

Original Article

Ontogeny of *Takahashiceras eureka* (Matsumoto), a Cenomanian lytoceratid ammonoid from Hokkaido, Japan

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Abstract. Ontogenetic shell development of a well-preserved specimen of the early Cenomanian ammonoid *Takahashiceras eureka* (Matsumoto) from the Hobetsu area is studied from a diameter range of about 20 to 40 mm by utilizing X-ray CT (computed tomography). At a diameter of 21.5 mm, the specimen exhibits a fairly narrow umbilicus and fairly depressed whorl section. As diameter increases, the whorl section gradually become more compressed and relative umbilical size becomes narrower. Ornamentation at a diameter of 30 mm of a specimen recently found in the Hobetsu area consists of delicate spiral lines and weak, low, rursiradiate ribs as well as growth lines, which curve backward on the flank and form a shallow sinus on the venter. Ribs gradually develop into more distant, rounded, band-like ribs, which increase in strength as diameter increases.

Key words: ammonoid, Cenomanian, Cretaceous, Hokkaido, ontogeny, *Takahashiceras eureka*
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Introduction

Takahashiceras eureka (Matsumoto, 1984), one of the extremely rare ammonoid taxa belonging to family Lytoceratidae, is represented by only three specimens from the lower Cenomanian of the Yezo Group in Hokkaido, northern Japan. The holotype (GK. H5567), which is wholly separate, was described from the Ikushumbetsu area (Matsumoto, 1984), and had its body chamber been preserved, the shell diameter would be fairly large, up to 250 mm in diameter (Klein *et al.*, 2009). Specimen HMG-1524 was reported from the Hobetsu area (Shigeta *et al.*, 2010) and consists of part of the body chamber and phragmocone, which is 42.9 mm in diameter at the last septum. Although somewhat deformed, specimen HMG-1701, also from the Hobetsu area, Shigeta and Izukura (2017) is estimated to have had a diameter in range of 70–80 mm. Recently, a specimen (HMG-2007) that exhibits well-preserved ornamentation in the shell diameter range of 30–60 mm was discovered in the Hobetsu area.

Observation of the first three specimens revealed some of the ontogenetic characteristics of

Takahashiceras eureka (Shigeta and Izukura, 2017), but the taxon's ontogeny at a diameter less than 30 mm is still unknown. X-ray CT (computed tomography), an effective method for non-destructively examining an ammonoid's inner whorls, was utilized to observe the inner whorls of specimen HMG-1524 and describe its ontogenetic shell development. In addition, the ontogenetic change in ornamentation of the newly collected specimen (HMG-2007) is described.

Institution abbreviations.—HMG, Hobetsu Museum, Mukawa; MCM, Mikasa City Museum, Mikasa; NMNS, National Museum of Nature and Science, Tsukuba; TKD, Institute of Geoscience, University of Tsukuba, Tsukuba.

Material and methods

Material

Two specimens were examined for this study (Figure 1). HMG-1524, a specimen earlier reported by Shigeta *et al.* (2010), was found in a float calcareous concretion in the Sasao-no-sawa River in the Hobetsu area. HMG-2007 was recently collected by Yukiharu

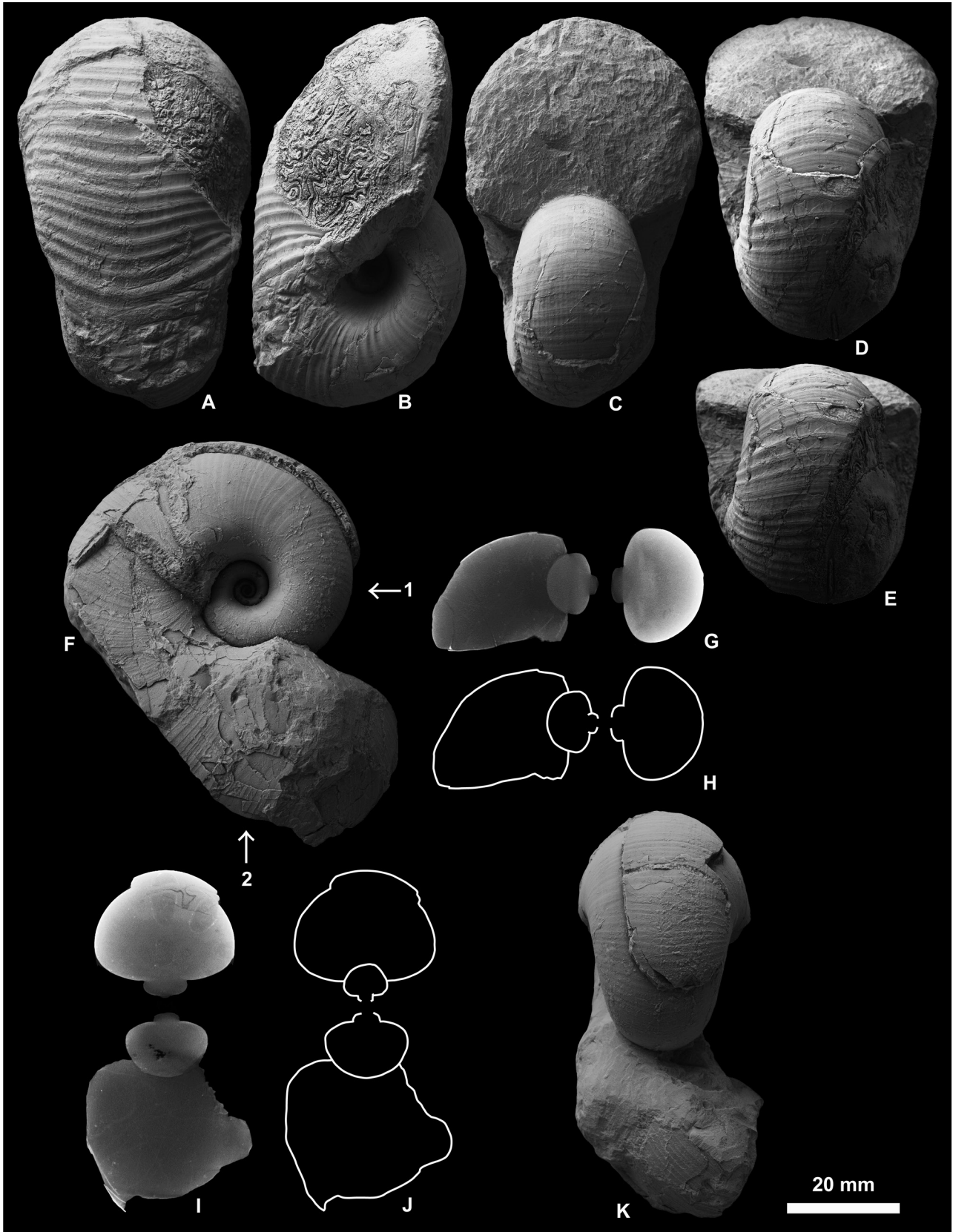


Figure 1. *Takahashiceras eureka* (Matsumoto, 1984) from the Hobetsu area, Hokkaido. A–E, HMG-2007; A, ventral view; B, left lateral view; C, apertural view; D, view rotated 45 degree in the adapical direction from C; E, view rotated 45 degree in the adapical direction from D; F–K, HMG-1524; F, right lateral view; G, X-ray CT image at arrow 1; H, line drawing of G; I, X-ray CT image at arrow 2; J, line drawing of I; K, apertural view.

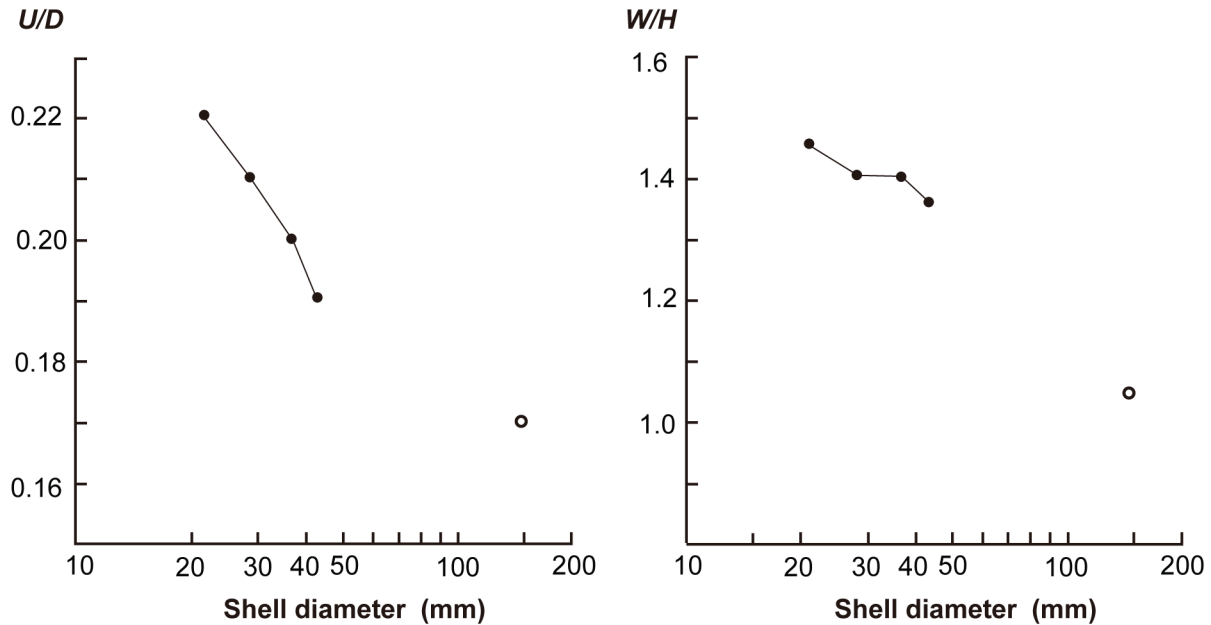


Figure 2. Scatter diagrams of U/D (umbilical diameter/shell diameter) versus D (shell diameter) and W/H (whorl width/whorl height) versus D (shell diameter) for *Takahashiceras eureka* (Matsumoto, 1984) (solid circles, HMG-1524; open circle, holotype GK. H5567)

Hayashi from a float calcareous concretion found 900 m upriver from the mouth of the Penke-wakka-tannenai-zawa River (42.865°N, 142.183°E), a branch of the Hobetsu River in the Hobetsu area. Although the exact horizon from which the concretions came is uncertain, judging from where they were found and their lithologies, they most likely came from the lowest Cenomanian mudstone of the Inasato Formation of the Yezo Group (Takahashi *et al.*, 2002). HMG-1524 was subjected to biometric analysis and HMG-2007 was used for observation of the ornamentation.

X-ray microtomography

Specimen HMG-1524 was scanned utilizing X-ray computed tomography (inspeXio SMX-225CT FPD HR, Shimadzu, Japan) at the National Museum of Nature and Science, Tsukuba. Settings for X-ray scanning are as follows: 0.037 mm resolution, 225 kV, and 70 mA. The 3D images were reconstructed utilizing the software VG Studio Max 3.2.

Biometric analysis

For biometric analysis of the shell morphology of HMG-1524, its shell diameter (D), umbilical diameter (U), whorl height (H) and whorl width (W) were measured every quarter whorl using X-ray CT images

of the cross sections. Two geometric parameters, relative umbilical size (U/D) and relative whorl thickness (W/H), were calculated for each quarter-whorl section.

Results

Ontogenetic change in ornamentation

Ornamentation on HMG-2007 at a diameter of 30 mm consists of delicate spiral lines and weak, low, rursiradiate ribs as well as growth lines, which curve backward on the flank, forming a shallow sinus on the venter (Figure 1). Ribbing gradually develop into more distant, rounded, band-like ribs, which increase in strength as diameter increases.

Ontogenetic shell development

Ontogenetic changes in whorl morphology of specimen HMG-1524, expressed by relative umbilical width (U/D) and relative whorl thickness (W/H) versus shell diameter (D), show a noticeable decrease with growth (Figure 2, Table 1). At a diameter of 21.5 mm, the specimen exhibits a fairly narrow umbilicus ($U/D = 0.22$) and fairly depressed whorl section ($W/H = 1.45$). As diameter increases, the whorl section gradually become more compressed and relative umbilical size

Table 1. Measurements (in mm) of *Takahashiceras eureka* (Matsumoto, 1984), specimen HMG-1524, from the Hobetsu area of Hokkaido. *D*, shell diameter; *U*, umbilical diameter; *H*, whorl height; *W*, whorl width. Values in the first three lines were measured every quarter whorl using X-ray CT images of the cross sections. Values in the bottom line were measured at the last septum.

<i>D</i>	<i>U</i>	<i>H</i>	<i>W</i>	<i>U/D</i>	<i>W/H</i>
21.5	4.9	10.6	15.4	0.22	1.45
28.1	6.0	14.4	20.3	0.21	1.40
37.3	7.7	18.8	26.4	0.20	1.40
42.9	8.4	21.9	29.9	0.19	1.36

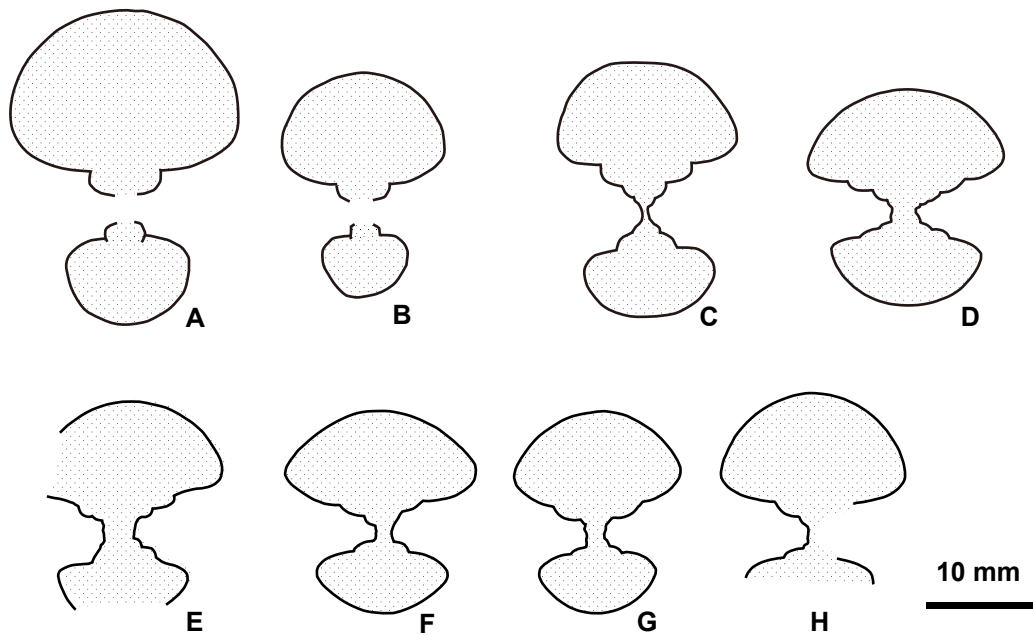


Figure 3. Whorl cross sections of *Takahashiceras*, *Parajaubertella*, *Obataceras* and *Tanabeceras* from Hokkaido. **A, B**, *Takahashiceras eureka* (Matsumoto, 1984), HMG-1524, from the lower lower Cenomanian; **C**, *Parajaubertella kawakitana* Matsumoto, 1943, NMNS PM35839, from the lower lower Cenomanian in the Horokanai area; **D**, *Obataceras manjiense* Shigeta *et al.*, 2012, NMNS PM7442 (holotype) from the upper Albian in the Manji area; **E**, *Tanabeceras pombetsuense* Shigeta *et al.*, 2012, MCM.M0184 (holotype) from the upper Albian in the Mikasa area; **F**, *Tanabeceras yezoense* (Shigeta, 1996), NMNS PM23457, from the lower lower Cenomanian in the Horokanai area; **G**, *Tanabeceras horokanaiense* Shigeta, 2013, TKD 3051 (holotype), from the lower lower Cenomanian in the Horokanai area; **H**, *Tanabeceras mikasaense* (Shigeta, 1996), MCM.A400 (paratype), from the upper lower Cenomanian in the Mikasa area.

becomes narrower. At the last septum (diameter 42.9 mm), *U/D* is 0.19 and *W/H* is 1.36. For the holotype (GK. H5567) at a diameter 145 mm, *U/D* is 0.18 and *W/H* is 1.11.

Discussion

The juvenile shell of *Takahashiceras eureka* at a diameter of 20–40 mm is characterized by a very

involute, fairly depressed shell with a wide-elliptical whorl section and convex flanks that gradually converge to an arched venter from rounded umbilical shoulders. The umbilicus is fairly narrow and deep with a high, gently convex, sub-vertical wall. Ornamentation consists of delicate spiral lines and weak, low, rursiradiate ribs as well as growth lines.

Among late Albian to early Cenomanian ammonoids, the juvenile shell of *Takahashiceras*

eureka is somewhat similar to those of *Obataceras* Shigeta *et al.*, 2012, *Tanabeceras* Shigeta *et al.*, 2012 and *Parajaubertella* Matsumoto, 1943, in having a very involute and fairly depressed shell, but it differs in having a sub-vertical umbilical wall. *Obataceras* and *Tanabeceras* have a depressed, reniform whorl section and a fairly narrow, deep, funnel-shaped umbilicus with an angular or subangular shoulder (Shigeta *et al.*, 2012; Figure 3). *Parajaubertella* has a wide-elliptical whorl section and a fairly narrow, deep umbilicus with a high, vertical wall (Matsumoto, 1943, 1995; Figure 3). Whereas the growth lines and ribs project forward on the venter in *Obataceras* and *Parajaubertella*, they form a very shallow sinus in *Tanabeceras* and *Takahashiceras* (Matsumoto, 1943, 1995; Shigeta, 1996, 2013; Shigeta *et al.*, 2010, 2012).

It is reported that many juvenile shells assignable to *Tanabeceras* and *Parajaubertella* have been found in the lower Cenomanian of Hokkaido and Sakhalin (Zonova *et al.*, 1993; Matsumoto, 1995; Nishida *et al.*, 1996, 1997; Yazykova *et al.* 2004; Shigeta and Izukura, 2013), but juvenile shell of *Takahashiceras eureka* at a diameter less than 30 mm has never been found. This study clarifies the characteristics of the juvenile shell of the taxon and provides a key understanding for future discoveries and identification of its juvenile shells.

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(要 旨)

穂別地域で採集された保存良好なセノマニアン前期アンモナイト *Takahashiceras eureka* (Matsumoto) 標本の成長に伴う殻形態の変化が, X線CT (コンピュータ断層撮影) を用いることによって, 殻直径約 20 mm から 40 mm まで研究された. 殻直径 21.5 mm の殻は, かなり狭いへそと横に大きく膨らんだ螺管断面を持つ. 殻の直径が増加するにつれて, 螺管の横への膨らみは徐々に減り, へそは殻直径に対してやや狭くなる. 穂別地域で最近発見された標本の直径 30 mm 付近の殻表面には, 成長方向に延びる繊細な条線と成長線と共に弱い肋が観察される. 肋は殻側面で後方に曲がり, 腹側中央部で浅い湾入を形成する. 肋は次第に頂部が丸みを帯び幅広くなり, 殻の直径が増すにつれて, その強度が増す.