A New Cryptocrinid Genus (Eocrinoidea, Echinodermata) from the Bioherm-related Volkhov Facies (Late Arenigian, Ordovician), Leningrad Region

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2 authors:

Sergey Vladimirovich Rozhnov
Russian Academy of Sciences

Petr Fedorov
Saint Petersburg State University

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A New Cryptocrinid Genus (Eocrinoidea, Echinodermata) from the Bioherm-related Facies of the Volkhov Stage (Late Arenigian, Ordovician), Leningrad Region

S. V. Rozhnov* and P. V. Fedorov**

**Paleontological Institute, Russian Academy of Sciences, ul. Profsoyuznaya 123, Moscow, 117997 Russia*
***St. Petersburg State University, Universitetskaya nab. 7/9, St. Petersburg, 199164 Russia*
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Abstract—A new cryptocrinid, *Paracryptocrinites bockeliei* gen. et sp. nov. (Eocrinoidea, Echinodermata), from the Volkhov (Upper Arenigian, Ordovician) Bioherm-related Facies of the eastern Leningrad region is described. The structure of the bioherms associated with this genus is described.

INTRODUCTION

The Ordovician adaptive radiation of marine invertebrates currently attracts the attention of many researchers, since it is thought to be associated with a great reorganization of marine biota and the rise of many higher taxa (Rozhnov and Palmer, 1992; Guensburg and Sprinkle, 1992; Rozhnov, 1993, 1994, 1998, 2001; Droser, 1995). The structural patterns of many invertebrate classes were established in the Ordovician. Subsequently, only the taxa of lower ranks arose among marine invertebrates (Rozhnov, 1995, 1998, 2001). Simultaneously with the last event of the formation of class-level archetypes, many animal groups of uncertain taxonomic position appeared. Such groups were peculiar in morphology and combined similar features with sharp distinctions from well-known classes. It was difficult to propose a model for their phylogenetic relationships; therefore, their ancestors and descendants seemed to be unknown in the fossil records. This was the case, at least partially; however, an important role in the formation of these taxa belonged to the pedomorphism, i.e., slowed down individual development. In this case, intermediate morphological states are either extremely rare or occur as aberrant forms (Rozhnov, 1995, 1998, 2001). All these reasons make the investigation of such groups quite important for a better understanding of the early evolution of the higher taxa. One such group with uncertain affinities is the family Cryptocrinitidae.

The family Cryptocrinitidae Bassler, 1938 was established on the basis of the genus *Cryptocrinites* Von Buch, 1840 from the lower Middle Ordovician of the Leningrad Region. Another genus of the family, *Lysocystites* S.A. Miller, 1889, occurs in the Silurian of North America (Ubaghs, 1967). The morphology of the oral area of the latter genus makes its affiliation to the Cryptocrinitidae doubtful. Until recently, the occurrence of *Cryptocrinites* in a section was thought to indicate the Azeri Stage. However, Bockelie (1981) described a representative of this genus from the Upper Arenigian of Sweden. Despite the poor preservation of the specimen, Bockelie pointed out that the new species clearly differs from typical *Cryptocrinites* in a greater number of plate circlets and some other features. He proposed that the detailed investigation of future findings would allow one to rank the species described by him as a new genus. The cryptocrinitid species described in the present paper strongly differs from both typical *Cryptocrinites* and the specimen described by Bockelie, and it existed earlier than these forms. It has previously been shown that *Cryptocrinites* is closely related to the Rhipidocystidae, an extensive group characterized by a flattened theca (Rozhnov, 1994b). The new species described below will probably clarify the relationships between the Cryptocrinitidae and an extensive paracrinoid group.

CRYPTOCRINITES-BEARING FACIES

The new species of the Cryptocrinitidae extends our knowledge of both the stratigraphic range and paleoecology of this group. All specimens of *Cryptocrinites* come from Azeri and Lasnamyagin marls. These marls cover large areas and were formed in relatively calm offshore biotopes of a vast shallow-water carbonate epeiric sea with significant clay-size sediment influx and soft ground. In contrast, all three whole thecae and numerous isolated plates of the new cryptocrinid from the Volkhov of eastern Leningrad Region were yielded from biohermal facies. These bioherms are quite interesting paleoecologically and, therefore, merit a brief description.

Vishnyakov and Hecker (1937) described a positive structure covered by a thick limestone layer with numerous surface inflations in the Syas River Valley. This structure was called Syas Hump and was inter-

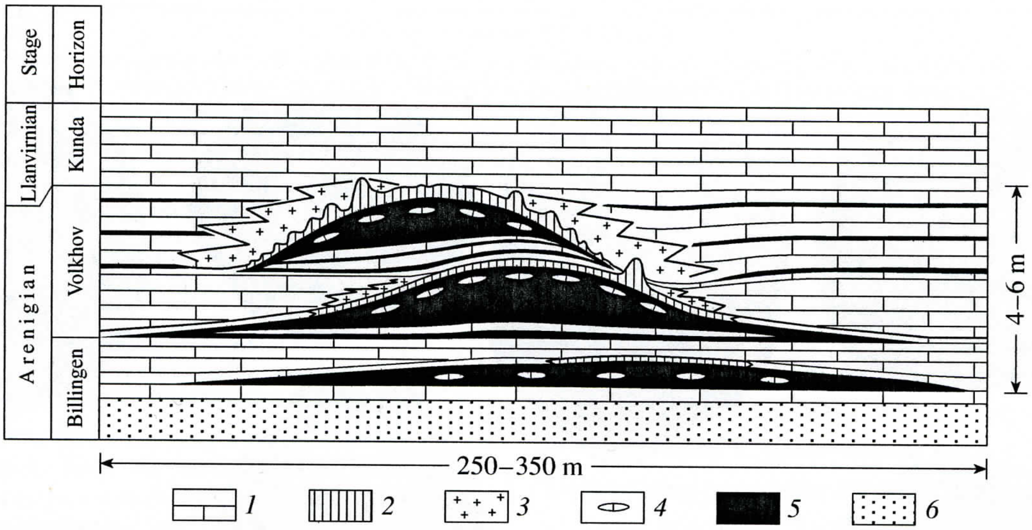


Fig. 1. Plot of a large Hecker hump: (*1*) host glauconite-bearing wackestone-grainstone, (*2*) micrites (mudstone), (*3*) brachiopod–crinoidal sparitized grainstone–rudstone of hump flanks, (*4*) lenses and lenticular beds of bioclastic limestone in shales, (*5*) shales and marls, and (*6*) quartz-glauconitic sands.

preted as a synsedimentary fold accounted for by a short-term lateral pressure. This interpretation was based on two evidences, i.e., the development of a hardground surface on the top of covering limestone and the position of the overlying strata that they abut against this surface.

A detailed study of this stratigraphic interval performed by researchers from St. Petersburg State University in the 1990s has shown that the Syas Hump is not a unique structure of this kind (Fedorov and Dronov, 1998; Fedorov, *et al.*, 1998; Fedorov, 1999). More than ten large synsedimentary anticlinal swells have been found in the Russian part of the Baltic-Ladoga Klint. They are similar in inner structure and more complex than was proposed by Vishnyakov and Hecker (1937), who examined only the apical part of the Syas Hump. These structures were interpreted as organogenic buildups of mud mound type and, by analogy with the Syas Hump, designated as Hecker humps (Dronov and Fedorov, 1994).

These bioherms consist of at least three sequential convex structures (Fig. 1). Each convex structure is a shale lens armored by a wackestone-to-micrite limestone bed. The limestone bed in places increase several times in thickness. Such inflations are thought to be a result of sponge-cyanobacterial expansion. All lenticular structures and their micritic caps from the entire Russian part of the klint occur in a relatively narrow interval from the Upper Billingen to the Upper Dikari of the Volkhov Horizon. The shale lenses vary in size and flank steepness even within the same hump. The largest shale lenses (250–300 m wide) usually lay directly on the Billingen–Volkhov regional unconformity. The centers of the shale lenses at each level are displaced with reference to each other.

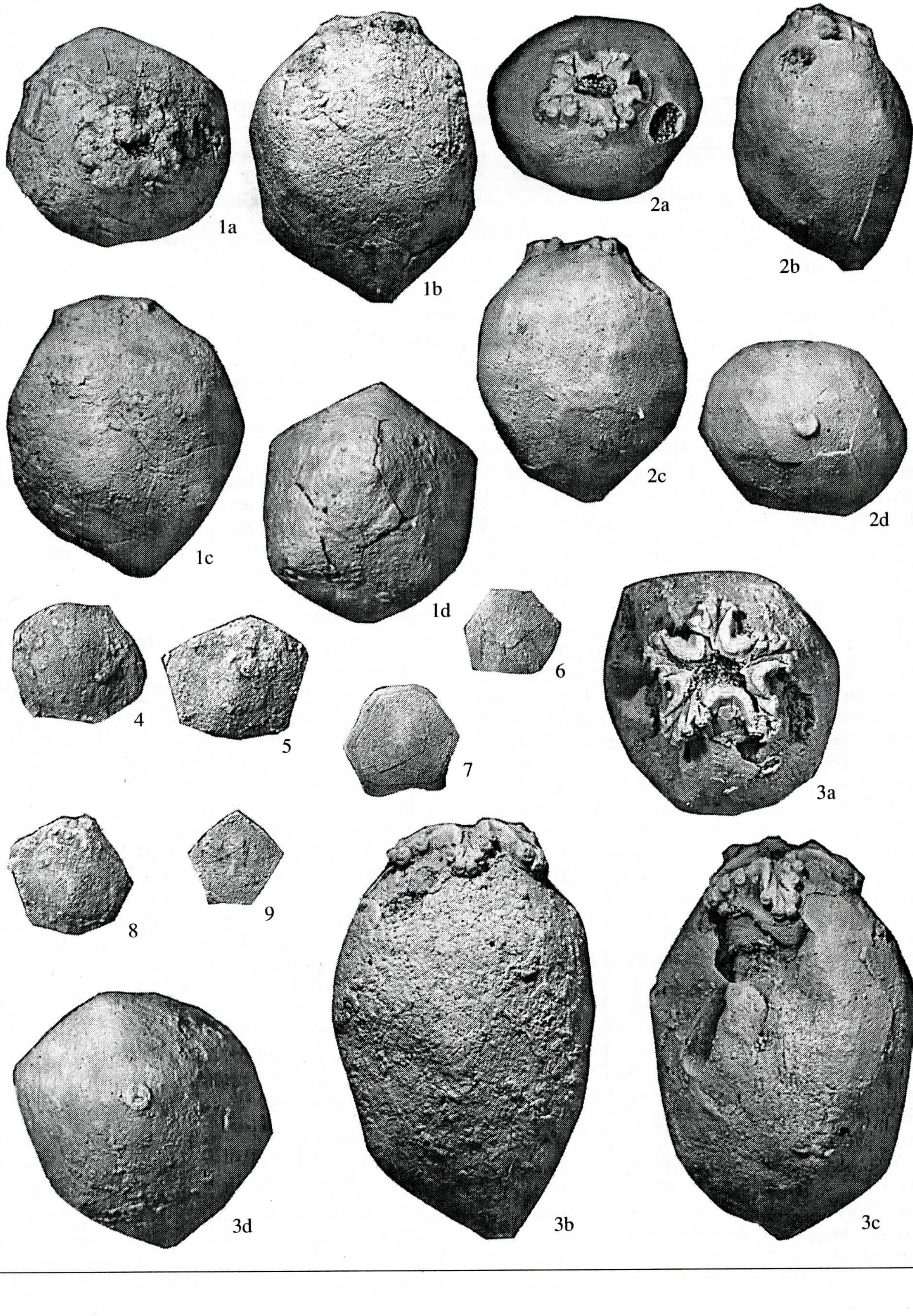
Shale lenses enclose lenticular seams of wackestone-to-sparite limestone and horizons of thin limestone lenses. A large part of limestone seams are peculiar in structure and texture and occur at certain levels within shale lenses. Lenticular limestone horizons gradually become thin at the shale lens periphery. Limestone seams also become thin to the periphery or are shaped into thin amalgamated layers of the host rock.

Shales and enclosed limestones contain abundant benthic fossil fauna dominated by articulate brachiopods, ostracodes, and fragmentary columniferous echinoderms. Relatively numerous crinoid holdfasts and cryptocrinitid plates are present (Pl. 6, figs. 4–9). The cryptocrinid plates apparently belong to the genus described below. Accessory groups are bryozoans, inarticulate brachiopods, trilobites, hyolites, siliceous sponges (in the form of spicules replaced by calcite and dolomite), nautiloids, foraminifers, and small gastropods. Pelagic fauna consists of conodonts and graptolites. Tolmacheva accounted 8–15 thousand conodonts per kg of dry residue, which corresponds to their concentration in host limestones (Tolmacheva and Fedorov, 2000). Rhabdosomes of *Expansograptus herundo* graptolite assemblage frequently occur as thin lenticular accumulations in the middle and upper shale lenses (T.N. Koren, personal communication). Shales contain a rich assemblage of Early Ordovician acritarchs (E.G. Raevskaya, personal communication).

Shales are strongly bioturbated in the peripheral parts, under lenticular limestone seams, and under micritic limestone caps. Other parts of shale lenses are weakly bioturbated.

The lamination of shales, the bedding of lenticular limestones, and the excellent preservation of brittle shells and graptolites suggest that bioherms are a result

Plate 6



Explanation of Plate 6

Figs. 1–3. *Paracryptocrinites bockeliei* Rozhnov et Fedorov, gen. et sp. nov., thecae: (1) specimen PIN, no. 4125/116, (1a) top view, (1b) lateral view of the B ray, (1c) lateral view of the CD interray, and (1d) bottom view, Putilovo Quarry, dumps, eastern Leningrad Region; Volkhov, Upper Arenigian; (2) specimen PIN, no. 4125/757: (2a) top view, (2b) lateral view of the B ray, (2c) lateral view of the CD interray, and (2d) bottom view, Babino Quarry, dump above the central part of the bioherm; the same region and beds; and (3) holotype PIN, no. 4125/756: (3a) top view, (3b) lateral view of the B ray, (3c) lateral view of the D ray, and (3d) bottom view; Putilovo Quarry, gutter with cascade 100 m south of the bioherm; shale bed in the upper part of the upper limestone/marl alternation unit, Frizy–Lower Podkoroby Beds, Volkhov Horizon, Upper Arenigian.

Figs. 4–9. *Paracryptocrinites* sp., plates: (4) specimen PIN, no. 4125/758; (5) specimen PIN, no. 4125/759; (6) specimen PIN, no. 4125/760; (7) specimen PIN, no. 4125/761; (8) specimen PIN, no. 4125/762; and (9) specimen PIN, no. 4125/758; all plates come from the shale of Baf-9-6 Bioherm, quarry near the village of Babino, eastern Leningrad Region; Volkhov Horizon, Upper Arenigian.

of *in situ* accumulation rather than extrusion, as Vishnyakov and Hecker (1937) proposed.

Micritic limestones capping the shale lenses are 5 to 70–80 cm thick. They are interpreted as more or less segregated sponge-cyanobacterial bioherms. In plane outline, these bioherms are isometric, oval, or elongated, varying in diameter from several centimeters to several meters.

Biohermal micrites contain only echinoderm holdfast clusters and large isolated spicules of siliceous sponges that have been completely replaced by crystalline calcite. Conodont concentrations in micrites are two orders lower than those of shales and host limestones, which may suggest higher growth rates of bioherms. The tops of micritic horizons and slopes of bioherms are overprinted by hardgrounds with *Trypanites* borings and echinoderm holdfasts. Micritic horizons taper in the hump periphery and pass into thin (1–3 cm) wackestone to packstone beds of the host rock; in the top of these beds, hardground developed. This suggests the positive limestone structures left after perished sponge-cyanobacterial communities were proper substrates for numerous encrusters, primarily, pelmatozoan echinoderms.

The skeletal debris of echinoderm encrusters accumulated around buildups as sparry limestone aprons. The noticeable enrichment in pelmatozoan debris, especially in shale interlayers between the limestone beds of the Middle and Upper Volkhov, occur at a distance of several hundred meters from the humps. These sparry limestone aprons have yielded numerous remains of cryptocrinitids and other echinoderms, some of which are unique. For example, an unusual eocrinoid, *Simonkovicrinus*, was found in similar facies near the village of Simonkovo on the right bank of the Volkhov River (Rozhnov, 1991).

In addition to large multilevel bioherms, each clayey lens horizon hosts smaller positive structures. These structures are gently sloping isometric solitary shale lenses, some of which are capped by a thin micritic crust. Such structures are currently considered to be rudimentary Hecker-type mud mounds (Hecker humps).

Although isolated cryptocrinitid plates are abundant in the Volkhov bioherm-related facies, complete thecae are scarce.

SYSTEMATIC PALEONTOLOGY

CLASS EOCRINOIDEA

Family Cryptocrinitidae Bassler, 1938

Genus *Paracryptocrinites* Rozhnov et Fedorov, gen. nov.

E t h y m o l o g y. From the Latin *para* (near) and the genus *Cryptocrinites*.

T y p e s p e c i e s. *Paracryptocrinites bockeliei* sp. nov.

D i a g n o s i s. Elongated ovoid theca composed of six plate circlets, including brachiole-bearing plates. Ambulacra in adults long.

C o m p a r i s o n. The new genus differs from *Cryptocrinites* by a greater number of theca circlets and longer ambulacra.

R e m a r k s. The new genus is distinguished from *Cryptocrinites* (?) *similis* Bockelie, 1981 from the Upper Arenigian of Sweden by a substantially smaller theca, elongated ovoid rather than spherical theca, and a smaller number of basals. It also may be distinct in some other features that have not been preserved or are obscure in Bockelie's species.

S p e c i e s c o m p o s i t i o n. Type species.

Pararyptocrinites bockeliei Rozhnov et Fedorov, sp. nov.

Plate 6, figs. 1–3

E t h y m o l o g y. In honor of Norwegian paleontologist F. Bockelie.

H o l o t y p e. PIN, no. 4125/756, theca, Leningrad Region Putilovo Quarry, gutter with cascade 100 m south of a bioherm; Upper Arenigian, Volkhov Horizon, Frizy–interbedding Lower Podkoroby Beds, shale band in the upper part of the upper unit.

D e s c r i p t i o n (Figs. 2–4). The theca is medium-sized, to 17 mm deep, spherical to ovoid in small individuals and elongated ovoid in larger individuals. The oral area of some specimens slants to the A ray or EA interray, which makes the theca somewhat asymmetrical. The opposite side of the theca (CD or C) is correspondingly more inflated than other lateral sides. The plates of the theca are arranged in six weakly ordered circlets: basal, first lateral, second lateral, third lateral, oral, and brachiole-bearing. The number, shape, and arrangement of the plates in each circlet show the signs of five-rayed symmetry. Therefore, most plates and

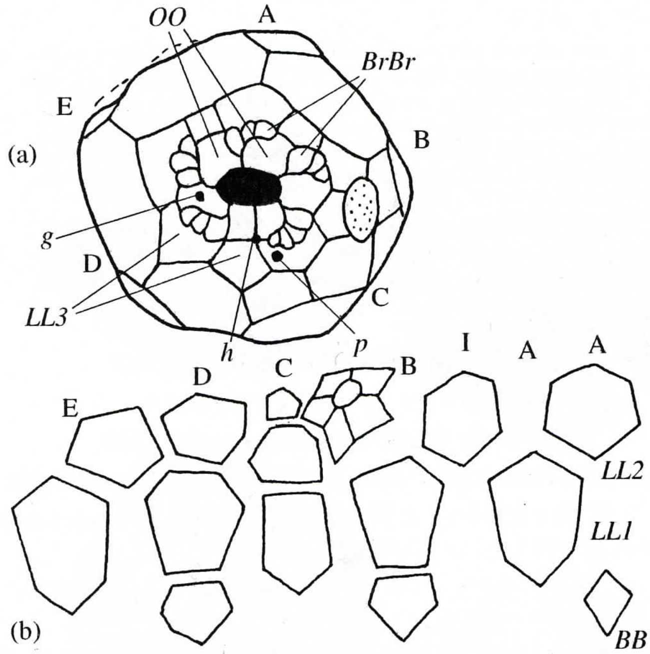


Fig. 2. Schematic pattern of plates and circlets in *Paracryptocrinites bockeliei* Rozhnov et Fedorov, gen. et sp. nov. based on specimen PIN, no. 4125/116: (a) top view and (b) unfolded (*BB*) basal, (*LL1*) first lateral, and (*LL2*) second lateral circlets. Designations: (*LL3*) third lateral circlet, (*OO*) oral circlet, and (*BrBr*) brachiole-bearing circlet; (*h*) madreporite, (*g*) genital pore, and (*p*) pore of unclear function; the mouth is blackened; the anus is speckled.

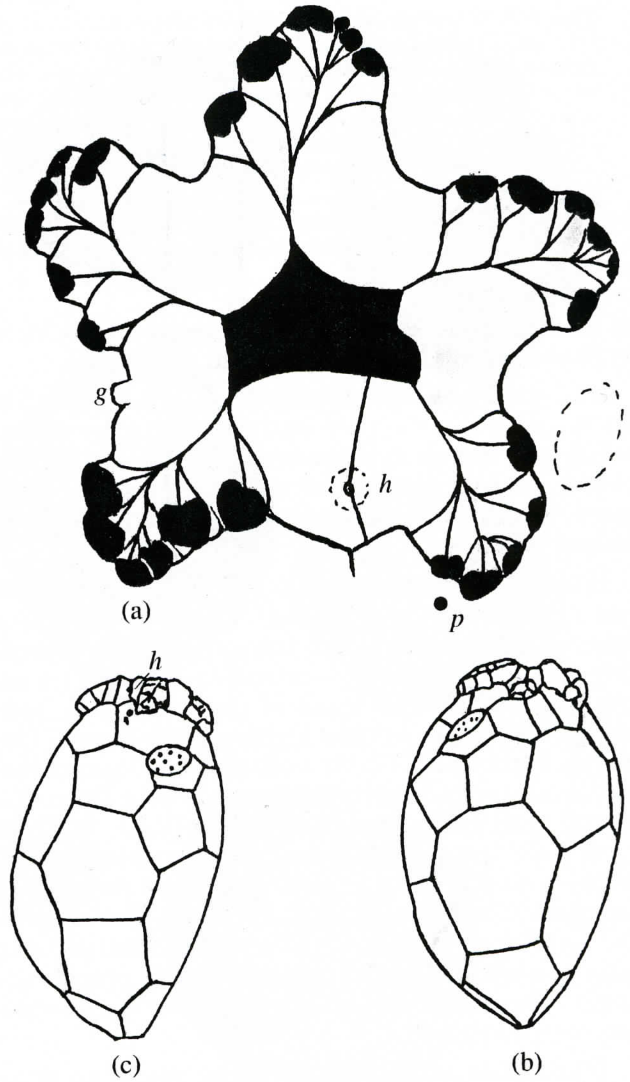


Fig. 3. The shape of the theca, arrangement of plates, and structure of the oral area in *Paracryptocrinites bockeliei* Rozhnov et Fedorov, gen. et sp. nov., holotype PIN, no. 4125/756: (a) top view of the oral area, (b) lateral view of the B ray, and (c) lateral view of the C ray; the mouth and facets are blackened; the anus is speckled; (*h*) madreporite, (*g*) genital pore, and (*p*) pore of unclear function.

structures can be designated according to Carpenter's system as A, B, C, D, and E ray elements and AB, BC, CD, DE, and EA interray elements. We proceed from the assumption that the madreporite opens in the CD interray; the actinal furrow is on the opposite side and extends in the A ray, between the oral plates.

The basal circlet consists of two wide and one narrow plate. The narrow plate sits in the BC interray. The two wide plates can be considered as undivided CD + DE and EA + AB. The base of the basal circlet bears a narrow, round, and slightly concave columnal facet 0.6–1.0 mm in diameter perforated by a very narrow (0.1–0.2 mm) rounded triangular axial canal.

The first lateral circlet is located above the basal circlet and consists of five large plates. The plate lying in the C ray is paired and consists of smaller lower and larger upper plates. The upper plate extends beyond the first lateral circlet into the second lateral circlet. The lower C plate is smaller than other plates of this circlet, while the B and D plates are the largest.

The second lateral circlet is outlined to a lesser extent than the first, because the upper C of the first lateral circlet intrudes into the second circlet and the arrangement of the places is influenced by close position of the anus. Four plates of this circlet are large and approximately equal in size. In addition, at least three plates sit near the anus. The upper lateral C of the first lateral circlet is just below two plates of the second lateral circlet; the right plate contours the left side of the anus. The other plate of the second lateral circlet contours the lower side of the anus. Thus, the second lateral circlet usually consists of seven plates. In some cases, however, two plates instead of one are presented below the anus and one tiny plate arises lower to the right of the anus (specimen PIN, no. 4125/757). In the holotype, two plates (paired plates) above the upper C of the first lateral circlet are so shifted to the B ray that the anus is contoured by the left plate. The right plate sits below the anus and is separated from the latter by an additional low and wide plate located above the right plate. The plate that in other specimens contours the

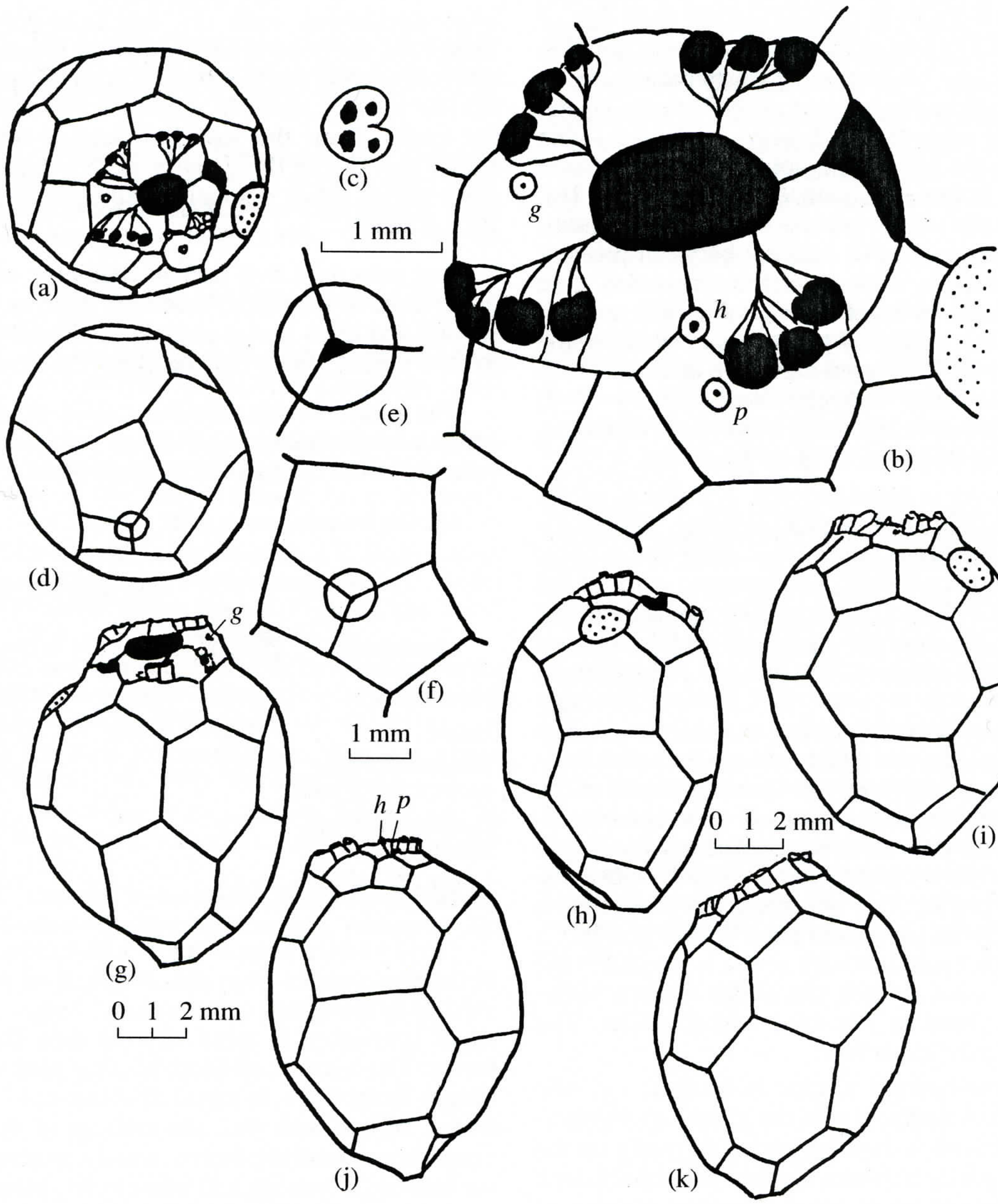


Fig. 4. A small theca of *Paracryptocrinites bockeliei* Rozhnov et Fedorov, gen. et sp. nov., specimen PIN, no. 4125/757: (a) top view, (b) oral area, (c) schematic facet for brachiole attachment, ligamental pits shown black, (d) bottom view, (e) columnal facet with the axial canal (blackened), (f) basal circlet, (g) lateral view of the A ray, (h) lateral view of the BC interray, (i) lateral view of the CD interray, (j) lateral view of the D ray, and (k) lateral view of the E ray; black areas are the mouth, facets for brachiole attachment, and the place of the lost brachiole-bearing plates in the B ray; speckled area is the anus; (*h*) madreporite, (*g*) genital pore, and (*p*) pore of unclear function.

anus from below, is shifted in the holotype to the right, i.e., counterclockwise. With such arrangement of plates, in the anal region, it is difficult to distinguish between the plates of the circlets and anal series. A similar statement is true for the third lateral circlet.

The third lateral circlet is ordered to the least extent. It consists of 8–11 plates, including two that contour the anus from the right and from above. The smallest number of plates in the third lateral circlet is in specimen 4125/764. These are the following: (1) a small plate located in the left part of the BC interray and contouring the anus from above; (2) the next clockwise plate located in the C ray and the right part of the CD interray; (3 and 4) paired plates[1] outlined as one plate,

[1] Paired plates are characteristic of three circlets. In the oral circlet, they sit in the CD interray. In the third lateral circlet located below the oral circlet, the similar pair is shifted clockwise with reference to the oral pair and sits in the D ray. In the second lateral circlet, the similar pair of plates is shifted counterclockwise with reference to the oral pair and located in the C ray.

which sit in the left part of the CD and the right part of the D; (5, 6, and 7) a row of three plates almost equal in size and shape (plate 7 is somewhat smaller than plates 5 and 6) spanning from the left part of the D to the B; and (8) a plate of the same size and shape as plates 5–7 but with a notch on the left side; it contours the anus from the right. In a larger specimen (PIN, no. 4125/116), paired plates in this circlet are less distinct and an additional plate arises in the AB interray between primary plates 5–6 and 6–7. This specimen possesses nine plates, although plates 6 and 7 are smaller than usually. Specimen PIN, no. 4125/757 possesses 11 plates in the third lateral circlet. The paired plates are distinct. Three additional plates arise between four primary (5–8) plates. Although this circlet in the holotype is damaged, similar additional plates seem to be presented.

The oral circlet is most ordered. It consists of six plates, two of which sit in the CD interray. The proximal parts of all the plates adjoin each other and contour the rounded crescent mouth. The concave edge of the mouth is turned to the CD interray. The median parts of the oral plates are concave and their distal ends are drawn out as short tongues. The left and right sides of each plate are slightly asymmetrical, because the ridge on the right side is longer than that on the left side. The proximal parts of the oral plates are placed apart from each other, especially strongly in the external part of the theca, and alternate with the plates of a special brachiole-bearing circlet. An extended tubercle terminating in the madreporite sits between two plates of the CD interray of the oral circlet. The oral plate DE also bears a similar tubercle with a terminal pore. This is possibly a gonopore. Another tubercle with a pore is present in the left part of the plate, which sits under the brachiole-bearing C-ray plates in the third lateral circlet. The function of the pore is unclear.

The brachiole-bearing circlet is broken; i.e., the plates of a ray lack contacts with the plates of neighboring rays. The brachiole-bearing plates sit partly on the oral plates and partly between the oral and third lateral plates. The holotype possesses the greatest number of brachiole-bearing plates, i.e., six plates in each ray, except for the C ray bearing only five plates. Each plate bears apically a facet for the brachiole attachment. The facets are oval or almost circular, with a small V-shaped notches left by the ambulacral groove. Each facet bears two pairs of depressions. The anterior pair is divided by the ambulacral groove notch. The posterior pair is divided by a weak ridge. The facets and the plates having facets vary is sizes; i.e., the distal facet is the largest, and the proximal facet is the smallest. The sequence of plate and facet development can be inferred from facet sizes and the sequence of ambulacral groove branching. The distal left plate was the first; then, in sequence, a left plate, a distal right plate, a left plate, a right plate, and, finally, a left plate. Due to this pattern of plate appearance and ambulacral groove branching, the ends of ambulacra are round in smaller individuals with only three brachiole-bearing plates and pointed in large specimens with six brachiole-bearing plates. Therefore, the general outlines of the brachiole-bearing and oral circlets are five-bladed in small specimens and starlike in large ones. In specimen PIN, no. 4125/757, the cavity from the lost B brachiole-bearing plates shows that two or three plates were in contact with the inner cavity, while ontogenetically younger plates lack such contact.

The anus is 1.5–2 mm in diameter, sitting in the upper third of the theca, in the BC interray between the second and third lateral circlets. The anus is contoured by 4–6 plates, which may be clearly different in origin.

The plates of the theca are thin, usually smooth, often with distinct growth lines and a characteristic tubercle in the center of each large plate.

M e a s u r e m e n t s, mm:

Measurement	Holotype 4125/756	Specimen PIN, no. 4125/757	4125/116	4125/764
Maximal width	10.5	7.0–8	8.5	11 × 8.5
Height	17.0	10.3	11.5	15.1
Height of maximal width, from the base	10.5	6.5	7.0	8.5
Diameter of the columnal facet	0.9	1.1	0.6	1.0
Length of ambulacra	2.5	1.5	1.2	2.0

I n d i v i d u a l a n d a g e v a r i a t i o n. The shape of the theca varies from almost spherical in small individuals to elongated ovoid in large forms. The theca of small specimens is more oblique than those of large forms. The number of facet-bearing plates in each ray ranges from three in small specimens to six in large forms. In line with this, the endings of the ambulacra range from round to pointed, and the general outlines of the brachiole-bearing and oral circlets range from five-bladed to starlike. The number of plates in the third lateral circlet varies from eight in small specimens to eleven in large forms.

M a t e r i a l. All specimens come from the Bioherm-related facies of the Volkhov Stage. The holotype and other two thecae were found in the Putilovo Quarry. One theca was found in a quarry near the village of Babino. Numerous plates of *Paracryptocrinites* sp. were collected in the above two quarries and a desolate quarry near the village of Simonkovo on the right bank of the Volkhov River (Pl. 6, figs. 1–9).

ACKNOWLEDGMENTS

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