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2

3 A large fossil baleen whale from the Shikiya Formation (early Middle Miocene) of

4 Wakayama, Japan

5

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16 Key words: Mysticeti, Caeomysticeti, “cetotheres” *sensu lato*, Kumano Group,

17 Langhian

18

19 **ABSTRACT**

20 A new large Caeomysticeti indet., WMNH-Ge-1140240005 from the Shikiya

21 Formation of Kumano Group (early Middle Miocene; about 16 to 15 Ma) of

22 Wakayama, Japan is described here. It preserves a large rostrum (about 50 cm width

23 at the base of the rostrum), which has gently tapered lateral margins of the rostrum,

24 narrow mesorostral groove at the level of the narial fossa, wide premaxillae and

25 maxillae. There are no diagnostic features on the specimen in family level, but it is

26 comparable to two “cetotheres” *sensu lato* such as *Pelocetus calvertensis* and
27 *Diorocetus hiatus* by having wide premaxillae, which occupy 1/3 width of the rostrum
28 at anterior to the narial fossa in dorsal view, which implies that WMNH-Ge-
29 1140240005 is a possible member of “cetotheres” *sensu lato*. Its size is possibly
30 between the two large species *Pelocetus calvertensis* and *Diorocetus hiatus* of the
31 early Middle Miocene, and larger than the reported Middle Miocene mysticete
32 specimens from Japan (“*Diorocetus*” *chichibuensis*, “*Diorocetus*” *shobarensis*,
33 *Parietobalaena* sp. (SMNH-VeF-62)). The rostral width of WMNH-Ge-1140240005
34 suggests that this animal was middle size compare to extant species, but the largest
35 class baleen whale as its age.

36

37

INTRODUCTION

38 Modern baleen whale, mysticetes are the largest animal on Earth. However, the largest
39 mysticetes from the Oligocene to Middle Miocene were less than 10 meters long
40 (Slater *et al.*, 2017; Tsai and Kohno, 2016). The causes of gigantism of the Mysticeti
41 have been thought as emergence of large predators since the early Middle Miocene
42 (Lambert *et al.*, 2010), increasing near-shore productivity from the Late Miocene
43 (Pyenson and Vermeij, 2016), the onset of upwelling regimes of the Late Pliocene
44 (Slater *et al.*, 2017), efficiency of filter feeding (Friedman, 2012; Potvin *et al.*, 2012),
45 for long distance migration related to iron-mediated changes in glacial marine
46 productivity (Marx and Fordyce, 2015). Tsai and Kohno (2016) suggested “intrinsic
47 factors” such as developmental constraint.

48

49 Several Middle Miocene mysticetes are known from Japan, such as “*Diorocetus*”
50 *chichibuensis*, “*Diorocetus*” *shobarensis*, *Parietobalaena* sp. (SMNH-VeF-62),

51 *Taikicetus inouei* and *Pelocetus* sp. (Egashira and Kimura, 1998; Kimura *et al.*, 2007;
52 Kimura and Ozawa, 2002; Kimura *et al.*, 1998; Otsuka and Ota, 2008; Tanaka *et al.*,
53 2018; Yoshida *et al.*, 2003). All of them are belonging to an extinct mysticete group,
54 “cetotheres” *sensu lato* of Marx *et al.* (2017). Among them, only *Taikicetus inouei*
55 (the skull preserves the median line and right side of the zygomatic process) and
56 *Pelocetus* sp. (HMN-F00003) are about 60 cm of the skull width, and their estimated
57 body length are about 6 meters using Pyenson and Sponberg (2011) formula for stem
58 Balaenopteroidea. Tsai (2017) reported a fetal specimen of a Middle Miocene whale,
59 *Parietobalaena yamaokai* of Otsuka and Ota (2008), and estimated its size of
60 adulthood could be over 10 meters.

61

62 Here, we report a Mysticeti rostrum and mandible from the early Middle Miocene,
63 Shikiya Formation, Kumano Group of Wakayama Japan. The specimen is fragmental,
64 but the rostral width suggests that this animal was middle size compare to extant
65 species, but the largest class baleen whale as its age.

66

67 *Institutional abbreviations.*- AMP, Ashoro Museum of Paleontology, Hokkaido,
68 Japan; HMN, Hiwa Museum of Natural History, Hiroshima, Japan; OU, Geology
69 Museum, Dunedin, University of Otago, New Zealand; SMNH, Saitama Museum of
70 Natural History, Saitama, Japan; USNM, Department of Paleobiology, National
71 Museum of Natural History, Smithsonian Institution, Washington, D.C., U.S.A.;
72 WMNH, Wakayama Prefectural Museum of Natural History, Wakayama, Japan.

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74

75

SYSTEMATIC PALEONTOLOGY

76 Order Cetacea Brisson, 1762
77 Unranked taxon Neoceti Fordyce and de Muizon, 2001
78 Suborder Mysticeti Gray, 1864
79 Infraorder Chaeomysticeti Mitchell, 1989
80 gen. et sp. indet.

81
82 Figures 2, 3 and Table 1

83
84 *Referred specimen.*- WMNH-Ge-1140240005, a large rostrum and a middle part of a
85 left mandible was collected by Yukio Sako in 1973, and was prepared by one of the
86 authors, Masaaki Ohara and preparators of WMNH.

87
88 *Remarks.*- WMNH-Ge-1140240005 is identified as Chaeomysticeti by lacking teeth in
89 the maxilla and mandible, and in having the palatal foramina and sulci, the palatal
90 keel and dorsoventrally flattened maxilla. WMNH-Ge-1140240005 is comparable to
91 two “cetotheres” *sensu lato* such as *Pelocetus calvertensis* and *Diorocetus hiatus* by
92 having wide premaxillae, which occupy 1/3 width of the rostrum, at anterior to the
93 narial fossa in dorsal view. The size of WMNH-Ge-1140240005 is about between the
94 species; about 80% of the type of *Pelocetus calvertensis* (USNM11976) and about
95 120% of the matured referred specimen of *Diorocetus hiatus* (USNM23494) (see
96 more in discussion).

97
98 *Locality.*- WMNH-Ge-1140240005 was dug up from a cliff at so-called Sugano-hama
99 of Uematsu, Kushimoto Town, Wakayama Prefecture, Japan (Figure 1, A and B):
100 Latitude 33°27'54.34"N, longitude 135°46'32.71"E

101

102 *Horizon and age.*- The Kumano Group is about 4000 m thick, and contains three
103 Formations such as the Shimosato, Shikiya and Mitsuno Formations from bottom to
104 top (Hisatomi, 1981). The original horizon of WMNH-Ge-1140240005 is the Shikiya
105 Formation, which is only exposed sediment at the locality (Figure 1).

106

107 The Shikiya Formation is equivalent to the planktonic foraminiferal zone N8 of Blow
108 (1969) (Hoshi *et al.*, 2003). Some key foraminifera species of the zone N8;
109 *Lepidocyclina*, *Miogypsina*, *Globigerinoides japonicus*, *Globigerinoides sicanius*,
110 *Praeorbulina glomerosa curva*, *Praeorbulina transitoria*, *Globoquadrina cf.*
111 *langhiana* and *Globorotalia quinifalcata* were reported by Ikebe *et al.* (1975), and
112 without the genus *Orbulina*, which is the diagnostic taxon for N9, (Hoshi *et al.*, 2003).
113 The emergence of *Praeorbulina glomerosa* is estimated as 16.1 Ma, and the bottom of
114 N9 is estimated as 15.1 Ma (Berggren *et al.*, 1995; Saito, 1999). Thus the estimated
115 age of the Shikiya Formation is about 16 to 15 Ma (the early Middle Miocene).

116

117 The Shikiya Formation was known as forearc-basin sediments (Hisatomi, 1981). The
118 basin was shallower in the north and inclined to the south. Deposits of the Shimosato
119 and Shikiya Formations filled the basin. The fossil locality was the southern part of
120 the basin, which was deeper part on the shelf. A new gastropod subspecies,
121 *Entemnotrochus rumphii kushimotoensis* from the locality and formation was
122 described by Tomida and Sako (2016). The study suggested that the taxon
123 accompanied by the lower sublittoral to bathyal mollusks and lived tropical marine
124 climate. The fossil fauna from the area is comparable to the tropical Kurosedani
125 Fauna (Honda *et al.*, 1998).

126

127

GENERAL DESCRIPTION

128 Morphological terms follow Mead and Fordyce (2009).

129

130 *Estimated body size.*- The estimated body size of WMNH-Ge-1140240005 is
131 calculated using Pyenson and Sponberg (2011) formula for stem Balaenopteroidea,
132 which uses bizygomatic width ($\log L < -0.92 * (\log_{10}(\text{bizyg}) - 1.64) + 2.67$). The preserved
133 width at the base of the rostrum is 52 cm. The zygomatic process is not preserved, but
134 if WMNH-Ge-1140240005 had similar proportion with *Diorocetus hiatus* (USNM
135 23494) and *Pelocetus calvertensis* (USNM 11976) (see remarks), the zygomatic width
136 is about 70 cm. Using the estimated bizygomatic width (70 cm), the estimated body
137 size of WMNH-Ge-1140240005 is about 7 m (and at least larger than 5.5 m). The size
138 can be stated as large (more than 5 m long, Tsai and Kohno (2016)).

139

140 *Rostrum.*- WMNH-Ge-1140240005 has a broad and flat rostrum. The palatal keel is
141 formed by the maxilla and vomer, and runs anteroposteriorly on the medial line of the
142 ventral surface of the palate. Because of deformation, the rostrum is slightly flattened
143 and skews to left. The surface of the specimen is eroded.

144

145 *Premaxilla.*- The premaxillae are wide and occupy 1/3 width of the rostrum in dorsal
146 view (Figure 2, C and D). The preserved anterior most part of the premaxilla is
147 anteriorly widen. The premaxillae are very close anteriorly (about 1 cm), but the
148 posterior end is separated and forms the narial fossa. At the level, the lateral margin of
149 the premaxilla rises and forms an anteroposteriorly long crest near the narial fossa,
150 narial crest of the premaxilla [new term], which projects dorsolaterally and shallow

151 depression on the medial surface for the narial fossa. Possible homologous structure
152 can be seen on many mysticete specimens, such as extant balaenopterids, *Cetotherium*
153 *riabinini* (see Figure 6 of (Gol'din *et al.*, 2014)), *Tiucetus rosae* (see Figure 2 of (Marx
154 *et al.*, 2017)) and *Incakujira anillodefuego* (see Figure 4 of (Marx and Kohno, 2016))
155 as mediolaterally narrow ridge.

156

157 *Maxilla.*- The maxilla is dorsoventrally thin; especially the lateral margin is thinner
158 than the medial part of the maxilla. In dorsal view, the maxilla has an
159 anteroposteriorly long depression medially for the contact of the premaxilla. At the
160 level of the narial fossa, several dorsal infraorbital foramina open continuously medial
161 to the lateral process of the maxilla. Anterior margin of the lateral process, the
162 antorbital notch (about 100 mm height, 50 mm depth) runs transversely. Posterior to
163 the notch, on the dorsal surface of the maxilla, there is a depressed area for the frontal
164 in the part of the orbital plate (Miller, 1923) of the maxilla. The area is very small and
165 even the longest distance is 87 mm. Ventrally, the maxilla covers lateral surface of the
166 vomer. Posteriorly the maxilla increases its height (about 13 cm at the preserved
167 posterior end) (Figure 2, B and D). Ventrally, the palatal sulci locate about the level of
168 the narial fossa, and are very faint (about 4 mm deep and 10 mm wide).

169

170 *Vomer.*- The vomer forms an anteriorly shallower and posteriorly deeper, dorsally
171 widely opened mesorostral groove. The ventral margins of the maxilla are broken, so
172 it is difficult to know how the vomer exposed ventrally or not. The posterior end of
173 the vomer has a couple of shallow depressions beside an anteroposteriorly long ridge.
174 These structures might be for contact with the maxillae.

175

176 *Mandible*.- The left mandible weakly curves, and does not show teeth. Its anterior and
177 posterior ends were preserved as contact with the rostrum (Figure 2). The broken
178 cross section shows dorsoventrally long elliptical, and its ventral side is sharper than
179 the dorsal side. The medial side of the mandible is flatter.

180

181

DISCUSSION

182 *Comparisons to Middle/Late Miocene whales*.- Figure 2 of Marx and Fordyce (2015),
183 phylogeny and geological time scale of the Mysticeti shows that there are only three
184 families (Balaenidae, Cetotheriidae, Balaenopteridae), and so-called “cetotheres”
185 *sensu lato* (Marx *et al.*, 2017) during the Middle to Late Miocene.

186

187 A stem balaenid, *Peripolocetus vexillifer* is known from the Langhian (early Middle
188 Miocene) of the Temblor Formation of California (Kellogg, 1931), but does not
189 preserve comparable rostral part. The balaenids are characterized by having arched
190 and narrow rostrum (Marx *et al.*, 2016), which is different from the one of WMNH-
191 Ge-1140240005.

192

193 Early members of the Cetotheriidae, *Joumocetus shimizui* and *Titanocetus*
194 *sammarinensis* have posteriorly wider triangular rostra (Capellini, 1901; Kimura and
195 Hasegawa, 2010), which are different from the gently tapered rostrum of WMNH-Ge-
196 1140240005. *Kurdalagonus mchedlidzei*, *Metopocetus durinasus*, “*Cetotherium*”
197 *megalophysum* and *Cephalotropis coronatus* do not have preserved rostra (Cope,
198 1896; Tarasenko and Lopatin, 2012), but their preserved frontals implies that the base
199 of the rostra are obviously smaller than the one of WMNH-Ge-1140240005. The Late
200 Miocene cetotheriids, *Cetotherium riabinini* and *Brandtocetus chongulek* are smaller

201 than WMNH-Ge-1140240005 (the two species' bizygomatic width are about 40 to 30
202 cm: see Table 1 of Gol'din and Startsev (2014)). *Cetotherium riabinini* shows much
203 narrower premaxilla and the base of the rostrum (see Gol'din *et al.* (2014)).

204

205 There are two early members of the Balaenopteridae among the Middle Miocene.

206 "*Balaenoptera*" *ryani* of Hanna and McLellan (1924) does not preserve comparable

207 rostral part, but much smaller than WMNH-Ge-1140240005. *Plesiobalaenoptera*

208 *quarantellii* of Bisconti (2010) shows anteriorly gradually tapering rostrum, and its

209 width is about 40 cm, which is about 20% smaller than the one of WMNH-Ge-

210 1140240005. The Late Miocene whale, *Uranocetus gramensis* was placed basal to the

211 Balaenopteridae (Marx *et al.*, 2017; Steeman, 2009; Tanaka *et al.*, 2018). *Uranocetus*

212 *gramensis* has very similar size of the width of the base of the rostrum (51.7 cm,

213 Steeman (2009)) and morphology of wide maxilla and premaxilla. But, *Uranocetus*

214 *gramensis* shows stronger degree of mesorostral groove expansion at the level of the

215 narial fossa. In addition, *Uranocetus gramensis* has the premaxilla, which has weakly

216 curved sigmoidal lateral margin of the premaxilla. But, WMNH-Ge-1140240005

217 shows weakly curved C-shape lateral margin of the premaxilla.

218

219 WMNH-Ge-1140240005 is comparable to two "cetotheres" *sensu lato* such as

220 *Pelocetus calvertensis* and *Diorocetus hiatus* of the early Middle Miocene (see

221 remarks). WMNH-Ge-1140240005 is comparable to *Pelocetus calvertensis* in having

222 wide each premaxilla in dorsal view. The genus *Pelocetus* includes second species,

223 *Pelocetus mirabilis*, which was established by Ginsburg and Janvier (1971) using a

224 mandible from France. The first Northwestern Pacific record of the genus *Pelocetus*;

225 *Pelocetus* sp. (HMN-F00003) was reported from the Middle Miocene, Korematsu

226 Formation of Hiroshima, Japan by Kimura *et al.* (2007). *Pelocetus* sp. (HMN-
227 F00003) and WMNH-Ge-1140240005 are possibly more or less the same size based
228 on the preserved bizygomatic width. WMNH-Ge-1140240005 is different from
229 *Pelocetus calvertensis* in having a narrower mesorostral groove, especially at the level
230 anterior to the narial fossa, and wider premaxillae.

231
232 Several other supposed members of “cetotheres” *sensu lato* are “*Aglaocetus*” *patulus*,
233 “*Diorocetus*” *chichibuensis*, “*Diorocetus*” *shobarensis*, *Isanacetus laticephalus*,
234 *Parietobalaena campiniana*, *Parietobalaena palmeri*, *Parietobalaena* sp. (SMNH-
235 VeF-62), *Pinocetus polonicus*, *Uranocetus gramensis*, *Parietobalaena yamaokai*,
236 *Tiphyocetus temblorensi*, *Thinocetus arthritis* and undescribed OU 22705 (Marx *et al.*,
237 2017). These species show smaller size and much more tapered rostrum compare to
238 WMNH-Ge-1140240005, except *Uranocetus gramensis*, *Diorocetus hiatus* and
239 “*Diorocetus*” *shobarensis*. A large sized “*D.*” *shobarensis* established by Otsuka and
240 Ota (2008) is similar to WMNH-Ge-1140240005, by having wide rostrum. But, the
241 width of premaxillae on the rostrum is much narrower than the one of WMNH-Ge-
242 1140240005. The size of WMNH-Ge-1140240005 is about 120% of “*Diorocetus*”
243 *shobarensis*, HMN-F00005 (Figure 4).

244
245 *Gigantism of mysticetes.*- The all reported Middle to Late Miocene “cetotheres” *sensu*
246 *lato* from Japan (*Joumocetus shimizui*, *Parietobalaena yamaokai*, “*Diorocetus*”
247 *chichibuensis* *Isanacetus laticephalus*, and *Taikicetus inouei*) are smaller compare to
248 WMNH-Ge-1140240005. Tsai (2017) reported potentially large but juvenile specimen
249 of *Parietobalaena yamaokai* from the Middle Miocene of Hiroshima, Japan. However,
250 WMNH-Ge-1140240005 is much larger than the type subadult specimen, HMN-

251 F00022, which is about the same size to *Isanacetus laticephalus* (see Figure 4, E).
252 There are two more similar large sized (to WMNH-Ge-1140240005) Miocene
253 mysticetes; *Pelocetus* sp. (HMN-F00003) as discussed above, and a “cetotheres” *sensu*
254 *lato* (MFM 18124) from Gifu Prefecture (Kimura, 2002; Kimura *et al.*, 2000), which
255 has a 1777 mm long mandible, are known. These facts suggest that, at Japanese coasts,
256 there was/were large unknown species of the Mysticeti as their size in the early
257 Middle Miocene. The size is between *Pelocetus calvertensis* and *Diorocetus hiatus*.
258 Previously, large sized “cetotheres” *sensu lato* are known, such as *Pelocetus*
259 *calvertensis* and *Diorocetus hiatus*. As Tsai and Kohno (2016) mentioned that there
260 are multiple origins of gigantism among lineages of the mysticetes. Indeed, recently
261 large sized fossil mysticetes, Llanocetidae (Fordyce and Marx, 2018) and Aetiocetidae
262 (Tsai and Ando, 2016) of the Oligocene, and the Balaenopteridae during the
263 Pleistocene (Tanaka and Taruno, in press) are reported. The new material implies that
264 gigantism of “cetotheres” *sensu lato* was already happened in the early Middle
265 Miocene.

267 CONCLUSION

268 Chaemysticeti indet., WMNH-Ge-1140240005 from the Shikiya Formation of
269 Kumano Group (early Middle Miocene) of Wakayama, Japan is large sized rostrum
270 (50 cm width at the base of the rostrum) and left mandible. The specimen shows a
271 gently tapered lateral margins of the rostrum, narrow mesorostral groove at the level
272 of the narial fossa, huge width of the premaxillae and mesorostral groove, and wide
273 each premaxilla its own. There are no diagnostic features on the specimen, but it can
274 be comparable to two “cetotheres” *sensu lato* such as *Pelocetus calvertensis* and
275 *Diorocetus hiatus* by having wide premaxillae, which occupy 1/3 width of the rostrum,

276 at anterior to the narial fossa in dorsal view. This implies that WMNH-Ge-
277 1140240005 is a possible member of “cetotheres” *sensu lato*, but it needs more
278 preserved parts to identify. The estimate size is about 7 meters, and larger than the
279 reported Middle Miocene mysticetes from Japan (“*Diorocetus*” *chichibuensis*,
280 “*Diorocetus*” *shobarensis*, *Parietobalaena* sp. (SMNH-VeF-62), *Parietobalaena*
281 *yamaokai* and *Taikicetus inouei*), except not directly comparable *Pelocetus* sp. and
282 *Taikicetus inouei*. WMNH-Ge-1140240005 adds an evidence of large sized Mysticeti
283 during the Middle Miocene in the Northwest Pacific Ocean. The preserved rostral
284 width suggests that this animal was middle size compare to extant species, but the
285 largest class baleen whale (more than 5 m long) as its age (see Figure 6 of Pyenson
286 and Sponberg (2011)). The new material implies that gigantism of “cetotheres” *sensu*
287 *lato* was already happened in the early Middle Miocene.

288

289

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294

295

REFERENCES

296 Berggren, W.-A., Kent, D.V., Swisher, C.C.I. and Aubry, M.P., 1995: A
297 revised Cenozoic geochronology and chronostratigraphy, p. 129-212.
298 In Berggren, W.A., Kent, D.V., and Aubry, M.P. (eds.), *Geochronology,*
299 *Time Scales and Global Stratigraphic Correlation*. SEPM, Tulsa.
300 Bisconti, M., 2010: A new balaenopterid whale from the Late Miocene of

301 the Stirone River, northern Italy (Mammalia, Cetacea, Mysticeti).
302 *Journal of Vertebrate Paleontology*, vol. 30, p. 943-958.

303 Blow, W.H., 1969: Late Middle Eocene to Recent Planktonic Foraminiferal
304 Biostratigraphy. *Proceedings of the First International Conference on*
305 *Planktonic Microfossils*, vol. 1, p. 199-422.

306 Capellini, G., 1901: *Balenoptera miocenica* del Monte Titano Repubblica di
307 S. Marino. *Memorie della R. Accademia delle Scienze dell'Instituto di*
308 *Bologna*, vol. 9, p. 1-26.

309 Cope, E., 1896: Sixth contribution to the knowledge of the marine Miocene
310 fauna of North America. *Proceedings of the American Philosophical*
311 *Society*, vol. 35, p. 139-146.

312 Egashira, F. and Kimura, M., 1998: A new fossil Mysticeti from the Taiki
313 town, Hiroo County, Hokkaido. *Nature and Science*, vol. 111, p. 7-22.

314 Fordyce, R.E. and de Muizon, C., 2001: Evolutionary history of whales: a
315 review, p. 169-234 In Mazin, J.-M., and de Buffrenil, V. (eds.),
316 *Secondary Adaptation of Tetrapods to Life in Water*. Pfeil, München,
317 Germany.

318 Fordyce, R.E. and Marx, F.G., 2018: Gigantism precedes filter feeding in
319 baleen whale evolution. *Current Biology*, vol. 28, p. 1670-1676. e2.

320 Friedman, M., 2012: Parallel evolutionary trajectories underlie the origin
321 of giant suspension-feeding whales and bony fishes. *Proceedings of*
322 *the Royal Society of London B: Biological Sciences*, vol. 279, p. 944-
323 951.

324 Ginsburg, L. and Janvier, P., 1971: Les mamiferes marins des faluns

325 Miocenes de la Touraine et de l'Anjou. *Bulletin du Museum National*
326 *d'Histoire Naturelle, Sciences de la Terre*, vol. 6, p. 161-195.

327 Gol'din, P. and Startsev, D., 2014: *Brandtocetus*, a new genus of baleen
328 whales (Cetacea, Cetotheriidae) from the late Miocene of Crimea,
329 Ukraine. *Journal of Vertebrate Paleontology*, vol. 34, p. 419-433.

330 Gol'din, P., Startsev, D. and Krakhmalnaya, T., 2014: The anatomy of
331 *Cetotherium riabinini* Hofstein, 1948, a baleen whale from the late
332 Miocene of Ukraine. *Acta Palaeontologica Polonica*, vol. 59, p. 795-
333 814.

334 Hanna, G.D. and McLellan, M.E., 1924: A new species of fin whale from
335 the type locality of the Monterey Group. *Proceedings of the California*
336 *Academy of Sciences*, vol. 13, p. 237-241.

337 Hisatomi, K., 1981: Geology and sedimentology of the Kumano Group in
338 the southeastern part of the Kumano basin, Kii Peninsula. *The*
339 *Journal of the Geological Society of Japan*, vol. 87, p. 157-174.

340 Honda, Y., Ushiro, S. and Moritani, S., 1998: Miocene mollusks from the
341 Kumano Group of the Ukui area, southeastern part of the Kii
342 Peninsula, southwestern Honshu, Japan. *Paleontological Research*,
343 vol. 2, p. 12-24.

344 Hoshi, H., Iwano, H., Danhara, T. and Yoshida, T., 2003: Fission-track
345 dating of the Shionomisaki Igneous Complex, Kii Peninsula, Japan.
346 *Journal of Geological Society of Japan (Chishitsugakuzassi)*, vol. 109,
347 p. 139-150.

348 Ikebe, N., Chiji, M. and Morozumi, Y., 1975: *Lepidocyclina* horizon in the

349 Miocene Kumano Group in reference to planktonic foraminiferal
350 biostratigraphy. *Bulletin of the Osaka Museum of Natural History*,
351 vol. 29, p. 81-89.

352 Kellogg, R., 1931: Pelagic mammals from the Temblor Formation of the
353 Kern River region, California. *Proceedings of the California Academy*
354 *of Sciences*, vol. 19, p. 217-397.

355 Kellogg, R., 1965: Fossil marine mammals from the Miocene Calvert
356 Formation of Maryland and Virginia 1. A new whalebone whale from
357 the Miocene Calvert Formation. *United States National Museum*
358 *Bulletin*, vol. 247, p. 1-45.

359 Kimura, T., 2002: Feeding strategy of an Early Miocene cetothere from the
360 Toyama and Akeyo Formations, central Japan. *Paleontological*
361 *Research*, vol. 6, p. 179-189.

362 Kimura, T. and Hasegawa, Y., 2010: A new baleen whale (Mysticeti:
363 Cetotheriidae) from the earliest late Miocene of Japan and a
364 reconsideration of the phylogeny of cetotheres. *Journal of Vertebrate*
365 *Paleontology*, vol. 30, p. 577-591.

366 Kimura, T., Hasegawa, Y., Ohzawa, H., Yamaoka, T., Furukawa, Y., Ueda,
367 T., Kiyoshi, T., Sugihara, M. and Sakuda, M., 2007: A mysticete whale
368 (Cetacea) skeleton from the Middle Miocene Bihoku group, Shobara,
369 Hiroshima, Japan. *Miscellaneous Reports of the Hiwa Museum for*
370 *Natural History* vol. 48, p. 1-10.

371 Kimura, T., Okumura, Y. and Iwamura Town Board of Education, 2000: An
372 Early Miocene cetothere from the Iwamura Group, Gifu Prefecture,

373 Japan, and its feeding mechanism. *Bulletin of the Mizunami Fossil*
374 *Museum*, vol. 27, p. 1-12.

375 Kimura, T. and Ozawa, T., 2002: A new cetothere (Cetacea: Mysticeti) from
376 the early Miocene of Japan. *Journal of Vertebrate Paleontology*, vol.
377 22, p. 684-702.

378 Kimura, T., Sakamoto, O. and Hasegawa, Y., 1998: A cetothere from the
379 Miocene Chichibumachi Group, Saitama Prefecture, Japan. *Bulletin*
380 *of the Saitama Museum of Natural History*, vol. 16, p. 1-13.

381 Lambert, O., Bianucci, G., Post, K., de Muizon, C., Salas-Gismondi, R.,
382 Urbina, M. and Reumer, J., 2010: The giant bite of a new raptorial
383 sperm whale from the Miocene epoch of Peru. *Nature*, vol. 466, p.
384 105-108.

385 Marx, F., Lambert, O. and Uhen, M.D., 2016: *Cetacean Paleobiology*, p.
386 320. Wiley-Blackwell.

387 Marx, F.G. and Fordyce, R.E., 2015: Baleen boom and bust: a synthesis of
388 mysticete phylogeny, diversity and disparity. *Royal Society Open*
389 *Science*, vol. 2, p. 140434.

390 Marx, F.G. and Kohno, N., 2016: A new Miocene baleen whale from the
391 Peruvian desert. *Royal Society Open Science*, vol. 3, p. 27.

392 Marx, F.G., Lambert, O. and de Muizon, C., 2017: A new Miocene baleen
393 whale from Peru deciphers the dawn of cetotheriids. *Royal Society*
394 *Open Science*, vol. 4, p. 1-22.

395 Mead, J.G. and Fordyce, R.E., 2009: The therian skull: a lexicon with
396 emphasis on the odontocetes. *Smithsonian Contributions to Zoology*,

397 vol. 627, p. 1-248.

398 Miller, G.S., 1923: The telescoping of the cetacean skull. *Smithsonian*
399 *Miscellaneous Collections*, vol. 76, p. 1-70.

400 Mitchell, E.D., 1989: A new cetacean from the Late Eocene La Meseta
401 Formation Seymour Island, Antarctic Peninsula. *Canadian Journal of*
402 *Fisheries and Aquatic Sciences*, vol. 46, p. 2219-2235.

403 Otsuka, H. and Ota, Y., 2008: Cetotheres from the early Middle Miocene
404 Bihoku Group in Shobara District, Hiroshima Prefecture, West Japan.
405 *Miscellaneous Reports of the Hiwa Museum for Natural History*, vol.
406 49, p. 1-66.

407 Potvin, J., Goldbogen, J.A. and Shadwick, R.E., 2012: Metabolic
408 expenditures of lunge feeding rorquals across scale: implications for
409 the evolution of filter feeding and the limits to maximum body size.
410 *PLoS ONE*, vol. 7, p. e44854.

411 Pyenson, N.D. and Sponberg, S.N., 2011: Reconstructing body size in
412 extinct crown Cetacea (Neoceti) using allometry, phylogenetic
413 methods and tests from the fossil record. *Journal of Mammalian*
414 *Evolution*, vol. 18, p. 269-288.

415 Pyenson, N.D. and Vermeij, G.J., 2016: The rise of ocean giants: maximum
416 body size in Cenozoic marine mammals as an indicator for
417 productivity in the Pacific and Atlantic Oceans. *Biology Letters*, vol.
418 12, p. 1-4.

419 Saito, T., 1999: Revision of Cenozoic magnetostratigraphy and the
420 calibration of planktonic microfossil biostratigraphy of Japan against

421 this new time scale. *Journal of the Japanese Association for*
422 *Petroleum Technology*, vol. 64, p. 2-15.

423 Slater, G.J., Goldbogen, J.A. and Pyenson, N.D., 2017: Independent
424 evolution of baleen whale gigantism linked to Plio-Pleistocene ocean
425 dynamics. *Proceedings of the Royal Society B: Biological Sciences*, vol.
426 284, p. 1-8.

427 Steeman, M.E., 2009: A new baleen whale from the Late Miocene of
428 Denmark and early mysticete hearing. *Palaeontology*, vol. 52, p.
429 1169-1190.

430 Tanaka, Y., Ando, T. and Sawamura, H., 2018: A new species of Middle
431 Miocene baleen whale from the Nupinai Group, Hikatagawa
432 Formation of Hokkaido, Japan. *PeerJ*, vol. 6:e4934, p. 1-20.

433 Tanaka, Y. and Taruno, H., in press: The first cetacean record from the
434 Osaka Group (Middle Pleistocene, Quaternary) in Osaka, Japan.
435 *Paleontological Research*, vol., p.

436 Tarasenko, K. and Lopatin, A., 2012: New baleen whale genera (Cetacea,
437 Mammalia) from the miocene of the northern caucasus and
438 ciscaucasia: 1. *Kurdalagonus* gen. nov. from the middle-late
439 Sarmatian of Adygea. *Paleontological Journal*, vol. 46, p. 531-542.

440 Tomida, S. and Sako, Y., 2016: A new subspecies, *Entemnotrochus rumphii*
441 *kushimotoensis*, (Gastropoda: Pleurotomariidae) from the Middle
442 Miocene of Wakayama Prefecture, Central Japan. *VENUS*, vol. 74, p.
443 27-34.

444 Tsai, C.-H., 2017: A Miocene breeding ground of an extinct baleen whale

445 (Cetacea: Mysticeti). *PeerJ*, vol. 5, p. e3711.
446 Tsai, C.-H. and Ando, T., 2016: Niche partitioning in Oligocene toothed
447 mysticetes (Mysticeti: Aetiocetidae). *Journal of Mammalian*
448 *Evolution*, vol. 23, p. 33-41.
449 Tsai, C.-H. and Kohno, N., 2016: Multiple origins of gigantism in stem
450 baleen whales. *The Science of Nature*, vol. 103, p. 1-8.
451 Yoshida, K., Kimura, T. and Hasegawa, Y., 2003: New cetothere (Cetacea:
452 Mysticeti) from the Miocene Chichibumachi Group, Japan. *Bulletin*
453 *of the Saitama Museum of Natural History*, vol. 20, p. 1-10.

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456 List of figures

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462 view; **C**, photo; **D**, key features.

463 Figure 3. The skull and left mandible, Chaemysticeti indet., WMNH-Ge-
464 1140240005. **A** and **B**, anterior view; **A**, photo; **B**, key features; **C** and **D**, right
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467 Figure 4. Size comparisons. **A**, *Pelocetus calvertensis*, type modified from Kellogg
468 (1965); **B**, Chaemysticeti indet., WMNH-Ge-1140240005 of this study; **C**,
469 *Diorocetus hiatus*, matured referred specimen USNM 23494 modified from

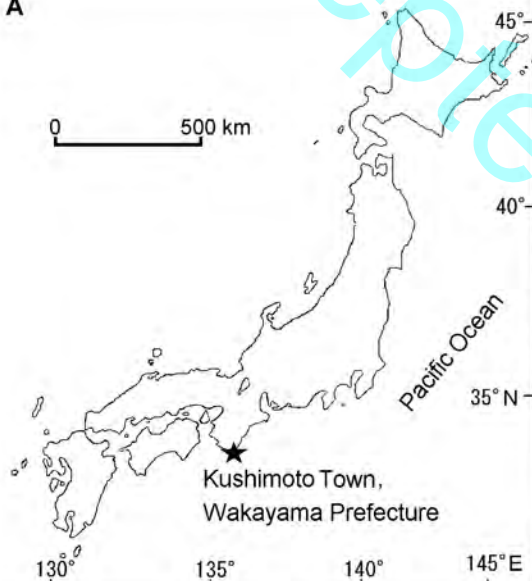
470 Kellogg (1968); **D**, “*Diorocetus*” *shobarensis*, type modified from Otsuka and
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472 Ozawa (2002).

473 Table 1. Measurements in cm of the skull and left mandible, WMNH-Ge-1140240005,
474 Chaeomysticeti indet. The asterisk (*) means restored measurement from the
475 one of the right side.

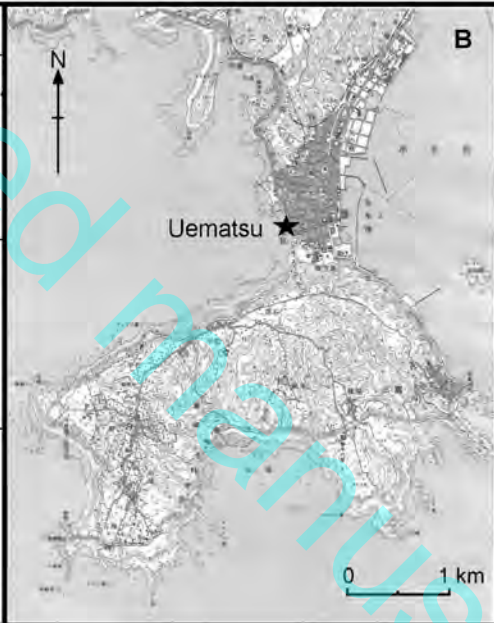
476

Accepted manuscript

A

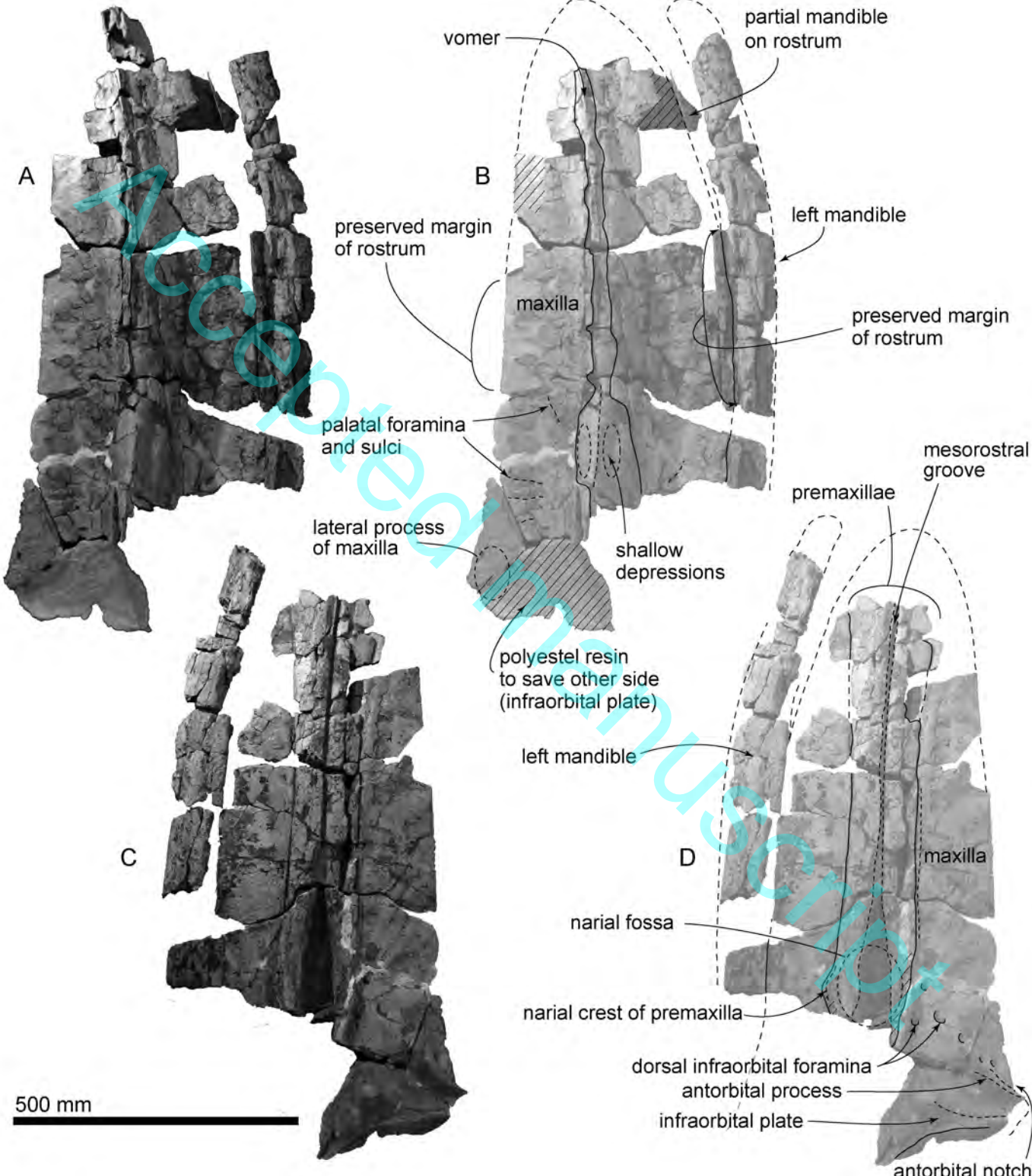


B



C

| | | Foraminifera zone | Formations |
|----------------|----|-------------------|------------|
| Middle Miocene | N9 | Mitsuno | ↓ 15.1 Ma |
| | N8 | Shikiya | ↓ 16.1 Ma |
| E. Mio. | N7 | Shimosato | |



A

B

C

D

vomer

partial mandible
on rostrum

preserved margin
of rostrum

left mandible

maxilla

preserved margin
of rostrum

palatal foramina
and sulci

lateral process
of maxilla

shallow
depressions

polyestel resin
to save other side
(infraorbital plate)

mesorostral
groove

premaxillae

left mandible

maxilla

narial fossa

narial crest of premaxilla

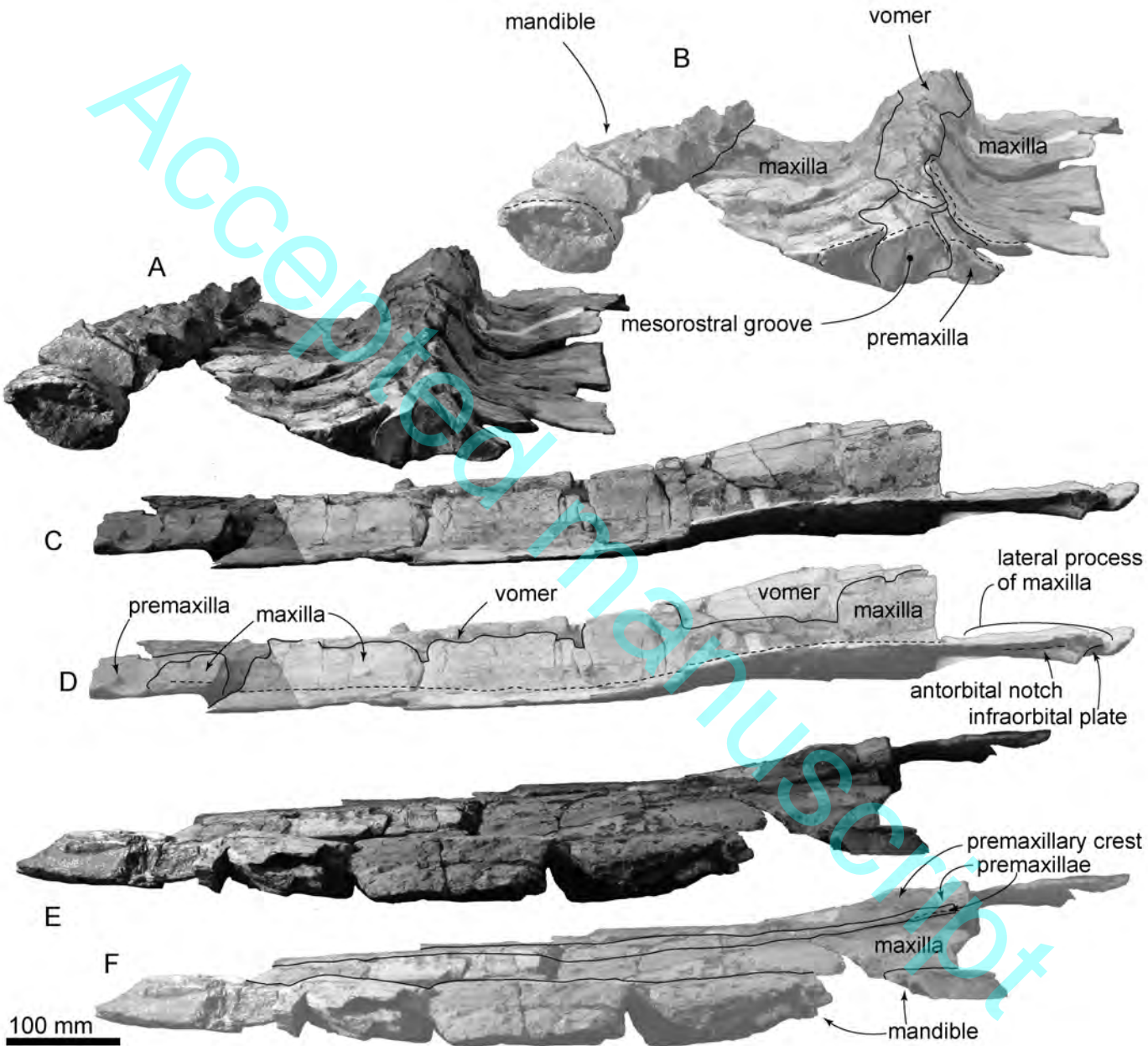
dorsal infraorbital foramina

antorbital process

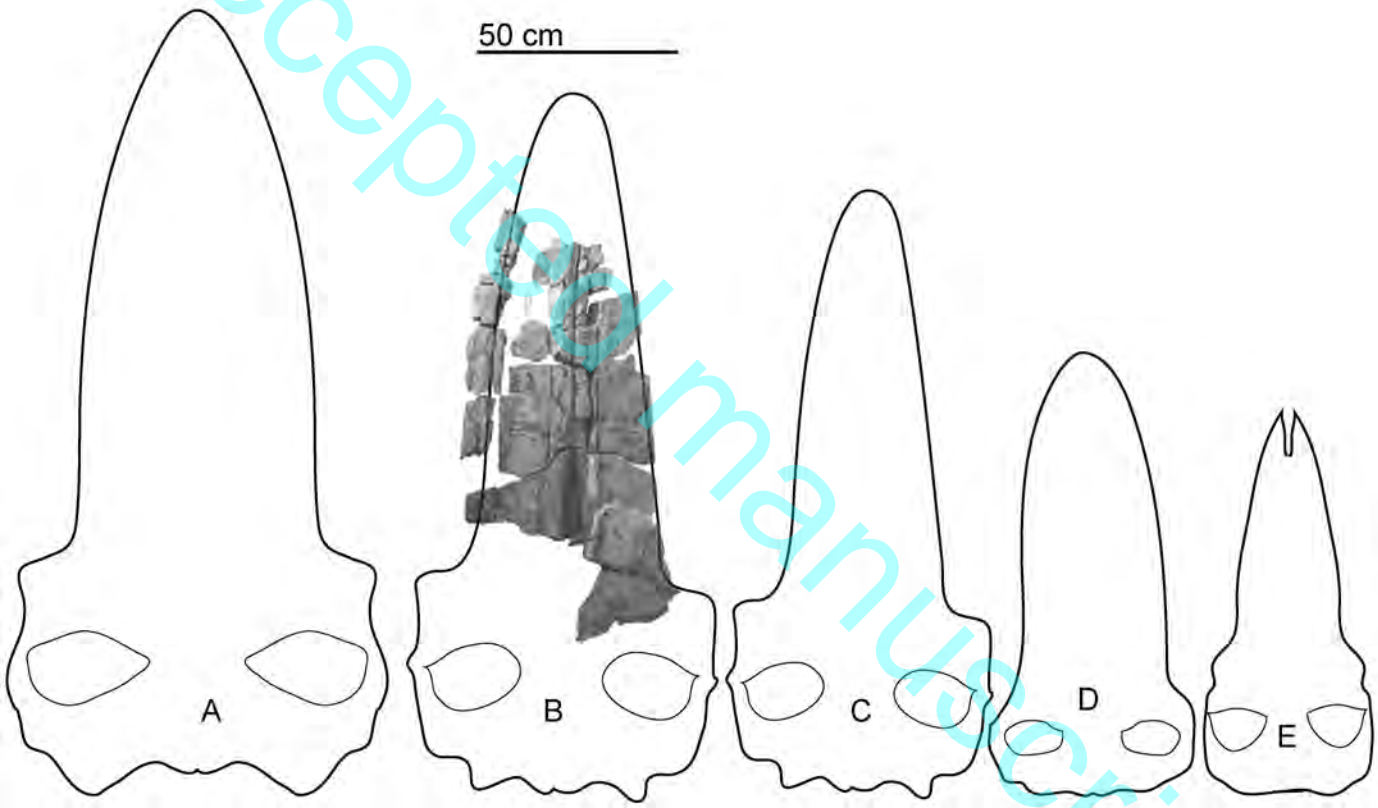
infraorbital plate

antorbital notch

500 mm



50 cm



| Cranium | cm |
|-----------------------------------|-------|
| total preserved length | 110.0 |
| maximum preserved width | 50.0 |
| rostrum width at antorbital notch | 52.0* |
| maximum width of vomer | 13.0 |
| maximum height of vomer | 12.0 |
| maximum length of premaxilla | 84.5 |
| maximum width of right premaxilla | 6.0 |
| maximum width of premaxillae | 15.0 |
| Mandible | |
| total preservd length | 90.0 |
| maximum height | 9.0 |
| maximum width | 5.0 |

Accepted manuscript