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Reappraisal of a rhinocerotid (Mammalia, Perissodactyla) from the lower Miocene Yotsuyaku Formation, Northeast Japan, with an overview of the early Miocene Japanese rhinocerotids

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Abstract.

A fragmentary femur of the Rhinocerotidae (Perissodactyla, Mammalia) from the lower Miocene Yotsuyaku Formation of the Shiratorigawa Group, Ichinohe, Iwate Prefecture, Northeast Japan is redescribed, and the fossil record of Japanese early Miocene rhinocerotids, including footprints, is briefly reviewed. The femur is identified as belonging to an indeterminate species of rhinocerotid, cf. Aceritherini, in having the distal portion of the base of the lesser trochanter situated near the apex of the third trochanter and a less

projected third trochanter than in most rhinocerotids. Since *ca*. 20 Ma, rhinocerotids have inhabited and been widely distributed in Japan, which formed an eastern margin of continental East Asia at that time.

Keywords: early Miocene, femur, Iwate Prefecture, Japan, Perissodactyla, Rhinocerotidae

Introduction

The Rhinocerotidae, a perissodactyl recorded from the Eocene Epoch onward (Antoine *et al*., 2003), became particularly diversified during the Miocene (Heissig, 1989; Antoine *et al*., 2010). In East Asia, especially in China, abundant Miocene rhinocerotid fossils have been reported. (e.g. Deng and Downs, 2002). In Japan, rhinocerotids have also been reported in Miocene deposits, especially in the lower Miocene (Tomida *et al*., 2013), and Miocene rhinocerotid footprints have been found (Okamura, 2016). However, comprehensive discussion of early Miocene Japanese rhinocerotids has not yet been carried out. In China, rhinocerotid fossil record from the lower Miocene are scarce compared to those from the middle to upper Miocene (e.g. Deng and Downs, 2002). Therefore, the records of early Miocene rhinocerotids can contribute to the discussion of the distribution

of the family in Far East Asia.

However, of the early Miocene rhinocerotids found in Japan, only a few cheek teeth and mandibles have been identified at the genus-level (Okumura *et al*., 1977; Kamei and Okazaki, 1974; Okazaki, 1977, 1980; Fukuchi and Kawai, 2011). The taxonomic revisions of other remains including postcranial elements have not been undertaken since their initial descriptions.

Here, I redescribe a fragmentary rhinocerotid femur from the lower Miocene Yotsuyaku Formation of the Shiratorigawa Group, Iwate Prefecture, Northeast Japan, and compare it with femora of Miocene rhinocerotids and chalicotheriids. This specimen was originally described by Oishi *et al*. (2001) as an indeterminate rhinocerotid. They compared this specimen (IPMM 60488) with only two other fossil rhinocerotid femora. One of these specimens (GPM Fo-259) from the lower Miocene Mizunami Group of central Japan, was identified as *Chilotherium pugnator*. The other is a femur (IGPS 8372) of Recent Indian rhinoceros, *Rhinoceros unicornis*. Oishi *et al*. (2001) noted that IPMM 60488 resembled the femur of *C. pugnator*. However, Handa and Kawabe (2016) reidentified the femur of *C. pugnator* (GPM Fo-259) as a schizotheriine chalicotheriid. Thus, an appraisal of the taxonomic status of IPMM 60488 is necessary to determine whether it is a rhinocerotid or a chalicotheriid. Additionally, I briefly review the fossil record and distribution of early

The taxonomies of the Rhinocerotidae and Chalicotheriidae used in this study follows Antoine *et al*. (2010) and Fahlke and Coombs (2009), respectively. Anatomic terminology follows Guérin (1980). The standard measurement method of Guérin (1980) was used.

Institutional abbreviations.— AMNH, American Museum of Natural History, New York, USA; BSPG, Bayerische Staatsammlung für Paläontologie und Geologie, Munich, Germany ; F:AM, Frick American Mammals stored in AMNH; GPM, Gifu Prefectural Museum, Seki, Japan; HMV, the Hezheng Paleontological Museum, Hezheng, China; MNHN, Muséum National d'Histoire Naturelle, Paris, France; IGPS, the Institute of Geology and Paleontology, Tohoku University, Sendai, Japan; IPMM, Iwate Prefectural Museum, Morioka, Japan; PA, Palaeontological and Geological Museum of Athens, Athens, Greece.

Anatomical abbreviations.—fh, femoral head; gt, greater trochanter; lt, lesser trochanter; tt, third trochanter.

Other abbreviations.—*L*, length; DT head, transverse diameter of the femoral head; *DAP head*, antero-posterior diameter of the femoral head; *DT dia*, transverse diameter of the shaft; AR, Artenay, France; Ba, Baigneaux-en-Beauce, France; GAR: Le Garouillas, France; MAR, Maragheh, Iran; MTLB, Mytilinii Basin, Samos, Greece; ZT, Zhaotong

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Geological setting

IPMM 60488 was found in the lower Miocene Matsukura Siliciclastic Rock Member of the Yotsuyaku Formation of the Shiratorigawa Group at Numayama, Ichinohe, in the Ninohe District, Iwate Prefecture, Northeast Japan (Figure 1, locality number 4). The Yotsuyaku Formation is the basal formation of the Shiratorigawa Group. The Yotsuyaku Formation is subdivided into four members: in ascending order, the Matsukura Siliciclastic Rock Member (non-marine), Koiwai Mudstone Member (marine), Keiseitoge Volcanic Rock Member, and Sukohata Siliciclastic Rock Member (non-marine) (Oishi *et al*., 2001; TuZino and Yanagisawa, 2017; TuZino *et al*., 2018). According to the marine molluscan fauna of the Koiwai Mudstone Member (Akeyo fauna: Matsubara, 1995) and the K-Ar age of the Keiseitoge Volcanic Rock Member (17.4±0.3 Ma, and 16.9±0.3 Ma: Ishizuka and Uto, 1995), the age of the Yotsuyaku Formation is estimated to be *ca*. 18.0–16.8 Ma (the late early Miocene; by TuZino and Yanagisawa (2017) and *ca*. 18–16 Ma by TuZino *et al*. (2018). The age of the Matsukura Siliciclastic Rock Member, which yields IPMM 60488, is likely estimated to be *ca*. 17–18 Ma because the member is stratigraphically located lower

than the Keiseitoge Volcanic Rock Member.

Systematic paleontology

Family Rhinocerotidae Gray, 1821

Subfamily Rhinocerotinae Gray, 1821

Tribe cf. Aceratheriini Dollo, 1885

gen. et sp. indet.

Figures 2, 3A

Rhinocerotidae gen. et sp. indet. Oishi *et al*., 2001, fig. 3.

Material.—IPMM 60488, a proximal left femur.

Repository.—Iwate Prefectural Museum, Morioka, Japan.

Description.—IPMM 60488 is a proximal fragment of a left femur missing the greater trochanter. The shaft is compressed craniocaudally, so that the exact craniocaudal dimensions of IPMM 60488 are uncertain. On the surface of the specimen, some gravel derived from the sediment is attached. The femoral head is hemispherical in shape (Figure 2A–B) and completely fused with the neck. The fovea capitis is unclear because the surface of the femoral head is damaged. The trochanteric fossa is also unclear because of the poor

preservation. The third trochanter on the lateral side of the shaft is preserved; it is slightly curved cranially (Figure 2C). The apex of the third trochanter is partially broken and its margin is rounded in cranial view. The lesser trochanter is almost lacking, and is only preserved on the proximomedial side of the shaft. The distal portion of the base of the lesser trochanter is situated near the apex of the third trochanter in cranial view.

Comparisons and discussion.—IPMM 60488 is not assigned to the Chalicotheriidae but to the Rhinocerotidae. Based on the preserved part, IPMM 60488 differs from the femur of schizotheriine chalicotheriids in having a thicker third trochanter that is well developed and curved cranially (Figures 2C, 3). In addition, the transverse diameters of the femoral head and shaft of IPMM 60488 are smaller than that of the Scizotheriinae (Table 1). *Ancylotherium pentelicum*, a species of the Schizotheriinae, has no projected third trochanter (Roussiakis and Theodorou 2001; Giaourstakis and Koufos 2009). Therefore, IPMM 60488 is not assigned to the Schizotheriinae. The femur of the chalicotheriine chalicotheriids (such as *Anisodon grande*) is well distinguished from IPMM 60488 in having no projections for the third- or lesser trochanters on the shaft (e.g. Guérin, 2012), indicating that IPMM 60488 is also not assigned to the Chalicotheriinae.

IPMM 60488 is more comparable to the femur of the Rhinocerotidae in that the third trochanter is developed and curved cranially and in that the lesser trochanter is less

projected than that of the Schizotheriinae (Figure 2C). Among the Rhinocerotidae, IPMM 60488 is characterized by the distal portion of the base of the lesser trochanter that is situated near the apex of the third trochanter, and by the third trochanter that is less projected than that of most of the rhinocerotids.

Judging from these characteristics, IPMM 60488 are similar to femora of the rhinocerotid tribe Aceratheriini (such as those of *Aceratherium incisivum* by Hünermann, 1989 and *Chilotherium wimani* by Deng, 2002; Figure 3B, C). It differs from femora of *Plesiaceratherium gracilis* described by Young (1937), Rhinocerotini gen. et sp. indet. from the Zhaotong Basin by Lu *et al*. (2019), *Iranotherium morgani* by Mecquenem (1908), and *Prosantorhinus douvillei* by Cerdeño (1996) in having a more distally-situated lesser trochanter relative to the position of the greater trochanter (Figure 4D–G). It is also distinguished from the femur of *Diaceratherium aurelianense* described by Cerdeño (1993) in having a proportionally larger third trochanter (Figure 4H).

Metrically, the dimensions of the femoral head of IPMM 60488 are similar to those of the rhinocerotids (Table 1). The transverse diameter of the shaft (DT) of IPMM 60488 is similar to those of *Brachypotherium brachypus*, *Diaceratherium aurelianense*, *Chilotherium wimani*, and *Diceros pachygnatus* (= *Ceratoherium neumayri*: e.g. Geraads, 1988), although the shaft of IPMM 60488 is slightly deformed medio-laterally (Table 1).

In sum, IPMM 60488 is certainly assigned to the Rhinocerotidae and is morphologically and dimensionally similar to the femora of two species of the Aceratheriini, *Aceratherium incisivum* and *Chilotherium wimani*. However, the identification at the tribe-level is difficult due to the poor preservation of IPMM 60488.

Early Miocene rhinocerotid record in Japan

Twenty localities of early Miocene rhinocerotid fossils, including footprints, are known from Japan (Figures 1, 4, 5). In this study, these fossil records are provisionally divided into three categories by age as follows: around 20 Ma, around 18 Ma and around 16 Ma (Figure 5).

Around 20 Ma

An isolated lower molar was found in the Shiote Formation in Tochikubo, Minamisoma in Fukushima Prefecture. This specimen was briefly identified as *Chilotherium* sp. based on a comparison with the remains of *C. pugnator* from Kani in Gifu Prefecture (Taira, 2009). Several footprints were found in the Yoka Formation of the Hokutan Group in several localities in the Kyoto and Hyogo prefectures (Yasuno, 2005, 2006, 2009, 2012; Yasuno

and Miki, 2013; Okamura, 2016). Several rhinocerotid footprint fossils were also found in the Ito-o and Kunimi Formations in a few early Miocene localities in the Fukui Prefecture (Yasuno, 2010, 2015a, 2016; Okamura, 2016).

Around 18 Ma

Several localities in the Gifu Prefecture yielded abundant rhinocerotid remains including an upper jaw, mandibles, isolated cheek teeth, postcranial fragments, and footprints (Matsumoto, 1921; Kamei and Okazaki, 1974; Okumura *et al*., 1977; Okazaki, 1977, 1980; Kawai, 1996; Fukuchi and Kawai 2011; Okamura, 2016 and references therein). The remains have been identified as *C. pugnator* or *Chilotherium* sp. (e.g. Okumura *et al*., 1977; Kamei and Okazaki, 1974; Okazaki, 1977, 1980). A few of the specimens, however, were recently redescribed as *Brachypotherium*? *pugnator* and *Plesiaceratherium* sp. by Fukuchi and Kawai (2011). A rhinocerotid partial mandible was found in the Tomikusa area, Nagano Prefecture. This specimen was derived from the Oshimojo Formation of the Tomikusa Group (The Records of Anan Town Editing Committee, 1987). This specimen was considered to be *C. pugnator* without any discussion or comparison. A third or fourth cervical vertebral fragment of a rhinocerotid was reported from the Sendani Sandstone and Mudstone Member of the Tsuchiyama Formation of the Ayugawa Group, Shiga Prefecture

(Kimura *et al*., 1994). Two isolated upper and lower cheek teeth, and a postcranial skeleton, possibly from the subtribe Teleoceratina, were reported from the Nojima Group on Kuroshima Island and Takashima Island, respectively, without any descriptions or pictures (Kawano and Kawano, 2000; Miyata *et al*., 2012; Murakami *et al*., 2012, 2016). The Nojima Group in Nagasaki and Saga prefectures also yielded rhinocerotid footprints (Inuzuka *et al*., 2009; Okamura and Kitabayashi, 2012; Okamura, 2016). The present specimen from the Yotsuyaku Formation is included in this age category as explained above.

Around 16 Ma

The Kurosedani Formation of the Yatsuo Group in Toyama Prefecture yielded several rhinocerotid footprints (Okamura, 2016). The Asakawa Formation in Daigo Town, Ibaraki Prefecture also yielded numerous trackways (Ando *et al*., 2010). In addition, footprints which were possibly made by rhinocerotids have also been reported from the Kuma Group in Ehime Prefecture, although their precise provenances are unknown (Okamura, 2016).

Remarks

Rhinocerotidae were widespread throughout Eurasia during the early Miocene (e.g.

Heissig, 1989). They were among the most conspicuous elements of mammalian assemblages at these times, when the Japanese Islands were parts of the eastern margin of Far East Asia. Before *ca*. 20 Ma, proto-Japan was a part of the eastern margin of the Asian Continent. It was separated from the continent with the opening of the Japan Sea, caused by rifting with intensive volcanic activities by *ca*. 15 Ma (e.g. Otofuji *et al*., 1994; Hoshi and Takahashi, 1999; Kano *et al*., 2002; Baba *et al*., 2007; Yanai *et al*., 2010; Hoshi *et al*., 2015). Given the paleogeography of Japan from *ca.* 20–16 Ma (Figure 5), early Miocene records of rhinocerotids suggest that the Rhinocerotidae existed in Japan by at least *ca*. 20 Ma and were widely distributed in the eastern margin of Far East Asia throughout the early Miocene.

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Captions

Figure 1. Map showing early Miocene rhinocerotid fossil localities in Japan including footprint localities.

Figure 2. A left proximal femur of cf. Aceratheriini gen. et sp. indet. (IPMM 60488) from the Lower Miocene Yostsuyaku Formation of Japan. **A**, cranial view; **B**, caudal view; **C**, distal view of the third trochanter. Abbreviations: fh, femoral head; gt, great trochanter; lt, lesser trochanter; tt, third trochanter.

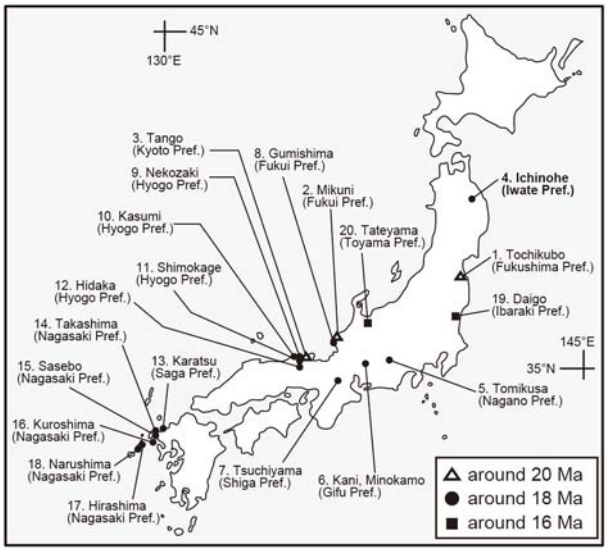
Figure 3. Comparison between IPMM 60488 with selected rhinocerotid and schizotheriine chalicotheriid femora. **A**, cf. Aceratheriinae gen. et sp. indet. from the Yostsuyaku Formation in Japan (IPMM 60488); **B**, *Aceratherium incisivum* (after Hünermann, 1989: Rh. F/54); **C**, *Chilotherium wimani* (after Deng, 2002: HMV1062); **D**, *Plesiaceratherium gracile* (after Young, 1937: unnumbered); **E**, Rhinocerotini gen. et sp. indet. (after Lu *et al*., 2019: ZT-2015-02695); **F**, *Iranotherium morgani* (after Mecquenem, 1908: MNHN-MAR 1579); **G**, *Prosantorhinus douvillei* (after Cerdeño, 1996: Ba 2769); **H**, *Diaceratherium aurelianense* (after Cerdeño, 1993: AR 2160); **I**, Schizotheriinae gen. et sp. indet. (after Handa and Kawabe, 2016: GPM Fo-259); **J**, *Moropus elatus* (after Coombs, 1978: AMNH

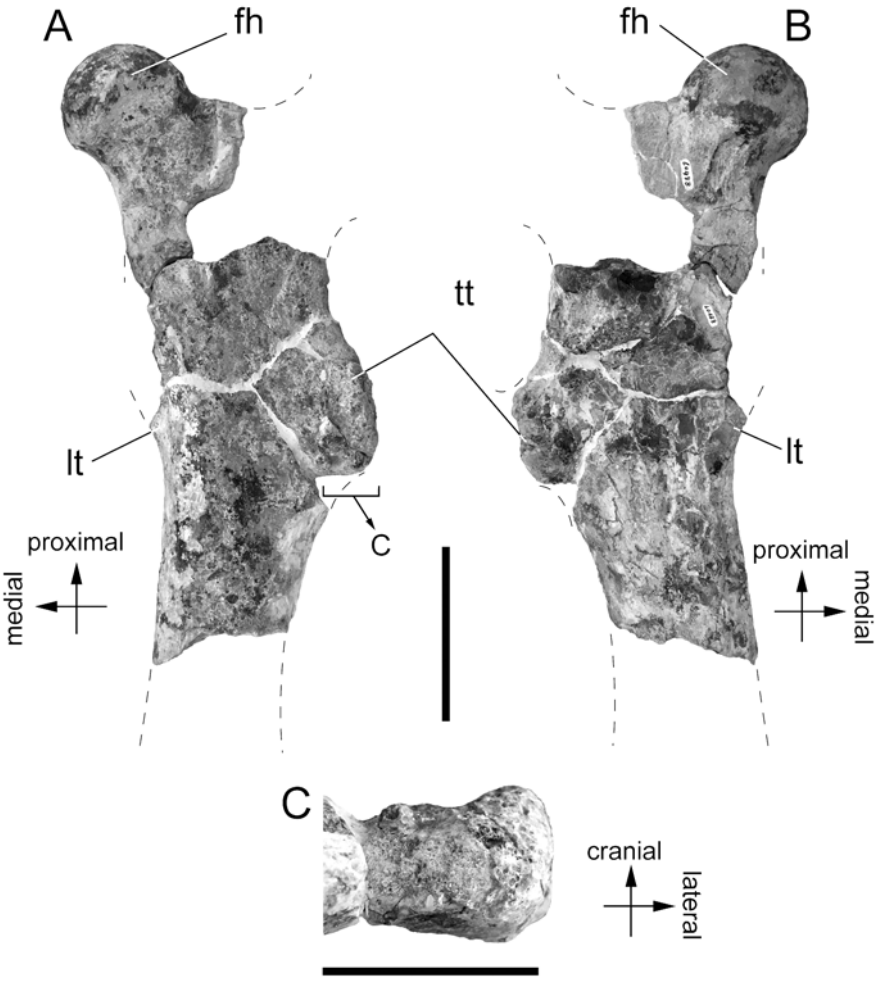
14,378); **K**, *Metaschizotherium bavaricum* (after Coombs, 1979: F:AM 54915); **L**, *Metaschizotherium bavaricum* (after Coombs, 2009: BSPG 1959 II 11636); **M**, *Ancylotherium pentelicum* (after Roussiakis and Theodorou, 2001: PA 2070/91); **N**, *Ancylotherium pentelicum* (after Giaourtsakis and Koufos, 2009: MTLB-338); **O**, *Schizotherium priscum* (after de Bonis, 1995: GAR 33). Gray shaded area indicates damaged surface. A–H, Rhinocerotidae, I–O, Schizotheriinae (Chalicotheriidae). C, F, H, I, J, K, M, O: right side. A, B, D, E, G, L, N: left side. All figures are cranial view. Abbreviations are shown in Figure 2.

Figure 4. Correlation of the early Miocene rhinocerotid-bearing horizons in Japan (after Tomida *et al*., 2013). The references for the ages are as follows: TuZino and Yanagisawa, (2017) for the Yotsuyaku Formation; Yamamoto (1996) for the Shiote Formation; Sako and Hoshi (2014) for the Oshimojo Formation; Saegusa (2008) and Tomida *et al*. (2013) for the Asakawa Formation; Ozawa (2016) for the Kurosedani Formation; Muramatsu (1992) for the Ayugawa Group; Sakiyama *et al*. (2012) for the Yoka Formation; Circle marks indicate the paleontological record. Triangle marks indicate the paleoichnological record. Numbers (1–20) next to the prefectural names indicate the fossil localities shown Figure 1.

Figure 5. Paleomaps of three ages (*ca*. 20 Ma, 18 Ma, and 16 Ma) during the early Miocene, showing rhinocerotid occurrences (after Noda and Goto, 2004). Gray shaded area indicates land area. Numbers (1–20) indicate the fossil localities shown Figure 1.

Table 1. Compared measurements (in mm) of IPMM 60488 and selected specimens of the Rhinocerotidae and Chalicotheriidae.


45°N
130°E
3. Tango
(Kyoto Pref.)
8. Gumishima
(Fukui Pref.)
9. Nekozaki
(Hyogo Pref.)
2. Mikuni
(Fukui Pref.)
4. Ichinohe
(Iwate Pref.)
10. Kasumi
(Hyogo Pref.)
20. Tateyama
(Toyama Pref.)
1. Tochikubo
(Fukushima Pref.)
11. Shimokage
(Hyogo Pref.)
12. Hidaka
(Hyogo Pref.)
19. Daigo
(Ibaraki Pref.)
14. Takashima
(Nagasaki Pref.)
145°E
35°N
15. Sasebo
(Nagasaki Pref.)
13. Karatsu
(Saga Pref.)
5. Tomikusa
(Nagano Pref.)
16. Kuroshima
(Nagasaki Pref.)
18. Narushima
(Nagasaki Pref.)
7. Tsuchiyama
(Shiga Pref.)
6. Kani, Minokamo
(Gifu Pref.)
17. Hirashima
(Nagasaki Pref.)
around 20 Ma
around 18 Ma
around 16 Ma


A
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B
fh
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lt
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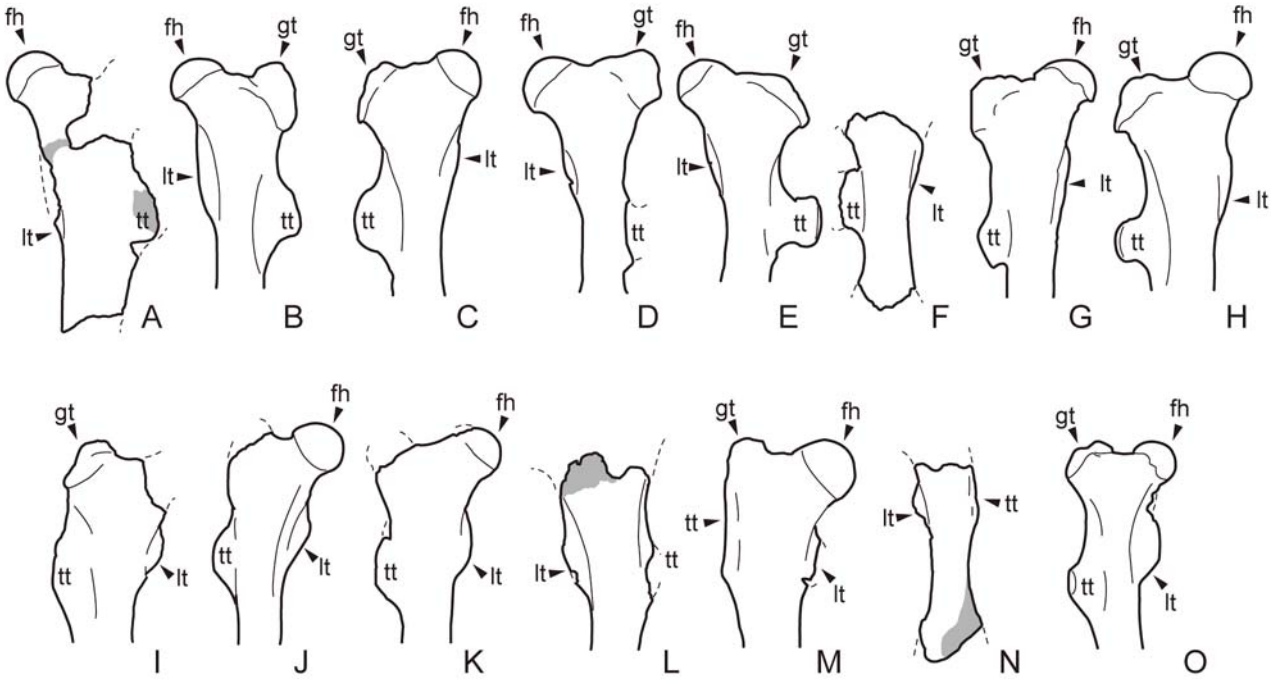
C
proximal
medial
proximal
medial
C
cranial
lateral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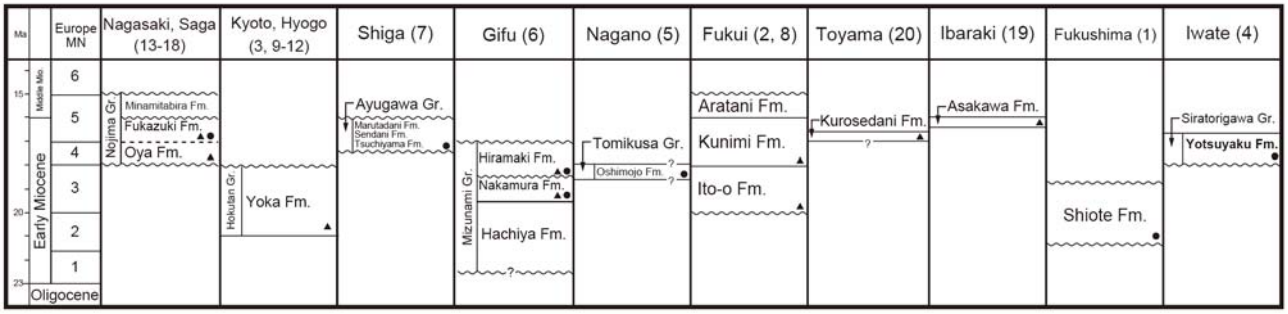
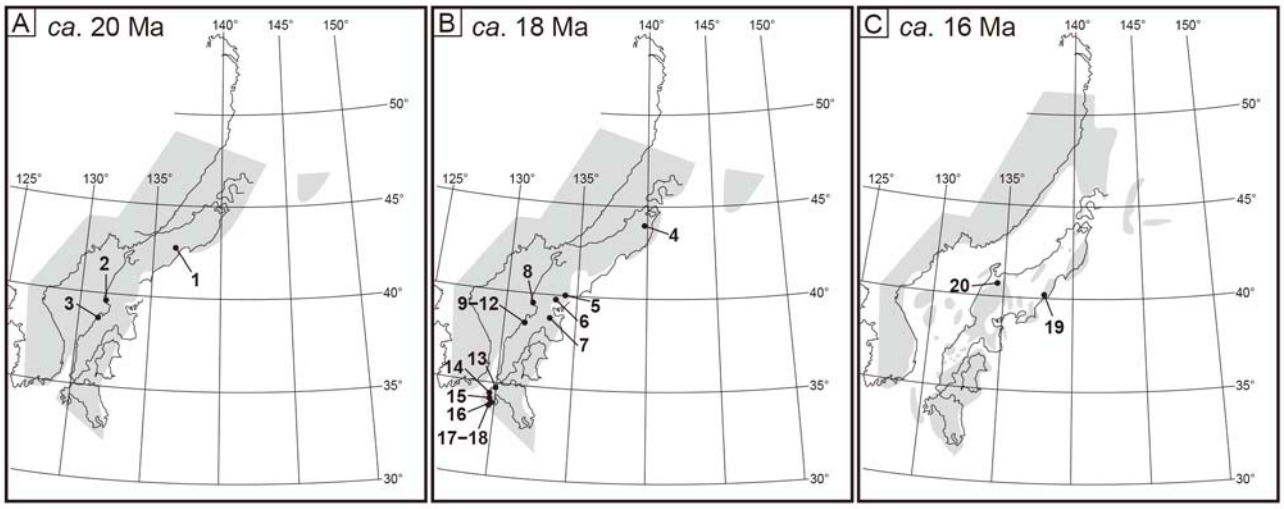

Ma
Europe MN
Nagasaki, Saga (13-18)
Kyoto, Hyogo (3, 9-12)
Shiga (7)
Gifu (6)
Nagano (5)
Fukui (2, 8)
Toyama (20)
Ibaraki (19)
Fukushima (1)
Iwate (4)
15
20
23
Middle Mio.
Early Miocene
Oligocene
6
5
4
3
2
1
Nojima Gr.
Minamitabira Fm.
Fukazuki Fm.
Oya Fm.
Hokutan Gr.
Yoka Fm.
Ayugawa Gr.
Marutadani Fm.
Sendani Fm.
Tsuchiyama Fm.
Mizunami Gr.
Hiramaki Fm.
Nakamura Fm.
Hachiya Fm.
Tomikusa Gr.
Oshimojo Fm.
Aratani Fm.
Kunimi Fm.
Ito-o Fm.
Kurosedani Fm.
Asakawa Fm.
Shiote Fm.
Siratorigawa Gr.
Yotsuyaku Fm.


A
ca. 20 Ma
B
ca. 18 Ma
C
ca. 16 Ma
140°
145°
150°
125°
130°
135°
50°
45°
40°
35°
30°
1
2
3
4
5
6
7
8
9–12
13
14
15
16
17–18
19
20

Family	Species	*L*	*DT head*	*DAP head*
	IPMM 60488	>338	76.2	72.2
Rhinocerotidae	*Brachypotherium brachypus*	468.0	-	-
	Diaceratherium aurelianense	433–471	-	-
	Plesiaceratherium gracilis	385.0	-	-
	Chilotherium wimani	375–395	72.5–85	59.5–74.5
	Aceratherium incisivum	411.0	67–76	67–70
	Acerorhinus tsaidamensis	395.0	-	-
	Hoploaceratherium tetradactylum	471.0	-	84.5
	Dicerorhinus schleiermacheri	523.0	100.0	103.0
	Diceros pachygnathus	480–517	94–110	88–97
	Rhinocerotini gen. et sp. indet.	566.0	113.0	105.0
Chalicotheriidae	*Metaschizotherium bavaricum*	>427	-	-
	Ancylotherium pentelicum	662.0	123.7	-
	Ancylotherium pentelicum	-	-	-
	Moropus elatus	650.0	95.0	93.0
	Schizotherium priscum	348.0	-	43.0
	Anisodon grande	441.0	90.4–91	-
	Schizotheriinae gen. et sp. indet.	608.0	-	-

DT dia	Remarks
78.8	Oishi *et al* . (2001); present study
74.5	Cerdeño (1993)
59–77.5	Cerdeño (1993)
44.0	Young (1937)
59.5–75	Deng (2002)
58–59	Hünermann (1989)
132.0	Bohlin (1937)
62.5	Guérin (1980)
76.0	Guérin (1980)
76.5–87.5	Guérin (1980)
85.0	Lu *et al* . (2017)
62.4	Coombs (2009)
126.3	Roussiakis and Theodorou (2001)
95.4	Giaourtsakis and Koufos (2009)
-	Holland and Peterson (1914)
-	de Bonis (1995)
78.0	Roussiakis and Theodorou (2001)
93.4	Handa and Kawabe (2016)