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A new fossil rorqual aff. *Balaenoptera bertae* specimen from the Shinazawa Formation (late Pliocene to early Pleistocene), Yamagata, Japan

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Abstract. More than 23 extinct species and 10 extant species of the Balaenopteridae are known. Our knowledge of the family Balaenopteridae is increasing quickly, however, few fossil records support a circum-north Pacific distribution of balaenopterid genera and species. Because of limited preservations, most rorqual fossils reported from the western North Pacific can only be identified to the family level. A skull from the Shinazawa Formation (late Pliocene to early Pleistocene) in Yamagata, Japan, is identified as aff. *Balaenoptera bertae* by possessing two diagnostic features of the species: large occipital condyles, and a posteriorly elongate postglenoid process. Combination of four more features also support that the specimen is a closely related to *B. bertae*. The specimen is probably a slightly older individual than the holotype of *B. bertae*, based on the estimated bizygomatic width and slightly longer posterior process of the tympanoperiotic. The first and only report of *B. bertae* was from the Pliocene Purisima Formation in California, USA. The specimen from Japan is incompletely preserved, but implies that the occurrence of *B. bertae* in the western North Pacific for the first time, as many living balaenopterids are distributed across the North Pacific, such as *Balaenoptera musculus, B. physalus, B. borealis, B. acutorostrata,* and *Megaptera novaeangliae*.

Key Words: Balaenopteridae, Mysticeti, Cetacea, Neogene, Quaternary, Pacific

Introduction

Our knowledge of the fossil record of the rorqual whales, family Balaenopteridae, has been improving recently, such establishing new balaenopterids from Belgium, the Netherlands, Italy, California, Peru, Chile and Japan, and taxonomic revision of Europian problematic fossils (Deméré *et al.*, 2005; Bisconti, 2007, 2010; Bosselaers and Post, 2010; Boessenecker, 2013a; Bisconti and Bosselaers, 2016; Marx and Kohno, 2016; Bisconti *et al.*, 2019, 2020a; Bisconti and Bosselaers, 2020). More than 23 extinct species and 10 extant species are known (Rosel *et al.*, 2021). Among fossil balaenopterids, few records suggest a circum North Pacific distribution because there are only a few records of extinct balaenopterid species from the western side of the North Pacific.

The Miocene through Pleistocene fossil record of balaenopterid whales in Japan has improved recently (Oishi *et al.*, 1985; Hasegawa *et al.*, 2002; Kohno *et al.*, 2007; Kimura *et al.*, 2015; Tanaka and Taruno, 2019). Some records with species level identification are as follows；*Megaptera novaeangliae* from the middle Pleistocene (about 0.12 to 0.15 Ma) at Chiba (Nagasawa and Mitani, 2004), *Burtinopsis tatsunokuchiensis* from the early Pliocene at Iwate (Hatai *et al.*, 1963), and *Miobalaenoptera numataensis* from the late Miocene at Hokkaido (Tanaka and Watanabe, 2019). These limited fossil records from the western North Pacific are insufficient to document the past distribution of balaenopterids across the Pacific. However, fossils of other whale families such the pygmy right whale from Okinawa and the right whale from Taiwan provide their past global distribution (Tsai *et al.*, 2017; Tsai and Chang, 2019).

Here, we describe a balaenopterid cranium from the late Pliocene to early Pleistocene found at Yamagata, Japan, which was preliminary reported by Nagasawa *et al.* (2003). The specimen is incompletely preserved but tentatively identified to species level. This record implies that there was a widely distributed extinct balaenopterid species across the Pacific.

Materials and method

Morphological terminology follows Mead and Fordyce (2009). The specimen was measured using calipers in mm. Distances are either horizontal or vertical, unless identified as point to point (Table 1). Comparison was made with all named balaenopterid fossils with the skull (Table 2) by combination of examination on literatures and through our own examination of specimens.

Institutional Abbreviation.– YPM, Yamagata Prefectural Museum, Japan.

Systematic paleontology

Order Cetacea Brisson, 1762

Neoceti Fordyce & de Muizon, 2001

Suborder Mysticeti Gray, 1864

Family Balaenopteridae Gray, 1864

Genus *Balaenoptera* La Cépède, 1804

Balaenoptera bertae Boessenecker, 2013a

aff. *Balaenoptera bertae*

Figures 2 to 4 and Table 1

Diagnosis.–YPM 11852 preserves the supraoccipital, right exoccipital, basioccipital, right squamosal, right alisphenoid, and parietals. YPM 11852 can be identified as a member of the Balaenopteridae by having combination of the temporal fossa invisible in dorsal view, which is overhanged by the temporal and nuchal crests, widely expanded posterior portion and anteriorly converging supraoccipital in dorsal view, weak protrusion of the posterolateral corner of the exoccipital in ventral view, and posteriorly well projected post glenoid process in ventral view (Bisconti and Bosselaers, 2016).

YPM 11852 is identified as aff. *Balaenoptera bertae* by having two diagnostic features of the species stated in 2013 such having large occipital condyles, and a posteriorly elongate postglenoid process (Boessenecker, 2013a). The ventral part of the postglenoid process of YPM 11852 is broken, but preserved part shows slender process with a strong excavation at the base of the postglenoid process, which is the same condition as the holotype of *B. bertae*. In addition, there are four shared features (see discussion) such a large fossa for the sternocephalicus, dorsally wider and ventrally narrower foramen magnum, occipital condyle borders the lateral and ventral sides, but not dorsolateral sides of the foramen magnum, and straight nuchal crest at the level of the subtemporal crest in dorsal view. Comparison with the holotype of *B. bertae*, YPM 11852 has more slender zygomatic process and straight lateral border of the supraoccipital. As Tsai and Fordyce (2014) mentioned, different heterochronic processes characterizing different mysticete clades. These differences might be affected by ontogenetic variation as these can be seen among *Balaenoptera acutorostrata* in Figure 2 of Nakamura and Kato (2014) (see more in ontogeny section).

Locality.–YPM 11852 was found ventral up in the Shinazawa Formation at the Shinazawa sandstone quarry, in Shonai Town (former Tachikawa Town), Yamagata Prefecture, Japan (Figures 1 and 2): Latitude 38°41'15.87"N, longitude 140° 0'14.97"E on 10 October 2000 by a student of Yamagata University on a field trip (Nagasawa *et al.*, 2003). The specimen was excavated by R. Abe and S. Oba on 4 November 2000.

Horizon.–Several fossiliferous stratigraphic units are exposed in the vicinity of the YPM 11852 locality near Shinazawa, including the middle Miocene Aosawa and Kusanagi Formations, the upper Pliocene Shinazawa Formation, and terrace deposits (Honda and Applied Geological Society of Yamagata, 2016).

The Shinazawa Formation is exposed in a small geographic area where YPM 11852 was discovered (Zinbo, 1965). This unit at the YPM 11852 locality is reported that the sequence of fossil locality is about 90 m in thickness and is overlain by unnamed unconsolidated Pleistocene sediments (Nagasawa *et al.,* 2003). The Shinazawa Formation of the fossil locality can be divided into three parts. The lower part is about 40 m thick, which is composed mainly of massive fine sandstone with burrows and bioturbation, and intercalated thin silt and fine gravel layers. The middle part, about 20 m thick, is formed by mainly massive fine sandstone with burrows and bioturbation, shell fragments, carbonaceous materials, and shell bed. Grain size in the middle part coarsens upwards. The upper part, about 30 m thick, consists of cross-laminated coarse sandstone at the bottom, alternated coarse sandstone and fine gravel at the middle, and fine sandstone with a lignite layer at the top.

YPM 11852 was collected from the lower part. The fossil horizon is approximately 10 m below the 20 cm thick shell marker bed. Other vertebrate remains have been reported, such as a skull (still unprepared), mandible, rib and an atlas of cetacean specimens belonging to different individuals from different horizon of the lower and middle parts, and two sirenian ribs from the upper part of the unit at the Shinazawa quarry (Nagasawa *et al.*, 2003). Foraminifera *Elphidium* from the lower part of the formation also indicates that the environment was shallow marine (Ozawa *et al.*, 1986). The area was shallowing upward sequence.

The Shinazawa Formation has not been directly dated, but thought to be the late Pliocene (Honda and Applied Geological Society of Yamagata, 2016), based on fossils such as a Pliocene plant *Comptonia kidoi* (Suzuki, 1961) and various mollusks belonging to the Omma-Manganzian fauna (Otuka, 1939), such as *Yabepecten tokunagai*, *Mizuhopecten yessoensis*, *Turritella saishuensis* and others (Sato, 2000). The Omma-Mangazian fauna is composed of mainly cold water species and existed from the Pliocene to the early Pleistocene age in the northeastern Sea of Japan area (Amano, 2007). A previous geological map (Ozawa *et al.*, 1986) did not use the term Shinazawa Formation, and recognized the fossil locality area as the Kan-nonji Formation (lower Pleistocene) in the northern Shonai area based on similar lithology. At present, it is not possible to correlate the two formations because lack of dating for the Shinazawa Formation. Based on the mollusc fauna, we estimate the age of YPM 11852 as late Pliocene, and also include possibility of the early Pleistocene.

General description

Ontogeny.–YPM 11852 can be identified as an immature individual. It has visible parietal/squamosal and alisphenoid/pterygoid sutures; and does not preserve other cranial sutures. The holotype of *Balaenoptera bertae* identified as an immature individual also has a visible parietal/squamosal suture (Boessenecker, 2013a). The posterior process of tympanoperiotic grows during ontogeny (Bisconti, 2001). YPM 11852 shows slightly longer posterior process of the tympanoperiotic (about 105.0 mm long, based on the fossa of the skull for the posterior process) than that of *B. bertae* (about 80.0 mm long). In addition, estimated bizygomatic width of YPM 11852 from the right side is 719 mm+. It is wider than that of the holotype of *B. bertae*: 614 mm (Boessenecker, 2013a). Thus, YPM 11852 possibly was slightly ontogenetically older than the holotype of *B. bertae*.

Supraoccipital, exoccipital and basioccipital.–The supraoccipital is triangular in dorsal view (Figure 3D) with an almost straight nuchal crest. The posterolateral part of the nuchal crest is expanded laterally. The occipital tuberosities are formed as a horizontal ridges and depressions ventral to the ridges. The foramen magnum is teardrop shaped with a bluntly triangular ventral margin. The occipital condyles are wide and project posteroventrally beyond the surface of the occipital shield. The intercondyloid notch is shallow. Ventrally, the exoccipital has a weakly depressed paroccipital concavity (Figure 4). Medial to the paroccipital concavity, there is an anteroposteriorly running shallow jugular notch medially. The lateral end of the exoccipital stops medial to the postglenoid process and forms a strong posteroexternal angle.

Squamosal.–The zygomatic process projects anterolaterally and is bounded medially by a shallow and vertical squamosal crease. A shallow squamosal cleft is developed, running horizontally from the posterior end of the alisphenoid to the dorsal broken base of the zygomatic process. A small elliptical opening filled by matrix (24.5 mm long, 13.5 mm high) located anterior to the squamosal cleft, ventral to the parietal/squamosal suture on the temporal fossa; this might be a junction of the parietal, squamosal and alisphenoid. The postglenoid process is slender (preserved length is 88.0 mm) and projects posterolaterally. The lateral surface of the zygomatic process is weakly excavated, and the anterior tip of the zygomatic process orients anterolateral. Posterior to the postglenoid process, there is a shallow transverse groove of the external auditory meatus. In ventral view, the external auditory meatus is narrow anteroposteriorly (about 14 mm long) but wider medially (about 27 mm long). On the lateral surface of the squamosal, dorsal to the external auditory meatus, there is a shallow depression of the fossa for the sternocephalicus. On the ventral surface and just lateral to a broken anterior process of the periotic, only the base of the falciform process is preserved.

Pterygoid.–The right pterygoid (Figure 3E) is exposed laterally within the temporal fossa, located anterior to the squamosal, and contacts the alisphenoid.

Parietal.–The parietal shows a weakly excavated surface and forms the temporal wall and a dorsoventrally thin nuchal crest. The parietal/squamosal suture is visible.

Alisphenoid.– Based on relative position with other structures, the presumed alisphenoid has a small exposure (17.9 mm long, 6.0 mm high) on the anterolateral surface of the temporal fossa, anteroventral to the squamosal and dorsal to the pterygoid. The alisphenoid contacts with the squamosal cleft (Figure 3E). Its anterior part was possibly damaged as mentioned above.

Periotic.–The incomplete right periotic preserves only the dorsal part of the anterior and posterior processes and showing fresh broken surface (Figure 4). The lateral end of the posterior process of the tympanoperiotic is damaged, and the posterior process was possibly exposed on the lateral surface of the skull. The anterior process was at least 25.5 mm long. The preserved pars cochlearis is 48.5 mm long anteroposteriorly, 43.5 mm wide mediolaterally. The ventral surface of the pars cochlearis is broken away, and the section of a presumed internal acoustic meatus is exposed, and its preserved anteroposterior length is 13.5 mm. The remnants of a long posterior process projects posterolaterally from the damaged pars cochlearis. Though incomplete, the posterior process appears laterally narrowing (maximum length of the part is 15.5 mm). The posterior process was probably about 105.0 mm long (preserved maximum length is 86.0 mm) when complete.

Discussion

Comparison with fossil balaenopterids and linkage in the North Pacific of the Balaenopteridae

As mentioned above, YPM 11852 is identified as aff. *Balaenoptera bertae*, because it has two diagnostic features of the species, such as large occipital condyles occupied one third of the bizygomatic width, and a posteriorly elongate postglenoid process (Boessenecker, 2013a). YPM 11852 and *B. bertae* also have four shared features such as having 1) a large fossa for the sternocephalicus on the lateral surface of the squamosal, 2) a dorsally wider and ventrally narrower foramen magnum, and 3) a occipital condyle borders the lateral and ventral sides, but not dorsolateral sides of the foramen magnum, and 4) a straight nuchal crest at the level of the subtemporal crest. YPM 11852 is closely related to *B. bertae* by the two diagnostic features and four shared features.

Having elongate and posteroventrally projecting postglenoid processes can be seen also in *Marzanoptera tersillae*, which formed a clade with *Balaenoptera bertae* by phylogenetic analysis of Bisconti *et al.* (2020b). In comparison with presumed closely related *Marzanoptera tersillae*, YPM 11852 and *Balaenoptera* have slenderer postglenoid process, larger occipital condyles, and also dorsally wide and ventrally narrow foramen magnum. On the other hands, *M. tersillae* shows an elliptical foramen magnum.

Of note, Bisconti *et al.* (2020b) established the genus *Marzanoptera* with combination of some diagnostic features on the skull and periotic, such a remarkably short premaxilla, strongly narrowed ascending process of the maxilla and so on. *Balaenoptera bertae* was transferred to the genus as *Marzanoptera bertae*. However, the premaxilla, maxilla and body of the periotic were not preserved on the holotype of *Balaenoptera bertae*, which is currently only one specimen of the species (Boessenecker, 2013a). Thus, we reserve to use the genus name *Marzanoptera* for *Balaenoptera bertae* here.

In comparison with all named balaenopterids preserving skulls (Table 2), *"Balaenoptera" siberi* also possesses a long postglenoid process (longer than in *Norrisanima miocaena, Parabalaenoptera baulinensis, Nehalaennia devossi, Incakujira anillodefuego, Archaebalaenoptera castriarquati, Plesiobalaenoptera hubachi*), but the postglenoid process of *"B." siberi* is shorter than in *B. bertae* and YPM 11852. *Archaebalaenoptera liesselensis* also shows larger occipital condyles, occupying almost one half of the exoccipital width compare with other balaenopterids (*"Balaenoptera" siberi, Norrisanima miocaena, Protororqualus wilfriedneesi, Fragilicetus velponi, Parabalaenoptera baulinensis, Nehalaennia devossi, Incakujira anillodefuego, "Balaenoptera" ryani, Marzanoptera tersillae, Protororqualus cuvieri, Plesiobalaenoptera hubachi*).

A large fossa for the sternocephalicus can be seen on not only YPM 11852 and *B. bertae*, but also on *Norrisanima miocaena, Protororqualus wilfriedneesi* and *Diunatans luctoretemergo*. *Parabalaenoptera baulinensis* and *Marzanoptera tersillae* have a much smaller single fossa for the sternocephalicus. *Archaebalaenoptera liesselensis, Fragilicetus velponi, Incakujira anillodefuego* and *Plesiobalaenoptera hubachi* possess two fossae for the sternocephalicus. The foramen magnum is rounded to dorsoventrally long elliptical in most balaenopterids (*Norrisanima miocaena, Protororqualus wilfriedneesi, Parabalaenoptera baulinensis, Nehalaennia devossi, Marzanoptera tersillae* and *Plesiobalaenoptera hubachi*), but only YPM 11852, *B. bertae* and *Incakujira anillodefuego* have dorsally wider and ventrally narrower foramen magnum. YPM 11852, *B. bertae* and most of other balaenopterids (*"Balaenoptera" siberi, Norrisanima miocaena, Protororqualus wilfriedneesi, Fragilicetus velponi, Nehalaennia devossi, Incakujira anillodefuego,* and *"Balaenoptera" ryani*) possess occipital condyles that are positioned ventrolaterally, and do not extend to the dorsolateral margin of the foramen magnum. Only *Parabalaenoptera baulinensis, Marzanoptera tersillae* and *Plesiobalaenoptera hubachi* have occipital condyles that completely encircle the foramen magnum. Among balaenopterids, the lateral margin of the exoccipital at the level of the subtemporal crest in dorsal view is posteriorly concave (*Norrisanima miocaena, Archaebalaenoptera liesselensis, Diunatans luctoretemergo, Incakujira anillodefuego, Marzanoptera tersillae, Archaebalaenoptera castriarquati* and *Plesiobalaenoptera hubachi*), posteriorly convex (*Fragilicetus velponi, Nehalaennia devossi, Protororqualus cuvieri*), or straight (YPM 11852, *B. bertae, "Balaenoptera" siberi, Protororqualus wilfriedneesi* and *Parabalaenoptera baulinensis*). Combination of the diagnostic features and other features' conditions support that YPM 11852 is the most closely related to *B. bertae*.

Presumed closely related specimens, YPM 11852 and the holotype of *Balaenoptera bertae* show that the extinct balaenopterid was distributed both the eastern and western North Pacific during the late Pliocene to possibly into the early Pleistocene. Currently, many balaenopterids have circum North Pacific distributions, including *Balaenoptera musculus, B. physalus, B. borealis, B. acutorostrata,* and *Megaptera novaeangliae* (Jefferson *et al.*, 2008). There are some other marine mammal species and/or genera known to have a circum-North Pacific distribution during the Pliocene to early Pleistocene; *Eschrichtius* spp.(Tsai and Boessenecker, 2015; Kimura *et al.*, 2018), *Balaenoptera physalus* (Tsai and Boessenecker, 2017), *Herpetocetus* (Oishi *et al.*, 1985; Boessenecker, 2013a, 2013b) *Callorhinus gilmorei* and *Thalassoleon* (Repenning and Tedford, 1977; Kohno, 1992; Kohno and Yanagisawa, 1997), and *Hydrodamalis* (Domning and Furusawa, 1995). This new record/YPM 11852 indicates that the extinct rorqual species *Balaenoptera bertae* can be added to this list of marine mammals with a circum-North Pacific distribution during the pre-glacial Pliocene-Pleistocene interval.

Conclusion

We report a skull YPM 11852 from the Shinazawa Formation (late Pliocene to early Pleistocene) in Yamagata, Japan, as aff. *Balaenoptera bertae*. The specimen shows two diagnostic features of the species such having large occipital condyles, and a posteriorly elongate postglenoid process. Combination of the four more shared features also support this. YPM 11852 is probably slightly ontogenetically older individual than the holotype of *B. bertae*, based on the estimated bizygomatic width and slightly longer posterior process of the tympanoperiotic. YPM 11852 suggests that fossil balaenopterids had a circum North Pacific distribution, like several modern balaenopterid species. YPM 11852 is incompletely preserved, however nonetheless demonstrates the occurrence of *Balaenoptera bertae* and/or closely related taxa in the western North Pacific for the first time.

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List of figures and tables

Figure 1. A-B, Maps showing the locality of YPM 11852. The base map of A is from a topographic map published by the Geospatial Information Authority of Japan. C, Stratigraphic sections of the locality modified from Nagasawa *et al.* (2003).

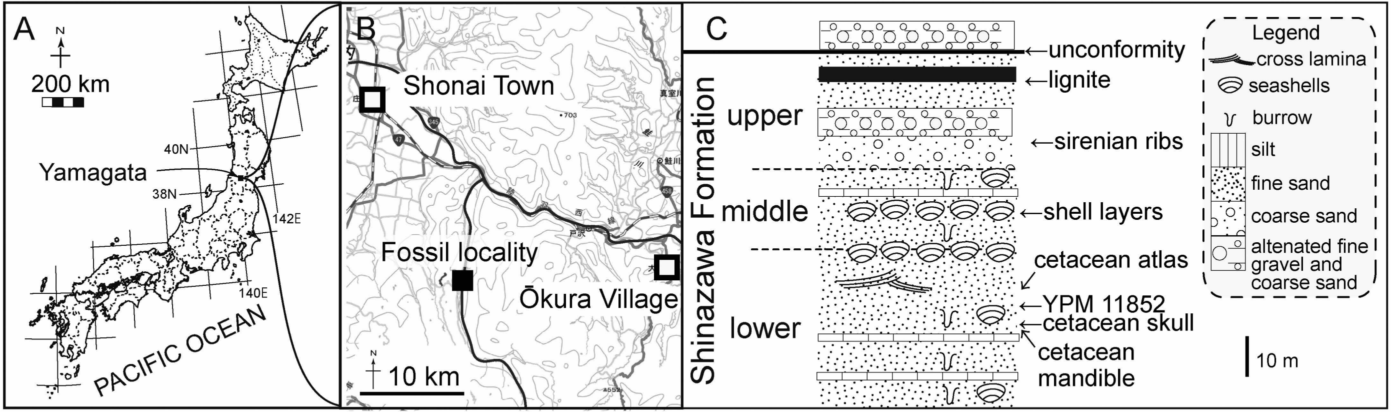
Figure 2. Field photo of YPM 11852, aff. *Balaenoptera bertae*.

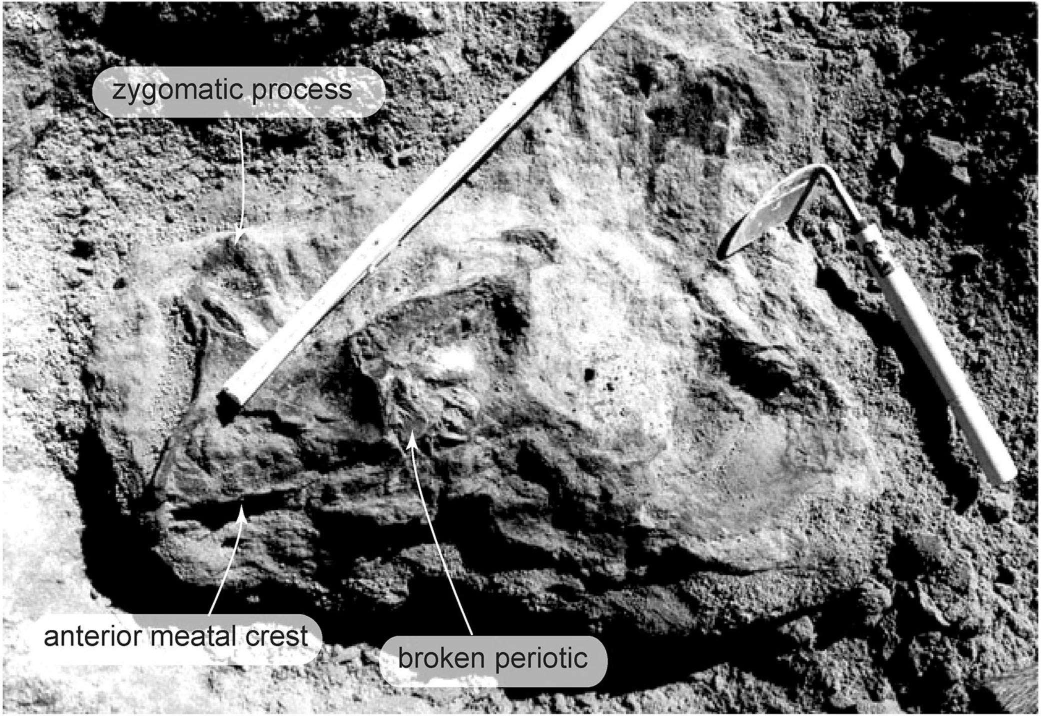
Figure 3. A-E, Skull of YPM 11852, aff. *Balaenoptera bertae*. A, ventral view. B, right lateral view. C, left lateral view. D, dorsal view. E, anterior view. F, posterior view.

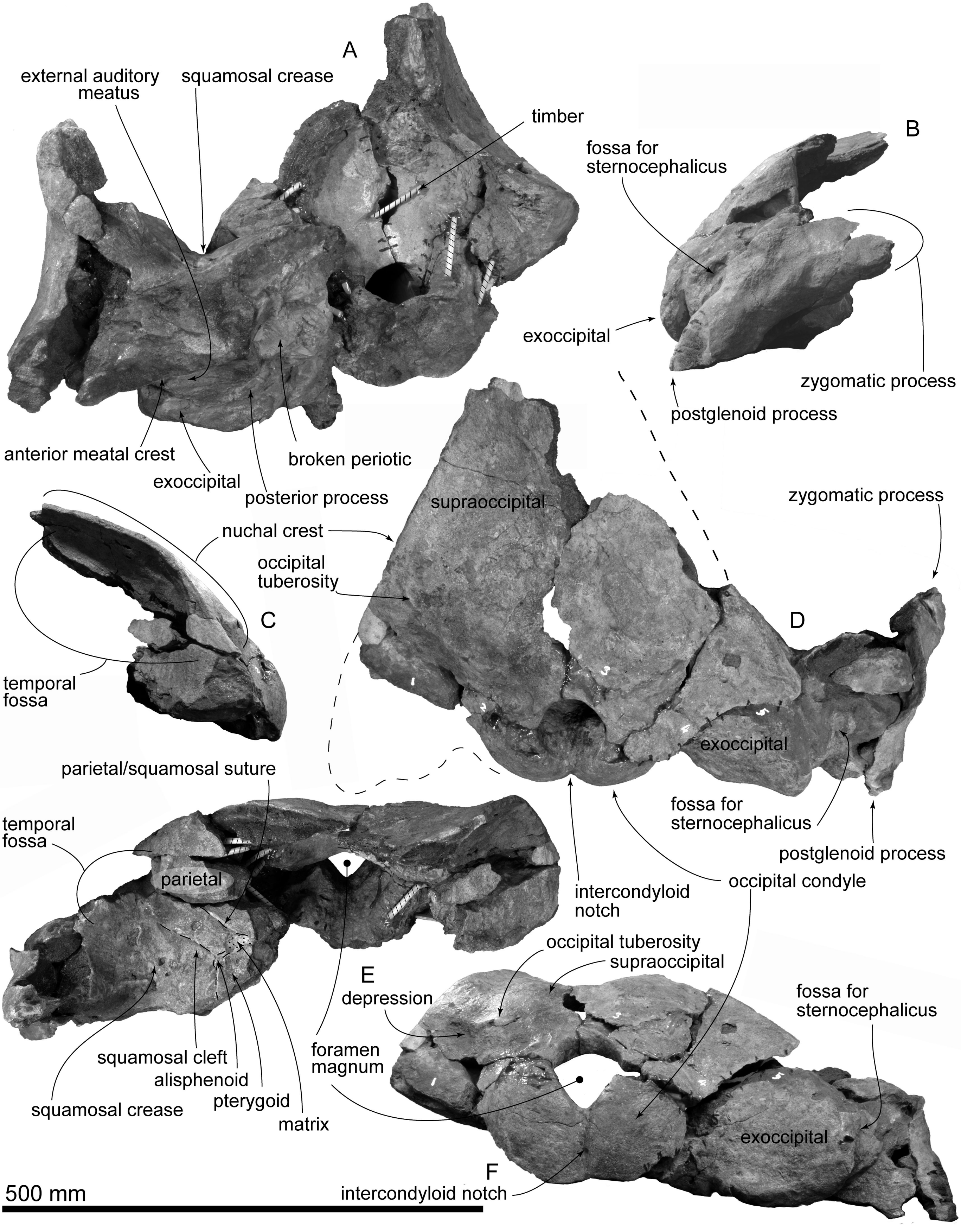
Figure 4. Squamosal and broken periotic of YPM 11852, aff. *Balaenoptera bertae* in ventral view.

Table 1. Measurements of skull, aff. *Balaenoptera bertae* (YPM 11852) in mm. + are maximum preserved measurements of broken parts. * means only right side.

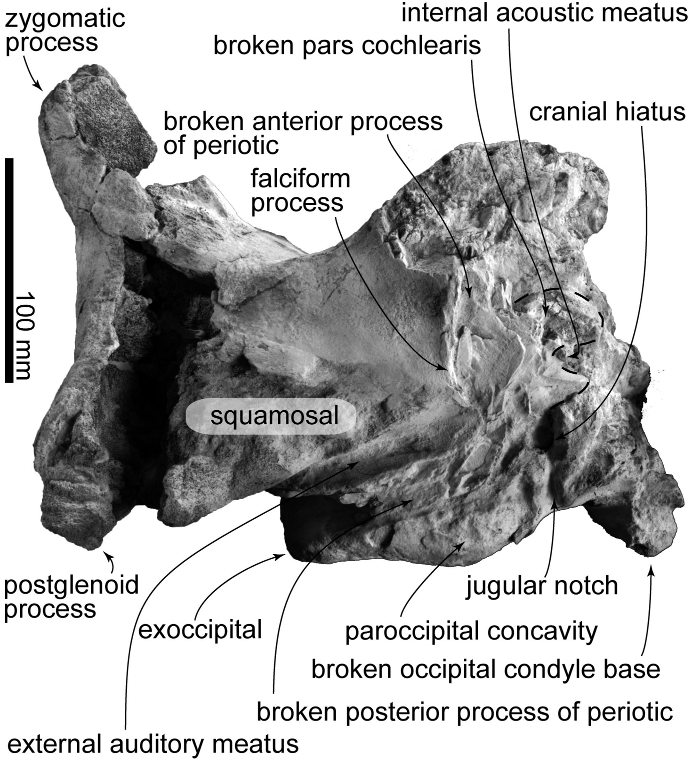
Table 2. Compared named fossil balaenopterids. * means directly observed specimens.


A
N
200 km
40N
Yamagata
38N
142E
140E
PACIFIC OCEAN
B
Shonai Town
Fossil locality
Ōkura Village
N
10 km
C
unconformity
lignite
upper
sirenian ribs
Shinazawa Formation
middle
shell layers
cetacean atlas
lower
YPM 11852
cetacean skull
cetacean mandible
Legend
cross lamina
seashells
burrow
silt
fine sand
coarse sand
altenated fine gravel and coarse sand
10 m


zygomatic process
anterior meatal crest
broken periotic



A
external auditory meatus
squamosal crease
timber
anterior meatal crest
exoccipital
broken periotic
posterior process
B
fossa for sternocephalicus
exoccipital
zygomatic process
postglenoid process
C
nuchal crest
temporal fossa
D
supraoccipital
occipital tuberosity
zygomatic process
exoccipital
fossa for sternocephalicus
postglenoid process
intercondyloid notch
occipital condyle
E
parietal/squamosal suture
temporal fossa
parietal
squamosal cleft
alisphenoid
pterygoid
matrix
squamosal crease
foramen magnum
F
occipital tuberosity
supraoccipital
depression
fossa for sternocephalicus
exoccipital
intercondyloid notch
500 mm



zygomatic process
broken pars cochlearis
internal acoustic meatus
cranial hiatus
broken anterior process of periotic
falciform process
100 mm
squamosal
postglenoid process
exoccipital
external auditory meatus
broken posterior process of periotic
paroccipital concavity
jugular notch
broken occipital condyle base

Squamosal length	230 +
Height between postglenoid process to dorsal border of zygomatic process	110 +
Median line to lateral border of exoccipital	240 *
Median line to lateral border of zygomatic process	355 *
Maximum width of occipital condyles	180
Foramen magnum height	65
Foramen magnum width	58
Preserved maximum length, from ventral border of occipital condyles to anterior most of supraoccipital	395

Scienfitic name	Age	Localities	Reference
YPM 11852, aff. *Balaenoptera bertae*	Late Pliocene to Eary Pleistocene	Yamagata, Japan	This study *
Archaebalaenoptera liesselensis	Late Pleistocene	Noord Brabant, The Netherlands	Bisconti et al, 2020a
Balaenoptera bertae	Late Pliocene	Half Moon Bay, California	Boessenecker, 2013a *
Marzanoptera tersillae	Pliocene	Serra Domenico locality, Italy	Bisconti et al, 2020b
Protororqualus wilfriedneesi	Early Pliocene	Wommelgem, Belgium	Bisconti and Bosselaers, 2020
Archaebalaenoptera castriarquati	Early Pliocene	Rio Carbonari, Italy	Bisconti, 2007; Bisconti et al, 2020a
Plesiobalaenoptera hubachi	Early Pliocene	Bahia de Guayacan, Chile	Dathe, 1983; Bisconti et al, 2020b
Fragilicetus velponi	Early Pliocene	Antwerp, Belgium	Bisconti and Bosselaers, 2016
Diunatans luctoretemergo	Early Pliocene	Antwerp, Belgium	Bosselaers and Post, 2010
Miobalaenoptera numataensis	Late Miocene	Hokaido, Japan	Tanaka and Watanabe, 2019 *
Parabalaenoptera baulinensis	Late Miocene	Balinas Point, California	Zeigler et al, 1997 *
Nehalaennia devossi	Late Miocene	Westerschelde, the Netherlands	Bisconti et al, 2019
Incakujira anillodefuego	Late Miocene	Aguada de Lomas, Peru	Marx and Kohno, 2016 *