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Source: Paleontological Research, 19(4) : 269-282

Published By: The Palaeontological Society of Japan

URL: https://doi.org/10.2517/2015PR010

Paleontological Research, vol. 19, no. 4, pp. 269–282, October 1, 2015

doi:10.2517/2015PR010

Thylacocephala (Arthropoda) from the Lower Triassic of the South Kitakami Belt, Northeast Japan

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Received November 13, 2014; Revised manuscript accepted March 1, 2015

Abstract. **A thylacocephalan fauna from the upper Olenekian (Lower Triassic) Osawa Formation in the South Kitakami Belt, Northeast Japan, is described. The fauna comprises three species belonging to three genera: *Ankitokazocaris bandoi* Ehiro and Kato sp. nov., *Kitakamicaris utatsuensis* Ehiro and Kato gen. et sp. nov., and *Ostenocaris* sp. This is the first report of fossils belonging to the class Thylacocephala from Japan, and it expands their paleogeographic distribution. As almost all genera of Thylacocephala inhabited low-latitude areas in each relevant geological time, their occurrence from the Osawa Formation supports previous opinions that the South Kitakami Belt was located in the equatorial region during the Triassic.**

Key words: Arthropoda, Early Triassic, Osawa Formation, South Kitakami Belt, Thylacocephala

Introduction

The Lower Triassic (upper Olenekian: Spathian) Osawa Formation distributed in the South Kitakami Belt, Northeast Japan, is famous for yielding rich ammonoid faunas and the oldest ichthyopterygian, *Utatsusaurus hataii* Shikama, Kamei and Murata, 1978. Our recent field research on the fossil assemblage of the Osawa Formation, in cooperation with the Educational Committee of Minamisanriku Town, unearthed a new fossil group belonging to the class Thylacocephala Pinna, Arduini, Pesarini and Teruzzi, 1982 from the middle part of the formation distributed in the Motoyoshi and Utatsu areas.

Thylacocephala is an enigmatic fossil group of arthropods, probably belonging to the subphylum Crustacea (e.g. Lange *et al.*, 2001). Occurrences of thylacocephalan fossils are very rare, but the group has a long stratigraphic record ranging from the Cambrian (Vannier *et al*., 2006) or Silurian (Schram, 2014; Haug *et al*., 2014) to the Cretaceous (Vannier *et al*., 2006; Schram, 2014; Haug *et al*., 2014). They are distributed over a wide geographical region and Schram (2014) listed more than 20 genera from Australia, Austria, China, the Czech Republic, France, Germany, Italy, Lebanon, Madagascar, Scotland and the United States. They are also known from Mexico (Hegna *et al.*, 2014), Slovenia (Križnar and Hitij, 2010) and Spain (Calzada and Mañé, 1993), but have yet to be recorded from the Japanese Islands.

Early taxonomic controversies were settled by Rolfe (1985) with Thylacocephala becoming the accepted name for the class and both Conchyliocarida Secrétan, 1983 and Concavicarida Briggs and Rolfe, 1983 becoming orders within the Thylacocephala. The composition of the orders and subsequently named families has been chaotic. Schram (2014) attempted to classify the thylacocephalans to the family level, but no clear definition was given to these families and it seems that further examination is necessary for family-level classification.

In this paper, we describe the thylacocephalan fauna of the Osawa Formation, the first discovered in Japan, and discuss its significance.

A brief note on the Osawa Formation

The Osawa Formation is the second formation of the Lower–Middle Triassic Inai Group, which is widely distributed in the southern part of the Southern Kitakami Massif, Northeast Japan (Figure 1). The Southern Kitakami Massif belongs to the South Kitakami Belt, characterized by early Paleozoic basement rocks and a cover of shallow marine Ordovician to Lower Cretaceous strata. In contrast, the Northern Kitakami Massif is mainly composed of Jurassic accretionary complexes. The basements of the South Kitakami Belt were formed

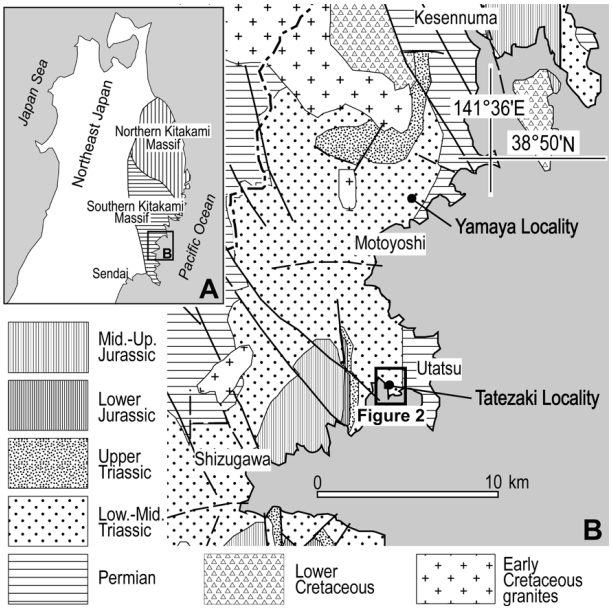

Figure 1. Index map showing the distribution of the Triassic strata in the southern part of the Southern Kitakami Massif (South Kitakami Belt), Northeast Japan, and fossil localities (Yamaya and Tatezaki localities).

along the northern margin of Gondwana, and the overlying middle Paleozoic to Triassic strata were deposited in an equatorial region near the South China block (e.g. Ehiro and Kanisawa, 1999; Ehiro, 2001).

In the Motoyoshi–Utatsu area of the Southern Kitakami Massif, Permian to Jurassic strata form a large syncline whose axis trends NNE-SSW (Figures 1, 2). The Inai Group is divided, in ascending order, into the Hiraiso, Osawa, Fukkoshi, and Isatomae formations (Onuki and Bando, 1959). The Hiraiso Formation is 200–250 m thick. The lower part of the formation consists of a thin basal conglomerate, which unconformably covers late Permian mudstone-dominated strata, and coarse- to medium-grained calcareous sandstone with thin mudstone. The upper part is composed of alternating beds of medium- to fine-grained calcareous sandstone and mudstone. The latter alternating beds grade upward into thin alternating beds of mudstone and sandstone of the lowermost part of the Osawa Formation. The Osawa Formation, also 200–250 m thick, consists mainly of laminated mudstone, which is often intercalated with thin sandstone or alternating beds of sandstone and mudstone. These sedimentary rocks are all calcareous, containing *ca*. 10% CaO (Onuki, 1981). The formation has almost no trace fossils, and the fine sandy laminations in it are sharp with no evidence of bioturbation. The Fukkoshi Formation has a thickness of 200–300 m and is composed of thick sandstone and alternating beds of sandstone and mudstone. The Isatomae Formation has a thickness of more than 1,000 m and consists of sandy laminated mudstone often with thick sandstone or alternating beds of sandstone and mudstone. The sandy laminae of the formation, except for those in its lowermost part, are markedly disturbed by bioturbation. The Inai Group is overlain unconformably by the Upper Triassic Saragai and Lower Jurassic Shizukawa groups on the eastern wing of the syncline, but it is directly overlain by the Middle–Upper Jurassic Hashiura Group in the axial part and western wing of the syncline.

The Osawa Formation has a rich ammonoid fauna and is divided biostratigraphically into two ammonoid zones: the *Subcolumbites perrinismithi* Zone (occupying the lowermost to upper part of the formation) and the *Arnautoceltites* Zone (uppermost part) (Bando and Shimoyama, 1974). The former zone yields ammonoids such as *Preflorianites* aff. *sulioticus* (Arthaber, 1911), *Columbites parisianus* Hyatt and Smith, 1905, *Subcolumbites perrinismithi* (Arthaber, 1908), *Metadagnoceras motoyoshiense* Ehiro, 1993, *Keyseringites* cf. *middendorffi* (Keyserling, 1845), *Eophyllites* cf. *dieneri* (Arthaber, 1908), and *Leiophyllites* sp. (Bando and Shimoyama, 1974; Ehiro, 1993). *Columbites* and *Subcolumbites* (Figure 3) range over the zone. The latter zone contains *Procarnites kokeni* (Arthaber, 1908), *Arnautoceltites* sp., *Isculitoides* aff. *originis* (Arthaber, 1911), *Prenkites* cf. *timorensis* Spath, 1930, and *Eosturia towaensis* Bando and Ehiro, 1982 (Bando and Shimoyama, 1974; Bando and Ehiro, 1982). Based on these ammonoids, the Osawa Formation is correlated with the upper Olenekian (Spathian).

Aside from these ammonoids, the Osawa Formation has yielded pelecypods including *Promyalina* sp., *Leptochondoria hataii* Murata, 1973, and *Pecten* (*Pinna*) *quadrata* (Sugiyama, 1942) (Murata, 1973, 1978); a tooth of the hybodontid shark *Hybodus* sp. (Kato *et al*., 1995); two ichthyopterygian species, namely, *Utatsusaurus hataii* and Ichthyopterygia indet. Takahashi *et al*., 2014; and the land plants *Pleuromeia hataii* Kon'no, 1973 and *Neocalamites muratae* Kon'no, 1973. Fragments of land plants are common fossil elements of the Osawa Formation. Coprolites with bone inclusions are also known (Nakajima and Izumi, 2014).

Kamada (1991) concluded, based on sedimentary facies analysis, that the Inai Group was deposited in a sedimentary environment changing gradually from coastal alluvial fan–nearshore marine (Hiraiso Formation) to offshore marine (Osawa, Fukkoshi and Isatomae formations). The lack of trace fossils and bioturbation suggests an anoxic or dysoxic depositional environment

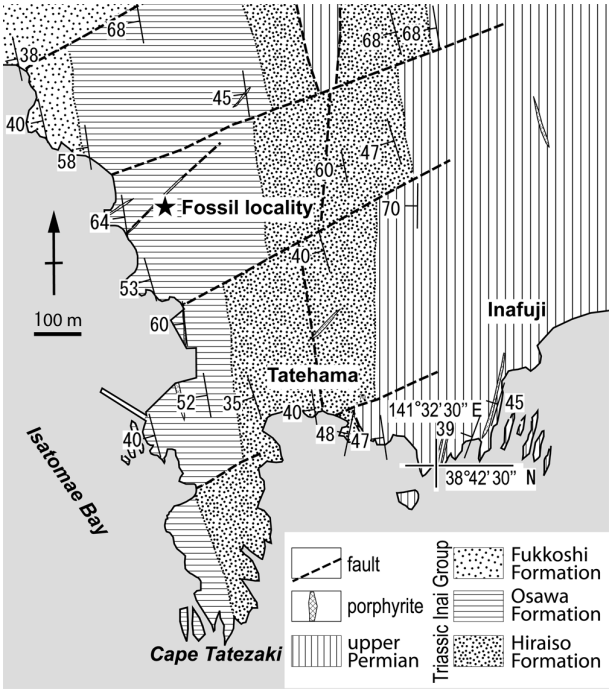

Figure 2. Geologic map of the Tatezaki area, Utatsu, Minamisanriku Town, Miyagi Prefecture, showing the fossil locality (Tatezaki locality).

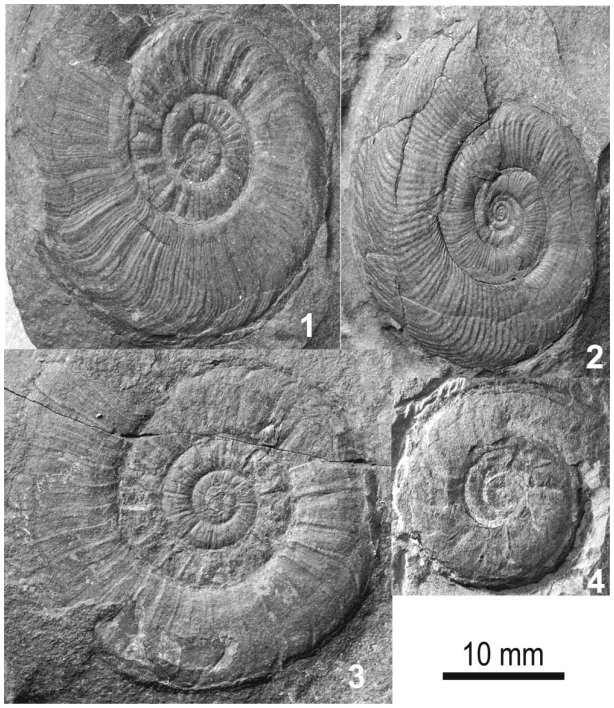

Figure 3. Ammonoid fossils from the middle part of the Osawa Formation. **1**, **2**, from the Yamaya locality; 1, *Columbites parisianus* Hyatt and Smith, 1905; 2, *Subcolumbites perrinismithi* (Arthaber, 1908); **3**, **4**, from the Tatezaki locality; 3, *Columbites parisianus* Hyatt and Smith; 4, *Hellenites elegans* Guex, Hungerbühler, Jenks, Taylor and Bucher, 2005.

of the Osawa Formation despite its limited depth (not far from the land) evoked by the common occurrence of land plants.

Fossil localities and occurrence

We collected more than 150 thylacocephalan specimens from the laminated mudstones of the Osawa Formation. Two specimens were from the middle part of the formation at the Yamaya locality (38°48′40″N, 141°32′54″E, Figure 1), Motoyoshi-cho, Kesennuma City, Miyagi Prefecture, and the rest were from the middle part of the formation at the Tatezaki locality, situated about 900 m north of Cape Tatezaki (38°42′50″N, 141°32′07″E, Figures 1, 2), Utatsu, Minamisanriku Town, Miyagi Prefecture. Because many thylacocephalan specimens from the Osawa Formation are fragmentary, 65 relatively well preserved or distinctive specimens (IGPS coll. cat. no. 111442–111497 and UIM 30601–30610) were selected to study.

The Yamaya locality coincides with the ammonoid locality of Ehiro (1993) and is associated with ammonoids such as *Columbites parisianus*, *Subcolumbites perrinismithi*, *Metadagnoceras motoyoshiense*, *Keyserlingites* cf. *middendorffi*, etc. The Tatezaki locality has also yielded many ammonoid fossils including *C. parisianus* and *S. perrinismithi*, although the ammonoid fauna of this locality is still under investigation. These two localities are nearly the same stratigraphic horizon, but their exact stratigraphic relationship remains unclear because there is no key bed in the Osawa Formation.

In both localities, in addition to the thylacocephalan and ammonoid fossils, many fragments of land plants and some pelecypods, as well as some ichthyopterygian bones, decapod crustaceans and fishes from the Tatezaki locality, were collected. Most of the molluscan and plant fossils from the Osawa Formation are molds; in contrast, some thylacocephalan specimens contain black-colored carapace fragments. These may be the remains of original carapaces, but more detailed study is needed. The thylacocephalan fossils from the Tatezaki locality are usually isolated, but sometimes densely arranged. They rarely co-occur with other fossils such as decapod crustaceans. These fossils are oriented parallel to the bedding planes, and flattened perpendicular to the bedding planes probably due to synsedimentary deformation. At the Yamaya locality, ammonoid fossils are also deformed lat-

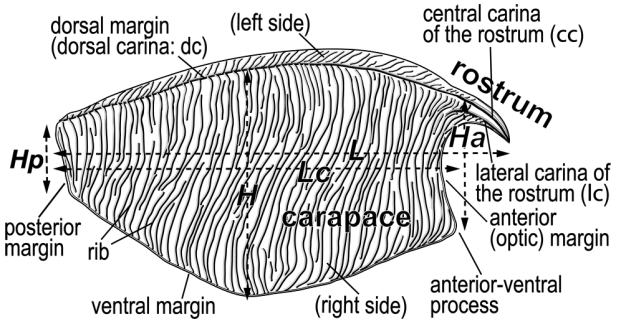

Figure 4. Morphological terminology, dimensions, and their abbreviations. *Kitakamicaris utatsuensis* Ehiro and Kato gen. et sp. nov. as an example. *H*, maximum height of carapace; *Ha* and *Hp*, anterior and posterior height of carapace; *L*, maximum length of carapace; *Lc*, length of carapace excluding the rostrum.

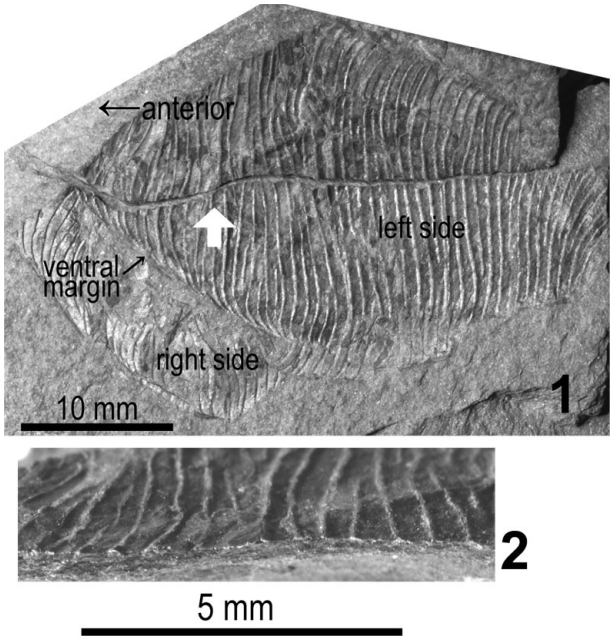

Figure 5. *Kitakamicaris utatsuensis* Ehiro and Kato gen. et sp. nov. from the Osawa Formation, IGPS coll. cat. no. 111497. **1,** left lateral view; **2,** cross section of the carapace at the position indicated by arrow.

erally into an ellipsoidal form (Figure 3.1, 3.2), but they maintain their original circular outline at the Tatezaki locality (Figure 3.3, 3.4). Therefore, we do not have to take into account the post-depositional horizontal deformation of the thylacocephalan specimens from the Tatezaki locality, where most of the specimens are from.

Systematic description

by Masayuki Ehiro and Hisayoshi Kato

The specimens described here are held in the Tohoku University Museum (Institute of Geology and Paleontology, Tohoku University: IGPS) and in the Utatsu Ichthyosaur Museum (Educational Committee of Minamisanriku Town: UIM). The morphological terminology, dimensions, and their abbreviations are shown in Figure 4. In this paper, we provisionally follow Schram (2014) for the taxonomic classification.

The term "terrace structure" was often used previously for the wrinkle-like lineations on the carapace of some thylacocephalan genera, e.g. *Atropicaris* Arduini and Brasca, 1984 and *Microcaris* Pinna, 1974. A similar set of structures was also recognized in the Osawa thylacocephalan specimens belonging to the new genus *Kitakamicaris*. However, they are not stepwise structures but rather a combination of rather wide, flat planes and triangular ridges in cross section (Figure 5.2). Therefore, we adopt the term "rib" for this structure in regard to the specimens described in this paper.

Class Thylacocephala Pinna, Arduini, Pesarini, and Teruzzi, 1982
Order Concavicarida Briggs and Rolfe, 1983

Family Concavicarididae Schram, 2014
Genus ***Ankitokazocaris*** Arduini, 1990

Type species.—*Ankitokazocaris acutirostris* Arduini, 1990, by monotypy.

Diagnosis.—Thylacocephala with a strong rostrum and a convex dorsal margin; anterior third of it is rectilinear. The anterior margin is concave on the upper third.

Included species.—*Ankitokazocaris acutirostris*; *A. bandoi* Ehiro and Kato sp. nov.

Ankitokazocaris bandoi Ehiro and Kato sp. nov.

Figure 6

Materials.—Eight specimens: IGPS coll. cat. nos. 111442 (holotype), 111443–111446 and 111496, and UIM 30601–30602, all collected from the middle part of the upper Olenekian Osawa Formation to the north of Cape Tatezaki (Tatezaki locality, Figure 2), Utatsu, Minamisanriku Town, Miyagi Prefecture.

Etymology.—The specific epithet honors Yuji Bando who studied the Triassic stratigraphy and ammonoid faunas of Japan, including the South Kitakami Belt.

Diagnosis.—*Ankitokazocaris* has a broad-based, large rostrum with a triangular shape in cross section, and

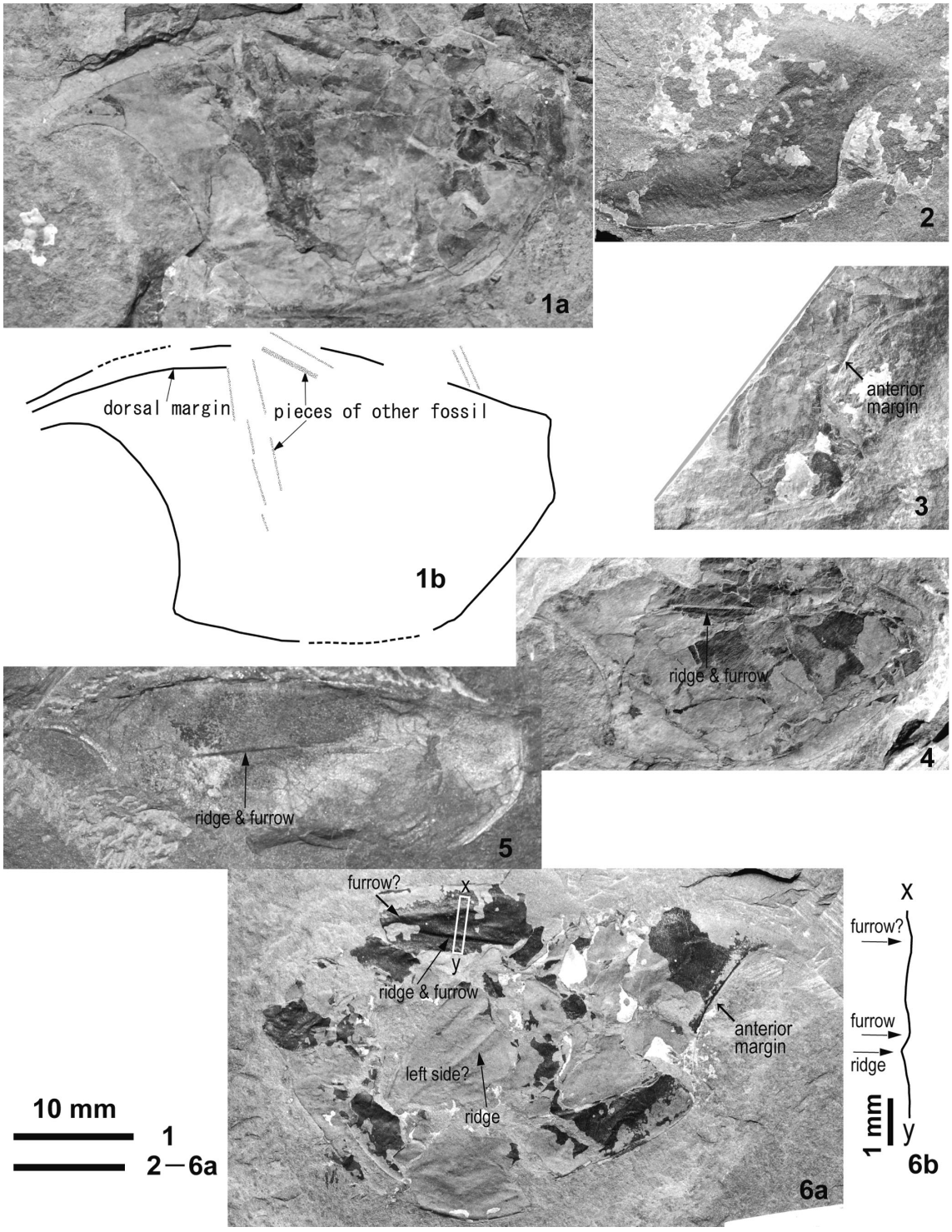

Figure 6. *Ankitokazocaris bandoi* Ehiro and Kato sp. nov. from the Osawa Formation. **1**, IGPS coll. cat. no. 111442 (holotype), with other fossil fragments (possible appendages of a decapod crustacean); 1a, left lateral view; 1b, sketch of 1a; **2**, IGPS coll. cat. no. 111443, right lateral view of anterior part; **3**, IGPS coll. cat. no. 111444, right lateral view of anterior part; **4**, UIM 30601, left lateral view, dorsal margin missing; **5**, IGPS coll. cat. no. 111496, right lateral view (outer mold), ventral margin missing; **6**, IGPS coll. cat. no. 111446; 6a, left lateral view (outer mold), partly fragmented, with a piece of right side (another specimen?); 6b, cross section of the ridge and furrows on the carapace (x–y section of 6a). All from the Tatezaki locality.

broad and symmetrically concave anterior margin.

Description.—The carapace is trapezoidal in lateral view, with a broadly convex dorsal margin, wide and broadly concave anterior (optic) margin, bending ventral margin, and narrow and slightly concave posterior margin. The dorsal margin is partly broken. The anterior three-fifths of the ventral margin is broadly convex and nearly parallel to the dorsal margin, but the posterior two-fifths extending to an upward bend is nearly straight. The type specimen has a length of about 46.5 mm and a height of 23 mm, with $H/L = ca.$ 0.5. The dorsal margin is extended anteriorly into a stout rostrum. It has a triangular cross section, without carina, and has broad bases. The lower surface of the rostrum connects smoothly to the upper two-thirds of the anterior margin, showing broad concavity. The lower part of the anterior margin is connected to the anterior part of the ventral margin with a narrowly rounded, nearly right-angled process (average 88°, range 88°–89°, $n = 3$) in specimens IGPS 111442 (holotype), IGPS 111444, and UIM 30601 (Figure 6.1, 6.3, and 6.5), but it is more obtuse in IGPS 111443 (97°, Figure 6.2) and 111446 (106°, Figure 6.6).

The surfaces of the carapace and rostrum seem to be smooth and without ornamentation, except for a fine and straight, longitudinal ridge and furrow. The ridge runs on the dorsal side, but its exact length is unknown due to poor preservation. It is asymmetrical in cross section having gentle ventral and steep dorsal slopes (Figure 6.6b). Along the dorsal side of the ridge, a shallow furrow is associated. IGPS 111446 (Figure 6.6) has an additional shallow and wide furrow? near the dorsal margin.

Comparison.—*Ankitokazocaris bandoi* sp. nov. is distinguished from *A. acutirostris* (Arduini, 1990, p. 199, figs. 2 and 3: Lower Triassic of Madagascar) by having a larger, broad-based rostrum and symmetrically concave anterior margin.

Family Microcarididae Schram, 2014

Included genera.—*Atropicaris* Arduini and Brasca, 1984; *Ferrecaris* Calzada and Mañé, 1993; *Microcaris* Pinna, 1974; *Kitakamicaris* Ehiro and Kato gen. nov.

Discussion.—Schram (2014) grouped three Middle–Late Triassic genera, *Atropicaris*, *Ferrecaris* and *Microcaris*, with the Cretaceous genus *Thylacocephalus* Lange, Hof, Schram and Steeman, 2001, into the family Microcarididae. Hegna *et al.* (2014) compared the genus *Polzia* Hegna, Vega and González-Rodríguez, 2014 with *Microcaris*. The genera *Thylacocephalus* and *Polzia*, however, have a posterior spine and are considered to be grouped with other Cretaceous genera such as *Protozoea* Dames, 1886 and *Pseuderichthus* Dames, 1886 (Protozoeidae Schram, 2014).

Genus ***Kitakamicaris*** Ehiro and Kato gen. nov.

Type species.—*Kitakamicaris utatsuensis* Ehiro and Kato sp. nov., by monotypy.

Etymology.—Named after the Kitakami Massif where the fossil-bearing Osawa Formation is distributed.

Diagnosis.—Thylacocephala with a trapezoidal carapace, on which vertical ribs develop, and with a distinct tricarinate rostrum. The concave anterior margin is connected at a right angle to the ventral margin. The narrow posterior margin is flat or slightly concave.

Description.—Same as for the type species.

Discussion.—*Kitakamicaris* gen. nov. (Early Triassic) is characterized by a trapezoidal lateral view of the slender carapace, distinct rostrum, and vertical ribs on the carapace. It is similar to the genera *Atropicaris* (Late Triassic), *Ferrecaris* (Middle Triassic), and *Microcaris* (Late Triassic), especially to *Atropicaris*, and considered to belong to the family Microcarididae. *Kitakamicaris* gen. nov. is clearly distinguished from other Triassic genera by having a right-angled anterior-ventral process and a stout tricarinated rostrum. *Ferrecaris* differs especially from the other three genera by lacking a flat or concave posterior margin.

The general shapes of the carapace and rostrum of the Triassic Microcarididae somewhat resemble those of the Devonian–Carboniferous genus *Concavicaris* Rolfe, 1969, especially *C. sinuata* (Meek and Worthen, 1868) (Rolfe, 1969, p. 317, fig. 140.1a). In addition, several species of *Concavicaris* have fine ribs on the carapace (e.g. *C. milesi* Briggs and Rolfe, 1983, p. 252, text-fig. 1b, pl. 35, fig. 18, pl. 36, fig. 3). The anterior-ventral process of *Concavicaris* is more acute than that of *Kitakamicaris*, which suggests the possibility that the genus *Kitakamicaris* is positioned in the middle of the lineage *Concavicaris*—*Kitakamicaris*—*Atropicaris* (*Microcaris*). As mentioned by Schram (2014), however, the genus *Concavicaris* comprises several genera and so has been subdivided into four species groups. To reveal the relationship between the Paleozoic *Concavicaris* spp. and Triassic genera, further information, especially Permian data, is required.

Kitakamicaris utatsuensis Ehiro and Kato gen. et sp. nov.

Figures 5, 7–9

Materials.—Fifty-six specimens: IGPS coll. cat. nos. 111448 (holotype), 111449–111495 and 111497, and UIM 30604–30610, all collected from the middle part of the upper Olenekian Osawa Formation to the north of Cape Tatezaki (Tatezaki locality, Figure 2), Utatsu,

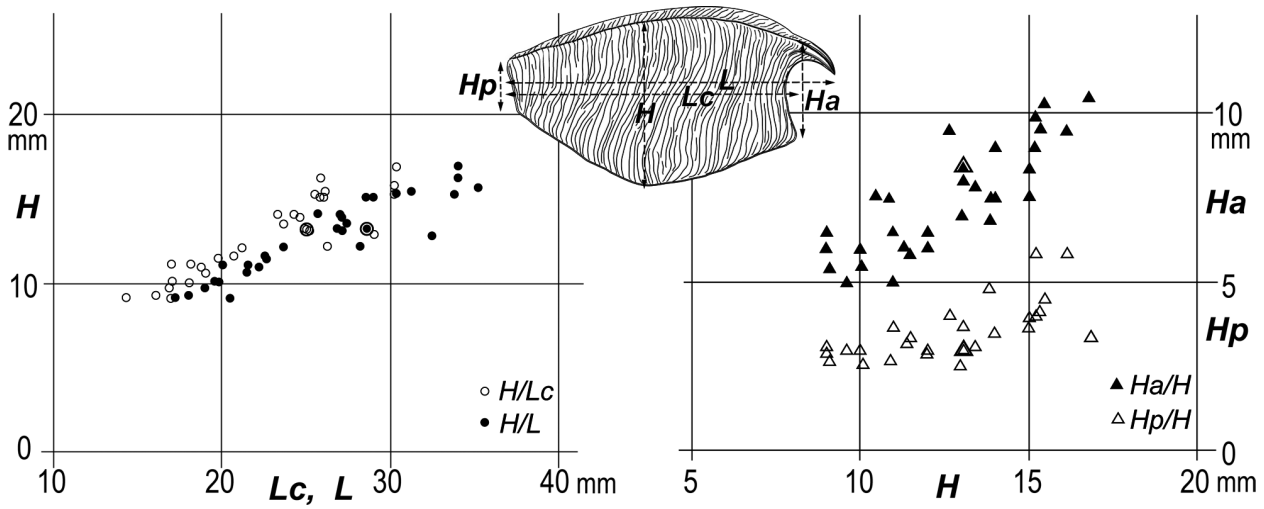

Figure 7. Scatter diagrams of carapace maximum height (*H*) versus carapace maximum length (*L*) or carapace length (*Lc*) and anterior height (*Ha*) or posterior height (*Hp*) versus carapace maximum height (*H*) of specimens of *Kitakamicaris utatsuensis* Ehiro and Kato gen. et sp. nov. Double circles and double triangles are holotype.

Minamisanriku Town, Miyagi Prefecture, except for IGPS coll. cat. no. 111449–111450 which are from Yamaya (Yamaya locality: Figure 1), Motoyoshi-cho Kesennuma City, Miyagi Prefecture.

Etymology.—The specific epithet refers to the type locality.

Diagnosis.—Trapezoidal carapace is longer than it is high and has remarkable vertical ribs on it. The carinated dorsal margin is broadly convex. The ventral margin bends in the central part and is connected with the concave anterior margin at almost a right angle. The rostrum is distinct with central and lateral carinae.

Description.—The carapace is trapezoidal in lateral view, with a broadly convex dorsal margin, concave and broad anterior (optic) margin, mound-shaped ventral margin with a vertex in its central part, and slightly concave or nearly straight, narrow posterior margin. The carinated dorsal margin extends into a distinct and straight to gently curved rostrum. The rostrum is triangular in cross section and bears remarkable central (top) and a pair of lateral carinae. The central carina runs through the rostrum and passes into the carinated dorsal margin. The lateral carinae pass through the base of the rostrum and then bend downward posteriorly and thin out to obsolescence. There is a slight difference in the length and thickness of the lateral carinae among the specimens, and in some specimens they are partly discontinuous. The lower surface of the rostrum and the upper half of the anterior margin have a semicircular shape. The lower half of the anterior margin is nearly straight and is connected to the nearly straight anterior half of the ventral margin with a narrowly rounded, nearly right-angled process (average 89.1°, range 86–91°, n = 23). The posterior half of the ventral margin is slightly convex. The maximum height (*H*) of the carapace is at its middle part where the ventral margin is bent. The maximum length of the carapace (*L*) is 17.2 mm to 35.2 mm, and *H*/*L* is *ca*. 0.5, but the *H*/*L* value is smaller in the specimen with length larger than *ca*. 30 mm (Figure 7). The *H*/*Lc* (*Lc*; length of carapace excluding the rostrum) is about 0.55. The height of the anterior margin (*Ha*) is smaller than *H* and *Ha*/*H* is about 0.6 (Figure 7). The height of the posterior margin (*Hp*) is smaller than that of the anterior one, and *Hp*/*H* is 0.3–0.5, although the value of *Hp* is somewhat unreliable in some specimens due to poor preservation.

The whole carapace bears vertical falciform ribs that slightly incline forward and taper toward both ends. The surfaces of the carapace as a whole are nearly flat and only the ribbed parts are bent and project outward, forming triangular ridges. This bending structure affects the inside of the carapace (Figure 5.2). There are 45 to 55 primary ribs running parallel to each other from the dorsal to the ventral margin. This is, however, an approximate number because the ribs sometimes thin, branch off, and/or join together. Near the dorsal margin, they all bend slightly backward. On the other hand, near the ventral margin, they bend remarkably backward in the anterior half but bend slightly forward in the posterior half. Some secondary short ribs are inserted sporadically in both the dorsal and ventral margins, especially along the

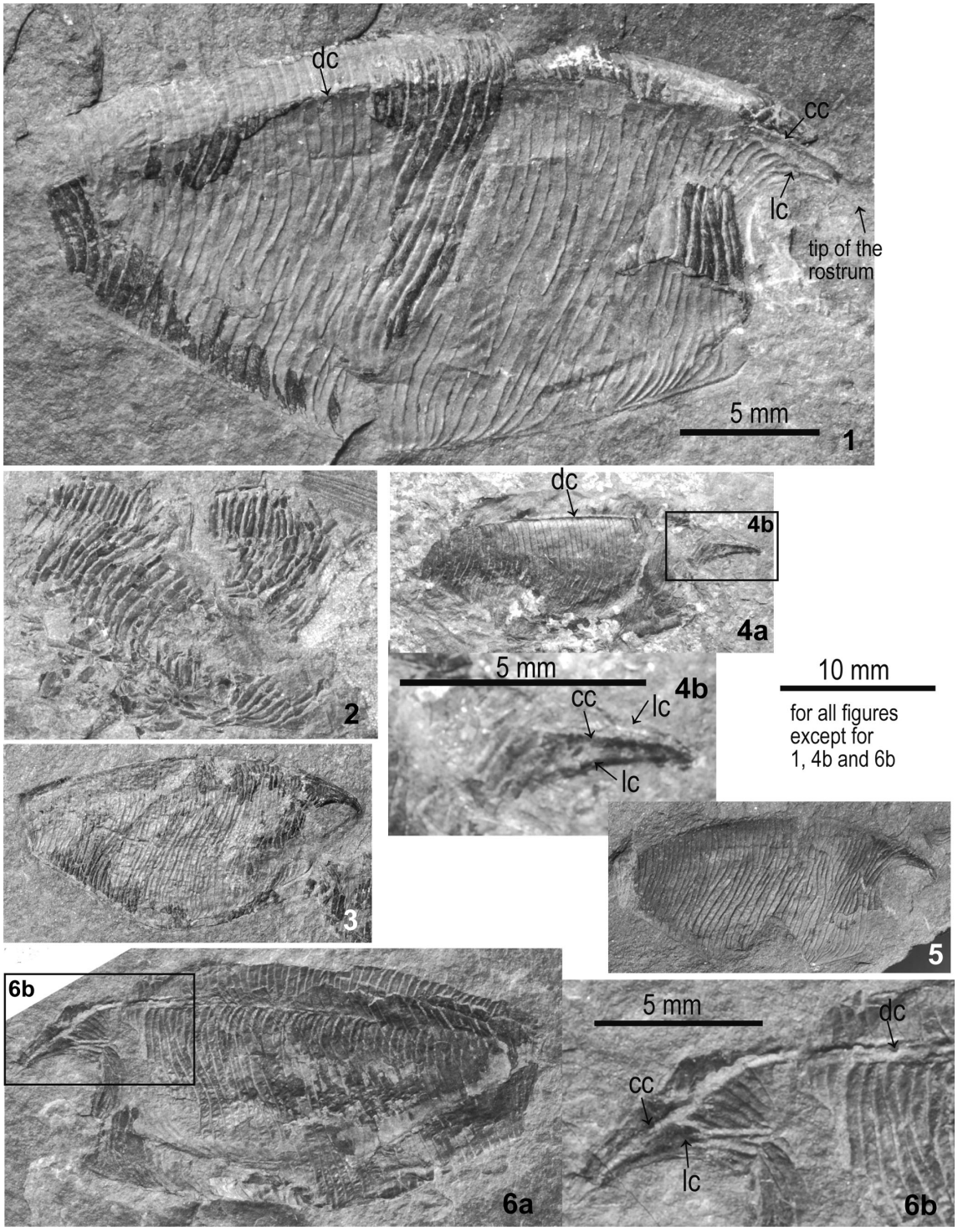

Figure 8. *Kitakamicaris utatsuensis* Ehiro and Kato gen. et sp. nov. from the Osawa Formation. **1**, IGPS coll. cat. no. 111448 (holotype), right lateral view, with a part of left side; **2**, IGPS coll. cat. no. 111450, right lateral view, partly squashed, rostrum and posterior parts missing; **3**, IGPS coll. cat. no. 111452, right lateral view; **4**, IGPS coll. cat. no. 111456; 4a, right lateral view, partly squashed, with a part of left side; 4b, enlarged view of the rostrum; **5**, IGPS coll. cat. no. 111458, right lateral view; **6**, IGPS coll. cat. no. 111457; 6a, left lateral view, with a part of right side; 6b, enlarged view of the rostrum. All from the Tatezaki locality, except for Figure 8.2 (from the Yamaya locality). For abbreviations, see Figure 4.

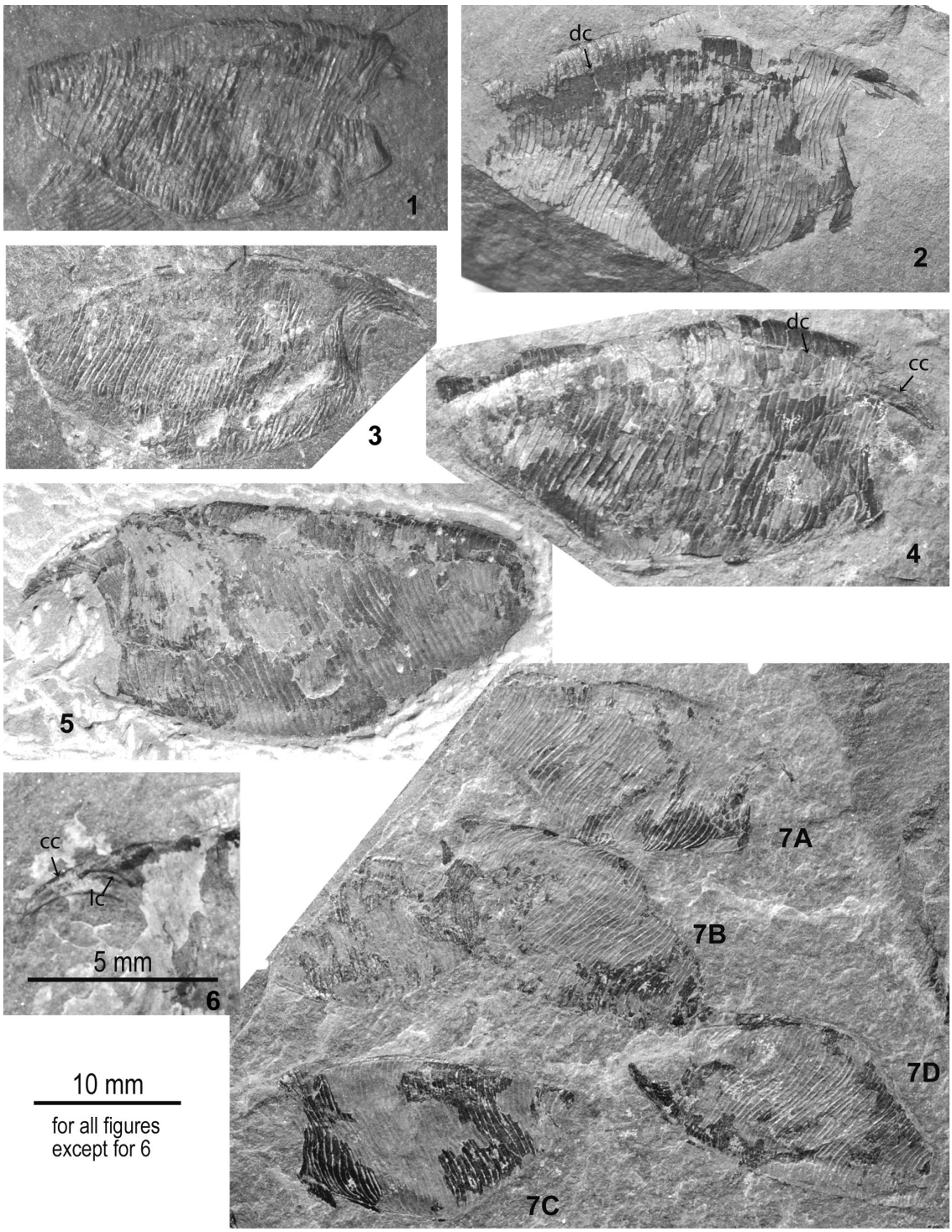

Figure 9. *Kitakamicaris utatsuensis* Ehiro and Kato gen. et sp. nov. from the Osawa Formation. **1**, IGPS coll. cat. no. 111459, right lateral view; **2**, IGPS coll. cat. no. 111464, right lateral view, with a part of left side; **3,** IGPS coll. cat. no. 111465, right lateral view; **4**, UIM 30604, right lateral view, with a part of left side; **5**, IGPS coll. cat. no. 111466, left lateral view; **6**, IGPS coll. cat. no. 111486, left lateral view of the rostrum; **7**, a densely packed occurrence of *Kitakamicaris utatsuensis*; 7A, IGPS coll. cat. no. 111451, right lateral view; 7B, IGPS coll. cat. no. 111454, right lateral view; 7C, IGPS coll. cat. no. 111453, right lateral view; 7D, IGPS coll. cat. no. 111452, left lateral view. All from the Tatezaki locality. For abbreviations, see Figure 4.

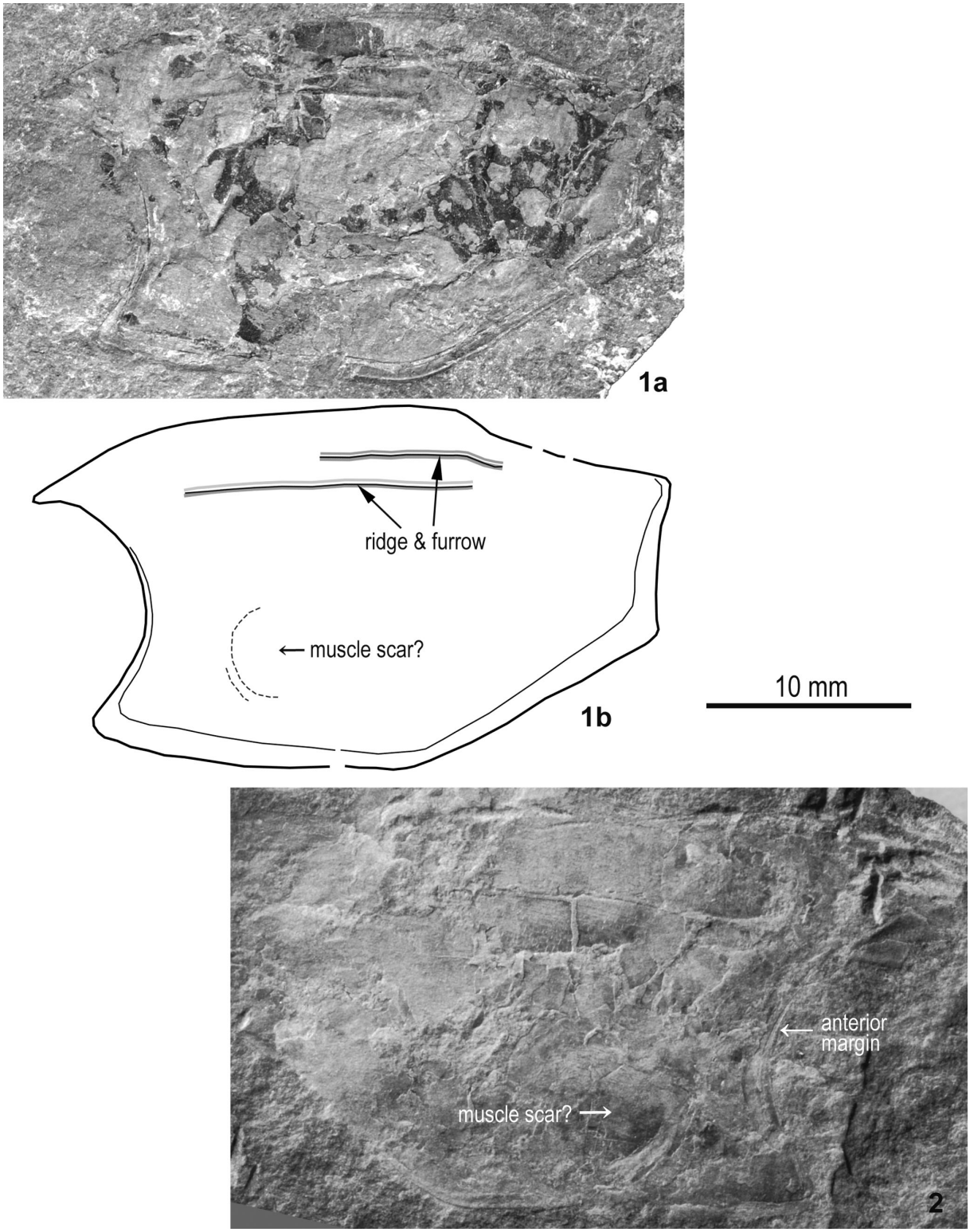

Figure 10. *Ostenocaris* sp. from the Osawa Formation. **1**, IGPS coll. cat. no. 111447; 1a, right lateral view (outer mold); 1b, sketch of 1a; **2**, UIM 30603, right lateral view, posterior part missing. Scale bar for all figures. All from the Tatezaki locality.

Table 1. Previously described thylacocephalan genera from Triassic strata.

Genus	Age	Locality	References	Remarks
Ankitokazocaris Arduini, 1990	E. Triassic	Madagascar	Arduini, 1990	
Atropicaris Arduini and Brasca, 1984	M. Triassic	Slovenia	Križnar and Hitij, 2010	originally as *Microcaris*: emended by this paper
	L. Triassic	Italy	Arduini and Brasca, 1984; Arduini, 1988; Dalla Vecchia and Muscio, 1990	
Austriocaris Glaessner, 1931	L. Triassic	Austria	Glaessner, 1931; Forchielli and Pervesler, 2013	
Clausocaris Arduini, 1992	L. Triassic	Italy	Arduini, 1992	
Ferrecaris Carzada and Mañé, 1993	M. Triassic	Spain	Calzada and Mañé, 1993	
Microcaris Pinna, 1974	L. Triassic	Italy	Pinna, 1974, 1976; Arduini, 1988; Dalla Vecchia and Musscio, 1990; Dalla Vecchia, 1993	
Ostenocaris Arduini, Pinna and Teruzzi, 1980	E. Triassic	Madagascar	Arduini, 1990	
	L. Triassic	Austria	Glaessner, 1931	originally as *Austriocaris striata*: emmended by Briggs and Rolfe, 1983
Yangzicaris Shen, 1983	M. Triassic	South China	Shen, 1983	
undetermined Thylacocephala	M. Triassic	Slovenia	Križnar and Hitij, 2010	presumably a species of the genus *Dollocaris* Van Straelen, 1923

posterior third of the dorsal margin. On the rostrum, the ribs sometimes cross the lateral carinae but do not reach the central carina.

Order Conchyliocarida Secrétan, 1983
Family Ostenocarididae Schram, 2014
Genus ***Ostenocaris*** Arduini, Pinna, and Teruzzi, 1984

Type species.—*Ostenia cypriformis* Arduini, Pinna, and Teruzzi, 1980.

Included species.—*Ostenocaris ambatolokobensis* Arduini, 1990; *O. cypriformis* (Arduini, Pinna, and Teruzzi, 1980); *O. striata* (Glaessner, 1931); *Ostenocaris* sp. nov. (Briggs and Rolfe, 1983); *Ostenocaris* sp. Ehiro and Kato.

Ostenocaris sp.

Figure 10

Materials.—Two specimens, IGPS coll. cat. no. 111447 and UIM 30603, all collected from the middle part of the upper Olenekian Osawa Formation to the north of Cape Tatezaki (Tatezaki locality), Utatsu, Minamisanriku Town, Miyagi Prefecture.

Description.—The carapace is trapezoidal in lateral view, with a broadly convex dorsal margin that bends down at the posterior third, concave anterior (optic) margin, and slightly concave posterior margin. The ventral margin is mound-shaped with a vertex in its central part. The anterior half of it is nearly straight and nearly parallel to the dorsal margin, and the straight anterior half inclines upward with an angle of 140°–150° to the posterior half. *L*, *H*, *Ha*, and *Hp* are about 32.6, 18.7, 13.3, and 8.2 mm, respectively, in the one specimen (IGPS

coll. cat. no. 111447). The posterior margin is rather wide for the genus, showing a ratio of $H/L = 0.57$. The general outline of UIM 30603 is similar to that of IGPS coll. cat. no. 111447, and *L* and *Ha* are about 31.0 and 14.5 mm, respectively. However, its precise *H* and *Hp* are unknown because of poor preservation. Both edges of the concave anterior margin project with acute angles (32° and *ca*. 30° for the dorsal, and 68° and 74° for the ventral one). The more acute anterior-dorsal one, probably a short rostrum, is slightly longer than the other. The anterior, posterior, and ventral margins are relatively wide. The ventral one is widest, occupying 4–8% of the height. The surface of the carapace is smooth, but two fine, straight, longitudinal ridges with furrows run near the dorsal margin. The upper one is longer and wider than the lower one. The cross section of the ridges and furrows seem to be symmetrical, but their exact shapes are unknown due to poor preservation. A semicircular impression (muscle scar?) is in the lower part of the anterior third.

Remarks.—The general carapace outline of the present specimen is somewhat similar to that of *Ostenocaris ambatolokobensis* Arduini (Arduini, 1990, p. 202, fig. 4) from the Lower Triassic of Madagascar. However, the posterior margins of the Osawa specimens are considerably wider than in *O. ambatolokobensis*. The present specimens are thought to be a new species, but we refrain from identifying them at the specific level until a well preserved, more complete specimen is available.

Discussion

Significance of the thylacocephalan fauna from the Osawa Formation

The Triassic is the most diversified period for the Thylacocephala at the generic level, and nine genera, including an unnamed one, have been previously described from the Tethys and Peri-Gondwana provinces (Table 1).

The Osawa thylacocephalan fauna comprises three species: *Ankitokazocaris bandoi* Ehiro and Kato sp. nov., *Kitakamicaris utatsuensis* Ehiro and Kato gen. et sp. nov., and *Ostenocaris* sp. *K. utatsuensis* is dominant and constitutes more than 90% of the collection. Both *A. bandoi* (*ca*. 7%) and *Ostenocaris* sp. (1–2%) are rare. This is the first report of the occurrence of Thylacocephala from Japan and the second one from the Early Triassic worldwide.

Kitakamicaris gen. nov. is the tenth known Triassic thylacocephalan genus. *Ankitokazocaris* from the Osawa Formation is the second report of the genus, which has hitherto been known only from the Lower Triassic of Madagascar (Arduini, 1990). The genus *Ostenocaris*, originally described as *Ostenia*, is known from the upper Carboniferous of USA (Briggs and Rolfe, 1983), the Lower Triassic of Madagascar (Arduini, 1990), the Upper Triassic of Austria (Glaessner, 1931 as *Austriocaris*: emended by Briggs and Rolfe, 1983), and the Lower Jurassic of Italy (Arduini *et al*., 1980, 1984). Thus, this genus is long-ranging and is the only one that survived the end-Permian mass extinction. The present occurrence of *Ankitokazocaris* and *Ostenocaris* from South Kitakami reveals that their distributions were wider than so far documented, extending far into the Tethys-Panthalassa border.

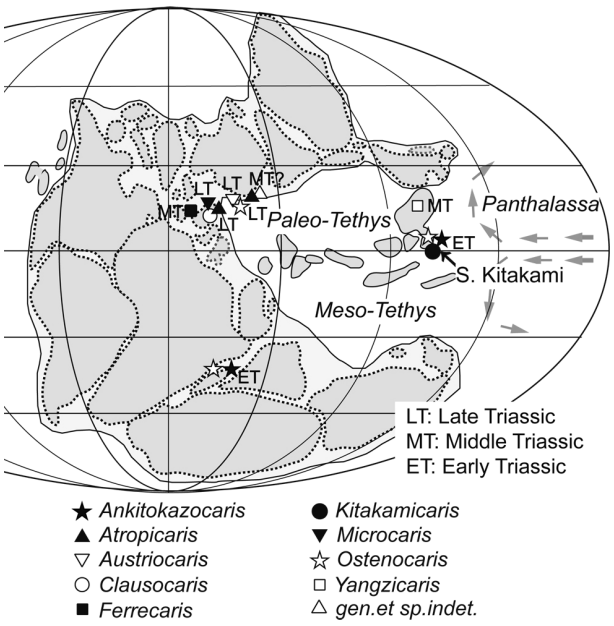

Figure 11. Paleomap showing distributions of the Triassic Thylacocephala genera (base map modified from Scotese, 2002).

Paleogeography of the South Kitakami Belt during the Early Triassic

The thylacocephalan localities listed by Vannier *et al*. (2006) and Schram (2014) were almost all located, based on the paleomap of Scotese (2002), in low latitudes from the Cambrian to the Cretaceous, although there is a possibility that the distribution pattern is somewhat caused by sampling bias (Hegna *et al*., 2014). The Triassic thylacocephalan localities mentioned above were also located in low latitudes, with the sole exception of Madagascar, which was located in the middle latitudes of the Southern Hemisphere (Figure 11). As stated above, *Kitakamicaris* gen. nov., dominant in the Osawa fauna, somewhat resembles some European Late Triassic genera such as *Atropicaris* and *Microcaris*, and other genera of the Osawa fauna, *Ankitokazocaris* and *Ostenocaris*, are known from the Lower Triassic of Madagascar. From

these data, we consider that the South Kitakami Belt, Japan, was located at a low latitude and was connected paleobiogeographically with the western Tethys and northern Peri-Gondwana (Madagascar) areas during the Triassic. This is consistent with previous opinions, based on the ammonoid fauna of the Osawa Formation, that the South Kitakami Belt was located at a low latitude near South China during the Early Triassic (Ehiro, 1997; Brayard *et al*., 2009).

Acknowledgments

The authors wish to express their deep gratitude to the Educational Committee of Minamisanriku Town and Abei-Gumi Co. Ltd. for their support during field work. Deep appreciation is also due to Yukihiro Takaizumi, Yasuhiro Toyoda, and the members of Michinoku Hakubutsu-Gakudan for their kind assistance in field work and for providing specimens. The manuscript was greatly improved by the constructive reviews of Sylvain Charbonnier and Thomas A. Hegna.

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