Summary of micro-CT studies on Late Cretaceous bryozoans

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Aims

Bryozoans are mostly marine, small and colonial invertebrate animals, which have an extensive distribution in Recent seas and a rich fossil record extending from the Early Ordovician. Molecular research suggests that bryozoans already existed in the Cambrian but either have yet to be discovered or were soft-bodied only and did not fossilize. Bryozoa can be used for biostratigraphy, palaeoecological and palaeobiogeographic reconstructions. Traditionally, thin sections or acetate peels have been used to study internal structures in fossil bryozoans. At present, X-ray micro-CT is one of the most promising methods for studying internal features in fossil bryozoans as it is non-destructive and allows easily producing myriads of virtual sections of a bryozoan colony in a variety of planes. Furthermore, it allows creating a 3-dimensional image (Viskova & Pakhnevich 2010; Schmidt 2013; Wyse Jackson & McKinney 2013; Matsuyama et al. 2015; Koromyslova & Pakhnevich 2016; Fedorov et al. 2017; Martha et al. in press; Koromyslova et al. 2018).

Method

X-ray microcomputed tomography (micro-CT) was carried out at the Borissiak Palaeontological Institute, Russian Academy of Sciences (PIN), Moscow, Russian Federation using an X-ray Skyscan 1172 on selected samples showing excellent preservation. An Al filter (1 mm) was used. The voltage used was at 100 kV, while the current was at 100 mA. For each sample, 520 virtual sections in three directions (transverse: parallel to the transverse walls of the zooids; coronal: parallel to the frontal and basal walls of the zooids; and sagittal: parallel to the lateral walls of the zooids) were produced at a rotation of 180°. The resolution was 4–5 μm for each sample and the rotation angle was 0.7°.

Results

Beisselinopsis quincunx Voigt, 1962*, Pachydermopora grodnoensis* Koromyslova & Pakhnevich, 2016, *Beisselina skyscanica* Koromyslova & Pakhnevich, 2016 and several species of the genus *Acoscinopleura* Voigt, 1956, all cheilostome bryozoans from the Late Cretaceous of Central and Eastern Europe, have complex colonies. Traditionally, internal features would have been studied using thin sections or artificial casts, but we used micro-CT instead (Koromyslova & Pakhnevich, 2014, 2016; Koromyslova et al., 2018). Micro-CT allowed visualization of the internal morphology of colonies, zooid chambers, vertical and basal walls, cryptocyst, frontal shield and ovicells.

Zooid chamber. Bryozoan colonies consist of individual polymorphs (or modules) called zooids. The shape of zooid chambers is not visible on the colony surface but can be visualized using micro-CT if not filled by calcitic sediment. Zooid chambers of the studied bryozoans have different shapes (Figs 1E, 2C, G, J); boot-shaped in species of the genus *Acoscinopleura*, and inverted pear-shaped in *Beisselinopsis quincunx*, *Pachydermopora grodnoensis* and *Beisselina* *skyscanica*. The size of the zooidal chambers corresponds to the approximate size of the zooidal soft body. Obviously, *Pachydermopora grodnoensis* had the largest soft body, while *Beisselinopsis quincunx* and *Beisselina skyscanica* had the shortest soft body.

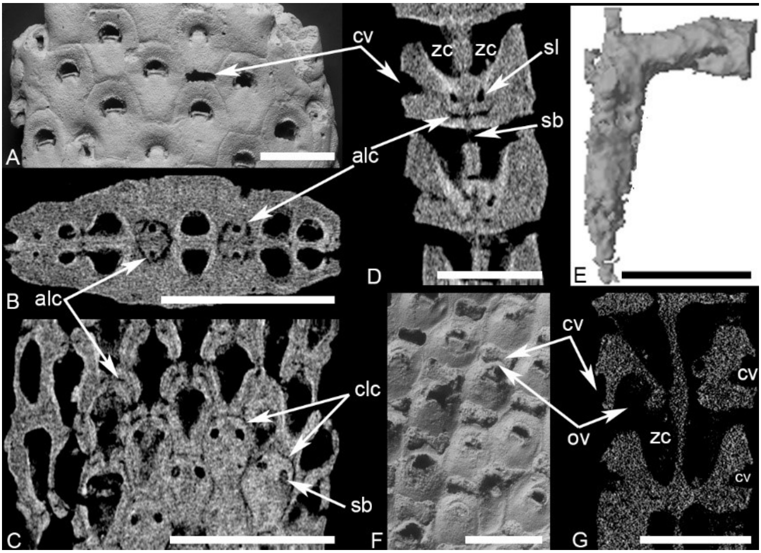

Figure 1: **A-E.** *Acoscinopleura crassa* Koromyslova et al., 2018, holotype, SMF 29950, late Maastrichtian, Hemmoor, Lower Saxony, Germany. A: Part of colony showing the frontal surface of zooids. B: Transverse section. C: Coronal section showing the basal walls (lower right). D: Sagittal section through zooid chambers perpendicular to basal walls. E: 3-dimensional model of zooid chamber. **F-G.** *Acoscinopleura albaruthenica* Koromyslova et al., 2018, holotype, PIN 2922/244, late Campanian, Grodno, Belarus. F: Part of colony showing the frontal surface of zooids with peripheral caverns and ovicells. G: Sagittal section. *Abbreviations*: alc, arch-like cavities; clc, channel-like cavities; cv, peripheral cavern; sl, septulum in lateral wall; sb, septulum in basal wall; ov, ovicell; zc, zooid chamber. *Scale bars*: A, D, G, F = 500 µm; B, C = 1 mm; E = 200 µm.

Zoooid walls. The most interesting morphology of zooid walls was observed in *Acoscinopleura* spp. (Fig. 1). The species have a very thick calcification. Interzooidal communication is done via septules located in the vertical and basal walls and connecting each zooid with all surrounding zooids. Channel-like cavities were observed in the lateral and transverse vertical walls. They are interconnected and form a network near the basal walls. The majority of Recent cheilostome species have double lateral walls separated by an unpaired intercalary cuticle but single transverse vertical walls. The lateral and transverse channel-like cavities in *Acoscinopleura* spp. may therefore have been occupied during lifetime by the intercalary cuticle. However, in this case, transverse walls in *Acoscinopleura* should have been double walls. Unclear channel-like cavities were observed in the vertical walls of *Beisselinopsis quincunx* and in some specimens of *Pachydermopora grodnoensis* and *Beisselina skyscanica*. The morphology of the vertical walls of species of *Pachydermopora* and *Beisselina* need more detailed investigations. Arch-like cavities were only observed in the transverse vertical walls of species of *Acoscinopleura*. The function and formation of arch-like cavities remains dubious. The basal wall of some extant erect, bilaminar cheilostome bryozoans is double, indicating that the colony grew as two independent layers, back-to-back. However, species of *Acoscinopleura* have a single basal wall, while *Beisselinopsis quincunx*, *Pachydermopora grodnoensis* (Fig. 2E) and *Beisselina skyscanica* have apparent double basal walls.

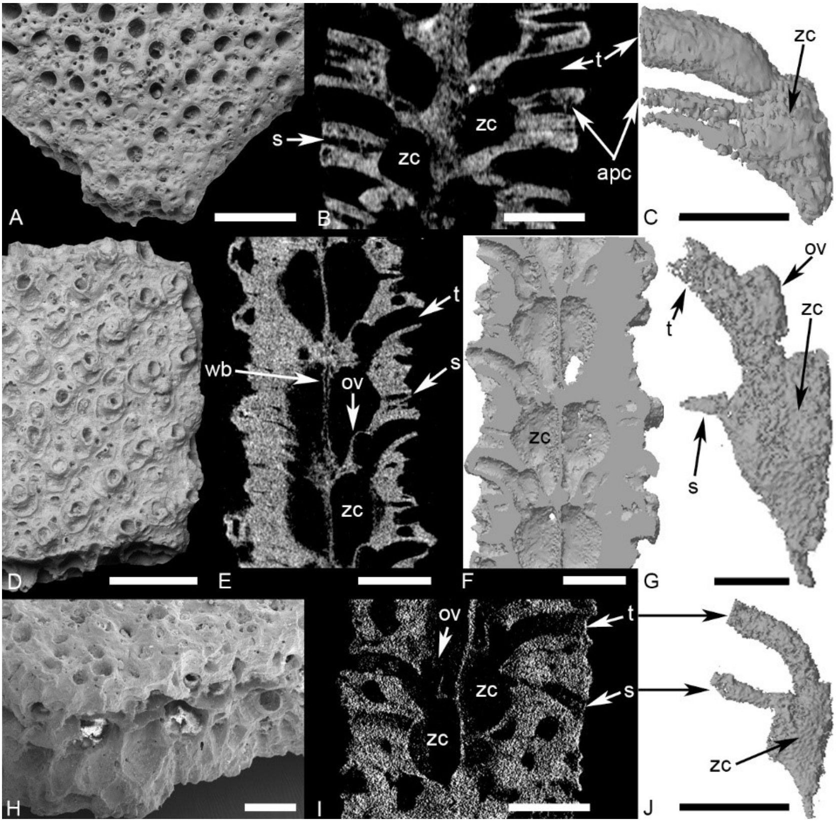

Figure 2: **A-C.** *Beisselinopsis quincunx* Voigt, 1962, holotype, ESM MSU 57/13, early Maastrichtian, Ukraine. A: Part of colony showing frontal surface of zooids. B: Sagittal section. C: 3-dimensional model of zooid chamber. **D-G.** *Pachydermopora grodnoensis* Koromyslova & Pakhnevich, 2016, late Campanian, Grodno, Belarus. D, G. Holotype, PIN 2922/313. D: Colony fragment. G: 3-dimensional model of zooid chamber. E, F. Paratype, PIN 2922/258. E: Sagittal section. F: 3-dimensional model of sagittal section. **H-J.** *Beisselina skyscanica* Koromyslova & Pakhnevich, 2016, late Campanian, Grodno, Belarus. H-I. Paratype, PIN 2922/259. G: Part of colony. H: Sagittal section. J. Holotype, PIN 2922/311, 3-dimensional model of zooid chamber. *Abbreviations*: apc, areolar pore canals; ov, ovicell; s, spiramen; t, tube for passage of lophophore; wb, basal wall; zc, zooid chamber. *Scale bars*: A, D = 1 mm; B, C, E, F, I, J = 500 µm; G = 250 µm; H = 300 µm.

Cryptocyst. The cryptocyst (= calcareous layer on the basal side of the frontal membrane) in zooids of *Acoscinopleura* species examined is unusually thick. Peripheral caverns are hollow structures developed inside the cryptocyst of many zooids of *Acoscinopleura* species (Fig. 1A, D, F, G). They take up less than half or half of the cryptocystal thickness. Micro-CT studies showed that peripheral caverns were covered during lifetime by a thin cryptocystal lid, which is rarely preserved.

Frontal shield. The calcified frontal surface (i.e. frontal shield) in *Beisselina skyscanica* is thicker (310–530 µm) than the height of the zooid chamber (Fig. 2I), while the frontal shield in *Pachydermopora grodnoensis* is thinner (140–300 µm) than the height of the zooid chamber (Fig. 2E, F). In *Beisselinopsis quincunx*, the thickness of the frontal shield (220–410 µm) is comparable to the height of the zooid chamber (Fig. 2B).

Ovicells are skeletal chambers for brooding of larvae. Ovicells of *Acoscinopleura* species are immersed inside the proximal cryptocyst of the distally adjacent zooid, and sometimes they are located underneath a peripheral cavern (Fig. 1F, G). Only the external surface of the ovicells is usually visible on the colony surface. Ovicells in *Pachydermopora grodnoensis* and *Beisselina skyscanica* are located at the base of the peristome and not visible at all on the colony surface (Fig. 2E-G, I).

Conclusions

- Micro-CT allows the non-destructive study of the internal morphology in fossil bryozoans that show a reasonable preservation.
- Internal skeletal features may be useful to add characters needed for taxon differentiation in groups with few morphological characters.

Acknowledgements

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References

1. Fedorov, P.V., Koromyslova, A.V., Martha, S.O. The oldest bryozoans of Baltoscandia from the lowermost Floian (Lower Ordovician) of north-western Russia: Two new rare, small and simple species of Revalotrypidae. PalZ 91 (3), 353-373, 2017. doi: 10.1007/s12542-017-0351-y
2. Koromyslova A.V., Martha S.O., Pakhnevich A.V. The internal morphology of *Acoscinopleura* Voigt, 1956 (Cheilostomata, Bryozoa) from the Campanian and Maastrichtian of Central and Eastern Europe. PalZ, 2018. doi: 10.1007/s12542-017-0385-1.
3. Koromyslova, A.V., Pakhnevich, A.V. X-ray micro-CT of the fossil ascophoran bryozoans *Beisselinopsis quincunx* from the museum collections. Abstr. Bruker Micro-CT Users Meeting, Ostend, Belgium, 235–240, 2014.
4. Koromyslova, A.V., Pakhnevich, A.V. New species of *Pachydermopora* Gordon, 2002 and *Beisselina* Canu, 1913 (Bryozoa: Cheilostomida) from a Campanian erratic block (Belarus) and their micro-CT investigation. Paleontological Journal 50 (1), 41–53, 2016. doi: 10.1134/S0031030116010044.
5. Martha, S.O., Ruthensteiner, B., Taylor, P.D., Hillmer, G. Description of a new cyclostome species from the middle Santonian of Germany using micro-computed tomography. Memoir of the Association of Australasian Palaeontologists, in press.
6. Matsuyama, K., Titschack, J., Baum, D., Freiwald, A. Two new species of erect Bryozoa (Gymnolaemata: Cheilostomata) and the application of non-destructive imaging methods for quantitative taxonomy. Zootaxa 4020 (1), 81–100, 2015. doi:10.11646/zootaxa.4020.1.3.

7. Schmidt, R. High resolution non-destructive imaging techniques for internal fine structure of bryozoan skeletons. In: Bryozoan Studies 2010, ed. A. Ernst, P. Schäfer, J. Scholz, 321–326. Berlin: Springer, 2013.
8. Viskova, L.A., Pakhnevich, A.V. A new boring bryozoan from the Middle Jurassic of the Moscow Region and its micro-CT research. Paleontological Journal 44 (2), 157–167, 2010. doi: 10.1134/S0031030110020073.
9. Voigt, E. Untersuchungen über *Coscinopleura* Marss. (Bryoz. foss.) und verwandte Gattungen. Mitteilungen aus dem Geologischen Staatsinstitut in Hamburg 25, 26–75, 1956.
10. Voigt, E. Верхнемеловые мшанки европейской части СССР и некоторых сопредельных областей [Upper Cretaceous bryozoans of the European part of the USSR and neighbouring territories]. Москва [Moskva]: Издательство Московского университета [Moscow University Press], 1962, 126 pp.
11. Wyse Jackson, P.N., McKinney, F.K. A micro-computed tomography and scanning electron microscopy investigation of the structure of *Polyfenestella* Bancroft, 1986 (Bryozoa: Fenestrata), from the Mississippian of Scotland: revealing the nature of its heteromorphs. Irish Journal of Earth Sciences 31, 1-6, 2013. doi:10.3318/IJES.2013.31.3