Paleontological Research, vol. 16, no. 3, pp. 244–251, September 30, 2012

doi:10.2517/1342-8144-16.3.244

Gaudryceras tombetsense Matsumoto, a Maastrichtian ammonoid from the Aridagawa area, Wakayama, southwestern Japan

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Received December 8, 2011; Revised manuscript accepted March 14, 2012

Abstract. **Discovery of *Gaudryceras tombetsense* Matsumoto, 1984 in the Futakawa Formation of the Sotoizumi Group in the Aridagawa area, Wakayama, southwestern Japan establishes that this formation includes sediments of early Late Maastrichtian age, which is the youngest record of the Sotoizumi Group distributed in Shikoku and the Kii Peninsula. The occurrence of the youngest fossils from the easternmost area of the Sotoizumi Group may support the suggestion that the depocenter of the Sotoizumi basin migrated eastward due to movement along the Kurosegawa Tectonic Zone (KTZ), which was still active during Campanian to Maastrichtian time.**

Key words: ammonoid, Cretaceous, Futakawa Formation, *Gaudryceras tombetsense*, Sotoizumi Group, Wakayama

Introduction

Ammonoids attributable to *Gaudryceras* Grossouvre, 1894 are abundant in the Upper Cretaceous of the North Pacific realm and include strongly ornamented species that exhibit various ribbing styles, most of which have a restricted stratigraphic range (Matsumoto, 1995). Recent work involving the stratigraphy and fossil assemblages of the Upper Cretaceous of Sakhalin revealed that several species of *Gaudryceras* occur successively in Maastrichtian strata (Maeda *et al*., 2005). Shigeta *et al*. (2010) demonstrated that *Gaudryceras izumiense* Matsumoto and Morozumi, 1980 is very useful for correlation of Lower Maastrichtian strata in Southwest Japan, Hokkaido and Alaska. Because of its widespread distribution in the circum-North Pacific realm, *Gaudryceras* is an ideal ammonoid for precise biostratigraphic correlation of Maastrichtian strata in this particular realm.

The Cretaceous Sotoizumi Group is widely distributed in the Aridagawa area, Wakayama, which is located in the Chichibu Belt in the Outer Zone of Southwest Japan. Various megafossils have been reported from the western part and its biostratigraphy has been well documented (e.g. Matsumoto, 1947, 1954; Hirayama and Tanaka, 1956a, b; Obata and Ogawa, 1976; Tanaka, 1985; Ohara, 2005; Misaki *et al*., 2008; Misaki and Maeda, 2009, 2010a, 2010b). In contrast, the combination of rare megafossils and a complicated geologic structure has precluded the establishment of a precise biostratigraphic correlation in the eastern part (Misaki and Ohara, 2012).

We have recently discovered several specimens referable to *Gaudryceras tombetsense* Matsumoto, 1984 in the Futakawa Formation of the eastern part of the Aridagawa area. These specimens are herein described and we discuss their biostratigraphic significance.

Geologic notes

Outcrops of the Futakawa Formation, which is the upper part of the Sotoizumi Group, are well exposed along a small tributary of the Aridagawa River in the western area of Kunohara (Figure 1). In the lower reaches of the tributary (Locs. 1–4), these outcrops include alternating beds of mudstone and sandstone, which dip 85–90°

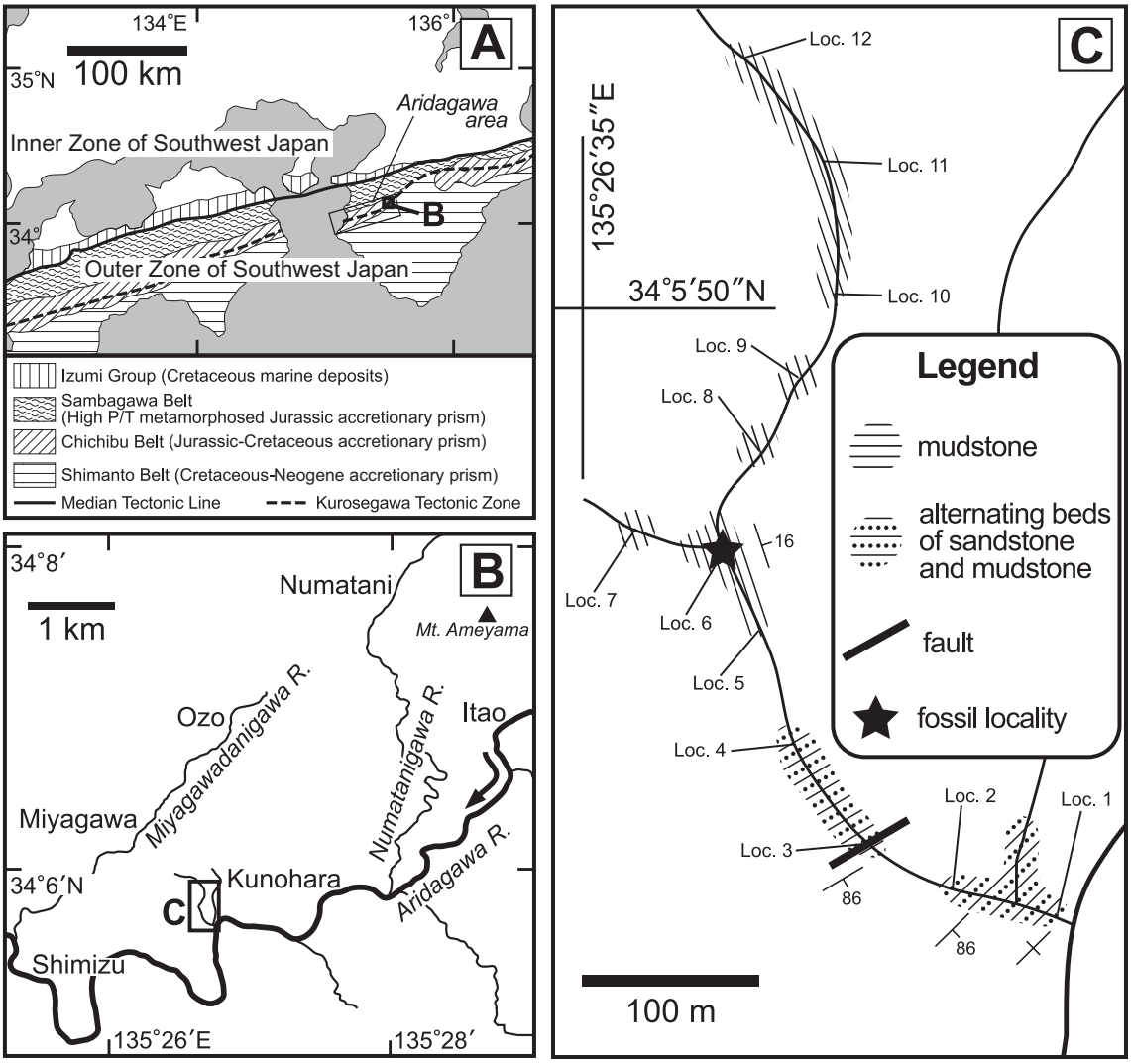

Figure 1. Index maps (A and B) and route map (C) showing locality from which *Gaudryceras tombetsense* was collected. Modified after Taira (2001) and Yamakita and Otoh (2000a).

eastward and strike N45–60°E. The sandstones generally show turbiditic features such as graded bedding and current ripple lamination. Along the middle reaches (Locs. 5–12), exposures include dark gray bioturbated mudstones that dip 15–20° eastward and strike N15–20° W. The stratigraphic relationship between sediments in the lower and middle reaches is unclear because of poor exposures in this particular region. All specimens of *Gaudryceras tombetsense* were obtained from dark gray bioturbated mudstones at Loc. 6.

Paleontological description

Systematic descriptions basically follow the classification established by Klein *et al*. (2009). Morphological terms in the systematic description are those used in the Treatise on Invertebrate Paleontology (Moore, 1957). Quantifiers used to describe the shape of the ammonoid shell replicate those proposed by Matsumoto (1954, p. 246) and modified by Haggart (1989, table 8.1).

Institution abbreviations.—WMNH = Wakayama Prefectural Museum of Natural History, Kainan.

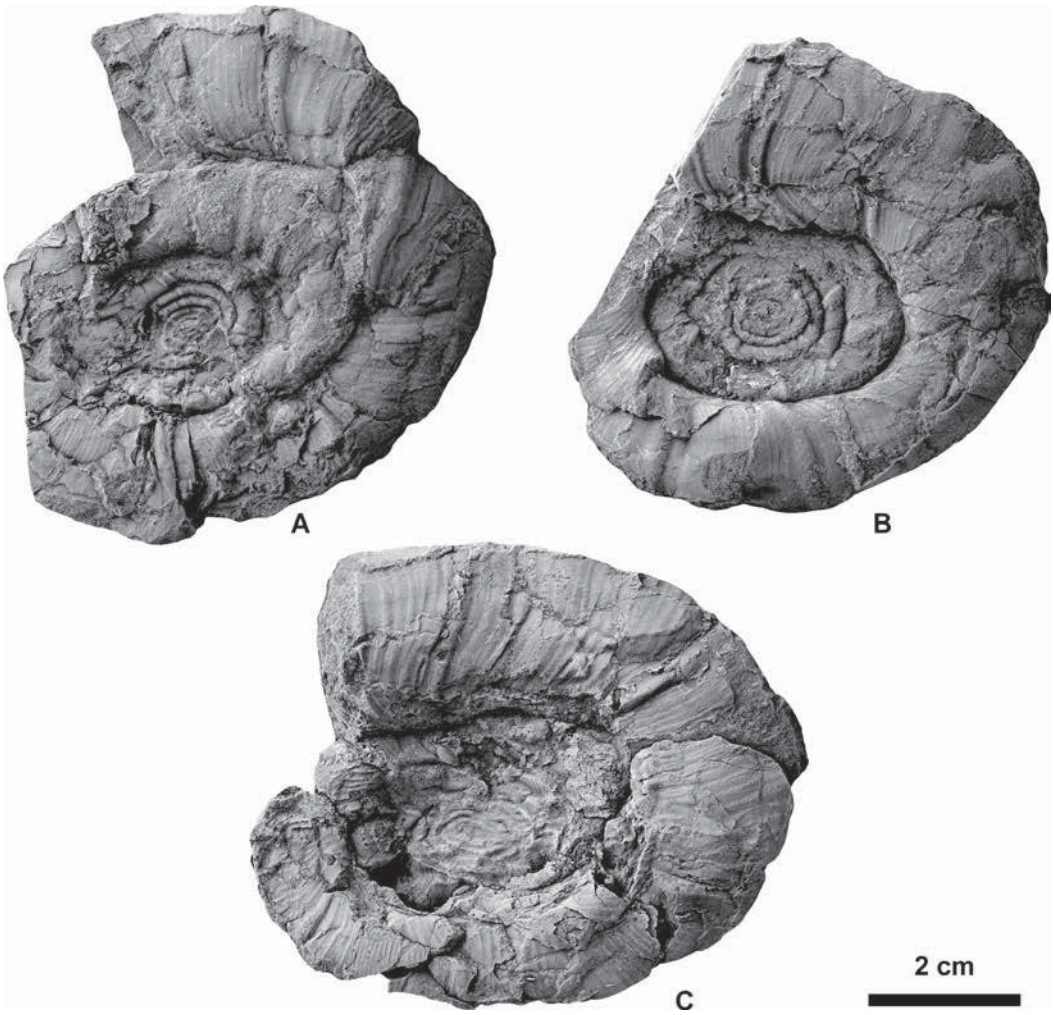

Figure 2. *Gaudryceras tombetsense* Matsumoto, 1984, from the Futakawa Formation at Loc. 6 in the Aridagawa area, Southwest Japan. **A**, WMNH-Ge-1140210134; **B**, WMNH-Ge-1140210132; **C**, WMNH-Ge-1140210136.

Superfamily Tetragonitoidea Hyatt, 1900
Family Gaudryceratidae Spath, 1927
Genus ***Gaudryceras*** Grossouvre, 1894

Type species.—*Ammonites mitis* Hauer, 1866.

Gaudryceras tombetsense Matsumoto, 1984

Figures 2–4

Gaudryceras sp. nov. Matsumoto, 1980, p. 289, pl. 46, figs. 3–5, pl. 47, figs. 3–6.
Gaudryceras tombetsense Matsumoto, 1984, p. 2, pl. 1, figs, 1–2, pl. 2, figs.1-4; Shigeta *et al*., 1999, pl. 6, fig. 1; Maeda *et al*., 2005, p. 66, figs. 26.3, 27–31.
Gaudryceras hamanakense Matsumoto and Yoshida. Zonova, 1990, p. 33, pl. 1, figs. 1–3, pl. 2, figs. 1–5, pl. 3, figs. 1–6; Yazykova, 1992, p. 196, pl. 111, figs. 1–2; Yazikova, 1994, p. 292, pl. 3, figs. 2–3.
Gaudryceras denmanense Whiteaves. Yazykova, 1993, p. 153, pl. 88, fig. 2; Yazikova, 1994, p. 291, pl. 6, fig. 3.
?*Gaudryceras* cf. *tombetsense* Matsumoto. Maeda *et al*., 2005, p. 67, fig. 40.1–40.3; Tsujino *et al*., 2010, p. 682, fig. 4.

Holotype.—GK.H5991, figured by Matsumoto (1984, p. 2, pl. 1, figs. 1–2), from the Maastrichtian Heitaro-zawa Formation of the Yezo Group exposed along the Kikusui-gawa Valley , a branch of the Tombetsu River, in the Nakatombetsu area, northern Hokkaido, Japan.

Material examined.—Eight specimens were collected from dark gray bioturbated mudstones at Loc. 6 along a small tributary of the Aridagawa River in the western area of Kunohara. Three specimens, WMNH-Ge-1140210132 (Figure 2B), 1140210134 (Figure 2A), 1140210136 (Figure 2C), are immature shells (60–70 mm in diameter), whereas the others are probably mature shells (over 150 mm in diameter). WMNH-Ge-1140210279 consists of a partly

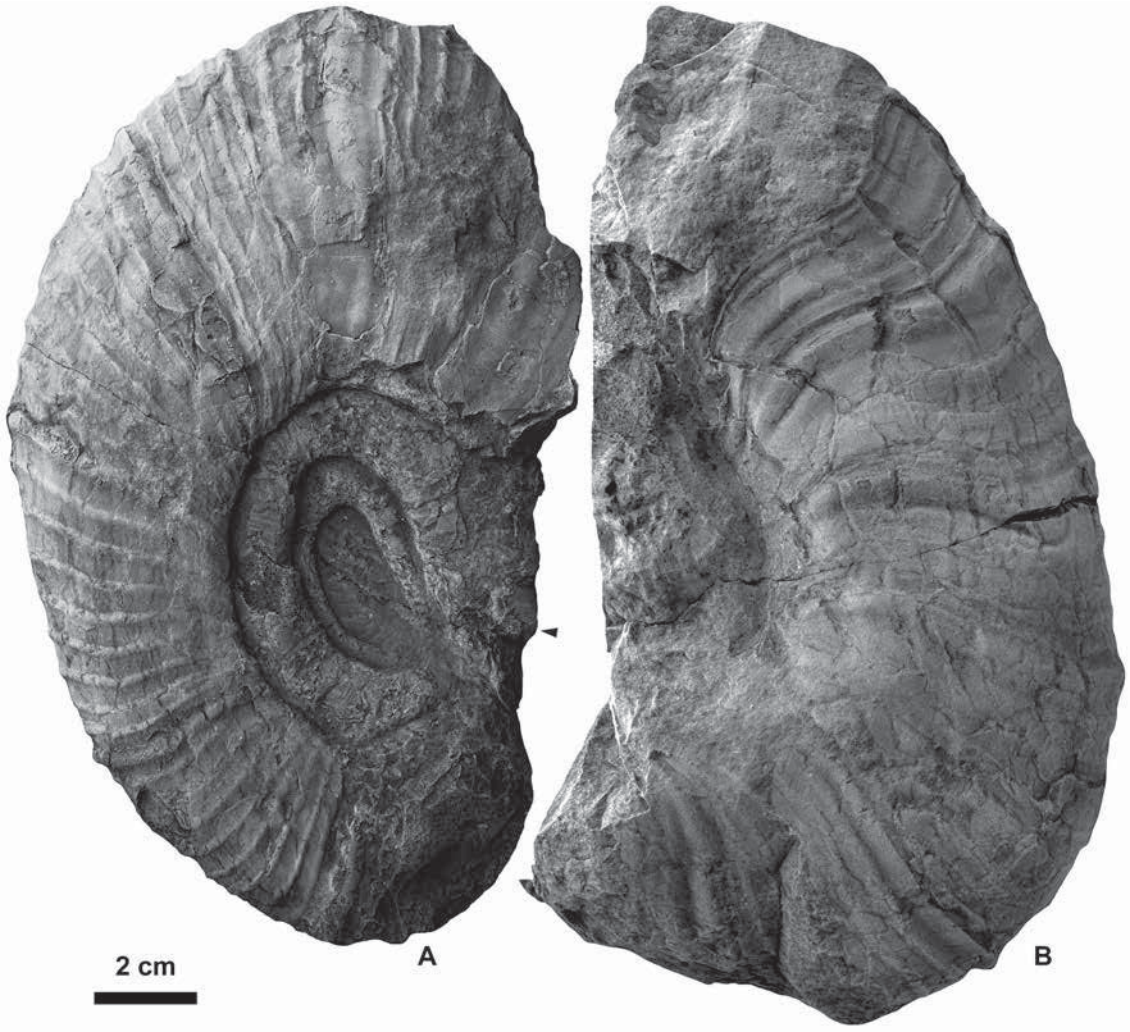

Figure 3. *Gaudryceras tombetsense* Matsumoto, 1984, from the Futakawa Formation at Loc. 6 in the Aridagawa area, Southwest Japan. **A**, WMNH-Ge-1140210279; **B**, WMNH-Ge-1140210059-b. Black arrow indicates position of last septum.

preserved phragmocone and most of the body chamber (Figure 3A). WMNH-Ge-1140210135-b consists of the phragmocone and a partly preserved body chamber (Figure 4A). Specimens WMNH-Ge-1140210135-d (Figure 4B), WMNH-Ge-1140210059-b (Figure 3B) and WMNH-Ge-1140210088 consist only of body chamber fragments. All specimens are significantly deformed and crushed.

Description.—Early whorls (up to 50 mm in diameter, Figure 2): Very evolute shell with moderately inflated whorl section characterized by arched venter and convex flanks. Umbilicus fairly wide with shallow umbilicus and rounded shoulders. Ornamentation consists of very fine, dense lirae, which arise at umbilical seam and approach a sigmoidal pattern before passing over the venter in a broad convex arch. Intercalation of lirae occurs on umbilical shoulder and lower flank. Each whorl has variable close or distant, rounded, collarlike ribs, running parallel to lirae.

Middle whorls (50–100 mm in diameter, Figure 3A): As size increases, whorl section tends to become slightly compressed. Lirae gradually develop into slightly more distant, narrowly raised ribs, which increase in strength and frequency as diameter increases. These ribs follow the same sigmoidal pattern as those in the early whorls. Collarlike ribs become more frequent.

Later whorls (over 100 mm in diameter, Figures 3, 4): As shell grows larger, whorl section becomes even more compressed. Ribs become much coarser and more distant and collarlike ribs become more frequent. These ribs tend to become more sinuous as diameter increases. Suture line finely and deeply incised, partly visible (Figure 4A).

Remarks.—These specimens exhibit remarkable onto-

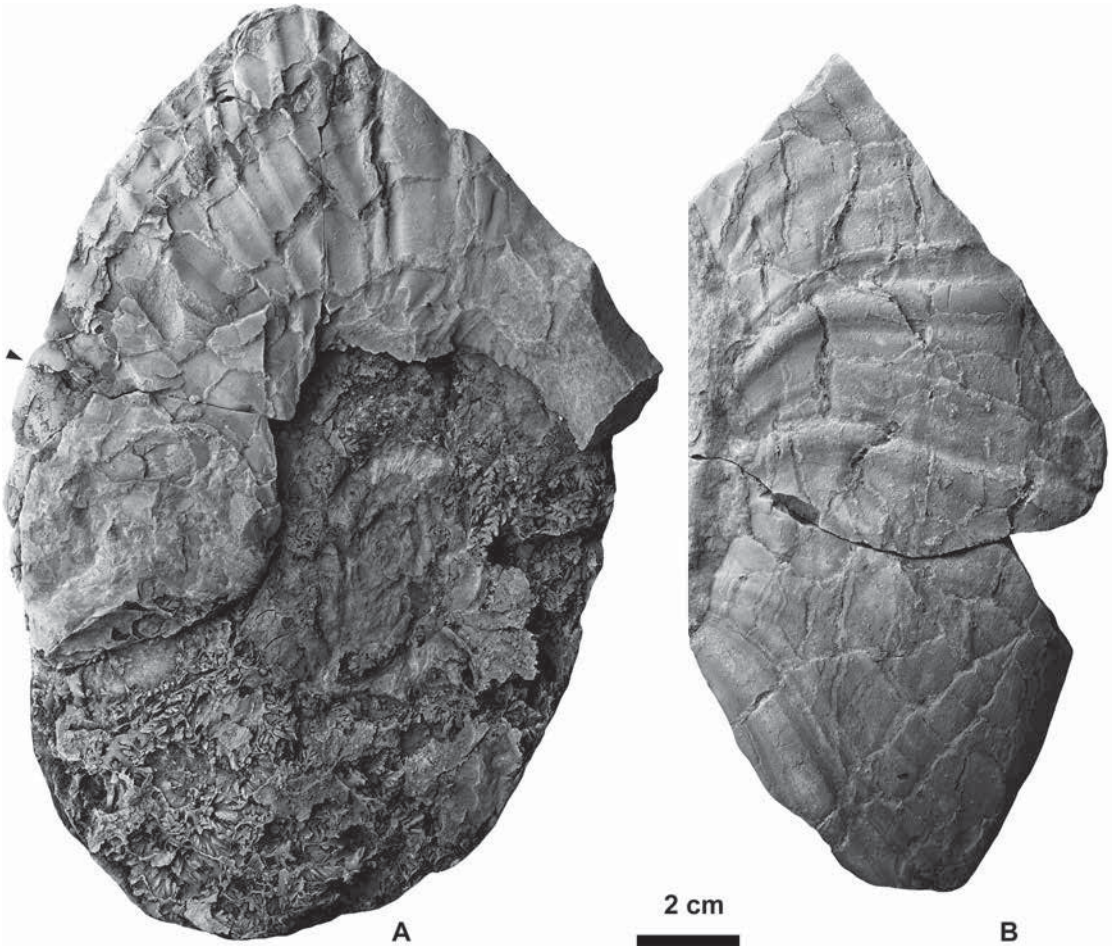

Figure 4. *Gaudryceras tombetsense* Matsumoto, 1984, from the Futakawa Formation at Loc. 6 in the Aridagawa area, Southwest Japan. **A**, WMNH-Ge-1140210135-b; **B**, WMNH-Ge-1140210135-d. Black arrow indicates position of last septum.

genetic changes in ribbing ornamentation, which is characteristic of *Gaudryceras tombetsense* as described by Matsumoto (1984) and Maeda *et al*. (2005). Therefore, we assign them with confidence to *G. tombetsense*.

As Matsumoto (1984, p. 4) pointed out, specimens described as *Gaudryceras* sp. nov. from the Sukumo-Nakamura area in western Shikoku, Japan (Matsumoto 1980) are conspecific with *G. tombetsense*. Specimens assigned to *Gaudryceras hamanakense* Matsumoto and Yoshida (1979) by Zonova (1990), Yazykova (1992) and Yazikova (1994) are identical to juvenile shells of *G. tombetsense*. A large specimen described as *G. denmanense* Whiteaves (1901) by Yazykova (1993) and Yazikova (1994) closely matches the adult shell of *G. tombetsense*.

Maeda *et al*. (2005, p. 67) and Tsujino *et al*. (2010) described *Gaudryceras* cf. *tombetsense* from Sakhalin and eastern Shikoku based respectively on a single juvenile specimen. However, juvenile shells of *Gaudryceras* resemble each other and a proper species assignment can sometimes be very difficult. Their attribution of this specimen to *G. tombetsense* may be correct, but additional specimens showing the different growth stages are necessary in order to make a species assignment with a higher degree of confidence.

Inouye (1933) reported *Gaudryceras crassicostatum* (Jimbo, 1894) from a locality in the Kunohara area, which may in fact be the same fossil locality as ours. Hirayama and Tanaka (1956b) also listed *Gaudryceras*(?) sp. from the Itao area, about 3 km east of Kunohara. However, since they provide neither an illustration nor a detailed description, it is very difficult to restudy them.

Discussion

Gaudryceras tombetsense has been reported from the Maastrichtian of various areas in the Northwest Pacific,

e.g. Shikoku, Hokkaido and Sakhalin. Details of their stratigraphic position and associated fauna are understood very well in the Makarov area of southern Sakhalin (Maeda *et al*., 2005).

Gaudryceras tombetsense occurs abundantly in Unit K2 of the Krasnoyarka Formation in the Makarov area together with inoceramid *Sphenoceramus hetonaianus* (Matsumoto, 1952), which is diagnostic of the upper Lower to lower Upper Maastrichtian (Toshimitsu *et al*., 1995). Maeda *et al*. (2005, Fig. 14.1, 14.4) illustrated a specimen that they attributed to *Pachydiscus gracilis* Matsumoto, 1979 from the same horizon, but we herein refer it to a peculiar morphotype belonging to *P. flexuosus* Matsumoto, 1979 by having a much compressed whorl section. *P. flexuosus* is normally indicative of the Upper Maastrichtian (Toshimitsu *et al*., 1995). *P. flexuosus* seems to appear in the Lower Maastrichtian, while the stratigraphic range obviously extends upward to the Upper Maastrichtian (Maeda *et al*., 2005; Maeda and Shigeta, 2005). Such associated fossils suggest that the *G. tombetsense*-bearing bed should be correlated with the lower Upper Maastrichtian.

The occurrence of *Gaudryceras tombetsense* in the Futakawa Formation in the Kunohara area demonstrates that this particular horizon is of early Late Maastrichtian age, which is the youngest record of the Sotoizumi Group distributed in Shikoku and the Kii Peninsula. This evidence supports the suggestion by Tashiro (1985, 1993) that the age of the Sotoizumi Group becomes younger toward the eastern part of the basin because our fossil locality occurs in the easternmost area of the Sotoizumi basin.

According to Taira *et al*. (1981, 1983), sediments of the Cretaceous Period, including the Sotoizumi Group, were deposited in a strike-slip basin along the Chichibu Belt formed by movement along the Kurosegawa Tectonic Zone (KTZ). Tashiro (1985, 1994) and Yamakita and Otoh (2000a) thought that the movement occurred mainly during the Early Cretaceous, but Misaki and Maeda (2009) pointed out that the movement was still active during Campanian to Maastrichtian time. The discovery of early Late Maastrichtian fossils in the Futakawa Formation may support the suggestion of Misaki and Maeda (2009) that the depocenter of the Sotoizumi basin migrated eastward by movement along the KTZ, which was still active during Campanian to Maastrichtian time.

The Campanian-Maastrichtian Izumi Group is distributed along the Median Tectonic Line (MTL) of south-central Japan. This group is considered to have been deposited in a strike-slip basin formed by left-lateral strike-slip movement along the MTL (e.g. Taira *et al*., 1981, 1983; Miyata, 1990; Yamakita and Ito, 1999; Yamakita and Otoh, 2000b). The results of Misaki and Maeda (2009) as well as those from this study suggest that there were two parallel strike-slip basins along the eastern margin of Asia during latest Cretaceous time. This suggestion may provide an important key for reconstruction of the geotectonic history of southwestern Japan during the Cretaceous.

Acknowledgments

We thank Yasuyuki Tsujino (Tokushima Prefectural Museum, Tokushima), René Hoffmann (Ruhr University, Bochum) and Haruyoshi Maeda (Kyushu University, Fukuoka) for their valuable comments on the first draft. We are also grateful to Kuniharu Kamei (Hannan, Osaka) and Yukio Sako (Kushimoto, Wakayama) for donating specimens and providing information about their collection locality. Thanks are extended to Jim Jenks (West Jordan, Utah) for his helpful suggestions and improvement of the English text. This study was supported by a grant from the National Museum of Nature and Science in 2011 to Y. Shigeta (No. 20112001).

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