Systematic paleontology of two brachiopod specimens (*Karavankina* sp. and *Choristites* sp.) from the Arakigawa Formation in the Hida Gaien belt, central Japan

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Abstract

It has been reported that two brachiopod species, namely, productid *Karavankina* sp. and spiriferid *Choristites* sp., occur from felsic tuff beds correlated to the Arakigawa Formation of the Hida Gaien belt, central Japan. Since previous studies have focused primarily on paleobiogeography and only secondarily on description, we reexamined morphological details of these fossils using clear photographic images. For each species, there only exists a ventral valve specimen but morphological features are present to determine the genera. The examined specimen of *Karavankina* sp. is characterized by concentric bands and rugae with numerous regularly arranged spines on the external surface of the ventral valve, while the arrangement of the long spines is altered on the marginal rugae, a trait which appears to be unique to this species. The examined *Choristites* sp. has a pair of dental plates (adminicula) enclosing the adductor and diductor muscle scars on the ventral floor.

Key words: Brachiopoda, Productida, Echinoconchoidea, Spiriferoidea, paleogeography, taxonomy.

Introduction

Biogeographic studies in recent years have established a variety of possibilities in terms of biological adaptation and its relevant geographic, environmental condition (e.g., Dera et al.,
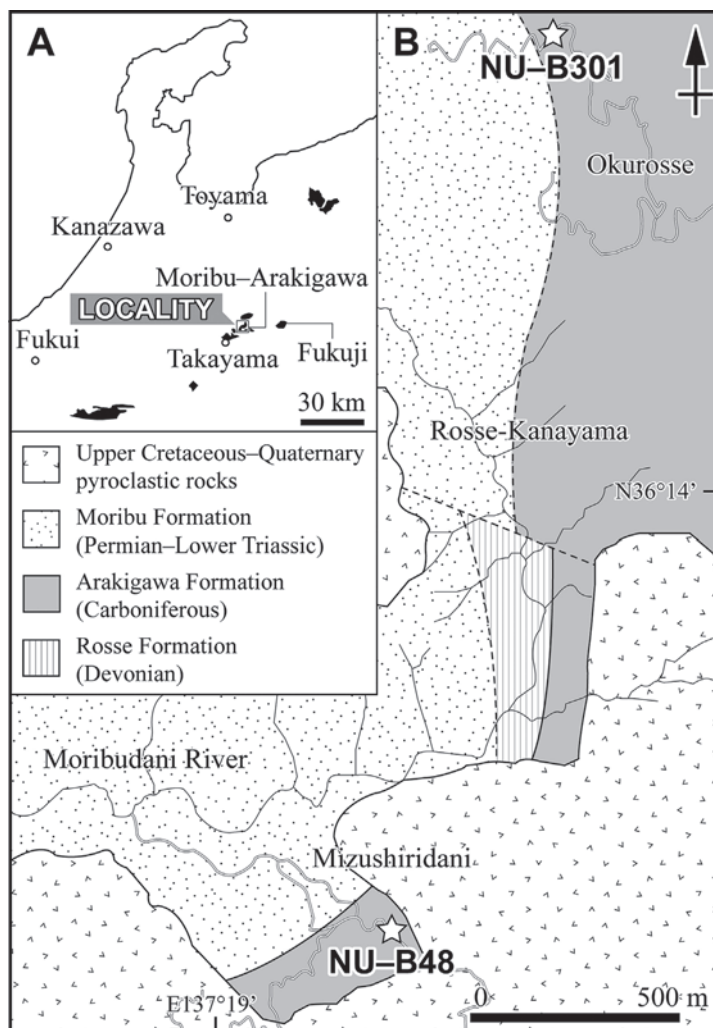
Fig. 1. Geological information of the Hida Gaien belt. A) Map showing the location of the Hida Gaien belt (black areas). B) Simplified geological map of the Moribu–Arakigawa area showing the fossil localities of the described specimens.

2011; Crônier and François, 2014; Wang et al., 2014; Qiao and Shen, 2015). In the case of Paleozoic strata, brachiopod fossils are useful for biogeography because their adaptations depend heavily on the benthic environment (Rudwick, 1970). Hence, the occurrence of brachiopod fossils with certain stratigraphic evidence provides a fundamental framework for paleobiogeography, based on rigorous taxonomic examination.

The Hida Gaien belt, central Japan (Fig. 1A), is one of the enigmatic terranes where Paleozoic strata with shelly fossil taxa are exposed. Of these, the occurrences of Permian brachiopods in the Moribu–Arakigawa area have been historically assigned to the Boreal–Tethyan mixed fauna, the terrane that was geographically close to the continental margin

of East Asia including the North China block and the Central Asian Orogenic Belt (CAOB) (Tazawa, 2001, 2018). On the other hand, the Permian fusulinid fauna in the Fukuji area consists of Tethyan elements, suggesting a paleogeographic relationship with the continental margin of the South China block rather than the North China block and the CAOB (Tsukada et al., 1999). Considering the evidence, the Hida Gaien belt is composed of complicated geological records, instead of merely a single terrane, which have developed individually at the continental margins of the North and South China blocks (Wakita et al., 2001; Tsukada, 2003). However, the paleogeography and the relevant geological history of this belt remain problematic, because current attempts to evaluate both hypotheses of the Hida Gaien belt depend solely on the differing fossil taxa, with no integrated discussion of paleogeography.

A clue to reconstruct the geological history of terranes in the Hida Gaien belt arises from comparison of the Carboniferous brachiopods of the Moribu–Arakigawa and Fukuji areas (Tazawa and Hasegawa, 1994; Tazawa et al., 2000; Tazawa, 2010). In the Fukuji area, the spiriferid *Purdonella* occurs from the Carboniferous limestone of the Ichinotani Formation (Tazawa, 2010), which is a cool water element from the Late Carboniferous to Early Permian (e.g., Shi and Waterhouse, 1991). In the Moribu–Arakigawa area, the occurrence of productid *Karavankina* and spiriferid *Choristites* from the Arakigawa Formation has been reported (Tazawa and Hasegawa, 1994; Tazawa et al., 2000). Each species within these two genera has a relatively long stratigraphic range from the Carboniferous to Early Permian, and it has been suggested that they belong to the Boreal and bipolar realms (e.g., Ivanov and Ivanova, 1937; Nelson and Johnson, 1968; Ramovš, 1971). Detailed taxonomic considerations may allow a more definitive conclusion regarding the ongoing paleogeographic problems in the Hida Gaien belt; however, previous studies of *Karavankina* and *Choristites* have reported no morphological information for the specimens (Tazawa and Hasegawa, 1994; Tazawa et al., 2000).

The present study describes two brachiopod species, *Karavankina* sp. and *Choristites* sp., from the Arakigawa Formation of the Hida Gaien belt in the Moribu–Arakigawa area (Fig. 1B), with special reference to the detailed morphology of external and internal features. The specimens of both species have already been reported in previous studies (Tazawa and Hasegawa, 1994; Tazawa et al., 2000) and are housed in the collections of the Department of Geology, Faculty of Science, Niigata University, Japan (NU–B48: *Karavankina* sp.; NU–B301: *Choristites* sp.).

Fossil locality

Two brachiopod specimens, one of *Karavankina* sp. (NU–B48) and one of *Choristites* sp. (NU–B301), were collected from the Arakigawa Formation in the Moribu–Arakigawa area in previous studies (Fig. 1B; Tazawa and Hasegawa, 1994; Tazawa et al., 2000). According to

Tazawa and Hasegawa (1994), *Karavankina* sp. occurs from an outcrop of pale-greenish felsic tuff on the Mizushiridani forest road. Surrounding the outcrop, there are many sandstone boulders, possibly originating from the forest road nearby (Tazawa and Hasegawa, 1994). The boulders contain the fusulinid *Quasifusulina* sp., indicative of the Late Carboniferous to Early Permian (Tazawa and Hasegawa, 1994), though the exact outcrop containing these fossils has not been found. *Choristites* sp. was reported from the matrix portion of pale-greenish tuff breccia on the Okurosse forest road (Tazawa et al., 2000).

Systematic paleontology

Order Productida Sarycheva and Sokolskaya, 1959
Superfamily Echinoconchoidea Stehli, 1954
Family Echinoconchidae Stehli, 1954
Genus *Karavankina* Ramovš, 1966

Karavankina sp.
Figs. 2 and 3

Material: One ventral valve (NU–B48) of external and inner molds. The specimen is 38 mm in length and 44 mm in width.

Description: The ventral valve is transversely subcircular to subquadrate in outline with gently concave profile (Figs. 2, 3). The specimen has a ventral beak and trails but lacks ears of posterior right and left corners. The beak is comparatively narrow, protruding dorsally and anteriorly, up to 2 mm in maximum anterior–to–hinge line (Fig. 3C, D). The exterior ornamentation of the valve is characterized by concentric bands with abundant spines (Fig. 2B–G). Concentric bands around the posterior half of the valve are weak relief with 3.5 mm each in width (Fig. 2D), while those around the anterior half are elevated externally to form sharp, fringe-like reliefs of rugae (Fig. 2F). The width of ruga ranges from approximately 1.5 mm, narrower than the posterior concentric band, down to 1 mm in width. On the concentric bands of the posterior portion, spine bases are vaguely delineated and seem to be conglutinated with the external surface of the valve (Fig. 2E). On the outside of concentric bands where the rugae start to develop, spine bases are distinct with the ends of spines facing anteriorly (Fig. 2G). There are two types of spines on concentric bands and rugae, exhibiting large and small spine bases. The large spines are each approximately 0.5 mm in diameter and arranged singly low on each band, 2 to 3 mm distance from each other (Fig. 2E). On the anterior portion of the valve, the interval between two adjacent large spines decreases down to 0.5 mm at a minimum, with a random arrangement (Fig. 2G). Basements of large spines are positioned at the posteriormost edge of each band or ruga and extend radially along the surface of the ventral valve. The small spines usually occur in up to three
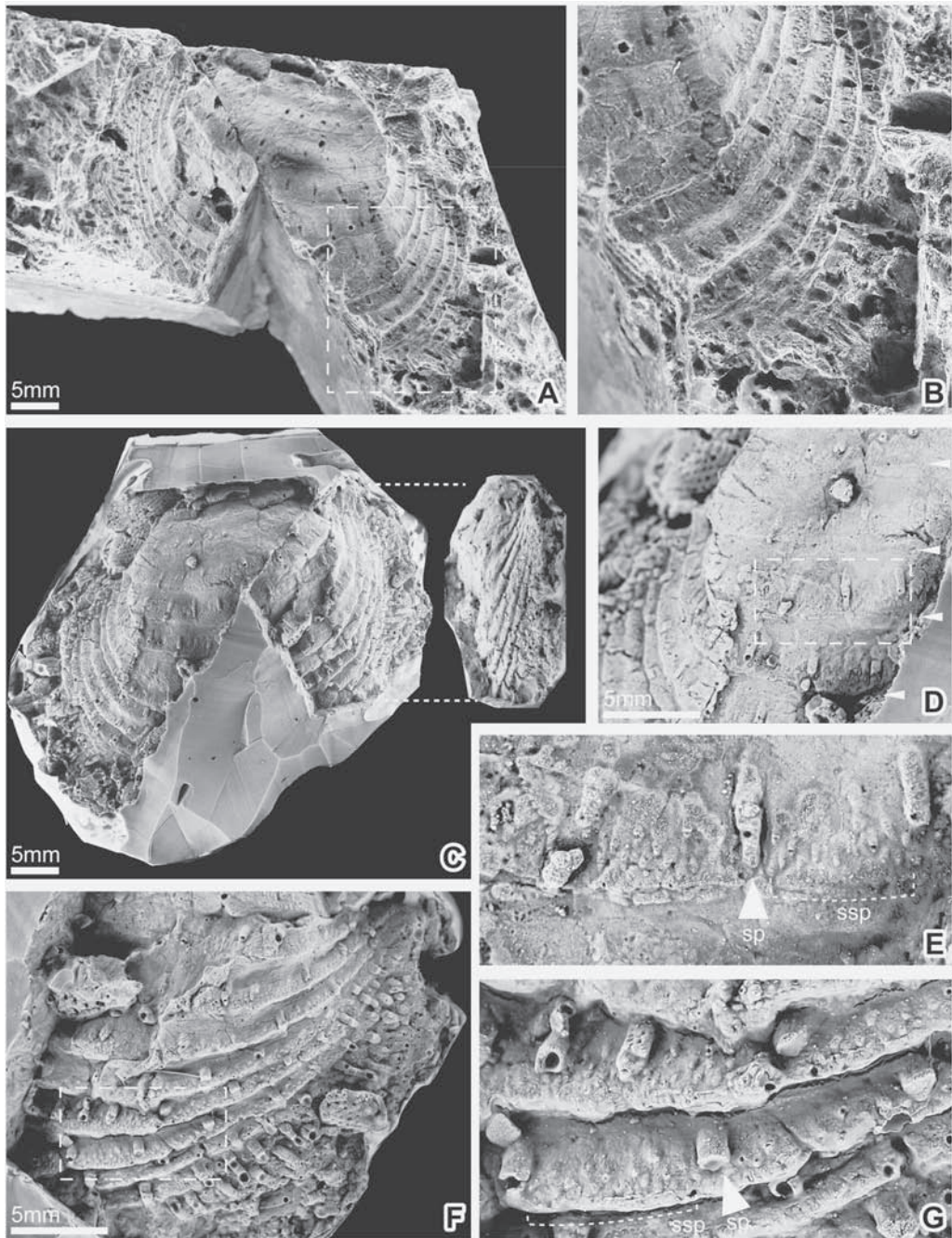
Fig. 2. External morphology of *Karavankina* sp. (NU–B48). A) External mold in ventral view showing outline and ornamentation. B) Concentric bands with abundant spines. Magnified photograph of dashed square in A. C) Silicon rubber cast of external mold in ventral and lateral views. D) Magnified concentric bands around posterior half of C. White arrowheads indicate boundaries of concentric bands. E) Low relief of concentric bands with large and small spine bases. Magnified photograph of dashed square in D. F) Magnified concentric bands (rugae) around shell margin of C. G) Low relief of rugae with large and small spine bases. Magnified photograph of dashed square in F. sp: large spine, ssp: short spine.
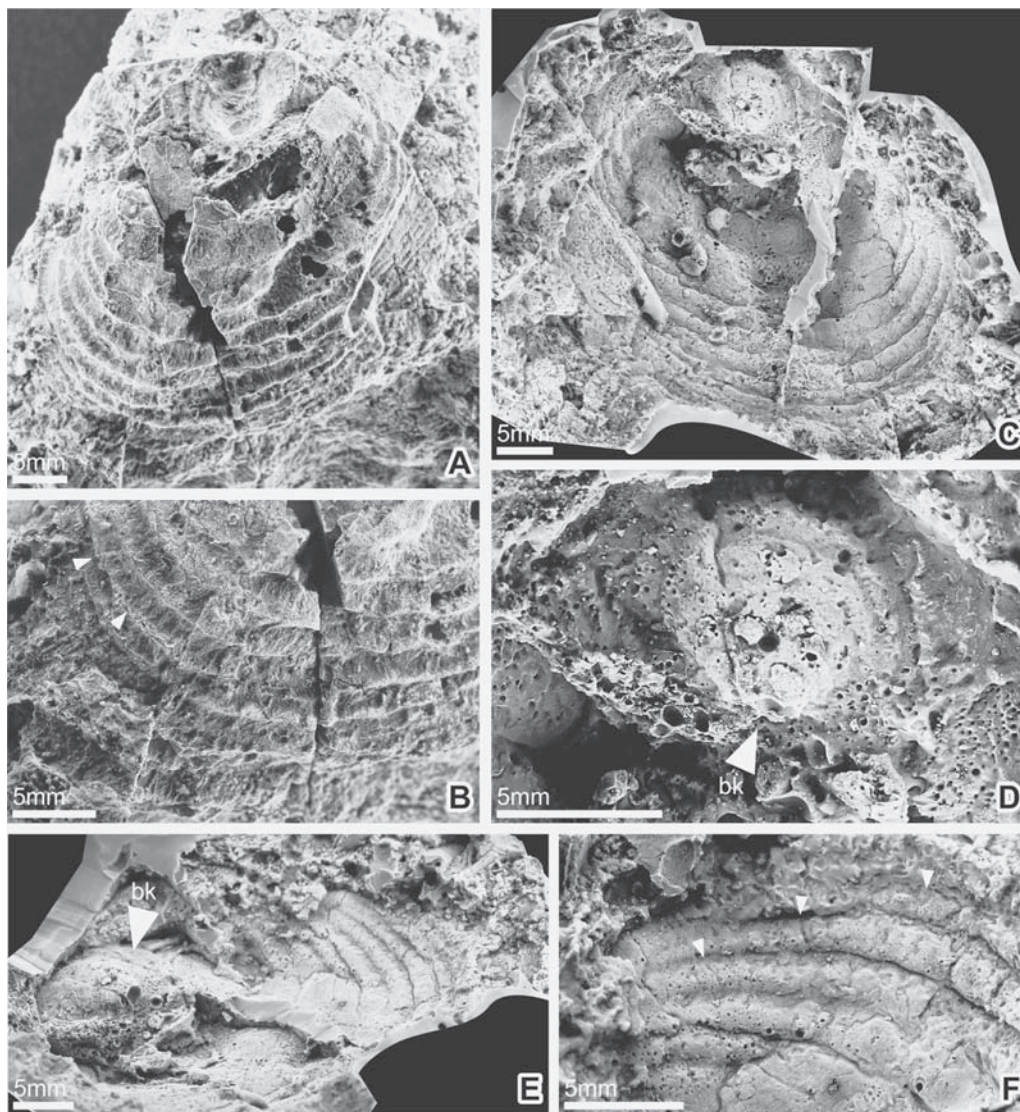
Fig. 3. Internal morphology of *Karavankina* sp. (NU–B48). A) Inner mold in ventral view showing outline. B) Magnified anterior half of A. C) Silicon rubber cast of inner mold in ventral view. D) Magnified beak on posterior part of C. E) Lateral oblique view of C. F) Magnified concentric bands showing saw-tooth relief with unclear furrows around anterior part of C. White arrowheads in B and F indicate furrows extending radially. bk: beak.

rows of quincuncial arrangement between the large spine bases (Fig. 2E, G). Occasionally, the concentric band includes four rows of small spine bases. In the posterior area with the concentric bands, the small spines are 0.4 mm in length and 0.1 to 0.2 mm in width, as if adhering onto the external surface of the ventral valve. The small spines on the anterior rugae exhibit a granular appearance, each spine being 0.2 mm in width (Fig. 2G).

The inner surface of the ventral valve shows a smooth posterior area where the supposed muscle scars are attached, and its outside area exhibits a saw-tooth relief (Fig. 3).

Because of fossil preservation, there are no internal structures associated with the soft parts. On the outside of the smooth area, the internal surface has saw-tooth relief in a lateral view (Fig. 3C, E, F), which corresponds to the counterpart of the external fringe-like rugae. The bands of saw-tooth relief have unclear furrows extending radially (Fig. 3F). Each furrow is 0.2 mm in width.

Remarks: The described species is characterized by having weak concentric bands posteriorly with faint spines and distinct rugae anteriorly with distinct spines. These morphological features are typical in several echinoconchoid genera. In addition to these characteristics, several types of spine bases on each concentric band or ruga are characteristic of Subfamilies Echinoconchinae and Juresaniinae, the latter differing from the presently described species in having concentric bands at only the anterior area. Within the Subfamily Echinoconchinae, the arrangement pattern of long and small spines as observed in the present species best fits with the diagnosis of Genus *Karavankina*, although it is impossible to identify the detail of the species based only on the ventral valve. The external surface of the present species is similar to that of *Karavankina wagneri* Winkler Prins, 1968. The size of the present species is greater than for other *Karavankina* species.

Age and occurrence: Because *Karavankina* has been reported from the Lower Carboniferous (upper Visean) to Middle Permian (Roadian?) (e.g., Ramovš, 1966, 1969; Winkler Prins, 1968; Lazerew, 1990; Tazawa and Hasegawa, 1994; Sone et al., 2003), the correlation of detailed age requires the other fossil evidence. A hint of the detailed age is the occurrence of *Quasifusulina*, as reported from a sandstone boulder nearby the present fossil locality (Tazawa and Hasegawa, 1994), suggesting the Upper Carboniferous (Kasimovian) to Lower Permian (Sakmarian) (Rosovskaya, 1975). Both evidences of *Karavankina* and *Quasifusulina* in the present area still remain problems of species identifications and stratigraphic horizons, so we avoid determining the detailed age.

Order Spiriferida Waagen, 1883
Superfamily Spiriferoidea King, 1846
Family Choristitidae Waterhouse, 1968
Genus Choristites Fischer de Waldheim, 1825

Choristites sp.
Fig. 4

Material: One ventral specimen (NU–B301) of inner mold. The specimen is 29 mm in length and 35 mm in width.

Description: The ventral valve is rounded pentagonal to subovate in outline, although the actual outline is unclear (Fig. 4A, B). The beak is prominent and strongly incurved dorsally (Fig. 4B). The interarea is lost but assumed to be transverse rectangular to trapezoidal in
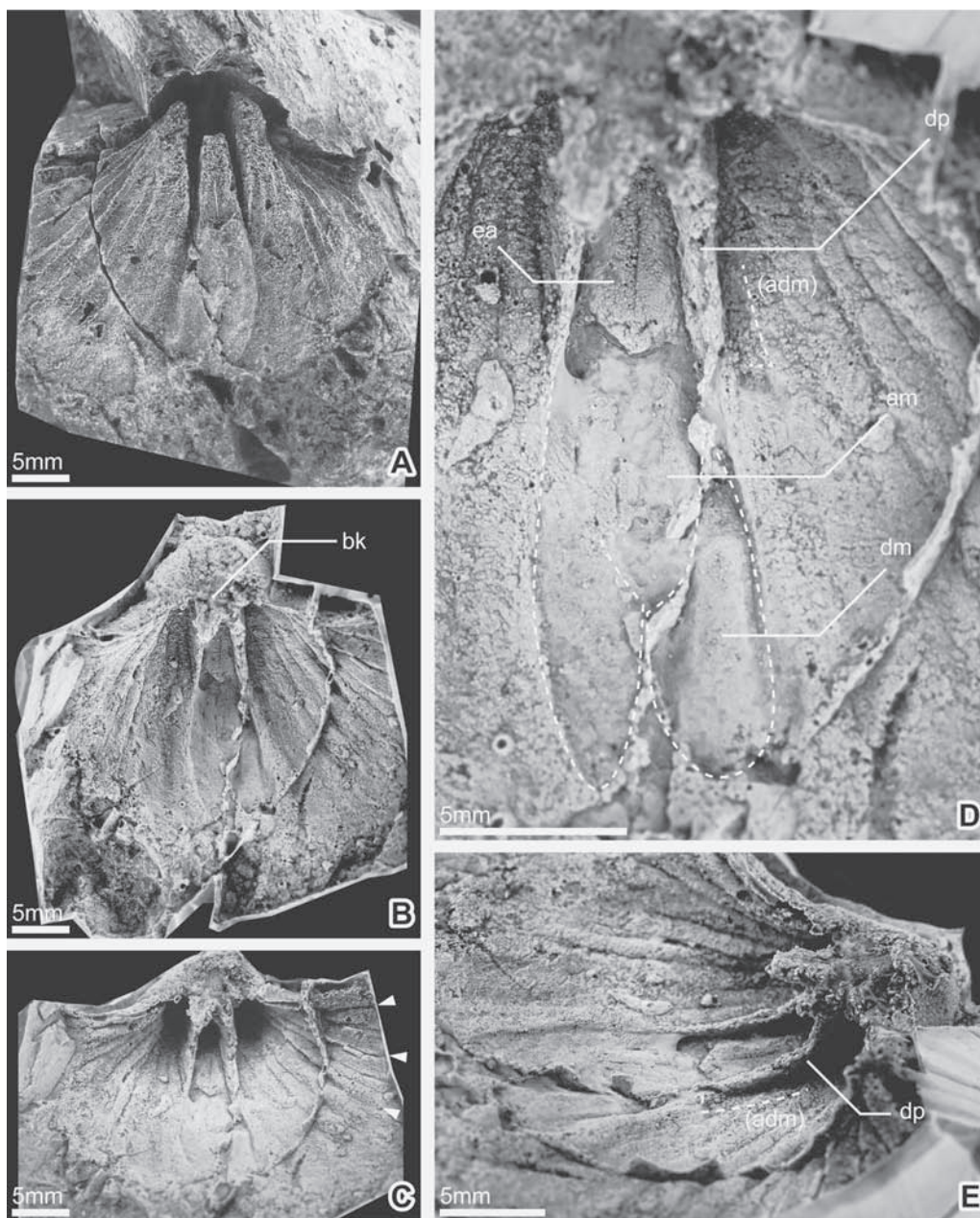
Fig. 4. Internal morphology of *Choristites* sp. (NU–B301). A) Inner mold in ventral view showing outline. B) Silicon rubber cast of inner mold in dorsal view. C) Silicon rubber cast of inner mold in anterodorsal view. White arrowheads indicate furrows extending radially. D) Magnified internal structures in dorsal view around posterior area of B. E) Magnified internal structures in lateral oblique view of B. bk: beak, dp: dental plate (adm: adminicula), am: adductor muscle scar, dm: diductor muscle scar, ea: elevated area.

dorsal view (Fig. 4E). The internal sides of the interarea form a triangular area, which seems to have originally been a triangular delthyrium (Fig. 4E). The interior of the valve shows a

pair of dental plates and muscle scars. The posterior side of the dental plates around the teeth and sockets are broken, while the shape of the rubber cast suggests the presence of a pair of dental plates extending from the inner sides of the interarea (Fig. 4B, C). In turn, the dental plates extend toward the ventral floor, and the blade-like dental plates (adminicula) around the floor continue to extend and taper anteriorly (Fig. 4B–E). The adminicula are slightly flared with respect to the ventral floor. The anterior ends of adminicula reach 7 mm anterior to the hinge line. On the ventral floor, two types of muscle scars occur between the adminicula (Fig. 4D). Based on comparative anatomy with extant brachiopods, the posterior scar is an adductor muscle scar, while a pair of anterior scars are diductor muscle scars (Fig. 4D). The adductor scar in the center of the valve is longitudinally elongate and elliptical in shape (Fig. 4D). The pair of diductor scars are positioned anterolaterally to the adductor scars, as a pair of long, tear-shaped smooth impressions (Fig. 4D). Anterior ends of diductor muscle scars are 10 mm distant from ventral adminicula. Both adductor and diductor scars are separated by faint ridges (Fig. 4D). Outside of the adminicula, slit-like furrows extend radially, which may correspond to the counterparts of the external costae (Fig. 4C). The internal surface just posterior to the adductor muscle scars is slightly elevated with respect to the ventral floor (Fig. 4D, E). The anterior margin of the elevated area is triangular, possibly the boundary of muscle scars. The elevated area appears comparatively smooth with a thin and shallow median furrow (Fig. 4D). This furrow never reaches the anterior margin of the elevated area.

Remarks: The described specimen only includes a portion of the internal ventral valve. Species identification requires evidence of both internal and external features of the ventral and dorsal valves. Despite the limited information from the present ventral valve, it is worth noting that the morphology of the dental plates is unique to the Genus *Choristites*. The genus is characterized by having a dorsally incurved ventral beak, as well as long and slender adminicula nearly parallel to each other, both characteristics which agree very well with the present specimen. The internal furrows extending radially at the outside of the adminicula are probably unique to the present *Choristites* sp., although the typical *Choristites* has reticulate or pitted ornamentation instead of the furrows. Similar structures have been reported in other *Choristites* sp. from Austria (Gauri, 1965). Based on the outline and size, Tazawa et al. (2000) pointed out that *Choristites* sp. from the Arakigawa Formation is similar to *C. loczyi* Fredericks, 1926 and *C. teshevi* Ivanov and Ivanova, 1937.

Age and occurrence: Tazawa et al. (2000) suggested that many species of the genus mainly occur from the middle Upper Carboniferous (Moscovian) (Ivanov and Ivanova, 1937; Sarytcheva and Sokolskaja, 1952; Boucot et al., 1965) and regarded the presently discussed specimen as a species of the coeval geologic time. However, *C. loeyensis* has been reported from limestone of the Lower Permian Nam Maholan Formation (Asselian) in Northeast Thailand, which supports the conclusion that *Choristites* has a relatively long stratigraphic

range of occurrence from the Carboniferous to Early Permian (Yanagida, 1966; Pérez-Huerta et al., 2007). Apart from the paleontological evidence, Suzuki and Kurihara (2018) reported an Early Permian zircon U–Pb age of ca. 280 Ma (Kungurian) from felsic tuff in Rosse-Kanayama, an outcrop that is stratigraphically close to the present fossil locality. Consequently, the age based on the occurrence of *Choristites* sp. is not necessarily the middle Late Carboniferous. It still remains a possibility that the stratigraphic horizon of the present fossil locality correlates with the Upper Carboniferous to Lower Permian, as well as the case of *Karavankina* mentioned above.

Acknowledgements

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