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The first cetacean record from the Osaka Group (Middle Pleistocene, Quaternary) in Osaka, Japan

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Abstract. A new partial skeleton consisting of a left mandible and five caudal vertebrae, OMNH-QV 282 from the Osaka Group (Middle Pleistocene, about 0.3 million years ago) of Osaka City is reported as the first cetacean record from the Group. The skeleton is identified as Balaenopteridae gen. et sp. indet. based on the combination of mandibular characters, such as having a small mandibular foramen, reflected neck in dorsal view and lack of satellite process of the mandible. OMNH-QV 282 expands diversity for the local fauna, and also adds an evidence of existence for large sized balaenopterids from the poorly known epoch, the Middle Pleistocene.

Key words: Balaenopteridae, Balaenopteroidea, baleen whale, fossil, Marine Clay 10, Mysticeti

Introduction

Disparity through time for mysticete body size declined dramatically around 5 Ma (Slater *et al.*, 2017). Prior to the period, there were small sized mysticetes, such as cetotheriids (El Adli *et al.*, 2014; Hasegawa *et al.*, 1985; Oishi and Hasegawa, 1995; Tanaka *et al.*, in press; Whitmore and Barnes, 2008), and some of them survived by the Early to Middle Pleistocene (Boessenecker, 2013). The Balaenopteridae is a modern family including two extant genera, *Balaenoptera* and *Megaptera*. Here, we use the term Balaenopteridae as above, and the superfamily Balaenopteroidea including Balaenopteridae and Eschrictiidae. Deméré *et al.* (2005) indicated that Pleistocene records of the Balaenopteridae are limited, and its evolution to the modern species fails to be documented in detail. From Osaka, some Holocene whale bones have been reported (Ogino, 1998; Okazaki, 1975; Omura, 1976; Shindo, 1975; Tanaka and Taruno, 2017). Here, we report the first fossil whale from the Middle Pleistocene of upper part of the Osaka Group (Figures 1 and 2), with an additional evidence of large sized balaenopterid in the Pleistocene.

Institutional abbreviations.- AMP, Ashoro Museum of Paleontology, Hokkaido, Japan; CBM, Natural History Museum and Institute, Chiba, Japan; HUES, Hokkaido University of Education Sapporo campus, Hokkaido, Japan; KBC, Kuromatsunai Buna Center, Hokkaido, Japan; NHMT, Natural History Museum of Tokai University, Shizuoka, Japan; OMNH, Osaka Museum of Natural History, Osaka, Japan.

Systematic paleontology

Order Cetacea Brisson, 1762

Unranked taxon Neoceti Fordyce and de Muizon, 2001

Suborder Mysticeti Gray, 1864

Superfamily Balaenopteroidea Gray, 1868

Family Balaenopteridae Gray, 1864

gen. et sp. indet.

Figures 3, 4, Table 1

Referred specimen.- OMNH-QV 282, the left mandible, five caudal vertebrae and bulk of fragments, collected by a construction crew on 24th Apr 1990.

Remarks.- OMNH-QV 282 is a member of the superfamily Balaenopteroidea (Balaenopteridae + Eschrichtiidae) based on combination of these characters; presence of a synapomorphy, such as having a small mandibular foramen (character 62 in Deméré *et al.* (2005)) and reflected neck in dorsal view (character 55 in Deméré *et al.* (2008)). OMNH-QV 282 is not a member of the family Eschrichtiidae among the Balaenopteroidea, because it lacks one key synapomorphy for the family: a satellite process on the mandible (character 262 in Boessenecker and Fordyce (2015)). OMNH-QV 282 is not likely *Megaptera novaeangliae,* because the curvature of the mandible on *Megaptera novaeangliae* seems stronger than the ones of OMNH-QV 282 and *Balaenoptera* spp. However, the mandible fragments of OMNH-QV 282 do not have contacts each other and not show the curvature completely.

Locality.- OMNH-QV 282 was dug up from 12 m depth from the surface at

Minamisenba 1-16-10, Cyuo-Ku, Osaka City (Figure 1A, B): latitude 34°40'36"N, longitude 135°30'25"E.

Horizon and age.- In Osaka Plain, Quaternary marine clay beds (Ma (marine clay) -1 to 13 from bottom to top) are known, based on boring core surveys against land subsidence (e.g. Mitamura *et al.* (1998); Yoshikawa *et al.* (1987)). All marine clay beds except Ma13 are contained to the Tanaka Formation. The Holocene, Ma13 is a part of the Namba Formation. Among the Tanaka Formation, Ma -1 to 10 are intercalated in the Osaka Group at the hill land around the Osaka Plane (Yoshikawa and Mitamura, 1999). There are the Brunhes-Matuyama boundary in Ma4 and deposits of the last interglacial period in Ma12 (Yoshikawa and Mitamura, 1999). Ma-1 to lower Ma4, middle Ma4 to Ma11, and Ma12 belong to the Early, Middle and Late Pleistocene respectively.

Ma13, 12, 10, 9 can be observed continuously and understood wider distributions except a part of Uemachi Upland. The upland and its around, Ma11 cannot be recognized, based on previously published data (Kansai Gio-informatics Research committee, 2007; Mitamura *et al.*, 1998).

The dig point, so-called 10Ac33 in Kansai Branch of The Japanese Geotechnical Society and Kansai Geotechnical Consultants Association (1987) is located about 60 meters southwest from the locality of OMNH-QV 282, and the data helps to identify the original horizon of OMNH-QV 282 (Figure 2). The fossil was discovered about 12 m below the ground surface in a bed of clay. This clay bed might be a part of the marine clay bed, which distributes 14 to 26 meter depth of the dig point 10Ac33

(Figure 1C). Here, we provide figures, which show levels at the bottom of Ma12, top and bottom of Ma10 using bulk of boring columnar section data, which were taken from other construction sites in the city. At the fossil locality next to the western edge of the Uemachi Upland, the Namba Formation (but not marine clay Ma13 of the Formation) distributes only top 5m, which is not the original layer of the fossil (Figure 1C). The Pleistocene sediments at the area are north to northwest side down because of the Upland rising. So, Ma 12 exists northwest from the fossil locality (Figure 2A). As it is discussed above, Ma11 cannot be the fossil layer at the locality. Ma10 is about 10 m thick, and its west-northwest side down (Figure 2B, C). OMNH-QV 282 is from Ma10, upper and lower limits of Ma 10 around at the fossil locality are about 10 and 25 meters (Figure 2B, C). Ma10 is referred to the Stage 9 of the Marine Isotope Stages, and its age is 0.3 million years ago, the Middle Pleistocene (Yoshikawa and Mitamura, 1999).

On the mandible of OMNH-QV 282, a shell impression of *Dosinia* sp. (identification by Dr. S. Ishida) is preserved. We made a cast using the shell impression and cleaned the matrix from the mandible (Figure 5). The impression preserved only one side surface of the shell, thus it is unclear the shell was articulated or not. We report the shell, because mollusk shells are rare in the Osaka Group.

General description

Morphological terms follow Mead and Fordyce (2009) for the mandible and Flower (1885) for the vertebrae.

Ontogeny.-Preserved caudal vertebrae show unfused bodies and epiphyses. The order of vertebral fusion through ontogeny is initiated from the neck and caudal regions to the middle (Galatius and Kinze, 2003; Ito and Miyazaki, 1990; Moran *et al.*, 2015). Thus, having unfused epiphyses of the caudal vertebrae suggest that OMNH-QV 282 is a juvenile.

Mandible.- The incomplete left mandible is preserved in three unconnected fragments (Figure 3, Table 1). The most anterior part shows anteriorly opening mental foramina with anteroposteriorly long grooves. The anterior part is shallower than preserved posterior part around at the coronoid process. The ventral margin is sharply triangular in cross section at the anterior part, but the mandibular canal is not evident because of damage. The mandible is laterally bowed at the medial part. The posterior part shows broken base of the coronoid process, which rises gradually. There is a small notch for a small mandibular foramen (5.5 cm high and 2.5 cm wide). The mandibular fossa continues from the mandibular foramen to the level of the dorsoventrally narrowing part like a neck. Matrix is present on the mandibular condyle, indicating that the posterior end was broken prior to burial. Matrix sticks around the mandibular condyle. It means that the posterior end of the mandible had been broken away before burial. In dorsal view, posterior to the neck part is curved laterally. Overall shape of the mandible is sinuated.

Caudal vertebrae.- Five fragments of caudal vertebrae are preserved (Figure 4). A and C in Figure 4 show very low neural arch and lack transverse processes, identifying the vertebrae as caudals, especially anterior to the caudal vertebrae of the fluke. A shows a dorsally broken neural spine, robust anterior zygapophysis, low neural canal (5.5 cm height, 4.8 cm wide) and wide neural arch (maximum width is 10.2 cm). B and C in Figure 4 have the bodies, which are partially isolated from the epiphyses (thickness is about 2.5 cm). D and E in Figure 4 show totally separated bodies from the epiphyses. Maximum preserved height of E in Figure 4 is 19.7 cm.

Discussion

Pleistocene balaenopterid fossil.- Deméré *et al.* (2005) summarized the evolutionary history of the Balaenopteridae. The Pleistocene records of Balaenopteridae are limited, and the evolutionary history of modern species has not been documented in detail. Three nominal species of extinct Pleistocene Balaenopteridae have been named from the Early Pleistocene (Gelasian) Red Crag of England; *Balaena definata*, *Balaena emarginata* and *Balaena gibbosa* were established by Owen (1845). These species were declared nomina dubia by Deméré *et al.* (2005), because their holotypes (tympanic bullae) are considered non-diagnostic at the species level. They can not be directly compared to OMNH-QV 282, which lacks a bulla. There are several reports of other Pleistocene occurrences of extant species of Balaenopteridae have been published; *Megaptera novaengliae* from the Upper Pleistocene of Florida (Morgan, 1994), *Balaenoptera physalus* from the Lower Pleistocene of Northern California (Tsai and Boessenecker, 2017), *Megaptera novaengliae* from the Pleistocene of Champlain Sea, Canada (Harington, 1977) and several *Balaenoptera* spp. from the Lower Pleistocene of southern Scandinavian area (Aaris-Sørensen *et al.*, 2010), but no balaenopterid reports from the western Pacific, except several Japanese records.

Furusawa *et al.* (2010) summarized seven occurrences of balaenopterids from the

Pleistocene of Japan, which is revised here (Table 2). Table 2 shows that OMNH-QV 282 is one of two balaenopterid record from the Middle Pleistocene of Japan. During reviewing Japanese Pleistocene Balaenopteridae records, we removed a record from the Middle Pleistocene of Okinawa (Hasegawa and Oshiro, 1987), because the original study stated "can not identify" as the Balaenopteridae. The specimen still in the field was including eroded 28 vertebrae and a possible scapula, and was documented as two photos. Furusawa *et al.* (2010) reported that another specimen AMP 33 (previously numbered as HUES 10002) was originally reported as *Balaenoptera borealis* by Kimura and Earth Science Research Group of Obihiro Hakuyo High School (1973) and Kimura (1978). Deméré *et al.* (2005) stated AMP 33's identification as "needs to be confirmed". The original author reidentified AMP 33 as *Balaenoptera* sp. (Kimura, 1992) then Eschrichtiidae (Kimura, 2006). In addition, a few Pleistocene mysticetes (non-balaenopterids) have been reported from Japan, such as *Eschrichtius akishimaensis* from the Lower Pleistocene of Tokyo (Kimura *et al*, 2018), *Caperea* sp. and cf. *Caperea* from the Lower to Middle Pleistocene of Okinawa (Tsai *et al*, 2017), and a mysticeti from the Middle Pleistocene of Chiba (Kimura *et al.*, 2004).

Body size evolution.- OMNH-QV 282 gives additional information about body size evolution of the Mysticeti. As it is discussed above, OMNH-QV 282 is a juvenile. Comparison with the modern balaenopterid mandibles (see Table 3), the comparable measurements OMNH-QV 282 with other specimens suggest that OMNH-QV 282 is larger than *Balaenoptera acutorostrata* specimens (body length, 5.4 and 7.7 m) and is smaller than a specimen of *B. physalus* (body length, 17 m), and about the same size with 7 meters long body and young *Megaptera novaeangliae* (OMNH-M 3042). Adult

Megaptera novaeangliae reaches 11 to 17 m (Jefferson *et al*, 2008). In short, OMNH-QV 282 can be estimated as a juvenile of large sized balaenopterid (more than 10 m: following the definition of the large size by Slater *et al.,* 2017) compare to the modern balaenopterids. A large Balaenopteridae gen. et sp. indet. (KBC-F003) from the Lower Pleistocene of Setana Formation suggested that “large species of the Balaenopteridae already speciated and radiated before the Early Pleistocene” (Furusawa *et al.*, 2010). Indeed, Matsuura and Nagasawa (2000) also reported large sized mandible (25 cm height at anterior to the coronoid process, which is larger than OMNH-QV 282) from the Lower Pleistocene of Omma Formation. Chronologically later specimens include a skull of Megaptera novaeangliae (CBM-PV-662) from the Middle Pleistocene of Kioroshi Formation (Nagasawa and Mitani, 2004) and OMNH-QV 282 adds an evidence of existence for large sized balaenopterids from the poorly known epoch, Middle Pleistocene.

Rare fossil suggests that larger faunal diversity in Pleistocene Osaka.- OMNH-QV 282 is the first record of whales, or even marine tetrapods from the Osaka Group. Prior to this report, only terrestrial mammals, such as elephants, and deer were reported from the Osaka Group (Taruno and Kamei, 1993). Crocodiles and turtles were also known from the Osaka Group, which were from a tideland and fresh water respectively (Iijima *et al.*, 2018; Kobayashi *et al.*, 2006; Taruno, 1999; Taruno and Kamei, 1993). Thus, OMNH-QV 282 expands diversity for the local fauna.

Conclusion

The mandible and vertebrae, OMNH-QV 282 is the first evidence of whales

(Balaenopteridae gen. et sp. indet.) from uppermost part of the Osaka Group (Middle Pleistocene). Prior to this report, only terrestrial mammals (elephants and deer) and reptiles (crocodiles and turtles) were reported from the Osaka Group. OMNH-QV 282 expands diversity for the local fauna. OMNH-QV 282 also adds an evidence of existence for large sized balaenopterids from the poorly known epoch, the Middle Pleistocene.

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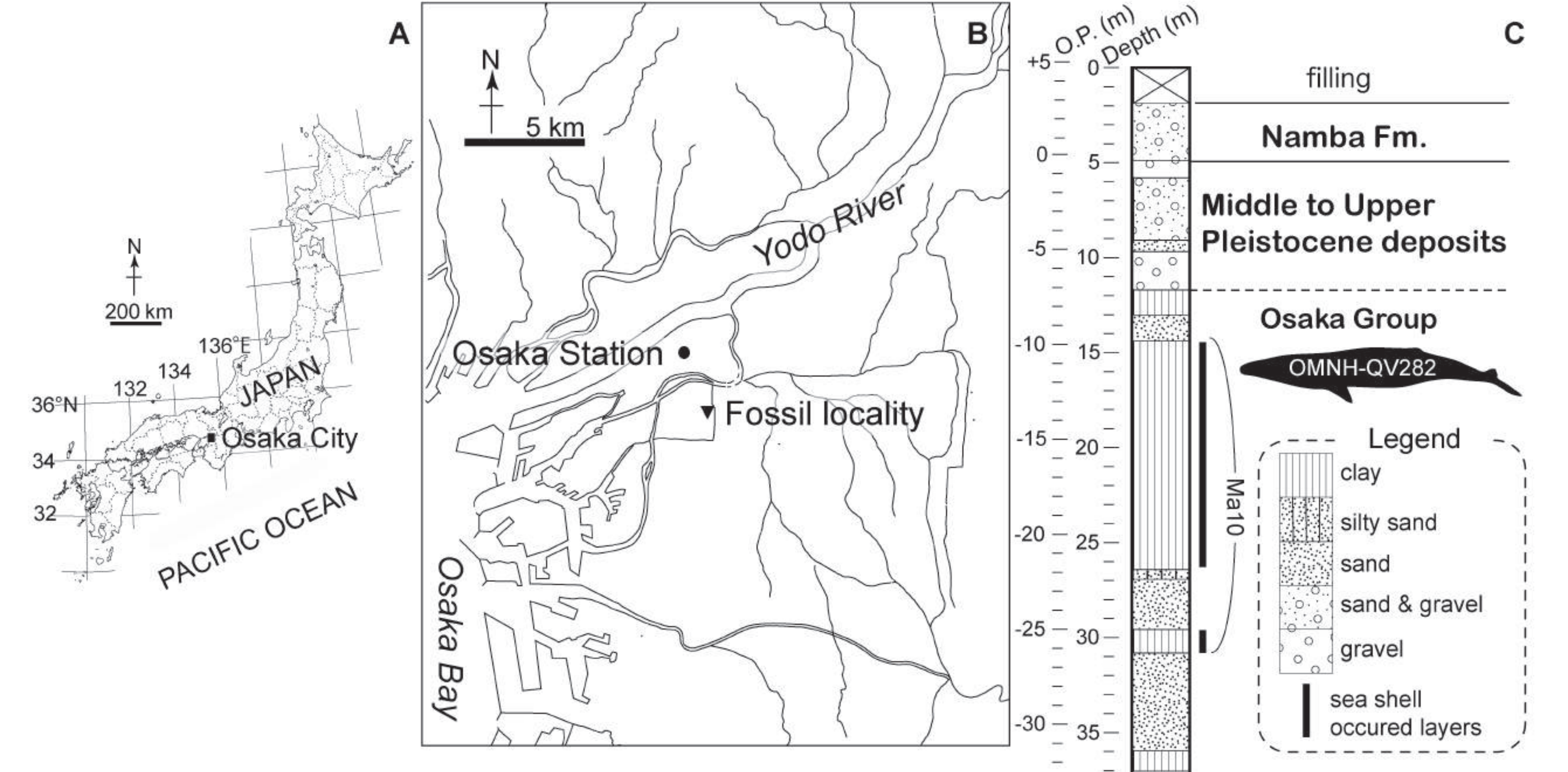
List of figures

Dimensions follow Tanaka *et al.* (in press). For mandible, distances are either horizontal or vertical.

Table 2. A list of Japanese Pleistocene balaenopterid records, modified from (Furusawa *et al.*, 2010).

Table 3. Measurements in cm of balaenopterid mandibles.



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JAPAN
Osaka City
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5 km
Yodo River
Osaka Station
Fossil locality
Osaka Bay
C
O.P. (m)
Depth (m)
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-5
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-15
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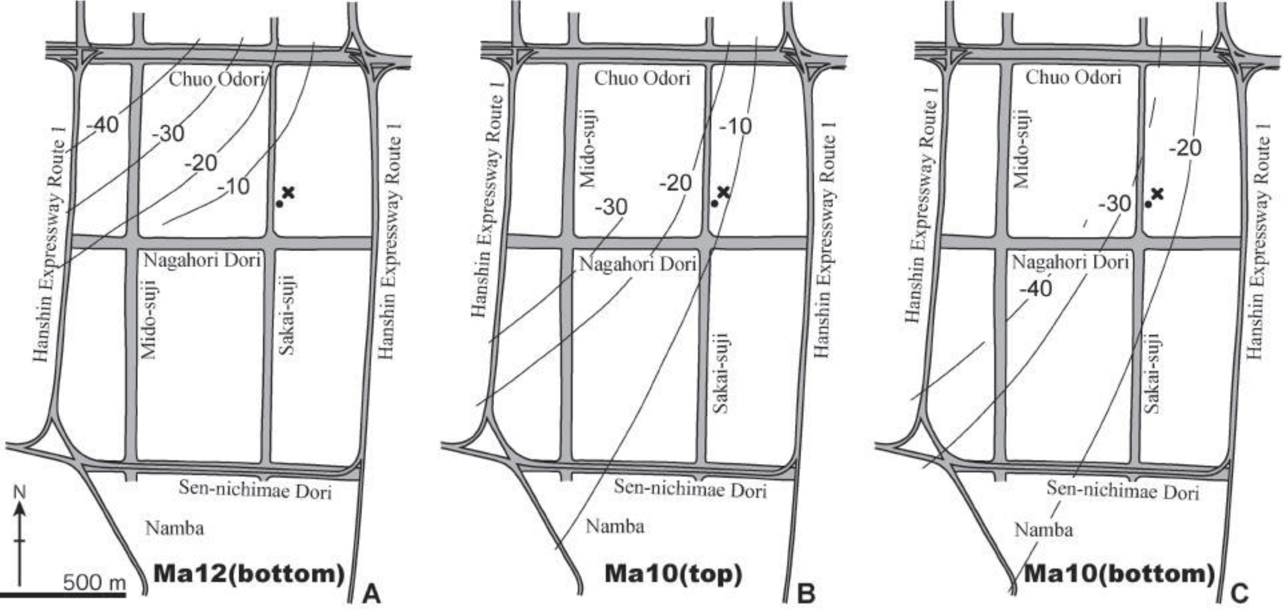
filling
Namba Fm.
Middle to Upper Pleistocene deposits
Osaka Group
OMNH-QV282
Ma10
Legend
clay
silty sand
sand
sand & gravel
gravel
sea shell occured layers



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Nagahori Dori
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Namba
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Sakai-suji
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B
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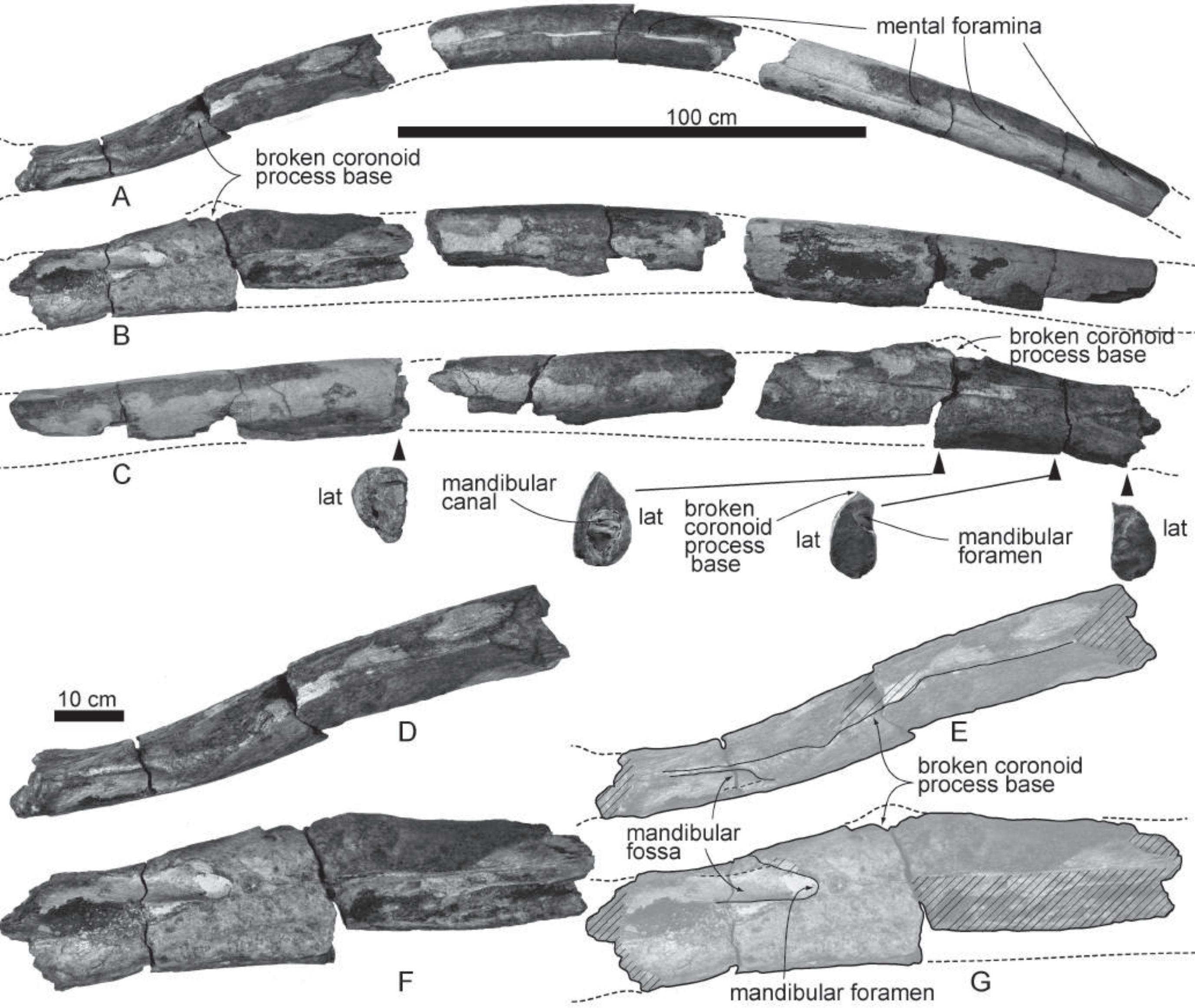
C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B
broken coronoid process base
C
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mandibular canal
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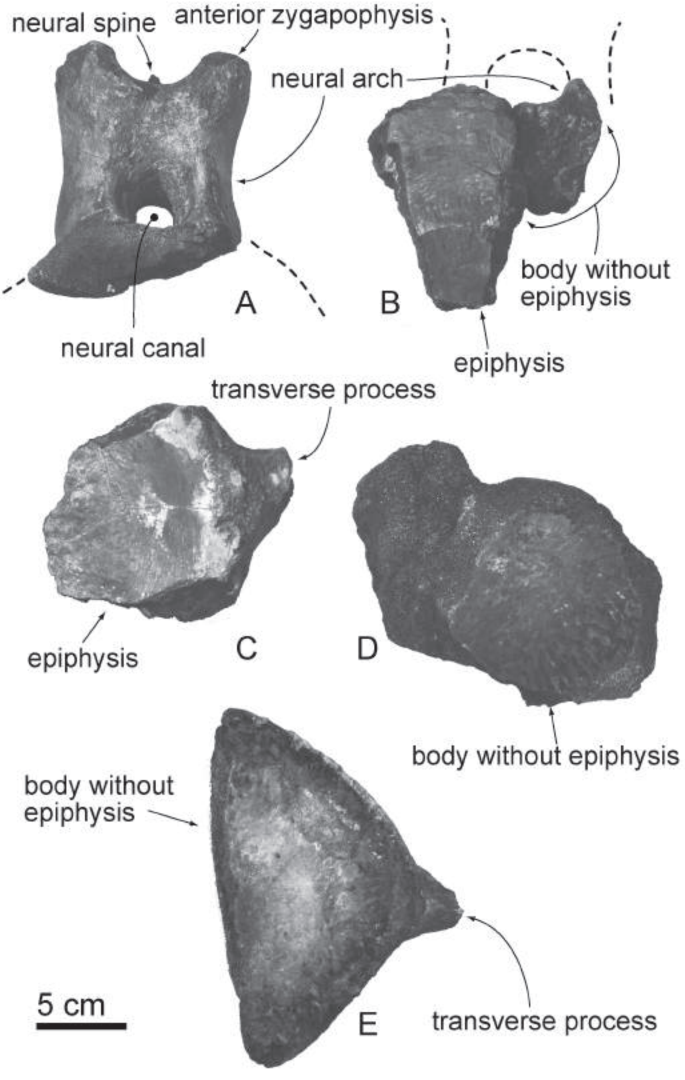
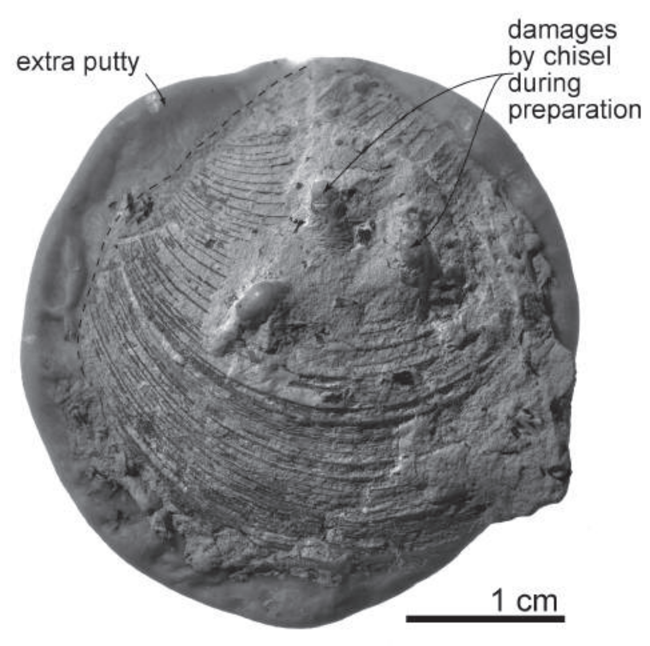
lat
mandibular foramen
lat
10 cm
D
E
broken coronoid process base
mandibular fossa
F
mandibular foramen
G


neural spine
anterior zygapophysis
neural arch
neural canal
A
B
body without epiphysis
epiphysis
transverse process
epiphysis
C
D
body without epiphysis
body without epiphysis
5 cm
E
transverse process


extra putty
damages
by chisel
during
preparation
1 cm

Mandible [cm]	**OMNH-QV 282**
Length of mandible, as preserved in straight line	210.0+
Height of mandible, from coronoid process to ventral margin	18.5+
Maximum preserved height of mandible	18.5+
Maximum preserved width of mandible	10.5
Height of body at just anterior to coronoid process	13.5+
Width of body at just anterior to coronoid process	10.0

Specimen	Identification	Parts	Age	Formation	Localities	Reference
SMAC 2732 (HUES 10006)	Balaenopteridae gen. et sp. indet.	Vertebra	Late Pleistocene	Atsuma Fm.	Atsuma, Hokkaido	Kimura, 1984, Furusawa *et al* , 2010
OMNH-QV 282	Balaenopteridae gen. et sp. indet.	left mandible and five caudal vertebrae	Middle Pleistocene	Tanaka Fm. Osaka Gr.	Osaka City, Osaka	This study
CBM-PV 662	*Megaptera novaeangliae*	Skull	Middle Pleistocene	Lower Kioroshi Fm.	Inba, Chiba	Nakagawa and Mitani, 2004
No. 1 in the publication	*Megaptera* (?) sp.	Mandible	Early Pleistocene	Omma Fm.	Kanazawa, Ishikawa	Matsuura and Nagasawa, 2000
No. 2 in the publication	Balaenopteridae gen. et sp. indet.	Mandible	Early Pleistocene	Omma Fm.	Kanazawa, Ishikawa	Matsuura and Nagasawa, 2000
No. 3 in the publication	*Megaptera* (?) sp.	Mandible	Early Pleistocene	Omma Fm.	Kanazawa, Ishikawa	Matsuura and Nagasawa, 2000
KBC-F003	Balaenopteridae gen. et sp. indet.	Skull	Early Pleistocene	Setana Fm.	Kuromatsunai, Hokkaido	Furusawa *et al* , 2010

Identification	Specimen number	Total body length	Height of mandible, from coronoid process to ventral margin	Maximum preserved width of mandible	Height of body at just anterior to coronoid process	Width of body at just anterior to coronoid process
Balaenopteridae gen. et sp. indet. (juvenile)	OMNH-QV 282	-	18.5+	10.5	13.5+	10.0
Balaenoptera acutorostrata	OMNH-M 3400	540	14.0	5.5	9.0	5.0
Balaenoptera acutorostrata	OMNH-M 3500	770	17.0	7.5	11.5	6.0
Balaenoptera physalus	OMNH-M no number, 3rd exhibition room	1700	47.5	16.5	30.5	16.5
Megaptera novaeangliae	OMNH-M 3042	700	23.5	10.5	16.0	10.0
Megaptera novaeangliae	OMNH-M 2222	690	23.0	9.0	17.5	9.5
Megaptera (?) sp.	from Matsuura and Nagasawa (2000)	-	-	-	25.0	-