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Tohokubelus gen. nov., the oldest belemnite from the Olenekian (Lower Triassic) of Northeast Japan

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Abstract. **A new sinobelemnitid belemnite genus, *Tohokubelus*, is described based on *T. takaizumii* sp. nov. from the late Olenekian (late Early Triassic) mudstone of the Osawa Formation belonging to the South Kitakami Belt in the Utatsu area, Miyagi Prefecture, Northeast Japan. The present discovery is important because this species is the oldest belemnite and extends downwardly the range of the Belemnitida from the Carnian (early Late Triassic). We concluded that the order appeared first in the earliest Triassic in the low-latitude area of the westernmost part of the Panthalassa, then belemnites spread to habitats in the Paleo- and Neo-Tethys in the Early Jurassic by the equatorial currents from the Panthalassa to the Tethys.**

Keywords: **Belemnitida, Osawa Formation, Sinobelemnitidae, South Kitakami Belt, Triassic**

Introduction

The Belemnitida (= belemnites *sensu stricto*) is an order of cephalopods that evolved probably from the xiphoteuthidid Aulacoceratida (Jeletzky, 1966; Keupp and Fuchs, 2014). Its general body plan is characterized by an internal shell consisting of three parts (rostrum, phragmocone, and pro-ostracum), subcylindrical mantle, paired fins, and ten arms with hooks (Spaeth, 1975; Donovan and Crane, 1992; Fuchs and Hoffmann, 2017; Hoffmann and Stevens, 2020). In comparison with numerous detailed research results in Europe (e.g. Miller, 1829; Riegraf, 1995; Riegraf *et al*., 1998; Dera *et al*., 2016), our knowledge about Japanese belemnites is limited, and only six named species have been described previously: *Neohibolites miyakoensis* Hanai, 1953, from the Lower Cretaceous of Iwate Prefecture, *N. kubotai* Niko and Hayakawa, 2005, from the Lower Cretaceous of Hokkaido, *Acrocoelites* (*Odontobelus*) *mantanii* Niko and Kameya, 2006, from the Early Jurassic of Yamaguchi Prefecture, *Sichuanobelus utatsuensis* Iba, Sano, Mutterlose and Kondo, 2012, from the Lower Jurassic of Miyagi Prefecture, *Nipponoteuthis katana* Iba, Sano and Mutterlose, 2014, from the Lower Jurassic of Miyagi Prefecture, and *Eocylindroteuchis*? *yokoyamai* Iba, Sano and Mutterlose, 2014, from the Lower Jurassic of Miyagi Prefecture. This study primarily aims to describe the seventh species, *Tohokubelus takaizumii* gen. et sp. nov., based on material discovered from the Lower Triassic Osawa Formation, Miyagi Prefecture.

Modern researchers agree that the Belemnitida became extinct by the end of the Cretaceous, but its early history is still in debate and the following genera had been proposed for the oldest representative: *Eobelemnites* (Middle Mississippian; Flower, 1945), *Jeletzkya* (Early Pennsylvanian; Johnson and Richardson, 1968), *Palaeobelemnopsis* (late Permian; Chen and Sun, 1982), *Sinobelemnites* and *Sichuanobelus* (early Late Triassic; Zhu and Bian, 1984), and *Schwegleria* (early Early Jurassic; Riegraf, 1980). Among them *Eobelemnites* and *Jeletzkya* were excluded by Doyle (1994) and Doyle *et al*. (1994) who concluded that the stratigraphic information of the former is unreliable and the latter should be placed in the order Phragmoteuthida rather than the Belemnitida. Although assigning *Palaeobelemnopsis* to the Belemnitida was questioned by Doyle (1994), Doyle *et al*. (1994) and Riegraf (1995), it remains *incertae sedis* in the subclass Coleoidea or was questionably placed in the Aulacoceratida without morphological discussion. Iba *et al*. (2012) confirmed that *Sinobelemnites* and *Sichuanobelus* are true belemnites. They were the only genera that indisputably occur from the Triassic before the present new discovery. Limited to Europe, the middle Hettangian genus, *Schwegleria*, is the oldest belemnite. Doyle (1994), Schlegelmilch (1996), and Weis and Delsate (2006) considered that *Schwegleria* forms the stock of the Belemnitida and attempted reconstructions of early phylogenetic lineages without information from East Asia. Therefore, this study also aims to discuss the origin of the Belemnitida with reexamination of *Palaeobelemnopsis*.

Stratigraphy and ammonoid age of the Osawa Formation

The Osawa Formation in the South Kitakami Belt, Northeast Japan is the second formation of the Lower–Middle Triassic Inai Group, which is divided into the Hiraiso, Osawa, Fukkoshi and Isatomae formations, in ascending order (Onuki and Bando, 1959). The Inai Group, distributed widely in the southern part of the Kitakami Massif (Figure 1), is composed of continuous, fossiliferous, shallow marine (partly alluvial to near-shore marine) clastic sediments, total thickness of which exceeds 2000 m, and therefore, one of the most important reference sequences of the Lower–Middle Triassic of Japan.

The Hiraiso Formation, resting unconformably on the Upper Permian formations, is 200–250 m thick and dominated by coarse- to medium-grained calcareous sandstone with subordinate thin mudstone. Only one age-diagnostic ammonoid, *Tirolites* cf. *ussuriensis* Zharnikova (*in* Buryi and Zharnikova, 1981), has been described from the middle part of the formation (Shigeta and Nakajima, 2017). *Tirolites ussuriensis* was known from the lower part of the Spathian (upper Olenekian) in the South Primorye, Far East Russia (Zakharov and Popov, 2014).

The Osawa Formation is 250–350 m thick and is dominated by laminated mudstones, intercalated with sandstone beds in the lower to middle part. It has yielded rather rich ammonoids, consisting of 27 genera (Bando and Shimoyama, 1974; Ehiro, 1993, 2016; Ehiro *et al*., 2016a; Ehiro, 2022). The lower to middle part of the formation (the *Subcolumbites* Zone of Bando and Shimoyama, 1974) is characterized by *Columbites parisianus* Hyatt and Smith, 1905 and *Subcolumbites perrinismithi* (Arthaber, 1908), in association with such genera as *Hemilecanites*, *Albanites*, *Pseudosageceras*, *Tardicolumbites*, *Yvesgalleticeras*, *Hellenites*, *Metadagnoceras*, *Procarnites*, *Olenekoceras*, *Nordophiceratoides*, etc. (Figure 2). The lower part of the upper part (the *Arnautoceltites* Zone of Bando and Shimoyama, 1974) consists of *Arnautoceltites*, *Nordophiceras*, *Prenkites*, etc. And the uppermost part, the *Eodanubites* Zone (Ehiro, 2022), yields *Pseudosageceras multilobatum* Noetling, 1905, *Arnautoceltites* sp., *Procarnites kokeni* (Arthaber, 1908), *Japonites* cf. *meridianus* Welter, 1915, *Eodanubites* aff. *xinyuanensis* Wang, 1978, *Procladiscites towaensis* (Bando and Ehiro, 1982), etc. (Bando and Ehiro, 1982; Ehiro, 2022). Based on these ammonoids, the lower to upper part and the uppermost part of the Osawa Formation are correlated with the upper Olenekian and the uppermost Olenekian, respectively (Bando and Shimoyama, 1974; Ehiro *et al*., 2016a; Ehiro, 2022).

The Fukkoshi Formation is composed of thick sandstone and alternating beds of sandstone and mudstone, with a total thickness of 200–300 m. Because of its dominant sandstone facies, the Fukkoshi Formation is almost barren of ammonoids. Only some Anisian species, *Gymnites* cf. *watanabei* (Mojsisovics, 1888), *Hollandites* sp. and *Balatonites* cf. *kitakamicus* (Diener, 1916) were considered to come from the middle part of the Fukkoshi Formation (Onuki and Bando, 1959); however, there are some doubts about the stratigraphic position and locality of these ammonoids (Ishibashi, 2006).

The Isatomae Formation is more than 1,000 m thick and consists of sandy laminated mudstone often with thick sandstones or alternating beds of sandstone and mudstone. From the lowermost part at Kudanohama in Utatsu area, Ishibashi (2006) reported, although not yet described, *Grambergia kitakamiensis* Ishibashi, 2006, *Tropigastrites* cf. *lahontanus* Smith, 1914, *Lenotropites isatomaensis* Ishibashi, 2006, *Ussurites* sp., *Paracrochordiceras* sp. and *Leiophyllites pseudopradyumna* (Welter, 1915). This Kudanohama ammonoid fauna corresponds to the *Lenotropites–Japonites* Zone (Aegean: lowermost Anisian) of Qinghai, China (He *et al*., 1986), *Pseudokeyserlingites guexi* beds to *Lenotropites caurus* Zone (lower Anisian) of Nevada (Bucher, 1989), *Paracrochordiceras–Japonites* beds (Aegean) of Deşli Caira Hill, Romania (Grădinaru *et al*., 2007) and Chios (Assereto, 1974; Fantini Sestini, 1981). Thus, the Olenekian/Anisian boundary is considered to locate somewhere in the lower part of the Fukkoshi Formation.

Material and methods

The belemnite fossil described here was collected from mudstone float in an outcrop of the Osawa Formation to the north of Heiseinomori, Utatsu area (Figure 1: 38°43′20″N, 141°32′05″E). This outcrop, produced when the preparation work of the athletic field of Heiseinomori was conducted (completed in 1991), is occupied by laminated to poorly laminated, calcareous mudstones (20–30 m in thickness), which strike N-S and dip westerly with moderate angle. The belemnite-bearing boulder is one of the rock lumps scattered by the construction and its lithology is identical with that of the Osawa Formation. The mudstone of the Isatomae Formation, cropping out to the northwest of this outcrop (Figure 1C) is easily distinguished from that of the Osawa Formation and belemnite-

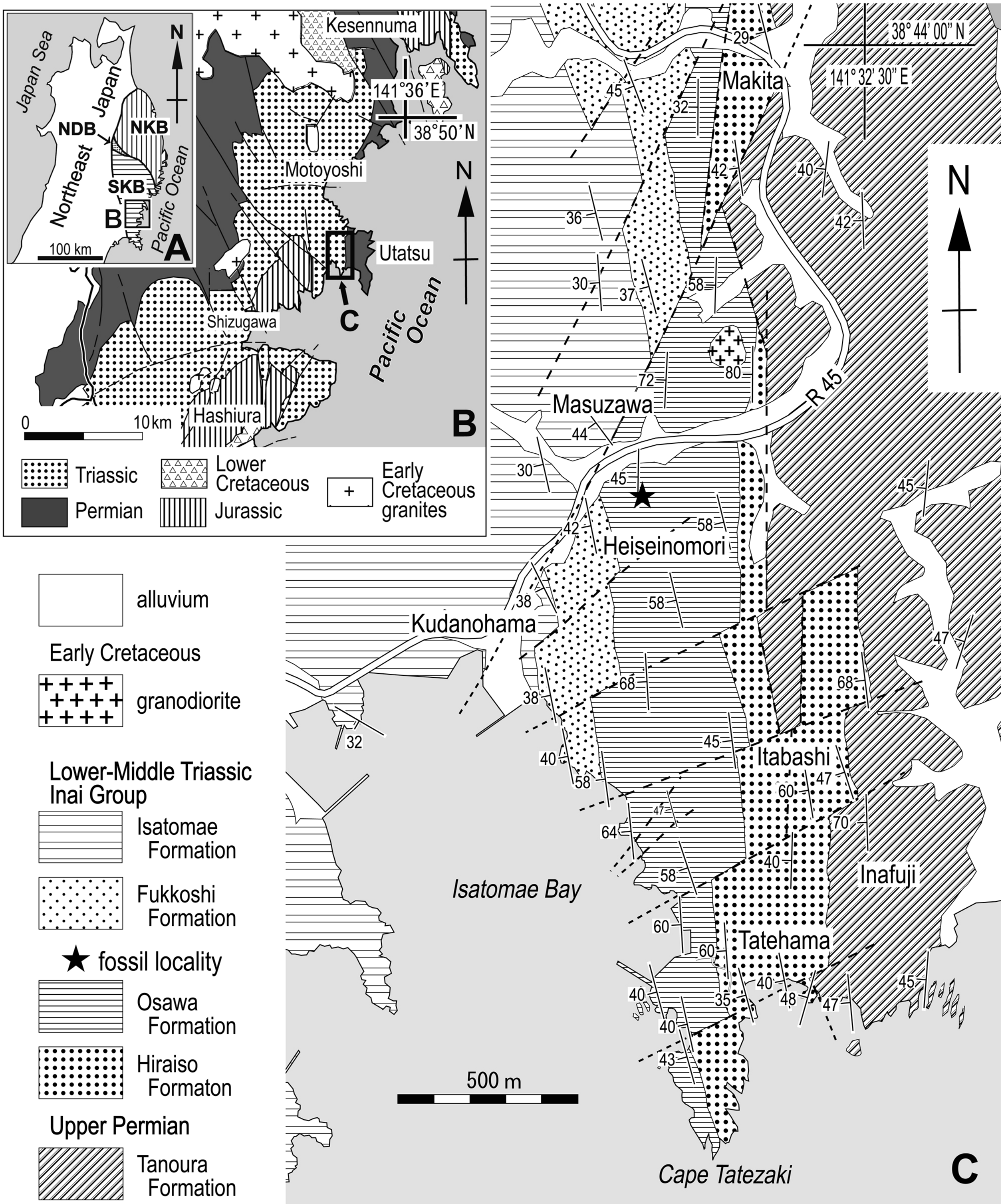

Figure 1. Geological maps of study area, showing distributions of the Pre-Cretaceous tectonic belts in Northeast Japan **(A),** geology of the southern part of the Kitakami Massif **(B),** and detailed geology near fossil locality **(C)**. NDB: Nedamo Belt; NKB: North Kitakami Belt; SKB: South Kitakami Belt.

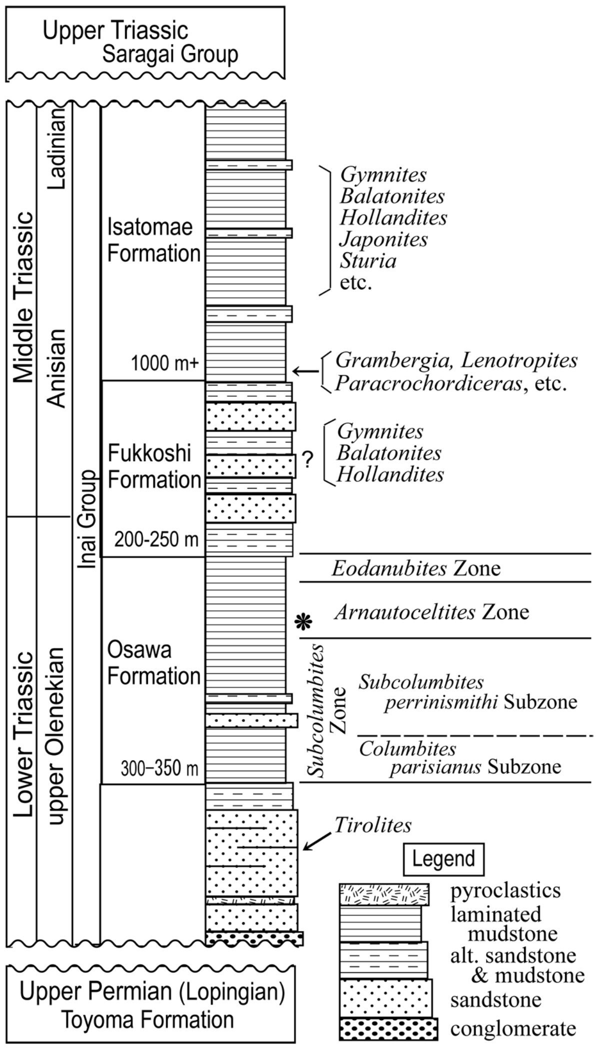

Figure 2. Generalized columnar section of the Inai Group in the South Kitakami Belt and the stratigraphic occurrences of ammonoids. The probable horizon with occurrence of *Tohokubelus takaizumii* gen. et sp. nov. is indicated by asterisk.

bearing mudstone by its rather sandy lithofacies showing remarkable bioturbation. Post-Triassic mudstones distribute far from this site (Figure 1B) and their non-calcareous lithofacies differ from the Osawa Formation. Therefore, it is certain that the belemnite fossil is derived from the Osawa Formation.

The specimen must come from the middle to upper part of the Osawa Formation. But the precise horizon of the belemnite-bearing bed in the Osawa Formation is unknown, because both boundaries of the Hiraiso/Osawa and Osawa/Fukkoshi formations are not exposed near the fossil site. When the preparation work of the athletic field was conducted, many ammonoid specimens were collected from the present fossil site and its southern extension (present-day Heiseinomori athletic field). They are *Xenoceltites* cf. *crenoventrosus* Chao, 1959, *Nordophiceras* sp., *Preflorianites utatsuensis* Ishibashi, 2006, *Inyoites* aff. *oweni* Hyatt and Smith, 1905, *Stacheites floweri* Kummel, 1969, *Arnautoceltites* sp., *Prenkites* cf. *timorensis* Spath, 1930, and *Leiophyllites pitamaha* (Diener, 1895) (Educational Committee of Utatsu Town, 1996; Ishibashi, 2006). Due to the presence of *Arnautoceltites* species and the absence of *Columbites*, *Subcolumbites* and *Eodanubites* species in this fauna, it is most probable that the fossil horizon belongs to the *Arnautoceltites* Zone (lower part of the upper Osawa Formation: upper Olenekian) (Figure 2).

An almost complete rostrum with an indwelling phragmocone (IGPS coll. cat. no. 112442) was available for study, and it is designated herein as the holotype. We did not adopt any invasive methods, such as preparation of polished and new fracture sections, elimination of the rostrum on the phragmocone, and etching, for the holotype in view is of importance. This specimen sustains the condition when it was donated to the Tohoku University Museum. Although detailed internal structure of the phragmocone, accurate position of the protoconch, and nature of fissure of the rostrum are unknown for this reason, observable characteristics described below are enough for the familial assignment and comparisons with related taxa. Determination of ventral and dorsal sides on the rostrum was made by the siphunclar position observable in fracture section (Figure 3D), where cut surfaces and parts of two septa appeared (Figure 3H). These morphologies serve in identification of a dorsal groove and determinations of septal shape and distance. Measurement of an alveolar angle (= apical angle of phragmocone) can be performed at the exfoliated part of the rostrum (Figure 3A).

Systematic paleontology

Subclass Coleoidea Bather, 1888
Order Belemnitida Zittel, 1895
Suborder uncertain
Family Sinobelemnitidae Bian and Zhu *in* Zhu and Bian, 1984

Genus ***Tohokubelus*** gen. nov.

Type species.—*Tohokubelus takaizumii* sp. nov., by monotypy.

Diagnosis.—Rostrum relatively thick with nearly circular transverse sections; apex acute; apical region conical; stem and alveolar regions subcylindrical; outline cylindriconical; profile asymmetrical; a deep groove develops on dorsal surface of rostrum; lateral lines absent; alveolus

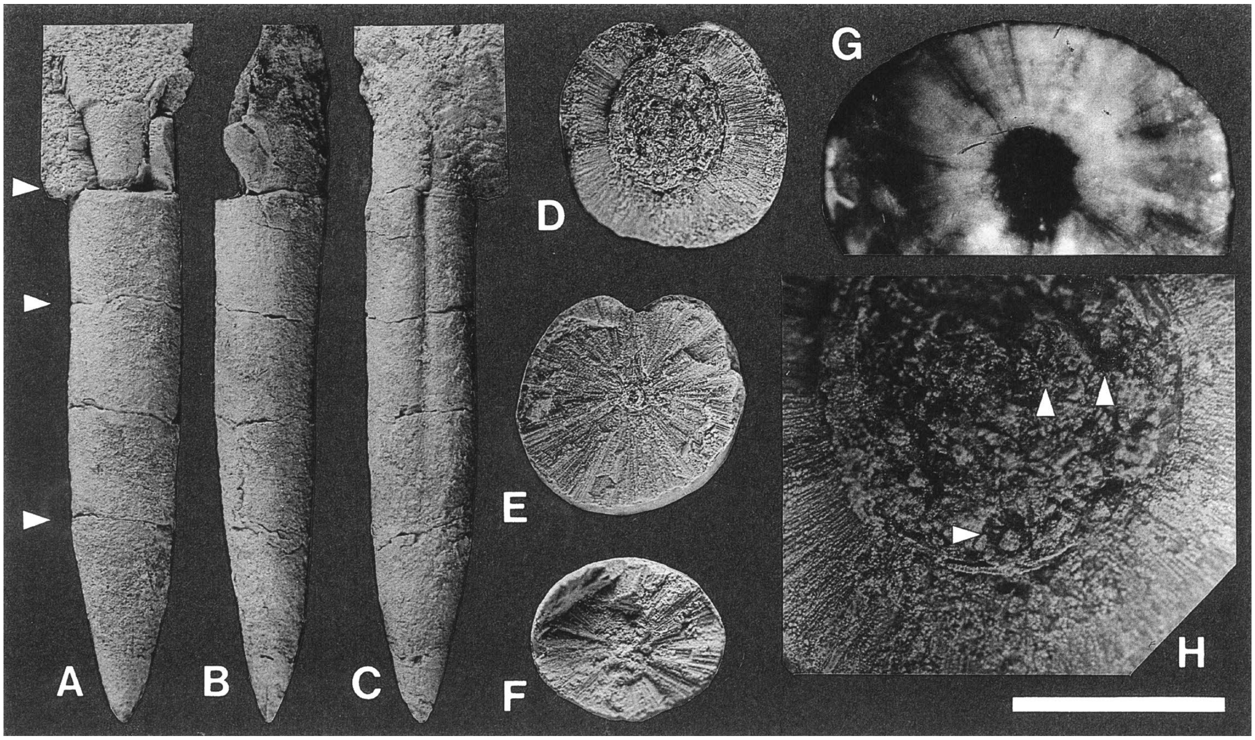

Figure 3. *Tohokubelus takaizumii* gen. et sp. nov., holotype, IGPS coll. cat. no. 112442. **A,** ventral view; lower, middle, and upper arrows indicate respectively positions of F, E, and D; **B,** left lateral (ventral on left) view; **C,** dorsal view; **D,** transverse section (fracture surface) at alveolar region, venter down; **E,** transverse section (fracture surface) at alveolar region (near protoconch), venter down; **F,** transverse section (fracture surface) at apical region, venter down; **G,** partial enlargement of F to show concentric growth rings, venter up; **H,** partial enlargement of D to show septa (upper two arrows) and siphuncle (lower arrow). A–F, H; coated with ammonium chloride. G; submerged in water. Scale bar is 12 mm in A–C, 6 mm in D–F, 3 mm in G, 2 mm in H.

(and phragmocone) laterally compressed; alveolar angle moderate, approximately 20°.

Etymology.—The generic name refers to the Tohoku District, from which the type species of the new genus was recovered, and a Greek word "βέλος" (belus) meaning arrow.

Remarks.—The most diagnostic character of *Tohokubelus* gen. nov. is a single dorsal groove on the rostrum that suggests it should be included within the Sinobelemnitidae. Two genera, *Sinobelemnites* Zhu and Bian (1984; type species, *S. cornutus* Zhu and Bian, 1984) and *Sichuanobelus* Zhu and Bian (1984; type species, *S. longmenshanensis* Zhu and Bian, 1984), were previously known from this family. Among them, *Sichuanobelus* is most similar to the new genus, but its rostrum has a conical outline and laterally compressed transverse sections, and the dorsal groove is somewhat shallower than that of *Tohokubelus*. *Sinobelemnites* clearly differs from *Tohokubelus* by the presence of lateral lines.

Tohokubelus takaizumii sp. nov.

Figure 3

Diagnosis.—As for the genus.

Description.—Rostrum is relatively thick, non-hastate and small sized, having 39 mm in total length. Except for apical region having dorsoventrally depressed oval cross sections, transverse sections of rostrum are nearly circular. Rostral diameters 6.0 mm near estimated position of protoconch and 6.2 mm (maximum diameter) at adoral end. Apex acute with apical angle of 27° and slightly displaced toward dorsal side. Postalveolar region divided into conical apical and subcylindrical stem regions, but their boundary is rather ambiguous. Length of postalveolar region is approximately 24 mm. Alveolar region subcylindrical, short, approximately 15 mm in length. Outline cylindriconical. Profile slightly asymmetrical. Dorsal surface of rostrum marked by a single deep groove that begins posteriorly near boundary of apical and stem regions and reaches adoral end of alveolar region. Profiles of groove are V-shaped with 0.5 mm in depth and 2.1 mm in width at alveolar region. Lateral lines absent.

Alveolus (= rostrum cavum; and phragmocone preserved in it) is conical, laterally compressed in transverse section with 0.8 in ratio of lateral diameter per dorsoventral one. Alveolar angle (= apical angle of phragmocone) moderate for the Belemnitida, approximately 20°. Septa are concave adapically and closely spaced. Siphuncle along ventral margin. Diameter of siphuncle is 0.4 mm at lateral phragmocone diameter of 3.1 mm. Apical line (observed in transverse sections) faintly shifts dorsal from central axis of rostrum, indicating position ratio (distance from apical line to ventral surface/diameter of rostrum) of 0.52. Pro-ostracum is not preserved. Microstructure of rostrum consists of radially arranged fibers (presumably calcite) showing concentric growth rings.

Age and occurrence.—Late Olenekian; lower part of the upper Osawa Formation in the Utatsu area, Miyagi Prefecture, Tohoku District, Northeast Japan.

Etymology.—The specific name honors Mr. Yukihiro Takaizumi who found the holotype of this species.

Remarks.—*Sichuanobelus utatsuensis* Iba, Sano, Mutterlose and Kondo (2012, p. 912, 913, figs. 3A–3J) from the Hettangian (Early Jurassic) Niranohama Formation in the Utatsu area was the only representative of the Sinobelemnitidae outside of Southwest China. The cylindriconical outline and a deep dorsal groove of *S. utatsuensis* resembles *Tohokubelus takaizumii* sp. nov. rather than the type species of *Sichuanobelus*. The principal difference between *S. utatsuensis* and *T. takaizumii* is in alveolar angles, the former indicates relatively rapid expansion attaining 30° whereas this value of the latter is moderate for the order. Laterally compressed oval sections with rather flattened lateral sides in *S. utatsuensis* also serve to differentiate.

Discussion

Systematic implications.—Its large alveolar angle (approximately 20°) for the Coleoidea, closely spaced septa, rostrum consisting of radially arranged fibers, and concentric growth rings warrant a placement of *Tohokubelus takaizumii* gen. et sp. nov. in the Belemnitida instead of the Aulacoceratida.

Chen and Sun (1982) stated that a Changhsingian (late Permian) genus *Palaeobelemnopsis* Chen *in* Chen and Sun (1982; type species, *P. sinensis* Chen *in* Chen and Sun, 1982) from the Dalong Formation in Jian-shi County, Hubei Province represents the first Paleozoic and the oldest occurrence of the order Belemnitida. Their view was supported by a subsequent study by Liu and Su (1999) that was based on material recovered from the adjoining Hunan Province. However, the phragmocone of *Palaeobelemnopsis* is a longiconic orthocone with low expansion angle, long camera, and possibly simple cone-like apex, the characteristics of which are apparently beyond the diagnosis of the Belemnitida. Rather, they show affinity to aulacoceratids and xiphoteuthidids belonging to the order Aulacoceratida. Although surface shapes of the rostra in these genera are different, the "double-sphere" transverse sections provided by the paired dorsolateral depressions on the rostra of *Palaeobelemnopsis* may suggest relationship with an aulacoceratid genus, *Miyagiteuthis* Niko and Ehiro (2018; type species, *Dictyoconites nipponicus* Shimizu and Mabuti, 1941) from the Upper Triassic Saragai Group in the South Kitakami Belt. We think, therefore, *Palaeobelemnopsis* should be removed from the Belemnitida and placed in the Aulacoceratida.

Paleogeographic and paleobiogeographic implications.—Undoubted Triassic records of belemnites were limited to *Sinobelemnites* and *Sichuanobelus* that occur in the Carnian (lower Upper Triassic) part of the Maantang Formation in the Longmen Mountains, Sichuan Province, South China (Zhu and Bian, 1984; Iba *et al.*, 2012). Furthermore, some uncertain records of Triassic belemnites are present in South China, including Hu *et al*. (2011; the Middle Triassic of Yunnan Province) and Iba (2016; the Upper Triassic of Yunnan Province), but they remain undescribed. In the subsequent Early Jurassic age, belemnites extended their habitats westward and reached northern Europe in the Paleo-Tethys (Riegraf, 1980; Weis and Delsate, 2006) and Tibet belonging to the northern margin of Gondwana in the Neo-Tethys (Chen, 1982; Iba *et al*., 2015).

The paleogeography of the South Kitakami Belt, Northeast Japan, where the Inai Group was deposited, has been reconstructed by using paleobiogeographic data, because no valid palaeomagnetic data have been obtained from the Pre-Cretaceous rocks of the belt due to the thermal effect by the Early Cretaceous granites. The belt is thought to have been located near the South China continent during middle Paleozoic to Triassic based on the Silurian-Permian faunal and floral similarities with those of South China (see Ehiro, 2001; Ehiro *et al*., 2016b). The Early Triassic ammonoids from the Osawa Formation belong to the *Columbites*-*Subcolumbites* fauna, which is characteristic in the low latitudinal areas (Ehiro, 1997; Brayard *et al*., 2009).

Thus, it is likely that South Kitakami had been located at or near South China (Ehiro, 2001; Ehiro *et al*., 2016b). On the other hand, the Late Permian araxoceratid ammonoid fauna of South Kitakami resembles closely that of the western Tethys Province, not with that of South China (Ehiro, 2019). Brayard *et al*. (2009) stated that the ammonoid fauna of the Osawa Formation (Early Triassic) had a close paleobiogeographic relationship with the eastern area of the equatorial Panthalassa (California, Nevada and Idaho), although South Kitakami was located near South China at that time. Ehiro *et al*. (2016b) also stressed that the Osawa ammonoid fauna is most like that of the western United States and next to those in the western Tethys province such as Albania, Croatia and Greece, not to that of South China.

Based on the paleomagnetic data, the South China continent was located in the low latitude near the equator during the Late Permian to Early Triassic, then migrated to the north and reached to the middle latitude at Late Triassic to Jurassic (e.g. Seguin and Zhai, 1992; Yin and Nie, 1993). During this process, the South and North China continents began to collide, initially at the eastern end, during the Late Permian (Yin and Nie, 1993) or Early Triassic (Zhao *et al*., 2020). Therefore, at the Early Triassic, it is considered that the connection between the Tethys Sea and the Panthalassa Ocean was already closed on the north of South China, and the potential currents between these two oceans passed to the southern side of South China. Brayard *et al*. (2009) and Ehiro *et al*. (2016b) considered that South Kitakami was located at the low-latitude area of the westernmost part of the Panthalassa (the Tethys–Panthalassa border) during the Early Triassic and the Early Triassic ammonoid faunal connection among the eastern Panthalassa, South Kitakami and western Tethys was influenced by these potential currents along the equator. We think that the above-mentioned belemnite migrations from the Panthalassa to the Tethys have also related to these equatorial currents.

Conclusions

1) *Tohokubelus takaizumii* gen. et sp. nov. (Sinobelemnitidae: Belemnitida) is described from the late Olenekian (late Early Triassic) Osawa Formation in the Utatsu area in Miyagi Prefecture, Northeast Japan. This species represents the oldest and the first Early Triassic record of the order Belemnitida, which was previously thought to have appeared in the Carnian (early Late Triassic). This discovery extends the range of the order back at least 17 m.y. 2) Differentiation from the probable ancestor (xiphoteuthidid Aulacoceratida; see above) into the Belemnitida, chanced in the earliest Triassic near South Kitakami and South China, areas which were situated at the low-latitude area of the westernmost part of the Panthalassa. 3) The equatorial currents from the Panthalassa to the Tethys formed by northward migration of a landmass consisting of South Kitakami and South China had an impact on the expansion of the habitats of belemnites to the Paleo- and Neo-Tethys in the Early Jurassic age.

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Author contributions

S. N. conceived the original idea, designed the project, and contributed to paleontological aspects of the research.

M. E. contributed to geological and paleo-geographical aspects of the research. The two authors discussed the results and wrote the final version of the manuscript.