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A new species of *Gaudryceras* (Ammonoidea, Gaudryceratidae) from the lowest Maastrichtian of Hokkaido, Japan and its biostratigraphic implications

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Abstract. ***Gaudryceras hobetsense*** **sp. nov. is described from the** ***Nostoceras hetonaiense*** **Zone (= lowest Maastrichtian) of the Hobetsu area, south-central Hokkaido, Northern Japan. Its shell is characterized by fine lirae on early whorls, distant rounded or flat-topped, narrow band-like ribs on middle and later whorls, and frequent collar-like ribs on later whorls. The occurrence of this new species strongly suggests the presence of lowest Maastrichtian strata in southern Alaska, and sheds light on the age delineation of the chronologically poorly defined beds in northern and eastern Hokkaido.**

Key words: ammonoid, Cretaceous, ***Gaudryceras*****, Hobetsu, Hokkaido, Maastrichtian**

Introduction

The genus *Gaudryceras* de Grossouvre, 1894 is characterized by an evolute shell with a wide, shallow umbilicus, rounded venter and various ribbing styles. Although species of the genus ranging in age from late Albian to Maastrichtian are known worldwide (Kennedy and Klinger, 1979; Hoffmann, 2010), their typical occurrence is in the Tethyan and Indo-Pacific realms. Specimens attributed to the genus are fairly abundant in the Upper Cretaceous of the North Pacific realm and more than twenty species have been described over the past 100 years (Jimbo, 1894; Matsumoto, 1995; Klein *et al*., 2009).

Recently, Maeda *et al*. (2005) studied Santonian to Maastrichtian stratigraphy and fossil assemblages in southern Sakhalin, Russia, and documented the occurrence of several successive species of *Gaudryceras* in the uppermost Cretaceous. Shigeta *et al*. (2010) correlated upper lower Maastrichtian strata in Southwest Japan, Hokkaido and Alaska based on the common occurrence of *G. izumiense* Matsumoto and Morozumi, 1980. Furthermore, the discovery of *G. tombetsense* Matsumoto, 1984 in the Sotoizumi Group of Southwest Japan demonstrated that the group includes sediments of early late Maastrichtian age (Shigeta *et al*., 2012). Because of the successive occurrence of several species and their restricted stratigraphic ranges, *Gaudryceras* is an ideal ammonoid for precise biostratigraphic correlation of Maastrichtian strata in the North Pacific realm.

The biostratigraphic zonation scheme established for the lowest Maastrichtian of Japan is based mainly on ammonoids and inoceramid bivalves from the Hakobuchi Formation in the Hobetsu area, south-central Hokkaido (Figure 1, Toshimitsu *et al*., 1995). Although this formation contains rich ammonoid faunas (Matsumoto, 1942), most of its ammonoid taxa are known only from south-central Hokkaido. Since *Nostoceras hetonaiense* Matsumoto, 1977 is the only taxon that occurs in both south-central Hokkaido and Southwest Japan (Morozumi, 1985; Iwaki and Maeda, 1989), it has been regarded as a zonal-index taxon (Toshimitsu *et al*., 1995). *Inoceramus shikotanensis* Nagao and Matsumoto, 1940 occurs in lowest Maastrichtian sediments of various areas including Hokkaido (Ando *et al*., 2001; Ando and Ando, 2002), Shikotan Island in the Kuril Islands (Zonova *et al*., 1993), Sakhalin (Zonova *et al*., 1993; Shigeta *et al*., 1999) and Southwest Japan (Iwaki and Maeda, 1989), but it also occurs in the uppermost Campanian of Hokkaido (Matsunaga *et al*., 2008). Because of this lack

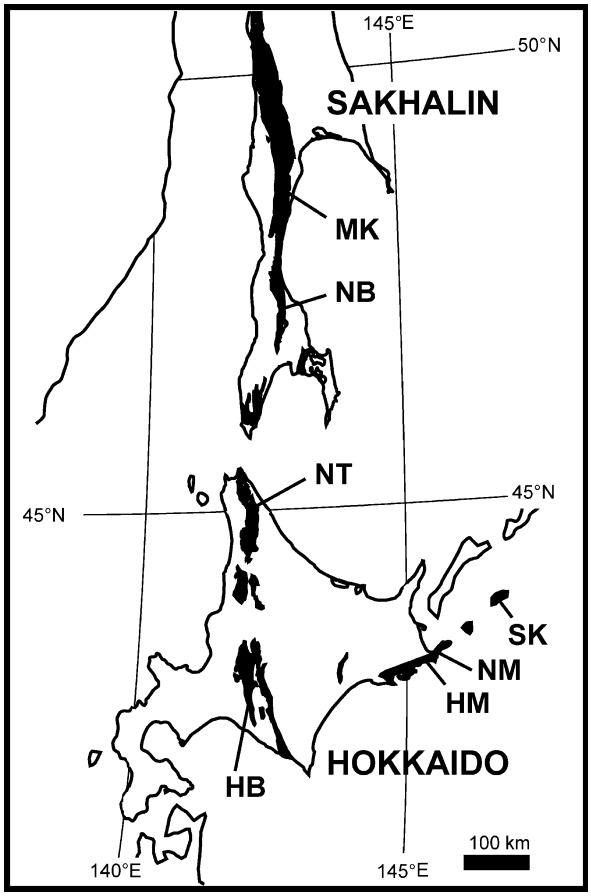

Figure 1. Index map showing distribution of Yezo Group and Nemuro Group exposures (black areas) in Hokkaido, Japan and Russian Far East. MK, Makarov; NB, Naiba; NT, Nakatombetsu; HB, Hobetsu; HM, Hamanaka; NM, Nemuro; SK, Shikotan Island.

of common zonal-index taxa, a precise biostratigraphic correlation of lowest Maastrichtian strata between the Hakobuchi Formation in south-central Hokkaido and other Cretaceous deposits in the North Pacific realm remains elusive.

Several specimens referable to *Gaudryceras* from the earliest Maastrichtian *Nostoceras hetonaiense* Zone in the Hobetsu area are reposited in the National Museum of Nature and Science, Tsukuba and Hobetsu Museum, Mukawa. We examined these specimens and recognized them as a new species of *Gaudryceras*. In this paper, we describe them and discuss the biostratigraphic correlation of lowest Maastrichtian strata in the North Pacific realm.

Notes on stratigraphy

The Hakobuchi Formation, which is the uppermost part of the Yezo Group in Hokkaido and is about 800 m thick, is widely distributed in the Hobetsu area (Takahashi and Wada, 1987; Takashima *et al*., 2004). It consists mainly of sandstone and is divided into four lithologic units, IVa-IVd (Matsumoto, 1942) and Ha-Hd (Tanaka, 1960). With regard to lithology, the units of each scheme are identical, but differ only by letter designation.

Unit IVa, composed mainly of sandstone in association with conglomerate, sandy mudstone and coal beds, contains the Campanian index inoceramid bivalves *Sphenoceramus schmidti* (Michael, 1899) and *S. orientalis* (Sokolov, 1914) in the middle part (Tanaka, 1960). Unit IVb, dominated by sandy mudstone, contains *Nostoceras hetonaiense* and *Pachydiscus japonicus* Matsumoto, 1947 (Tanaka, 1960), both of which are indicative of the lowest Maastrichtian (Toshimitsu *et al*., 1995). Unit IVc, consisting of sandstone with intercalations of conglomerate and sandy mudstone beds, includes the upper lower Maastrichtian fossils *P. kobayashii* (Shimizu, 1935), *P. gracilis* Matsumoto, 1979, *Gaudryceras izumiense* Matsumoto and Morozumi, 1980, and *S. hetonaianus* (Matsumoto, 1952) (Matsumoto, 1979; Matsumoto and Toshimitsu, 1992; Matsumoto *et al*., 1993; Shigeta *et al*., 2010). Unit IVd is composed mainly of unfossiliferous sandy mudstone.

The specimens upon which we based our new species of *Gaudryceras* were obtained from float calcareous concretions that most likely came from the Unit IVb sandy mudstone in the Hobetsu area.

Paleontological description

The systematic description follows 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).

Abbreviations for shell dimensions.—D = shell diameter; U = umbilical diameter; H = whorl height; W = whorl width; US = height of umbilical shoulder.

Institution abbreviations.—HMG = Hobetsu Museum, Mukawa, Hokkaido; MCM = Mikasa City Museum, Mikasa, Hokkaido; NMNS = National Museum of Nature and Science, Tsukuba.

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

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

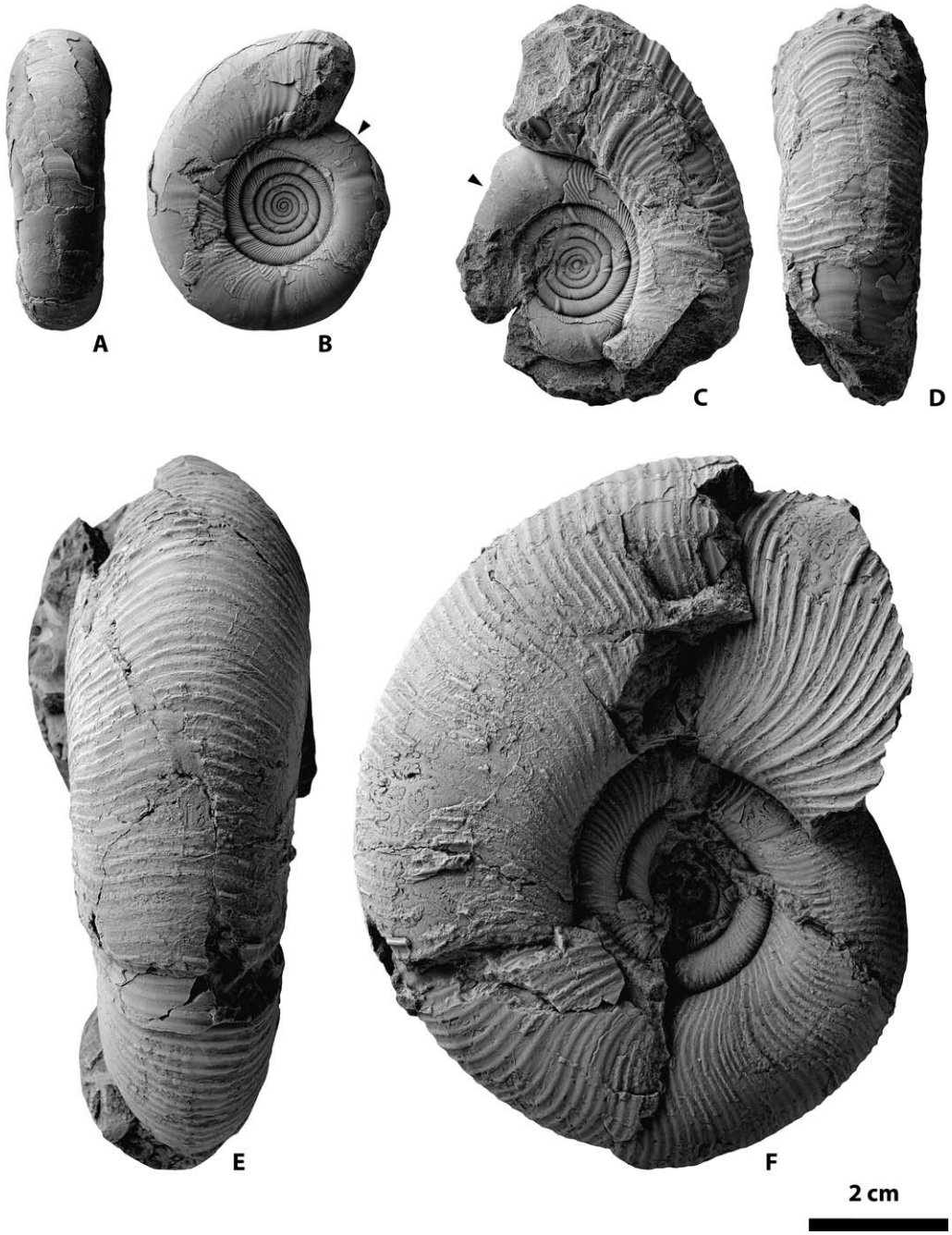

Figure 2. *Gaudryceras hobetsense* Shigeta and Nishimura sp. nov. from the Hobetsu area, Hokkaido. **A, B**, NMNS PM23449 (paratype); A, ventral view; B, left lateral view; **C, D**, HMG-1592 (paratype); C, right lateral view; D, ventral view; **E, F**, HMG-134 (paratype); E, ventral view; F, left lateral view. Black arrow indicates position of last septum.

Gaudryceras hobetsense sp. nov.

Figures 2–4

Gaudryceras tenuiliratum Yabe, 1903. Jones, 1963, p. 26, pl. 10, figs. 1–3.

Gaudryceras sp. Naruse *et al*., 2000, fig. 3-2.

Type specimens.—Holotype, HMG-1573, Figures 3 and 4 (previous register: MCM-A0355), measuring about 230 mm in diameter, was extracted from a float calcareous concretion found in a small tributary of the Tonai-zawa River (42°43′58″N, 142°14′16″E), a branch of the Saru River, in the Hobetsu area. Specimen consists of the

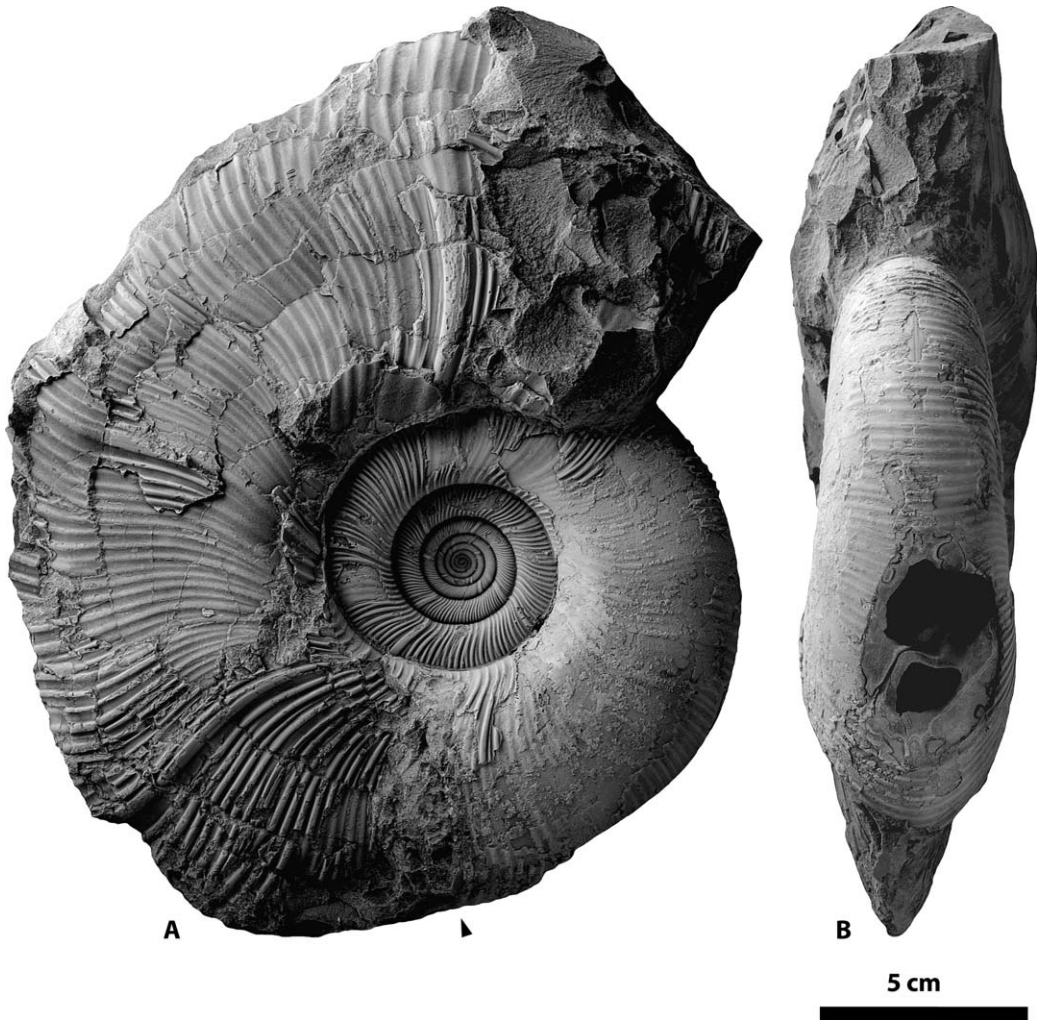

Figure 3. *Gaudryceras hobetsense* Shigeta and Nishimura sp. nov., HMG-1573 (holotype), from the Hobetsu area, Hokkaido. **A**, left lateral view; **B**, apertural view. Black arrow indicates position of last septum.

phragmocone and the majority of the body chamber, which begins at about 125 mm in diameter and occupies nearly two-thirds of the outer whorl.

Paratype, HMG-134 (Figure 2E–F), consisting only of the phragmocone measuring about 100 mm in diameter, was collected from a float calcareous concretion found in the Omagari-no-sawa River, a tributary of the Mukawa River, in the Hobetsu area.

Paratype, NMNS PM23449 (Figure 2A–B), measuring about 44 mm in diameter, was collected from a float calcareous concretion in the Shirakaba-sawa River, a tributary of the Hobetsu River, in the Hobetsu area. Specimen consists of the phragmocone and the majority of the body chamber, which begins at about 25 mm in diameter and occupies nearly the entire outer whorl.

Paratype, HMG-1592 (Figure 2C–D), was extracted from a float calcareous concretion found in a small tributary of the Ichiyanagi-no-sawa River (42°45′21″N, 142°12′48″E) in the Hobetsu area. Body chamber begins at about 33 mm in diameter and occupies much of the outer whorl, but most of the rear portion is missing.

Diagnosis.—Large-sized *Gaudryceras* with fine lirae on early whorls, distant rounded or flat-topped, narrow band-like ribs on middle and later whorls, and frequent collar-like ribs on later whorls.

Etymology.—Named after the Hobetsu area, south-central Hokkaido.

Description.—Early whorls (up to 40 mm in diameter, Figure 2A–D): Very evolute, slightly depressed shell with arched venter, indistinct ventral shoulders, and slightly convex flanks with maximum whorl width at mid-flank. Umbilicus fairly wide with moderately high, vertical wall and rounded shoulders. Ornamentation consists of fine, dense, slightly sinuous lirae, which arise at

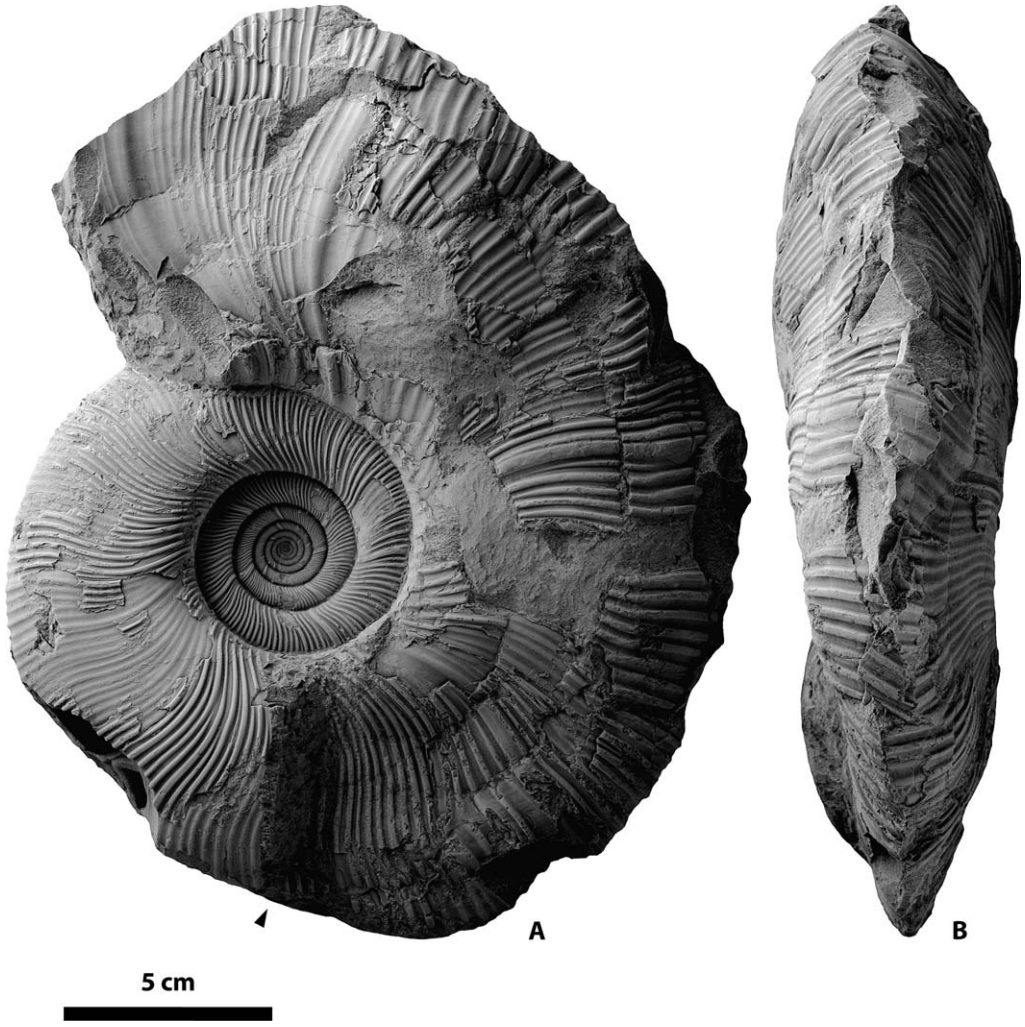

Figure 4. *Gaudryceras hobetsense* Shigeta and Nishimura sp. nov., HMG-1573 (holotype), from the Hobetsu area, Hokkaido. **A**, right lateral view; **B**, ventral view. Black arrow indicates position of last septum.

umbilical seam and pass over venter in a broad convex arch. Intercalation of lirae occurs on umbilical shoulder and lower flank. Each whorl has variable close or distant, rounded, collar-like ribs, running parallel to lirae.

Middle whorls (40–100 mm in diameter, Figure 2E–F): As size increases, whorl section tends to become slightly compressed, and umbilical width becomes narrower. Lirae gradually develop into more distant, narrowly raised rounded or flat-topped, band-like ribs, which increase in strength as diameter increases. These ribs follow the same flexuous, nearly sigmoidal pattern as those on early whorls. A few additional ribs are intercalated between primary ribs at the umbilical shoulder and lower flank.

Later whorls (over 100 mm in diameter, Figures 3, 4): As shell grows larger, whorl section becomes more compressed. Dense ribs increase in strength as diameter increases, and collar-like ribs become more frequent. Suture line finely and deeply incised, partly visible.

Measurements.—Taken at D = 44.0 mm of NMNS PM23449, U = 18.8 mm, H = 15.0 mm, W = 15.0 mm, U/D = 0.43, W/H = 1.03; at D = 99.4 mm of HMG-134, U = 33.3 mm, H = 38.4 mm, W = 34.2 mm, U/D = 0.34, W/H = 0.89; and at D = 125.0 mm (at last septum) of HMG-1573, U = 43.0 mm, H = 59.0 mm, W = 49.0 mm, U/D = 0.34, W/H = 0.83.

Comparison.—The adult stages of *Gaudryceras hobetsense* sp. nov. and *G. makarovense* Shigeta and Maeda (2005, p. 73) are very close, but *G. hobetsense* sp. nov. differs by the finer lirae on its early whorls and denser rounded or flat-topped, band-like ribs on middle whorls. *Gaudryceras makarovense* is characterized by ribs on middle to later whorls that exhibit a gently sloping adoral face and nearly vertical adapical face. Specimens identified as *G. tenuiliratum* by Jones (1963, pl. 10, figs. 1–3)

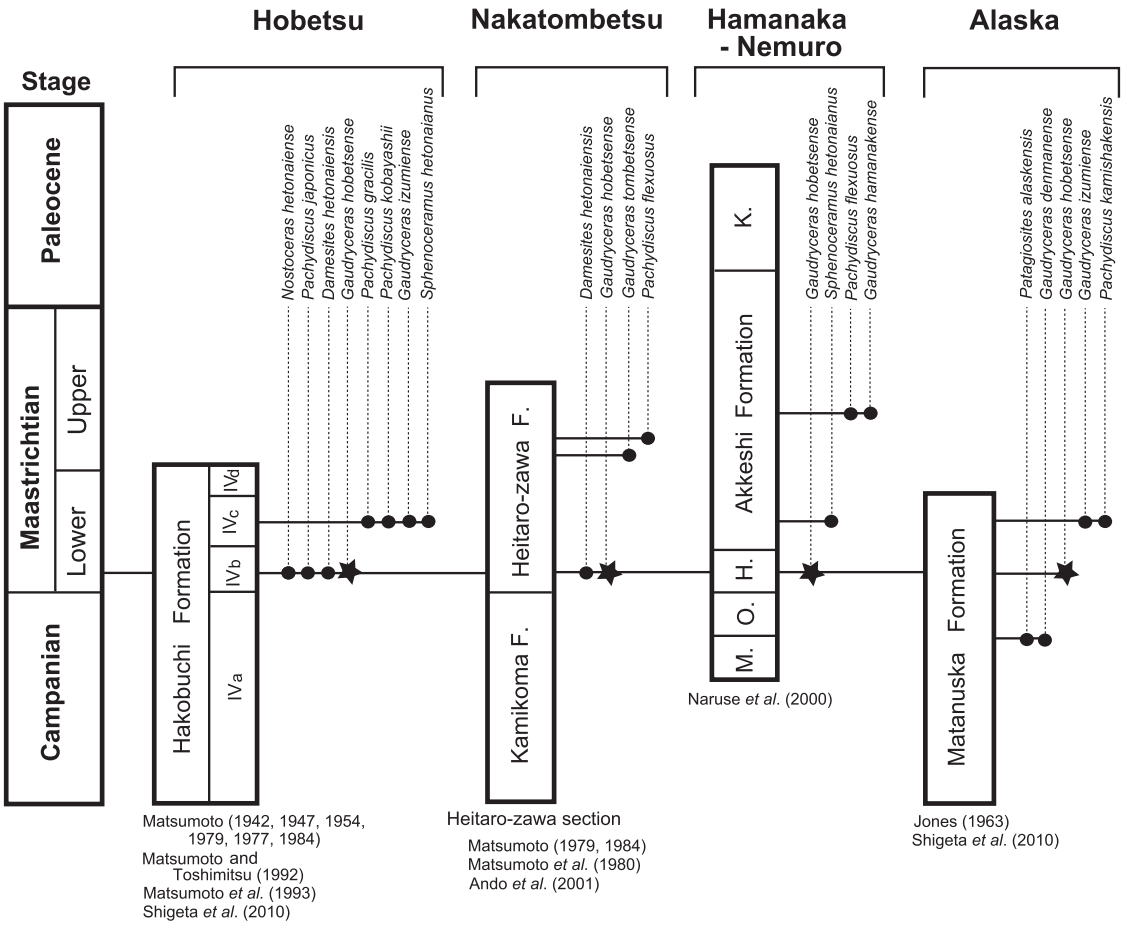

Figure 5. Diagram showing biostratigraphic correlation between Campanian-Maastrichtian deposits in Hokkaido (Hobetsu, Nakatombetsu, Hamanaka) and Alaska. *Gaudryceras hobetsense* Shigeta and Nishimura sp. nov. is an ideal ammonoid for the precise biostratigraphic correlation of the lowest Maastrichtian in these areas of the North Pacific realm. H.: Hamanaka Formation; K.: Kiritappu Formation; M.: Monshizu Formation; O.: Oborogawa Formation.

from the upper part of the Matanuska Formation in southern Alaska and termed *Gaudryceras* sp. by Naruse *et al*. (2000) from the Hamanaka Formation of the Nemuro Group in eastern Hokkaido share many similarities with *G. hobetsense* sp. nov., such as having distant rounded or flat-topped ribs, and we herein assign them to our new species.

Occurrence.—Described specimens were obtained from float calcareous concretions in the Hobetsu area. Although the exact horizons from which the concretions originated are uncertain, judging from their localities and lithologies, they almost certainly came from the sandy mudstone of Unit IVb, which is correlated with the *Nostoceras hetonaiense* Zone of earliest Maastrichtian age (Toshimitsu *et al*., 1995).

Discussion

Specimens assignable to *Gaudryceras hobetsense* sp. nov. are known from Upper Cretaceous deposits in northern and eastern Hokkaido and southern Alaska (Figure 5). The occurrence of this ammonoid species sheds light on the age delineation of the chronologically poorly defined beds in these regions as discussed below.

Northern Hokkaido

A continuous succession of the Heitaro-zawa Formation, which is the uppermost part of the Yezo Group in northern Hokkaido and the stratigraphic equivalent of the Hakobuchi Formation in south-central Hokkaido, is exposed along the Heitaro-zawa River in the Nakatombetsu area, northern Hokkaido (Figures 1, 5, 6). Because it includes *Damesites hetonaiensis* Matsumoto, 1954 in the lower part and *Pachydiscus flexuosus* Matsumoto, 1979 and *Gaudryceras tombetsense* Matsumoto, 1984 in the upper part, the section is regarded as one of the best sections for studying the biostratigraphy of the

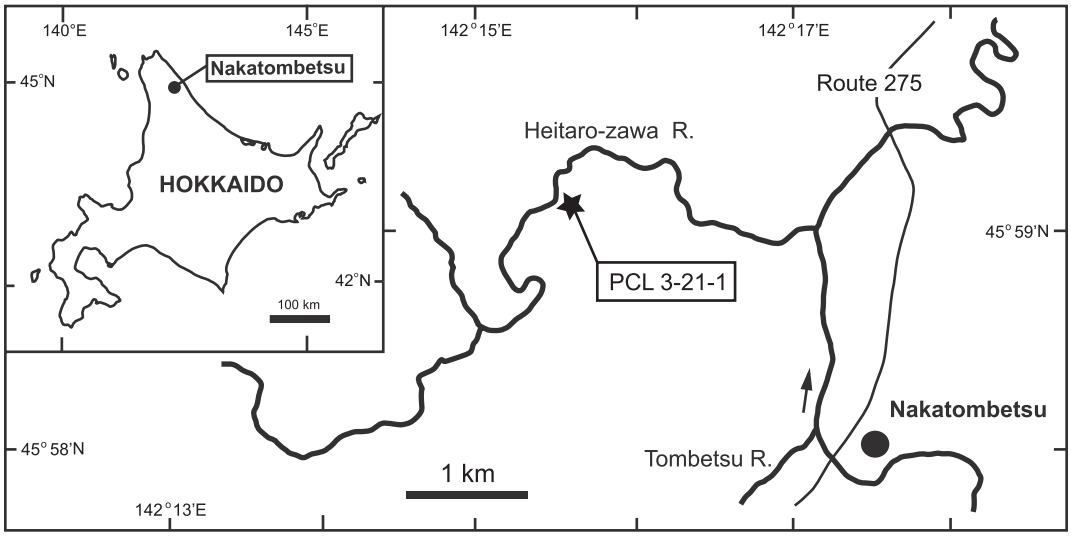

Figure 6. Index map showing the locality of *Gaudryceras hobetsense* Shigeta and Nishimura sp. nov. in the Nakatombetsu area, northern Hokkaido. Locality (NMNS PCL 3-21-1: 44°59′13″N, 142°15′15″E) occurs in a roadside cliff along the Heitaro-zawa River, 3 km west of Nakatombetsu, which is composed mainly of sandy siltstone with intercalated sandstone beds in the lower part of the Heitaro-zawa Formation. *Inoceramus shikotanensis* is fairly abundant in this outcrop and *Damesites hetonaiensis* occurs only rarely.

uppermost Cretaceous in northern Hokkaido (Matsumoto *et al*., 1980, Toshimitsu, 1999; Ando *et al*., 2001). Unfortunately, the zonal index ammonoid, *Nostoceras hetonaiense*, has not been found in the section and consequently, a precise biostratigraphic correlation of the lowest Maastrichtian between the Heitaro-zawa Formation in northern Hokkaido and the Hakobuchi Formation in south-central Hokkaido remains obscure.

The first author recently collected three specimens referable to *Gaudryceras hobetsense* sp. nov. together with *Damesites hetonaiensis* from the lower part of the Heitaro-zawa Formation along the Heitaro-zawa River (Loc. NMNS PCL 3-21-1; Figure 6). Although the specimens are fragmentary (Figure 7), their distant rounded or flat-topped ribs allows us to assign them to *G. hobetsense* sp. nov. This occurrence strongly suggests that Unit IVb of the Hakobuchi Formation in south-central Hokkaido can be correlated with the lower part of the Heitaro-zawa Formation in northern Hokkaido.

Gaudryceras izumiense occurs in Unit IVc just above the *G. hobetsense* sp. nov.-bearing beds (Unit IVb) in south-central Hokkaido (Shigeta *et al*., 2010; Figure 5). Although this ammonoid species has not yet been discovered in northern Hokkaido, its occurrence may be expected in the middle part of the Heitaro-zawa Formation, because the younger ammonoids, *Pachydiscus flexuosus* and *G. tombetsense,* occur in the upper part of the formation (Matsumoto *et al*., 1980; Matsumoto, 1984). *G. tombetsense* is abundant in the middle part of Unit K2 of the Krasnoyarka Formation in the Makarov section, southern Sakhalin, Russia (Maeda *et al*., 2005). This portion of the Krasnoyarka Formation is the stratigraphic equivalent of the Hakobuchi and Heitaro Formations of Hokkaido. In this section, *G. hamanakense* Matsumoto and Yoshida, 1979 occurs in the upper part of Unit K2 and *G. makarovense* Shigeta and Maeda, 2005 occurs in the lower part of Unit K3. Taken together, this evidence demonstrates that five species of *Gaudryceras* (*G. hobetsense* sp. nov., *G. izumiense*, *G. tombetsense*, *G. hamanakense* and *G. makarovense*) occur in succession in the Maastrichtian of Hokkaido and Sakhalin, and it strongly suggests that *Gaudryceras* has great potential for improvement of the previous Maastrichtian biostratigraphic scheme proposed by Toshimitsu *et al*. (1995) and Yazikova (1994).

Eastern Hokkaido

The uppermost Cretaceous-Paleogene Nemuro Group, which is widely distributed in eastern Hokkaido and the southern Kuril Islands, consists of hemipelagic mudstones and sediment gravity flow deposits such as turbidites and submarine slump deposits (Kiminami, 1978; Naruse, 2003). In the Hamanaka-Nemuro areas (Figures 1, 5), the group is divided into the following five formations, in ascending order: the Monshizu Formation, alternation of thick-bedded sandstone and thin mudstone; the Oborogawa Formation, massive mudstone; the Hamanaka Formation, alternation of sandstone and mudstone; the Akkeshi Formation, slump deposits; and the Kiritappu Formation, conglomerate (Kiminami, 1978). The upper Maastrichtian ammonoids, *Gaudryceras hamanakense*

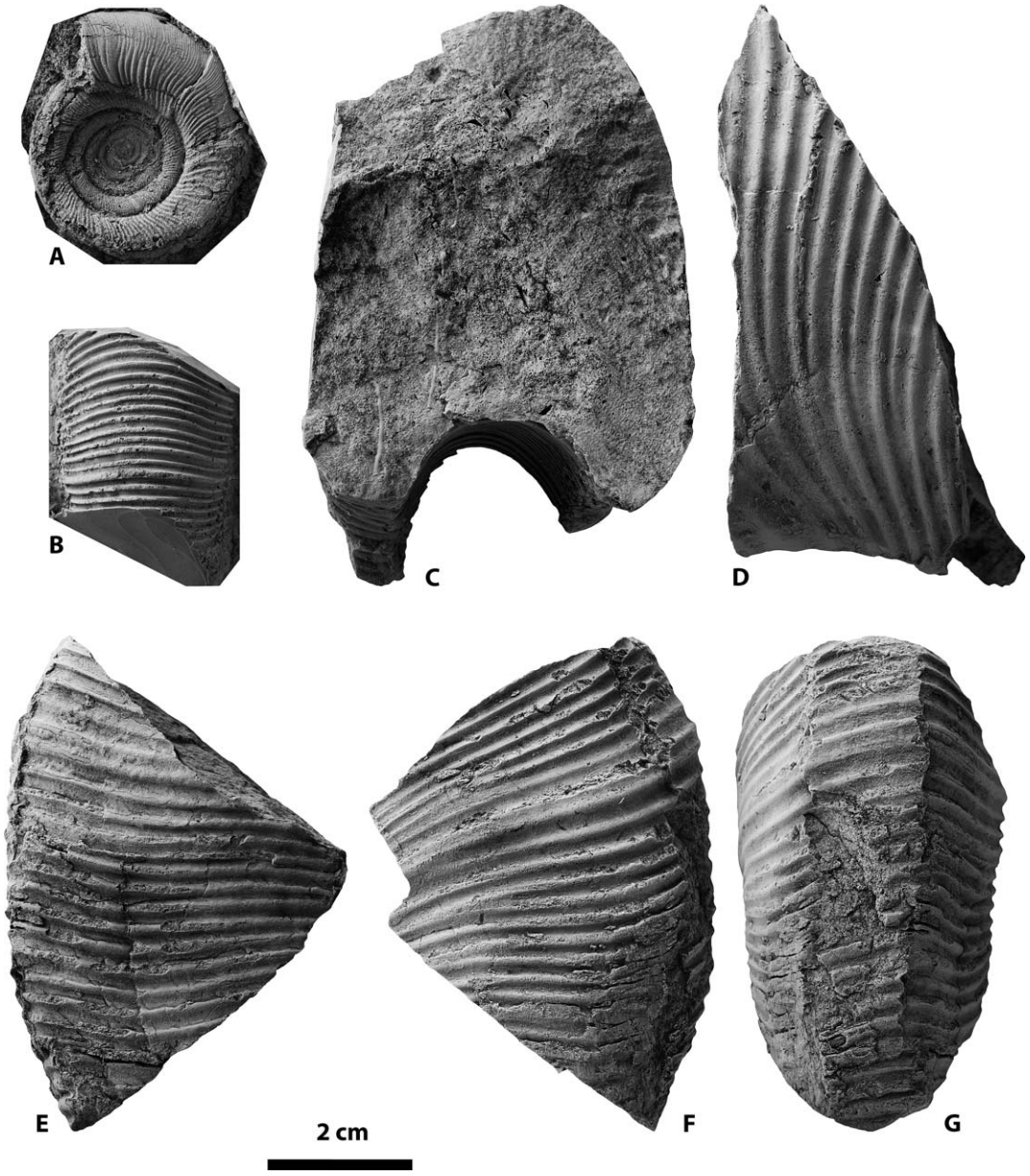

Figure 7. *Gaudryceras hobetsense* Shigeta and Nishimura sp. nov. from the Nakatombetsu area, Hokkaido. **A**, NMNS PM23450 (silicon rubber cast), right lateral view; **B-D**, NMNS PM23451; B, silicon rubber cast of ventral part of previous whorl; C, apertural view; D, right lateral view; **E-G**, NMNS PM23452; E, left lateral view; F, right lateral view; G, ventral view.

and *Pachydiscus flexuosus* occur in the middle part of the Akkeshi Formation (Matsumoto and Yoshida, 1979; Naruse *et al*., 2000). Based on the occurrences of the Paleocene foraminifera and nannofossils, the Cretaceous/Paleocene boundary is tentatively placed between the middle and upper Akkeshi Formation (Naruse *et al*., 2000). In contrast to the Akkeshi Formation, the lower formations are unfossiliferous, and their precise biostratigraphic correlation remains obscure.

A specimen assignable to *Gaudryceras hobetsense* sp. nov. that was collected from the Hamanaka Formation by Naruse *et al*. (2000, fig. 3-2), consists of a fragment of middle-growth shell, but its distant, rounded ribs enable us to assign it to our new taxon. This occurrence suggests that the Hamanaka Formation can be correlated with the lowest Maastrichtian. This correlation is also supported by the occurrence of *Sphenoceramus hetonaianus*, which was reported from the lower part of the Akkeshi Forma-

tion by Naruse *et al.* (2000). This inoceramid species occurs just above the horizon of *G. hobetsense* sp. nov. in south-central Hokkaido (Figure 5).

Southern Alaska

Upper Cretaceous deposits are widely distributed throughout southern Alaska, and well preserved macrofossils are abundant in various horizons. Jones (1963) recognized two fossil zones in the upper part of the Matanuska Formation, the lower *Sphenoceramus schmidti* Zone (Campanian) and the upper *Pachydiscus kamishakensis* Zone (Campanian-Maastrichtian). Later, Shigeta *et al*. (2010) restudied the faunal list of Jones (1963, table 1) and pointed out that the *P. kamishakensis* Zone can be subdivided into two taxon-range zones, namely, the *Patagiosites alaskensis* Zone and the *P. kamishakensis* Zone in ascending order. Furthermore, Shigeta *et al*. (2010) correlated the *P. kamishakensis* Zone with the *Gaudryceras izumiense* Zone of the upper lower Maastrichtian of Hokkaido and Southwest Japan.

Jones (1963) illustrated two specimens as *Gaudryceras tenuiliratum* from the upper part of the Matanuska Formation in southern Alaska. One specimen (USNM 131178, Jones, 1963, pl. 9, figs. 1–3) has sawtooth-like ribs, which are sharply raised with a gently sloping adoral face and an abrupt, very steep adapical face. Such rib features make it possible to assign the specimen to *Gaudryceras denmanense* Whiteaves, 1901 (Matsumoto, 1984; Haggart, 1989), which is restricted to the upper Campanian of the Nanaimo Group distributed in British Columbia and Washington State (Northeast Pacific realm). According to Jones (1963, table 1), the specimen was found in the *Patagiosites alaskensis* Zone (Jones, 1963, table 1). This particular taxon occurs in the *Pravitoceras sigmoidale* Zone of the upper Campanian in Hokkaido (Matsunaga *et al*., 2008). Overall, this evidence suggests that the *P. alaskensis* Zone of southern Alaska is of late Campanian age.

The other specimen (USNM 131179, Jones, 1963, pl. 10, figs. 1–3) exhibits many similarities to *G. hobetsense* sp. nov. and is assignable to this species, based on its distant rounded and flat-topped ribs. Although diagnostic ammonoids of the lowest Maastrichtian are not known from Alaska, the occurrence of *G. hobetsense* sp. nov. strongly suggests the presence of beds containing an earliest Maastrichtian fauna in the upper part of the Matanuska Formation, probably between the *Patagiosites alaskensis* Zone and the *Pachydiscus kamishakensis* Zone (Figure 5). These beds can be correlated with the *Nostoceras hetonaiense* Zone of Hokkaido and Southwest Japan.

Concluding remarks

The biostratigraphic zonation schemes established for the uppermost Cretaceous strata in the North Pacific realm are based mainly on endemic ammonoids restricted to each region. Because of this lack of common zonal-index taxa, the biostratigraphic correlation of Maastrichtian strata in this particular realm has been less than precise. As demonstrated herein and in Shigeta *et al*. (2010, 2012), *Gaudryceras* is an ideal ammonoid for the precise biostratigraphic correlation of uppermost Cretaceous strata in this particular realm. Further taxonomic and biostratigraphic studies of *Gaudryceras* may shed light on the age delineation of these chronologically poorly defined beds and thus provide an important key for the establishment of a precise biostratigraphic framework for uppermost Cretaceous strata in the North Pacific realm.

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