Early Cenomanian (Late Cretaceous) Ammonoids from the Miyanohara Formation in the Sakawa Area, Shikoku, Southwestern Japan

Authors: Misaki, Akihiro, Okazaki, Yoshihiko, Mizuno, Yoshiaki, and Matsunaga, Takeshi

Source: Paleontological Research, 24(1) : 72-81

Published By: The Palaeontological Society of Japan

URL: https://doi.org/10.2517/2019PR008

Paleontological Research, vol. 24, no. 1, pp. 72–81, January 1, 2020

doi:10.2517/2019PR008

Early Cenomanian (Late Cretaceous) ammonoids from the Miyanohara Formation in the Sakawa area, Shikoku, southwestern Japan

AKIHIRO MISAKI[1], YOSHIHIKO OKAZAKI[1], YOSHIAKI MIZUNO[2] AND TAKESHI MATSUNAGA[3]

[1]*Kitakyushu Museum of Natural History and Human History, 2-4-1 Higashida, Yahatahigashi-ku, Kitakyushu, Fukuoka 805-0071, Japan (e-mail: misaki_a@kmnh.jp)*
[2]*Tokai Fossil Society, 9-21 Sawashita, Atsuta-ku, Nagoya, Aichi 456-0006, Japan*
[3]*Osaka Prefectural Semboku Senior High School, 3-2-2 Wakamatsudai, Minami-ku, Sakai, Osaka 590-0116, Japan*

Received February 2, 2019; Revised manuscript accepted April 3, 2019

Abstract. Mid-Cretaceous ammonoids, *Euhystrichoceras nicaisei*, *Mantelliceras japonicum*, and *Hypostlingoceras japonicum* were collected from float rocks probably derived from the middle part of the Miyanohara Formation in the Sakawa area, Shikoku, southwestern Japan. Although it has been suggested that the stratigraphic correlation of this formation based mainly on bivalves such as trigoniids needs to be reexamined, the occurrence of these ammonoids confirms that the middle part of the Miyanohara Formation is correlated to the lower Cenomanian. The results of this study support the suggestion that the shallow marine deposits of the mid-Cretaceous that contain similar molluscan faunas are widely distributed throughout the northwestern Pacific region.

Key words: ammonoid, Cenomanian, Cretaceous, Miyanohara Formation, Sakawa, Sotoizumi Group

Introduction

Paleozoic and Mesozoic strata are intricately distributed in the Sakawa area, Kochi, located in the Chichibu Belt in the Outer Zone of southwestern Japan, where a number of geological and paleontological studies have been conducted since the 19th century (e.g. Naumann and Neumayr, 1890; Yabe, 1901, 1927; Yehara, 1923; Kobayashi, 1931, 1941; Matsumoto, 1954; Tashiro, 1985; Tashiro and Matsuda, 1986; Kozai and Ishida, 2006). The uppermost part of the Cretaceous deposits in this area is composed of the Miyanohara Formation (Yehara, 1927; Kobayashi, 1932; Fukuji, 1941; Katto *et al*., 1961) belonging to the Sotoizumi Group and exposed in a narrow region that extends from Miyanohara district within Sakawa Town to Ochiko district within Ochi Town (Katto and Tashiro, 1982; Wakita *et al.*, 2007) (Figure 1). Diverse bivalve fossils, such as trigoniids, are known from the Miyanohara Formation, and the formation has been correlated to the upper Albian–Cenomanian based on these bivalves (Amano, 1956; Tashiro and Matsuda, 1983a, b; Matsuda, 1985; Tashiro and Katto, 1995; Wakita *et al.*, 2007).

On the other hand, Yoshihara and Komatsu (2006) have suggested that stratigraphic correlations of the Miyanohara Formation and other mid-Cretaceous strata in southwestern Japan based on trigoniids need to be reexamined. In addition, although ammonoids *Desmoceras* sp., *Mantelliceras* sp., *Calycoceras*? sp., and *Sharpeiceras* sp. were also reported from the Miyanohara Formation and were shown to be consistent with the correlation based on bivalves (Matsumoto, 1954, 1977; Matsumoto *et al.*, 1982; Katto and Tashiro, 1982; Matsuda, 1985; Wakita *et al.*, 2007), details on these ammonoids, such as figures and localities, have not been provided.

In the course of the geological survey of the Cretaceous strata in southwestern Japan, we discovered six specimens of three ammonoid species, *Euhystrichoceras nicaisei* (Coquand, 1862), *Mantelliceras japonicum* Matsumoto, Muramoto and Takahashi, 1969, and *Hypostlingoceras japonicum* Matsumoto and Takahashi, 2000, from the Miyanohara Formation. We describe these ammonoids and discuss their significance here.

Geologic notes and fossil occurrences

Wakita *et al.* (2007) divided the Miyanohara Formation into the following four parts: lowest (My1), lower (My2),

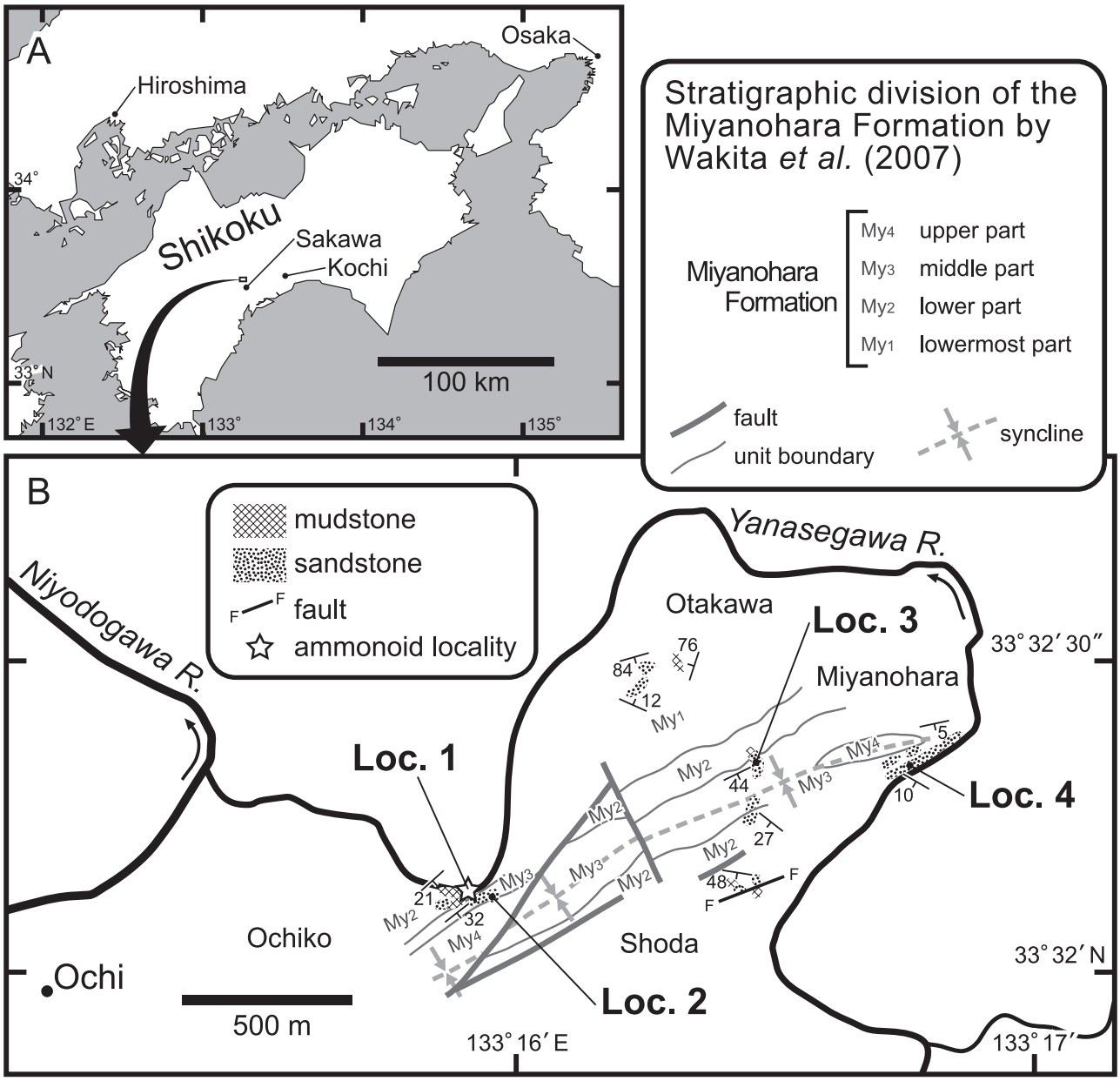

Figure 1. Index map (A) and route map (B) of the study area in the Sakawa area, Shikoku, southwestern Japan. The stratigraphic division of the Miyanohara Formation by Wakita *et al.* (2007) is also shown in B.

middle (My3), and upper parts (My4) (Figure 1). They indicated that each part consisted of slumping deposits dominated by mudstone >150 m thick, mudstone ~55 m thick, very fine- to fine-grained sandstone ~30 m thick, and mudstone-dominated strata >170 m thick, respectively.

In this study, sandstones and mudstones of the Miyanohara Formation were observed in some localities along the Yanasegawa River, a tributary of the Niyodogawa River, and along roads in Miyanohara, Otakawa, and Shoda districts within Sakawa Town (Figures 1, 2). Conglomerate beds up to several decimeters thick and composed of rounded pebbles up to 5 cm in diameter were also intercalated in the bluish gray, fine-grained sandstone at Loc. 2. Sandstones at Locs. 2–4 contain abundant bivalve and gastropod fossils and are thought to be within the My3 of Wakita *et al.* (2007).

The six ammonoid specimens (Figure 3) described in

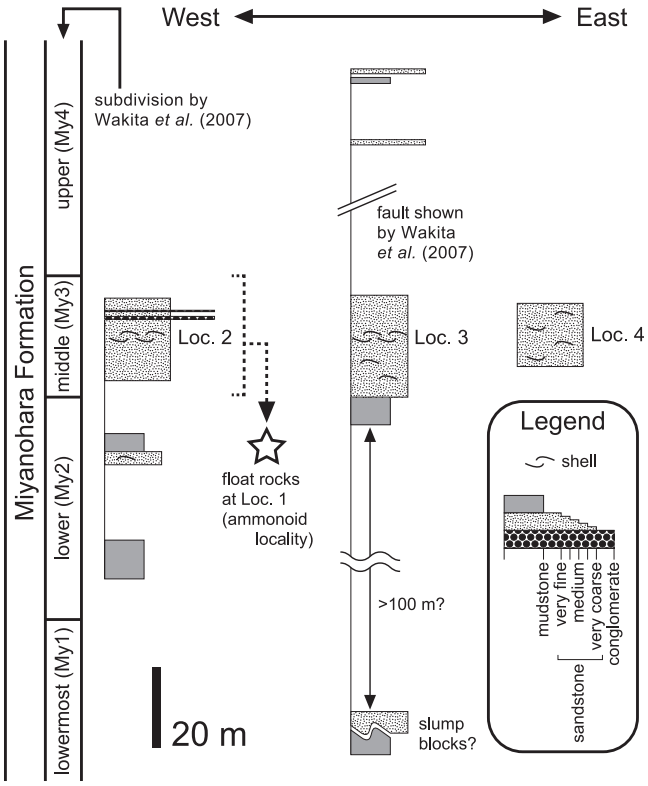

Figure 2. Columnar sections of the Miyanohara Formation in the study area.

this paper were collected from float rocks at Loc. 1 along the Yanasegawa River. The four specimens of KMNH IvP 905002–905005 were found in the same large rock of about 3 m in diameter, and the two specimens of KMNH IvP 905001 and 905006 were from other smaller rocks of several decimeters in diameter. These float rocks are bluish gray, fine-grained calcareous sandstone and contain several bivalve fossils. Judging from the localities and lithologic characters, these float rocks are considered to be derived from the My3. The collected ammonoids are generally well preserved, including their body chambers; however, cheilostome bryozoan colonies are attached to the internal surfaces of the body chamber of one *Mantelliceras japonicum* specimen (KMNH IvP 905001; Figure 3C), which indicates that there was a specific period of time between death and complete burial of the animal.

Systematic paleontology

Morphological terminology and measurements follow Matsumoto (1954, p. 246), Arkell (1957), Haggart (1989, table 8.1), and Matsumoto and Takahashi (2000). Higher-level classifications are adopted from Wright *et al*. (1996). Cooper and Owen (2011) considerably revised the classification of Schloenbachiidae and included *Euhystrichoceras* in this family; however, it has been suggested that further examination of its classification is needed (Kennedy, 2013; Wilmsen *et al.*, 2013). Thus, the suprageneric classification of *Euhystrichoceras* also follows Wright *et al*. (1996).

Institution abbreviations.—GK, Department of Earth and Planetary Sciences, Kyushu University, Fukuoka, Japan; KMNH, Kitakyushu Museum of Natural History and Human History, Kitakyushu, Japan; MCM, Mikasa City Museum, Mikasa, Japan.

Other abbreviations.—*D*, shell diameter (diameter of the preserved last whorl in the case of *Hypostlingoceras*); *U*, umbilical diameter; *H*, whorl height; *W*, whorl width; *NW*, number of preserved whorls; *Hp*, total height of the preserved whorls; *Ht*, total shell height from the preserved last whorl to the estimated apex; *ap*, estimated apical angle; *h*, height of an exposed outer flank of a late whorl; *d*, diameter of the same whorl; *R*, number of ribs on the same whorl; *T*, number of upper tubercles; *t*, number of lower tubercles (*D* and *NW* to *t* for *Hypostlingoceras* were originally used by Matsumoto and Takahashi, 2000).

Suborder Ammonitina Hyatt, 1889
Superfamily Acanthocerataceae Grossouvre, 1894
Family Brancoceratidae Spath, 1934
Subfamily Mortoniceratinae H. Douvillé, 1912
Genus ***Euhystrichoceras*** Spath, 1923

Type species.—*Ammonites nicaisei* Coquand, 1862.

Euhystrichoceras nicaisei (Coquand, 1862)

Figures 3D–I, 4A

Ammonites nicaisei Coquand, 1862, p. 323, pl. 35, figs. 3–4.
Mortoniceras (?) *nicaisei* (Coquand). Pervinquière, 1907, p. 235, pl. 11, figs. 13a–b, 14a–c, 15a–c, text-figs. 95, 96; Pervinquière, 1910, p. 65, pl. 6, figs. 6–19, text-figs. 95, 96.
Mortoniceras nicaisei (Coquand). Collignon, 1928–1929, p. 31, pl. 16, fig. 16.
Schloenbachia (*Inflaticeras*) *nicaisei* (Coquand). Collignon, 1931, p. 74, pl. 3, figs. 16, 17.
Euhystrichoceras nicaisei (Coquand). Juignet and Kennedy, 1976, p. 79, pl. 5, figs. 5a–b, 6a–c; Kennedy and Wright, 1981, p. 420, pl. 59, figs. 1–16, 21–23, text-figs. 1a, 2d; Kennedy and Juignet, 1984, p. 131, fig. 26a–c; Matsunaga, 2005, pl. 8, figs. 4, 5; Cooper and Owen, 2011, p. 301, fig. 5E–F.

Lectotype.—One of Coquand's specimens from west of Boghar, Algeria, refigured by Pervinquière (1910, pl. 6, fig. 7) and Kennedy and Wright (1981, pl. 59, figs. 8–10), designated by Juignet and Kennedy (1976, p. 80).

Material.—Two specimens, KMNH IvP 905002 (Figures 3D–G, 4A) and KMNH IvP 905003 (Figure 3H–I),

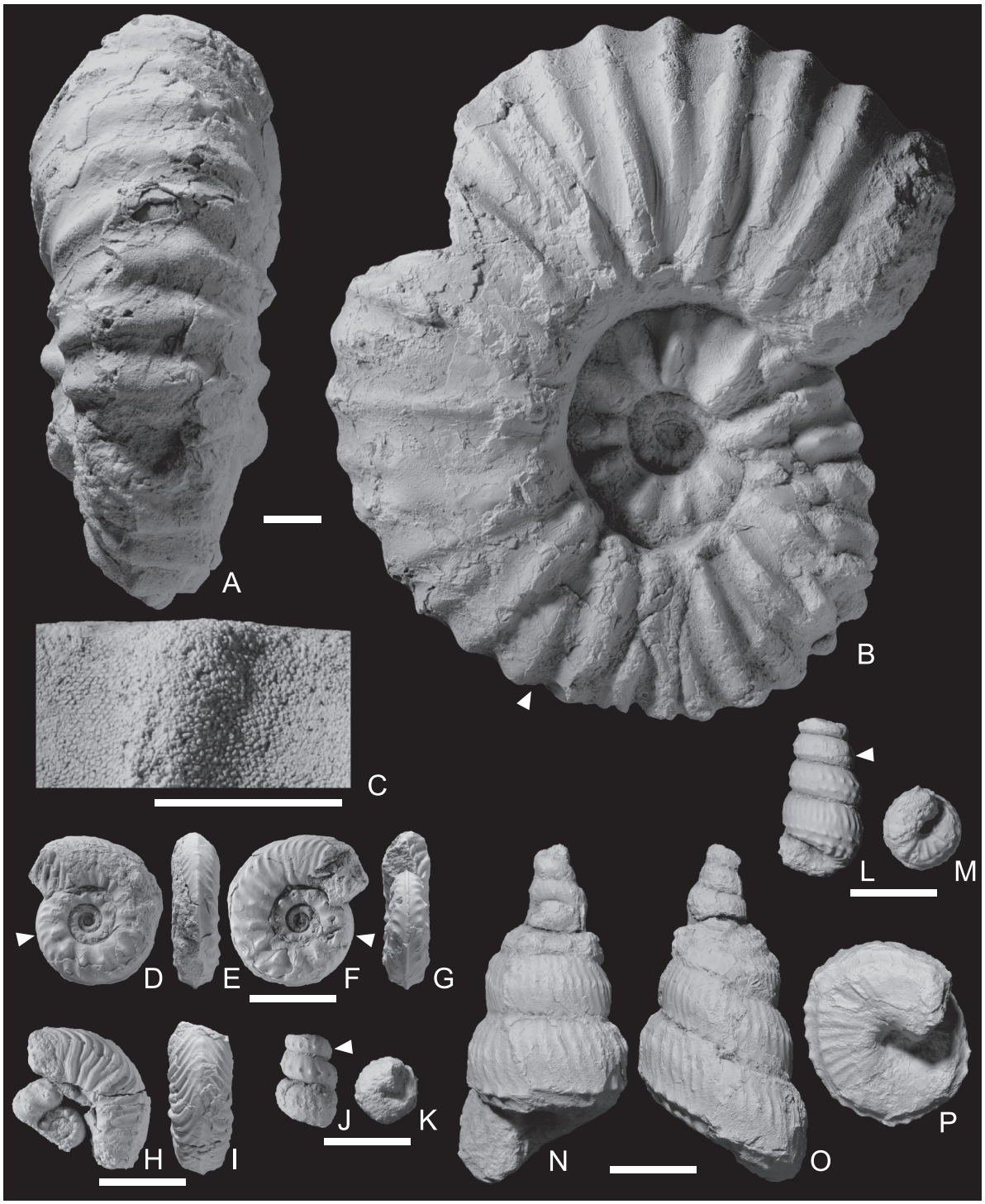

Figure 3. Ammonoids from float rocks at Loc. 1 probably derived from the middle part of the Miyanohara Formation (My3). **A–C**, *Mantelliceras japonicum* Matsumoto, Muramoto and Takahashi, KMNH IvP 905001; A, ventral view; B, left lateral view; C, closeup of the internal mold of the body chamber encrusted by a cheilostome bryozoan colony; **D–I**, *Euhystrichoceras nicaisei* (Coquand); D–G, KMNH IvP 905002; D, right lateral view; E, ventral view; F, left lateral view; G, apertural view; H, I, KMNH IvP 905003; H, right lateral view; I, ventral view; **J–P**, *Hypostlingoceras japonicum* Matsumoto and Takahashi; J, K, KMNH IvP 905004; J, lateral view; K, basal view; L, M, KMNH IvP 905005; L, lateral view; M, basal view; N–P, KMNH IvP 905006; N, O, lateral view; P, basal view. Scale bars are 10 mm. White arrows indicate the positions of the last septa. The positions of the last septa of two specimens (KMNH IvP 905003 and 905006) cannot be determined because of the mode of preservation.

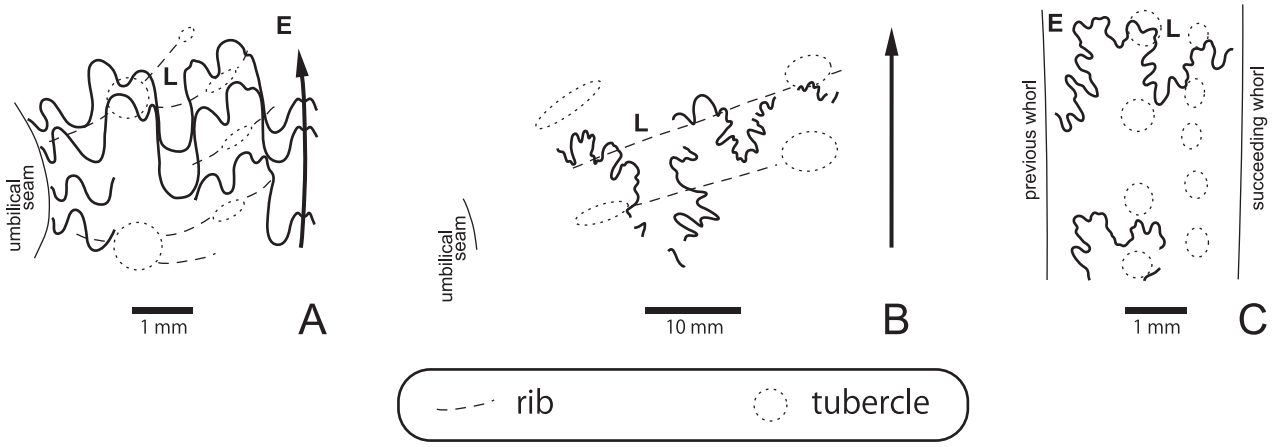

Figure 4. External sutures of ammonoids from float rocks at Loc. 1 probably derived from the middle part of the Miyanohara Formation (My3). **A**, *Euhystrichoceras nicaisei* (Coquand), KMNH IvP 905002, at H = 3.8 mm; **B**, *Mantelliceras japonicum* Matsumoto, Muramoto and Takahashi, KMNH IvP 905001, at H = 30.7 mm; **C**, *Hypostlingoceras japonicum* Matsumoto and Takahashi, KMNH IvP 905005, at 3.2 mm in height of an exposed outer flank. E, external (ventral) lobe; L, lateral lobe (= adventive lobe, A, of Korn *et al.*, 2003).

were collected from the same float rock at Loc. 1 along the Yanasegawa River, a tributary of the Niyodogawa River, in the Sakawa area, Shikoku (Figure 1).

Description.—Very small, fairly evolute shell with moderately wide umbilicus. Slightly compressed to slightly depressed whorl section with a broadly rounded to slightly fastigate and keeled venter, rounded ventral shoulders, rounded (early growth stage) to slightly convex (later growth stage) flanks with maximum whorl width near rounded umbilical shoulders, and low, steeply inclined umbilical walls. Ornamentation consists of inner lateral and ventrolateral tubercles, concave to slightly sinuous, prorsiradiate ribs, and lirae (visible on body chamber of KMNH IvP 905003). Secondary ribs frequently branched from primary ribs at inner lateral tubercles. In the last part of the body chamber, ribs become denser and tubercles weaken. Suture line simple, with broad external lobe and asymmetrically bifid first and second lateral saddles. Lateral lobe relatively narrow and simple.

Measurements.—At D = 17.7 mm of KMNH IvP 905002, U = 6.3 mm, H = 6.4 mm, W = 5.3 mm, U/D = 0.36, W/H = 0.83.

Occurrence.—*Euhystrichoceras nicaisei* is known from lower Cenomanian strata in France, Tunisia, Algeria, and Madagascar (Kennedy and Juignet, 1984). This species also occurs in the lower Cenomanian of the Yezo Group in the Soeushinai (e.g. Matsumoto *et al.*, 2004) and Kami-ashibetsu (Matsunaga, 2005) areas, Hokkaido, northeastern Japan. The present specimens were found in float rocks probably derived from the middle part of the Miyanohara Formation (My3), Sotoizumi Group in the Sakawa area.

Family Acanthoceratidae Grossouvre, 1894
Subfamily Mantelliceratinae Hyatt, 1903
Genus ***Mantelliceras*** Hyatt, 1903

Type species.—*Ammonites mantelli* J. Sowerby, 1814.

Mantelliceras japonicum Matsumoto, Muramoto and Takahashi, 1969

Figures 3A–C, 4B

Mantelliceras japonicum Matsumoto, Muramoto and Takahashi, 1969, p. 253, pl. 25, figs. 1, 2, pl. 26, figs. 1–3, pl. 27, figs. 1, 2, text-figs. 1, 2; Matsunaga, 2005, pl. 9, fig. 1; Misaki *et al*., 2008, fig. 4.1, 2.

Holotype.—GK.H5428, from Loc. Ik. 1100 (Matsumoto *et al*., 1969, text-fig. 9) along the Ikushunbetsu River in the Mikasa area, Hokkaido, northeastern Japan (Matsumoto *et al*., 1969, p. 253, pl. 25, fig. 1, pl. 26, fig. 1, text-figs. 1, 2)

Material.—One specimen, KMNH IvP 905001 (Figures 3A–C, 4B), was collected from a float rock at Loc. 1 along the Yanasegawa River, a tributary of the Niyodogawa River, in the Sakawa area, Shikoku (Figure 1).

Description.—Medium-sized, moderately involute (early growth stage) to fairly evolute (later growth stage) shell with moderately wide umbilicus. Suboval to subcircular whorl section with a broadly rounded venter, rounded ventral shoulders, slightly convex flanks with maximum whorl width near rounded umbilical shoulders, and nearly vertical umbilical walls. Ornamentation consists of straight to slightly convex, rectiradiate to slightly rursiradiate ribs, lirae, and inner and outer umbilical and

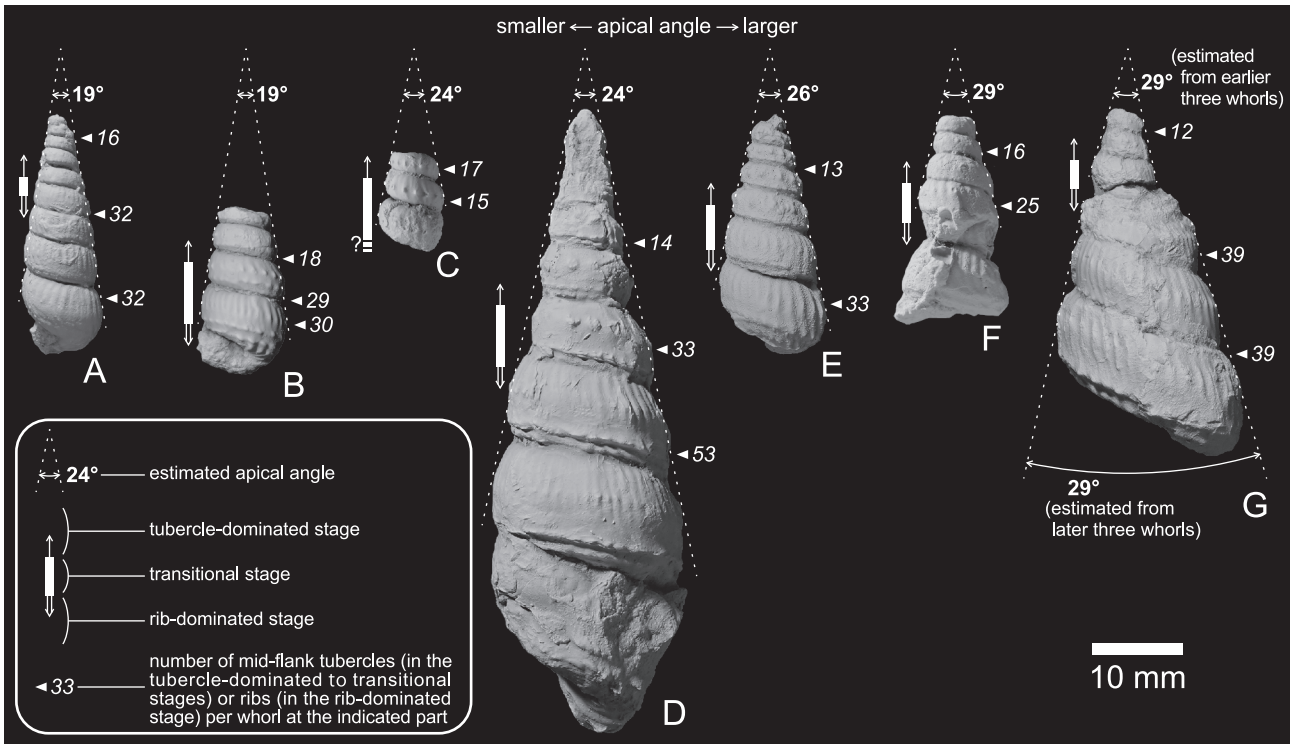

Figure 5. Comparison of apical angles and ornamentation of *Hypostlingoceras japonicum* Matsumoto and Takahashi specimens. **A**, resin cast of the paratype of *H. japonicum* (GK.H8541) originally illustrated by Matsumoto and Takahashi (2000, fig. 9), from the lower Cenomanian *Mantelliceras japonicum* Zone of the Mikasa Formation along the Suido-no-sawa River in the Mikasa area, Hokkaido; **B**, KMNH IvP 905005, from Loc. 1 in the Sakawa area, Shikoku; **C**, KMNH IvP 905004, from Loc. 1 in the Sakawa area, Shikoku; **D**, resin cast of the holotype of *H. japonicum* (GK.H8542) originally illustrated by Matsumoto and Takahashi (2000, figs. 7, 8), from the lower Cenomanian *M. japonicum* Zone of the Mikasa Formation along the Ganseki-zawa River (a tributary of the Kami-ichino-sawa River) in the Mikasa area, Hokkaido; **E**, resin cast of the holotype of *H. mikasaense* (GK.H8540) originally illustrated by Matsumoto and Takahashi (2000, fig. 11), from the lower Cenomanian *M. japonicum* Zone of the Mikasa Formation along the Ganseki-zawa River (a tributary of the Kami-ichino-sawa River) in the Mikasa area, Hokkaido; **F**, MCM-A0875, plaster cast of an unregistered specimen from a float rock from the Kami-ichino-sawa River in the Mikasa area, Hokkaido; **G**, KMNH IvP 905006, from Loc. 1 in the Sakawa area, Shikoku.

inner and outer ventrolateral tubercles. Ribs generally alternate between long and short. Long ribs arise from umbilical seam and short ribs begin near mid-flank. On main part of body chamber, long ribs on one side extend to short ones on other side, and alternate from side to side. Tubercles become weaker on body chamber. Suture line only partly exposed, and broad first lateral saddle and narrower lateral lobe visible.

Measurements.—At D = 119.3 mm of KMNH IvP 905001, U = 43.5 mm, H = 45.6 mm, W = 42.6 mm, U/D = 0.36, W/H = 0.93.

Occurrence.—This species is known from the lower Cenomanian of the Mikasa Formation, Yezo Group in the Mikasa (Matsumoto *et al.*, 1969) and Kami-ashibetsu (Matsunaga, 2005) areas, Hokkaido, northeastern Japan and the lower Cenomanian of the Sotoizumi Group in the Aridagawa area, Wakayama, southwestern Japan (Misaki *et al*., 2008). The specimen described here was found in a float rock probably derived from the middle part of the Miyanohara Formation (My3), Sotoizumi Group in the Sakawa area.

Suborder Ancyloceratina Wiedmann, 1966
Superfamily Turrilitaceae Gill, 1871
Family Turrilitidae Gill, 1871
Genus ***Hypostlingoceras*** Matsumoto and Takahashi, 2000

Type species.—*Hypostlingoceras japonicum* Matsumoto and Takahashi, 2000.

Hypostlingoceras japonicum Matsumoto and Takahashi, 2000

Figures 3J–P, 4C, 5A–G

Hypostlingoceras japonicum Matsumoto and Takahashi, 2000, p. 269,

figs. 7–10.
Hypostlingoceras mikasaense Matsumoto and Takahashi, 2000, p. 271, figs. 11–12.

Holotype.—GK.H8542, from the Ganseki-zawa River (a tributary of the Kami-ichino-sawa River), Mikasa area, Hokkaido, northeastern Japan (Matsumoto and Takahashi, 2000, p. 269, figs. 7, 8)

Material.—Three specimens, KMNH IvP 905004 (Figures 3J–K, 5C), KMNH IvP 905005 (Figures 3L–M, 4C, 5B) and KMNH IvP 905006 (Figures 3N–P, 5G), were collected from float rocks at Loc. 1 along the Yanasegawa River, a tributary of the Niyodogawa River, in the Sakawa area, Shikoku (Figure 1). Four specimens, GK.H8540–8542 and MCM-A0875, from the Mikasa area, Hokkaido were also examined for comparison. GK.H8540 is the holotype of *Hypostlingoceras mikasaense* from the Ganseki-zawa River (Matsumoto and Takahashi, 2000, fig. 11). GK.H8541 is the paratype from the Suido-no-sawa River (Matsumoto and Takahashi, 2000, fig. 9). GK.H8542 is the holotype (see details above). To avoid damaging these type specimens, resin casts taken from GK.H8540–8542 were whitened with magnesium oxide and illustrated (Figure 5A, D, E). MCM-A0875 (Figure 5F) is a plaster cast of an unregistered specimen from a float rock in the Kami-ichino-sawa River.

Emended diagnosis.—Rather small shell, with low to moderate apical angle. In the early growth stage, whorl section relatively angular with mid-flank shoulder bearing coarse and strong tubercles. In the next transitional stage, low transverse ribs arise and mid-flank tubercles gradually weaken. In the later growth stage, exposed side relatively rounded and ornamented with dense transverse ribs with obscure mid-flank tubercles. Tubercles aligned on the two ridges at lower end of exposed side throughout growth.

Description.—Sinistral, tightly coiled helical shell, with apical angle of about 20–30°. Ornamentation generally consists of tubercles on the mid-flank and the two ridges at lower end of exposed side and transverse ribs, and their characteristics change with growth. In the early growth stage (less than 6–8 mm in diameter for KMNH IvP 905004–905006), there are coarse and strong tubercles on the mid-flank shoulder. In the next transitional stage, low transverse ribs gradually develop and mid-flank tubercles on these ribs become weaker. In the later growth stage (over 8–10 mm in diameter for KMNH IvP 905004–905006), transverse ribs become denser and mid-flank tubercles become obscure. Throughout these growth stages, tubercles are aligned on the two narrow parallel ridges separated by a narrow groove at lower end of exposed side. Tubercles on the lower rows often more numerous than that on the median row in the younger stage (at 8.2 mm in diameter of KMNH IvP 905005, T = 18, t = 21), but the former become less numerous than the latter in the later stage (see *Measurements* for T and t of a late whorl in KMNH IvP 905005 and 905006). An additional row of tubercles rarely arises below the lower two rows (visible only on the basal surface of the last whorl in KMNH IvP 905005). Whorl section relatively angular with mid-flank shoulder and lower two ridges during the younger stage. Then, as mid-flank tubercles become weaker, exposed side becomes relatively rounded. Suture line partially observed on the exposed side of KMNH IvP 905005, and relatively broad first lateral saddle and relatively shallow lateral lobe visible.

Measurements.—KMNH IvP 905004: NW = 2.5, Hp = 10.9, Ht = 22.2, D = 7.4, ap = 24°, h = 3.9, d = 6.6, h/d = 0.59, T = 15, t = 15; KMNH IvP 905005: NW = 4, Hp = 18.3, Ht = 35.5, D = 9.4, ap = 19°, h = 6.2, d = 9.3, h/d = 0.64, T = 29, t = 24; KMNH IvP 905006: NW = 6.5, Hp = 39.4, Ht = 46.2, D = 21.7, ap = 29° (estimated from undeformed parts), h = 10.9, d = 21.4, h/d = 0.51, T = 39, t = 34. Measurements basically follow Matsumoto and Takahashi (2000); however, whereas Matsumoto and Takahashi (2000) measured T and t on the whorl two volutions before where h and d were measured, these values were measured on the same late whorl where h and d were measured in this study because three successive volutions in specimens from the Miyanohara Formation are rarely preserved in good condition. R is not shown because R corresponds to T on the same late whorl.

Discussion.—Matsumoto and Takahashi (2000) have distinguished *Hypostlingoceras mikasaense* from *H. japonicum* by its larger apical angle, smaller h/d value, stronger mid-flank tubercles in the younger stage, and coarser and less numerous ribs on the later whorls; however, each specimen of *Hypostlingoceras* shows a considerable range in the apical angle, h/d, and tubercle strength (Figure 5; measurements of this study and Matsumoto and Takahashi, 2000), and although both KMNH IvP 905004 and 905005 show a relatively small apical angle and rather large h/d value, they have relatively strong mid-flank tubercles in the younger stage. In addition, KMNH IvP 905006 has a relatively large apical angle, relatively small h/d value, and relatively weak mid-flank tubercles in the younger stage. The timing of the end of the tubercle-dominated stage (= early growth stage) and beginning of the rib-dominated stage (= later growth stage) and rib density also vary depending on the specimen and its growth stage (Figure 5); GK.H8540 (holotype of *H. mikasaense*) does not have especially coarse ribs. These observations suggest that the two taxa are conspecific.

A plaster cast of an unregistered specimen of *Hypostlingoceras* from a float rock from the Kami-ichino-sawa River, Mikasa area, Hokkaido is housed in the Mikasa

City Museum, Hokkaido (MCM-A0875; Figure 5F). Because of its characteristics, this specimen is also considered to belong to this species.

On the other hand, mid-flank tubercles of GK.H8541 become obscure much earlier than those in other specimens. In addition, the tubercles along the lower two rows in GK.H8541 are very weak throughout growth, although those of other specimens are relatively strong in the later stage. These facts may indicate the necessity for further examination of the taxonomic affiliation of GK.H8541. However, following Matsumoto and Takahashi (2000), GK.H8541 is tentatively referred to this species at this time, because specimens similar to GK.H8541 and significant information about it were not obtained from the Miyanohara Formation in this study.

Occurrence.—This species is known from the lower Cenomanian of the Mikasa Formation, Yezo Group in the Mikasa area, Hokkaido, northeastern Japan (Matsumoto and Takahashi, 2000). The present specimens were found in float rocks probably derived from the middle part of the Miyanohara Formation (My3), Sotoizumi Group in the Sakawa area.

Discussion

The ammonoids obtained in this study are useful for stratigraphic correlation. *Mantelliceras japonicum* and *Hypostlingoceras japonicum* are known from the lower Cenomanian of the Yezo Group in Hokkaido, northeastern Japan (e.g. Matsumoto *et al.*, 1969; Matsumoto and Takahashi, 2000), and *Euhystrichoceras nicaisei* occurs in the lower Cenomanian of Algeria, Tunisia, Madagascar, and France, and the Soeushinai and Kami-ashibetsu areas in Hokkaido (e.g. Kennedy and Wright, 1981; Matsumoto *et al.*, 2004; Matsunaga, 2005). Bivalves have typically been used as important index fossils for correlation of the Miyanohara Formation, and the middle part of this formation (My3) has been correlated to the lower Cenomanian mainly based on trigoniids such as *Pterotrigonia pustulosa* (Nagao), *P. mifunensis* (Tamura and Tashiro), and *P. amakusensis* Tashiro and Matsuda (e.g. Tashiro and Matsuda, 1983a, b; Matsuda, 1985; Tashiro and Katto, 1995; Wakita *et al.*, 2007). However, Yoshihara and Komatsu (2006) have suggested that it is necessary to reexamine the correlation of this formation because the distribution of trigoniids is controlled by the depositional environment. The results of this study reconfirm that the My3 is correlated to the lower Cenomanian.

The wide distribution of mid-Cretaceous shallow marine deposits containing a similar bivalve fauna in Japan has been remarked by many researchers, and it has also been observed that the species composition of bivalves of the Miyanohara Formation is similar to that of the upper Albian–lower Cenomanian strata in the Mikasa area in Hokkaido, Misakubo area in Shizuoka, Aridagawa area in Wakayama, Monobe area in Kochi, and Goshoura Island in Kumamoto (e.g. Matsuda, 1985; Komatsu and Maeda, 2005; Yoshihara and Komatsu, 2006; Misaki *et al.*, 2008). On the other hand, the ammonoid species *Mantelliceras japonicum* and *Hypostlingoceras japonicum* are also found from the Mikasa area (Matsumoto *et al.*, 1969; Matsumoto and Takahashi, 2000), and *M. japonicum* and *M.* cf. *japonicum* are known from the Aridagawa and Monobe areas, respectively (Matsumoto, 1982; Misaki *et al.*, 2008); therefore, the results of this study suggest that ammonoid faunas in these areas are also similar to each other, as suggested by Misaki *et al.* (2008). It seems that similar shallow marine environments were widely distributed in the northwestern Pacific region in mid-Cretaceous time.

In this study, the cosmopolitan ammonoid species *Euhystrichoceras nicaisei* was also collected from the Miyanohara Formation. *Euhystrichoceras nicaisei* and/or *E.* cf. *nicaisei* have hitherto been reported from the Soeushinai and Kami-ashibetsu areas in Hokkaido (Hashimoto *et al.*, 1965, p. 19, 22; Matsumoto *et al.*, 1969, p. 287, 2004, p. 72; Matsumoto, 1975, p. 156; Inoma, 1980, p. 178; Matsumoto and Inoma, 1999, p. 36; Matsunaga, 2005, pl. 8, figs. 4, 5). Matsumoto (1975) considered that the *E. nicaisei*-bearing bed in the Soeushinai area is older than the *Mantelliceras japonicum*-bearing bed in the Mikasa area; however, Matsumoto *et al.* (2004) have remarked that *E. nicaisei* is contained in the atypical part of the *Stoliczkaia* (*Lamnayella*) *japonica* Assemblage Zone in the Soeushinai area and that this zone is correlated to the *M. japonicum* Assemblage Zone in the Mikasa area. They thought that the difference in ammonoid faunas of the Mikasa and Soeushinai areas was caused by the depositional environment of the former being shallower than that of the latter. Matsumoto *et al.* (2004) have also suggested that the atypical part in the Soeushinai area may represent more of an offshore open sea environment than the typical part, considering that the ammonoid fauna of the atypical part is composed of cosmopolitan species. On the other hand, in the Kami-ashibetsu area, Matsunaga (2005) recovered *E. nicaisei* from just below the horizon where *M. japonicum* was obtained. In addition, along the Ganseki-zawa River in the Mikasa area, *H. japonicum* was reported from the *M. japonicum* Zone (Matsumoto and Takahashi, 2000), and *Mantelliceras* sp. and *Euhystrichoceras* sp. were collected as float at the same locality (Futakami, 1986, table 1). In this study, *E. nicaisei*, *M. japonicum*, and *H. japonicum* were collected from float rocks at Loc. 1 probably derived from the middle part of the Miyanohara Formation (My3). This indicates that the stratigraphic ranges

of these species are either very close or overlap, although their detailed relationship is not clear. More studies are needed to elucidate the detailed stratigraphic relationship of these ammonoids and the relationships between their distributions and depositional environments.

Acknowledgments

We wish to thank Hiroyoshi Sano, Haruyoshi Maeda, and Manabu Kano for their help in accessing museum collections and references; Toshifumi Komatsu and Matthew H. Dick for identification of bryozoans; Tomihiro Mizobuchi for fruitful discussions; and Tomohiro Nishimura, Yasuyuki Tsujino and Yasunari Shigeta for their valuable comments on the first draft. This study was supported in part by the Sasakawa Scientific Research Grant of the Japan Science Society and JSPS KAKENHI Grant Number JP25800290 and JP17H02028.

References

Amano, M., 1956: Some Upper Cretaceous fossils from southwestern Japan (Part 1). *Kumamoto Journal of Science*, *Series B*, *Section 1 (Geology)*, vol. 1, p. 63–93.

Arkell, W. J., 1957: Introduction to Mesozoic Ammonoidea. *In*, Arkell, W. J., Furnish, W. M., Kummel, B., Miller, A. K., Moore, R. C., Schindewolf, O. H., Sylvester-Bradley, P. C. and Wright, C, W. *eds*., *Treatise on Invertebrate Paleontology*, *Part L*, *Mollusca 4*, *Ammonoidea*, p. L81–129. Geological Society of America, New York and University of Kansas Press, Lawrence.

Collignon, M., 1928–1929: Paléontologie de Madagascar, XV. Les céphalopodes du Cénomanien pyriteux de Diégo-Suarez. *Annales de Paléontologie*, vols. 17 and 18, p. 137–160 and p. 1–56.

Collignon, M., 1931: Paléontologie de Madagascar, XVI. La faune du Cénomanien à fossiles pyriteux du nord de Madagascar. *Annales de Paléontologie*, vol. 20, p. 43–104.

Cooper, M. R. and Owen, H. G., 2011: Evolutionary relationships among Schloenbachiidae (Cretaceous Ammonoidea: Hoplitoidea), with a revised classification of the family. *Neues Jahrbuch für Geologie und Paläontologie Abhandlungen*, vol. 262, p. 289–307.

Coquand, H., 1862: Géologie et paléontologie de la région sud de la province de Constantine. *Mémoires de la Société d'Émulation de la Provence*, *Marseille*, vol. 2, p. 1–341.

Douvillé, H., 1912: Évolution et classification des Pulchelliidés. *Bulletin de la Société Géologique de France*, vol. 11, p. 285–320.

Fukuji, S., 1941: Geology of the Ochi basin, province of Tosa, Shikoku. *Journal of the Geological Society of Japan*, vol. 48, p. 547–559. (*in Japanese*)

Futakami, M., 1986: Stratigraphy and paleontology of the Cretaceous in the Ishikari Province, central Hokkaido, Part 2. Stratigraphy of the Cretaceous in the southern areas. *Bulletin of the National Science Museum*, *Tokyo*, *Series C*, vol. 12, p. 7–34.

Gill, T., 1871: Arrangement of the families of Mollusks. *Smithsonian Miscellaneous Collections*, no. 227, p. i–xvi, 1–49.

Grossouvre, A., 1894: *Recherches sur la craie supérieure. Deuxième partie, Paléontologie. Les ammonites de la craie supérieure*, 264 p. Mémoires pour Servir à l'Explication de la Carte Géologique Détaillée de la France, Imprimerie Nationale, Paris.

Haggart, J. W., 1989: New and revised ammonites from the Upper Cretaceous Nanaimo Group of British Columbia and Washington State. *Geological Survey of Canada Bulletin*, 396, p. 181–221.

Hashimoto, W., Nagao, S. and Kanno, S., 1965: *Explanatory Text of the Geological Map of Japan, Scale 1:50000, Soeushinai (Asahikawa-35)*, 92 p. Geological Survey of Hokkaido, Sapporo. (*in Japanese with English abstract*)

Hyatt, A., 1889: Genesis of the Arietidae. *Smithsonian Contributions to Knowledge*, no. 673, p. 1–238.

Hyatt, A., 1903: *Pseudoceratites* of the Cretaceous. *Monographs of the United States Geological Survey*, vol. 44, p. 1–352.

Inoma, A., 1980: Mid-Cretaceous ammonites from the Shumarinai-Soeushinai area, Hokkaido, Part II. *In*, Igo, H. and Noda, H. *eds*., *Professor Saburo Kanno Memorial Volume*, p. 167–183. Memorial Association of Professor Saburo Kanno's Retirement, Tsukuba.

Juignet, P. and Kennedy, W. J., 1976: Faunes d'ammonites et biostratigraphie comparée du Cénomanien du nord-ouest de la France (Normandie) et du sud de l'Angleterre. *Bulletin Trimestriel de la Société Géologique de Normandie et des Amis du Muséum du Havre*, vol. 63, p. 1–193.

Katto, J., Kojima, J., Suyari, K. and Sawamura, T., 1961: *Geological and mineral resources map of Kochi Prefecture, 1:200,000 with explanatory text*, 129 p. Kochi Prefecture, Kochi. (*in Japanese*)

Katto, J. and Tashiro, M., 1982: On the Cretaceous System in the Sakawa Area, Kochi, Japan. *Research Reports of the Kochi University*, *Natural Scienc*e, vol. 30, p. 109–119. (*in Japanese with English abstract*)

Kennedy, W. J., 2013: On variation in *Schloenbachia varians* (J. Sowerby, 1817) from the Lower Cenomanian of western Kazakhstan. *Acta Geologica Polonica*, vol. 63, p. 443–468.

Kennedy, W. J. and Juignet, P., 1984: A revision of the ammonite faunas of the type Cenomanian. 2. The families Binneyitidae, Desmoceratidae, Engonoceratidae, Placenticeratidae, Hoplitidae, Schloenbachiidae, Lyelliceratidae and Forbesiceratidae. *Cretaceous Research*, vol. 5, p. 93–161.

Kennedy, W. J. and Wright, C. W., 1981: *Euhystrichoceras* and *Algericeras*, the last mortoniceratine ammonites. *Palaeontology*, vol. 24, p. 417–435.

Kobayashi, T., 1931: Geologic structure and Paleozoic strata in the Sakawa basin. *Journal of the Geological Society of Japan*, vol. 38, p. 497–519. (*in Japanese*)

Kobayashi, T., 1932: Stratigraphic study on the Torinosu, Ryoseki and Monobegawa Series in the Sakawa basin. *Journal of the Geological Society of Japan*, vol. 39, p. 1–25. (*in Japanese*)

Kobayashi, T., 1941: Sakawa Orogenic Cycle and its bearing on the origin of the Japanese Islands. *Journal of the Faculty of Science*, *Imperial University of Tokyo*, *Section 2*, vol. 5, p. 219–578.

Komatsu, T. and Maeda, H., 2005: Stratigraphy and fossil bivalve assemblages of the mid-Cretaceous Goshoura Group, southwest Japan. *Paleontological Research*, vol. 9, p. 119–142.

Korn, D., Ebbighausen, V., Bockwinkel, J. and Klug, C., 2003: The A-mode sutural ontogeny in prolecanitid ammonoids. *Palaeontology*, vol. 46, p. 1123–1132.

Kozai, T. and Ishida, K., 2006: Lower Cretaceous litho- and bivalve-stratigraphy of the Sakawa-Ochi area, Kochi Prefecture, SW Japan. *Research Bulletin of Naruto University of Education*, vol. 21, p. 283–293.

Matsuda, T., 1985: The bivalve fauna from the Miyanohara Formation (Lower Cenomanian) of Sakawa area, Shikoku. *Transactions and Proceedings of the Palaeontological Society of Japan*, *New Series*, no. 137, p. 1–18.

Matsumoto, T., 1954: *The Cretaceous System in the Japanese Islands*, 324 p. The Japan Society for the Promotion of Scientific Research, Tokyo.

Matsumoto, T., 1975: Additional acanthoceratids from Hokkaido (Studies of the Cretaceous ammonites from Hokkaido and Saghalien-XXVIII). *Memoirs of the Faculty of Science*, *Kyushu University*, *Series D*, *Geology*, vol. 22, p. 99–163, pls. 11–23.

Matsumoto, T., 1977: Zonal correlation of the Upper Cretaceous in Japan. *Palaeontological Society of Japan*, *Special Papers*, no. 21, p. 63–74.

Matsumoto, T., 1982: Upper Cretaceous ammonites from the Monobe Area, Shikoku. *Palaeontological Society of Japan*, *Special Papers*, no. 25, p. 31–52.

Matsumoto, T. and Inoma, A., 1999: The first record of *Mesoturrilites* (Ammonoidea) from Hokkaido (Studies of the Cretaceous ammonites from Hokkaido and Sakhalin-LXXXIII). *Paleontological Research*, vol. 3, p. 36–40.

Matsumoto, T., Muramoto, T. and Takahashi, T., 1969: Selected acanthoceratids from Hokkaido (Studies of the Cretaceous ammonites from Hokkaido and Saghalien-XIX). *Memoirs of the Faculty of Science*, *Kyushu University*, *Series D*, *Geology*, vol. 19, p. 251–296.

Matsumoto, T., Nishida, T. and Toshimitsu, S., 2004: The early Cenomanian (Cretaceous) ammonite fauna from the Soeushinai area of Hokkaido, North Japan. *Bulletin of the Geological Survey of Japan*, vol. 55, p. 67–92.

Matsumoto, T., Obata, I., Tashiro, M., Ohta, Y., Tamura, M., Matsukawa, M. and Tanaka, H., 1982: Correlation of marine and non-marine formations in the Cretaceous of Japan. *Fossils (Palaeontological Society of Japan)*, no. 31, p. 1–26. (*in Japanese with English abstract*)

Matsumoto, T. and Takahashi, T., 2000: Further notes on the turrilitid ammonoids from Hokkaido-Part 1 (Studies of the Cretaceous ammonites from Hokkaido and Sakhalin-LXXXIX). *Paleontological Research*, vol. 4, p. 261–273.

Matsunaga, T., 2005: *Definition and implications of a neostratotype of the Upper Cretaceous Yezo Supergroup, northern Japan*, 74 p. Doctoral dissertation, Kyoto University, Kyoto.

Misaki, A., Kadota, H. and Maeda, H., 2008: Discovery of mid-Cretaceous ammonoids from the Aridagawa area, Wakayama, southwest Japan. *Paleontological Research*, vol. 12, p. 19–26.

Naumann, E. and Neumayr, M., 1890: Zur Geologie und Paläontologie von Japan. *Denkschriften der Mathematisch-Naturwissenschaftlichen Classe der Kaiserlichen Akademie der Wissenschaften*, vol. 57, p. 1–42, pls. 1–5.

Pervinquière, L., 1907: *Études de paléontologie tunisienne. I, Céphalopodes des terrains secondaires*, 438 p. Carte Géologique de la Tunisie, Paris.

Pervinquière, L., 1910: Sur quelques ammonites du Crétacé algérien. *Mémoires de la Société Géologique de France, Paléontologie*, vol. 42, p. 1–86.

Sowerby, J., 1814: The mineral conchology of Great Britain, Part 10. *In*, Sowerby, J. *ed.*, *The Mineral Conchology of Great Britain*, *Volume 1*, p. 109–124. Benjamin Meredith, London.

Spath, L. F., 1923: On the ammonite horizons of the Gault and contiguous deposits. *Summary of Progress of the Geological Survey of Great Britain for 1922*, p. 139–149.

Spath, L. F., 1934: A monograph of the Ammonoidea of the Gault. Part XI, *Palaeontographical Society Monograph (London)*, vol. 86, p. 443–496.

Tashiro, M., 1985: The Cretaceous System of the Chichibu belt in Shikoku—On the Early Cretaceous lateral fault in the Chichibu Belt—. *Fossils (Palaeontological Society of Japan)*, no. 38, p. 23–35. (*in Japanese with English abstract*)

Tashiro, M. and Katto, J., 1995: Description of several selected bivalve fossils from the Cretaceous Miyanohara Formation of the Sakawa area in Shikoku. *Memoirs of the Faculty of Science*, *Kochi University*, *Series E*, *Geology*, vol. 16, p. 1–13.

Tashiro, M. and Matsuda, T., 1983a: The biostratigraphy of the Cretaceous pterotrigonians in Japan. *Research Reports of the Kochi University*, *Natural Scienc*e, vol. 31, p. 25–60. (*in Japanese with English abstract*)

Tashiro, M. and Matsuda, T., 1983b: A study of the Pterotrigoniae from Japan (I) Taxonomy. *Memoirs of the Faculty of Science, Kochi University*, *Series E*, *Geology*, vol. 4, p. 13–52.

Tashiro, M. and Matsuda, T., 1986: Lower Cretaceous bivalves from the Sakawa area, Shikoku. *Transactions and Proceedings of the Palaeontological Society of Japan*, *New Series*, no. 142, p. 366–392.

Wakita, K., Miyazaki, K., Toshimitsu, S., Yokoyama, S. and Nakagawa, M., 2007: *Geology of the Ino district. Quadrangle Series, 1:50,000*, 140 p. Geological Survey of Japan, AIST, Tsukuba. (*in Japanese with English abstract*)

Wiedmann, J., 1966: Stammesgeschichte und System der posttriadischen Ammonoideen, ein Überblick (2. Teil). *Neues Jahrbuch für Geologie und Paläontologie Abhandlungen*, vol. 127, p. 13–81.

Wilmsen, M., Storm, M., Fürsich, F. T. and Majidifard, M. R., 2013: Upper Albian and Cenomanian (Cretaceous) ammonites from the Debarsu Formation (Yazd Block, Central Iran). *Acta Geologica Polonica*, vol. 63, p. 489–513.

Wright, C. W., Calloman, J. H. and Howarth, M. K., 1996: *Treatise on Invertebrate Paleontology, Part L, Mollusca 4, Revised, Vol. 4, Cretaceous Ammonoidea*, 362 p. Geological Society of America, Boulder, and University of Kansas Press, Lawrence.

Yabe, H., 1901: An ammonite from the Mt. Kaiseki, Sakawa, Tosa. *Journal of the Geological Society of Japan*, vol. 8, p. 233–235. (*in Japanese*)

Yabe, H., 1927: Cretaceous stratigraphy of the Japanese Islands. *Science Reports of Tohoku Imperial University, Second Series*, vol. 11, p. 27–100.

Yehara, S., 1923: Cretaceous Trigoniae from south-western Japan. *Japanese Journal of Geology and Geography*, vol. 2, p. 59–84.

Yehara, S., 1927: Faunal and stratigraphical study of the Sakawa Basin, Shikoku. *Japanese Journal of Geology and Geography*, vol. 5, p. 1–40.

Yoshihara, K. and Komatsu, T., 2006: Geology and molluscan fossils from the Cretaceous Misakubo Formation, northern part of Shizuoka Prefecture, Japan. *Journal of Geography*, vol. 115, p. 626–637. (*in Japanese with English abstract*)

Author contributions

A. M., Y. O. and Y. M. collected and prepared materials and are responsible for their geological settings. A. M. conducted the field work and examined the materials and is responsible for the stratigraphic and taxonomic aspects of the specimens. T. M. contributed on the discussion of the biostratigraphic aspect. All authors contributed to the writing of the paper.