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First discovery of *Pravitoceras sigmoidale* Yabe from the Yezo Supergroup in Hokkaido, Japan

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Abstract. An almost intact specimen of an uppermost Cretaceous heteromorph ammonoid, *Pravitoceras sigmoidale* Yabe, was recently discovered from the Hakobuchi Formation of the Yezo Supergroup in the Hidaka area, Hokkaido. The specimen is preserved in a lenticular calcareous nodule. It retains two whorls of planispiral phragmocone and a succeeding retroversal hook, which is associated with a lower jaw apparatus near the aperture. *P. sigmoidale* occurs within the *Inoceramus shikotanensis* Zone at the Hidaka section. *Patagiosites alaskensis, Gaudryceras* sp., *Inoceramus shikotanensis*, and *Gigantocapulus problematicus* cooccur with *P. sigmoidale*. The megafossil assemblage resembles those of the Upper Campanian-Lower Maastrichtian in the Sakhalin area. *P. sigmoidale* has a very short range assignable to the Upper Campanian. However, it has been assumed to be an endemic species of the Izumi Group in southwest Japan, and has never before been found from northeast Japan. Scarcity of common zone-indexing taxa is a bottleneck for biostratigraphic research of the uppermost Cretaceous System in Japan. The first discovery of *P. sigmoidale* from the Hidaka area is a significant step for much more precise biostratigraphic correlation between the Yezo Supergroup and the Izumi Group.

Key words: ammonoid, Hokkaido, *Pravitoceras sigmoidale*, uppermost Cretaceous, Yezo Supergroup

Introduction

Pravitoceras sigmoidale Yabe is an Upper Cretaceous heteromorph ammonoid species belonging to the Family Nostoceratidae in the Superfamily Turrilitaceae (Wright *et al.*, 1996). It shows a peculiar shell morphology, i.e., the nearly planispiral polygyral phragmocone is succeeded suddenly by an S-shaped, backward-twisted body chamber (= retroversal hook) in the last growth stage. The present species was first described from the Izumi Group on Awaji Island by Yabe (1902). Afterwards, it has been found abundantly occurring in various places in Tokushima, Hyogo, and Osaka prefectures. Its distribution, however, seemed limited to the Izumi Group except for a very rare occurrence of a fragmentary specimen from the Sotoizumi Group in Toyajo, Wakayama (Yabe, 1915). Therefore, *P. sigmoidale* has been regarded as an endemic species which is peculiar to the uppermost Campanian of the Izumi Group (Matsumoto *et al.*, 1981). A Campanian-Maastrichtian biostratigraphic zonation based on short-ranging ammonoids was established in the Izumi Group (Matsumoto *et al.*, 1981). However, precise stratigraphic correlation of the Cretaceous System between northeast and southwest Japan remained obscure because of lack of common zone-indexing taxa.

We recently discovered an almost intact specimen (= Hidaka specimen: MCM.A1040), which is identifiable as *Pravitoceras sigmoidale* Yabe in confidence, from the *Inoceramus shikotanensis* Zone along the Saru River

in the Hidaka area, Hokkaido (Figures 1–4). The site is more than 1,600 km northeast of previous localities from which the species was known. This paper describes the newly found *P. sigmoidale* from Hokkaido, and discusses the significance of the discovery for biostratigraphic correlation of the uppermost Cretaceous System in Japan.

Repository of specimen.—An illustrated specimen in this paper is housed in the Mikasa City Museum (Hidaka specimen: MCM.A1040). Another specimen from Awaji Island (Awaji specimen) is registered in the Osaka Museum of Natural History (OMNH.M2177).

Outline of stratigraphy

The Hidaka area, a valley along the Saru River, is in the easternmost of the bands of Upper Cretaceous deposits distributed in southern central Hokkaido (Figure 1). Stratigraphy of the Upper Cretaceous System in Hidaka province was studied by Osanai and Matsushita (1959, 1960, 1961), Obata *et al.* (1973), and Takahashi and Suzuki (1986). Here, we adopt the stratigraphic divisions by the geological studies mentioned above together with Toshimitsu *et al.* (1995) and Takahashi *et al.* (2003) with minor revisions.

The strata are cut and displaced by two major faults striking NNE-SSW. Besides, many small faults are

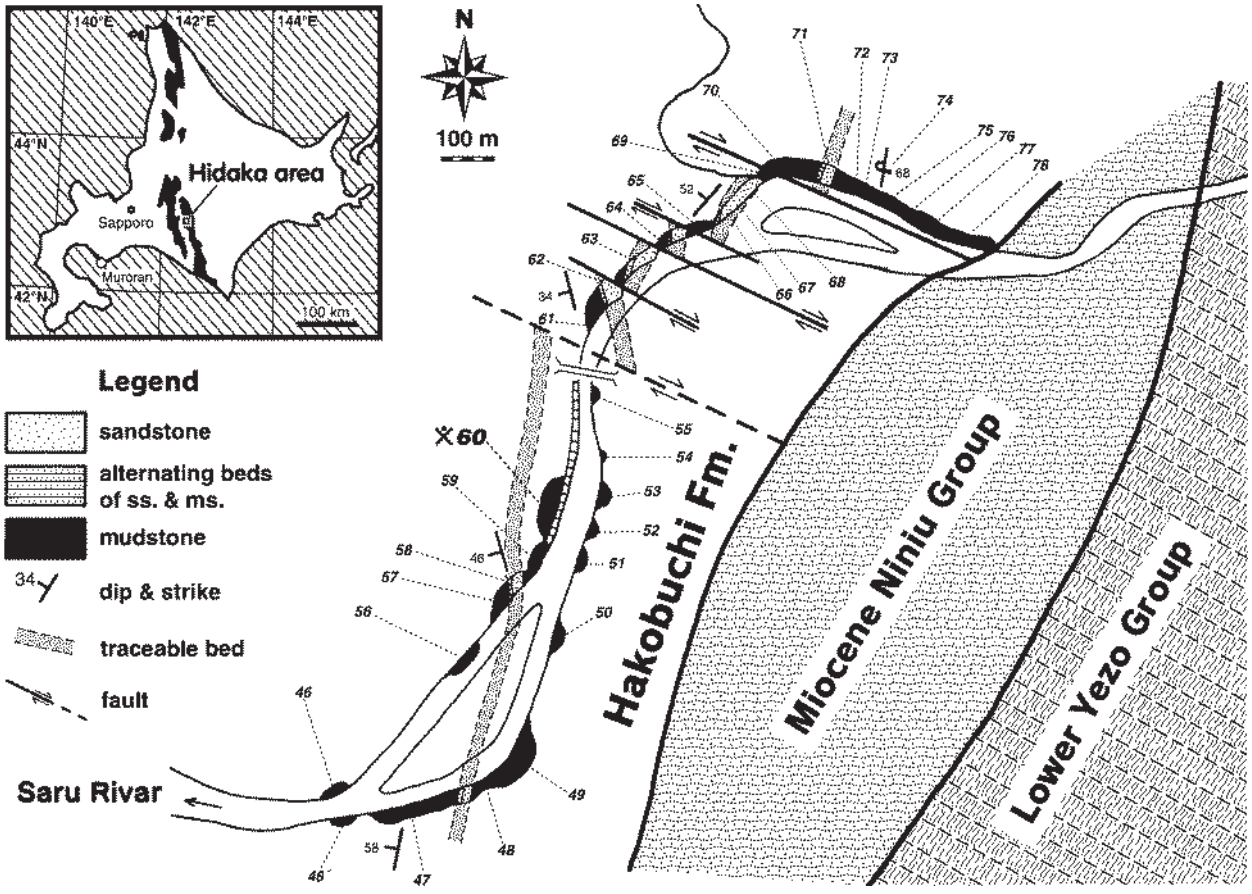

Figure 1. Index map (upper left) and route map (center) of the Hidaka area. *Pravitoceras sigmoidale* occurred from Loc. Sr60. The prefix "Sr" is omitted in the figure.

➡ **Figure 2.** *Pravitoceras sigmoidale* Yabe from the Hakobuchi Formation in the Hidaka area at Loc. Sr60 (Hidaka specimen: MCM. A1040) and photomicrograph of the deposit. **A**. left lateral view; **B**. frontal view; white scale bar is applicable to both A and B. **C**. lower jaw apparatus excavated from the calcareous nodule; scale bar is 1 cm long. **D**. photomicrograph of the host calcareous nodule (open nicol); a scale bar is 0.2 mm long. Note that the matrix mudstone contains very fine quartz, feldspar, and gray lithic grains, while green lithic fragments are very rare.


5cm
A
B
C
D

present, and the geologic structure is very complicated (Figure 1). The Lower to mid-Cretaceous Lower Yezo Group consisting of well laminated mudstone and alternating beds of sandstone and mudstone, is exposed in the eastern part of the area. The Miocene Niniu Group composed of conglomerate, sandstone, and sandy siltstone is distributed mainly in the middle part between the two major faults. The distribution of the uppermost Cretaceous Hakobuchi Formation, which is exposed in the western part, was newly discovered (Figure 1). Stratigraphy of the Hakobuchi Formation is reconstructed in part (Figure 3).

Hakobuchi Formation

The Hakobuchi Formation corresponds to the "Hakobuchi Sandstone" of Imai (1924). We rank this unit as a formation according to Takahashi *et al.*(2003).

Exposure.—Locs. Sr44-78 along the Saru River.

Thickness.—More than 200 m.

Stratigraphic relation.—Fault contact with the other strata in the area.

Lithology.—Dark gray massive coarse mudstone with sandstone intercalations predominates in the formation. The lower part of the formation (Locs. Sr48–55, 72–78 in Figures 1, 3) consists mainly of massive coarse mud-

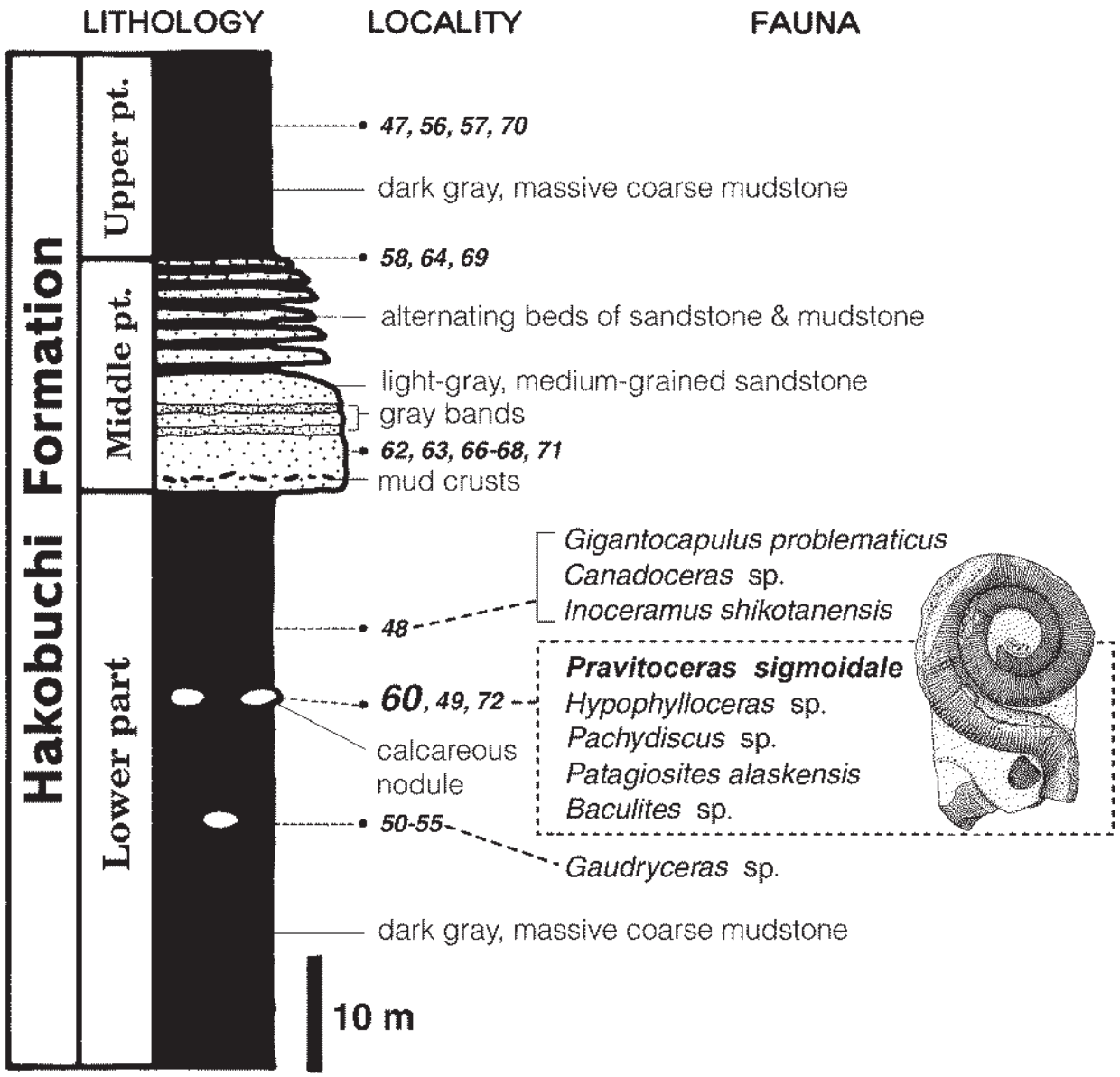

Figure 3. Columnar section of the Hakobuchi Formation in the Hidaka area. The prefix "Sr" of each locality number is omitted in this figure.

Table 1. Faunal list of the Hakobuchi Formation in the Hidaka area, Hokkaido.

Species	Locality		
Ammonoids			
Hypophylloceras sp.	72		
Gaudryceras sp.	55	70	
Zelandites sp.	76		
Desmophyllites sp.	70		
Canadoceras sp.	48		
Patagiosites alaskensis Jones	49	51	53
	60	72	75
Pachydiscus soyaensis Matsumoto and Miyauchi	46		
Pachydiscus sp.	60	76	
Pravitoceras sigmoidale Yabe	60		
Baculites sp.	72		
Inoceramids			
Inoceramus shikotanensis Nagao and Matsumoto	48	55	
Inoceramus cf. *yuasai* Noda	54		
Inoceramus cf. *hetonaianus* (Matsumoto)	60		
Inoceramus sp.	46'	49	55
Gastropods			
Gigantocapulus problematicus (Nagao and Otatsume)	48	76	77
Gastropoda gen. et sp. indet.	49	60	
Hexacorallia	54		
"Callianassa"	48		

stone. Thin gray lithic sandstones and white tuff layers are rarely intercalated. The mudstone contain very fine sand grains (Figure 2D). Unlike the middle part, green lithic fragments are very rare in the lower part. The mudstone commonly includes calcareous nodules. *Pravitoceras sigmoidale* occurred at Loc. Sr60 (Figures 1–3; Table 1). It was obtained from a flat-shaped calcareous nodule enveloping the shell (Maeda, 1987). *Patagiosites alaskensis, Gaudryceras* sp., *Canadoceras* sp., *Inoceramus shikotanensis, Zelandites* sp., and *Gigantocapulus problematicus* occur from the nodules in the lower part (Table 1).

The middle part of the formation (Locs. Sr58, 62–64, 66–69, 71 in Figures 1, 3) is composed of light-gray, massive, medium-grained lithic sandstone (5–10 m thick) and overlying alternating beds of sandstone and mudstone. The middle part attains a thickness of 10–20 m in total. The sandstone repeatedly crops out and is well traceable as a key in spite of the complex geologic structure created by faulting (Figure 1). The basal part is rich in mud crusts of 2–5 cm diameter (Figure 3). Gray bands 5–10 cm thick appear sometimes in the middle part of the massive sandstone bed. Green lithic fragments are abundant in the sandstone. These grains were often noted as "glauconite" (Obata *et al.*, 1973; Takahashi and Suzuki, 1986; etc.).

The upper part of the formation (Locs. Sr75–77 in Figure 3) is composed of dark-gray, massive coarse mudstone. It is often sheared by faults. Fossils are rare.

Systematic paleontology

Genus ***Pravitoceras*** Yabe, 1902

Type species.—*Pravitoceras sigmoidale* Yabe, 1902 (original designation).

Pravitoceras sigmoidale Yabe, 1902

Figures 2, 4, and 5

Pravitoceras sigmoidale Yabe, 1902, p. 3, pl. 1, figs. 2–4; Yabe, 1915, p. 19, pl. 2, figs. 1–4, pl. 3, fig. 1; Matsumoto *et al.*, 1981, p. 169–177, pl. 22, fig. 1, pl. 23, figs. 1, 2, pl. 24, figs. 1–3, pl. 25, figs 1, 2, pl. 26, fig. 1; Morozumi, 1985, p. 42, pl. 18, figs. 1, 2.

Type.—Syntypes (UMUT MM7478 and UMUT MM 7479) from Minato, Awaji Island. UMUT MM7478 (Yabe, 1902, p. 3, pl. 1, fig. 2); UMUT MM7479 (Yabe, 1902, p. 3, pl. 1, fig. 3) .

Material.—The newly found Hidaka specimen (MCM.A1040; Figures 2, 4, and 5A, B) and one of the most well preserved specimens from Awaji Island (OMNH.M2177; Figure 5C, D; first illustrated by Matsumoto *et al.*, 1981, pl. 22, fig. 1) for comparison.

Locality.—Loc. Sr60 along the right bank of the Saru River in Hidaka area, Hokkaido (Figure 1).

Description.—The newly found Hidaka specimen consists of outer two whorls of the polygyral phragmocone and the most part of the S-shaped body chamber. It represents the adult stage although the last apertural margin is worn by weathering. Compactional deformation is minimal because it is enveloped in a flat calcareous nodule. The shell material changed to calcite is retained. The longer diameter (vertical length in Figure 2A) approximates 221 mm or larger.

Preserved outer phragmocone is nearly planispiral, evolute, enlarging very slowly, having circular whorl section and coiling in slight contact but not overlapping. Shell surface is ornamented with fine slightly prorsiradiate single sharp ribs numbering about 32 per quarter whorl, and shallow periodic constrictions with faint collar ribs numbering 4 per whorl. Two rows of faint ventrolateral tubercles appear on every 3–5 ribs. Sutures consisting of deeply incised E and L are partly exposed (Figure 5B).

The body chamber initially follows the coiling of the phragmocone for about a quarter whorl, then is separated tangentially from the coiled part, and suddenly twists reversely to form a retroversal hook of U-shape. The Hidaka specimen represents the dextral morphotype, i.e., the retroversal hook is consequent on dextral twisting of

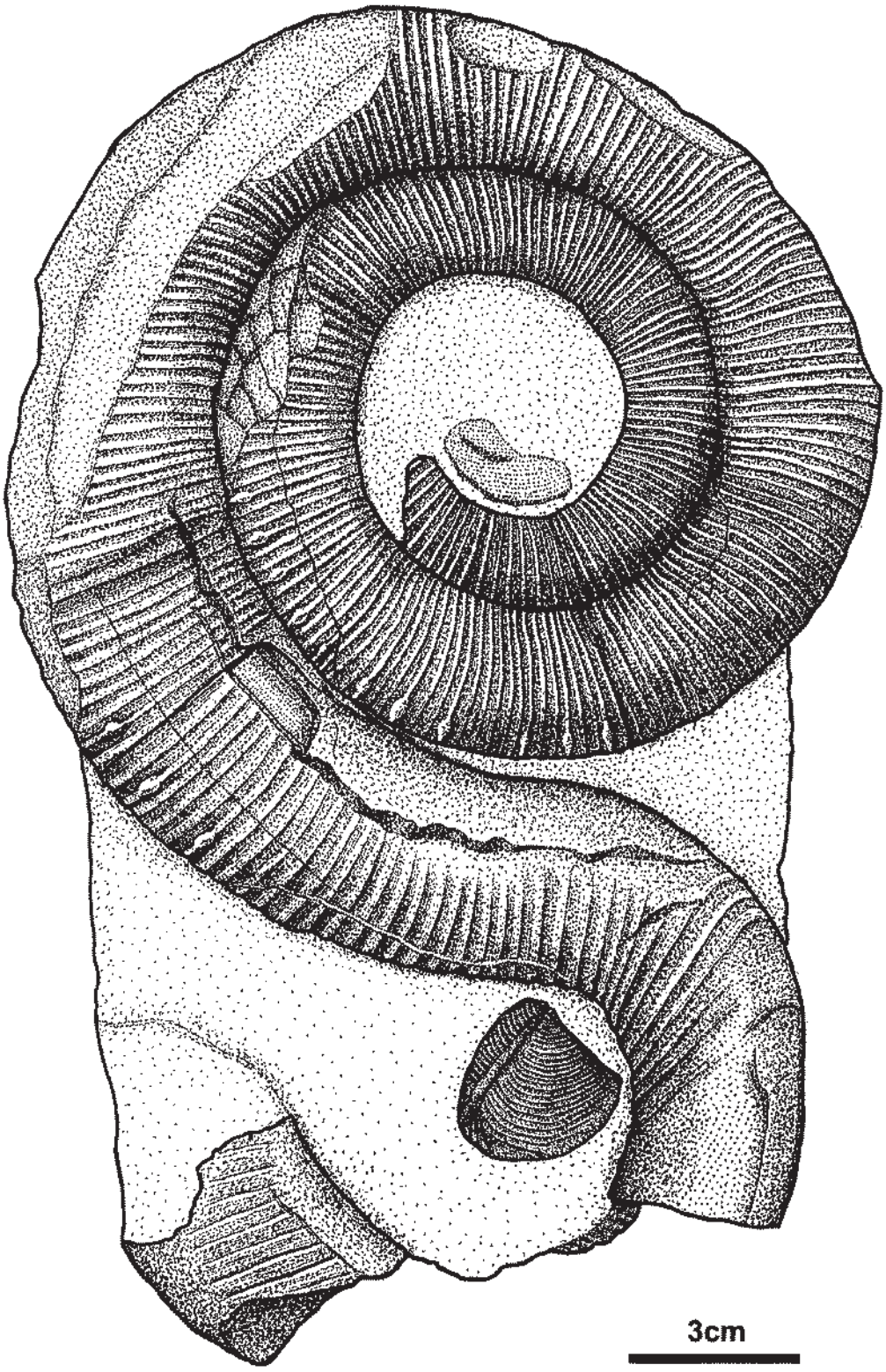

Figure 4. Schematic sketch of *Pravitoceras sigmoidale* Yabe from Loc. Sr60 (Hidaka specimen: MCM.A1040). Note that a lower jaw apparatus, which is now extracted from the matrix, is preserved nearby the aperture.

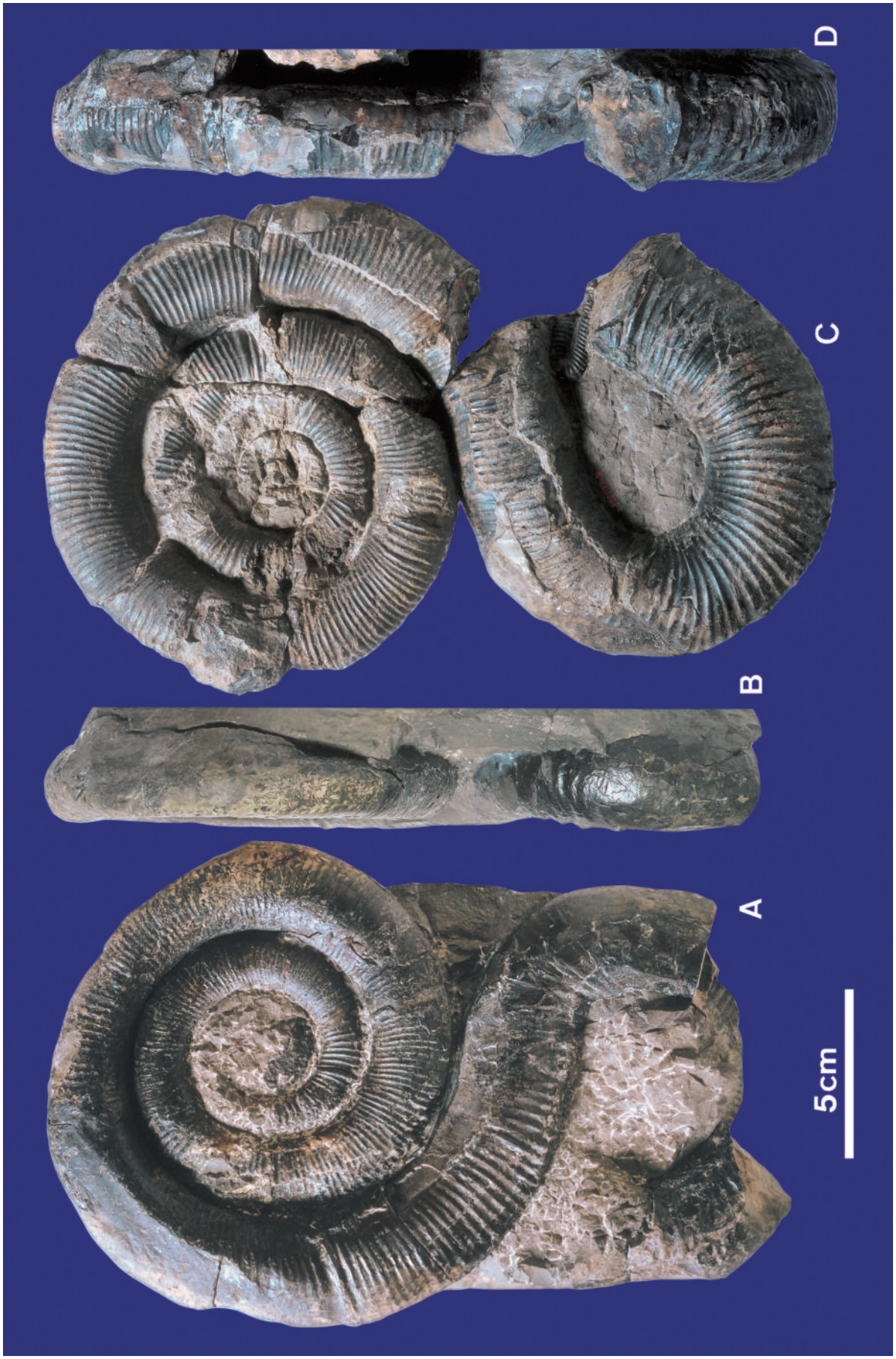

Figure 5. Comparison of *Pravitoceras sigmoidale* Yabe specimens from the Hidaka area with that from Awaji Island, southwest Japan. **A, B**: the Hidaka specimen (MCM. A1040). A: left lateral view; B: back view. Note that deeply incised E and L are partly observable. **C, D**: the Awaji Island specimen (OMNH. M2177). C: right lateral view; D: frontal view. A scale bar is applied to all figures.

the shaft (see Okamoto, 1993). The shell is mostly ornamented with slightly prorsiradiate fine sharp ribs, a pair of alternate or bilateral ventrolateral tubercles, and periodic shallow constrictions like in the phragmocone. Ribs become rusiradiate or weakened temporary in a short period after the inflection point on the strongly twisted shaft (Figures 2, 4).

Remarks.—A lower jaw apparatus was found together with the shell of *Pravitoceras sigmoidale* in the same calcareous nodule (Figure 2C). It is not housed in the body chamber *in situ* but preserved closely adjacent to the aperture (Figure 4). It was extracted from the rock matrix during preparation (Figure 2), and the burial position was restored in Figure 4. A black horny lamella covers the surface of the jaw apparatus, while calcitic shell material is also discernible at the beak. The outer horny lamella is divided into two parts by a lateral furrow, whose sides are markedly elevated ventrally. This is similar to the typical aptychus type with a long commissure and gently arched lateral margin (Type 4 or 5; Tanabe and Landman, 2002, text-fig. 3).

Other ammonoids are not found either from the calcareous nodule or in surrounding mudstone nearby. Our field observation reveals that similar occurrences of *Pravitoceras sigmoidale* shells associated with jaw apparatuses are common in the Izumi Group, southwest Japan. The line of evidence suggests that the shell and the lower jaw apparatus originated from the same animal.

Comparison.—Similar to the ancestral species *Didymoceras awajiense* Yabe, dextral and sinistral morphotypes are present within this species (Matsumoto *et al.*, 1981). OMNH.M2177, originally illustrated by Matsumoto *et al.* (1981, text-fig. 1, pl. 22), is one of the best specimens from the Izumi Group (Awaji specimen). It shows the typical morphological features of *Pravitoceras sigmoidale* (Figure 5C, D). In the Awaji specimen, "the tubercles on the shaft of the hooked part are shifted in accordance with the twisting of the body-chamber, which finally takes the position of its venter on the outer part of the hook" (Matsumoto *et al.*, 1981, p. 170). This clearly suggests that it belongs to the dextral morphotype, the same as the Hidaka specimen.

The Awaji specimen (OMNH.M2177) has slightly thicker whorls and stronger ribs compared with the Hidaka specimen (MCM.A1040). However, the other morphologic features including coiling patterns are almost identical (Figure 5). Large morphological variation in shell size in *Pravitoceras sigmoidale* was already noted by previous studies (Matsumoto *et al.*, 1981; Morozumi, 1985). According to them, the minimum longer diameter is 184 mm (OMNH.M2178), while the maximum attains 365 mm (KI01; Morozumi, 1985; pl. 18, fig. 1). The shell size of the Hidaka specimen (approx. 221 mm) and that of the Awaji specimen (OMNH.M2177; 235 mm) are included within a series of continuous variation. Many heteromorphs such as scaphitids also show large intraspecific variation in shell size (Landman and Waage, 1993). The other morphologic features of the Hidaka specimen do not deviate from the extent of the previously known intraspecific variation either. Therefore, the Hidaka specimen (MCM.A1040) is identifiable as *Pravitoceras sigmoidale* Yabe in confidence.

Occurrence.—This species occurs from the uppermost Campanian of Awaji Island and the Shikoku area, and also from the *Inoceramus shikotanensis* Zone in Hokkaido, Japan.

Discussion

Precise biostratigraphic correlation of the uppermost Cretaceous System between the Yezo Supergroup and the Izumi Group was previously difficult. This is attributable to the following two reasons.

1) In Hokkaido, fossiliferous mudstone facies decreases and fossil occurrence becomes intermittent in the uppermost Cretaceous Hakobuchi Formation by increasing influx of coarse-grained sediments.

2) Widespread zone-indexing taxa decrease toward the latest Cretaceous in the Far East Realm because of endemism.

Pravitoceras sigmoidale, whose range is very short in the Upper Campanian, has also been regarded as an endemic species of the Izumi Group (Matsumoto *et al.*, 1981). The faunal succession of ammonoids from the Upper Campanian to the Lower Maastrichtian is well defined there (Figure 6). The stratigraphic range of *P. sigmoidale* is situated between the *Didymoceras awajiense* and the *Pachydiscus awajiensis* zones (Morozumi, 1985). According to the scheme of magnetostratigraphy by Kodama (1990), the *P. sigmoidale* Zone is correlated to the lower part of C32n, which indicates the Upper Campanian stage (Kodama *et al.*, 2000, 2002; Gradstein *et al.*, 1995, 2004).

The new discovery of *Pravitoceras sigmoidale* with accompanying species is useful in delineating age in chronologically poorly defined beds in Hokkaido, north Japan. In the Izumi Group, *P. sigmoidale* occurs abundantly from a limited horizon, but the accompanying species are very rare. On the other hand, *P. sigmoidale* is accompanied by *Inoceramus shikotanensis*, *Inoceramus* sp. cf. *I. hetonaianus*, *Patagiosites alaskensis*, and *Gigantocapulus problematicus* in the Hakobuchi Formation in Hokkaido. This suggests that the range of *P. sigmoidale* apparently overlaps the well known *I. shikotanensis* Zone (Toshimitsu *et al.*, 1995).

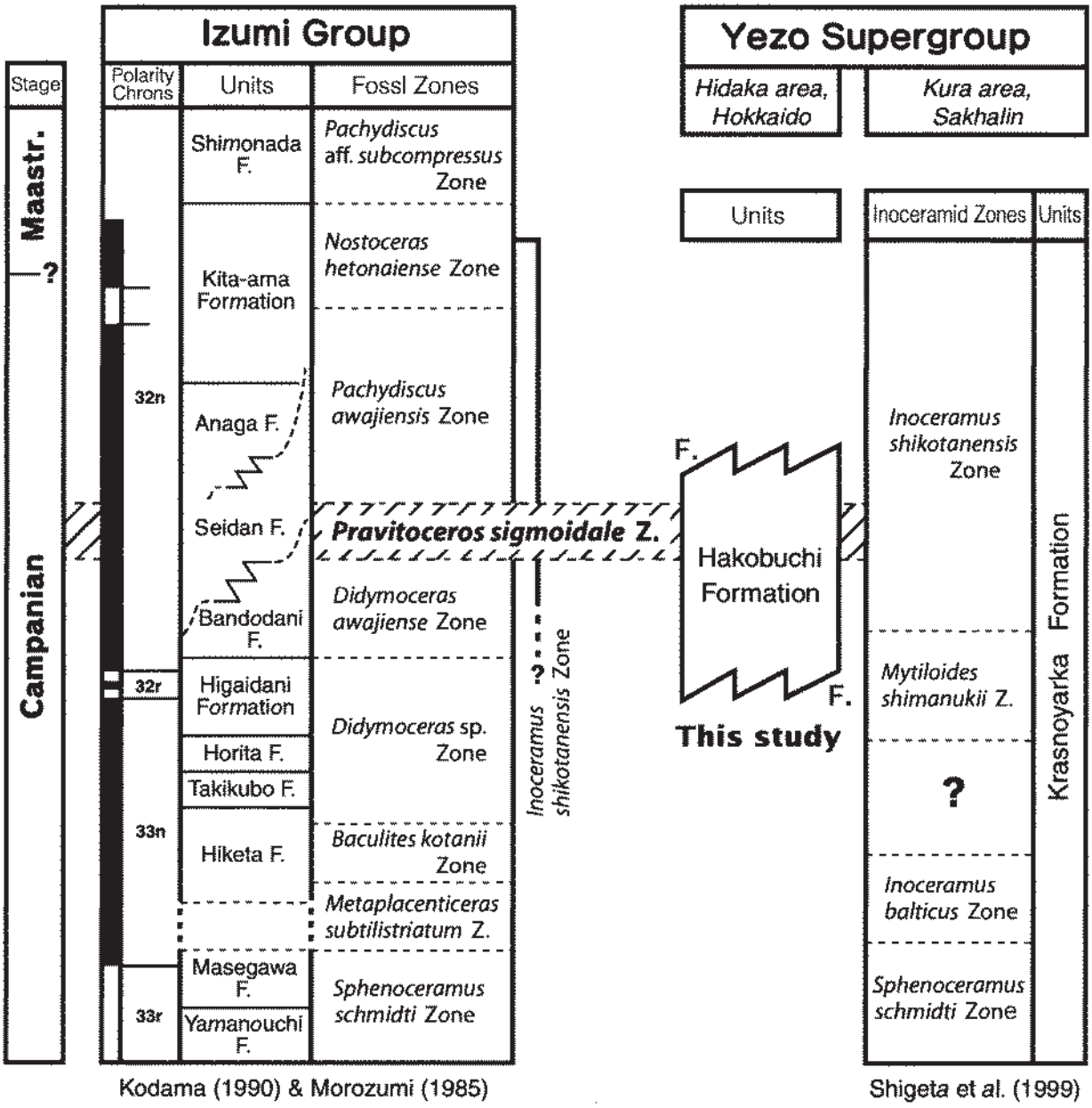

Figure 6. Diagram showing stratigraphic correlation of the Campanian-Maastrichtian deposits between southwest Japan (left) and Hokkaido/Sakhalin (right). The Hakobuchi Formation in the Hidaka area is in fault contact with the other units.

The Campanian-Maastrichtian biostratigraphic boundary in the Far East Realm remains debatable. Among the accompanying species with *Pravitoceras sigmoidale*, *Inoceramus shikotanensis* and *Inoceramus hetonaianus* were assumed to suggest the Lower Maastrichtian (Toshimitsu *et al.*, 1995). Another associated species: *Patagiosites alaskensis*, is one of the characteristic species of the *Pachydiscus kamishakensis* Zone, which has been correlated to the Upper Campanian-Lower Maastrichtian in southern Alaska (Jones, 1963). This assemblage was also reported from the uppermost Cretaceous in the Nakatombetsu area, northern Hokkaido. The stratigraphic level was also interpreted as the Lower Maastrichtian (Ando *et al.*, 2001). The present discovery stresses that the age interpretation around the *P. sigmoidale* Zone in southwest Japan (Upper Campanian) conflicts with that in north Japan.

On the other hand, the best lithologic and faunal suc-

cessions of the Upper Campanian-Lower Maastrichtian in the Far East Realm are preserved in Sakhalin, Russia (Maeda *et al.*, 2005; Shigeta and Maeda, 2005). The uppermost part of the Krasnoyarka Formation in Kura area, southern Sakhalin, which corresponds to the *Inoceramus shikotanensis* Zone, contains *I. shikotanensis* and *Patagiosites alaskensis* (Shigeta *et al.*, 1999). Both the mudstone-dominating lithology and the faunal contents are similar to those of the Hakobuchi Formation in the Hidaka area. Accompanying fossils resemble the Upper Campanian assemblages of the Izumi Group (Shigeta *et al.*, 1999). Therefore, Shigeta *et al.* (1999) insisted on the necessity of investigating in detail the biostratigraphic correlation of the horizon in Sakhalin with that in Japan. In Sakhalin, collaboration with microbiostratigraphy of calcareous nannoplankton (Maeda *et al.*, 2005), magnetostratigraphy (Kodama *et al.*, 2000; 2002), and stable-isotope stratigraphy (Hasegawa *et al.*, 2003) has already started (Shigeta and Maeda, 2005). The age of the *Pravitoceras sigmoidale* Zone will be much more precisely determined by such ongoing integrated studies.

Conclusion

A nostoceratid heteromorph ammonoid, *Pravitoceras sigmoidale*, which had been previously assumed to be an endemic species of the Izumi Group, has been discovered for the first time from the Hakobuchi Formation of the Hidaka area, Hokkaido. As *P. sigmoidale* is a short-ranging species suggesting late Campanian age, the discovery is a significant step in the biostratigraphic correlation between the Yezo Supergroup and the uppermost Cretaceous in Southwest Japan including the Izumi Group.

Acknowledgments

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