated, and five of which are in place in the left dentary (Pl. 1). The anterior-most three teeth in the left dentary fragment are procumbent (Fig. 3). Hirota and Barnes (1995) also noted similar procumbency of the anterior three teeth in the dentary of *Scaldicetus shigensis*. Based on homology with primitive Odontoceti, they concluded that the first three mandibular teeth of primitive sperm whales are homologous with the incisors of primitive whales and, ultimately, of terrestrial mammals.

The crowns of these anterior teeth in INM-4-012885 are conical in shape (Pl. 1), and they are covered with an enamel layer that is less than 1 mm thick. This enamel has a rugose, wrinkled surface. No distinct neck is present on the tooth proximal to the base of the enamel. The apices of the crowns of these teeth are nearly unworn, and this probably indicates that this animal was a young individual at the time of its death.

The roots of these teeth taper toward their extremities. The roots swell in their mid-parts, and this swelling of the roots is most pronounced on their lateral surfaces. However, the root of one of the isolated teeth does not show this pronounced swelling on its lateral surface, and it is almost straight (Pl. 1F). This morphology of the root is present on the anterior-most teeth that are preserved in place in the dentary (Fig. 3). Shallow longitudinal fluting is present on the surfaces of the roots, and
this fluting becomes pronounced as it approaches the extremity of the root.

Measurements of the largest well preserved tooth, shown in Pl. 1B, are: greatest length of the tooth as preserved, 158 mm; greatest anteroposterior diameter of the crown at the base of the enamel, 14.2+ mm; greatest height of the enamel crown, 24.4+ mm; greatest anteroposterior diameter of the root at the location of maximum swelling, 38 mm; and greatest transverse diameter of the root, 44.5 mm.

Typanic bulla (Fig. 4B-E)

The right typanic bulla of this specimen is relatively well preserved, but its anterior end and part of the ventral surface of the bulla, immediately posterior to the sigmoid process, are broken away. As is typical of members of the family Physeteridae, the sigmoid process is very large, and it is twisted at a right angle to the long axis of the bulla. Its bluntly rounded lateral extremity is thickened, and it is bent slightly anteriorly. The sigmoid process is positioned relatively far posteriorly on the bulla, as it is in Recent *Physeter macrocephalus*, and in other sperm whales. A thickened part of the margin of the involucrum of the bulla that is present in all known species of Physeteroida, and which has been termed the "accessory ossicle" (Kellogg, 1927, 1965; Luo and Marsh, 1996) is part of this bulla. As is typical of all other known species of the family Physeteridae, this "accessory ossicle" of the typanic bulla is firmly attached to the anterior process of the petrosal, and it usually breaks off of the bulla and remains attached to the petrosal (see following text). The posterodorsal part of the bulla is relatively thickened, and in medial view (Fig. 4C) the exterior surface of the involucrum is constricted in the mid-part of the bulla. This constriction also is present on the bulla of Recent *P. macrocephalus*, and in such fossil sperm whales as *Aulophyseter morrici* Kellogg, 1927, and *Orcytocetus crocodilinus* Cope, 1868, as well as of species of the pygmy sperm whales of the family Kogiidae, and it is a diagnostic character of the superfamily Physeteroidea.

Petrosal (Fig. 5)

The right petrosal is almost completely preserved. The extremity of the anterior process of the petrosal is tapered and bends ventrally, as is also the case in the Recent *P. macrocephalus* and in some specimens of *Aulophyseter morrici* and *Orcytocetus crocodilinus* (see Kellogg, 1927; and Luo and Marsh, 1996). The anterior process is much shorter than the promontorial length. An accessory ossicle is firmly fused to the ventral side of the anterior process of the petrosal. A rounded tuberosity is well developed on the dorsomedial part of the anterior process.

The fossa for the head of the malleus is relatively large. The ventrolateral tuberosity is relatively large, and it is positioned lateral to the fossa for the head of the malleus. An incudal process is present posterolateral to the fossa for the head of the malleus. The pars cochlearis is rounded, but it is not so inflated as it is in *P. macrocephalus*. The outline of the pars cochlearis is nearly hemispherical in ventral view. The fenestra rotunda opens on the posterior surface of the pars cochlearis. The transverse septum, which separates the facial foramen from the cochlear foramen, is thin and is slightly lower than the rim of the internal acoustic meatus. The outline of the internal opening of the facial canal is circular, and this canal is excluded from the internal acoustic meatus.

The posterior process of the petrosal is oriented posteroventrally in relationship to the longitudinal axis of the petrosal. The articular surface for the posterior process of the typanic bulla is slightly concave, and it has a low crest. The ridge-like process is present on the lateral surface of the posterior surface of the petrosal.

*Brygmophyseter* Barnes, new genus


**DIAGNOSIS OF GENUS**

A genus of Physeteridae of medium body size in adulthood, differing from all other genera in the family Physeteridae by having the following combination of characters: at least 11 teeth, and probably 12, in each dentary, probably a similar number of functional upper teeth in each side of the palate, teeth of relatively large diameter and bearing enamel-covered crowns, enamel on teeth ornamented with rugosities, maxillae formed into crests along lateral margins anterior to antorbital notches, right naris of very small diameter, orbits located anterior to anterior end of zygomatic process of squamosal, zygomatic process of squamosal relatively short and nearly triangular in shape in lateral view, temporal fossa relatively elongate anteroposteriorly, occipital shield emarginated by posterior part of temporal fossa, nuchal crest relatively low and broad and not greatly elevated; scapula not expanded dorsally toward vertebral border, humerus lacking distally-directed tuberosity on delto-pectoral crest, shaft of ulna expanded distally with posterior projection at distal end.

**ETYMOLOGY**

The genus name is a combination of *brygmos*, the Greek word for biting or gnashing, combined with the suffix *physeter*, which is the generic name of the living sperm whale, and which is also the Greek word for blower. This name alludes to the functional teeth in the mandible and palate of the holotype specimen of the type species, *Scaldicetus shigensis*, and to the assignment of this fossil species to the same family of cetaceans as the living sperm whale.
Figure 4 A, Brygmophyseter shigensis (Hirota and Barnes, 1995) (holotype: SFM-00001): right tympanic bulla, ventral view.
B-E, cf. Scaldicetus sp. (INM-4-012885): right tympanic bulla, ventrolateral (B), ventromedial (C), dorsomedial (D), dorsolateral (E) views. Scale bar equals 2 cm.

TYPE AND ONLY INCLUDED SPECIES
Scaldicetus shigensis Hirota and Barnes, 1995.

DISCUSSION
When Hirota and Barnes (1995) named Scaldicetus shigensis, they offered the following cautionary words: "Fossils from elsewhere previously referred to Scaldicetus, largely on the basis of tooth characters, range in age from Early Miocene to Pli- Pleistocene time. Cranial material that would clarify relationships is lacking for most of these, and this time range seems too long for a cetacean genus. Because of this simplistic approach to identifications, Scaldicetus is probably a grade taxon, not a natural biological grouping. The tooth morphology of Scaldicetus shigensis is correct for the genus Scaldicetus, however, so we provisionally assign it to this genus. Redefinition of the genus Scaldicetus and revision of the Physetidae are beyond the scope of the present study."

The original typology of the genus Scaldicetus is problematic. The type species of Scaldicetus is Scaldicetus caretti du Bus, 1867, and the holotype of that species is isolated teeth, presumably of one individual, of Middle Miocene age from the Antwerp Basin in Belgium. Hirota and Barnes (1995) noted these limitations to the continued utility of the generic name Scaldicetus. Kazár (2002:158) regarded Scaldicetus shigensis as a valid taxon, but classified it (Kazár, 2002:163) in Physetidae, incertae sedis.

Several specimens from the same area as the holotype of Scaldicetus caretti have been referred to that species, and specimens of various ages from elsewhere in the world have been assigned to various species of the genus, or have been simply identified as Scaldicetus sp. They do share in common the indication that the animals were of medium to large body size, and the presence of tooth crowns that are covered in coarsely ornamented enamel. Some of these specimens are relatively complete and informative, however, their identifications as members of the genus Scaldicetus must hinge on the validity of the holotype of S. caretti. Because different types of sperm whales have been assigned to Scaldicetus, this genus has become a scrap-basket taxon. It now appears likely that the tooth morphology which is commonly referred to as Scaldicetus, in which the roots are elongate and cylindrical and the crown is conical and clad in rugose enamel, occurs in various taxa of extinct Physetidae that are in different clades (Barnes et al., 2004).

Scaldicetus shigensis is based on a partial skeleton that has many pivotal physeterid characters that are well preserved and evident, and it is an interesting and relatively primitive sperm whale. Because of the problematic nature of the genus Scaldicetus, it is most prudent to now assign the relatively well-known and well-diagnosed fossil sperm whale Scaldicetus shigensis to a new genus, for which is proposed here the new generic name Brygmophyseter.
**Brygmophyseter shigensis** (Hirota and Barnes, 1995),
new combination

Figures 4A, 6, 7, 8 Plates 2 - 8


*Scaldicetus shigensis* Hirota and Barnes, 1995:456, figs. 5-17, 18a, 19a.


**DIAGNOSIS OF SPECIES**

The diagnosis of the species shall remain identical to that of the genus until further species are described in the genus.

**HOLOTYPE**

SFM-00001, nearly complete skeleton, including partial cranium, both dentaries, hyoid bones, vertebrae, ribs, manubrium of sternum, both scapulae, humeri, and radii, and the left ulna; collected in May 1988 by residents of the town of Shiga-mura and by employees of the Shiga Fossil Museum.

**TYPE LOCALITY**

In the bed of the Hofuku-ji River, Matsumoto (formerly Shiga-mura, Higashi-chikuma Gun), Nagano Prefecture, Japan (and see Hirota and Barnes, 1995:figs. 1, 3).

**FORMATION AND AGE**

The holotype of *Brygmophyseter shigensis* was excavated from the upper member of the Bessho Formation, and this horizon is of early Middle Miocene age and approximately 14 to 15 Ma (Kosaka et al., 1992; Hirota and Barnes, 1995:figs. 2, 4). In the area of outcrop at the type locality on the Hofuku-ji River the Bessho Formation has a northeast strike and dips to the north. Other marine vertebrate fossils have been discovered in the Bessho Formation, including undetermined mysticete whales (Kimura et al., 2004).

The age of the Bessho Formation is further corroborated by the fossils from the immediately overlying rock unit, which is the middle Middle Miocene age Aoki Formation. Two species of allodesmine otarioids, *Allodesmus sinanoensis* (Nagao, 1941), and *Allodesmus megalos* Hirota, in Barnes and Hirota, 1995, occur in the Aoki Formation, and these pinnipeds have a grade of evolution that is consistent with other middle Middle Miocene taxa in the subfamily Allodesminae. Because the Aoki Formation in which they occur is geochronologically younger than the underlying Bessho Formation, this dates the Bessho Formation as being older than middle Middle Miocene.

**DISCUSSION**

The holotype specimen consists of nearly the complete skeleton, including the well preserved cranium and mandible, and it is therefore one of the most complete fossil sperm whale specimens from any place in the world. Although no upper teeth are preserved in place, large dental alveoli on the palate (Fig. 6) clearly show the former presence of large functional upper teeth. The presence of functional upper teeth is the primitive character state for the Physetididae. *Brygmophyseter shigensis* has several other primitive characters for the Physetididae: anteriorly sloping occipital shield, large temporal fossa, relatively long and slender rostrum, and low tooth count (Hirota and Barnes, 1995; Barnes et al., 2004).

Hirota and Barnes (1995) described many of the bones of the holotype specimen. Subsequently, the holotype has been further cleaned, molded, and cast, and a mounted replica of the restored skeleton had been temporarily exhibited in the Gunma Museum of Natural History (Pl.8). Here we present some additional data that was not provided by Hirota and Barnes.

**ADDITIONAL DESCRIPTION**

Scapula (Fig. 7 and Pl. 2)

Both scapulae are preserved with the holotype of *Brygmophyseter shigensis*, but both of them lack their anterior and posterior margins. The glenoid fossa is partly preserved on the right scapula. The scapula is relatively large and has broad acromion and coracoid processes. The scapulae of most species of Odontoceti are wider anteroposteriorly than they are high, but in the living sperm whale, *P. macrocephalus*, the greatest vertical dimension (glenoid fossa to vertebral margin) of the
Figure 6  *Brygmophystes shigensis* (Hirota and Barnes, 1995) (holotype: SFM-00001): rostrum fragment, ventral (A) and cross sectional (B) views. Scale bar equals 10 cm.

Scapula exceeds its anteroposterior dimension (Flower, 1868). In contrast, the scapula of *Brygmophystes shigensis* more closely resembles that of other odontocetes because it is relatively wide anteroposteriorly (see Pl. 2). Its measurements are: preserved anteroposterior diameter, 327± mm; greatest vertical diameter, 368± mm in the left scapula.

The acromion process is broad, expands distally, is directed anteriorly, and gradually curves medially toward its extremity. The measurements of the length and vertical height at the narrowest part of the acromion process are respectively 136+ mm and 56+ mm on the right scapula, and 138+ mm and 53+ mm on the left. The process is located close to the anterior edge of the blade of the scapula. The supraspinatus fossa is very reduced. The stout coracoid process also projects anteriorly, curves slightly medially, and its extremity is slightly thickened. The length of the right coracoid process is 60 mm or more, and of the left is 61 mm or more. The narrowest part of the right coracoid process, near where it departs from the blade of the scapula, measures 37 mm, and of the left coracoid process measures 31 mm or more.

**Humerus** (Fig. 8D)

Humeri of fossil sperm whales are relatively uncommon. Both humeri are preserved with the holotype of *Brygmophystes shigensis*. These have the typical characteristics of sperm whale humeri: large head positioned obliquely to the humeral diaphysis, deltopectoral crest large and occupying the proximal half of the anterior margin of the diaphysis, capitular surface for articulation with the radius much inclined proximally relative to the long axis of the diaphysis, and trochlear surface for articulation with the ulna lacking a distinct separation into two facets as is typical of most Cetacea.

By comparison, humeri from the Middle Miocene age Sharktooth Hill Bonebed in California that can be referred to the sperm whale *Aulophystes morrici* are more primitive than that of *B. shigensis* by being more slender, but are more derived by having smaller capitular and trochlear surfaces (Fig. 8).

**Ulna**

We emphasize the previous observations (see Hirota and Barnes, 1995:467, fig. 17) that the ulna of *B. shigensis* is more primitive than that of Recent *P. macrocephalus* (see Flower, 1868:pl. 61) by having a longer and more slender diaphysis, a smaller radial facet, a smaller olecranon process that is not distally-directed, but is more derived by having a posteriorly-directed process at the distal end of its posterior margin.

**Vertebrae** (Pls. 3-7)

During the excavation of the holotype specimen, the vertebrae were found in almost their original undisturbed
sequence, so the anatomical positions of the vertebrae can be relatively confidently determined. No cervical vertebrae were found with the skeleton. The 35 vertebrae that were recovered (Pls. 3-7) are identified as follows; ten thoracic, ten lumbar, and 15 caudal vertebrae. In contrast, the skeleton of Recent Physeter macrocephalus (see Flower, 1868) has 11 thoracic, 8 lumbar, and 22 caudal vertebrae.

Byrhnophyseter shigensis is more primitive than P. macrocephalus by having one less thoracic vertebra (ten versus 11 thoracic vertebrae). The additional thoracic vertebra of P. macrocephalus probably was acquired by the inclusion of one anterior lumbar vertebra into the thoracic sequence by replication of a rib. Nonetheless, B. shigensis still has a slightly longer lumbar region than P. macrocephalus (ten lumbar vertebrae in contrast to eight in P. macrocephalus).

There are more substantial differences, however, in the proportional lengths of the tails of the two species. Byrhnophyseter shigensis has only 15 caudal vertebrae, compared to 22 in P. macrocephalus (see Flower, 1868:pl. 59), and the shorter tail of B. shigensis is the more primitive character state.

Most of the vertebrae have the epiphyses firmly ankylosed to the centrum, with a few exceptions in some posterior thoracic and anterior lumbar vertebrae. The centra of the vertebrae increase progressively in their anteroposterior lengths from the first thoracic vertebra to the seventh lumbar vertebra, then they begin to decrease progressing posteriorly toward the caudal region. Measured on the anterior side of the centrum, the transverse diameter of each centrum exceeds the vertical diameter in all of the thoracic vertebrae with exception of the tenth. The anterior or posterior surfaces of the centra of most of the thoracic vertebrae are relatively wide, but the centra of the lumbar and caudal vertebrae are more nearly circular in shape. The measurements of these vertebrae are shown in Table 1.

**DISCUSSION**

The type species of the genus Scaldicetus is S. caretti Du Bus, 1867, and this species is based upon 45 teeth, which are assumed to belong to one individual, of Middle Miocene age, from the Antwerp Basin in Belgium (and see Kellogg, 1925:7). Many fossil specimens have been subsequently reported and identified as belonging to the genus Scaldicetus, and other fossils have formed the basis for additionally named species in this genus.

Listed uncritically in alphabetical order by specific names these are: Santwerpiensix Du Bus, 1872; S. bellanensis Dal Piaz, 1922; S. caretti Du Bus, 1867; S. crispus Cigala-Fulgo and Pilleri, 1985; S. desjorii Varola, Landini, and Pilleri, 1988; S. grandis (Du Bus, 1872); S. inflatus Cigala-Fulgo and Pilleri, 1985; S. lodgei Chapman, 1917; S. macgeei Chapman, 1912; S. minor (Portis, 1886); S. mortezelenis (Du Bus, 1872); S. patagonicus (Lydekker, 1894); S. perpinguis (Pilleri and Pilleri, 1982); S. shigensis Hirota and Barnes, 1995.

Because S. caretti, the type species of the genus, is based only on teeth and not on cranial material, the status and true relationships of this genus remain unsettled. The naming of additional species in the genus based upon isolated teeth has confounded these uncertainties (see comments by Hirota and Barnes, 1995).

![Figure 7 Byrhnophyseter shigensis (Hirota and Barnes, 1995) (cast of holotype: SFM-00001): reconstructed left scapula, lateral view. Scale bar equals 10 cm.](image)

This is why Hirota and Barnes (1995) cautiously referred Byrhnophyseter shigensis to the genus Scaldicetus. They explained that the holotype specimen (SFM-00001) of Byrhnophyseter shigensis has "...large teeth with rugose enamel on conical crowns, similar to those of S. caretti,....." and "...it has teeth present in both the palate and mandible, and cranial characters that are similar to those of the holotype of S. mortezelenis...." (Hirota and Barnes, 1995:471).

Both of the specimens that we have described here (GMNH-PV-581 and INM-4-012885) also have large teeth with rugose enamel on their conical crowns. These characters agree with those of the teeth of the holotype (SFM-00001) of Byrhnophyseter shigensis, and they also agree with the generally accepted concept of the tooth morphology of the genus Scaldicetus. The size and general shape of the teeth GMNH-PV-581 and INM-4-012885 are also similar to the teeth of the holotype of B. shigensis, and there are no substantial morphological differences between all of these specimens. Because of this we choose to identify them simply as cf. Scaldicetus sp.

Moreover, the tympanic bullae of INM-4-012885 and the holotype of B. shigensis are similar in size, and both specimens share morphology that is typical for the Physeteridae (i.e., rectangular bulla in ventral view, constricted mid-part of the involucrum, large sigmoid process which is located relatively far posteriorly on the bulla). These similarities suggest a close relationship among GMNH-PV-581, INM-4-012885, and Byrhnophyseter shigensis. Because the diagnosis of B. shigensis is based mainly on cranial and mandibular characters, and because the teeth of GMNH-PV-581 and INM-4-012885 conform to the traditionally established concept of the genus Scaldicetus, we here identify them simply as cf. Scaldicetus sp.

Nagasawa and Oba (2002) suggested that GMNH-PV-581 is not closely related to B. shigensis, pointing out differences between the two in the lengths of the interalveolar septa between the mandibular teeth. However, as mentioned here in previous text, in GMNH-PV-581 the more posterior two teeth in the left dentary and the three teeth in the right dentary fragment
are dislocated, and the interalveolar septa are not clearly discernible. On the left dentary of GMNH-PV-581, the undistorted interalveolar septa are approximately 11 mm to 14 mm wide, and the interalveolar septa of *B. shigensis* range from approximately 11 mm to 24 mm. Thus, based only on the interalveolar septal lengths, we would not differentiate these two specimens. Based on the extent of wear on the apices of their tooth crowns, GMNH-PV-581 is the ontogenetically oldest individual of the three specimens, and INM-4-012885 is probably the youngest.

**Figure 8** A-C, *Aulophyseter morricei* Kellogg, 1927, referred right humeri in lateral views, middle Miocene Sharktooth Hill Bonebed, Round Mountain Silt, Kern County, California; LACM 21184 (A); LACM 127712 (B); LACM 21247 (C). D, *Brygmophyseter shigensis* (Hirota and Barnes, 1995) (holotype: SFM-00001), right humerus in lateral view. Scale bar equals 5 cm.

Very few fossils specimens from Japan have been referred to the genus *Scaldicetus*. Nagasawa and Oba (2002) identified a single isolated anterior tooth (YPM 7923) as *Scaldicetus* sp. That specimen was found in the uppermost Miocene Furukuchi Formation, and its age is 6.0 to 5.5 Ma (Nagasawa and Oba, 2002). Nagasawa and Oba (2002) suggested that the specimen represents *Scaldicetus* because it has the following combination of characters: "large single-root tooth, conical crown with striated thin enamel, point of occlusion in the unworn state, small worn and flattened facet on the lingual surface of crown, distinct growth layers of the dentine, long columnar root, and opened pulp cavity". Based on the above characters, they implied that YPM 7923 has close affinities with *B. shigensis*.

INM-4-012885 includes the anterior teeth, which are similar in size and curvature to the tooth YPM 7923. However, although the two specimens are similar in anteroposterior and transverse diameters of the roots, the enamel crowns of INM-4-012885 are much smaller than that of YPM 7923. Of course, there may be some ontogenetic and individual variability, and these must be examined for detailed consideration, but detailed discussion of the taxonomy of YFM 7923 is beyond the scope of this study.

Hasegawa et al. (1987) briefly mentioned a physeterid specimen (NSM-PV 2219) from Middle Miocene deposits at Mito, in Ibaraki Prefecture, Japan. This specimen consists of a mandibular fragment and teeth, and Hasegawa et al. (1987) mentioned that the teeth are morphologically similar to INM-4-012885. The locality of the specimen is relatively close to that of INM-4-012885, and the two specimens probably came from the same geologic horizon, and may be of almost the same age (Hasegawa et al., 1987). Therefore, this specimen may be another record of *Scaldicetus*-like sperm whale from Japan.

Referral of these archaic sperm whale specimens to the genus *Scaldicetus* is a conservative identification, and it is based upon the fact that they have teeth with crowns that are covered by corrugated enamel, and in this regard they agree with the type material of the type species of the genus. Future discoveries, in Japan and elsewhere, of crania and more complete dentaries associated with this type of tooth might suggest other generic assignments.

We noted in previous text that Hirota and Barnes (1995) and Barnes et al. (2004) concluded that a low tooth count, 11 and possibly 12 teeth in each dentary and presumably a similar
Table 1. Measurements (in mm) of vertebrae of Brygmophyseter shigensis (Hirota and Barnes, 1995) (SFM-00001). Abbreviations: a, anterior epiphysis missing; b, posterior epiphysis missing; c, both epiphysis missing; e, estimated; p, measurement of posterior side; +, less than true value.

<table>
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<th>Centrum length</th>
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<th>Centrum, anterior height</th>
<th>Height of vertebra</th>
<th>Width of vertebra</th>
<th>Neural canal, ant. width</th>
<th>Neural canal, ant. height</th>
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number in each side of the palate, is a primitive character state for the Physeteridae. The presence of functional upper teeth in Miocene sperm whales is another primitive character state. Both of these primitive character states exist in Brygmophyseter shigensis.

Conversely, the absence of functional upper teeth is a convergent derived character state in Recent Physeter macrocephalus and in the relatively highly derived fossil sperm whale Aulophyseter morrici from the middle Miocene age Sharktooth Hill Bonebed in central California, U.S.A. When Kellogg (1927) originally named A. morrici, he assumed that, like other Miocene sperm whales from elsewhere in the world, this species had large teeth with enamel-covered crowns. Thus, he referred several isolated teeth to the same species as the edentulous holotype cranium of A. morrici. These teeth that were referred by Kellogg (1927:pl. 7) to A. morrici are not that taxon. In fact, some of them are of other odontocetes, and several of them are actually the canine teeth and upper lateral incisors of large otarioid pinnipeds. These teeth are too large to have occupied the alveolar grooves on the palate of the holotype (Kellogg, 1927:pl. 3), and the enlarged area at the posterior end of the right alveolar groove on the holotype cranium is the result of a dental abscess.

The true teeth of A. morrici are relatively small, are curved lingually, are of small diameter, and lack enamel on their crowns (Fig.9). One such tooth has been found directly associated with a left dentary (Fig.9), and it fits perfectly within the small alveoli of this dentary. The dentary and tooth were both associated with a cranium of the same individual that closely corresponds morphologically with the large and massive holotype cranium of Aulophyseter morrici. This specimen, LACM 42816, is from the same deposit, the Sharktooth Hill Bonebed, that produced the holotype of A. morrici, and both specimens are probably adult males of the species. Another cranium (UCMP 81661, Fig.10) from the Sharktooth Hill Bonebed is smaller and more gracile than both the holotype cranium of A. morrici and the referred specimen (LACM 42816), and it probably represents an adult female of that
species.

Both of the specimens (UCMP 81661 and LACM 42816) that we here refer to *Aulophsyter morricei* have a completely preserved nuchal crest that is relatively high and an occipital shield is recumbent posteriorly. These specimens demonstrate that the nuchal crest of the holotype of *A. morricei* was eroded away, thus making the holotype appear to be more primitive than it actually is. The newly referred specimens of *A. morricei* also demonstrate that the holotype of *Brygnocephalos shigensis* is comparatively primitive by having a lower nuchal crest and an occipital shield that slopes anteriorly rather than posteriorly.

*Aulophsyter morricei* shares derived dental characters with *Orycterocetus crocodilinus* (see the teeth illustrated by Kellogg, 1965:pl. 30), and this is one of the reasons that Barnes et al. (2004) suggested a closer relationship between *Aulophsyter* and *Orycterocetus* than was suggested by Kazár (2002). It is now apparent, however, that among extinct sperm whales, species with similar cranial morphology did not necessarily have similar teeth, and conversely that sperm whales with similar teeth did not necessarily have similar skulls (Barnes et al., 2004).

It is significant that teeth of the type that would be traditionally identified as belonging to *Scaldicetus* have not been found associated in the same strata with specimens of *Orycterocetus* in the Chesapeake Group on the western North Atlantic margin (Gottfried et al., 1994:table 1). Similarly, only one tooth of the "*Scaldicetus* type" has been found (Thomas and Barnes, in press) in the prolific Sharktooth Hill Bonebed on the eastern North Pacific margin, where the fossils of *Aulophsyter morricei* are very abundant.

Table 2 shows a list of all reported and/or described Japanese physeterid fossils that have been attributed to the genus *Scaldicetus*, totaling at least three, and possibly four occurrences. Fossils of *Scaldicetus* that have been found previously in Europe (the North Atlantic basin), and from the eastern North Pacific realm are likewise relatively rare.

The Japanese fossil specimens described here as having affinities with the genus *Scaldicetus* suggest that there is probably a considerable as-yet unrecognized record of archaic sperm whales in Japan that were part of the cetacean assemblages living in the Western North Pacific during Middle Miocene and Late Miocene time. These fossils can provide basic information for the understanding of the paleobiogeographic and evolutionary history of the sperm whales.