ISOS-14 Field Guide
The Ordovician of Estonia

Edited by Olle Hints and Ursula Toom

14th International Symposium on the Ordovician System, Estonia, July 19-21, 2023
Pre-conference Field Excursion: The Ordovician of Estonia, July 15-18, 2023

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Tallinn, 2023

Stop 6: Vasalemma quarry

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Location: Latitude 59.23337°N, longitude 24.33032°E; Harju County, NW Estonia.
Stratigraphy: Early Katian, Keila to Rakvere regional stages, Kahula and Vasalemma formations.
Status: Active quarry; please follow safety instructions. Sampling and fossil collecting are welcome!
More information: https://geoloogia.info/en/locality/12431

The Vasalemma quarry is an active quarry located c. 28 km south-west of Tallinn, near Keila, Harju County. The large quarry exposes in its northern part, mainly the Kahula Formation, and in its southern part, the Vasalemma Formation, Keila Regional Stage (Sandbian, Ordovician). Locally, the overlying strata of the Oandu and Rakvere regional stages (Katian, Ordovician) are exposed.

History

The echinoderm limestone of the Vasalemma Formation has been quarried for centuries and is known in the region as the "Vasalemma Marble". The limestone was described and named in a stratigraphical context by Eichwald (1854) and Schmidt (1881). The names "Hemicosmitenkalk" (Eichwald 1854) and "cystoid limestone" (Männil 1960) refer to the rock-building abundance of echinoderm intraclasts (mainly of the genus *Hemicosmites*, Rhombifera). Within the massive echinoderm limestone beds, echinoderm-bryozoan-receptaculitid reefs are abundant (Fig. 6.1). Together, the echinoderm grainstone and the reefs form the "Wasalemm'sche Schicht" of Schmidt (1881), which is synonymous with the Vasalemma Formation of subsequent authors (e.g., Männil and Rõõmusoks 1984; Hints and Miidel 2008).

In Schmidt's system, the Vasalemma Formation was designated as D3, the topmost layer of sequence D, and thus formed the stage above the "Kegel'sche Schicht" (Keila Regional Stage, D2). In a series of field guides, Linda Hints and colleagues (Hints 1990, 1996; Hints et al. 2004; Kröger et al. 2014b) published several drill core sections and outcrop details. A comprehensive review and reappraisal of the stratigraphy and sedimentology of the formation was published by Kröger et al. (Kröger et al. 2014b, 2014c). Today, the Vasalemma Formation is stratigraphically placed within the Keila Regional Stage, being of late Sandbian age (Meidla et al. 2023).

Stratigraphy

The Vasalemma Formation is a partly discontinuity-bounded unit. The lower and the upper boundaries are diachronous. From the combined drill core and outcrop data, it is known that in the southern part of the Vasalemma quarry, the base is marked by a prominent hardground on top of the Pääsküla Member, Kahula Formation (Kröger et al. 2014b, 2014c). In other places, the base is less than a few meters above this hardground, within the overlying Saue Member of the Kahula For-

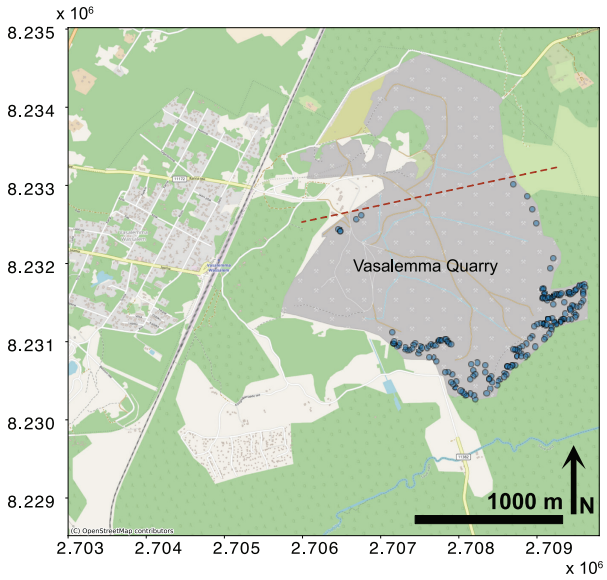

Fig. 6.1. Vasalemma quarry with mapped reef positions (blue dots) (westernmost corner of the quarry is unmapped). Red line indicates the maximum northward extension of the Vasalemma Formation, late Sandbian. Coordinate system: Web Mercator.

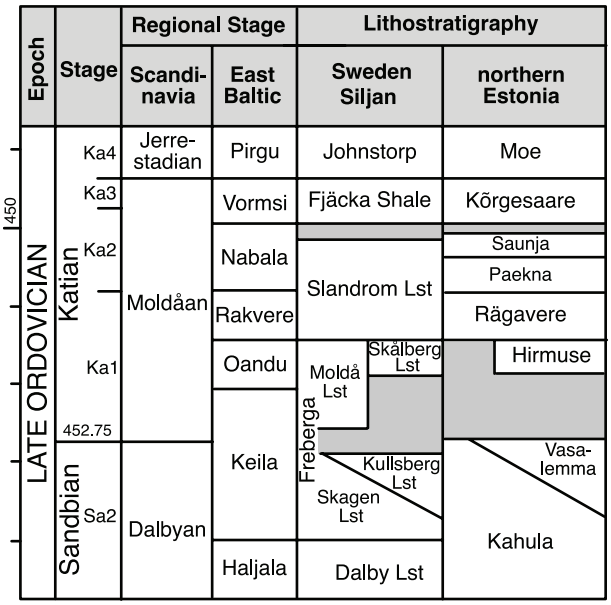

Fig. 6.2. Stratigraphic scheme of early Late Ordovician in northern Estonia compared with selected units from Scandinavia. Lithostratigraphic units are formations if not otherwise marked. Subdivisions in Stage column are Ordovician time slices (after Bergström et al. 2009). Compiled from Calner et al. (2010), Meidla et al. (2023), Nielsen et al. (2023). Lst, Limestone. Regio., Regional. Numbers give Million years ago. Grey fields are sedimentary hiati.

Fig. 6.3. A latest Sandbian reef body in the southern wall of the Vasalemma quarry, North Estonia. Photo: Olle Hints, 2023.

mation (Kröger et al. 2014a). Laterally the echinoderm limestone of the Vasalemma Formation grades into the skeletal wacke- to packstone lithologies of the Saue and Lehtmetsa members of the Kahula Formation. This gradual lateral change is exposed along the kilometre-long quarry wall of the Vasalemma quarry.

The top of the formation is formed by a distinct hardground surface on top of the reefs, which locally also represents an erosional surface, which cuts into the reefs and the echinoderm limestone. This upper surface is overlain by the argillaceous sediments of the Hirmuse Formation, Oandu Regional Stage, or locally by yellowish micritic limestone of the Rägavere Formation (Kröger et al. 2014a, 2014c).

The Vasalemma Formation is within the *Amorphognathus tvaerensis* conodont zone (Männik 2017). $\delta^{13}C_{carb}$ data from drill cores of the Vasalemma Formation record the rising limb of the upper Sandbian Guttenberg Isotopic Carbon Excursion (GICE; see e.g., Meidla et al. 2023) and a sharp drop of values at its upper discontinuity, indicating that the main interval of the GICE is younger than the formation (Fig. 6.2; Kröger et al. 2014a, 2014c).

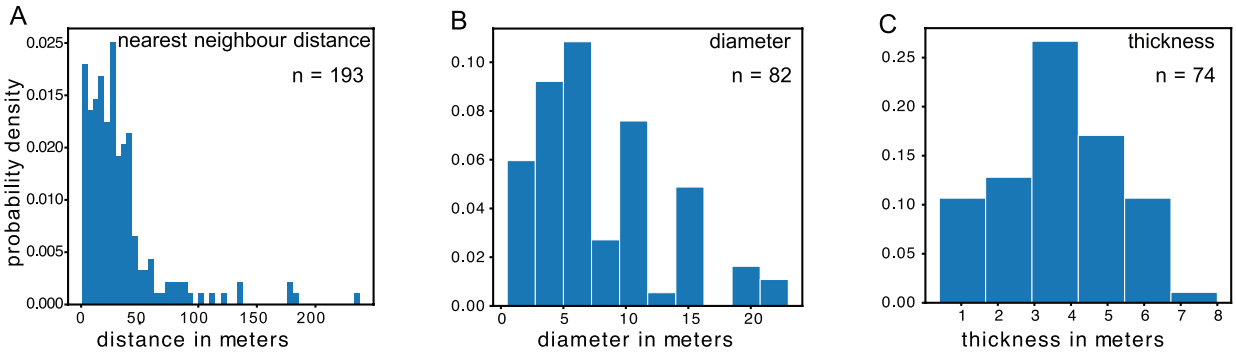

Fig. 6.4. Histograms of selected features of the reefs of the Vaselemma quarry, Vasalemma Formation, late Sandbian. **A** – Nearest neighbour distance; **B** – Reef diameter; **C** – Reef thickness.

Geological Setting and Sedimentology

The Vasalemma Formation occurs along c. 20 km E–W stretched belt with a N–S extension of c. 5 km. Toward the north, it is partly limited by an erosional front. The formation has a thickness of up to 15 m and consists mainly of a massive echinoderm grainstone with, in its central areas, concentrations of patch reefs. The echinoderm limestone is a massively bedded grainstone, almost completely composed of *Hemicosmites* ossicles held together by syntaxial cement (Fig. 6.5C). Ripple waves and crossbedding are widespread features within

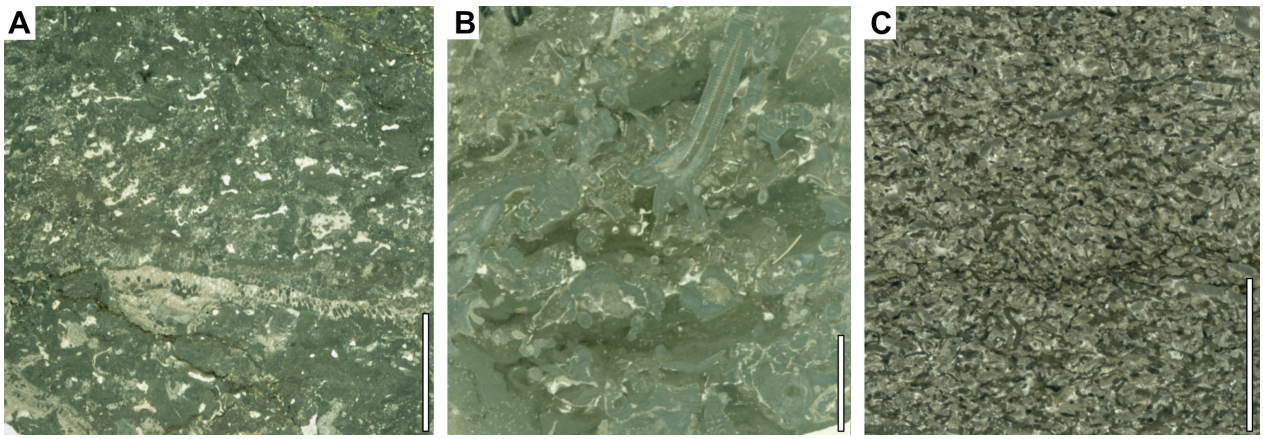

Fig. 6.5. Examples of microfacies of Vasalemma Formation, late Sandbian. **A** – Reef core limestone with encrusting bryozoan and clotted micrite as matrix; **B** – Reef core with abundant *Hemiscosmites* roots and clotted micrite as matrix; **C** – *Hemicosmites* grainstone with syntaxial cements. Note the abundance of sparitic fenestrae in A and B. Scale 10 mm.

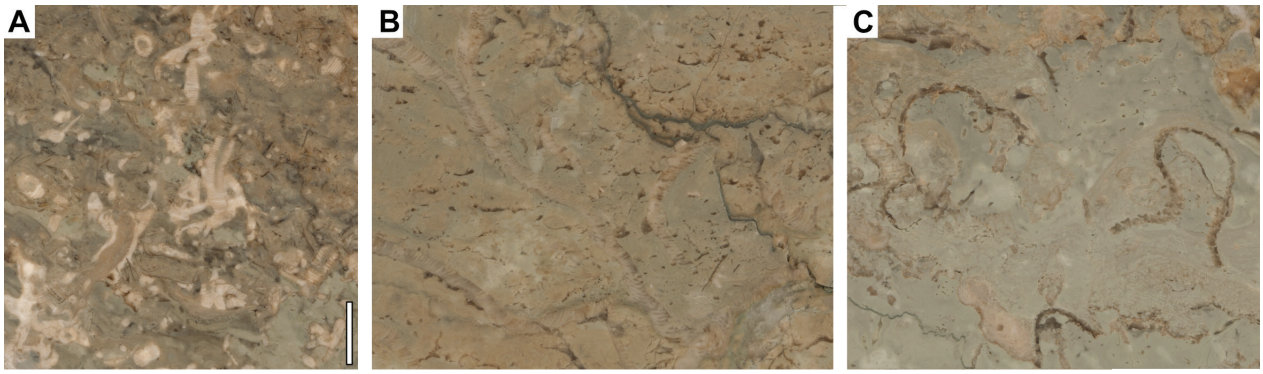

Fig. 6.6. Examples of polished slabs of reef core facies from Vasalemma quarry, Vasalemma Formation, late Sandbian; **A** – Area with abundant *Hemicosmites* roots; **B** – Area with abundant encrusting bryozoan colonies; **C** – Area with abundant receptaculitids. Scale 10 mm in A–C.

the echinoderm limestone. The reefs are up to c. 10 m thick and up to 50 m wide, and their cores are formed by a matrix-rich boundstone (50–80% matrix), with abundant echinoderms, bryozoans, and receptaculitids as main skeletal components and abundant fenestral fabric (Kröger et al. 2014a) (Fig. 6.5A–B, 6.6). Associated with the reef cores are commonly pockets, preserving locally restricted siliciclastic (marl, silt) and microbial limestone facies. In the north-eastern part of the quarry, the base of the formation forms the top hardground of the Pääskula Member, which here exposes a ripple surface and which is partly highly bioeroded with borings of *Trypanites*. The ripple-marks have a mean wavelength of c. 0.4 m and a NE/SW direction (Hints & Miidel 2008). The top of the Vasalemma Formation is formed by an iron (pyrite) impregnated and bioeroded hardground and erosional surface, which is locally covered by a conglomerate with highly rounded, pyrite-impregnated clasts from the Vasalemma Formation.

Sea level and paleoclimate

The top Vasalemma discontinuity reflects a major regional sea level drop (corresponding to the base of the depositional sequence VIII of Dronov et al. 2011, the Lower Wesenberg Sequence of Dronov 2017, and the Frognerkilen Lowstand Event of Nielsen 2011). This discontinuity and its associated facies and faunal change mark a massive change in the regional sedimentation regime and faunal composition during the late Keila to Rakvere time that has been termed Mid-Caradoc Event (Meidla et al. 1999) or Middle Caradoc Facies and Faunal Turnover (Ainsaar et al. 2004). The interval has been interpreted as related to climate change and associated changes in ocean circulation (Ainsaar et al. 2004). Oxygen isotope data suggest that the Mid-Caradoc Event (late Haljala – Keila stage) was an interval of global cooling that climaxed during the Frognerkilen Lowstand Event (Männik et al. 2021).

Fauna

The Vasalemma Formation contains extraordinarily rich and abundant fauna. Dozens of species of bryozoans were described from the Vasalemma Formation by Bassler (1911), Männil (1959), Modzalevskaya (1953),

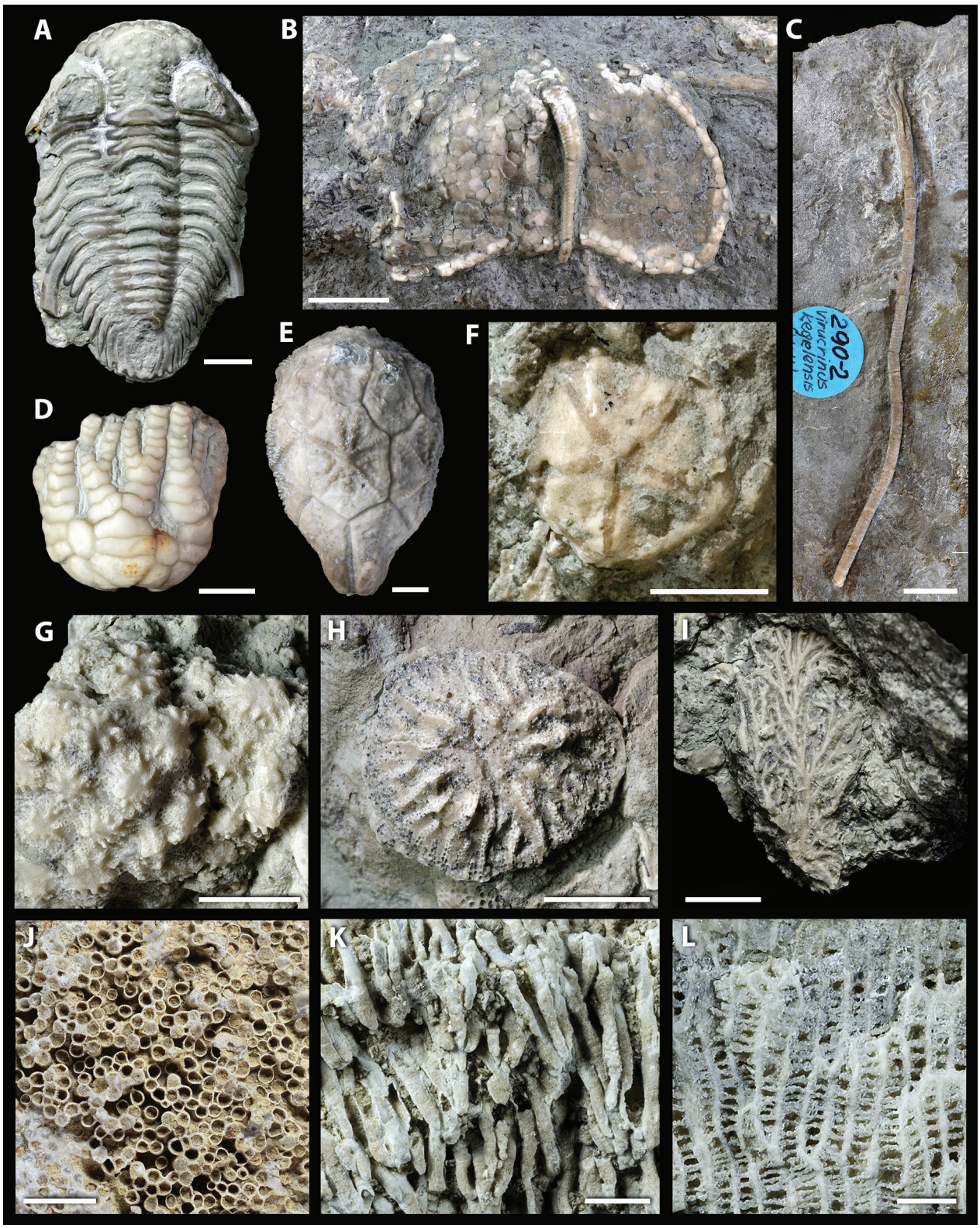

Fig. 6.7. Selected fossils from the Vasalemma quarry, Vasalemma Formation (Katian). Scale bars: A, D–H, L – 5 mm; B, C, I–K – 1 cm. **A** – trilobite *Atractopyge kutorgae*, TUG 1393-1. **B** – solutan echinoderm *Maennilia estonica*, GIT 609-1-1. **C**, **D** – crinoids; **C** – *Virucrinus kegelensis*, GIT 290-2; **D** – *Tintinnabulicrinus estoniensis*, GIT 653-3. **E** – blastozoans *Hemicosmites*, GIT 633-206. **F** – edrioasteroid *Cyathocystis rhizopora*, GIT 643-11-1. **G**, **I** – bryozoans; **G** – *Revalopora revalensis*, GIT 222-202; **H** – *Inconobotopora*, GIT 222-205; **I** – *Phylloporina*, GIT 222-204. **J**, **K**, **L** – tabulate corals; **J**, **K** – *Eoflecheria orvikui*, **J** – GIT 180-94, **K** – GIT 94-10; **L** – *Saffordophyllum tulaensis*, GIT 94-10.

Pushkin (1990) and Gorjunova & Lavrentjeva (1993). A thorough revision of the bryozoan fauna is still needed. The echinoderm fauna is strongly dominated by *Hemicosmites*, but locally edrioasteroids (*Cyathocystis*, Rozhnov 2004), rare solutans (Rozhnov & Jeffries 1996), asteroids (Blake & Rozhnov 2007) and crinoids (Ausich et al. 2015; Rozhnov 1990, 2012; Wright & Toom 2019) are worth mentioning. The reefs of the Vasalemma Formation contain rugose corals, such as *Lambelasma carinatum* which are among the oldest of the region.

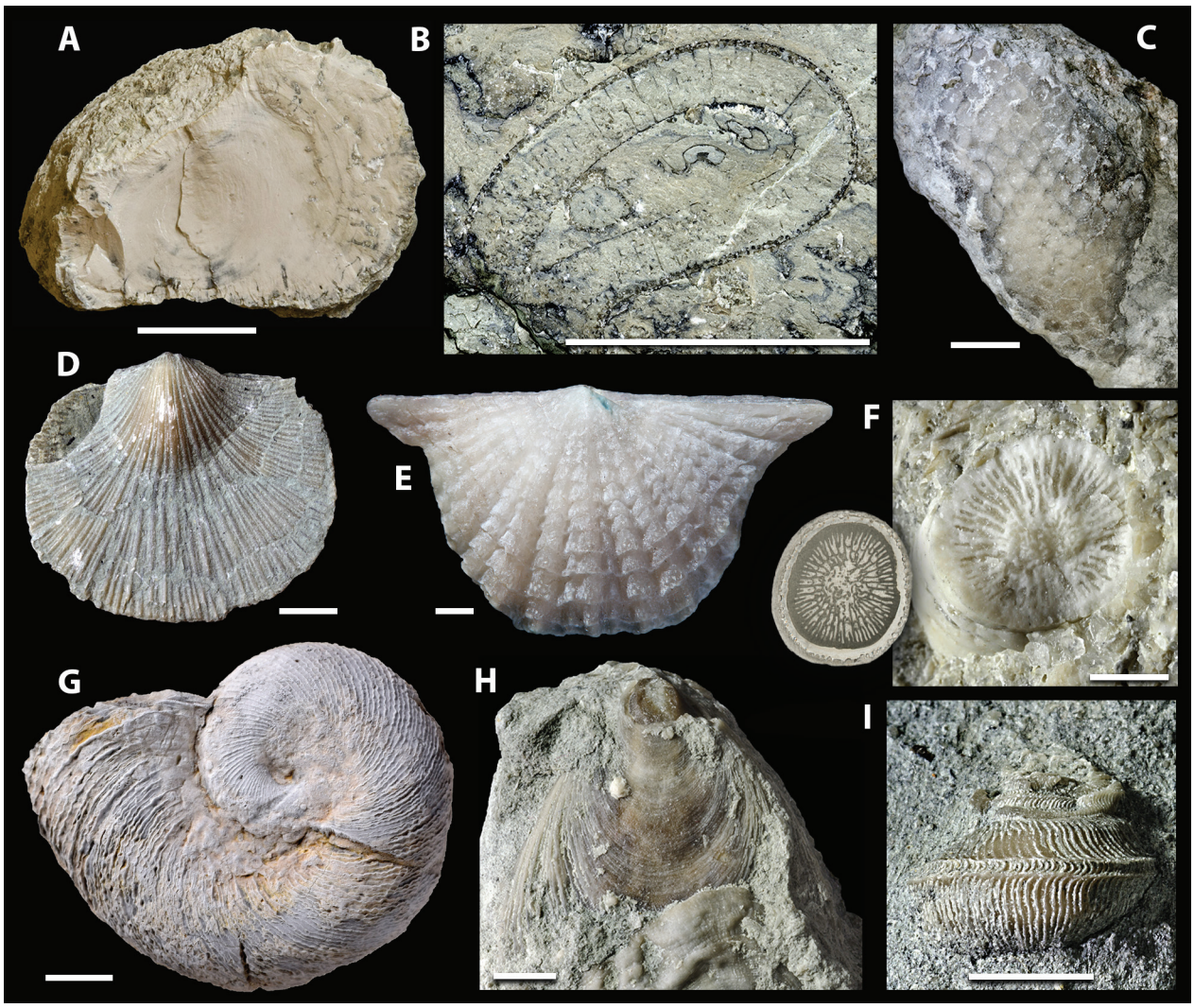

Fig. 6.8. Selected fossils from the Vasalemma quarry, Vasalemma Formation (Katian). Scale bars: A–D, F–J – 5 mm, E – 1 mm. **A** – *Solenopora*, GIT 339-1043. **B,C** – retceptaculitid *Receptaculites poelmi*; B – GIT 413-166, C – GIT 413-163. **D**, **E** – Brachiopods; D – *Horderleyella kegelensis*, GIT 207-2021; **E** – *Bassetella alata*, GIT 595-1. **F** – rugose coral *Lambelasma carinatum*, TUG 1393-7. **G** – cephalopod *Discoceras vasalemmense*, TUG 939-76. **H** – monoplacophorian *Pilina*, GIT 222-122-1. **I** – gastropod *Brachytomaria baltica*, GIT 222-114.

Receptaculites poelmi from the Vasalemma Formation has been described by Miagkova (1981). The chaetetid sponge *Solenopora* is locally common within the reefs. Bryozoans, echinoderms, receptaculitids and *Solenopora* form complex, partly densely intergrown assemblages (Vinn et al. 2018). Locally, the uppermost sections of the reefs contain large colonies of tabulate corals *Eofletcheria orvikui*, *Saffordophyllum tualensis* and *S. grande* (Klaamann 1975); also crusts of stromatoporoids such as *Cystistroma sakuaense* occur. The reefs contain a rich macrofauna with monoplacophorans (*Pilinia* sp.) and gastropods (*Brachytomaria baltica* and *Cyclonema lineatum*). The trilobites of the Vasalemma Formation are not systematically studied yet but the most common representatives include *Asaphus, Chasmops, Stenopareia* and *Toxochasmops*. A rich cephalopod fauna has been described by Kröger & Aubrechtová (2017). Cephalopods, trilobites and echinoderms occur frequently as concentrations in pockets associated with the reefs. Dense cornulitid infestations of the reef and echinoderm-limestone on the capping hardground surface are remarkable (Vinn & Toom 2015). In addition, the Hirmuse Formation contains a rich association of cornulitids and other calcareous tubicolous organisms (Vinn et al. 2023). Brachiopods *Estlandia pyron silicificata, Bassettella alata, Saukrodictya, Horderleyella kegelensis,* and *Apatorthis* sp. occur mainly in the argillaceous interlayers of the lower half of the Vasalemma Formation. Additionally, two forms of noncalcified algae have been discovered from dolomitic mudstone layers associated with the reefs.

References

Ainsaar, L., Meidla, T. & Martma, T. 2004. The Middle Caradoc Facies and Faunal Turnover in the Late Ordovician Baltoscandian palaeobasin. Palaeogeography, Palaeoclimatology, Palaeoecology, 210, 119–133.

Ausich, W. I., Rozhnov, S. V. & Kammer, T. W. 2015. Iocrinid crinoids from the Ordovician of the Baltic Region, Estonia. Paleontological Journal, 49, 145–152.

Bassler, R. S. 1911. The Early Paleozoic Bryozoa of the Baltic

Provinces Bulletin of the Smithsonian Institution, United States National Museum, 77, 1–382.
Bergström, S. M., Chen, X., Gutiérrez-Marco, J. C. & Dronov, A., 2009. The new chronostratigraphic classification of the Ordovician System and its relations to major regional series and stages and to δ13C chemostratigraphy. Lethaia, 42, 97–107.
Blake, D. B. & Rozhnov, S. 2007. Aspects of life mode among Ordovician asteroids: Implications of new specimen from Baltica. Acta Palaeontologica Polonica, 52, 519–533.
Calner, M., Lehnert, O. & Nõlvak, J., 2010. Paleokarst evidence for widespread regression and subaerial exposure in the middle Katian (Upper Ordovician) of Baltoscandia: Significance for global climate. Palaeogeography, Palaeoclimatology, Palaeoecology, 296, 235–247.
Dronov, A., 2017. Ordovician Sequence Stratigraphy of the Siberian and Russian Platforms. In Advances in Sequence Stratigraphgy. Special Issue: Stratigraphy & Timescale, Vol. 2 (Montenari, M., ed.), Elsevier, Oxford, 187–241.
Dronov, A., Ainsaar, L., Kaljo, D., Meidla, T., Saadre, T. & Einasto, R. 2011. Ordovician of Baltoscandia: facies, sequences and sea level changes. In Ordovician of the World: 11th International Symposium on the Ordovician System (Gutierrez-Marco, J. C., Rabano, I. & Garcia-Bellido, D. eds.) Cuadernos del Museo Geominero, 14, 143–150.
Eichwald, E. 1854. Die Grauwackenschichten von Liev- und Ehstland. Bulletin de la Societe Imperiale des Naturalistes de Moscou, 27, 1–111.
Gorjunova, R. V. & Lavrentjeva, V. D. 1993. Morphology and system of the cryptostome bryozoans. Trudy Paleontologicheskogo Instituta Akademii Nauk SSSR, 257, 1–151.
Hints, L. & Miidel, A. 2008. Ripple marks as indicators of Late Ordovician sedimentary environments in Northwest Estonia. Estonian Journal of Earth Sciences, 57, 11–22.
Hints, L., 1990. Locality 2:2. Vasalemma quarry. In Field Meeting Estonia 1990. An Excursion Guidebook (Kaljo, D. & Nestor, H., eds.), Estonian Academy of Sciences, Tallinn, 131–133.
Hints, L., 1996. Vasalemma quarry. In The Third Baltic Stratigraphical Conference. Abstracts. Field Guide (Meidla, T., Puura, I., Nemliher, J., Raukas, A. & Saarse, L., eds), Tartu University Press, Tartu, 93–96.
Hints, L., Männik, P. and Pärnaste, H., 2004. Stop 3. Vasalemma quarry. In WOGOGOB-2004. Conference Materials. Abstracts and Field Guidebook (Hints, O. & Ainsaar, L., eds.), Tartu University Press, Tartu, 121–124.
Klaamann, E. R. 1975. Zur Taxonomie einiger mittelordovizischer Tabulatenarten Norwegens, Schwedens und Estlands. Proceedings of the Academy of Sciences of the Estonian SSR. Chemistry and Geology, 24, 219–226.
Kröger, B. and Aubrechtová, M., 2018. Cephalopods from reef limestone of the Vasalemma Formation, northern Estonia (latest Sandbian, Upper Ordovician) and the establishment of a local warm-water fauna. Journal of Systematic Palaeontology, 16, 799–839.
Kröger, B., Hints, L. & Lehnert, O. 2014a. Age, facies, and geometry of the Sandbian/Katian (Upper Ordovician) pelmatozoan-bryozoan-receptaculitid reefs of the Vasalemma Formation, northern Estonia. Facies, 60, 963–986.
Kröger, B., Hints, L. & Lehnert, O. 2014b. Stop A2: Vasalemma (Nordkalk) quarry. In 4th Annual Meeting of IGCP 591, Estonia, 10-19 June 2014. Abstracts and Field Guide (Bauert, H., Hints, O., Meidla, T. & Männik, P. eds.). Tartu, University of Tartu, 138–144.
Kröger, B., Hints, L., Lehnert, O., Männik, P. & Joachimski, M. 2014c. The early Katian (Late Ordovician) reefs near Saku, northern Estonia and the age of the Saku Member, Vasalemma Formation. Estonian Journal of Earth Sciences, 63, 271–276.
Männik, P. 2017. Conodont biostratigraphy of the Oandu Stage (Katian, Upper Ordovician) in NE Estonia. Estonian Journal of Earth Sciences, 66, 1–12.
Männik, P., Lehnert, O., Nõlvak, J. & Joachimski, M. M. 2021. Climate changes in the pre-Hirnantian Late Ordovician based on δ18Ophos studies from Estonia. Palaeogeography, Palaeoclimatology, Palaeoecology, 569, 110347.
Männil, R. M. 1959. Questions of stratigraphy and bryozoans of the Ordovician of Estonia. Unpublished Ph.D. dissertation. Tallinn, Institut Geologii Akademii Nauk Estonskoi SSR.
Männil, R. M. & Rõõmusoks, A. 1984. Revisija litostratigraficheskoi schemi raschlenija ordovika Severnoi Estonii. In Stratigraphy of the Early Paleozoic sediments of the Baltic (Männil, R. M. & Mens, K. A. eds.). Tallinn, ENSV TA Geoloogia Instituut, pp 52–62.
Meidla, T., Ainsaar, L., Hints, L., Hints, O., Martma, T. & Nõlvak, J. 1999. The mid-Caradocian biotic and isotopic event in the Ordovician of the East Baltic. Acta Universitatis Carolinae Geologica, 43, 503–506.
Meidla, T., Ainsaar, L., Hints, O., Radzevičius, S. 2023. Ordovician of the Eastern Baltic palaeobasin and the Tornquist Sea margin of Baltica. Geological Society, London, Special Publications, 532, 317–343.
Miagkova, E. I. 1981. *Receptaculites poelmi* Miagkova sp nov. Transactions of the Institute of Geology and Geophysics, 481, 38–40.
Modzalevskaya, E. A. 1953. Trepostomata of the Ordovician of East Baltic and their stratigraphic significance. Trudy VNIGRI, 78, 91–167.
Nielsen, A. T. 2011. A re-calibrated revised sea-level curve for the Ordovician of Baltoscandia. Ordovician of the World: 11th International Symposium on the Ordovician System. Cuadernos del Museo Geominero, 14, 399–402.
Nielsen, A. T., Ahlberg, P., Ebbestad, J. O. R., Hammer, Ø., Harper, D. A. T., Lindskog, A., Rasmussen, C. M. Ø., Stouge, S., 2023. The Ordovician of Scandinavia: a revised regional stage classification. Geological Society, London, Special Publications, 532, 267–315.
Pushkin, V. I. 1990. Bryozoa of the family Ceramoporidae of Ordovician from the eastern European platform. In New representatives of the fossil fauna and flora of Belorussia and other regions of the USSR: collected scientific papers, 5–34. Minsk, Nauka i Tekhnika.
Rozhnov, S. 1990. Morphology and systematic position of Middle Ordovician *Virucrinus* Rozhnov gen. nov. (Crinoidea, Inadunata, Disparida) from North Estonia. Proceedings of the Estonian Academy of Sciences. Geology, 39, 68–75.
Rozhnov, S. V. & Jefferies, R. P. S. 1996. A new stem-chordate solute from the Middle Ordovician of Estonia. Geobios, 29, 91–109.
Rozhnov, S. V. 2004. Echinoderms of the bioherms of the Baltic Ordovician basin: comparison of the coldwater (Volkhovian) and tropical (Keila) communities. In WOGOGOB 2004, Conference materials Abstracts and Field Guidebook. Tartu, Tartu Univeristy Press, 86–87.
Rozhnov, S. V. 2012. Reinterpretation of Baltic Ordovician *Heckerites multistellatus* Rozhnov, 1987 as a possible paracrinoid based on new material. Zoosymposia, 7, 307–316.
Schmidt, F. 1881. Revision der ostabaltischen silurischen Trilobiten nebst geognostischer Übersicht des ostbaltischen Silurgebiets. Abt. I. Phacopiden, Cheiruriden und Encriniuriden. Memoires de L'Academie Imperiale des Sciences de St. Petersburg 7, 1–238.
Vinn, O. & Toom, U. 2015. Some encrusted hardgrounds from the Ordovician of Estonia (Baltica). Carnets de Geologie-Notebooks on Geology, 15, 63–70.
Vinn, O., Madison, A., Wilson, M. A. & Toom, U. 2023. Cornulitid tubeworms and other calcareous tubicolous organisms from the Hirmuse Formation (Katian, Upper Ordovician) of northern Estonia. Journal of Paleontology, 97, 38–46.
Vinn, O., Toom, U. & Ernst, A. 2018. Intergrowth of *Orbignyella germana* Bassler, 1911 (Bryozoa) and *Lambelasma carinatum* Weyer, 1993 (Rugosa) in the pelmatozoan-bryozoan-receptaculitid reefs from the Late Ordovician of Estonia. Palaeontologia Electronica, 21, 1–7.
Wright, D. F. & Toom, U. 2017. New crinoids from the Baltic region (Estonia): Fossil tip-dating phylogenetics constrains the origin and Ordovician–Silurian diversification of the Flexibilia (Echinodermata). Palaeontology, 60, 893–910.