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

Excursion Day 1

Stop 1: Pakerort cliff, Pakri Peninsula

Olle Hints

Location: Latitude 59.37747°N, longitude 24.03648°E; Harju County, NW Estonia.
Stratigraphy: From Cambrian Series 2 to Darriwilian, Pakerort to Uhaku regional stages.
Status: Cliff is under nature protection; no hammering, but loose material may be collected.
More information: https://geoloogia.info/en/locality/13546

Coastal cliffs on the Pakri Peninsula, ca 50 km west of Tallinn, provide the best exposures of Cambrian to Middle Ordovician rocks in NW Estonia. These cliffs are part of the Baltic Klint – a nearly 1200 km long escarpment that runs from Öland (Sweden) through the Baltic Sea and North Estonia to NW Russia (see also Stop 10 below). The sections on the Pakri Peninsula and the nearby Pakri islands have been well-known since the 1840s, nowadays regularly visited by geology students and geological field excursions (Hints 2014). The up-to-24-m-high Pakerort cliff is also an important geotourism site in Estonia.

The western coast of the Pakri Peninsula constitutes a nearly continuous outcrop subdivided into the Paldiski, Uuga and Pakerort cliffs (Fig. 1.1). This is one of the few places in Estonia where the gentle southward dip of bedrocks (ca 3–4 m per km) can be directly observed. The Pakerort cliff in the north is the etymon for the Pakerort Regional Stage and provides an opportunity to study the lower Cambrian (Series 2) to Tremadocian strata. The Floian to Darriwilian succession is best accessed at the Uuga cliff, close to the Paldiski Northern Port (see Stop 2 below).

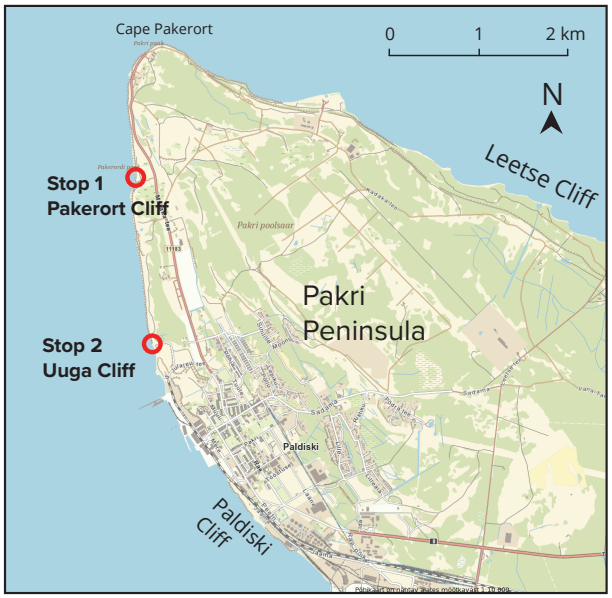

Fig. 1.1. Locality map of cliff sections on Pakri Peninsula, NW Estonia (from Hints 2014). The Pakerort Regional Stage is named after Cape Pakerort.

Fig. 1.2. Tremadocian to Darriwilian succession of the 24-m-high Pakerort Cliff, Cape Pakri in distance. Photo: Olle Hints, 2015.

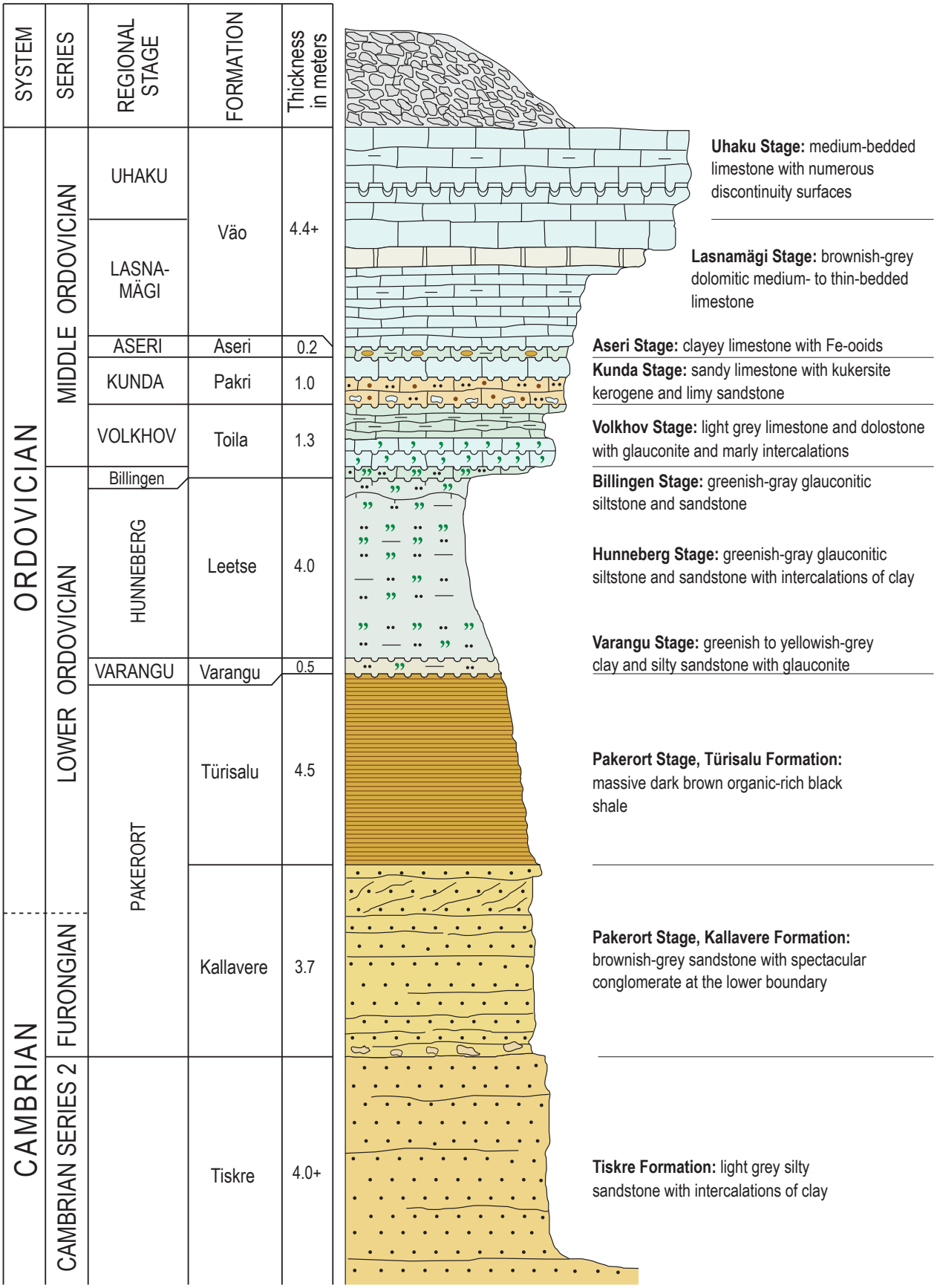

Fig. 1.3. Composite section of the cliffs on Pakri Peninsula, NW Estonia. After Mens and Puura (1996).

The composite section on the Pakri Peninsula (Fig. 1.2, 1.3) is characterised below, based on the descriptions and data by Mens et al. (1996, 1999), Nemliher and Puura (1996), Hints et al. (2014), Löfgren et al. (2005), Põldsaar and Ainsaar (2014), Tammekänd et al. (2010), Einasto and Rähni (2005), Mens and Puura (1996), Orviku (1940).

Fig. 1.4. Basal conglomerate on the boundary of the Cambrian Series 2 Tiskre Formation and the Furongian-Lower Ordovician Kallavere Formation. Photo: Olle Hints, 2020.

Fig. 1.5. The Cambrian-Ordovician boundary on Pakri Peninsula can be approximated with the base of the Suurjõgi Member within the Kallavere Formation indicated by the right hand of the student. Photo: Olle Hints, 2019.

Fig. 1.6. The topmost part of the Kallavere Formation just below the black shale is strongly pyritised ("Pyrite layer") and sometimes preserves ripple marks. Photo: Rutt Hints, 2015.

(1) The **Tiskre Formation** (4+ m, lower Cambrian) is composed of light grey sandy siltstones with interbeds of shaly siltstones and clays. Based on drill core data, the entire thickness of the formation reaches ca 18 m. Ripple marks are common in the upper part of the formation (Mens et al. 1996).

(2) The **Kallavere Formation** (ca 3.7 m, Furongian to Tremadocian) is represented by yellowish fine- to medium-grained sandstones with interbeds of dark brown kerogenous shale in the lower part. The contact with the underlying Tiskre Formation is sharp, marked by a conspicuous basal conglomerate (Fig. 1.4). This conglomerate comprises (1) loose cobbles and boulders of the Tiskre Formation, up to ca 40 cm in diameter and (2) dark-coloured flat pebbles and cobbles cemented with pyrite, apatite and carbonates (Nemliher and Puura 1996). The upper part of the Kallavere Formation (Suurjõgi Member) is represented by cross-bedded sandstones and a strongly pyritised sandstone layer on the top, sometimes with ripple marks (Fig. 1.6). The formation contains scattered debris of lingulate brachiopods, mostly belonging to the genus *Ungula* (Nemliher and Puura 1996).

Conodont and acritarch evidence suggest that the basal conglomerate formed slightly before or during the *Cordylodus proavus* time (Mens et al. 1996, 1999). Thus, the base of the Pakerort Stage, drawn at the appearance of *Cordylodus andresi* in Estonia (see Puura and Viira 1999), coincides with the base of the Kallavere Formation in the Pakerort section. The base of the Ordovician System cannot be precisely correlated on the Pakri Peninsula, but unpublished finds of conodonts and the age of the Suurjõgi Member elsewhere in Estonia allow us to approximate it with the base of the cross-bedded sandstones of the Suurjõgi Member (Fig. 1.5).

(3) The **Türisalu Formation** (4.5 m, Pakerort Regional Stage, Tremadocian) consists of homogenous dark brown kerogenous shale (commonly referred to as graptolite argillite, previously known as the "Dictyonema Shale") containing graptolites *Rhabdinopora flabelliformis flabelliformis* and *Rhabdinopora flabelliformis* cf. *norvegica* in Pakri sections (Mens et al. 1996). The formation is characterised by a high content of organic matter (10–20%), authigenic K-feldspar, pyrite and redox-sensitive trace elements, such as V, U and Mo. Based on microfabrics studies (Hints et al. 2014 and references therein), it has been suggested that dynamic sedimentation events, rather than slow net sedimentation, may have been the dominant mechanism behind the accumulation of these beds. Storm-related near-bottom flows and the bed-load transport of mud particles were likely common distribution

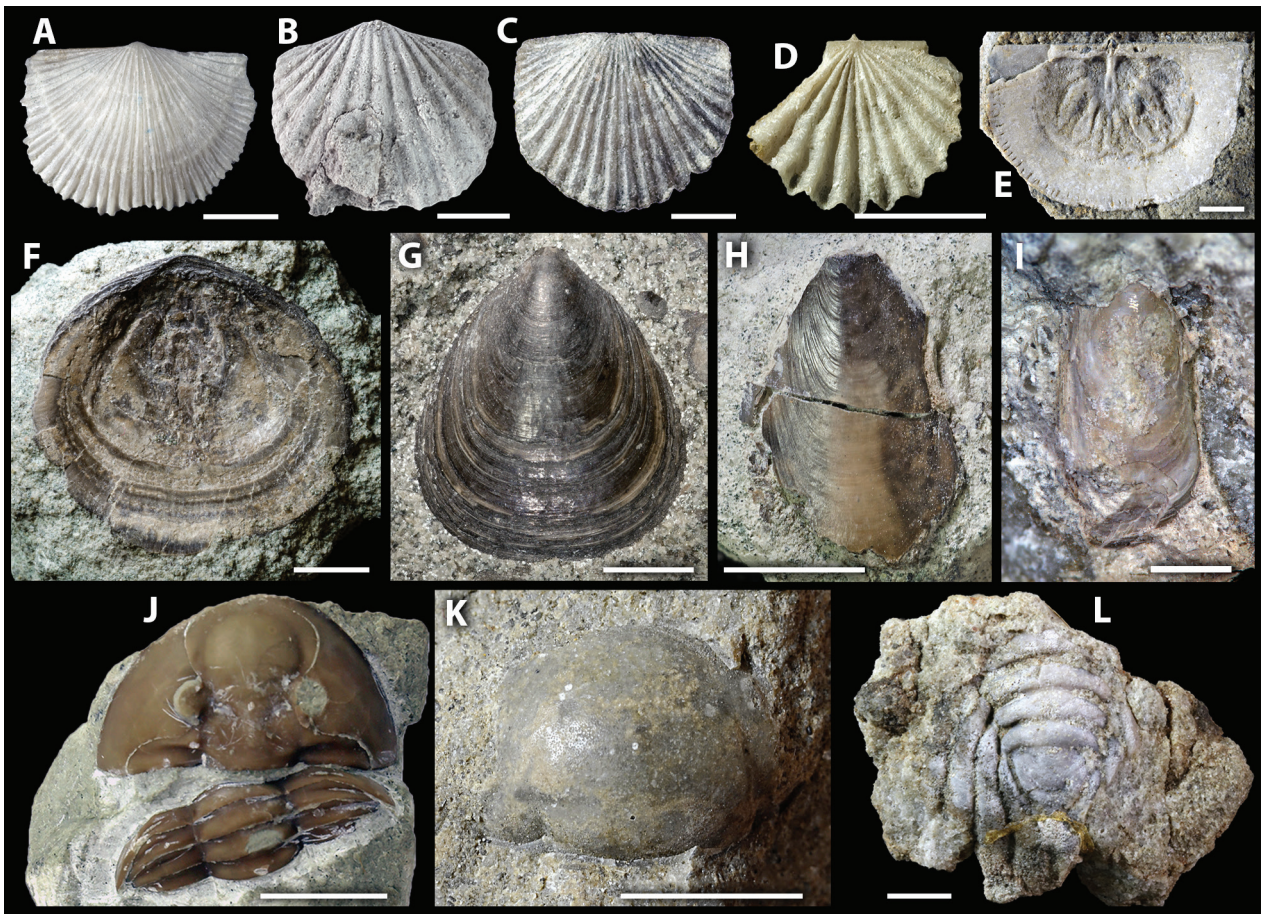

Fig. 1.7. Selected fossils from the Pakri Peninsula and Pakri islands. Scale bars: J – 1 cm; A–H, K, L – 5 mm; I – 1 mm. **A–I** – brachiopods; **A** – *Panderina pakriensis*, Väike-Pakri Cliff, Toila Formation (Dapingian), GIT 125-47; **B** – *Rogorthis pakriensis*, Väike-Pakri Cliff, Pakri Formation (Darriwilian), GIT 125-102; **C** – *Orthambonites fundata*, Paldiski, Pakri Formation (Darriwilian), GIT 125-89; **D** – *Nicolella pterygoidea*, Pakri, Pakri Formation (Darriwilian), GIT 125-174; **E** – *Ingria pakriana*, Väike-Pakri Cliff, Pakri Formation (Darriwilian), GIT 675-29; **F** – *Thysanotos siluricus*, Paldiski, Leetse Formation; GIT 275-86; **G** – *Leptembolon lingulaeformis*, Leetse, Leetse Formation; GIT 275-63; **H** – "*Lingulella*" *nitida*, Paldiski, Leetse Formation; GIT 275-70; **I** – lingulid *Rowellella* inside *Trypanites sozialis* boring, Uuga Cliff, Väo Formation (Darriwilian); TUG 1393-186. **J–L** – trilobites; **J** – *Paraptychopyge pahleni,* Väike-Pakri Cliff, Toila Formation (Dapingian), TUG 1355-410; **K** – *Panderia,* Väike-Pakri Cliff, Pakri Formation (Darriwilian), GIT 437-417; **L** – *Pliomera fisheri*, Väike-Pakri Cliff, Pakri Formation (Darriwilian), GIT 435-23.

agents of organic-rich mud, which can be viewed as a near-shore tongue of the Scandinavian Alum Shale complex.

(4) The **Varangu Formation** (0.5 m, Varangu Regional Stage, Tremadocian) is represented by greenish-grey to beige clay and silty sandstone with glauconite. It contains the zonal conodont *Paltodus deltifer deltifer* (Löfgren et al. 2005).

(5) The **Leetse Formation** (ca 3.9 m, Hunneberg and Billingen regional stages, Tremadocian to Floian) is composed of greenish-grey weakly lithified glauconitic sandstone (20–40% glauconite grains). The type locality of the formation is the Leetse cliff on the eastern coast of the Pakri Peninsula. The Leetse Formation corresponds to the *Paroistodus proteus* conodont Zone, and the base of the Floian Global Stage is identified within the lower third of this unit on the Pakri Peninsula (Löfgren et al. 2005). The upper ca 20 cm of the formation is distinguished as the Mäeküla Member, which becomes calcareous and corresponds to the *Oepikodus evae* conodont Zone. The *Prioniodus elegans* Zone seems to fall into a gap in this area (Löfgren et al. 2005). The transition to the overlying Toila Formation is gradual, characterised by increasing carbonate content.

(6) The **Toila Formation** (ca 1.3 m, Billingen and Volkhov regional stages, Floian to Dapingian) is represented by grey glauconitic limestones (packstones and wackestones). The lower ca 10 cm of the formation (Päite Member) corresponds to the *Oepikodus evae* conodont Zone (Löfgren et al. 2005) and is overlain by a distinct and geographically widespread discontinuity surface (hardground), informally known as the "Püstakkiht" in Estonia (Fig. 2.2). This surface indicates a regional hiatus. It is taken as the base of the Volkhov Regional Stage in northern Estonia and correlated with the base of the Dapingian. Conodonts of the Volkhov Regional Stage are insufficiently known on the Pakri Peninsula, but the top of the formation seems to fall into the *Paroistodus originalis* Zone (Hints et al. 2012). This suggests that the upper part of the Volkov Stage corresponds to a gap in NW Estonia.

(7) The **Pakri Formation** (ca 1.0 m, Kunda Regional

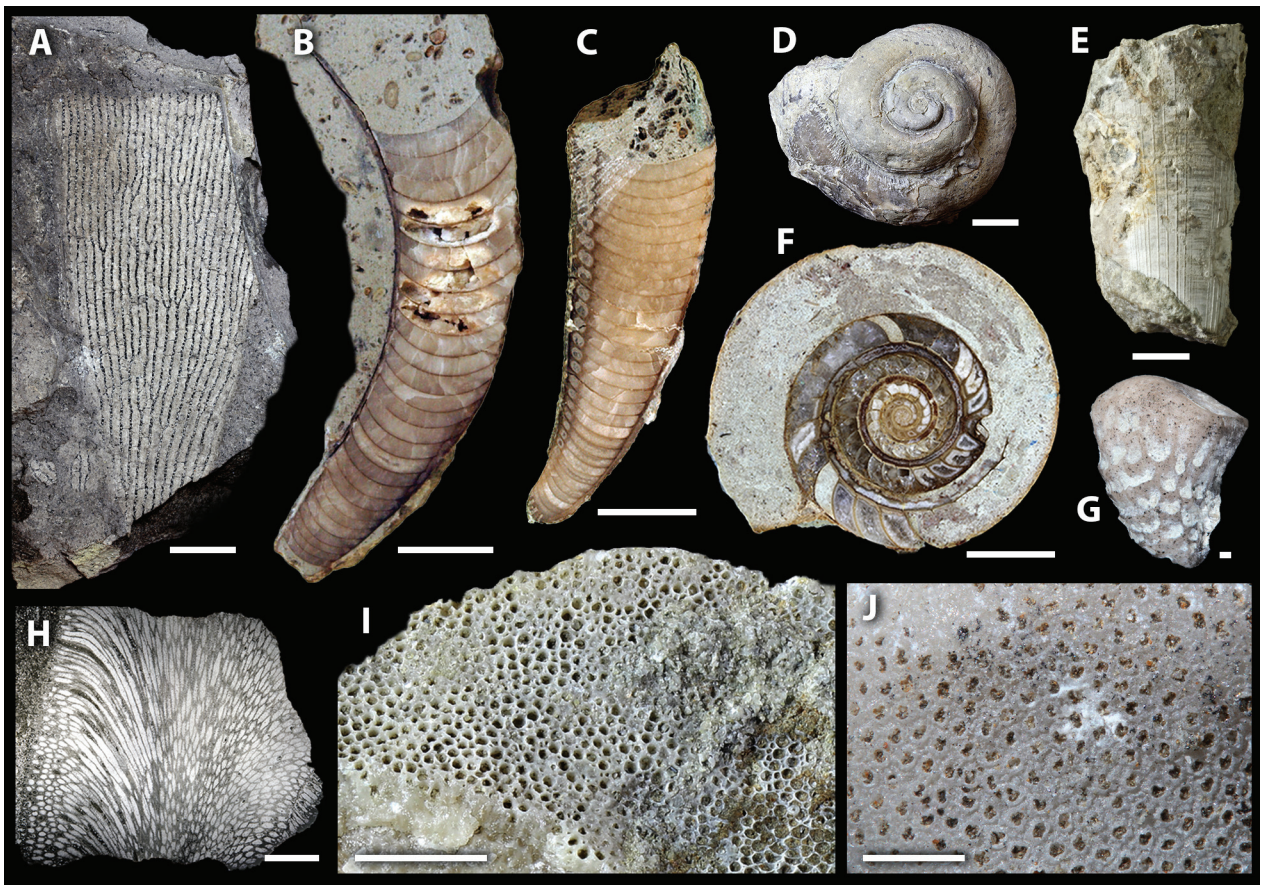

Fig. 1.8. Selected fossils from the Pakri Peninsula and Pakri islands. Scale bars: A, F–D – 1 cm; B–E, H, I – 5 mm; G, J – 1 mm. **A** – graptolite *Rhabdinopora flabelliformis flabelliformis*, Pakri, Türisalu Formation (Tremadocian), GIT 398-1034. **B**, **C**, **F** – cephalopods; ***B*** – *Richardsonoceras goldmanni,* Uuga Cliff, Kandle Formation (Darriwilian), TUG 1285-51; ***C*** – *Paldoceras paldiskense*, Uuga Cliff, Kandle Formation (Darriwilian), TUG 1285-10; **F** – *Trocholites depressus*, Väike-Pakri Cliff, Väo Formation (Darriwilian), GIT 145-1. **D** – gastropod *Proturritella cingulata*, Paldiski, Pakri Formation (Darriwilian), GIT 404-400. **E** – hyolith *Hyolithes gerhardi*, Paldiski, Väo-Kõrgekallas formations (Darriwilian), GIT 387-2. **G** – eocrinoid *Bolboporites* (*Bolboporites*) *uncinatus*, Pakri, Pakri Formation (Darriwilian), GIT 468-76. **H–J** – bryozoans; **H–I** – *Dianulites pakriensis*, Väike-Pakri Cliff, Pakri Formation (Darriwilian), GIT 537-1294; **J** – *Pakripora cavernosa*, Väike-Pakri Cliff, Pakri Formation (Darriwilian), GIT 537-1227-1.

Stage, Darriwilian) is composed of sandy limestone to limy sandstone (up to ca 80% quartzose sand according to Põldsaar and Ainsaar 2014). These sediments are spread in a limited area in NW Estonia, probably representing one of the few remains of a near-shore facies in the Ordovician Baltoscandian Basin. The unit contains numerous soft-sediment deformation structures (such as load casts, flame structures, ball-and-pillow morphologies, sedimentary dykes, autoclastic breccias, and sand volcanoes) that indicate large-scale liquefaction and fluidisation of the unconsolidated and water-saturated sediments, probably by a large earthquake (Põldsaar and Ainsaar 2014). The coincidence of a deformation event and the Middle Ordovician meteoritic bombardment period, and the occurrence of shock metamorphic features and extraterrestrial chromite in the Pakri Formation suggest that a meteorite impact might have caused such an earthquake (Alwmark et al. 2010). The basal part of the Kunda Stage corresponds to a gap in NW Estonia, and thus the base of the Darriwilian coincides with the Volkhov–Kunda stage boundary on the Pakri Peninsula. The upper part of the formation corresponds to the *Eoplacognathus pseudoplanus* conodont Zone and the *Cyathochitina regnelli* chitinozoan Zone. The Pakri Formation also contains several strong pyritic discontinuity surfaces, the oldest kukersite kerogen in the region and is rich in shelly faunas.

(8) The **Kandle Formation** (ca 0.1 m, =Aseri Formation in some previous publications; Aseri/Lasnamägi regional stages, Darriwilian) is composed of argillaceous limestone with brown or white ooids. In the Uuga cliff, this unit contains the zonal conodont *Yangtzeplacognathus foliaceus*, which is considered to indicate the lower Lasnamägi age. If this is true, the Aseri Regional Stage may be entirely missing in some parts of the Pakri Peninsula and other places in NW Estonia (Hints et al. 2012).

(9) The **Väo Formation** (ca 5.1 m, Lasnamägi and Uhaku regional stages, Darriwilian) is represented by grey thin- to medium-bedded limestones (wacke- to packstones), a discrete layer of dolostone (Pae Member) and numerous phosphatic and pyritic discontinuity surfaces. The dolomitic Pae Member is characterised by a positive magnetic susceptibility anomaly likely because of fluid migration, which produced secondary iron input and/or rearrangement of existing iron and precipitation of ferroan dolomite crystals (Plado et al. 2016). The age of the Väo Formation and individual members are well-con-

strained by conodont and chitinozoan biostratigraphy, the most useful being subzones of the *Pygodus serra* conodont Zone. The base of the Uhaku Regional Stage is drawn at the appearance of *Gymnograptus linnarssoni*, but as only a single find of this species comes from the Uuga cliff, the appearance of the conodont *Baltoplacognathus robustus* provides a more helpful level (Hints et al. 2012). The upper part of the Väo Formation, starting from the Pae Member, constitutes the so-called Building Limestone, which is widely quarried and utilised all over northern Estonia. Many of the individual layers are specifically named by local quarrymen, and some of these layers can be recognised over hundreds of kilometres (Einasto and Rähni 2005).

(10) The **Kõrgekallas Formation** (1.0+ m, Uhaku Regional Stage, Darriwilian) is composed of grey limestones, which are relatively more argillaceous than the underlying Väo Formation. The boundary between the formations is marked by six distinct successive discontinuity surfaces.

Younger rocks belonging to the Kukurse and Haljala regional stages, basal Sandbian, are distributed (but not well exposed) in the central part of the Pakri Peninsula.

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