Bull. Natn. Sci. Mus., Tokyo, Ser. C, 22(3, 4): pp. 117–131, December 22, 1996

A Large Amynodontid from Karatsu Coal-field, Kyushu, Japan and the Eocene-Oligocene Boundary

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Abstract A right maxillary fragment with M^{2-3} of a large amynodontid was found from the middle member of the Yoshinotani Formation of the Ōchi Group at Tatsukawa Colliery of the Karatsu Coal-field, Kyushu in 1962. It was identified as cf. *Zaisanamynodon borisovi*, within the family Amynodontidae, based mainly on its large size and lower crowned molars. *Z. borisovi* is characteristic of Ergilian age of the Asian land mammal scheme. The Eocene-Oligocene boundary was recently redefined and correlated at 34 Ma in absolute age. The Ergilian land mammal age is currently placed in late Eocene. There has been controversy concernig the locations of the Eocene-Oligocene boundary within the Ōchi and Kishima Groups in the Karatsu Coal-field. The presence of cf. *Z. borisovi* in the Yoshinotani Formation and a fission track age (34.6 Ma) obtained from the same formation support the correlation of the Eocene-Oligocene boundary with the boundary between the Ōchi and Kishima Groups.

Introduction

A right maxillary fragment with M^{2-3} of a large amynodontid was found in 1962 from Tatsukawa Colliery of Dainichi Mining Co. in Imari City, Saga Prefecture, Japan (Fig. 1). The specimen was once identified as *"Amynodon watanabei"*, and its age was estimated as the late Eocene (TAKAI, 1962), but it was never formally described. One of us (YT) recently had an opportunity to examine this specimen and identified it as cf. *Zaisanamynodon borisovi*, as described below. *Z. borisovi* was recently reviewed by LUCAS and EMRY (1996) and LUCAS *et al.* (in press); it is assigned to the late Eocene (Ergilian land mammal age in Asian land mammal scheme).

Paleogene sequence in the Karatsu Coal-field is subdivided into two groups in ascending order (Fig. 2): the Ōchi Group which represents roughly a single sedimentary cycle intercalating many coal seams, and Kishima Group which is entirely marine sediments. The Eocene-Oligocene boundary in this sequence has not been resolved by geologists and paleontologists, and there are some con-

Fig. 1. Distribution of Tertiary coal-fields in northwestern Kyushu, Japan. c.f., coal-field; V., volcano; Pen., Peninsula.

troversies. NAGAO (1927, 1928) placed the Eocene-Oligocene boundary at the base of Kishima Group based on the analysis of molluscan faunas. YAMASAKI (1952) correlated the Yoshinotani Formation (Fm.) of Ōchi Group with the late Eocene based on the fossil floras. In addition, YAMASAKI *et al.* (1960) and YAMASAKI (1967) recognized an unconformity between the Ōchi and Kishima Groups and proposed placement of the Eocene-Oligocene boundary at this unconformity, between the Ōchi and Kishima Groups. On the other hand, MATSUSHITA (1949a, b) included the Ōchi Group entirely within the Oligocene. MIZUNO (1962a, b, 1963, 1964) included the Yoshinotani Fm. of the Ōchi Group within the Oligocene with some question (Fig. 2). In figure 2, the correlation of

Age	Group (G.) & Formation (F.)		Member (thickness in m.)	Remarks (Key bed)	Group (G.), Formation (F.) & Member (M.) (thickness in m.)		Stages by Molluscs (MIZUNO, 1963)		
	Karatsu Coal-field				**Sakito-Matsushima Coal-field**				
Oligocene	Kishima Group	Hatazu Sh F.	Up (100~150) M (40~60) Lo (90~130)	 Tf. X̊ Flysh	Nishisonogi Group	Katashima Alt. (170~180) Ushinokubi SS (30) Higire Alt. (50~60)	Nishisonogi stage	V. vestoides Z.	Oligocene
Oligocene	Kishima Group	Hatazu SS F.	Up (30~70) Lo (70~100)	 Tf. X̊	Nishisonogi Group	Shiota SS (55~60) Tonowo Alt. (50~60)	Nishisonogi stage	V. vestoides Z.	Oligocene
Oligocene	Kishima Group	Yukiaino SS F.	Up (50~90) M (70~130) Lo (20~50)	Tf. X̊ ▲ X̊ ▲	Nishisonogi Group	Kotohira SS (60~70) Tsurusaki SS (70~100) Okuura Sh (40~50)	Nishisonogi stage	V. vestoides Z.	Oligocene
Oligocene	Kishima Group	Sari SS F.	Up (30~40) Lo (30~40)	Tf(1). FT(1) (32.4) X̊ Cg	Nishisonogi Group	Fukuura Tf (35~40) Tokuman SS (30)	Nishisonogi stage	V. vestoides Z.	Oligocene
Oligocene	Kishima Group	Kishima F.	Up (50~100) Lo (50~120)	X̊(1) X̊(1) Basal Cg	Nishisonogi Group	Maze F. (40~100) Itanoura F. (100~120)	Maze s. Funazu s.	V. y. Z.	Oligocene
Eocene	Ōchi Group	Yoshinotani F.	Up (0~160) M (40~100) Lo (40~100)	C(1) X X̊ C(2) ◎ Tf(2) X FT(2) (34.6) C(3) Tf(3) X	Matsushima G.	Sakito-Oshima Coal-b. F. (90~110)	Okinoshima stage	V. n. Zone	Eocene
Eocene	Ōchi Group	Kyuragi F.	Up (140~400) Lo (30~400)	X̊(2) ▲ C(4)	Matsushima G.	Nakato F.	Okinoshima stage	V. n. Zone	Eocene

Fig. 2. Stratigraphic division of the Paleogene sequence of the Karatsu Coal-field and the correlation with that of the Sakito-Matsushima Coal-field and the molluscan stages by MIZUNO (1963). Correlation with MIZUNO (1963) is partly changed (see text and YAMASAKI, 1967). Rock facies: Cg, conglomerate; SS, sandstone; Sh, shale; ▲, glauconite SS; Alt, alternation of SS and Sh; Tf, tuffaceous bed; Tf(1), so called "Honeishi" (YAMASAKI *et al.*, 1959); Tf(2),(3), Kishidake and Takeari tuffaceous beds (YAMASAKI *et al.*, 1960); C, coal seams; C(1)–C(4), main coal seams. Fossils: ◎, mammal; X̊, marine mollusk; X, plant; X̊(1), Upper *Pecten sakitoensis* Zone, X̊(2), Lower *P. sakitoensis* Zone and *Athleta japonica* Zone (NAGAO, 1927, 1928). FT, fission track age (KIMURA & TSUJI, 1989). V. n. Zone, *Venericardia nipponica* Zone; V. y. Z., *Venericardia yoshidai* Zone; V. vestoides Z., *Venericardia vestoides* Zone.

MIZUNO's molluscan stages is adjusted accordingly with the correlation of YAMASAKI (1967).

Recognition of cf. *Zaisanamynodon borisovi* (present paper), as well as a fission track age of 34.6 Ma obtained from the middle part of the Yoshinotani Fm. (KIMURA & TSUJI, 1989; Fig. 2) support correlation of the Yoshinotani Fm. in the late Eocene, hence the Eocene-Oligocene boundary is placed at the boundary between the Ōchi and Kishima Groups.

Geology of Karatsu Coal-field

Karatsu Coal-field is one of the several Tertiary coal-fields distributed in northwestern region of Kyushu (Fig. 1). The Paleogene sequence composing the Karatsu Coal-field is distributed to the southwest of the line between Saga and Karatsu Cities; its eastern end contacts basement rocks by either fault or unconformity. The basement rocks are primarily "Paleozoic" Sangun metamorphic rocks intruded by Mesozoic granitic rocks. For detailed stratigraphy and tectonics of the Karatsu Coal-field, as well as correlation with adjacent coal-fields, see YAMASAKI (e.g., 1953, 1959, 1967) and YAMASAKI *et al.* (1960). Stratigraphy and sedimentary environments related to the amynodontid fossil described in the present paper is summarized below.

Structure of the Karatsu Coal-field is roughly as follows: the beds, as a whole, are monoclinal that strike approximately northwest-southeast or east-west and dip 10–15 degrees to the southwest or south. The direction of dip approximately matches the original dip of sedimentation, which further indicates that the basin was formed as a bay open to the south.

Stratigraphy of the Paleogene sequence in the Karatsu Coal-field is divided into two groups in ascending order (Figs. 2 & 3): coal-seam bearing Ōchi and marine Kishima Groups; their contact is a gentle angular unconformity. The rock facies are generally coarse-grained, often conglomeratic, in the northeastern part of the coal-field, while they become fine-grained and extremely thickened toward the south. Therefore, typical contemporaneous heterotopic facies can often be recognized (Fig. 3). Figures 2 and 3 also show some notable key beds such as conglomerates, glauconite sandstones, fossil-bearing beds, tuffaceous beds (a representative bed of which is "Honeishi bed", (YAMASAKI *et al.*, 1959)), and major coal seams. Based mainly on these key beds, the stratigraphy of Karatsu Coal-field is correlated precisely with that of Sakito-Matsushima Coal-field (YAMASAKI, 1959) in figure 2. Correlation with the geologic stages by molluscan fossils proposed by MIZUNO (1962a, b, 1963, 1964) is also included in figure 2. However, correlation of the Sakito-Oshima Coal-bearing Fm. with the marine Funazu stage (=Funazu Sandstone Fm. at Takashima Coal-field), as MIZUNO (1963, 1964) proposed, is not rational, and the correlation in figure 2 is revised to

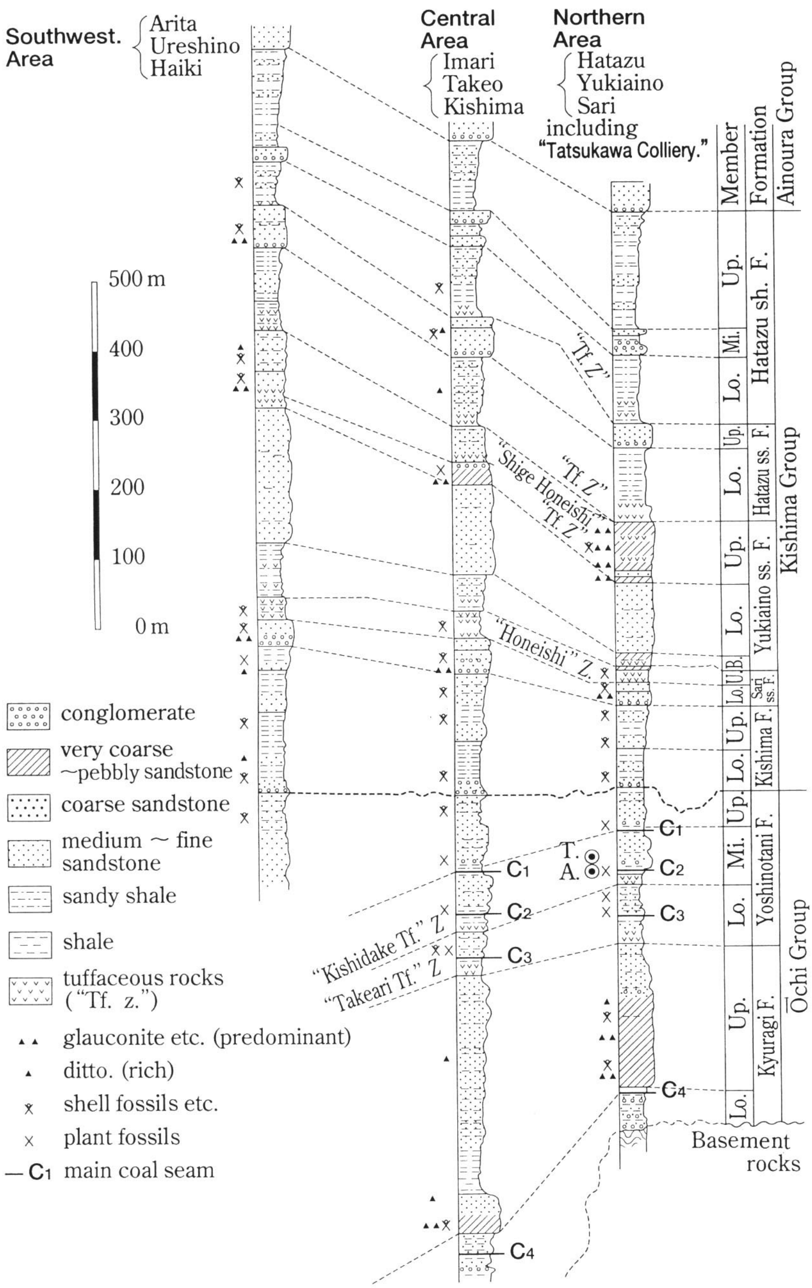

Fig. 3. Composite geologic columns of the Karatsu Coal-field. Northeast of the coal-field to the right and southwest to the left. A. ⦿, horizon of cf. *Zaisanamynodon borisovi*; T. ⦿, titanothere gen. et sp. indet.

reflect this interpretaion.

Ōchi Group: The Ōchi Group is about 300–800 meters in thickness; it is extremely thickened toward the south from the northeastern margin of the coal-field. The Group is divided into Kyuragi and Yoshinotani Fms., in ascending order, and represents roughly a single transgressive-regressive sedimentary cycle. The Kyuragi Fm. is composed mainly of coarse- to medium-grained, massive glauconite sandstones, occasionally includes lens-shaped beds of conglomerates, and bears abundant marine molluscan fossils. *Pecten sakitoensis* Zone and *Atheleta japonica* Zone by NAGAO (1928) are included in this formation. MIZUNO (1962a, b, 1963, 1964) called them as *Venericardia nipponica* Zone which he correlated with the Upper Eocene Okinoshima stage (Fig. 2). Lower part of the Kyuragi Fm. contains a major coal seam (Kyuragi Goshaku = C4; Fig. 3), and the basal part is extremely course grained and often includes so called "purple shales" (NAGAO, 1927; MATSUSHITA, 1949a) which are characteristic in the basal part of many Paleogene coal-fields in Kyushu.

Yoshinotani Fm. is composed mainly of coarse- to medium-grained, thick, massive, white arkose sandstones and coal-seam-bearing shales. This formation intercalates, at its lower part, with well continuous Takeari and Kishida tuffaceous beds (YAMASAKI *et al.*, 1960). Yoshinotani Fm. contains more than 20 coal seams; it is a brackish to fresh water sequence representing a fluctuating marine regression. Three of those coal seams are relatively continuous, major and workable coal seams, namely, in ascending order, the Iwaya Sanjaku, Kishima Sanjaku, and Kishima Goshaku which are shown as C3, C2, and C1, respectively, in figures 2 to 4. The middle member of the formation yields abundant plant fossils, including *Sabalites nipponicus*, *Musophyllum complicatum*, *Nelumbium nipponicus*, and *Lygodium Kaulfusi.* The fossils serve to correlate the formation with the late Eocene Ube Coal-bearing Fm. in Yamaguchi Prefecture (YAMASAKI, 1952). The shale beds above and below C2 (Kishima Sanjaku) yielded cf. *Zaisanamynodon borisovi*, titanothere gen. et sp. indet., as well as the mollusc *Corbicula mirabilis*; their sedimentary environments are interpreted as fan, delta, or lagoon in association with a bay, located at the northern end of this coal-field sedimentary basin.

Kishima Group: The Kishima Group overlies the Ōchi Group with an unconformity; it is composed entirely of marine sediments with no coal seams. For details, see YAMASAKI (1959, 1967) and YAMASAKI *et al.* (1960). The Kishima Group is extremely thick; about 600–1000 meters in total thickness. It is divided into five formations as shown in figures 2 and 3. As of the Ōchi Group, the Kishima Group also shows rock facies that are coarse-grained sediments, occasionally including conglomeratic rocks, at the northeastern part of its distribution in or near contact with basement rocks; it becomes finer grained and extremely thickened toward the southwest. The Kishima Fm., lower most unit of the Kishima Group, begins with basal conglomerates composed mainly of muddy sediments, indicating embayment environments, that yield abundant marine molluscan fossils. These marine molluscs were called Upper *Pecten sakitoensis* Zone by NAGAO (1927, 1928) and is correlated with the *Venericardia yoshidai* Zone by MIZUNO (1963, 1964) (Fig. 2). Upper part of Sari Sandstone Fm. also yields abundant marine molluscan fossils which were correlated with the *Venericardia vestoides* Zone by MIZUNO (1963, 1964). The Sari Fm. also yielded various fossils such as sharks, turtles, corals, and brachiopods.

Relationship between Ōchi and Kishima Groups: Figure 4 shows columnar sections of the Yoshinotani Formation below the basal conglomerates of the Kishima Group at various areas in northern part of the Karatsu Coal-field. Based on these data, a panel diagram is compiled (Fig. 5). As seen in figures 4 and 5, it is obvious that the upper part of Yoshinotani Fm. is partially removed by erosion. Amount of this erosion decreases toward the south (e.g., Tatsukawa, Iwaya) but becomes much deeper toward the north, and even the top portion of

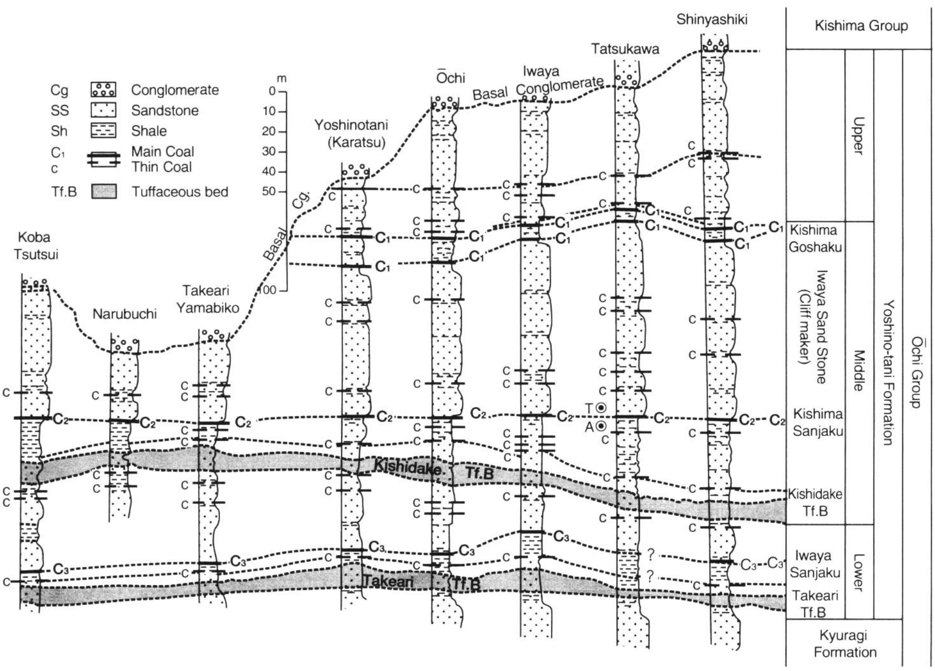

Fig. 4. Relationship between the Kishima and Ōchi Groups at northern part of the Karatsu Coal-field, including Tatsukawa Colliery (after YAMASAKI *et al*., 1960). Toward the northern end of the coal-field (to the left), the upper member (occasionally the middle member as well) of the Ōchi Group is eroded, and the basal conglomerate of the Kishima Group overlies directly on the top of this surface. A. ◉, horizon of cf. *Zaisanamynodon borisovi*; T. ◉, titanothere gen. et sp. indet.

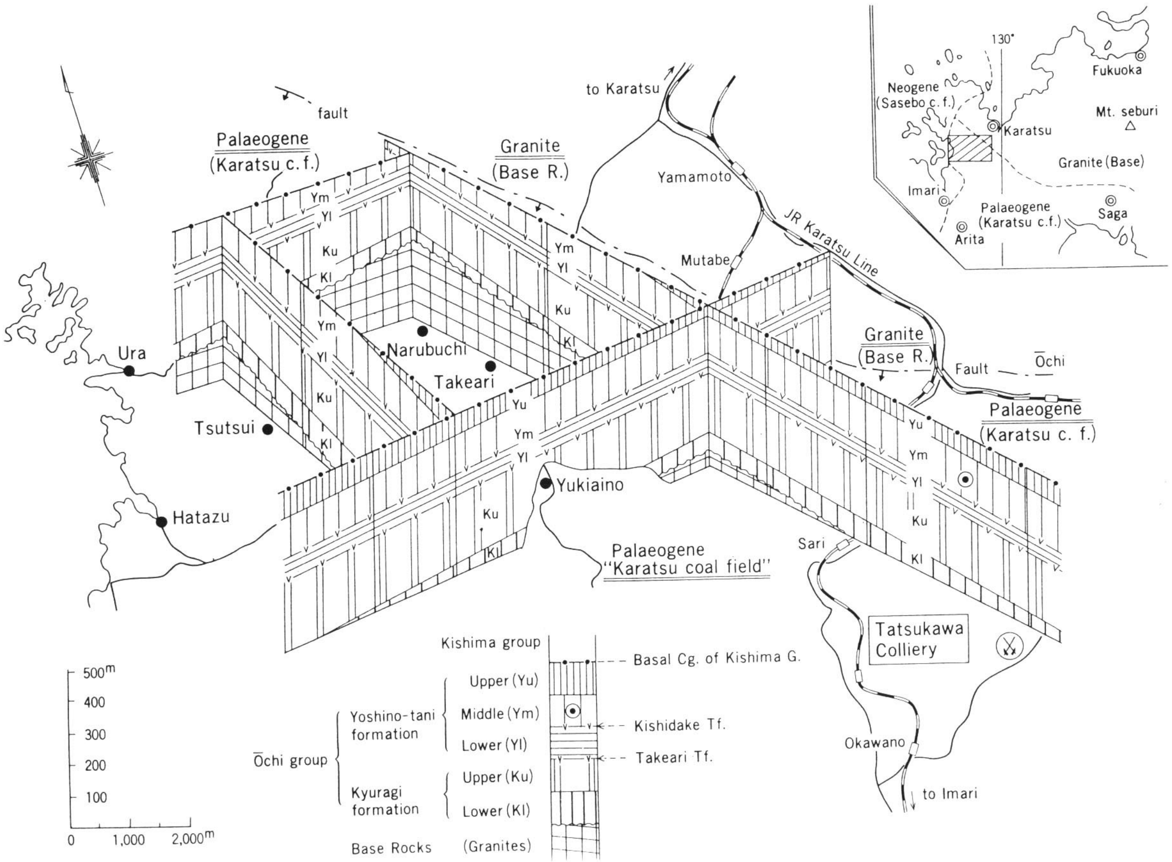

Fig. 5. Panel diagram showing the relationship between the Ōchi and Kishima Groups at northern part of the Karatsu Coal-field. ◎ indicates the horizon of cf. *Zaisanamynodon borisovi.*

the middle member of the Yoshinotani Fm. was eroded in the northern part of the coal-field (e.g., Takeari, Narubuchi). Furthermore, thickness of the upper member of the Yoshinotani Fm., based on boring data, changes drastically between certain neighboring two points in the southern part of the coal-field. From these facts, it is inferred that the contact relationship between the Ōchi and Kishima Groups is primarily a gentle angular unconformity not only at the northern part but also within the entire area of the Karatsu Coal-field. Considering the geology of the Sakito-Matsushima Coal-field where similar unconformities are well known, it is inferred that the sedimentary basin of the Karatsu Coal-field was open to the south during deposition of the Ōchi Group, then the eastern part of the basin was uplifted after deposition of the Ōchi Group, and a larger scale transgression occurred during deposition of the Kishima Group.

Systematic Paleontology

Order Perissodactyla OWEN, 1848
Suborder Ceratomorpha WOOD, 1937
Superfamily Rhinocerotoidea COPE, 1879
Family Amynodontidae SCOTT et OSBORN, 1883
Subfamily Amynodontinae SCOTT et OSBORN, 1883
Tribe Metamynodontini KRETZOI, 1942
Cf. ***Zaisanamynodon borisovi*** BELYAEVA, 1971
(Figures 6 and 7)

Referred specimen: A right maxillary fragment with partly broken M^{2-3}, stored at National Science Museum, Tokyo, Vertebrate Paleontology (NSM-PV) 20047.

Locality: A point on the main haulage gallery at about 1.2 km north-northwest from the main entrance of Tatsukawa Colliery of Dainichi Mining Company at Okawa-machi, Imari City, Saga Prefecture, Japan. The Tatsukawa Colliery is now closed but was located about 5 km northeast relative to Okawano Station of JR Chikuhi Line (Fig. 1).

Horizon: Just below the coal seam called "Kishima Sanjaku" (C2), which was also called "Goshaku-so" as a trade name at Tatsukawa Colliery, within the middle member of the Yoshinotani Fm. of Ōchi Group; the late Eocene.

Description: In the following description, dental terminology follows WALL (1982a). Although partially broken and fairly worn, both M^2 and M^3 have a pi (π) shaped arrangement of lophs with the protoloph and metaloph oblique to the ectoloph. Although fairly worn, it is observable that both molars are rather brachydont for a huge amynodont. M^2 is quadratic in outline; weak antecrochet is present; no crochet is present. Because the anterolabial portion is broken, it is not possible to observe positions of the parastyle and anterior rib of ectoloph. The

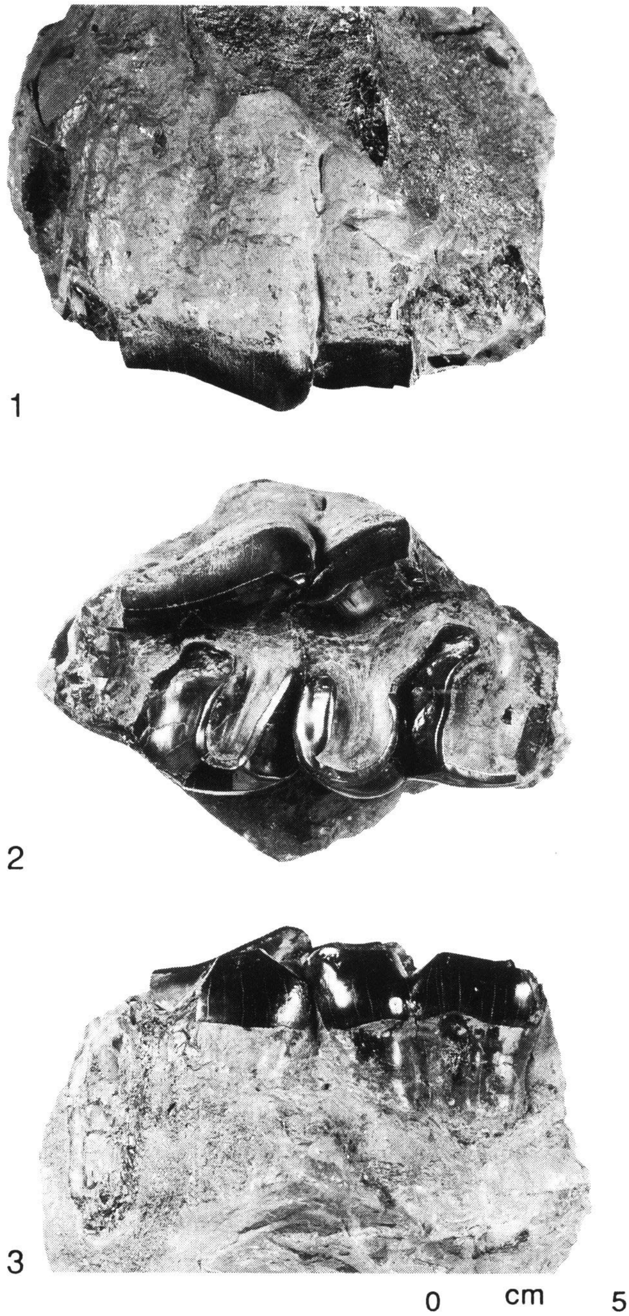

Fig. 6. Cf. *Zaisanamynodon borisovi* from Tatsukawa Colliery, Kyushu, Japan. 1–3, NSM-PV 20047. 1, buccal, 2, occlusal, and 3, lingual views.

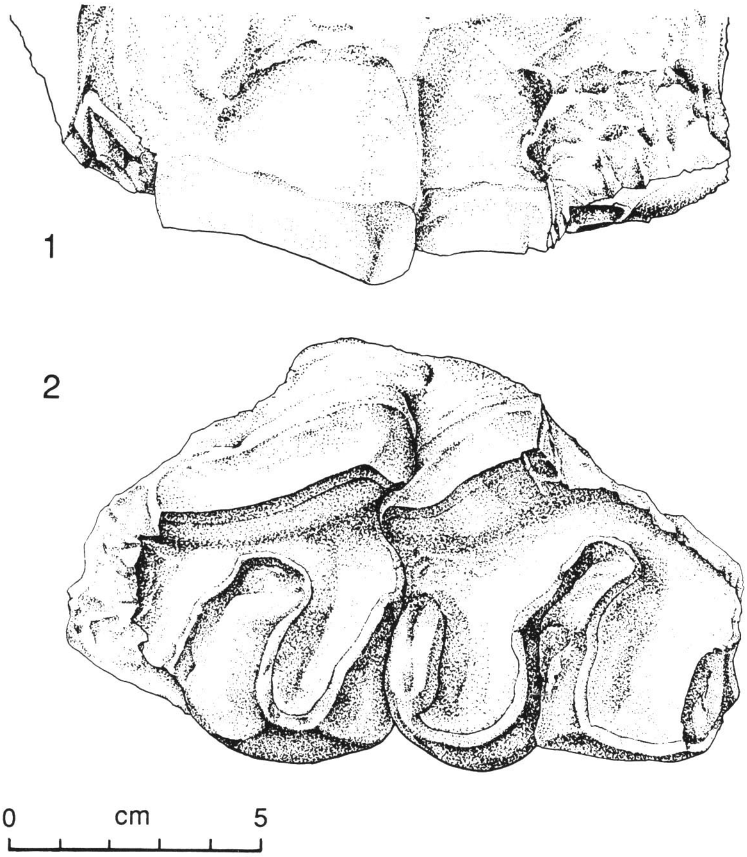

Fig. 7. Cf. *Zaisanamynodon borisovi* from Tatsukawa Colliery, Kyushu, Japan. 1–2, NSM-PV 20047. 1, buccal, and 2, occlusal views.

ectoloph is slightly convex labially at the position of the metacone. M^3 is trapezoidal in outline and is somewhat smaller than M^2. Although occlusal surface of the posterior margin is broken, it is estimated from the remaining part of the tooth that metastyle is large and deflected labially. No antecrochet is present. The anterior rib of ectoloph is distinct, but the parastyle is broken and therefore is not observable; the ectoloph is concave labially.

The size of the teeth is very large for an amynodontid (Fig. 8). Because neither of the molars is complete, it is not possible to obtain full measurements; only obtainable measurement is maximum width of M^3, which is 73 mm.

Discussion: Based on the arrangement of lophs of M^{2-3} and the quadratic or trapezoidal M^3 with large metastyle, the specimen belongs to the family Amynodontidae. Named taxa of the family include 24 genera and 55 species, but many of them are probably invalid (WALL, 1989). WALL (1982b, 1989) reviewed all

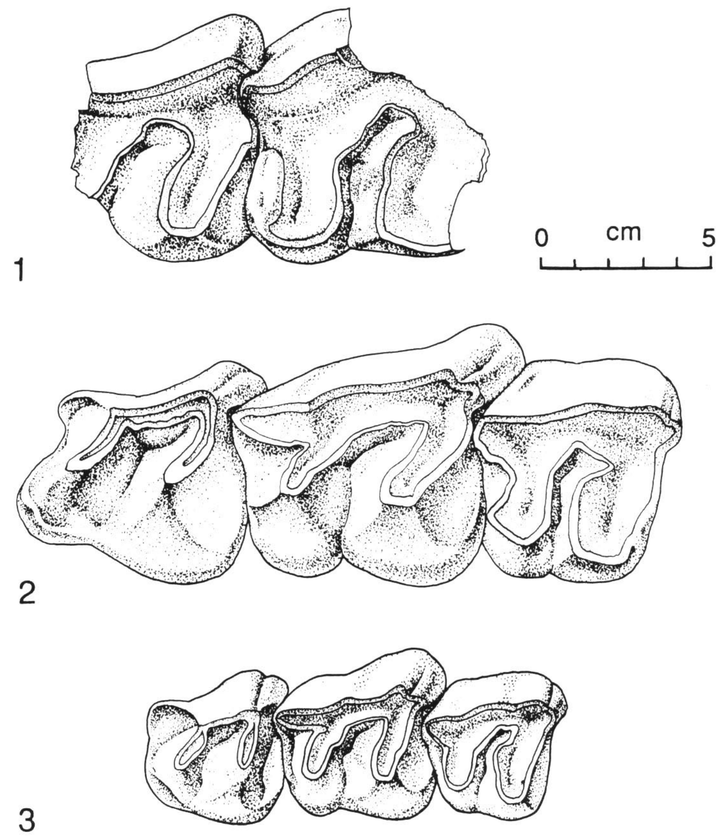

Fig. 8. Comparisons with the type of *Z. borisovi* and *Amynodon advenus*. 1, cf. *Zaisanamynodon borisovi* from Japan (NSM-PV 20047); 2, holotype of *Z. borisovi* (reversed; redrawn after BELYAEVA, 1971); 3, *Amynodon advenus* (reversed; redrawn after WILSON & SCHIEBOUT, 1981).

the genera and presented a realistic classification of the family, which seems well accepted (e.g., LUCAS & EMRY, 1996; LUCAS *et al.*, in press). We also follow WALL (1989).

Classification of the family Amynodontidae depends mostly on the skull morphology including dental formula (WALL, 1989). The Tatsukawa specimen (NSM-PV 20047) described above includes only M^{2-3}, and it is almost impossible to identify with certainty at the generic level by the diagnoses given by WALL (1989). However, its huge size and moderate crown height are useful for identification. Only three large sized genera are recognized: *Zaisanamynodon*, *Metamynodon*, and *Cadurcotherium*, which compose the tribe Metamynodontini. *Cadurcotherium* is similar in size to the Tatsukawa specimen but has much higher crowned molars. Also, the M^3 metaloph of *Cadurcotherium* is much reduced. *Metamynodon* is somewhat smaller than the Tatsukawa specimen and has still higher crowned molars. *Zaisanamynodon*, which has the lowest molar crown height among the tribe Metamynodontini, is as large as and has similar crown height with the Tatsukawa specimen. Actually, the Tatsukawa specimen is somewhat larger than the type specimen of *Z. borisovi* (BELYAEVA, 1971; Fig. 8). Thus, the Tatsukawa specimen most likely belongs to the genus *Zaisanamynodon*. The fact that *Zaisanamynodon* is known only from Asia (Kazakhstan and northern China), while *Metamynodon* is known only from North America may support the above identification. The genus *Zaisanamynodon* is currently known by a single species, *Z. borisovi*.

A few named taxa of huge amynodontids, e.g., "*Gigantamynodon*" spp., are known from Mongolia and China, but they are all considered to be *nomina dubia* (WALL, 1989; LUCAS *et al*., in press).

TAKAI (1962) identified the Tatsukawa specimen as "*Amynodon watanabei*". However, "*Amynodon watanabei*" reviewed by TAKAI (1950) seems a mixture of probably two taxa. The maxillary fragment with M^{2-3} from Uryu, Hokkaido is much smaller (maximum width of M^3 is 53 mm; about 27% smaller) than the Tatsukawa specimen; it more likely belongs to *Sharamynodon* or *Sianodon* according to WALL's (1989) classification.

Eocene-Oligocene Boundary at the Karatsu Coal-field

Zaisanamynodon borisovi is known from Inner Mongolia of China and Kazakhstan, and is currently restricted to the Ergilian land mammal age (lma) (LUCAS & EMRY, 1996); it may be an index taxon of the Ergilian lma (LUCAS *et al*., in press). The Ergilian lma was originally assigned to the early Oligocene by RUSSELL and ZHAI (1987). The stratotype for the Eocene-Oligocene boundary was recently designated in the Massignano section in Italy; it is correlated with calcareous nannofossil zones, planktonic foraminiferal zones, magnetic anomalies, and radiometric ages (PREMOLI-SILVA & JENKINS, 1993). Correlation of this boundary with non-marine strata in western North America using magnetostratigraphy and radiometric ages indicates that the Chadronian lma (North American correlative of the Ergilian) is best assigned to the late Eocene (PROTHERO & SWISHER, 1992). DUCROCQ (1993) also convincingly demonstrated by the analysis of faunal composition that the fauna previously assigned to the early Oligocene in Asia is in fact that of late Eocene. Based on these studies, the Ergilian is now assigned to the late Eocene.

Although we could not assign the large amynodontid from Tatsukawa Colliery to the genus *Zaisanamynodon* with certainty, the specimen is certainly closely related to *Z. borisovi*, and the Yoshinotani Fm. that yielded the specimen is probably correlated with Ergilian age, the late Eocene. A fission track age (34.6 Ma) obtained from the Yoshinotani Fm. (KIMURA & TSUJI, 1989) agrees with the assignment of the Yoshinotani Fm. to the late Eocene, since the absolute age of the Eocene-Oligocene boundary is assigned to 34 Ma (PREMOLI-SILVA & JENKINS, 1993). Another fission track age (32.4 Ma) was obtained from the Sari Sandstone Fm. of the Kishima Group (KIMURA & TSUJI, 1989), indicating an early Oligocene age for that formation (Fig. 2). Combining all these correlation and dates, it is best interpreted that the Eocene-Oligocene boundary within the Karatsu Coal-field is placed at the boundary between the Ōchi and Kishima Groups.

Acknowledgments

We thank Mr. Katsunori YAMASHITA, a geologist of the Tatsukawa Colliery, and late Mr. Denko ISHII, president of Dainichi Mining Company, who found and donated the specimen to one of us (T. YAMASAKI), who then donated it to the National Science Museum, Tokyo. We are grateful to Dr. Spencer G. LUCAS of New Mexico Museum of Natural History and Science who gave us valuable suggestions as well as providing unpublished manuscripts. Thanks are also due to Dr. Everett H. LINDSAY of University of Arizona for reading the manuscript and giving valuable comments. Figure 4 was compiled based mainly on the original data obtained from numerous coal mining borings of the area. Figures 1 through 5 were prepared by the staff of West Japan Engineering Consultants, Inc., and figures 7 and 8 were drawn by Ms. Yasuko OKAMOTO.

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