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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 a satellite process of the mandible. OMNH-QV 282 expands diversity for the local fauna, and also adds evidence for the existence of large-sized balaenopterids from a 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 this, there were small-sized mysticetes, such as cetotheriids (El Adli *et al.*, 2014; Hasegawa *et al.*, 1985; Oishi and Hasegawa, 1995; Tanaka *et al.*, 2018; Whitmore and Barnes, 2008), and some of which survived into the early to Middle Pleistocene (Boessenecker, 2013). The Balaenopteridae is a modern family including two extant genera, *Balaenoptera* and *Megaptera*. Herein we use the term Balaenopteridae as above, and the superfamily Balaenopteroidea including Balaenopteridae and Eschrichtiidae. 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 the upper part of the Osaka Group (Figures 1, 2), with additional evidence of a 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; ISKW, Ishikawa Museum of Natural History; 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
Balaenopteridae 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 April 1990.

Remarks.—OMNH-QV 282 is a member of the superfamily Balaenopteroidea (Balaenopteridae + Eschrichtiidae) based on combination of these characters; presence of synapomorphies, such as having a small mandibular foramen (character 62 in Deméré *et al.*, 2008) and reflected neck in dorsal view (character 55 in Deméré *et al.*, 2008). OMNH-QV 282 is not a member of the family Eschrichtiidae within 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 to be

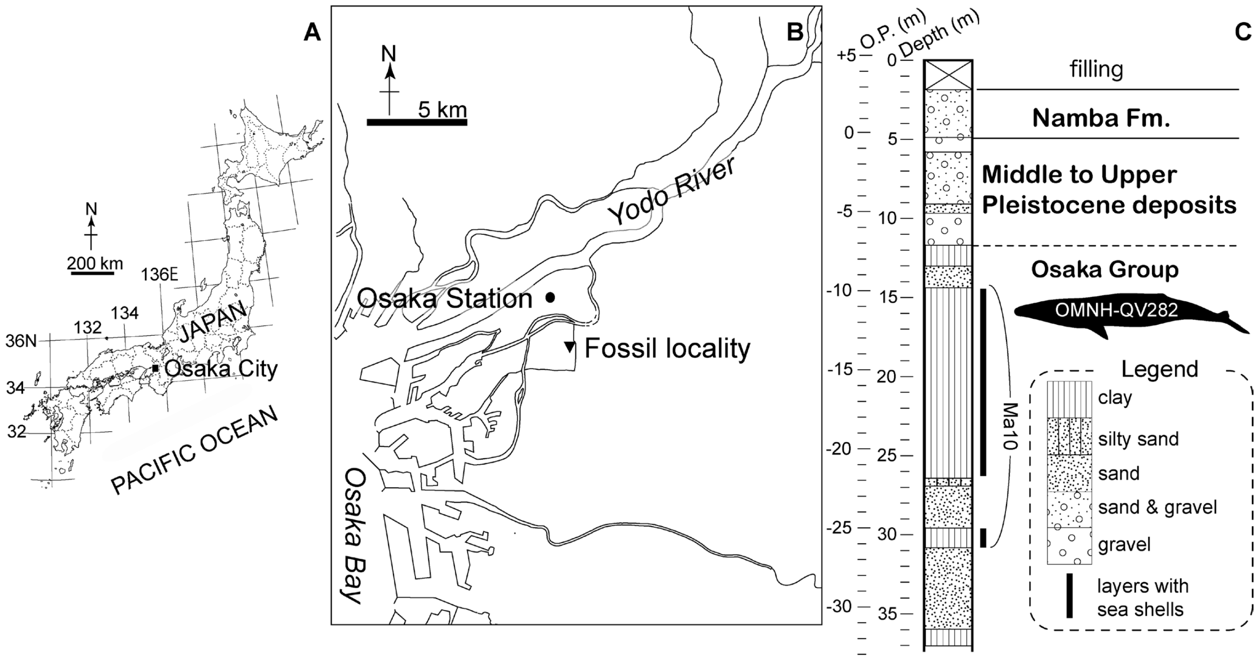

Figure 1. Locality maps (**A, B**) and stratigraphic section (**C**) of the dig point of 10Ac33 of Kansai Branch of The Japanese Geotechnical Society and Kansai Geotechnical Consultants Association (1987). The altitude of the surface at the dig point is 3.2 m. O.P. means Osaka Pail, the standard unit for elevation in Osaka.

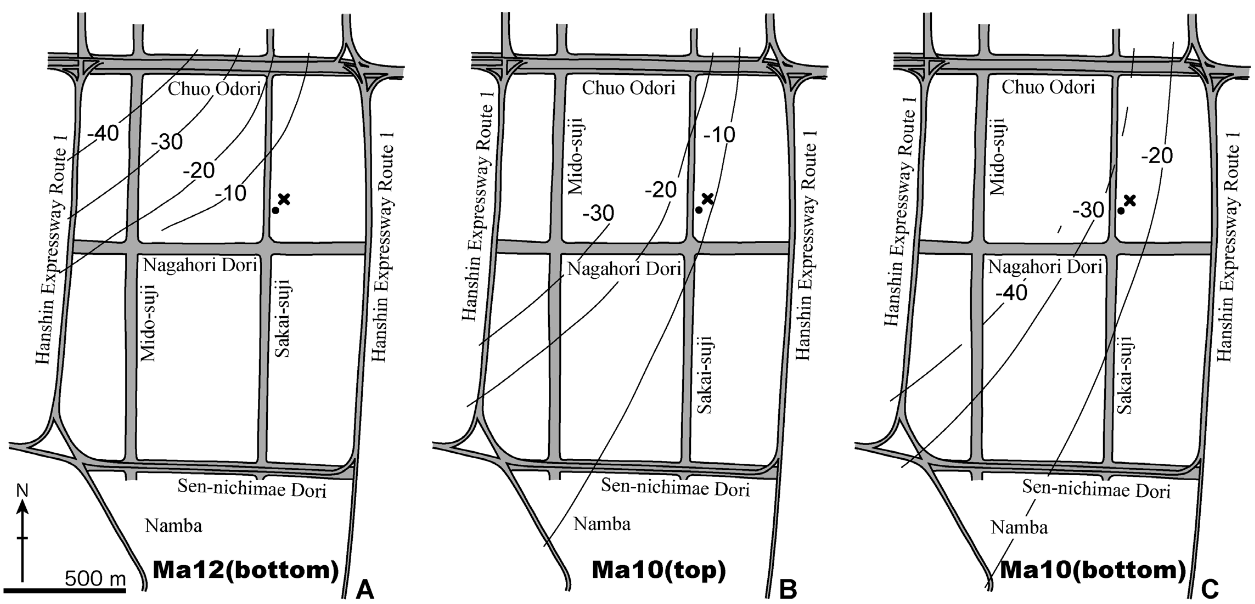

Figure 2. Bathymetry of marine clay beds based on data from Kansai Branch of the Japanese Geotechnical Society and Kansai Geotechnical Consultants Association (1987) and Kinki Branch of Architectural Institute of Japan and Kansai Branch of The Japanese Geotechnical Society (1966). **A,** bottom of Ma12; **B,** top of Ma10; **C,** bottom of Ma10. Cross mark shows the fossil locality. Bullet point shows the dig point of 10Ac33 of Kansai Branch of the Japanese Geotechnical Society and Kansai Geotechnical Consultants Association (1987). For counting the level, O.P. (Osaka Pail) was used. O. P. = T.P. (Tokyo Pail) + 1.3 m.

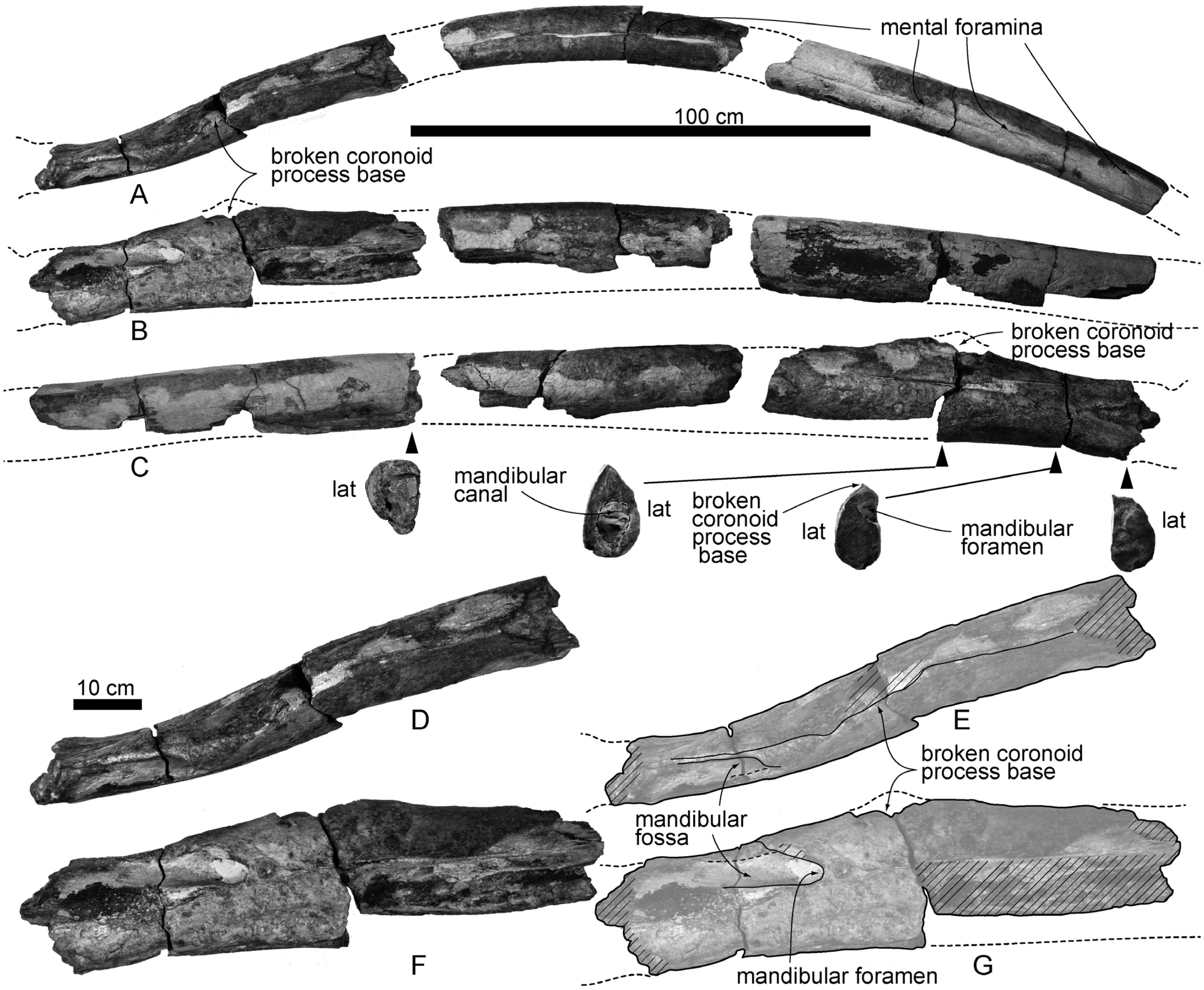

Figure 3. The left mandible of OMNH-QV 282, a balaenopterid. **A,** dorsal view; **B,** medial view; **C,** lateral view; **D,** dorsal view of posterior part; **E,** line art on D; **F,** median view of posterior part; **G,** line art on F. Note that "lat" in this figure menas lateral.

Megaptera novaeangliae, because the curvature of the mandible on *M. novaeangliae* seems stronger than in OMNH-QV 282 and *Balaenoptera* spp. However, the mandible fragments of OMNH-QV 282 do not abut one another and do not show the curvature completely.

Locality.—OMNH-QV 282 was dug up from 12 m depth from the surface at Minamisenba 1-16-10, Chuo-Ku, Osaka City (Figure 1A, B: 34°40′36″N, 135°30′25″E).

Horizon and age.—In the Osaka Plain, Quaternary marine clay beds (denoted as Ma 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 within the Tanaka Formation. The Holocene, Ma13 is a part of the Namba Formation. Within the Tanaka Formation, Ma1 to Ma10 are intercalated in the Osaka Group in the hilly land around the Osaka Plain (Yoshikawa and Mitamura, 1999). There are found the Brunhes-Matuyama boundary in Ma4 and deposits of the last interglacial period in Ma12 (Yoshikawa and Mitamura, 1999). Ma1 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 are understood to have wider distributions except for a part of the Uemachi Upland. In the upland and its surroundings, Ma11 cannot be recognized, based on previously published data (Kansai Geo-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

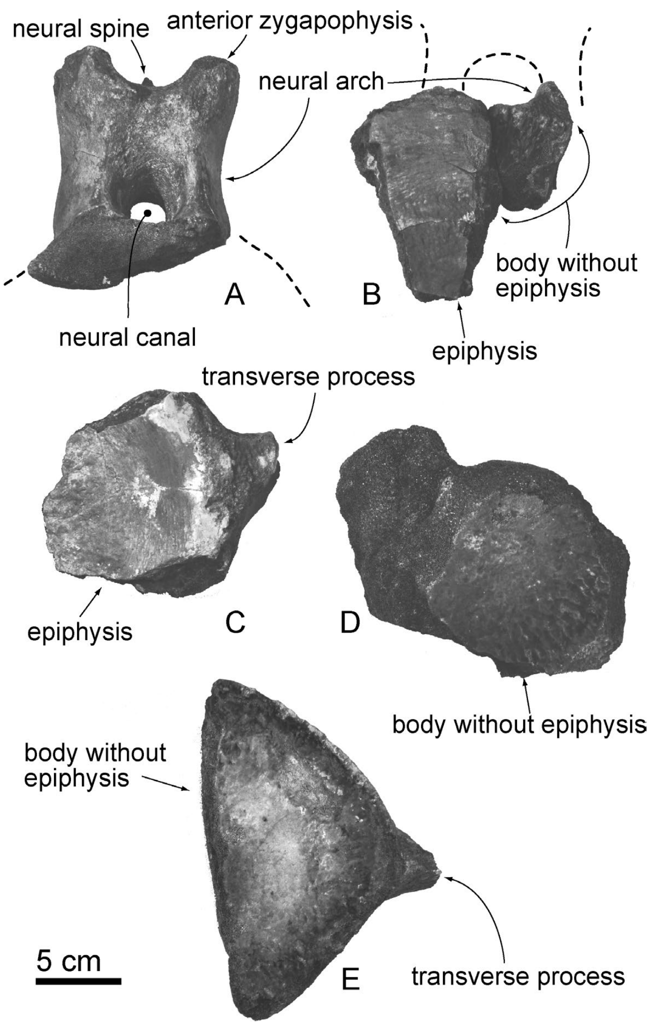

Figure 4. Photographs of five caudal vertebrae A to E of OMNH-QV 282, in anterior view. **A,** vertebra A, preserved dorsal neural arch part; **B, C,** vertebrae B and C, both representing dorsal part; **D,** vertebra D, preserved lateral? part; **E,** vertebra E, preserved lateral part.

Table 1. Measurements (in cm) of the left mandible of OMNH-QV 282, a balaenopterid. Dimensions follow Tanaka *et al.* (2018). For mandible, distances are either horizontal or vertical.

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

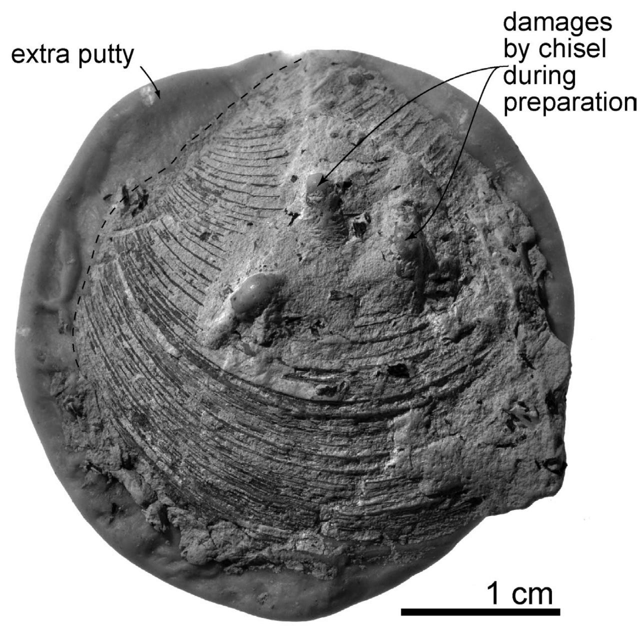

Figure 5. *Dosinia* sp., which was on the mandible of OMNH-QV 282.

282, and the data help 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 beds, which are distributed from 14 to 26 meter depth at the dig point 10Ac33 (Figure 1C). Here, we provide figures, which show levels at the bottom of Ma12, top and bottom of Ma10 using the 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) is distributed only in the top 5 m, which is not the original layer of the fossil (Figure 1C). The Pleistocene sediments in the area are on the north to northwest side downslope because of the upland rising. So, Ma12 exists northwest from the fossil locality (Figure 2A). As discussed above, Ma11 cannot be the fossil layer at the locality. Ma10 is about 10 m thick, and its west-northwest side is downslope (Figure 2B, C). OMNH-QV 282 is from Ma10; the upper and lower limits of Ma10 around the fossil locality are about 10 and 25 m (Figure 2B, C). Ma10 is referred to Stage 9 of the Marine Isotope Stages, and its age is 0.3 million years ago, or the Middle Pleistocene (Yoshikawa and Mitamura, 1999).

On the mandible of OMNH-QV 282, a shell impression of *Dosinia* sp. (identification by 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 lateral surface of the shell, thus it is unclear whether 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, 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 an anteriorly opening mental foramina with anteroposteriorly long grooves. The anterior part is shallower than the preserved posterior part around 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 medially. The posterior part shows a 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 necklike part. Matrix adheres to the mandibular condyle, indicating that the posterior end was broken prior to burial. In dorsal view, posterior to the neck the mandible is curved laterally. Overall shape of the mandible is sinuated.

Caudal vertebrae.—Five fragments of caudal vertebrae are preserved (Figure 4). Vertebrae A and C show a very low neural arch and lack transverse processes, identifying the vertebrae as caudals, especially anterior to the caudal vertebrae of the fluke. Vertebra 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). Vertebrae B and C have the bodies, which are partially isolated from the epiphyses (thickness is about 2.5 cm). Vertebrae D and E show totally separated bodies from the epiphyses. Maximum preserved height of vertebrae E 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 the 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*, *B. emarginata* and *B. 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. Several reports of other Pleistocene occurrences of extant species of Balaenopteridae have been published: *Megaptera novaeangliae* from the Upper Pleistocene of Florida (Morgan, 1994), *Balaenoptera physalus* from the lower Pleistocene of Northern California (Tsai and Boessenecker, 2017), *M. novaeangliae* 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 there have been no balaenopterid reports from the western Pacific, except for 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 records from the Middle Pleistocene of Japan. During our review of 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 Balaenopteridae. The eroded specimen still in the field included 28 vertebrae and a possible scapula, and was documented by 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), and then as 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 discussed above, OMNH-QV 282 is a juvenile. Compared to modern balaenopterids mandible (see Table 3), OMNH-QV 282 was larger than *Balaenoptera acutorostrata* specimens (body length, 5.4 and 7.7 m), smaller

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

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

Table 3. Measurements in cm of balaenopterid mandibles.

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	540.0	14.0	5.5	9.0	5.0
Balaenoptera acutorostrata	OMNH-M 3500	770.0	17.0	7.5	11.5	6.0
Balaenoptera physalus	OMNH-M no number, 3rd exhibition room	1700.0	47.5	16.5	30.5	16.5
Megaptera novaeangliae	OMNH-M 3042	700.0	23.5	10.5	16.0	10.0
Megaptera novaeangliae	OMNH-M 2222	690.0	23.0	9.0	17.5	9.5
Megaptera (?) sp.	Specimen number 1 in Matsuura and Nagasawa (2000), now at ISKW	–	–	–	25.0	–

than a specimen of *B. physalus* (body length, 17 m), and about the same size with a 7-meter-long body as a young *Megaptera novaeangliae* (OMNH-M 3042). An adult *M. novaeangliae* reaches 11 to 17 m (Jefferson *et al.*, 2008). In short, OMNH-QV 282 can be estimated as a juvenile of a large-sized balaenopterid (more than 10 m: following the definition of large size by Slater *et al.*, 2017) compared to modern balaenopterids. A large Balaenopteridae gen. et sp. indet. (KBC-F003) from the lower Pleistocene of the 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 a large-sized mandible (25 cm tall at anterior to the coronoid process, which is larger than OMNH-QV 282) from the lower Pleistocene of the Omma Formation. Chronologically later specimens include a skull of *Megaptera novaeangliae* (CBM-PV-662) from the Middle Pleistocene of the Kioroshi Formation (Nagasawa and Mitani, 2004), and OMNH-QV 282 is additional evidence of the existence of large-sized balaenopterids from the poorly known interval of the Middle Pleistocene.

Rare fossil evidence suggests that a greater faunal diversity existed in Pleistocene Osaka.—OMNH-QV 282 is the first record of whales, or even of 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 the known 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 the 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 the known diversity for the local fauna. OMNH-QV 282 is additional evidence for the existence of large-sized balaenopterids from the poorly known interval of the Middle Pleistocene.

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Author contributions

Y. T. and H. T. conceptualized this study and writes the original draft.