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Olenekian Brachiopods from the Kamenushka River Basin, South Primorye: New Data on the Brachiopod Recovery after the End-Permian Mass Extinction

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Abstract—The brachiopods (e.g., *Heterelasma* sp. nov., *Uniplicatorhynchia* sp. nov., *Quadratirhynchia* sp., and *Sphriganaria* sp.) discovered from the Olenekian deposits of the Kamenushka River basin and Russky Island, South Primorye, allow refining the information on the stratigraphic range of the relevant families and recovery of the biota after the Late Permian mass extinction. A new terebratulid genus, *Bittnerithyris* gen. nov., and a new rhynchonellid species, *Piarorhynchella tazawai* sp. nov., are established.

Keywords: rhynchonellids, terebratulids, Olenekian, Lower Triassic, South Primorye, Kamenushka River, mass extinction

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INTRODUCTION

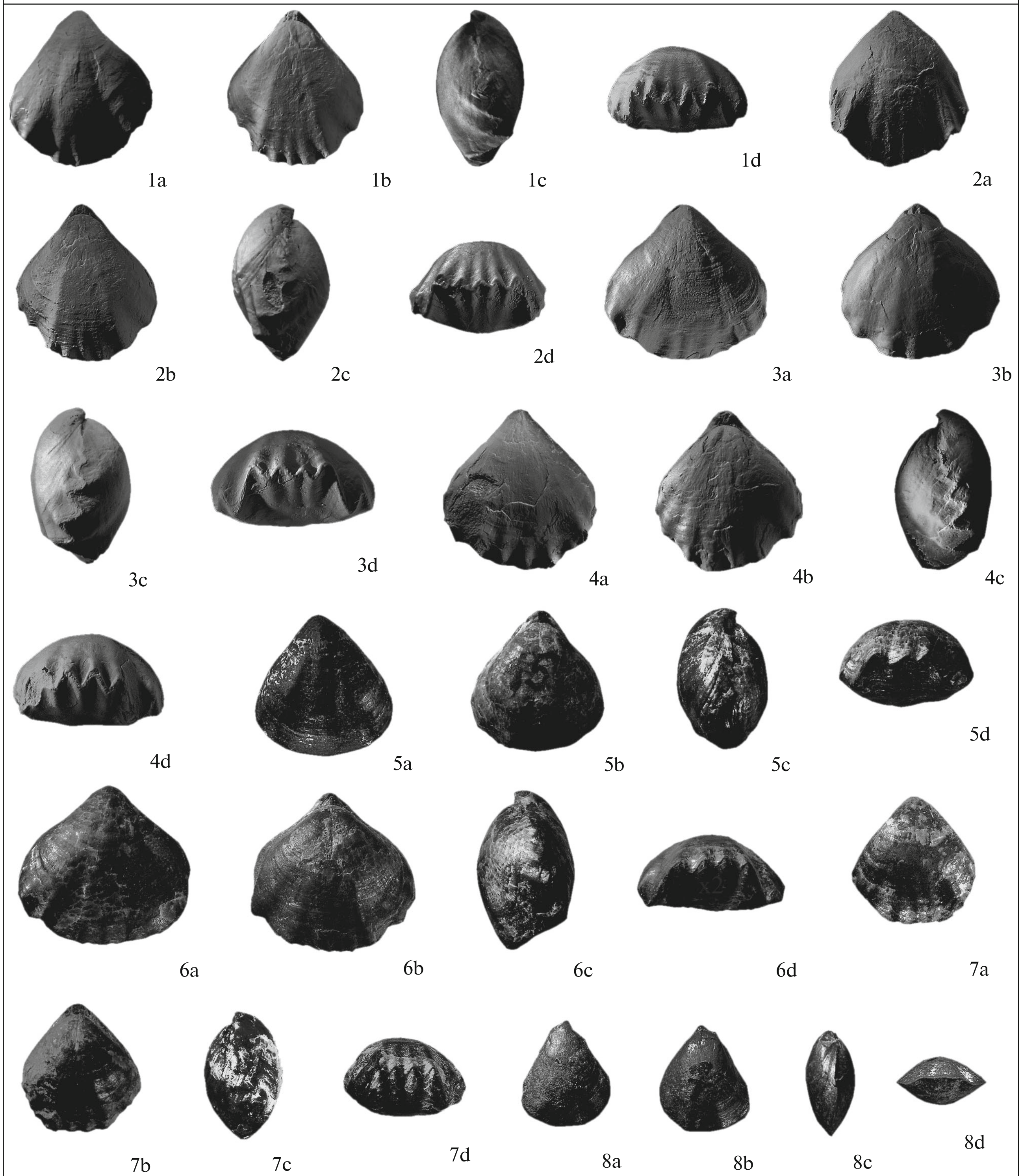
The Middle Olenekian articulate brachiopods from the South Primorye are numerous in the Early Spathian shallow-water facies of Russky Island (Schmidt Formation, beds with *Tirolites ussuriensis*) and in the recently found more deep-water Early- and Middle Spathian facies of the Kamenushka River basin in the northern South Primorye (middle and upper parts of the Kamenushka Formation, beds with *Bajarunia magna* and *Inyoceras singularis*; Zakharov and Smyshlyaeva, 2016).

In this paper, we describe the Lower Triassic brachiopods from the South Primorye, specify their stratigraphic range, determine the taxonomic composition of zonal assemblages, and distinguish new taxa. The articulate brachiopods were collected in the sections of Olenekian deposits of the Zhitkov Peninsula, Chernyshev Bay, Capes Konechny and Schmidt of Russky Island, and in the Kamenushka River basin (29 km southeast of Ussuriisk). The shells were photographed with the digital camera Sony Cyber-shot DSC-F707 with the following processing of photographs in the Adobe Photoshop and CorelDraw programs. The brachiopod shell interiors were studied using the original method of placing the calcined shells in the epoxy resin, grinding on the corundum round, and final polishing of the section surface on the glass with fine powder. The distances between the sections were measured with the caliper with a scale division 0.05 mm. The polished sections were photographed with the digital eyepiece camera DCM-800 on the Carl Zeiss binocular at different magnifications (lenses 0.63, 1, 1.6, 2.5, and 4.0). The photographs of shell sections were processed in CorelDraw. The shell measurements were statistically treated in the PAST program (Hammer et al., 2001).

The brachiopod assemblage from the beds with *Bajarunia magna* in the Kamenushka-1 and Kamenushka-2 sections is composed of rare accumulations of rhynchonellids *Piarorhynchella tazawai* sp. nov. (Pl. 5, figs. 1–7) and singular terebratulids *Bittnerithyris margaritovi* (Bittner) (Pl. 6, figs. 7–11) and *Sphriganaria* sp. (Pl. 6, fig. 16). The overlapping beds with *Inyoceras singularis* contain more diverse assemblage. *Piarorhynchella tazawai* sp. nov. considerably grows in number in the lower member of these beds in the Kamenushka-2 section, and higher in the section the number of *Bittnerithyris margaritovi* (Bittner) also rises. The brachiopod diversity increases in the middle part of the beds with *Inyoceras singularis* in the Kamenushka-1 and Kamenushka-2 sections, which contain numerous *Piarorhynchella tazawai* sp. nov., *Bittnerithyris margaritovi* (Bittner), *Lepismatina* sp., rare *Heterelasma* sp. nov. (Pl. 2, fig. 15), *Hustedtiella planicosta* Dagys, and so forth. The upper part of the beds with *Inyoceras singularis* in the Kamenushka-2 section contains remains of rhynchonellids *Piarorhynchella tazawai* sp. nov., *Uniplicatorhynchia* sp. nov. (Pl. 5, fig. 8), *Quadratirhynchia* sp., terebratulids *Bittnerithyris*? sp. and spiriferinids *Lepismatina* sp.

The listed above data on the stratigraphic distribution of brachiopods in the Kamenushka-1 and

Plate 5



Explanation of Plate 5

For all figures: (a) ventral valve view, (b) dorsal valve view, (c) lateral view, (d) anterior view.

Figs. **1–7.** *Piarorhynchella tazawai* sp. nov.: (1) holotype FEGI, no. 61/2054, ×2; (2) specimen FEGI, no. 59/2054, ×2; (3) specimen FEGI, no. 47/2054, ×2; (4) specimen FEGI, no. 49/2054, ×2; (5) specimen FEGI, no. 15/2054, ×2; (6) specimen FEGI, no. 19/2054, ×2; (7) specimen FEGI, no. 28/2054, ×2. Kamenushka-1 section, middle part of the Kamenushka Formation.

Fig. 8. *Uniplicatorhynchia* sp. nov., specimen FEGI, no. 7/2054, ×2; Kamenushka-1 section, middle part of the Kamenushka Formation.

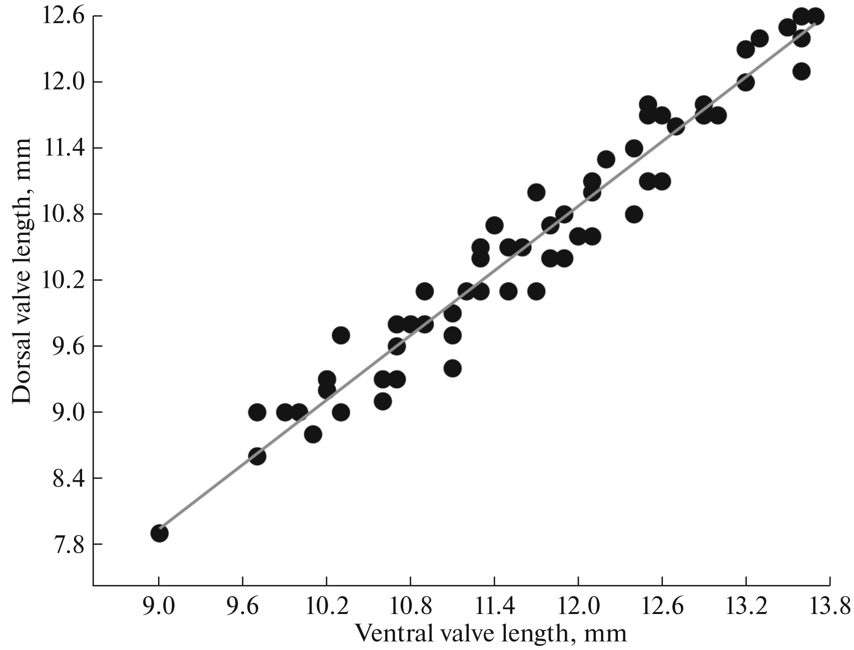


Fig. 1. A scatter diagram of the lengths of the ventral and dorsal valves of 64 specimens of *Piarorhynchella tazawai* sp. nov. from the Kamenushka-1 and Kamenushka-2 sections of the South Primorye.

Kamenushka-2 sections contribute to the already known data on the recovery of brachiopod assemblages, which survived after a mass extinction in the terminal Permian. It was considered up to recently that about sixteen brachiopod families including about ten subfamilies (Pontisiinae, Spirigerellinae, Punctospirellinae, Hustedtiinae, Dielasmatinae, Misoliinae, etc.) overpassed the Permian–Triassic boundary. The finding of *Heterelasma* sp. nov. in the upper part of the Kamenushka Formation of Olenekian age proves that the subfamily Cryptonellinae also survived after this extinction. The representatives of the subfamily Cryptonellinae previously were known only from the Devonian–Middle Permian of the North and South Americas and Europe (Cooper and Grant, 1976; Girty, 1909; Jin and Lee, 2006). Other findings of the Olenekian brachiopods in the Kamenushka River basin testify to the earlier appearance of some families (Eudesiidae, Cryptonellinae, Tetrarhynchiinae, Nucleusorhynchiinae, and Lepismatininae) and their wider stratigraphic range that it was previously considered. The finding of *Lepismatina* sp. in the lower part of the Olenekian Stage (beds with *Churkites syaskoi*) testifies to the existence of the subfamily Lepismatininae in the Lower Olenekian–Upper Triassic while previously its stratigraphic range was supposed to be Middle Olenekian–Upper Triassic (Zakharov et al., 2008). The data on *Sphriganaria* from Primorye, which was previously known from the Middle–Upper Jurassic of Saudi Arabia, Sinai Peninsula, and Egypt (Baker, 2006), widen the stratigraphic range of the family Eudesiidae (Olenekian–Middle Jurassic), and the range of the subfamily Tetrarhynchiinae is now specified to be from the Olenekian Stage of Lower Triassic to the Aptian. The subfamily Nucleusorhynchiinae also appeared in the Olenekian (Olenekian–Lower Jurassic) based on the find of *Uniplicatorhynchia* sp. nov.

The studied collection is stored in the Mineralogical Museum of the Far East Geological Institute (FEGI FEB RAS) with coll. nos. 2051, 2052, and 2054.

SYSTEMATIC PALEONTOLOGY

Order Rhynchonellida Kuhn, 1949

Superfamily Norelloidea Ager, 1959

Family Norellidae Ager, 1959

Subfamily Holcorhynchellinae Dagys, 1974

Genus *Piarorhynchella* Dagys, 1974

***Piarorhynchella tazawai* Al. Popov, sp. nov.**

Plate 5, figs. 1–7; Figs. 1–4

Etymology. In honor of the Japanese paleontologist Jun-ichi Tazawa.

Holotype. FEGI, no. 61/2054, complete shell; South Primorye, Kamenushka River basin; Lower Triassic, Olenekian Stage.

Description. The shell is biconvex and middle-sized (up to 9–14 mm long, 15 mm wide, and 9 mm thick). The length ratios of ventral and dorsal valves are well maintained, the correlation coefficient is 0.976 (by the measurements of 64 specimens) (Fig. 1). A scatter diagram of the shell lengths and widths for this sampling shows considerable spread of

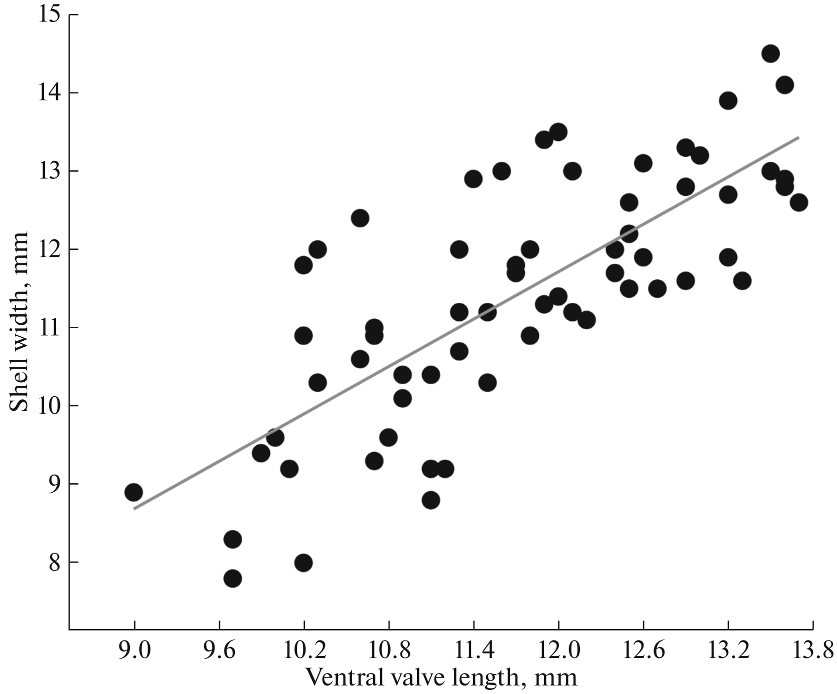


Fig. 2. A scatter diagram of the shell lengths and widths of 64 specimens of *Piarorhynchella tazawai* sp. nov. from the Kamenushka-1 and Kamenushka-2 sections of the South Primorye.

values with the correlation coefficient 0.76 that probably may be explained by the influence of number of folds in the sulcus (fold) (Fig. 2). The shells are from subtriangular to rounded subpentagonal and rhombic. The ventral valve in the transverse and longitudinal sections is considerably less convex than the dorsal valve. The maximum width is in the shell midlength or closer to the anterior margin; the maximum thickness is in the middle of the shell. The anterior parts of the ventral and dorsal valves bear well developed sulcus and fold, respectively, which stretch for two-thirds of the shell length and are well-bordered from the lateral sides. Each anterior part of lateral surfaces of both valves bears 1–2 folds. The sulcus and the median fold bear from one (two) to six (seven) longitudinal folds, which are better pronounced from the anterior margin to one-third of the valve length. The surfaces of both valves are covered with relatively regular concentric growth lines and fine radial capillae. The septum in the dorsal valve runs up to the valve midlength. The umbo is small and moderately curved; the foramen is small, about 0.5 mm in diameter, rounded, and submesothyrid. The beak ridges are smoothed; the apical angle varies from 70° to 106°, usually 80°–90° in the 10–14 mm wide shells.

Shell interior (Figs. 3, 4). The dental plates are diverging, slightly laterally inclined, and up to 1.1 mm long in adults. The pedicle collar is absent. The hinge plates are connected to the inner socket ridges; the inner hinge plates are slightly inclined to the median septum. The septalium is shallow and wide; the septum is thin, high (up to 1.15 mm), and reaches half or one-third of the valve length. The crura are calcariform.

Explanation of Plate 6

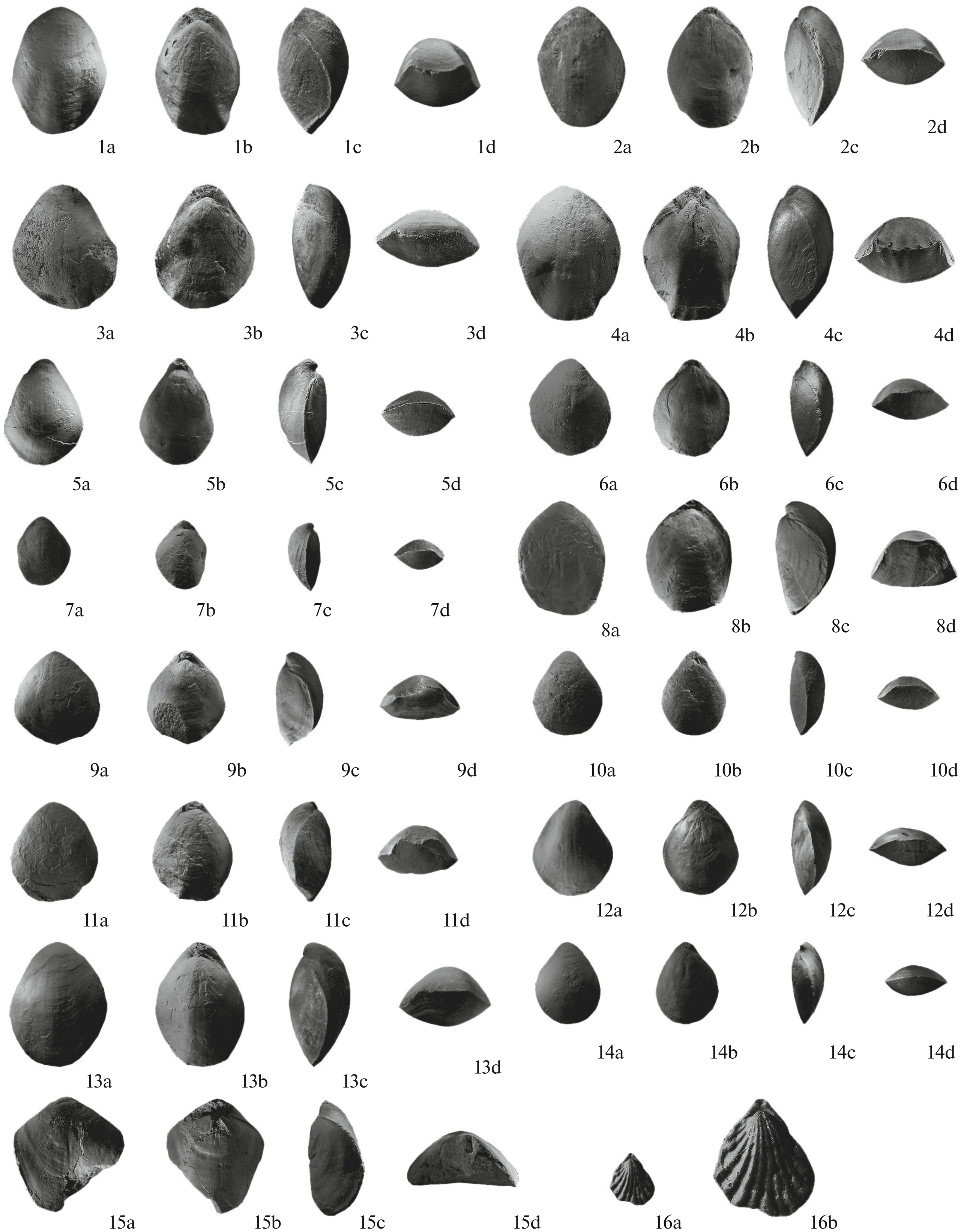
For all figures: (a) ventral valve view, (b) dorsal valve view, (c) lateral view, (d) anterior view.

Figs. 1–14. *Bittnerithyris margaritovi* (Bittner), 1899: (1) specimen FEGI, no. 112-182/2052, ×1; (2) specimen FEGI, no. 112-184/2052; (3) specimen FEGI, no. 112-185/2052; (4) specimen FEGI, no. 112-1872052, ×1; (5) specimen FEGI, no. 112-189/2052, ×1; (6) specimen FEGI, no. 112-190/2052, ×1; Chernyshev Bay, Russky Island, Schmidt Formation; (7) specimen FEGI, no. 511/2054, ×1; Kamenushka-1 section, Kamenushka River basin, middle part of the Kamenushka Formation; (8) specimen FEGI, no. 522/2054, ×1; (9) specimen FEGI, no. 527/2054, ×1; (10) specimen FEGI, no. 512/2054, ×1; (11) specimen FEGI, no. 513/2054, ×1; Kamenushka-2 section, Kamenushka River basin, middle part of the Kamenushka Formation; (12) specimen FEGI, no. 112-145/2052, ×1; (13) specimen FEGI, no. 112-186/2054, ×1; (14) specimen FEGI, no. 112-155/2052, ×1; Chernyshev Bay, Russky Island, Schmidt Formation.

Fig. 15. *Heterelasma* sp. nov., specimen FEGI, no. 531/2054, ×1. Kamenushka-2 section, Kamenushka River basin, middle part of the Kamenushka Formation.

Fig. 16. *Sphriganaria* sp., specimen FEGI, no. 532/2054, ×2: (16a) ×1; (16b) ×2; Kamenushka-2 section, Kamenushka River basin, middle part of the Kamenushka Formation.

Plate 6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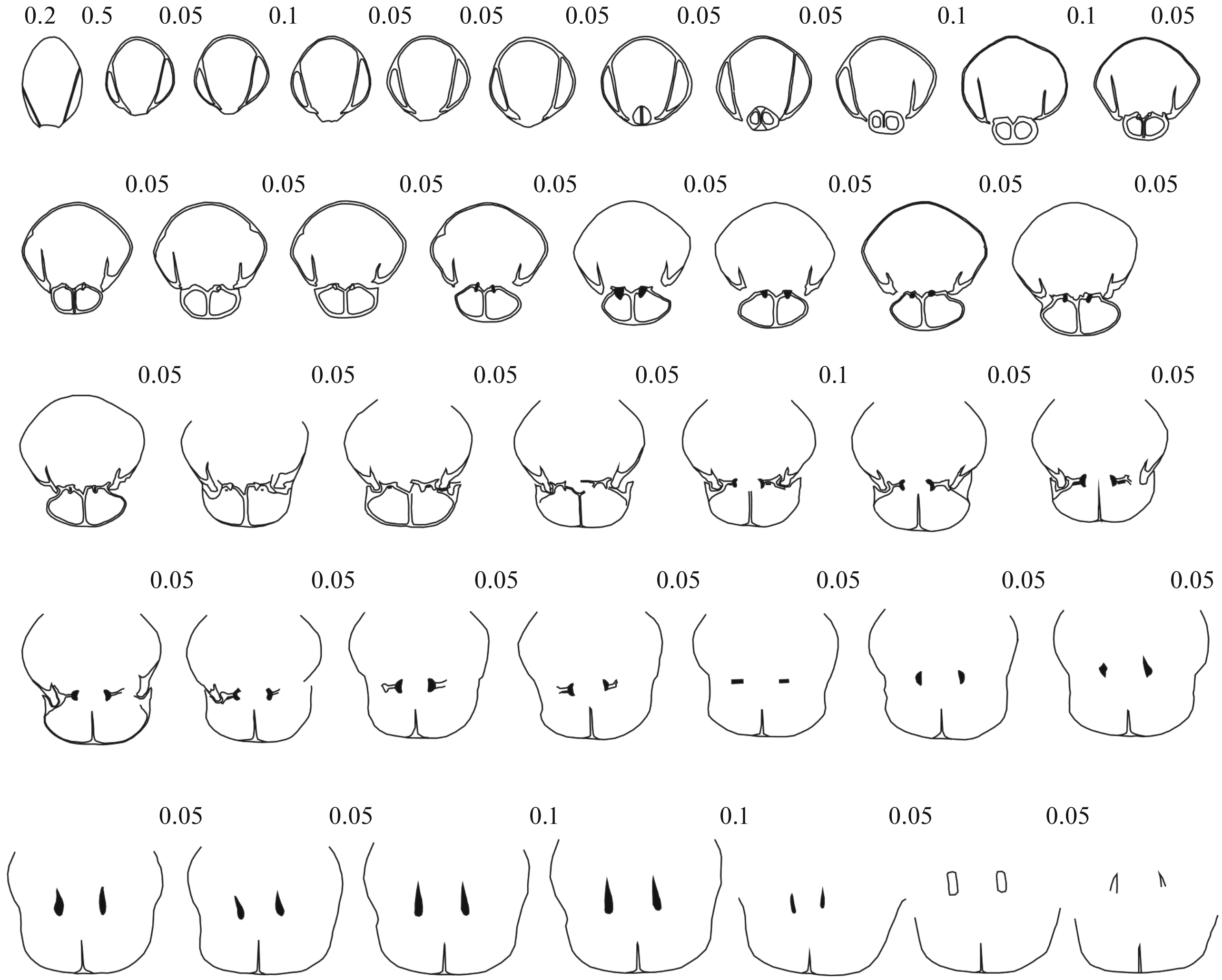

Fig. 3. *Piarorhynchella tazawai* sp. nov.; specimen FEGI, no. 42/2054, serial sections through the 12 mm long shell; figures indicate distances between the sections in mm; Kamenushka-2 section, Kamenushka River basin, middle part of the Kamenushka Formation.

D i m e n s i o n s i n m m a n d r a t i o s:

Specimen, no.	L	W	T	L/W	L/T
61/2054 holotype	13.2	11.9	7.4	1.11	1.78
1/2054	11.7	11.7	8.5	1	1.37
5/2054	12.9	13.3	7.3	0.97	1.77
12/2054	11.6	13	6.1	0.89	1.9
20/2054	11.4	12.9	6.2	0.88	1.84
29/2054	9.7	7.8	5.3	1.24	1.83
42/2054	12	11.4	7.7	1.05	1.56
46/2054	13.5	14.5	7.7	0.93	1.75
55/2054	10.9	10.4	6.7	1.05	1.63
59/2054	13.3	11.6	8.2	1.15	1.62
66/2054	10.7	9.3	6	1.15	1.78
70/2054	13.5	13	7.2	1.04	1.87

C o m p a r i s o n a n d r e m a r k s. The new species differs from the type species of the genus *Piarorhynchella*, *P. mangyshlakensis* Dagys (Dagys, 1974, p. 112) and *P. trinodosi* (Bittner) (Bittner, 1890, p. 13), in the more convex (especially in longitudinal section) ventral valve, smaller depth of a sinus, with a larger (up to 7) number of folds in a sinus, and shorter tongue. This species resembles *Piarorhynchella triassica* (Girty) from the Thaynes Formation, Lower Triassic of the State of Idaho, western USA (Alexander, 1977; Perry and Chatterton, 1979) in the plication of the anterior margin and, accordingly, of the sulcus and fold of both valves, but differs in the thinner shell and lower folds, which are larger in number.

O c c u r r e n c e. Olenekian Stage; South Primorye.

M a t e r i a l. Over ninety-five complete shells from South Primorye, Kamenushka River basin.

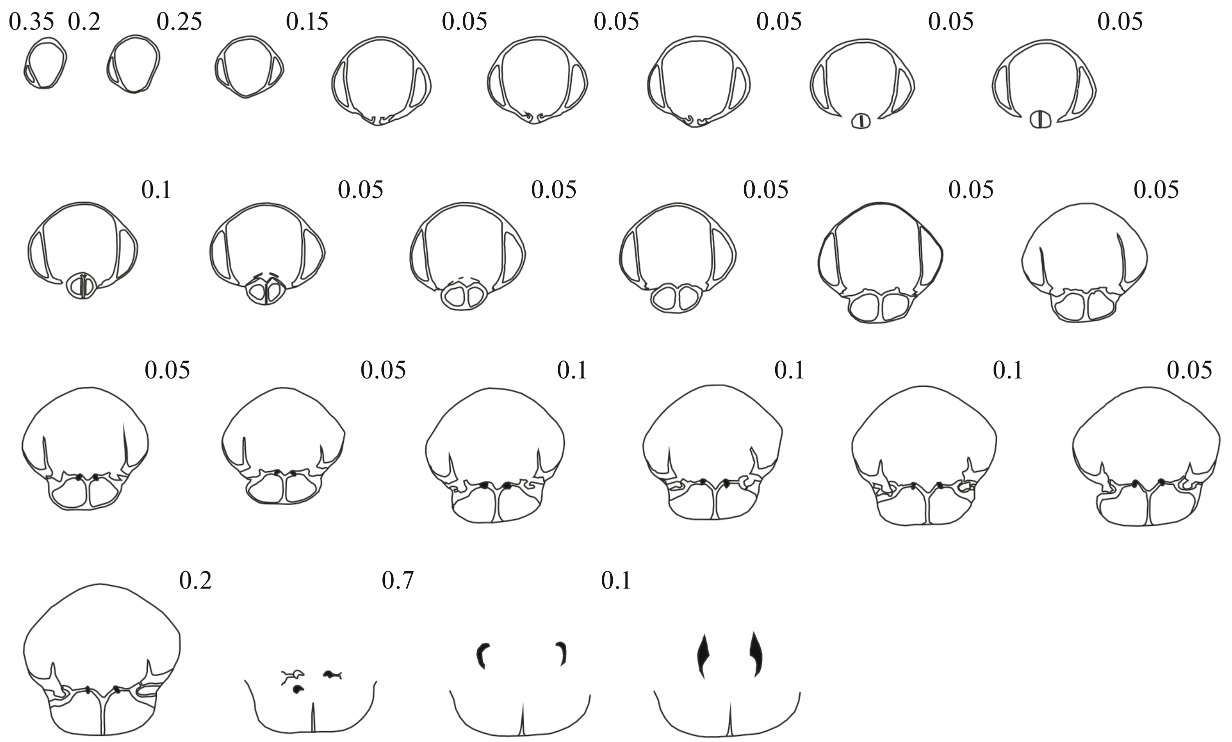

Fig. 4. *Piarorhynchella tazawai* sp. nov.; specimen FEGI, no. 46/2054, serial sections through the 13.5 mm long shell; figures indicate distances between the sections in mm; Kamenushka-2 section, Kamenushka River basin, middle part of the Kamenushka Formation.

Order Terebratulida Waagen, 1883

Superfamily Dielasmatoidea Schuchert, 1913

Family Dielasmatidae Schuchert, 1913

Subfamily Dielasmatinae Schuchert, 1913

Genus *Bittnerithyris* Al. Popov, gen. nov.

Fletcherina (pars): Dagys, 1965, p. 136 (non *Fletcherina* Lang et al., 1955).

Etymology. In honor of the Austrian paleontologist A. Bittner.

Type species. *Bittnerithyris margaritovi* (Bittner), 1899; Olenekian Stage, *Tirolites-Amphistephanites* Zone; South Primorye, Russky Island, Zhitkov Peninsula.

Diagnosis. Shell large and middle-sized, from elongated oval to elongated pentagonal, with maximum width and thickness in the middle or variously closer to posterior or anterior margins. Dorsal valve considerably more convex than ventral valve. Umbo strongly curved; foramen relatively large and permesothyrid. Anterior commissure rectimarginate to uniplicate and slightly biplicate and straight or slightly uniplicate in young specimens. Adult shells bear middle-sized sulcus on anterior margin of ventral valve with corresponding fold on dorsal valve. In ventral valve, short pedicle collar and short dental plates. In dorsal valve, low cardinal process. Outer hinge plates subhorizontal and connected to inner socket ridges. Septal plates form wide septalium supported by low median septum; septum length is half of valve length. Crural bases triangular; loop terebratuliform and half of dorsal valve length.

Species composition. Type species.

Comparison and remarks. The new genus is most similar in the shell exterior to the following genera of the family Dielasmatidae: *Dielasma* King, 1879, *Coenothyris* Douville, 1879, *Adygella* Dagys, 1959, *Fletcherithyris* Campbell, 1965, and *Tosuhuthyris* Sun et Ye, 1982. It differs from *Agygella* in the details of shell interior: presence of pedicle collar, low cardinal process, wide septalium supported by low median septum, and longer brachidium. It differs from *Dielasma* in the absence of wide keel-shaped fold on the ventral valve and details of the shell interior: fused inner hinge plates of *Bittnerithyris* are supported by a median septum while inner hinge plates of *Dielasma* are separated and reach the valve bottom. The new genus differs from *Coenothyris* in the short cardinal process and low but longer median septum. It differs from *Tosuhuthyris* in the larger umbo, permesothyrid foramen, more strongly curved lateral commissures, presence of pedicle collar, and fused inner hinge plates.

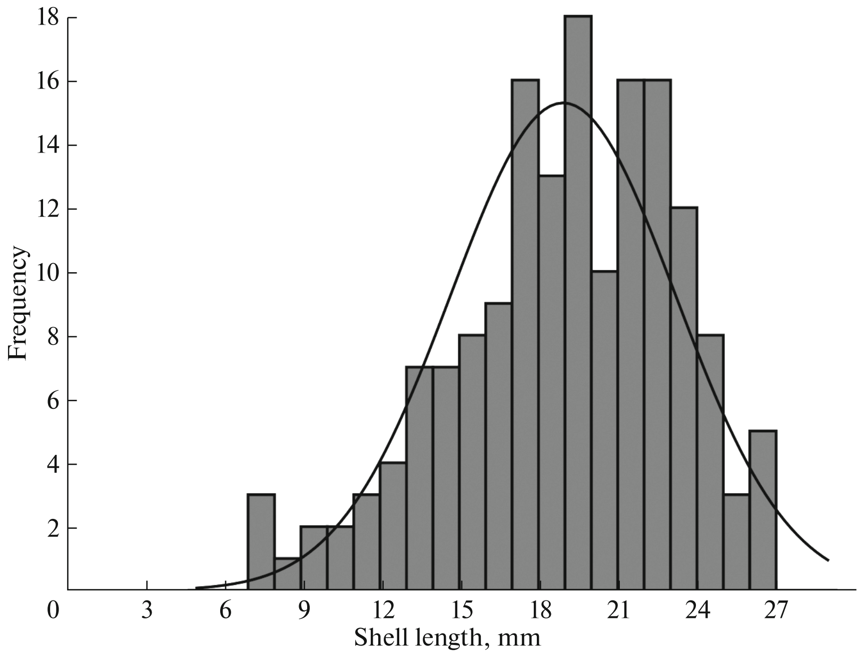

Fig. 5. A histogram of the distribution of shell lengths of 163 specimens of *Bittnerithyris margaritovi* (Bittner) from the Chernyshev Bay and Cape Schmidt of Russky Island, South Primorye.

It is noteworthy that A.S. Dagys did not include *Fletcherithyris* into the systematic part of his summary on the Triassic brachiopods (Dagys, 1974) but he used data on the distribution of the Lower Triassic *Fletcherithyris margaritovi* (Bittner) in the other parts of his monograph. Over the past decades the generic belonging of the Lower Triassic *F. margaritovi* (Bittner), 1899 was variously and repeatedly discussed in the papers on the Triassic brachiopods (Dagys, 1965, 1974; Hoover, 1979; Chen et al., 2005). *F. margaritovi* was distinguished in 1899 by the Austrian paleontologist Alexander Bittner based on the materials collected by V.P. Margaritov in the Lower Triassic of the Zhitkov Peninsula, southeastern Russky Island, South Primorye. This terebratulid species was not restudied for a long time until the new material was obtained in the course of geological mapping in the South Primorye in the 50th of the twentieth century and then studied by Dagys (1965), who redescribed this dielasmatid species and referred it to the Permian *Fletcherina* Stehli, 1961, which was renamed by K. Campbell (1965) in *Fletcherithyris* as the generic name *Fletcherina* was preoccupied in the description of the Devonian rugose coral (Lang et al., 1955, p. 261). Later P. Hoover (1979) questioned the correctness of referring by Dagys (1974) of the terebratulids from the Olenekian deposits of the State of Idaho and other localities in the North America to *Fletcherithyris margaritovi* (Bittner) and assigned them partly to a new genus *Periallus* and partly to *Rhaetina* based on the differences in the shell interior of the species from Primorye (Dagys, 1965, p. 136) and type species of *Fletcherithyris*, *F. amygdala* (Dana), 1847 from the Permian of East Australia (Stehli, 1961; Campbell, 1965). His opinion was shared by Zh.-Q. Chen et al. (2005), who supposed that *Fletcherithyris margaritovi* (Bittner) belongs to a new separate genus.

O c c u r r e n c e. Lower Triassic, Olenekian Stage; South Primorye, Mangyshlak, Balkans.

Bittnerithyris margaritovi (Bittner), 1899

Plate 6, figs. 1–14

Terebratula margaritovi: Bittner, 1899, s. 27, pl. 4, figs. 9–15.

Fletcherina margaritovi: Dagys, 1965, p. 137, pl. 24, figs. 3–5.

H o l o t y p e was not selected. The lectotype was figured by A. Bittner (1899, p. 27, pl. 4, fig. 9). TsNIGRMuseum, no. 112/221; Primorye, Russky Island, Zhitkov Peninsula; Lower Triassic, Olenekian Stage, *Tirolites–Amphistephanites* Zone.

D e s c r i p t i o n (Figs. 5–7). The shell is from middle-sized to large (up to 27 mm), biconvex, from elongated oval to elongated pentagonal; young shells usually are more isometric; the maximum width and thickness are in the middle or slightly closer to the posterior or anterior margins (Fig. 5). The dorsal valve is considerably more convex than the ventral valve. A scatter diagram of 148 specimens of this species shows high correlation ($r = 0.92$) of the shell lengths and widths ratio (Figs. 6, 7). The umbo is from slightly to strongly curved, with smoothed beak ridges; the foramen is relatively large (up to 2.5 mm) and permesothyrid. The anterior commissure is unipli-

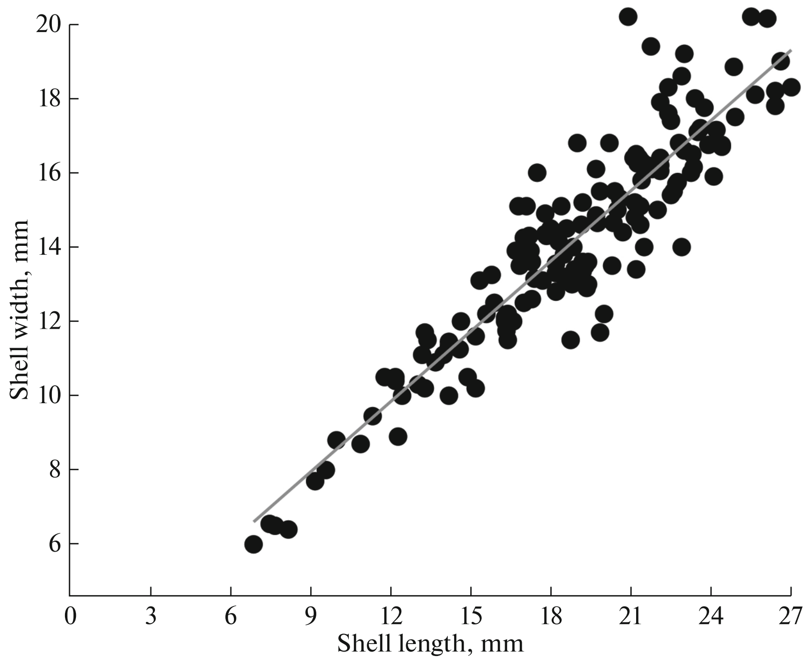

Fig. 6. A scatter diagram of shell lengths and widths of 148 specimens of *Bittnerithyris margaritovi* (Bittner) from the Chernyshev Bay and Cape Schmidt of Russky Island, South Primorye.

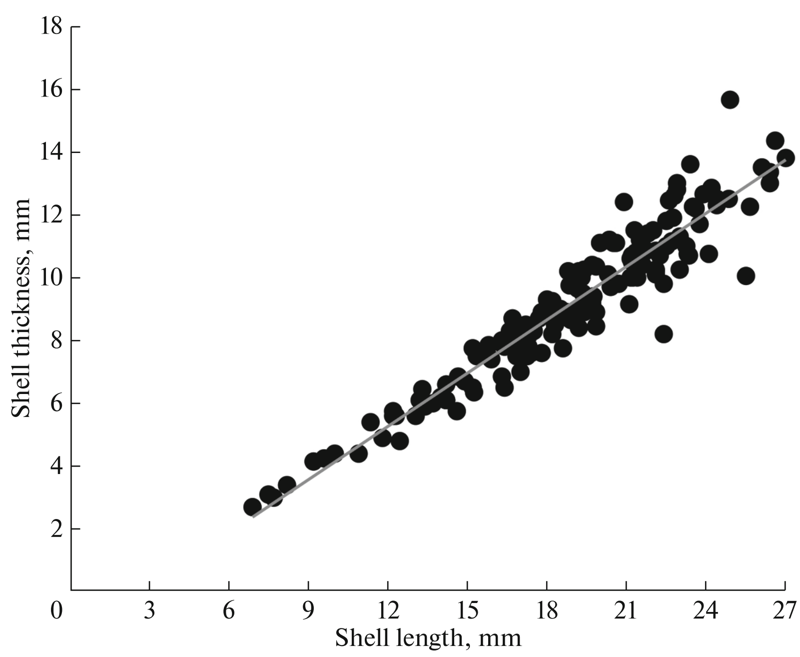

Fig. 7. A scatter diagram of the shell length and thickness values of 150 specimens of *Bittnerithyris margaritovi* (Bittner) from the Chernyshev Bay and Cape Schmidt of Russky Island, South Primorye.

cate to slightly biplicate and straight or slightly uniplicate in young specimens; the lateral commissures are ventrally curved, and more curved in adults. The adult shells bear on the anterior margin of the ventral valve middle-sized sulcus with corresponding fold on the dorsal valve. The shell surface is smooth, with concentric growth lines. The shell wall is pierced with numerous non-branching endopunctae.

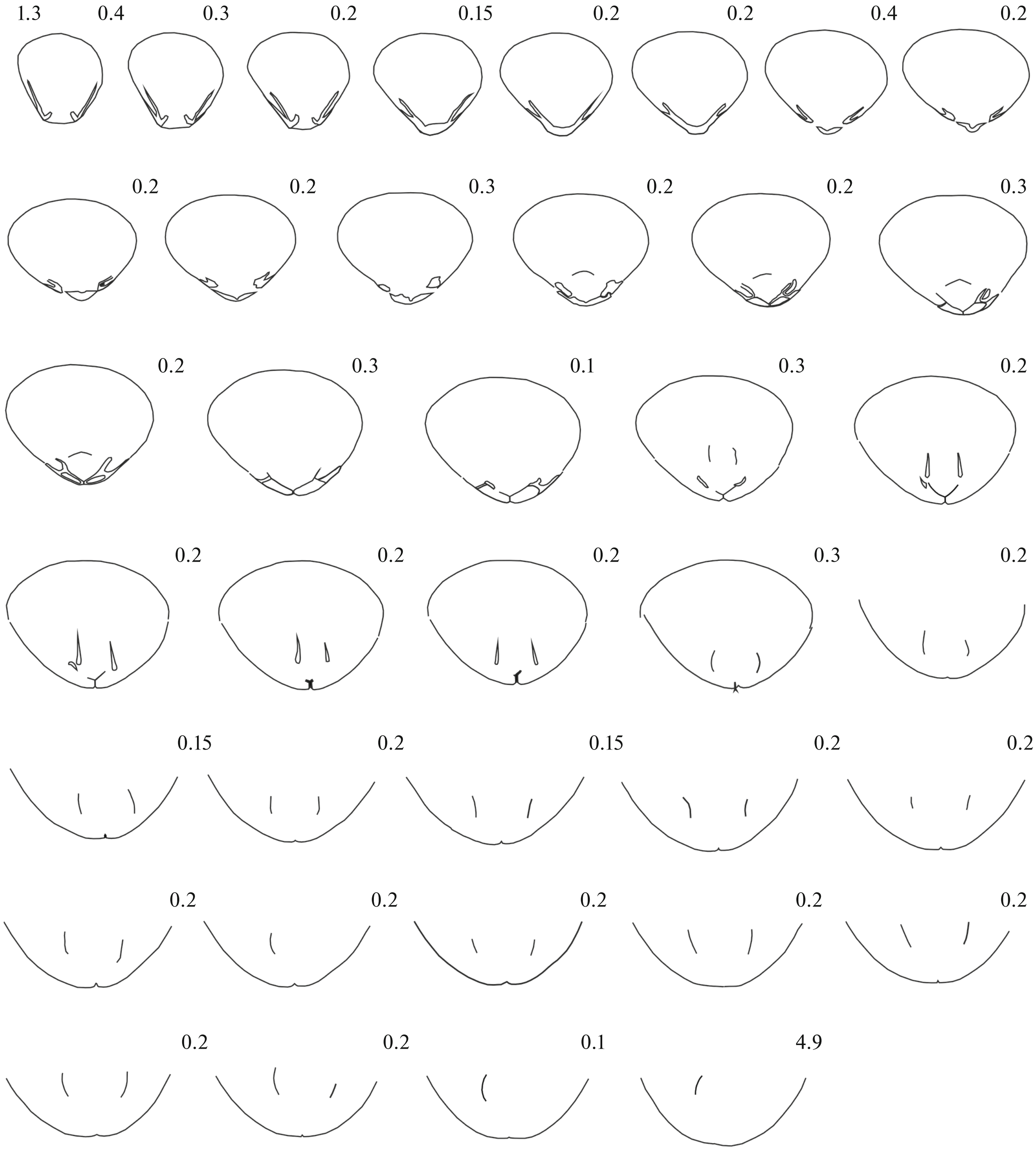

Fig. 8. *Bittnerithyris margaritovi* (Bittner), 1899; specimen FEGI, no. 112-96/2052, serial sections through the 21.5 mm long shell; figures indicate distances between the sections in mm; Chernyshev Bay, Russky Island, Schmidt Formation

S h e l l i n t e r i o r (Fig. 8). The umbonal region of the ventral valve contains well developed small pedicle collar and massive teeth supported by short and thin dental plates. In the dorsal valve, inner hinge plates are slightly medially inclined and fused with formation of wide and low septalium supported by low median septum. The crural bases are high, parallel, and ventrally directed. The brachidium is loop-shaped and terebratuliform; the loop reaches the midlength of the dorsal valve, the transverse band did not preserve.

Dimensions in mm and ratios:

Specimen, no.	L	W	T	L septum	L/W	L/T
111-24/2051	7.5	6.55	3.1	1.1	1.14	2.42
111-26/2051	13.2	11.1	6.1	5.4	1.19	2.2
111-13/2051	17	12.5	8.1	8.5	1.36	2.1
111-56/2051	24.85	18.85	12.5	9.8	1.32	1.99
112-86/2052	26.6	19	14.35	8.1	1.4	1.85
112-91/2052	21.75	19.4	10.85	8.5	1.12	2.08
112-108/2052	21.2	13.4	10.7	7.2	1.58	1.98
112-150/2052	6.9	6	2.7	2.5	1.15	1.55
112-153/2052	9.6	8	4.2	–	1.2	2.29
112-136/2052	16.3	12.1	6.85	5	1.35	2.38
112-135/2052	18.5	13.2	9	5.6	2.05	1.94
112-115/2052	22.7	15.7	11.15	9.8	1.44	1.93
112-155/2052	14.6	11.25	5.75	4.4	1.12	2.4

Occurrence. Lower Triassic, Olenekian Stage; South Primorye, Mangyshlak, Balkans (Bulgaria, possibly, Hungary and Romania).

Material. About 370 specimens: 1 specimen from the beds *Churkites syaskoi* of the *Anasibirites nevolini* Zone, Kamenushka-2 section; about 300 specimens from the localities on the Zhitkov Peninsula, Chernyshev Bay, near Capes Schmidt and Konechny of Russky Island; about 60 specimens from the Kamenushka River basin.

For all text tables: (L) shell length (mm); (W) shell width (mm); (T) shell thickness (mm); (L/W) shell length to width ratio; (L/T) shell length to thickness ratio

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