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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Geology of Estonia: An introduction

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Estonia lies on the east coast of the Baltic Sea, south of the Finnish Gulf, comprising about 45 000 km2 area extending from 57°30'34" to 59°49'12"N and from 21°45'49" to 28°12'44"E.

The topography of this area is generally flat; the area is located about 50 m above sea level on average. Variety of landscapes comprises extensive forests and wetlands intersected by agricultural landscapes, wide depressions surrounding big lakes Peipsi and Võrtsjärv, about 1400 lakes, several thousands of kilometres long coastline and more than 2000 marine islands, most of them very small but more than ten of them being large enough to support the permanent population. The largest islands are Saaremaa, Hiiumaa, Muhu and Vormsi.

Geologically, the area of Estonia corresponds to the southern slope of the Fennoscandian Shield located in the central-western part of the East European Craton. Estonia is located in the area where the Earth's crust is relatively thick (mostly 46–51 km but decreasing to 41–44 km in Saaremaa (Puura and Vaher 1997). The principal features of the crustal structure of the area formed during the Svecofennian orogeny dated about 2.0–1.75 Ga. Most of the crystalline basement belongs to the Palaeoproterozoic (1.8–1.9 Ga) Svecofennian orogenic complex that was also subjected to high-grade metamorphism. This complex is characterised by the gneisses of amphibolite facies in northern Estonia and represents an extension of the major structural units of southern Finland. In southern Estonia, the basement comprises gneisses of granulite facies belonging to the Belarussian–Baltic granulite subdomain.

The metamorphosed rocks of the Svecofennian orogenic complex is intersected by several generations of intrusive bodies, the most important of them being the rapakivi intrusions of the latest Palaeoproterozoic Vyborg Subprovince (the Naissaare, Neeme, Märjamaa and Ereda plutons, 1.62–1.67 Ga) and the huge Riga pluton of the Åland–Riga Subprovince. The Riga rapakivi pluton is of the earliest Mesoproterozoic age (1.54–1.58 Ga) and is associated with a few subvolcanic and volcanic rocks occurring on Saaremaa Island. The crystalline basement was subjected to long-lasting erosion (1.4–0.6 Ga) that resulted in the formation of a peneplane. (Puura et al. 1997). The sedimentary units and magmatic rocks from this period, although known in other parts of the Svecofennian region, are absent in Estonia. The crystalline rocks occasionally display evidence of weathering that may reach up to a depth of 100 m into the basement (Puura 1997; Puura and Vaher 1997).

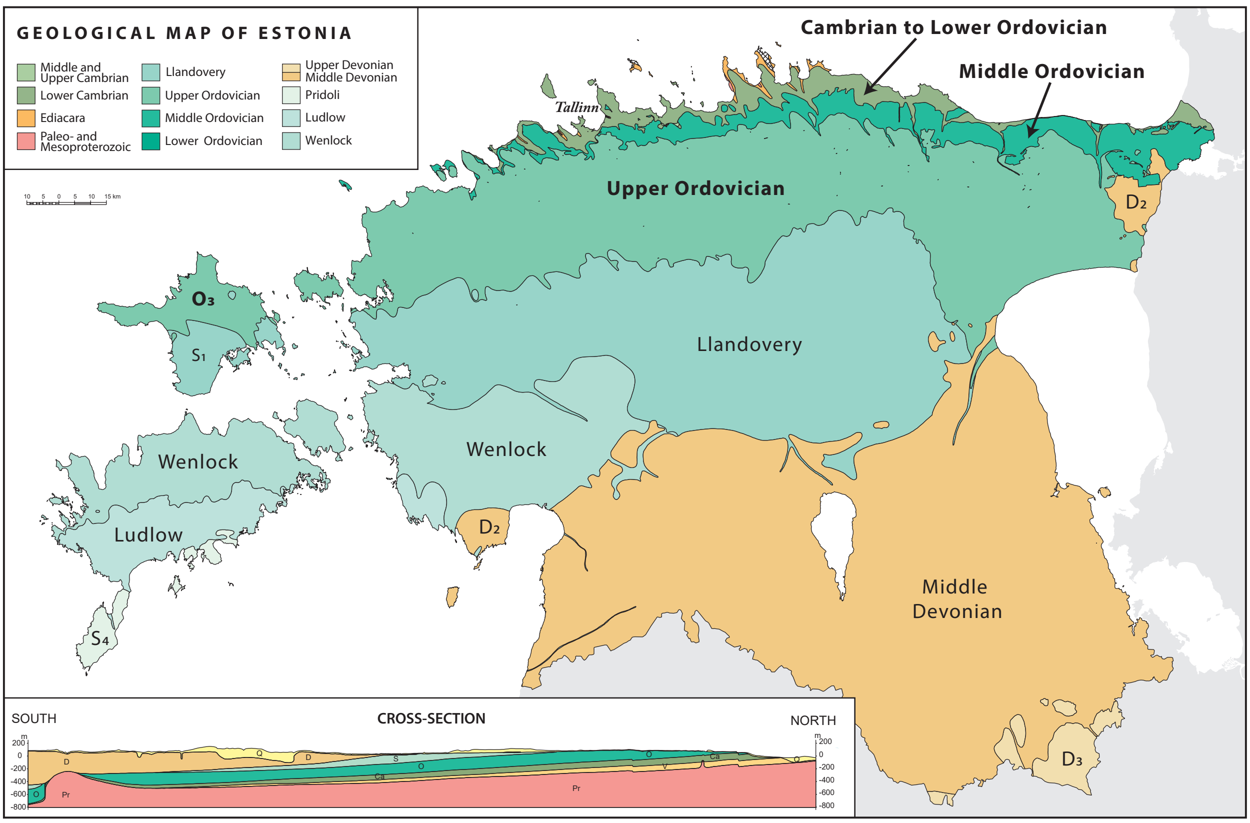

Fig. 1. Generalised bedrock geological map of Estonia with a cross-section, showing outcrop areas of lower and middle Palaeozoic rocks and a NS cross section shaped by the southward dip of the Proterozoic basement (modified from Puura 2008).

The top of the basement lies at a depth ranging from -120m (islands in the Finnish Gulf) up to -780m (the Island of Ruhnu, SW Estonia), dipping gently to the south within most of the territory but becoming slightly elevated again in SE Estonia forming the Mõniste Bedrock Uplift (altitude of the top at -232 m) (Tuuling and Vaher 2018). Because of this southward dipping, the thickness of the sedimentary cover is gradually increasing southwards. The northern border of the distribution area of sedimentary cover reaches the middle of the Gulf of Finland, dividing it into the shield and platform parts.

The sedimentary rocks Estonia are of latest Proterozoic to middle Palaeozoic age. Because of that, Estonia is sometimes called ‘a Palaeozoic country’. The Ediacaran–Devonian sedimentary cover is overlain by the sediments of the mid to late Quaternary. The thickness of the pre-Quaternary sedimentary rocks reaches over 100 m in northernmost mainland Estonia and exceeds 800 m in southeastern Estonia (Puura and Vaher 1997), generally reflecting the southward dipping of the upper surface of the crystalline basement. In the outcrop sections, the bedding of the sedimentary bedrock usually looks nearly horizontal but may occasionally show minor local deformations. Because of the gentle dipping of strata, 8–15’ (about 2–4.5 m/km) to the south, the outcrop belts of the series and stages display predominantly roughly west-east oriented pattern in the geological map (see Fig. 1).

The Ediacaran System (until the end of the 20th century referred to as the Vendian Complex or the Vendian System) comprises a subsurface unit distributed in northern, northeastern and eastern Estonia. These strata bear a signature of a cool climate as the Baltica Palaeocontinent was located in high latitudes in the late Ediacaran (Cocks and Torsvik 2005). The sandstones and clays prevailing in Estonia comprise a small segment of the latest Ediacaran (Meidla 2017), although a gap has been documented at the lower boundary of the Cambrian. The terrigenous sediments accumulated in a large water body located east of the Estonian area. Estonia comprised a part of its near-coastal zone, and the terrigenous sediments are coarser in the west. The total thickness of the Ediacaran reaches over 120 m, with the maximum in northeasternmost Estonia. Recent advances in the Ediacaran and Cambrian stratigraphy of Estonia are summarised by (Meidla 2017).

The overlying Cambrian is distributed nearly all over Estonia. The Cambrian rocks are predominantly sandstones and siltstones, with a limited supplement of clay, whilst coarser material is rare, occurring at some levels in West Estonia. An exception is the lowermost part of the succession that comprises the late Terreneuvian Blue Clay, a silty clay unit of a remarkable thickness (over 90 m – Meidla et al. 2017). Deposition of the Terreneuvian clays took place in an Ediacaran-like palaeogeographic setting in the course of a marine transgression advancing from the east, but the accumulation of younger Cambrian, Ordovician and Silurian strata was increasingly influenced by the developments along the southern slope of the Fennoscandian Shield. The Cambrian rocks, mostly sandstones, crop out in several coastal and riverside sections, whilst clays are mainly exposed in clay pits near the northern coast. The total thickness of the Cambrian strata is locally exceeding 120 m within the West Estonian archipelago.

The deposition of the Ordovician strata took place in a slowly subsiding marginal part of the East European Craton, initially of weak palaeobathymetric differentiation and slow deposition rate. The Lower Ordovician sandstones and thin clay-rich formations grade into the carbonates in the topmost Lower Ordovician, on the background of progressive depth differentiation due to the development of the Baltic Syneclise. The Middle and Upper Ordovician are represented by limestones that contain thin volcanic interbeds (K-bentonites) at several levels. Late diagenetic dolomitisation is unevenly distributed in limestones. Early Late Ordovician kukersite oil shale is a characteristic feature of northeastern Estonia, whilst Middle and Upper Ordovician red limestone packages and a few thin Upper Ordovician black shale units are known in the subsurface area. In many papers (e.g., Nestor and Einasto 1997) and references therein) the beginning of Katian (middle Upper Ordovician) is reported to mark a transition from cool-water to tropical carbonate sedimentation as the Baltica Palaeocontinent reached the southern tropical latitudes (Cocks and Torsvik 2005). Somewhat controversially, this seems to happen on the background of a gradual temperature decrease throughout the Late Ordovician (Männik et al. 2021). The Ordovician strata are exposed in coastal outcrops and escarpments, active pits and quarries of different ages, but the Upper Ordovician outcrops are mostly small and display only fragments of this unit that occasionally may reach about 100 m thickness. The topmost Ordovician is revealing evidence of the Hirnantian Glaciation, expressed as almost full faunal rearrangement (Nestor et al. 1986) and a major carbon and oxygen isotopic shift (Ainsaar et al. 2010; Männik et al. 2021). The latter feature is more clearly observable in the subsurface because of a gap in the outcrop area caused by the glacioeustatic sea level fall (Brenchley et al. 2003). Recent advances in Ordovician stratigraphy of Estonia and related areas are summarised in (Meidla et al. 2023).

The Silurian System has a more limited distribution, being absent in the northern and eastern parts of Estonia because of erosion. The Llandovery has the widest distribution, occurring both in the western islands and the mainland of Estonia. The distribution areas of the younger series are progressively smaller and gradually shifted to the southwest, to the Baltic Syneclise. The Přidoli Series occurs only in a very small area in southern Saaremaa Island and Ruhnu Island. The limestones and dolomites bear a signature of tropical sedimentation, and a number of K-bentonite beds (mainly lower Wenlock) is indicative of limited volcanic activity in the neighbouring areas. The rocks are locally exposed in the mainland, on Saaremaa Island and in smaller islands of West Estonia. The exposures, however, demonstrate only a minor part of the Silurian succession of over 400 m thickness.

The most recent overview of the Silurian stratigraphy in Estonia is provided by (Männik 2014).

Distribution of the Devonian System is confined to southern, eastern and northeastern Estonia. The latter occurrence represents a small isolated area in northeastern Estonia where the Middle Devonian dolomitic marls and sandstones of rather limited thickness overlie the Upper Ordovician limestones containing the kukersite oil shale commercial deposit. The main distribution area in eastern and southern Estonia represents a transition from the Scandinavian orogenic belt to the Devonian Basin within eastern Laurussia. The Middle Devonian and basal Upper Devonian are mainly represented by sandstones and overlain by a thin succession of Upper Devonian carbonates (mainly dolomites) confined to marginal southeastern Estonia and extending to the south and southeast. The lower Devonian has been recorded in the subsurface only, being confined to a narrow belt near the southern border of Estonia. The Middle and Upper Devonian are often exposed in river valleys of South Estonia and in occasional sand pits. The present state of Devonian stratigraphy in Estonia is summarised in (Mark-Kurik and Põldvere 2012).

The initial thickness of the Ordovician, Silurian and Devonian sedimentary strata may have reached 500-1000 m in North Estonia, and the maximum sediment load was probably reached during the Late Devonian (Kirsimäe et al. 1999). The very long erosional period during Carboniferous-Neogene has created the present-day bedrock topography, shaping bedrock cores of the major uplands of modern topography and depressions of the lakes Peipsi and Võrtsjärv and the Gulf of Finland.

The Quaternary glaciation caused the last stage of erosion of the sedimentary bedrock. The glaciers removed up to 60 m layer from the bedrock surface (Tavast 1997), leaving almost no chance of discovering any strata that might be younger than the Devonian but older than the Quaternary in Estonia.

The accumulation of Quaternary sediments during the Pleistocene and Holocene resulted in the formation of a nearly continuous layer of glacial, glaciofluvial and glaciolacustrine sediments, covered with genetically variable Holocene deposits that are mostly of limited thickness and patchy distribution. The total thickness of Quaternary sediments is usually less than 5 m in North Estonia but generally over 10 m in South Estonia. Thicknesses over 100 m are relatively common in South Estonia (Haanja and Otepää heights) and the Gulf of Finland (Raukas and Kajak 1997), but locally it may exceed 200 m. The bedrock topography, uneven thickness of the Quaternary cover and postglacial land rise have shaped the modern topography of Estonia. Only 10% of the area has an elevation over 100 m a.s.l. The highest point in South Estonia is 318 m a. s. l. but its relative height is only about 60 m (Raukas 1997). A revised stratigraphic chart of the Quaternary sediments in Estonia was recently published by (Hang et al. 2019).

A remarkable feature in Estonian topography is the North Estonian Klint, a nearly continuous escarpment along the northern coast that forms the middle part of the Baltic Klint. It exposes the Cambrian to Middle Ordovician part of the sedimentary succession in numerous outcrops of the lower Palaeozoic strata forming a fairly continuous belt of actively abraded and passive inland escarpments.

Although Estonia is a small country, it still is relatively rich in mineral resources. The most important actively exploited resource is the unique kukersite oil shale that comprises the world's largest exploitable resource of its kind. The Cambrian – Ordovician shelly phosphorite deposit in North Estonia is one of the largest phosphorite deposits within the European Union. It was industrially used between 1924 and 1991 but excluded from the list of active reserves in the late 1990s, mainly because of the past devastating mining and industrial use history. Another potential resource is the Dictyonema argillite which is relatively rich in organic matter (up to 20%) and contains various microelements (Mo, V, etc.) in elevated concentrations. The groundwater in the sedimentary rocks and Quaternary deposits is used as the source of drinking water throughout the country. It formed about 70% of the drinking water consumed in Estonia in the mid-1990s (Vallner and Savitskaja 1997). The Middle–Upper Ordovician, Silurian and Upper Devonian carbonate rocks are widely exploited in numerous quarries. Sand, gravel and peat deposits are in active use. Other resources are less important.

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