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Paleogene mammals from the Iwaki Formation in Japan: Their implications for the geologic age and paleobiogeography of this formation

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ABSTRACT

The mammalian fauna and geologic age of the Iwaki Formation of the Paleogene Shiramizu Group (Iwaki, southern Fukushima, northeastern Japan) are reviewed and previously undescribed specimens are described. The Iwaki mammalian fauna consists of three artiodactyl species: *Bothriogenys* sp. cf. *B. hui* (Anthracotheriidae), *Entelodon gobiensis* (Entelodontidae), and cf. *Notomeryx* sp. (Ruminantia). These three genera indicate an Ergilian Asian Land Mamma Age (=late Eocene [Priabonian] equivalent) correlation for the Iwaki Formation, demonstrating that the Eocene–Oligocene boundary exists within the Shiramizu Group. These three genera have never co-occurred in a single formation, although in Asia they have been recorded only in the late Eocene. In Asia, *Bothriogenys* has been recorded in the southern and middle regions, *Entelodon* has been mostly recorded in the northern and middle regions with one exception from the southern region, and *Notomeryx* has been recorded in the southern region. The co-occurrence of these three genera in the Iwaki Formation implies that *Bothriogenys*, *Entelodon*, and perhaps also *Notomeryx* can be useful late Eocene indicators in terrestrial eastern Asia. It also suggests that the Iwaki mammalian fauna is paleobiogeographically located between the northern and southern late Eocene faunas of eastern Asia, showing some faunal mixture. The Iwaki fauna is also unique in comprising diverse faunas of marine sharks and seashore birds together with terrestrial mammals. The Iwaki vertebrate fauna is key for reconstructing the faunas of the eastern coastal margin of the Asian Continent during the late Eocene.

1. Introduction

Paleogene land mammals have rarely been found in the Japanese Islands (Tomida, 1986; Miyata et al., 2011). Nevertheless, recent progress in field work and research have increased our understanding of Japanese Paleogene land mammals (Kato and Otsuka, 1995; Miyata and Tomida, 1998a, 1998b, 2008; Okazaki, 2003; Miyata, 2007; Tsubamoto et al., 2007; Saegusa and Tanaka, 2010; Miyata et al., 2011, 2013; Tsubamoto and Kohno, 2011; Kato, 2012). These recent studies have indicated that Japanese Paleogene land mammals contribute greatly to the age determination of terrestrial deposits in Japan and also to our understanding of the mammalian biochronology and evolution in continental Asia because the Japanese Islands were part of the eastern coastal margin of the Asian Continent until the middle Miocene (Taira et al., 1989; Taira, 2001).

This article reviews the fossil mammalian fauna of the Iwaki Formation of the Paleogene Shiramizu Group in Fukushima Prefecture, northeastern Japan. The Iwaki Formation contains coal seams and has yielded plant, molluscan, and many vertebrate fossils, but its geologic age has been determined only by a few pieces of evidence and old interpretation (Takai, 1961; Tomida, 1986; Yanagisawa et al., 1989; Okami, 1989; Koda, 1991; Ono and Suzuki, 1991; Suzuki, 1991; Ono and Hasegawa, 1991; Nemoto and O'Hara, 1996; Honda, 2000; Matsuoka et al., 2003; Suto et al., 2005). Three mammalian taxa have been reported from the Iwaki Formation so far: (1) *Entelodon* (Artiodactyla, Entelodontidae), which was originally described by Takai (1961) as an anthracotheriid artiodactyl, but was later identified as an entelodontid

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Entelodon by Tomida (1986); (2) an anthracotheriid briefly reported by Koda (1991); and (3) a ruminant briefly reported by Koda (1991). The present article describes the anthracotheriid and ruminant specimens reported by Koda (1991) and discusses the geologic age of the Iwaki Formation and the paleobiogeography of the Iwaki mammalian fauna. In particular, the anthracothere contributes greatly to the age determination of the Iwaki Formation and to the mammalian paleobiogeographical history in the Paleogene of the Asian Continent because anthracotheres are considered to be useful for the study of terrestrial biochronology and paleobiogeography from the middle Eocene to the Pliocene (Pickford, 1987, 1991; Rasmussen et al., 1992; Ducrocq, 1995, 1996; Lihoreau et al., 2004; Ducrocq and Lihoreau, 2006; Lihoreau and Ducrocq, 2007; Tsubamoto and Tsogtbaatar, 2008; Tsubamoto, 2010; Tsubamoto and Kohno, 2011; Tsubamoto et al., 2012).

2. Geological setting

The anthracotheriid and ruminant specimens described here were collected from the Iwaki Formation of the Paleogene Shiramizu Group at Iwaki City, Fukushima Prefecture, Tohoku Region, northeastern Japan (Fig. 1) during the excavation conducted in 1985 (Sato, 1991; Koda, 1991). They were briefly reported by Koda (1991).

The Shiramizu Group (Watanabe, 1928) consists of three formations: in ascending order, the Iwaki, Asagai, and Shirasaka Formations (Fig. 2; Yanagisawa et al., 1989; Suto et al., 2005). The Iwaki Formation consists of sandstones, mudstones, and coal seams; the Asagai Formation consists of massive sandstones; and the Shirasaka Formation consists of sandy mudstones (Yanagisawa et al., 1989; Suto et al., 2005).

The Iwaki Formation (Nakamura, 1913; Tokunaga, 1927) consists of fluvial sediments that were deposited near the seashore (Yanagisawa et al., 1989; Suto et al., 2005). It includes coal seams and is widely known as one of the famous coal mines in Joban Coalfield (Yanagisawa et al., 1989; Suto et al., 2005). It has yielded many plants, pollen, and molluscs (Takai, 1961; Nemoto and O'Hara, 1988, 2001, 2007, 2013; Sato, 1989; Soma and Takayanagi, 1991; Iwaki City Board of Education and Incorporated Foundation Iwaki City Education and Culture Corporation, 1991; Honda, 2000; Suto et al., 2005). It has also yielded vertebrate fossils, such as marine elasmobranch fishes (sharks) (*Heterodontus*, *Hexanchus*, *Odontaspis*, *Isurus*, *Negaprion*, *Squatina*, *Galeocerdo*, and *Lamna*) (Suzuki, 1991), actinopterygii fishes (Ono and Suzuki, 1991), chelonioid and trionychoid turtles (Ono and Suzuki, 1991), diverse seashore birds (procellarids, sulids, phalacrocoracids, pelagornithids, plotopterids, accipitrids, and alcids) (Ono and Hasegawa, 1991; Matsuoka et al., 2003), and terrestrial mammals (an anthracotheriid, *Entelodon*, and a ruminant) (Takai, 1961; Tomida, 1986; Koda, 1991). The pollen analysis by Soma and Takayanagi (1991) indicated that the Iwaki Formation was deposited in a warm and humid environment. The age of the Iwaki Formation is discussed below.

In the Iwaki Formation, an anthracotheriid (*Bothriogenys*) and a ruminant (cf. *Notomeryx*) were discovered at Locality 1 (Fig. 1), Tagashira, Iwaki City. Locality 1 is located in a granite mine (Sato, 1991). At Locality 1, the Iwaki Formation is thin and directly overlies the granitic rocks (basements) (Sato, 1991). The conglomerates of the formation at Locality 1 consist mainly of chert gravels and include almost no granite gravels (Sato, 1991). The precise stratigraphic horizon of the Iwaki Formation at Locality 1 in relation to the standard stratigraphy of the formation has not been well clarified. Suto et al. (2005) mentioned that the horizon at Locality 1 is within the upper part of the Iwaki Formation. On the other hand, *Entelodon* was discovered at Locality 2 (Fig. 1), which was a coal mine (Takai, 1961). Locality 2 is located about 11 km south of Locality 1. The horizon that yielded the specimen of *Entelodon* is within the upper part of the Iwaki Formation (Suto et al., 2005).

The Asagai Formation (Tokunaga, 1927) consists of seashore deposits (Yanagisawa et al., 1989; Suto et al., 2005). It has yielded many molluscs, fishes, and a plotopterid bird *Copepteryx hexeris* (Takai, 1961; Yanagisawa et al., 1989; Olson and Hasegawa, 1996; Suto et al., 2005; Nemoto and O'Hara, 2010). Its geologic age has been generally considered to be early Oligocene (Yanagisawa et al., 1989; Kurita, 2004; Suto et al., 2005). Mizuno (1964) considered the formation to be Oligocene based on its molluscan fauna. On the other hand, Asano (1962) correlated the formation to the European 'Lattorfian' stage on the basis of its foraminiferan fauna. The 'Lattorfian' stage is currently not used in the worldwide geologic timescale. It was correlated to either the uppermost Eocene or the lowermost Oligocene (Snyder et al., 1985); and it is recently correlated to the upper Eocene (Gradstein and Ogg, 2012). Suto et al. (2005) implied that the Asagai Formation is likely correlated to Calcareous Nannoplankton Zone CP16a–16b, which is correlated to the uppermost Eocene to lowermost Oligocene (Luterbacher et al., 2004). The Eocene–Oligocene boundary is within Calcareous Nannoplankton Zone CP16a (Luterbacher et al., 2004). Therefore, the possibility that the Asagai Formation might be correlated to the uppermost Eocene still remains.

The Shirasaka Formation (Tokunaga, 1927) consists of marine deposits (Yanagisawa et al., 1989; Suto et al., 2005). It has yielded many molluscs (Takai, 1961) and many microfossils and is well dated at the early part of the early Oligocene on the basis of its diatom and silicoflagellate faunas (Yanagisawa and Suzuki, 1987; Yanagisawa et al., 1989; Kurita and Matsuoka, 1994; Kurita, 2004; Suto et al., 2005). Suto et al. (2005) implied that the Shirasaka Formation is very likely correlated to Calcareous Nannoplankton Zone CP16c, which is correlated to the lowermost Oligocene (Luterbacher et al., 2004).

3. Materials and methods

The specimens from the Iwaki Formation described here are a maxillary fragment and isolated upper molar of an anthracotheriid and a mandibular fragment of a ruminant. They are housed in the Iwaki City Coal and Fossil Museum, Iwaki, Japan. The entelodontid specimen from the Iwaki Formation mentioned here is housed in The University Museum, University of Tokyo, Tokyo, Japan (Tomida, 1986). Epoxy casts of these specimens were made so that better photos of the specimens could be taken using the whitening method with ammonium chloride. Measurements were made using digital calipers. *Dental terminology*.—The anthracotheriid dental terminology used here basically follows Lihoreau and Ducrocq (2007). The ruminant dental terminology used here mostly follows Tsubamoto et al. (2003). *Dental abbreviations*.—**C**, upper canine; **M/m**, upper/lower molars; **P**, upper premolars. *Institutional abbreviations*.—**ISK-MF**, Iwaki City Coal and Fossil Museum (='Iwaki Sekitan Kasekikan' in Japanese) (Iwaki, Japan), mammalian fossil. **IVPP**, Institute of Vertebrate Paleontology and Paleoanthropology, Beijing, China. **UMUT**, The University Museum, University of Tokyo, Tokyo, Japan.

4. Systematic paleontology

Order Artiodactyla Owen, 1848
Family Anthracotheriidae Leidy, 1869
Subfamily Bothriodontinae Scott, 1940
Genus *Bothriogenys* Schmidt, 1913
Type species: Bothriogenys fraasi (Schmidt, 1913).