SILURIAN CLIFFS ON SAAREMAA ISLAND

Institute of Geology at Tallinn University of Technology
University of Turku, Department of Geology

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Silurian cliffs on Saaremaa island.
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Compiled: Tiiu Märss
Alvar Soesoo
Heldur Nestor

Acknowledgements: Olle Hints
Helle Perens
Kaidi Tilk
Igor Tuuling

Edited: MTÜ GEOGuide Baltoscandia

Layout: Andres Abe

Figures: Heikki Bauert

Photos: Heikki & Tarmo Bauert, Tiiu Märss, Oive Tinn, Igor Tuuling

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Back cover: Panga cliff (photo by T. Märss)

KESKKONNAINVESTEERINGUTE KESKUS

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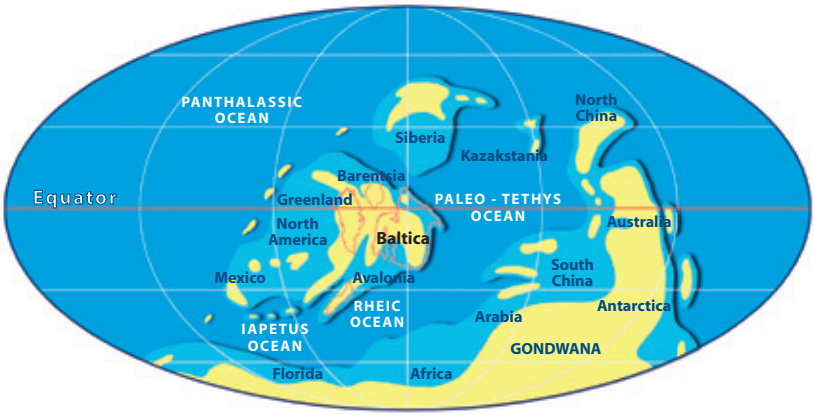
Cliffs are coastal escarpments abraded in bedrock by waves. In the West Estonian Archipelago, cliffs occur on the northern coast of Kesselaid and Kõinastu islets, Muhu and Vilsandi islands, and the eastern, northern, and western coast of Saaremaa Island. The appearance of cliffs may differ: some rise as vertical walls, some are dissected by wave-cut notches, and others retreat landward as several steps. Active cliffs rise directly from the sea and are washed by waves, while the extinct ones are located away from the modern shoreline. The latter are coastal escarpments of earlier stages of the Baltic Sea. The height of cliffs is different as well; the highest cliff in the West Estonian Archipelago is Mustjala Cliff (21.3 m high) on Saaremaa. The appearance of a cliff depends on the composition of the rocks forming the cliff, their bedding, the presence of fissures, and also the bedding conditions of rock beds and bedrock topography. Vertical cliffs are formed when the rocks are of a similar resistance. Wave-cut notches occur when the rocks forming a cliff's lower part are less resistant to abrasion than those in the cliff's upper part. The appearance of cliffs changes constantly. Severe storms, during which the sea level rises and the intensity of wave activity increases considerably, play an important role.

For geologists, cliffs are extensive outcrops allowing the study of rocks and fossils in them along extensive shore sections. The characteristics of rocks and their vertical and lateral changes allow one to restore the conditions that prevailed in the ancient sea. The cliffs on Saaremaa and other cliffs in western Estonia display the development of the Palaeobaltic Sea and its biota during the Silurian period (416 million to 443 million years ago).



Position of the continents in the mid-Silurian, ca 425 Ma ago (after C.R. Scotese "Plate tectonic maps and Continental drift animations", PALEOMAP Project, www.scotese.com)

SILURIAN PERIOD

The Silurian period started 443 million years ago and ended 416 million years ago, lasting 27 million years. The Silurian is an important time in the Earth's history. The rifting and dispersal of the Rodinia supercontinent, which had started in the Proterozoic eon, was substituted with the reassembling and reunion of the pieces of the continents. At that time, the territory of present-day Estonia was incorporated into the Baltica craton, which included what is now northern and eastern Europe. During the Silurian period, the Baltica and North America (Laurentia) drifted rapidly toward each other. They merged at the end of the period. The collision of these supercontinents started in the north and continued toward the south. As a result of the mutual stress of huge crust blocks, the northwestern edge of the Baltica craton started to uplift above the present-day Scandinavian mountains. Simultaneously, above what are now the Baltic Sea and the Baltic countries, there appeared a depression oriented northeast to southwest. The depression formed the deepest axial part of the ancient Palaeobaltic Sea. At the site of the collision of the continental plates, the Caledonian Mountains formed. The Caledonian Mountains extended over the British Isles, western Scandinavia, and eastern Greenland to Spitsbergen. As a result of uplift, the seas gradually retreated toward the margins of the continents. However, the retreat and shallowing of the sea was not a continuous and unidirectional process. It was interrupted by repeated transgressions and the deepening of the sea, the interruptions being at least partly related to changes in the sea level of the world ocean. As always, in the shallow areas near shore, carbonate sediments (limestones and dolostones) were deposited, while in the deeper parts there accumulated clayey sediments (marlstones, claystones, and shaley claystones). During the whole Silurian period, Baltica remained in the tropics. For this reason, its climate was not influenced by the ice ages that at the beginning of the Silurian took place in South America and Africa and that served as a continuation of the ice ages at the end of the Ordovician.

Silurian marine life consisted mainly of seafloor invertebrates. However, the share of freely swimming vertebrates increased considerably during the Silurian. In the seas, the diversity of corals and stromatoporoids grew rapidly and their contribution to reef forming increased. The first coral-stromatoporoid barrier reefs were formed; they were comparable to those at present and were hundreds of kilometers long. Among the echinoderms, primitive stalkless cystoids gave up their leading position to sea lilies (crinoids). The

latter formed dense thickets and generated an abundance of skeletal fragments for the formation of thick limestone beds. Among arthropods, the diversity and frequency of trilobites decreased steadily; at the same time, entirely new evolutionary branches developed (e.g., sea scorpions – eurypterids) that were capable of living in freshwater lagoons. They reached imposing dimensions. The fossils of the above life-forms can be found on Saaremaa in the cliffs and on stony beaches.

Some terrestrial plant fossils originate from approximately the same period. This suggests that in the second half of the Silurian low terrestrial vegetation, primitive and sparse, started to develop. It was made up of primitive cryptogams: psilophytes. Thus, the Silurian can be considered an epoch-making and revolutionary period also because the first firm evidence of terrestrial plants and animals comes from that time.

SILURIAN ROCKS IN ESTONIA

In Estonia, the Silurian is divided into 10 regional stages grouped into the four series of the global chronostratigraphical standard: Llandovery, Wenlock, Ludlow, and Přídoli.

Silurian stratigraphy in Estonia, thicknesses & prevailing rocks

AGE Ma		SERIES	STAGE	Thickness m	Prevailing rocks in Central Estonia	Prevailing rocks in South Estonia
416.0 ± 2.8	UPPER SILURIAN	PŘIDOLI	Ohesaare	29+	missing	dolomitic marl with limestone interbeds
			Kaugatuma	41-86	missing	marl with limestone interbeds
		LUDLOW	Kuressaare	19-27	missing	marl, clayey ja bioclastic limestone
			Paadla	11-28	missing	biomicritic & reef limestone, dolomite
422.9 ± 2.5	LOWER SILURIAN	WENLOCK	Rootsiküla	19-40	missing	clayey dolomite, limestone
			Jaagarahu	32-140	biomicritic & reef limestone, dolostone	marl (upper part), dolomitized limestone (lower)
			Jaani	24-70	marl, domerite, clayey limestone	marlstone, domerite
		LLANDOVERY	Adavere	10-52	marl, domerite, biomicritic limestone	marlstone, clay, domerite
			Raikküla	16-176	micritic-, biomicritic & reef limestone, dolomite	micritic limestone, marl, black shale
443.7 ± 1.5			Juuru	20-64	clayey, biomicritic, coquinoid & reef limestone	marl with limestone nodules

The System was earlier divided into the Lower and Upper Silurian. The Lower Silurian included the Llandovery and Wenlock; the Upper Silurian consisted of Ludlow and Přidoli. Unfortunately, the subdivision into Lower and Upper Silurian is no longer internationally accepted.

The Silurian strata overlie the Ordovician and are covered with the Devonian beds. They crop out in central and western Estonia to the south of the Haapsalu-Risti-Tamsalu-Mustvee line. In mainland Estonia they are discordantly overlain by the Devonian beds. The southern boundary of the Silurian outcrop area spreads over Tõstamaa-Pärnu-Suurejõe and Kolga-Jaani in the direction of Mustvee. The Devonian is missing on Saaremaa. In eastern Estonia, the Silurian rocks (except the lowermost, Juuru and Raikküla stages) had been eroded before the Devonian. Southwestward, the sections gradually become more complete. The Upper Silurian stages (Paadla, Kuressaare, Kaugatuma, Ohesaare) have been preserved only on Saaremaa and at the western margin of the Tõstamaa Peninsula. The uppermost stages (Kaugatuma, Ohessare) occur only on the Sõrve Peninsula.

In the beginning of the Silurian, nodular bioclastic limestones with interlayers of marlstone formed in central Estonia, while in southern Estonia marlstones with limestone nodules were deposited. In the second half of the Juuru Age, the sea became shallower. A huge shelly limestone deposit was formed of the shells of the brachiopod *Borealis*. It extended from the island of Hiiumaa as far as Alutaguse. This extremely pure limestone, popularly known as "ring" limestone, was used for lime burning. At the end of the Juuru, on Hiiumaa Island and the Ridala Peninsula, pure, granular crinoidal limestones consisting of the clasts of sea lilies and with coral and stromatoporoid reefs began to form. The process continued in the Raikküla time. Those platy limestones were used in the building of Haapsalu and Ungru castles and the churches at Ridala and Käina.

The **Raikküla Stage** is characterized by the alternation of muddy (micritic) and granular (bioclastic) limestones in central Estonia, and micritic limestones and marls in southern Estonia. At the end of the Raikküla time, western Estonia was subject to an extremely extensive lowering of the sealevel, in the course of which most of the earlier sediments were eroded. This is evidenced by the highly variable thickness of the Raikküla Stage, which ranges from 16 m on Hiiumaa Island to 176 m in Ikla in southernmost Estonia.

The deepest-water conditions developed in the Silurian Paleobaltic Sea, during the **Adavere and Jaani times**. They are represented mostly by marlstones. A bedrock

depression was later eroded into these relatively soft sediments, which proceeds over the Soela Strait, Matsalu Bay, and the Kasari lowland. Micritic and bioclastic limestones occurred in central Estonia at the beginning of the Adavere Stage (Rumba Member) and at the end of the Jaani Stage (Ninase Member). Their occurrence, as well as the presence of clayey bioclastic limestones, shows that the deepening and shallowing of the sea took place gradually.

The beginning of the **Jaagarahu time** is marked by an abrupt shallowing of the sea. At the northern margin of the Palaeobaltic basin a reef belt about 400 km long formed. It began at the Island of Gotland and continued in the bottom of the Baltic Sea, as well as along the northern coast of Saaremaa and Muhumaa islands, and the southern border of the Kasari-Matsalu lowland as far as Kaisma. In eastern Saaremaa, on Muhu Island, and on mainland Estonia, the reef rock is dolomitized and displays irregular hollows. Here, the reef belt is interrupted and represented by isolated reef hillocks up to a kilometer in diameter (e.g., on Salevere-Salumägi, in Lihula and Kirbla, and in the vicinity of Mihkli). In Estonia, shallow-water conditions that alternated with temporary deepenings continued throughout the Jaagarahu, **Rootsiküla, and Paadla times** and culminated in the **Rootsiküla time** (i.e., at the end of the early Silurian). In shallow lagoons clayey dolostones were deposited which contain dessication cracks and fossils of sea scorpions (eurypterids) and jawless fishes. Many significant dolostone deposits on Saaremaa are associated with these rocks (e.g., Kaarma, Tagavere, and Selgase). Kaarma dolostone was used as a building material for the construction of Kuressaare castle and several churches.

Reconstruction of an agnathan *Tolypelepis undulata* Pander. Its dorsal and ventral plates were found in the rocks of Ohesaare Cliff

Phlebolepis elegans Pander from Himmiste quarry (Paadla stage). The fish was around 7 cm long. Photo by G. Baranov

The last Silurian stages, **Kuressaare, Kaugatuma and Ohesaare**, stand out with their considerably increased content of clayey material. In the latter two stages marlstones prevail, containing mostly thin limestone interlayers, but also a few thicker deposits (3 m to 5 m). The latter are represented mostly by crinoidal limestone. The increased content of the clayey component indicates that, at the northwestern margin of the Baltica craton, the Caledonian Mountains had reached a stage of intensive upheaval. From there, flowing waters carried an abundance of fine clay material into the Palaeobaltic basin, which at the end of the Silurian retreated from the area of Estonia forever and by the beginning of the Devonian was entirely filled with clay sediments.

SILURIAN KLINT and CLIFFS

When speaking of klint, one thinks first of entire Baltic Klint. Some 1,200 km long, the Baltic Klint stretches from near Öland Island in Sweden across the Baltic Sea to Lake Ladoga in Russia and comprises Estonia's northern coast, with its magnificent cliffs. The latter is sometimes erroneously called the North Estonian Limestone Escarpment. Actually, the limestone forms only the escarpment's upper part. The lower portion is represented by Ordovician and Cambrian sandstones.

South of the Baltic Klint another klint occurs, known as Gotland–West Estonian Klint, which is cut into the Silurian rocks 443 Ma to 416 Ma in age. The Silurian Klint is less popular because its escarp-

The extent of klints

ments are shorter and lower than those of the Baltic Klint.

The West Estonian (Silurian) Klint is approximately 500 km long. It emerges from the sea on the north-western coasts of Gotland Island, continues eastward on the seafloor, and runs along the northern coast of Saaremaa Island and Kesselaid Islet and Muhu Island to the village of Linnamaa in central Estonia. In western mainland Estonia, the West Estonian Klint appears as small, isolated hills and cliffs, altogether some 100 km long. The cliffs and hillocks are generally 3 to 7 m, seldom up to 15 m high. In the West Estonian Archipelago, the Silurian Klint is more clearly exposed, forming several coastal escarpments and cliffs along a section some 90 km long. On Kesselaid Islet, Muhu, and Saaremaa, the cliffs are up to 20 m high and the escarpments up to 2.5 km long, while normally their length is couple of hundred meters. West of Saaremaa the klint submerges into the Baltic Sea and continues westward on the seafloor, forming escarpments in places 100 m high. The Silurian Klint is highest on Gotland and Fårö islands, where the escarpments may reach over 50 m above sea level.

KESSELAID & MUHU ISLAND

Kesse Cliff (Kesselaid Islet)

The cliff is situated on the northwestern coast of Kesselaid, an islet between Muhu Island and mainland Estonia. Its length is some 600 m and its height reaches 8.5 m. Due to inclined beds, 13.5 m of

Kesse Cliff (photo by I. Tuuling)

geological sequence is exposed. The cliff is a type section of the Kesselaid Member of the Muhu Formation, Jaagarahu Stage. In its lower part, 4.5 m of the dolomitic, calcareous marlstones of the Jaani stage are exposed, containing poorly preserved fossils (brachiopods, bryozoans). They are overlain by 4 to 5 m of somewhat stronger platy dolomites of the Jaagarahu Stage, with abundant and large pyrite nodules, which are partly weathered. The topmost part of the cliff is represented by massive, porous biohermal dolostone complex, the so-called reef dolomite. The upper part of Kesse Cliff retreats landward, forming three escarpments. The topmost two are the Litorina Sea coastal scarps. The respective Baltic Sea stage occurred some 4,000 to 7,500 years ago. Kesse Cliff is part of the Kesselaid Landscape Reserve.

Püssina Cliff (Muhu Island)

The cliff is located on Muhumaa, on the seashore 1.5 km east of the village of Lõetsa. The cliff is up to 600 m long and 5 m high, and 8.5 m of geological sequence is exposed. The geological setting is similar to that of Kesse Cliff. The lower part is represented by 3 m of dolomitic marlstones of the Jaani stage, which are overlain by 5.5 m of platy and reef dolomites of the Jaagarahu Stage. The latter occur in the northwestern part of the cliff, where they have plunged hollows in the underlying beds. Above the cliff numerous bioherms are found between the junipers as knobs and hillocks of irregular shape.

Kesselaid Cliff (photo by I. Tuuling)

Bioherms of the Jaagarahu Stage at the northernmost part of Püssina Cliff

Southernmost part of Püssina Cliff

Üügu (Anduvälja) Cliff

The cliff is situated on the seashore near the village of Kallaste between Raugi and Nõmmküla. The cliff is some 450 m long and its maximum height from the foot is 7 m. It is located somewhat landward from the present coastline, and its foot is 4 to 6 m above the sea level. On 13th of March 1959, Üügu, the biggest and most beautiful cliff on Muhumaa, was placed under protection as a single landscape element. Since 14th of March 1996, the cliff and its environs have formed the Üügu Landscape Reserve.

Üügu Cliff is an abrasional scarp of the Limnea Sea. It displays a good example of the succession of beds in lower part of the Jaagarahu Stage, the shape and dimensions of bioherms, and the impact of the Limnea Sea abrasion on the cliff. Its upper part consists of thinly bedded dolostones of the Jaagarahu Stage; the lower portion is represented by the marlstones of the Jaani stage, but this part of the cliff is not exposed.

Attention should be paid to the wave-cut notches, which form larger and smaller caves in the cliff. Many of them were destroyed a century ago when dolostone was quarried for the metallurgical plant in St. Petersburg. The quarries above the cliff are still observable.

Wave-cut notches at the foot of Üügu Cliff (photo by T. Märss)

Üügu Cliff

THE CLIFFS ON SAAREMAA ISLAND

Pulli (Oiu) Cliff

The cliff is situated on the seashore at Taaliku, less than a kilometer from Leisi Road. Pulli Cliff is 430 m long and 3.5 m high, ca 5 m of geological sequence is exposed. The cliff resembles the cliffs on Kesselaid and Muhumaa. The lower part consists of the dolomitized marlstones of the Jaani Stage that are covered by the flaggy and reef dolostones of the Jaagarahu Stage. The bioherms are covered by dome-like platy dolostone beds. Thus, the beds overlying the bioherms are present here also (they are not found on the cliffs in Muhumaa). The boundary of the Jaani and Jaagarahu stages is marked by a prominent pyritized discontinuity surface. The bed above this surface contains rounded rock particles (i.e., it is a bed of a shallow-water conglomerate). In the section of Pulli Cliff, bent strata are conspicuous. They have been formed in semisolid sediments under the weight of bioherms.


A bioherm

Pulli Cliff

Panga (Mustjala) Cliff

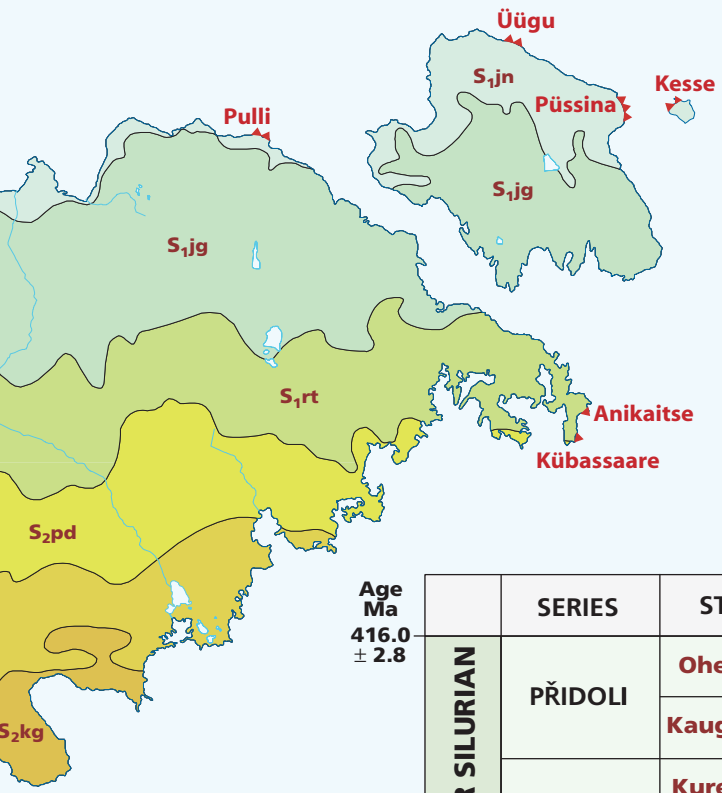
The cliff is located on the northern coast of Saaremaa, northwest of the Panga village. The cliff is about 3 km long and reaches a height of 21.3 m, that makes it the highest coastal escarpment in the West Estonian Archipelago. It consists of three escarpments, two of which are above the water level; the third, underwater escarpment is 10 to 12 m high.

On 13th of March 1959, a northern and western section of the cliff one kilometer long was taken under protection as a single landscape element. Since 13th of May 1959, it has belonged to the Panga Landscape Reserve, the aim of which is to protect the highest cliff of the West Estonian Klint and the local plant community. The cliff extensively displays the bedding conditions and composition of rocks and its vertical and lateral changes.

Most of the cliff consists of the argillaceous dolostones and dolomitic marlstones of the Jaani Stage, above which lie thickly bedded, strong platy dolostones, forming corners projecting out of the cliff. In almost all beds, shells of ancient marine invertebrates or their imprints occur. Some levels display large nests of calcite crystals. The rocks are cut by numerous vertical fissures, which caused huge blocks to fall down on the foot of the cliff.

The top of Panga Cliff is formed of the dolomites of the Jaagarahu Stage

LOCATION OF SILURIAN CLIFFS ON SAAREMAA & MUHU ISLANDS



Age Ma		SERIES	STAGE	index
416.0 ± 2.8	UPPER SILURIAN	PŘIDOLI	Ohesaare	S_2oh
			Kaugatuma	S_2kg
		LUDLOW	Kuressaare	S_2kr
			Paadla	S_2pd
422.9 ± 2.5	LOWER SILURIAN	WENLOCK	Rootsiküla	S_1rt
			Jaagarahu	S_1jg
			Jaani	S_1jn
		LLANDO-VERY	Adavere	S_1ad
			Raikküla	S_1rk
			Juuru	S_1jr
443.7 ± 1.5				

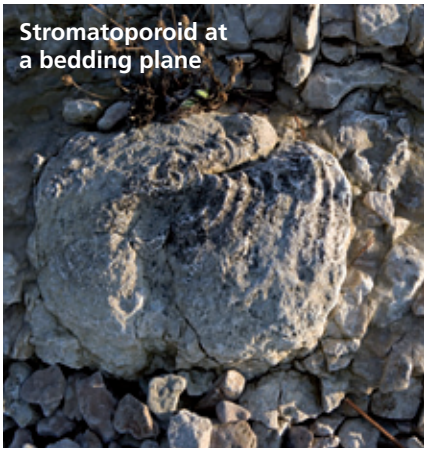
Ninase (Tagaranna) Cliff

The cliff is situated on the northern and western shore of the Ninase Peninsula. It is around 1.5 km long and 5 m high and displays 6 m of geological sequence. It is the type section of the Ninase Member, Jaani Stage. In the cliff's lower part are exposed the marlstones of the Mustjala Member, Jaani Stage. They are overlain by horizontally or wavy-bedded dolomitized bioclastic limestones of the Ninase Member. Noteworthy is a tectonic fault at the corner of the cliff and small circular bioherms consisting mainly of bryozoans. These, so-called embryonic reefs (in a very early stage of development) are less than a meter in diameter and 30 to 40 cm high. The rocks forming the cliff are rich not only in bryozoans but also in shells of brachiopods and crinoid fragments. Abundant fragments of fossils indicate that the rocks were deposited in a shallow sea.

Ninase Cliff

Abula Cliff

The cliff is located on the eastern shore of Tagalaht Bay. It is about 400 m long and 2 m high and displays more than 3 m of geological sequence. The cliff is in the Koorunõmme-Abula Nature Reserve. The cliff displays the boundary of the Vilsandi and Maasi beds of the Jaagarahu Stage and 2 m of the Maasi Beds. At the foot of the cliff, the dolomitic marlstones of the Vilsandi Beds are exposed, which are replaced by the platy ostracod-gastropod-oncolite limestones overlain by finely nodular bioclastic limestone. In the upper third of the section the rock beds become thicker. The whole section is rich in fossils. At the coastline some 200 m to the northwest of the end of Abula Cliff, the surface of the biohermal limestone of the Vilsandi Beds is exposed. It consists almost entirely of large spherical fossils of calcareous algae, stromatoporoids, and corals, that is why geologists call this place the Coast of Skulls.



Stromatoporoid at a bedding plane

Abula Cliff

Suuriku Cliff

The cliff is located on the Tagamõisa Peninsula at the seashore northeast of the Undva village. It is the second-highest coastal escarpment in the West Estonian Archipelago. The lower 8 m consists of bedrocks, whereas the top 3 m is represented by Quaternary deposits. The cliff is more than 500 m long. The rocks of the Jaani Stage are exposed. In the lower third, marlstones dominate, alternating with bioclastic limestones; in the middle part lies purer limestone with interlayers of clayey limestone. In the lateral direction, these rocks are replaced by bryozoan bioherms. In addition, a few tabulate corals, stromatoporoids, brachiopods, and ostracods and detritus of crinoids are found. The bioherms are 1 to 10 m in diameter and 0.5 to 3.0 m thick. In the upper third of the cliff, an alternation of bioclastic and clayey limestones is observed again, but bioherms are not found here. Fossils are represented by abundant brachiopods. In the cliff's southern part, tectonic faults occur; rock blocks are dislocated in relation to one another.


Suuriku Cliff

Undva (Tõrvasoo) Cliff

The cliff is located at the northern tip of the Tagamõisa Peninsula, on the north-eastern shore of Cape Undva. The cliff is about 500 m long and 1.8 m high. It is the westernmost outcrop of the Jaani Stage. At the lower part of the cliff, mainly marlstones are exposed; these are overlain by pure bioclastic limestones, which in the central part of the cliff contain small bioherms composed of bryozoans in a very early stage of development.

Undva Cliff (photo by T. Märss)

Elda Cliff

The cliff is in Vilsandi National Park on the northwestern tip of the Atla Peninsula. It is some 400 m long and 1.8 m high. In the cliff rocks of the Rootsiküla Stage: medium- to thickly bedded dolostones with conchoidal fractures are exposed containing small stromatolites and oncolites. In places pyrite patterns occur. In the lower, 70-cm thick dolostone bed there is a brownish, clayish, lens-like interbed with well-preserved bony plates that once covered the head of agnathans and the front of their trunk. The character of the rock and the preservation of the corals in their living position show the prevailing quiet-water conditions in the sea.

Elda Cliff

Eurypterid from the Rootsiküla Stage (photo by O. Tinn)

Soeginina pank

The cliff is in Vilsandi National Park on the western shore of the Atla Peninsula. The cliff is some 500 m long, reaches a height of 3.6 m, and displays 3.6 m of the geological sequence. It is the type section of the Soeginina Beds, exposing the boundary of the Soeginina and Vesiku Beds of the Rootsiküla Stage and the overlying Soeginina Beds, which are represented by thinly to thickly bedded dolostones. At the cliff's foot small stromatolites (thinly laminated structures formed by bacterial activity) are common fossils. Higher, the rocks are porous because of dissolved fossils (gastropods, ostracods, etc.). A characteristic feature is concentric oncolites, because of which the rocks are also known as "onion limestone".

Dessication polygons (above) and dolostone with oncolites (below)

Soeginina Cliff

Katri Cliff

The cliff is located about 4.5 km south of the village of Karala. It is 500 m long and a meter high.

The cliff displays biostrome, a wide, flat, horizontally stretched bed which formed in the shallow sea during the Paadla Age. It consists mainly of stromatoporoids (at least nine species), corals, and an assemblage of brachiopods. The share of corals and stromatoporoids reaches 60% of the rock volume. Many colonies are in a reverse position, which shows that they were formed under conditions of intense wave activity.

Fossils washed out by waves

Katri Cliff

Kaugatuma Cliff

The cliff is on the western coast of Sõrve Peninsula, south of the village Kaugatuma. It is 125 m long. The height of the escarpment reaches 2.8 m and the bedrock part 2 m. The cliff is the type section of the Kaugatuma Stage. On 18th of December 1973 Kaugatuma Cliff was placed under protection as single landscape element; on 21th of November 2000 it was incorporated into the Kaugatuma-Lõo Landscape Reserve. The cliff is located farther inland from the coastline and is not washed by the waves. Extremely severe storms have carried pebbles and shingle to its foot. This and the blocks of rocks which have fallen from it are the reason for the rapid levelling and overgrowing of the cliff foot. In the wave-cut notches in the lower part of the section, clayey nodular limestones with marlstone interbeds are exposed. The upper part consists of hard, coarse-skeletal crinoidal limestone. The rock contains abundant circular stem joints of crinoids and is known also as "ring limestone." Here and there in the escarpment small colonies of tabulate corals *Syringopora blanda* occur 20 to 30 cm in diameter. When the latter fall out of the cliff wall as a result of weathering, small cavities are left behind. Beach ridges at the foot of the klint are rich in fossils of invertebrates, such as brachiopods, the stem joints of crinoids, ostracods, fragments of trilobites, bryozoans, and gastropods.

Kaugatuma Cliff

About a kilometer south from Kaugatuma Cliff, on a rocky limestone beach at coastline, a 200 m long and up to 10 m wide area with ancient (400 Ma old), lithified ripple marks is exposed. As the bedding planes resemble an asbestos cement roofing material, called "eterniit" in Estonian, geologists call this place Eterniit-coast. The ripple marks are found on bedding planes throughout the entire exposed section. They are oriented east to west. The distance between their crests is 40 to 60 cm (in some cases even 80 cm) and the height of ripple marks reaches 10 cm. In places waves and ice have abraded the crests of the ripples, leaving behind a wavy rugged surface. The limestone contains fine stem fragments of sea lilies and the elongated, flat, calcareous skeletons of bryozoans. In addition, burrows occur on the bedding planes.

"Ring" limestone

Ancient ripple marks (photo by T. Märss)

Ohesaare Cliff

The cliff is located on the western shore of the Sõrve Peninsula, near the village of Jämaja. It is 700 m long and 3.5 m high and displays 4.3 m of geological sequence. The cliff is the type section of the Ohesaare stage. On 13th of March 1959 Ohesaare Cliff was placed under protection as a single landscape element; on 14th of March 1996 it was incorporated into the Ohesaare Landscape Reserve. In the section limestones of variable clay content alternate with marlstone. In some places, interbeds of clay occur. In the southern part of cliff, the topmost beds contain some silty components. These rocks were formed in a shallow, coastal sea.

The Ohesaare outcrop is extremely rich in fossils; skeletal fragments of representatives of all invertebrate and vertebrate groups of the Silurian of the Baltic region have been found here. Most common are brachiopods, but there are also ostracods, crinoids, bivalves, bryozoans, trilobites, gastropods, tentaculitids, nautiloids, tabulate and rugose corals. The rocks contain scales and fragments of agnathans and fishes. Bigger bone plates have been found but are rarer. Noteworthy are the shells of the bivalves *Grammysia obliqua*, preserved in a living position. The 50-cm marlstone layer at the top part of the outcrop is called *Grammysia* marlstone after them.


Ohesaare Cliff

Kübassaare Cliff

The cliff is on the southern end of the Kübassaare Peninsula on its eastern shore. It is 360 m long and up to 1.5 m high and displays 2.7 m of geological sequence. The cliff is in the Kübassaare Landscape Reserve. Normally the cliff is buried under shingle, with a few corners projecting out. After cleaning up of part of the escarpment, one can see something unique in Estonia. In the middle beds stromatolites occur. The latter are convex formations of a laminated cross-section, a couple of meters in diameter and consisting of small bulges. They were first considered as animal organisms, stromatoporoids; nowadays they are thought to have been formed by bacterial activity. They were formed in parts of the sea with special conditions. Stromatolites are overlain by wavy, bedded dolostones with ostracodes, gastropods, and often eurypterids. Beneath the stromatolites dolostone and conglomerate beds occur with dark-gray clay and oncolites. The latter are generally formed in near shore, with rather intense wave activity.

Obviously, the rocks cropping out of the Kübassaare Cliff belong to the Rootsiküla Stage.

Stromatolites

Kübassaare Cliff
(photo by T. Märss)

Anikaitse Cliff

The cliff is at the northern end of the Kübassaare Peninsula, on its eastern coast, 4 km northeast of the Kübassaare lighthouse. The escarpment is 3.5 m high and 2.3 m of geological sequence is displayed. On the cliff the rocks of the Rootsiküla Stage crop out. They are light gray, finely porous, medium- to thick-bedded dolostones with abundant fossils of gastropods and bivalves. They alternate with beds rich in oncolites and beds of argillaceous marlstone. In places, in lower part of the cliff, light-colored pebbles and dessication cracks occur on bedding planes.

Cephalopod mould

Anikaitse Cliff

GEOLOGICAL VOCABULARY

age – a time period in the geological development of a region; a subdivision of an epoch

Baltic Klint – a system of bedrock escarpment some 1,200 km long that stretches from the coast of Öland Island in Sweden across the Baltic Sea to Lake Ladoga in Russia; Baltic Klint also comprises the North Estonian Klint

barrier reef – a coral reef, an elongated offshore ridge built up from the calcareous skeletons of marine organisms (corals, calcareous algae, sponges, etc.)

bioherm – a seafloor elevation composed of fossil organisms (see also reef, mud bank)

biostrome – a layer of calcareous skeletons of organisms attached to each other

brachiopod – benthic marine animals whose soft parts are enclosed within a two-valved shell; the valves are of different sizes but symmetrical about a median plane

carbonate rocks – rocks composed of carbonate minerals (calcite, dolomite); popularly known as limestone

porous dolostone – a dolomite with an abundance of solution cavities

cliff – a bedrock escarpment produced by abrasion of sea

craton – a core of a stable continental crust, which in the geological past occurred as an independent continent. In the sense of modern geological structure, the term *platform* is also used

debris – crushed skeletal remains of organisms

bioclastic limestone – a limestone consisting of fragmented skeletal remains of organisms; divided into biomicritic limestone if lime mud was deposited between skeletal particles during sedimentation and biosparitic limestone if initially there was no mud between skeletal particles which acted as a skeletal sand. In the first case, sedimentation took place under deeper, calm-water conditions; in the latter case, sedimentation occurred in the shallow zone of wave action

dolostone – a rock consisting of the mineral dolomite

dolomitic marlstone – dolomitic rock rich in clay material

epoch – a subdivision of a geological period; its name is often derived by placing attributives (early, middle, late) in front of the name of the corresponding period

eurypterid - a sea scorpion; a large, extinct, jointed-limbed, scorpion-like arthropod

formation – a rock mass with a more or less uniform composition named after the geographic locality where it was first recognized and described and where it occurs in its typical form

fossils – mineralized or otherwise preserved remains or traces of animals, plants, and other organisms

gastropod – all snails and slugs living in the sea, in fresh waters and on land

klint – an extensive system of coastal bedrock escarpment resulted from an abrasion of sea

marlstone — a carbonate rock consisting of lime and clay material

member – a subdivision of a formation

micritic limestone – microcrystalline or cryptocrystalline limestone formed of lime mud and almost devoid of the skeletal fragments of organisms (debris)

outcrop – an area where rocks with a certain age or composition are exposed on ground surface or are covered with a thin layer of unconsolidated Quaternary deposits

ostracode – a tiny crustacean whose body was enclosed in a bivalved carapace

period – a division of geological time; a distinct interval of time in the evolution of the Earth, lasting tens of millions of years

psilophyte – a primitive cryptogam

reef – a ridge or elevation on the seafloor made up of skeletons of lime-secreting organisms (corals, calcareous algae, sponges, etc.)

reef hillock – a bedrock hillock formed of hard reef rocks in contemporary relief

series – a subdivision of a system, rocks formed during a relevant time period; the name of the series is usually formed by placing an attributive (lower, middle, upper) before the name of the corresponding system

Silurian Klint (also the **Gotland – West Estonian Klint**) – a system of escarpments in Silurian rocks running southward from the Baltic Klint; it begins from northwestern coast ofGotland Island, continues eastward on the seafloor, and runs along the northern coast of Saaremaa, Muhu and Kõinastu islands and southern coast of Matsalu Bay

stage – a unit of stratified rocks formed during a certain geological age; the name of the stage is derived from the name of the locality where it occurs in its typical form

stromatoporoid – a big, loaf-like fossil; an extinct colonial sponge

supercontinent – a large landmass that combined most of the continental crust of the Earth (e.g., Pangaea, Rodinia)

trilobite – an extinct arthropod

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IUGS ICS Geological Time Scale 2004 (www. stratigraphy.org)

adapted and modified by Estonian Commission on Stratigraphy (www.gi.ee/ESK/)

EON	ERA	SYSTEM	SERIES	AGE (Ma)
				0,00
Phanerozoic	Cenozoic	QUATERNARY	Holocene	0,0115
			Pleistocene	1,806
		NEOGENE	Pliocene	5,332
			Miocene	23,03
		PALEOGENE	Oligocene	33,9 ± 0,1
			Eocene	55,8 ± 0,2
			Paleocene	65,5 ± 0,3
	Mesozoic	CRETACEOUS	Upper Cretaceous	99,6 ± 0,9
			Lower Cretaceous	145,5 ± 4,0
		JURASSIC	Upper Jurassic	161,2 ± 4,0
			Middle Jurassic	175,6 ± 2,0
			Lower Jurassic	199,6 ± 0,6
		TRIASSIC	Upper Triassic	228,0 ± 2,0
			Middle Triassic	245,0 ± 1,5
			Lower Triassic	251,0 ± 0,4
	Paleozoic	PERMIAN	Lopingian	260,4 ± 0,7
			Guadalupian	270,6 ± 0,7
			Cisuralian	299,0 ± 0,8
		CARBONIFEROUS	Pennsylvanian	318,1 ± 1,3
			Mississipian	359,2 ± 2,5
		DEVONIAN	Upper Devonian	385,3 ± 2,6
			Middle Devonian	397,5 ± 2,7
			Lower Devonian	416,0 ± 2,8
		SILURIAN	Přídoli	418,7 ± 2,7
			Ludlow	422,9 ± 2,5
			Wenlock	428,2 ± 2,3
			Llandovery	443,7 ± 1,5
		ORDOVICIAN	Upper Ordovician	460,9 ± 1,6
			Middle Ordovician	471,8 ± 1,6
			Lower Ordovician	488,3±1,7
		CAMBRIAN	Furongian	501,0±2,0
			Middle Cambrian	513,0±2,0
			Lower Cambrian	542,0±1,0
Proterozoic	Neoproterozoic	EDIACARAN		630
		CRYOGENIAN		850
		TONIAN		1000
	Mesoproterozoic	STENIAN		1200
		ECTASIAN		1400
		CALYMMIAN		1600
	Paleoproterozoic	STATHERIAN		1800
		OROSIRIAN		2050
		RHYACIAN		2300
		SIDERIAN		2500
Archean	Neoarchean			2800
	Mesoarchean			3200
	Paleoarchean			3600
	Eoarchean			~4500

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