EKS. JUHT 1993

PACT course in Estonia 1993

ENVIRONMENTAL HISTORY OF THE BALTIC REGION

Intensive interdisciplinary graduate/post-graduate course in

Tartu, Estonia, 15-25 April, 1993,

organized by

University of Tartu in collaboration with **Stockholm University**

and the Council of Europe,

PACT Palaeoecological Network

EXCURSION GUIDE

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PREFACE

The arranging of an interdisciplinary course entitled "Environmental history of the Baltic region" at Tartu University in April 1993 has been in response to a heartfelt wish from young Baltic graduate students, post-graduate junior researchers and their professors.

Financial support from the bilateral collaboration funds of Stockholm University under the programme "Interdisciplinary research contacts with the Baltic countries" has made the realization of this wish possible. The course is the outcome of two years of training and research activities in Estonia and Sweden in which a group of about 20 junior researchers have participated.

The Council of Europe, PACT network has given this Baltic programme its very valuable patronage and also financed the publication, PACT volume 37 "Estonia: Nature, Man and Cultural Heritage", edited by Tony Hackens, Valter Lang and Urve Miller. A new PACT volume "Environmental and Cultural History of Coastal Estonia: Recent advances" is already in preparation and will contain the results of current interdisciplinary research from the Tondi, Maardu, Kunda, and Narva sites along the Gulf of Finland and the Tuiu site on Saaremaa.

The aim of the course in Tartu is to extend the interdisciplinary collaboration in the fields of palaeoecology, environmental sciences and cultural history in the Baltic countries. At the same time it affords an excellent forum for introducing the Baltic countries and their current research problems to European researchers by inviting them as lecturers. As a result of the excellent affirmative response from several outstanding scientists and humanists, the list of contributors is both impressive and multidisciplinary.

In the name of the coordinators of the PACT Palaeo-ecological Network I would like extend my thanks for all the goodwill and encouragement which we have received during the organisation of this course.

Stockholm 13th of April 1993.

Urve Miller

Urve Miller

INTRODUCTION TO ESTONIAN GEOLOGY

Volli Kalm, Juho Kirs & Ivar Puura

Estonia is located in the northwestern part of the East European Platform. Structurally, most of Estonia is considered to lie on the southern slope of the Baltic (Fennoscandian) Shield, only the southwestern part is referred to the northern slope of the Baltic Syneclise. The almost horizontal Vendian to Devonian sedimentary rocks cover the Archean and Proterozoic crystalline basement, dipping slightly southwards, normally not more than 3-4 metres per km (or 15'). From the point of view of plate tectonics, the pre-Quaternary sedimentary rocks of Estonia have been formed in a sea basin travelling with 'Baltica', an ancient plate, which, according to a recent synopsis of palaeomagnetic data, has been drifting since Vendian from the high southern palaeolatitudes to its present position in the northern hemisphere, crossing the equator during the Silurian and Devonian (Torsvik, et al., 1992). The Palaeozoic rocks are overlain by the Quaternary sedimentary cover, from none to over 200 m in thickness.

Archean and Proterozoic crystalline basement. As a part of southern slope of the Fennoscandian (Baltic) Shield, the Estonian crystalline basement belongs to the structural zone of Svecofennides (Puura et al., 1992). Its peneplained surface, buried under the Vendian and Palaeozoic sedimentary cover dips slowly, at 6' to 13' to the south. Thus, thickness of overlying beds varies from 100 m in southern coast of Gulf of Finland to 550 m in southern Estonia. The smaller unevenesses of the surface of the basement are related to the local structures, like scarps connected with platform faults and extending 30-50 m in length and uplifts from 0.3 to 4 km in diameter and 40-120 m in height (Sonda, Uljaste, Assamalla). An unique local structure, the buried Middle Ordovician (455 Ma) Kärdla meteoritic crater located in NW on Hiiumaa Island is about 540 m deep and 4 km in diameter (Puura & Suuroja, 1992). On the basis of gravimetric, magnetometric and drilling data the following structural zonation of the crystalline basement has been suggested.

In northern part of Estonia, mainly supracrustal migmatized gneisses with amphibolite facies assemblages (1.8-1.9 Ga in age) occur as Tallinn and Alutaguse synclinal zones. The latter are separated by Tapa anticlinal block, consisting of polymetamorphic rocks, similar to those in South Estonia. In northeastern Estonia sublatitudinal Jõhvi anticlinal zone has been revealed. Except various gneisses, it contains lense-like deeply dipping bodies of magnetite quartzites reaching some metres in thickness.

In South Estonia and North Latvia, intensely metamorphosed basic gneisses occur. Preliminary studies of Nd isotopes have indicated their Svecofennian age (Huhma et al., 1991). The youngest rock types in Estonian crystalline basement are represented by small stocks of postorogenic porphyraceous potassium granites and a huge Riga rapakivi-anorthosite batholith. The intrusions and rapakivi volcanics have ages typical of Fennoscandian rapakivi: 1.57-1.63 Ga.

The pre-Quaternary sedimentary cover of Estonia is characterized by sublatitudinal belts of Palaeozoic rocks, gradually younger towards the South (Fig. 1). In the north, the almost horizontal Cambrian to Devonian rocks lying on the southern slope of the Baltic Shield with a very slight southward dip ranging from 2 to 5 m per km can be followed to Lake Ladoga and eastwards, and in the seabed to the correlative sequences in Öland and Gotland islands and westwards. Vendian, Cambrian and lowermost Ordovician (Tremadocian) terrigenous rocks, mostly clays, silt- and sandstones and argillites are overlain by Ordovician and Silurian carbonate rocks represented by limestones, marls and dolomites. In southern Estonia, south of Pärnu-Mustvee line, terrigenous Devonian rocks form the uppermost layer of the pre-Quaternary. The thickness of the pre-Quaternary sedimentary cover is about 100 m in northernmost Estonia and reaches almost 800 m in Ruhnu island. The Palaeozoic rocks are quite well exposed in the natural outcrops of river and stream valleys over the whole Estonia and along the Baltic clint. Along the seashore cliffs on the Saaremaa island, Silurian carbonate rocks are exposed. Artificial exposures related to road construction, quarries, etc. are also common making bedrock well accessible for study. For the continuity and accessibility of the Lower Palaeozoic sequence and the abundance of well-preserved fossils, Estonia has become well-known as a classic region of Lower Palaeozoic.

Vendian rocks represented by sand- and siltstones, clays and conglomerates laying on the eroded surface of the crystalline basement are distributed in northern and eastern Estonia. Here, Vendian is not exposed, but is well represented in numerous drill cores. The closest Vendian outcrops are situated on Kotlin island in the Gulf of Finland and in the vicinity of St. Petersburg. The thickness of the Vendian rocks exceeds 100 m in NE Estonia.

Cambrian terrigenous sequence (Fig. 2) represented mostly by clays, silt- and sandstones is distributed in the whole territory of Estonia. Natural outcrops of the Cambrian are limited to the sections along the Baltic clint, an arc-shaped escarpment expressed as up to 56 m high coastal terrace in northern Estonia and continuing

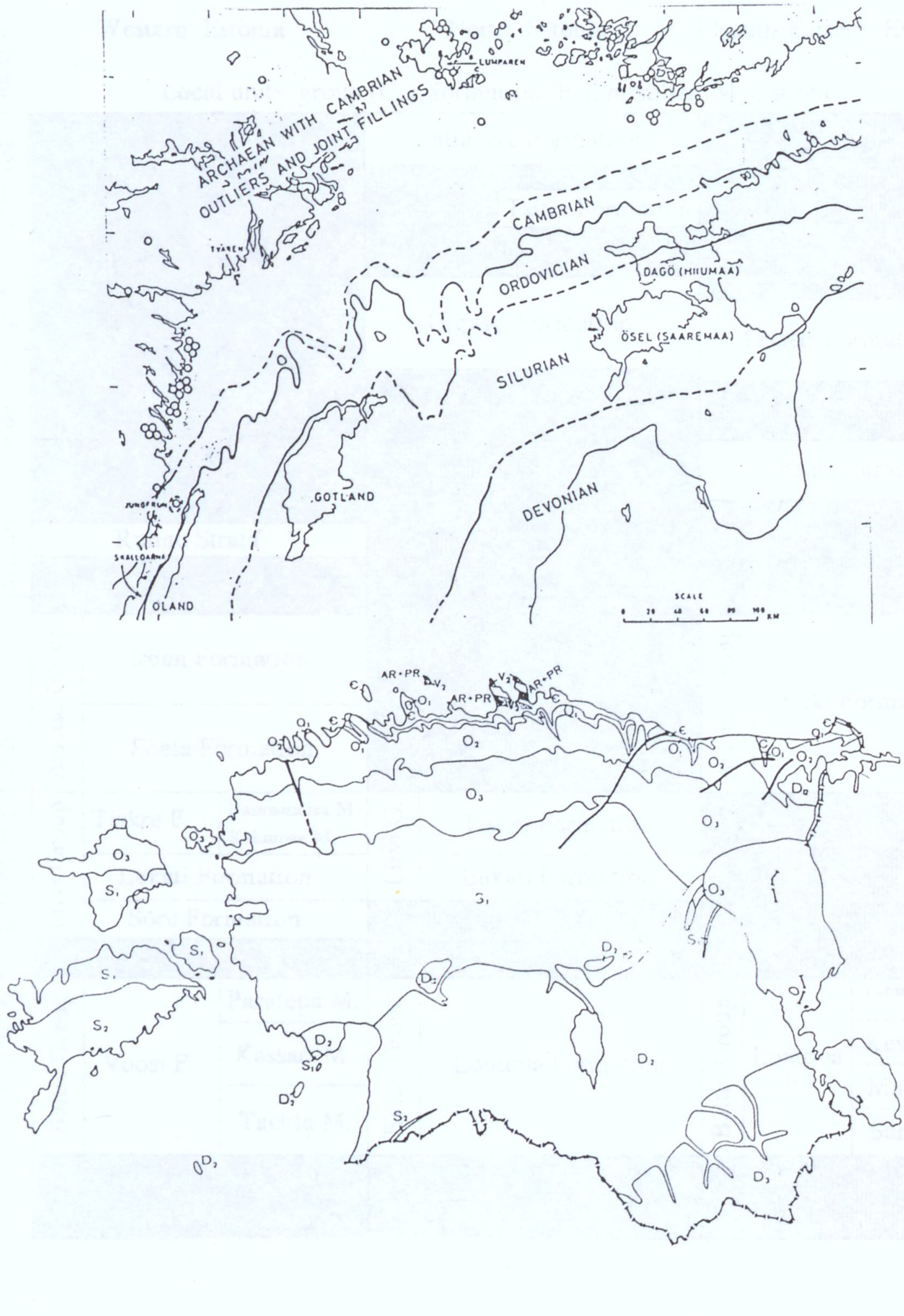


Fig. 1. Bedrock map of Estonia (from Valt, 1980) and generalized distribution of the Palaeozoic in the bottom of the Baltic Sea (from Martinsson, 1958).

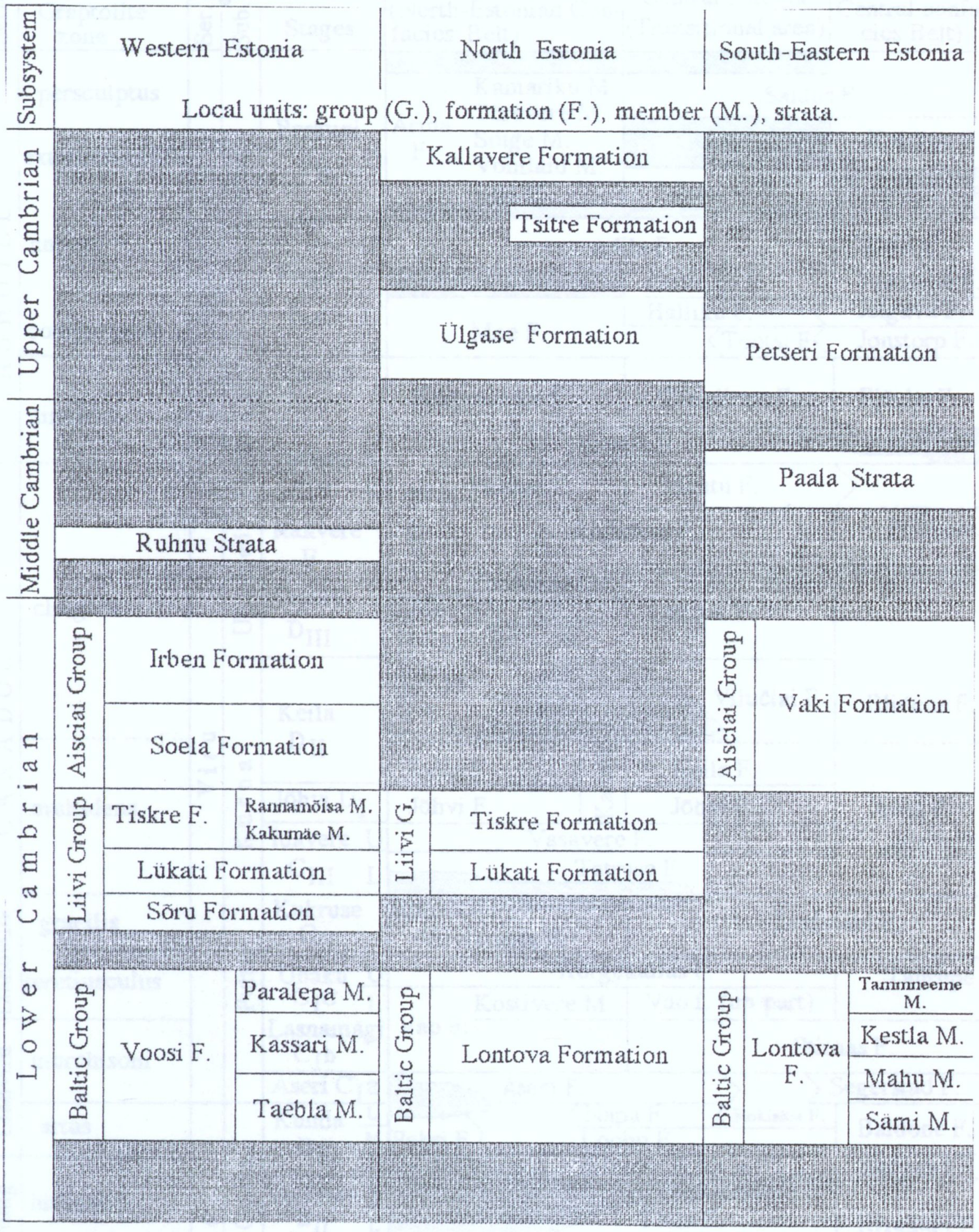


Fig. 2. Cambrian stratigraphy of Estonia (after Mens in Puura, et al., 1991).

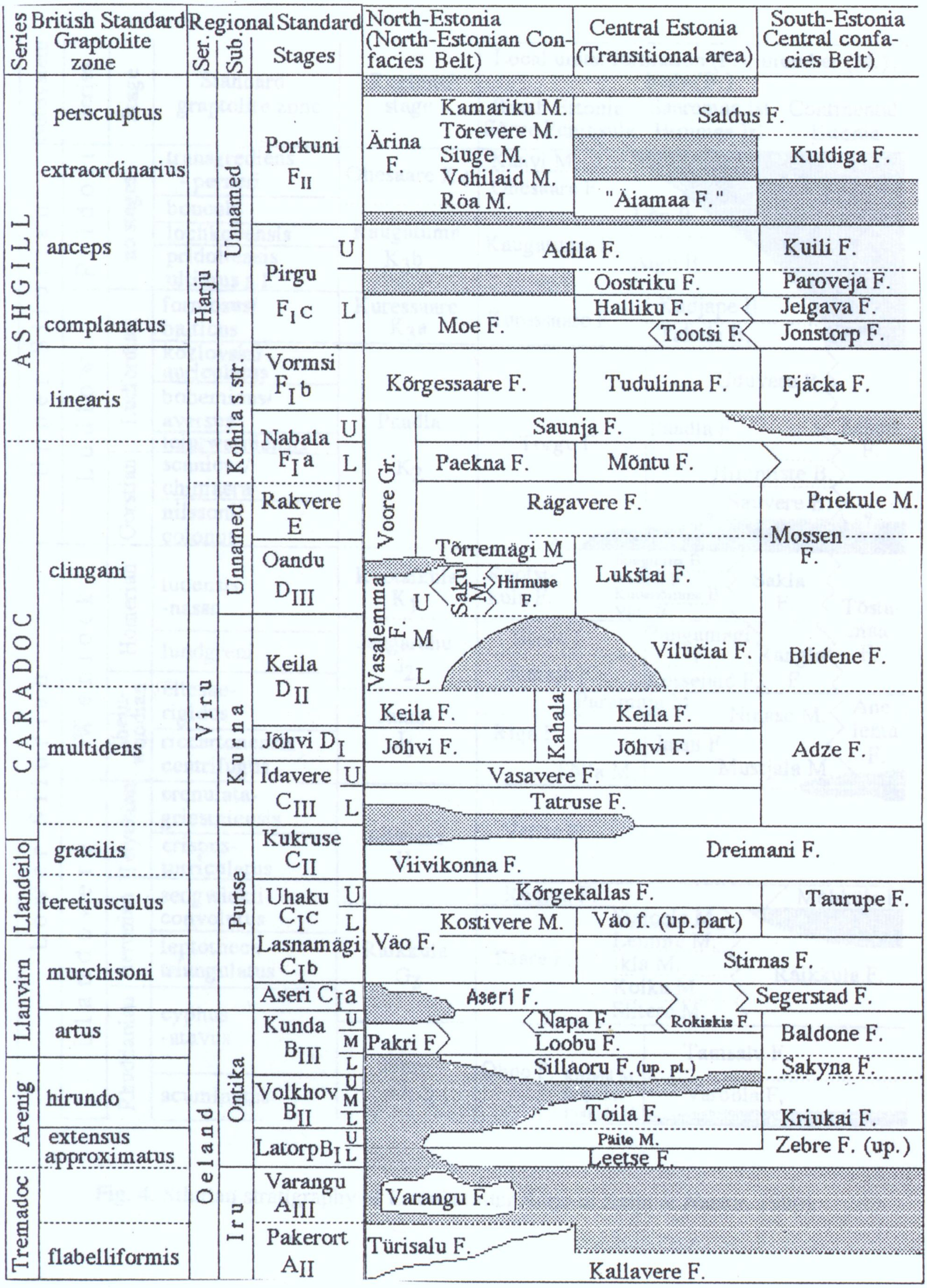


Fig. 3. Ordovician stratigraphy of Estonia (after Männil in Kaljo & Nestor, 1990)

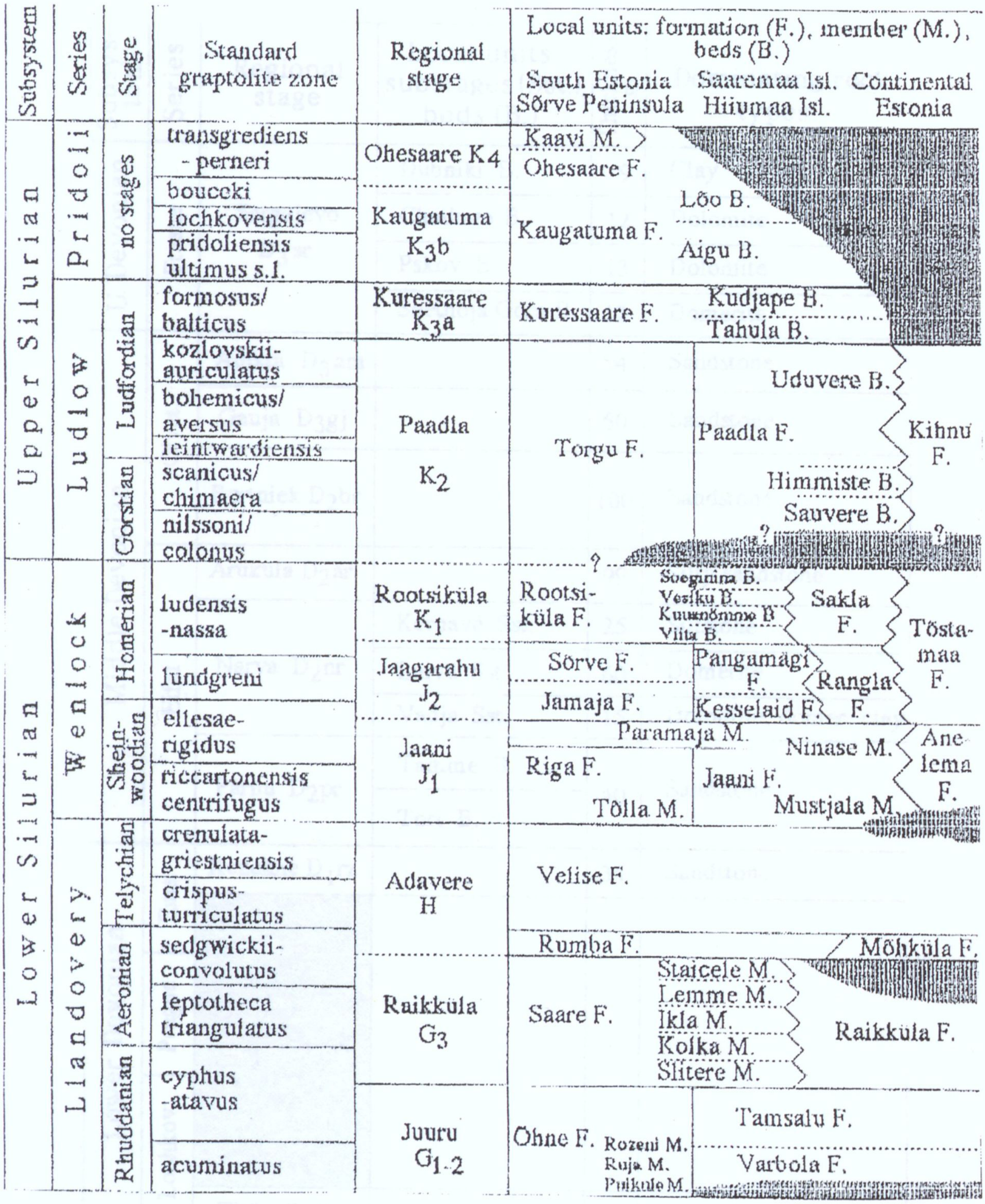


Fig. 4. Silurian stratigraphy of Estonia (after Kaljo in Kaljo & Nestor, 1990).

Subsystem	Series	Regional stage	Local units: substages (Sst.), beds (B.)	Thickness m	Dominating rock types
U. Devonian	Frasne	Sargajevo D_3sr	Dubniki B.	9	Clay
			Chudovo B.	12	Dolomite
			Pskov B.	13	Dolomite
			Snetnoja Gora B.	12	Domerite
Middle Devonian	Givet	Amata D_3am		34	Sandstone
		Gauja D_3gj		60	Sandstone
		Burtniek D_2br		100	Sandstone
	Eifel	Aruküla D_2ar		99	Silty sandstone
		Narva D_2nr	Kernavé Sst.	25	Siltstone
			Leivu Sst.	60	Domerite
			Vadja Sst.	15	Dolomite, domer, clay
		Pärnu D_2pr	Tamme B. Tori B.	40	Sandstone
Lower Devonian	Ems	Rezekne D_1rz		34	Sandstone
	Ems				
	Prague				
	Lochkov				
	Lochkov	Tilže D_1tl		22	Sandstone

Fig. 5. Devonian stratigraphy of Estonia (after Kleesment in Puura, et al., 1991).

Western Europe			East-European Plain			Estonia (Formations and subformations)	
Late Pleistocene	Weichsel	Late	Late Pleistocene	Valdai	Ostashkov (Late Valdai)	Järva	Upper Järva
		Middle			Leningrad (Middle Valdai)		Middle Järva
		Early			Olonets (Early Valday)		Lower Järva
	Eem			Mikulino		Prangli	
Middle Pleistocene	Saale	Warthe (Saale 2,3)	Middle Pleistocene	Middle Russia	Moscow	Ugandi	Upper Ugandi
		(Treene?)			Shklov (Odintsovo)		Middle Ugandi
		Drenthe (Saale 1)			Dniepr		Lower Ugandi
	Holstein			Likhvin		Karuküla	
	Elster		Early Pleistocene	Byelorussia	Oka	Sangaste	Upper Sangaste
	Cromer				Belovezhye		
					Dzukija		
				Vilnius			

Fig. 6. Pleistocene stratigraphy of Estonia and principal correlations. Based on Kajak et al., 1976; Ehlers et al., 1984, Velichko & Faustova, 1986; Raukas, 1978; Liivrand, 1991 and Raukas, 1992.

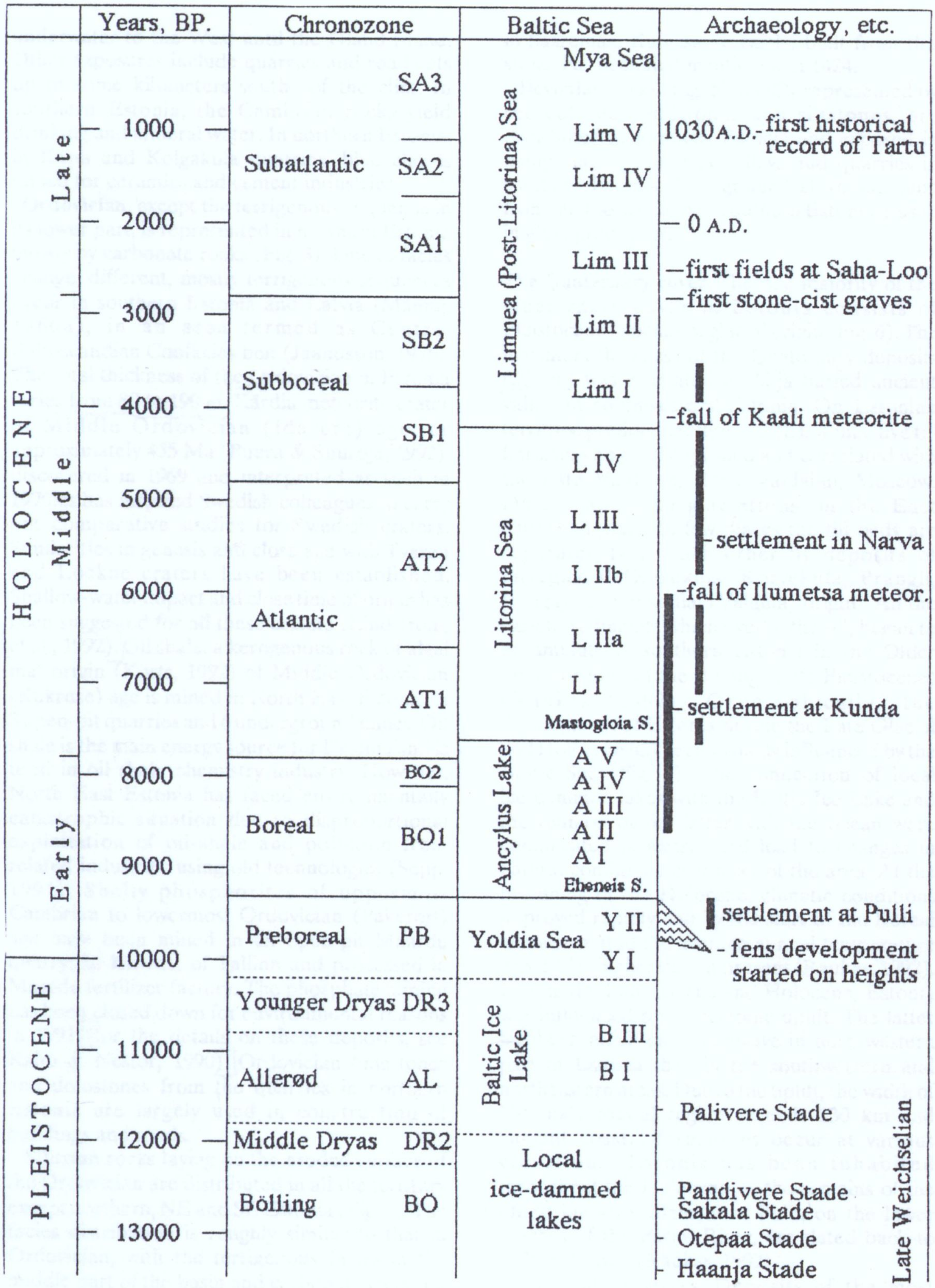


Fig. 7. Holocene and Late-Glacial stratigraphy of Estonia. Based on Kajak et al., 1976; Jaanits et al., 1982; Kessel & Raukas, 1984; Donner & Raukas, 1989; Raukas, 1992 and Lang, 1992.

underwater to the West until the Öland island. Other exposures include quarries and road cuts up to some kilometers south of the clint. In southern Estonia, the Cambrian rocks yield drinking and mineral water. In northern Estonia, in Kopli and Kolgaküla quarries, blue clay is mined for ceramics and cement industries.

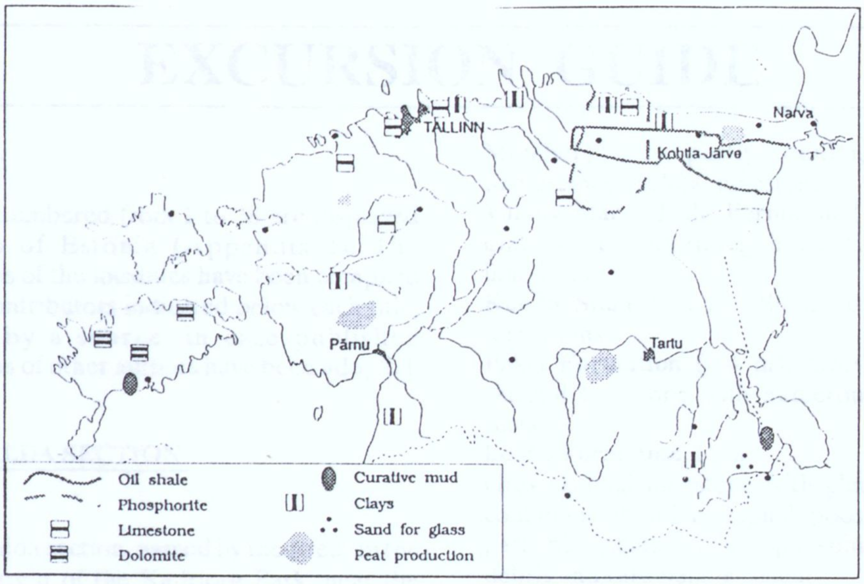
Ordovician, except the terrigenous sequence in its lower part, is represented in northern Estonia mostly by carbonate rocks (Fig. 3). Due to facies change, different, mostly terrigenous sequences occur in southern Estonia and Latvia (Männil, 1966a), in an area termed as Central Baltoscandian Confacies belt (Jaanusson, 1976). The total thickness of the Ordovician in Estonia varies from 80 to 190 m. Kärdla meteorite crater of Middle Ordovician (Idavere) age, or approximately 455 Ma (Puura & Suuroja, 1992), discovered in 1969 and interpreted as such in 1970ies has inspired Swedish colleagues to carry out comparative studies for Swedish craters. Similarities in genesis and close age with Tvären and Lockne craters have been established. Shallow-water impact and close time of origin has been suggested for all these craters (Lindström, et al., 1992). Oil shale, a kerogenous rock of algal mat origin (Kõrts, 1992) of Middle Ordovician (Kukruse) age is mined in North East Estonia in 3 open-pit quarries and 6 underground mines. Oil shale is the main energy source for Estonia and is used in oil shale chemistry industry. However, North East Estonia has faced environmentally catastrophic situation due to disproportional exploitation of oil-shale and pollution from related industries using old technologies (Sepp, 1991). Shelly phosphorites of uppermost Cambrian to lowermost Ordovician (Pakerort) age have been mined in an open-pit Maardu quarry, 10 km east of Tallinn and processed in Maardu fertilizer factory. The phosphate mining has been closed down for environmental reasons in 1991 (for the details on these deposits, see Kaljo & Nestor, 1990). Ordovician limestones and dolostones from the quarries in northern Estonia are largely used in construction of buildings and roads.

Silurian rocks laying on the eroded surface of the Ordovician are distributed in all the territory except northern, NE and SE Estonia (Fig. 4). The facies distribution is roughly similar to that in Ordovician, with the terrigenous facies in the middle part of the basin and carbonate facies on the flanks (Kaljo, 1970, 1977). Thus, in its exposure area in mid-Estonia and Saaremaa island, the Silurian is represented by carbonate rocks: limestones, marls and dolostones and in the drill cores of SW Latvia mostly by clayey and argillaceous rocks. For centuries, Silurian limestones and dolostones have been used for construction. The most famous building stone, Kaarma dolostone, comes from Kaarma quarry in Saaremaa. Kuressaare castle, built from this stone, has been first mentioned in 1424.

Devonian rocks (Fig. 5), mostly represented by red-colured sandstones and siltstones, are distributed in southern Estonia and exposed in many outcrops in river valleys and quarries in southern Estonia. Fine-grained Devonian sand from the Joosu quarry in southern Estonia is used in glass production.

The Quaternary cover. The vast majority of the Quaternary cover in Estonia consists of Pleistocene deposits of glacial origin (Fig. 6). The maximum thickness of the Quaternary deposits (207 m) was estimated in Abja buried ancient valley in southwestern Estonia. On Estonian territory, predominantly in South Estonia, five till horizons can be distiguished and correlated with the Late Valdaian, Early Valdaian, Moscow, Dniepr and Oka glaciations on the East European plain. In few places the till beds are separated from each other by deposits of interglacial (Karuküla, Kõrveküla, Prangli, Rõngu) or interstadial (Valguta) origin. All the various sediments which overlie the till, began to accumulate in southern Estonia in the Older Dryas or even in the Bölling (Late Pleistocene) (Raukas, 1992). Geographically, the development of Estonia during the Late Glacial and Holocene has been strongly influenced by the Baltic Sea (Fig. 7). The connection of local ice-dammed lakes with the Baltic Ice Lake and the reunion of the latter with the ocean were complicated processes and lead to changes in natural conditions over most of the area. At the beginning of the Holocene, climatic conditions improved rapidly and by the start of the Boreal climatic period the average annual temperature was 1-2° C higher than at present (Raukas, 1992). During the Late Glacial and Holocene, Estonia was influenced by neotectonic uplift. The latter has been much more intensive in northwestern part of Estonia than in the southwestern and northeastern areas. Due to the uplift, the width of Estonia's coastal region exceeds 130 km and ancient coastal formations occur at various elevations. Estonia has been inhabited throughout the Holocene — the remains of the oldest known settlement at Pulli, on the lower reaches of the Pärnu River, are dated back to 9575±115 B.P. (Raukas, 1992).

Mineral resources. Deposits of the most important mineral resources — oil shale, phosphorite, and carbonate rocks — are located in the northern and northeastern part of Estonia. (Fig. 8). Peat, sand and gravel resources are distributed almost evenly over the country. Two economically most important and geologically unique mineral resources are Lower Ordovician shelly phosphorite and Middle Ordovician oil shale. Unfortunately, both have been mined and



Deposits of mineral resources in Estonia

MINERAL RESOURCES

Resource	Unit	Explored resources	Mined in 1991
Oil shale	million tons	3,800	19.6
Phosphorite	million tons*	750	-
Limestone, dolomite	million m^3	250	3.1
Sand, gravel	million m^3	150	6.9
Peat	million tons	2,400	1.8
Lake mud	million tons	120	0.001
Sea mud	million tons	3.7	0.005

* as calculated per P_2O_5

Fig. 8. Mineral resources of Estonia (from National Report..., 1992).

industrially used for more than half a century in environmentally hazardous ways devastating large regions in northern and north-eastern Estonia.

The World's largest exploited oil shale deposits (3,800 million tons) in the northeast of Estonia form the basis for power production and chemical industry. Oil shale is mined in 3 quarries and 6 underground mines. In 1991, 10 million tons of oil shale was produced in mines and 9.6 million tons in quarries. The mined area was 380 and 291 hectares, respectively.

Phosphorite deposits (estimated as 750 million tons P_2O_5) are the largest in Europe. Until 1991, phosphorites were mined in the Maardu quarry, west of Tallinn, before the quarry was closed under the pressure of public opinion, because the technology and methods used caused serious damage to the environment.

Technological supplies of Ordovician and Silurian limestone include 100 million tons of cement limestone, 31 Mt suitable for lime and 1.8 Mt for glass production. The total explored resources of limestone and dolomite constitute 250 million cubic metres.

Explored resources of Quaternary sand and gravel (150 million cubic metres) are mostly of glacial origin. The value of such material has often been underestimated and as a result, in some parts of Estonia the resources of sand and gravel are almost exhausted.

There are 1598 bogs and fens in Estonia, with peat resources of industrial importance covering over 10 ha each. Peat, with the explored resources exceeding 2.400 million tons, is used in cattle-breeding and as fuel and fertilizer.

Sea and lake muds (3.7 and 120 million tons, respectively) have been used as curative muds since the beginning of the 19th century.

Mineral water is in use in many parts of Estonia. The total reserves at the five larger deposits: Häädemeeste, Ikla, Kärdla, Kuressaare and Värska reach 4700 cubic metres per day (National Report of ..., 1992).

EXCURSION GUIDE

GENERAL

Localities numbered from 1 to 38 are displayed on a map of Estonia (Appendix 2). The descriptions of the localities have been compiled by many contributors indicated below each title, followed by a source, in case published descriptions of other authors have been adopted.

1. MÄEKALDA SECTION

Ivar Puura

The Mäekalda section, named by the street in the eastern margin of the Kadriorg Park, near the centre of Tallinn, is exposed in a fresh roadcut for the construction of a new motorway since 1986. The sequence of Lower Palaeozoic rocks, from the siltstones of the Lower Cambrian Tiskre Formation to the Middle Ordovician Lasnamägi Stage is exposed. The following generalized description is adopted from detailed descriptions by Mens et al. (1989) and Mägi (1990). Stratigraphic units are followed by their thickness in brackets.

Lower Cambrian. Tiskre Formation (1 m +). Greenish-gray argillaceous sandstones.
Upper Cambrian. Ülgase Formation (3.2 m.). Light-grey coarse- grained siltstones intercalated by grey clays or argillaceous siltstones.
Uppermost Cambrian to Lower Ordovician. The Kallavere Formation.
The Maardu Member (1.5 m). Light-yellow quartzose sandstones, with frequent thin (from some mm to 10 cm) intercalations or films of dark kerogenous argillites. A lingulate brachiopod *Ungula ingrica* is abundant in basal coquina. In the areas where this coquina is thicker, it has been commercially mined as shelly phosphorite.
The Suurjõgi Member (0.9 m). Brownish-grey, fine- to medium-grained cross-bedded sandstones containing rounded brachiopod debris in high concentrations.
Lower Ordovician. Pakerort Stage. Türisalu Formation (4 m). Dark- brown to black kerogenous argillite (known as *Dictyonema* shale). Known to cause environmental problems when relocated in connection of mining the underlying shelly phosporite, because of self-ignition of organic matter and leaching of heavy metals.
Varangu Stage Varangu Formation (0.25 m). Beige argillite.
Latorp Stage. Leetse Formation (2.3 m). Greenish glauconitic siltstones and sandstones, with interbeds of clay. Upper 0.3 m (Päite Member): grey, partly nodular, dolomitized fine-grained skeletal limestone.
Volhov Stage. Toila Formaton (2.5 m). Grey, glauconite containing hard dolomites and limestones.
Kunda Stage (1.4 m). Subdivided into three formations:
Pakri Formation (0.4 m). Grey fine-grained skeletal limestone with numerous dicontinuity surfaces.
Loobu Formation. (1 m).
Grey skeletal limestone with glauconite grains containing abundant cephalopods. In the upper part, phosphatic oolites, phosphatized skeletal debris and rare pebbles occur.
Aseri Stage. Aseri Formation. (0.45 m). Grey fine-grained skeletal-oolitic limestone, rich in goethite oolites in middle part, with three levels of limonitized hardgrounds. Lower part contains rare fine glauconite grains.
Lasnamägi and lowermost Uhaku stage. Väo Formation (8.45 m).
Skeletal limestone with frequent argillaceous and up to 3 cm thick marly intercalations. The rock is bioturbated, containing numerous subvertical brownish burrows filled with clay. Rare white and brown goethite oolites occur at the base.
Uhaku Stage. Kõrgekalda Formation. (0.5 m +). Greenish-grey argillaceous fine-grained skeletal limestone with irregular nodular or wave bedded structure marked by argillaceous intercalations.

2. "CHAPEL STONE", A GLACIAL ERRATIC AT MUUGA.

Juho Kirs

The "Chapel Stone", the second biggest glacial erratic boulder in Estonia is located near by Tallinn, at Muuga Bay. Petrographically, the erratic is a viborgite-type rapakivi granite, containing K-feldspar ovoids, mantled by plagioclase. Its length, width and height are 19.3, 14.9 and 6.4 metres, respectively, the circumference 58.0 m and the volume above the surface 728 m^3. In the catalogue of Estonian big erratic boulders about 2000 erratics with the measures over 3 m are listed, including 60 boulders with a diameter exceeding 10 m (Viiding, 1986).

3. MAARDU QUARRIES

Tiia Kurvits

In Maardu quarries, located near Maardu settlement at the Eastern border of Tallinn, shelly phosphorite has been mined from 1940 to 1991. In 1921 the joint-stock company "Eesti Vosvoriit" started to mine phosphorite in nearby Ülgase quarry. The first quarry near Maardu was opened in 1940. During the following years, the mining extended and many quarries were developed. In the beginning, 2-3 m thick phosphorite beds with P_2O_5 content from 20 to 25 % laying on the surface were exploited; after the exhausting of the richer parts, the phosphorite beds only 0.3-0.4 m thick, containing 9.5 % P_2O_5 laying in the depth from 10 to 20 m were also included to exploitation. Phosphorite mined at Maardu has been used for making quite ineffective phosphorite flour, or used as an additional component in the production of superphosphate, the production of which in the Maardu Chemical Factory has been based on apatite imported from Kola Peninsula (Raudsep et al.,1991). Phosphorite mining, becoming economically unsound and environmentally hazardous mainly because of the leaching and self-ignition of the *Dictyonema* shale relocated from the beds overlying the phosphorite layer, was finished in Maardu in 1991 under public pressure. The sequence of Lower Ordovician rocks is analogous to that in Mäekalda section.

4. JÕELÄHTME STONE-CIST GRAVES

Volli Kalm

The earliest cemetery of stone-cist graves in Estonia (Bronze Age, 800 BC) was discovered at Jõelähtme. Such graves continue into, and are typical of the Pre-Roman Iron Age of Estonia (Lang, 1992). In 1982-1985, 36 burial mounds were studied at Jõelähtme. The limestone cists contained inhumation burials, together with numerous artifacts typical of Jutland or southern Scandinavia (razors, tweezers, bronze buttons), proving the connection with these areas (Lõugas, 1992). The opened stone-cist graves form an outdoor exibition right aside of the Tallinn - Narva motorway, 15 km east of Tallinn.

5. KOSTIVERE KARST FIELD

Erik Puura (after Heinsalu, 1991)

In northern Estonia, karst is often developed in the carbonate bedrocks of Ordovician and Silurian age. Kostivere karst field, 20 km east of Tallinn, south of Tallinn-Narva motorway displays most of the characteristic features formed in karst processes: hollows, sink holes, sink basins and caves occurring in the limestone beds of Lasnamäe Stage (Middle Ordovician). Under the 2.9 km long and 0.5 km wide karst field (Fig. 9), along a complicated underground system of karst hollows flows Jõelähtme river. Except the solubility of carbonate rocks and availability of the solvent (water), the tectonical dislocations have played a significant role in the karst development. The differential dissolution of harder limestones and softer marls has resulted in a variety of picturesque karst features, such as 'stone table' portraying a huge mushroom or 'cattle cellar', a 6 to 4 m cave reaching 2.5 m in height. The influence of karst is documented as deep as 30 m. Here, like in other karst areas, any pollution endangeres the ground water.

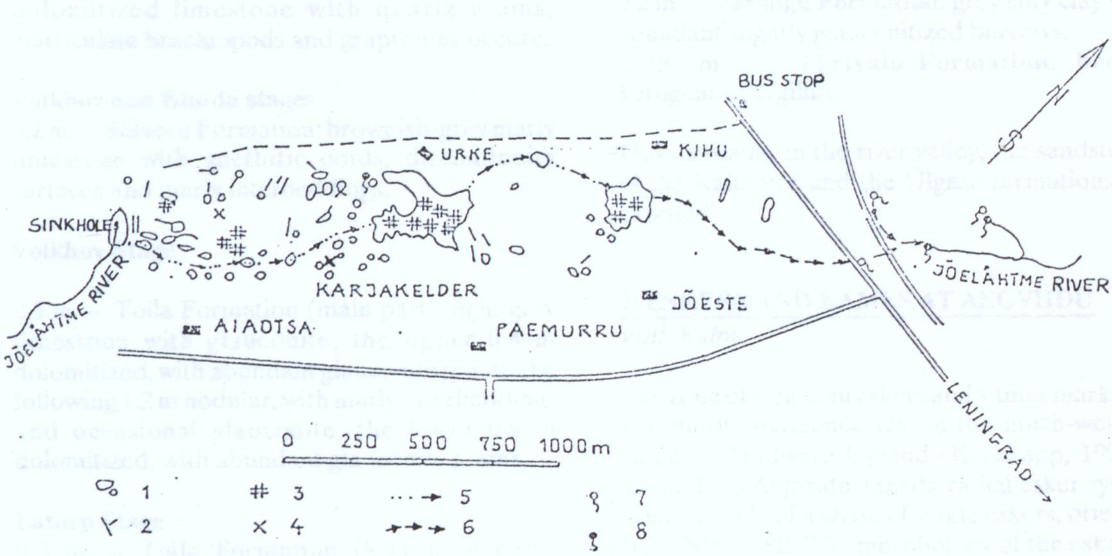


Fig. 9. Kostivere karst field. 1 - dolines (sink holes), 2 - channels along fractures, 3 - hums, 4 - cave Karjakelder, 5 - man-made channel, 6 - subaerial stream during high water, 7 - temporary springs, 8 - permanent springs.

6. JÄGALA FALL

Tõnu Meidla (adopted from Mägi, 1991)

Near the northern coast of Estonia, south of the North Estonian clint, several rivers and streams have cut deep valleys into the Ordovician carbonate bedrock. This has been explained by a continuous neotectonic land rise related to glacioisostasy. Jägala Juga (the Jägala Fall), the highest natural waterfall in Estonia is about 8 metres high. The water is falling from an escarpment in the valley of Jägala river, located 3 km south of the North Estonian clint and moving continuously southwards, nearly 3 m per 100 years.

The bedrock sequence exposed in the escarpment (Fig. 10), and the sections downstreams represent outcrops well known already in last century, from where many Estonian fossils deposited in different museums of the World originate.

Above the waterfall escarpment, marly limestone of the Aseri Stage is exposed (exposed thickness 0.6 m+). Goethitic ooids occur in the upper, and phosphatic ooids in the lower part of the bed; cystoids and nautiloids are common.

On the right bank of the river the section is as follows (adopted from Mägi, 1991, from the top):

Kunda Stage

2.65 m – **Loobu Formation:** grey to yellowish-grey thick-bedded dolomitized limestone with glauconite, with abundant phosphatic discontinuity surfaces and brachiopods.

0.1 m – **Pakri Formation**: yellowish-gray dolomitized limestone with quartz grains; inarticulate brachiopods and graptolites occure.

Volkhov and Kunda stages

0.2 m – Sillaoru Formation: brownish-grey marly limestone with goethitic ooids, discontinuity surfaces and marly interbeddings.

Volkhov Stage

2.5 m – Toila Formation (main part): light grey limestone with glauconite; the upper 0.4 m dolomitized, with abundant glauconite grains, the following 1.2 m nodular, with marly interbeddings and occasional glauconite, the lower 0.9 m dolomitized, with abundant glauconite grains.

Latorp Stage

0.3 m – **Toila Formation** (lowermost part): dolomitized glauconitic limestone.

1.2 m – **Leetse Formation**: in the uppermost part quartz- glauconite sandstone with carbonate cement, in main part poorly cemented glauconite sand with clay supplement.

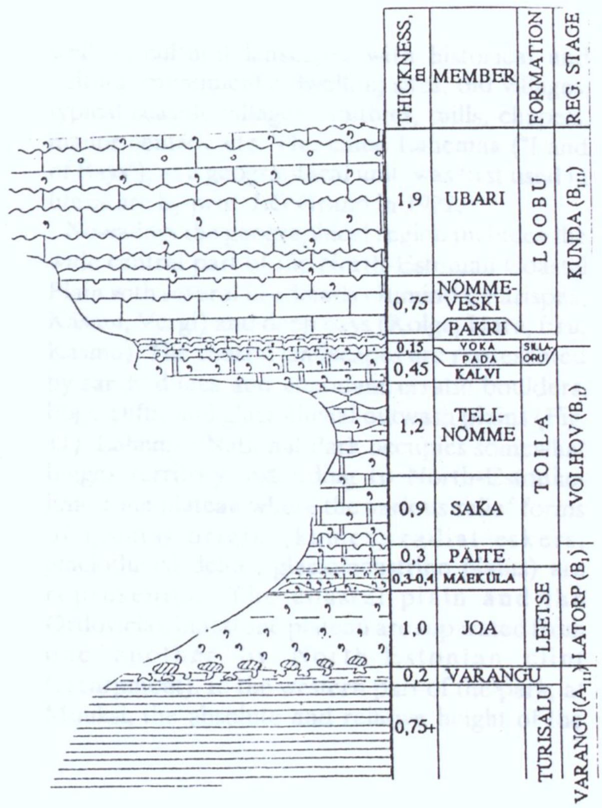


Fig. 10. Lower Ordovician sequence at Jägala Juga.

Varangu Stage

0.2 m – **Varangu Formation**: grey silty clay with abundant slightly glauconitized burrows.

0.75 m – **Türisalu Formation**: brown kerogenous argillite.

Downstreams, in the river valley, the sandstones of the Kallavere and the Ülgase formations are exposed.

7. ESKERS AND KAMES AT AEGVIIDU

Volli Kalm

The zone of Aegviidu eskers and kames marks the margin of continental ice on the north-western slope of Pandivere Upland (Karukäpp, 1991a). 25 km long Aegviidu-Jäneda radial esker system is an example of a chain of single eskers, oriented from NW to SE. The morphology of the eskers is typical of North Estonia: the considerably narrow ridge has a sharp crest and steep slopes (Karukäpp, 1992). The glaciofluvial gravelly-pebbly deposits are rich in carbonate material of local Ordovician bedrock. Eskers and associated kames belong to the formations of

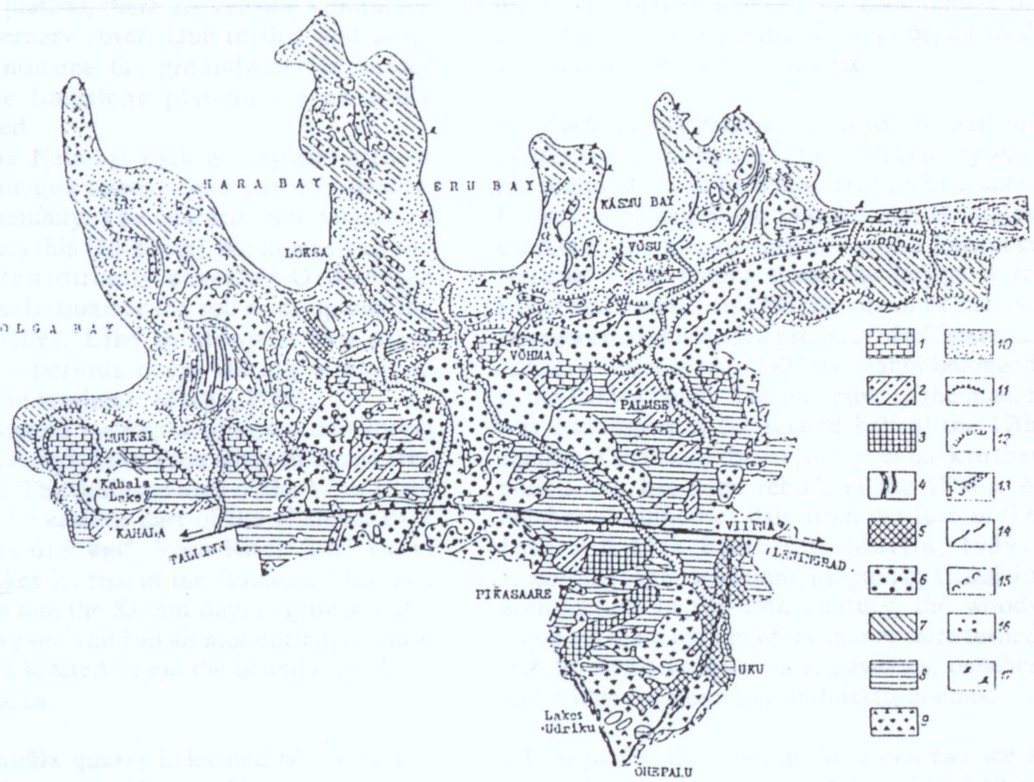
Pandivere Stade of Late Weichselian (dated back about 12.500 years), when the upland itself was almost free, but surrounded from north and north-west by active continental glaciers. Eskers and kame-fields at Aegviidu are accompanied by comparatively deep depressions of buried ice, nowadays occupied by lakes of Nikerjärv (7 m), Vahejärv (5 m), Urbukse (8.5 m), Sisaliku (8.7 m) ja Purgatsi (13 m).

8. LAHEMAA NATIONAL PARK

Volli Kalm , Kaisa Mens & Juho Kirs

Lahemaa National Park, 650 km^2 in area, was founded on June 1, 1971. The predominant part (70%) of the park is composed of natural landscape and reserve. Cultural landscapes (30%) made up of cultivated lands, forest land, recreation areas and villages. The task of the park is to preserve and protect, to investigate and introduce ecosystems typical of North Estonia, as well as cultural lanscapes with historical and cultural monuments: dwelling sites, old villages, typical seaside villages, smithies, mills, chapels, manor centres, etc. The name Lahemaa ("Land of Bays"), as a geographical unit, was first used in literature by prof. J.G.Granö in 1922.

Nowadays the geographical region includes the wide central part of the North-Estonian Coastal Plain with several headlands (Juminda, Pärispea, Käsmu, Vergi) and deep bays (Kolga, Hara, Eru, Käsmu). The coastal landscapes are represented by sandy dunes and abundant erratic boulders, bogs, cliffs, and glaciofluvial outwash plains (Fig. 11). Lahemaa National Park occupies somewhat bigger territory, extending to North-Estonian limestone plateau where the various relief forms of glacial origin (kames, radial eskers, glaciofluvial deltas, glaciolacustrine plains) are represented. The coastal plain and the Ordovician limestone plateau are separated from one another by North-Estonian clint (escarpment). In the western part of the park, at Muuksi, the absolute and relative height of the



Legend: 1- alvar, 2- till plain, 3- hummacky moraine; 4- radial eskers; 5- kame field; 6- glaciofluvial delta; 7- abraded till plain; 8- glaciolacustrine plain; 9- bog; 10- accumulative terraces of Baltic Sea; 11- North Estonian Cliff (escarpment, glint); 12- cliff in Quaternary deposits; 13- valley; 14- bars; 15- dunes; 16- fields of erratic boulders; 17- gigantic erratic boulders.

Fig. 11. Geomorphology of Lahemaa National Park (by R.Karukäpp and E. Linkrus).

clint reach 47 m and 20 m, respectively. At the edge of the limestone plateau there are some canyon-like river valleys (Valgejõgi, Loobu) with Cambrian- Ordovician outcrops and waterfalls in some places (Nõmmeveski, Vasaristi, Joaveski).

The glacier (Late Weichselian) retreated from the present National Park area between 12.500 to 11.500 BP. (Raukas, 1992). After that the area was submerged by late and postglacial water basins. The Baltic Ice Lake, the first stage of development of the Baltic Sea, covered the major part of the present National Park. Landforms developed during the maximum extension of that basin are located at 68-70 m a.s.l. The shoreline of the transgressive phase of the Ancylus Lake in the Lahemaa area lies at the height of 28-30 m a.s.l. During the maximum extent of the Litorina Sea, the water level in Lahemaa was 16-19 m higher than that at present. All the present headlands represent former islands that were joined to the mainland during the Post- Litorina time.

The thickness of Quaternary deposits in park area ranges from 1 to 20 m. However, on limestone plateau, there are regions with rather thin Quaternary cover. Due to that and some karst phenomena the groundwater resources within the limestone plateau are naturally unprotected.

Lahemaa National Park is a typical area of *alvars*, a unique terrain type with the specific plant community. The characteristic feature of alvars is very thin (10-20 cm), but humus-rich soil layer, often directly covering Ordovician limestones. In summer the soil dries up and the plants wither. Like in steppes, two plant recreation periods occur during a year: in summer and in winter (Martin, 1989).

An integrated hydrogeoecological monitoring has been carried out in Võsu River drainage area since 1992. The drainage area of the Võsu River occupies the eastern part of the National Park and covers 61.9 km^2. Võsu River (23.3 km in length) takes its rise in the Rauasoo Mire and discharges into the Käsmu Bay. 17 ground water exploratory wells and an air monitoring station at Palmse are located within the boundaries of this drainage area.

8.1. Kolgaküla quarry is located 60 km east of Tallinn, 6 km north of Tallinn-Narva motorway at a side road to Loksa. Here, the blue clay of Lower Cambrian Lontova and Lükati formations is exposed. The quarry is presently run by a company selling Lower Cambrian argillaceous rocks ('blue clay') mainly to the Tallinn Building Ceramics Factory as a raw material for rough ceramic products.

The Lontova Formation.
The Kestla Member (5 m +).
Multicoloured (red-brown and violet in greenish-grey) clay containing numerous pyritized trace fossils.
The Tammneeme Member (3.5 m). Greenish-grey silty clay, showing affinity to the rocks of the overlying Lükati Formation. From this level, *Platysolenites antiquissimus* and various pyritized trace fossils have been found. Lower boundary distinct, expressed in colour change and the decrease of silty component below the boundary level.

The Lükati Formation (4 m +). Greenish-gray clay with rare thin siltstone intercalations, with various imprints of bioglyphs abundant on their lower surfaces. Pyrite, glauconite and phosphate are common both in clay and siltstone layers. Tests of *Volborthella*, arenaceous foraminifers ("*Luekatiella*"), trilobite and lingulate brachiopod fragments have been found. Pyritized trace fossils are not very common. Lower boundary is lithologically indistinct despite the hiatus, in places marked by thin lenses of conglomerate containing dark phosphatized siltstone pebbles in clayey matrix.

8.2. The Manor of Palmse. The history of manoral estates in Estonia began in the 13th century with the conquest of the Estonian territory by Danes. In the second half of the 15th century, 14 estates existed on the present territory of the Lahemaa National Park; among them, the largest were Kolga and Palmse. In 1286 the manor of Palmse was recorded as a landed property of a Cistercian nunnery. From 1673 to 1923 the manor belonged to the Pahlen family. The ensemble of the manor was established in the second half of the 17th century. The manor- house, too, goes back to that period, but has been rebuilt in the 1780-s. A number of outhouses date from the turn of the 18th and 19th centuries (Martin, 1989). According to the traditions adopted by Classicist architecture in the 19th century, the woods adjoining the buildings of the manor were turned into forest parks with ways, pavilions, benches and bridges representing architectural units.

8.3. Altja. On the coast at Altja one can see a typical North- Estonian coastal boulder belt of originally glacial erratics. The provenance area of most of the boulders is Southern Finland. On the initiative of late Dr. Herbert Viiding and the staff of Lahemaa National Park, an open-air museum of erratics was established here. Prevailing rock type in the open-air museum is rapakivi from Wiborg batholith, followed by svecofennian gneisses, migmatites, granites and amphibolites. Olivine diabase and Jotnian sandstone from Satakunta, helsinkites, uralite porphyrites from Pellinge and Tammela are rare rock types in this area. At the Altja coast, in shallow water behind the netsheds, a gigantic viborgitic erratic, called "Babystone", is located. (Viiding, 1981).

9. VIRU PEAT-BOG

Hella Kink

Mires cover approximately 9150 km^2 (21.5%) of Estonian territory. Fens (eutrophic mires) make 57%, transitional (mesotrophic) mires 12%, and bogs (oligotrophic mires) 31% of this (Orru, 1992).

Viru peat-bog (oligotrophic mire), located within the boundaries of Lahemaa National Park, covers an area of 235 hectares. Peat layer is underlain by Ordovician limestones covered by 4-6 m thick bed of till and glaciofluvial deposits. In the northern part of peat-bog area 0.2-1 m thick gyttja layer separates the peat from clastic sediments on the bottom. After the lowering of the water level in the end of Baltic Ice Lake, a lake formed in a depression of Viru bog. Peat accumulation started in this area in the middle of the Atlantic Climatic Period, i.e. ca. 5000 years ago. At present the peat layer thickness reaches 6 m, being 3.4 m in average. From the area of 35 hectares peat was produced until 1986. In 1983 a net of stations for hydro-geological and hydrochemical monitoring was established (Kink, 1991a).

10. VIITNA KAME FIELD, ESKER AND LAKES

Volli Kalm

Viitna kame field, about 3 km^2 in area, is one of the most peculiar and distinctly formed radial formations in the Lahemaa National Park. It is situated in the depression (20-25 m) of an ancient relief. The relative height of kames is between 10-25 m, altitude up to 100 m a.s.l. (Karukäpp, 1991b). The kame field is associated with Viitna - Ohepalu radial esker of northeast-southwesterly orientation. Esker has a sharp crest and deep (up to 40°) slopes. Kames alternate with kettle-holes of various configuration, mainly of thermokarstic origin. Three of them are occupied by lakes. The deepest parts kettles are fulfilled by lacustrine sediments and peat. The thickness of gyttja in Lake Linajärv ranges between 2 to 8 m, in Lake Pikkjärv up to 5 m, and in Lake Nabudi - 10 m. The palynological data show that the deposition of lacustrine sediments started in Preboreal (Karukäpp, 1985).

The formation of the Viitna radial glacial complex is closely connected with the recession of the continental ice during the Pandivere Stade (12.500 B.P.). The active ice on the Pandivere upland and on its slopes gradually turned into "dead" ice with a dense network of cracks and crevasses. First of all in the disintegrating marginal zone of ice in open crevasses the esker was formed, whereas later, in more broken ice the meltwater flew between separated blocks of ice and kames were formed (Karukäpp, 1985).

11. ESKER AND LAKES AT NEERUTI

Volli Kalm

Northwest-southeasterly oriented radial eskers system at Neeruti, on northern part of Pandivere Upland is about 16 km in length; relative height of ridges reaches 30 m (Karukäpp, 1991b). Numerous (up to 6) ridges of subparallel eskers, branching and joining up, form a braided drainage pattern (Karukäpp, 1992). Depressions between single esker ridges are occupied by lakes. The esker system, as a whole, is a big gently sloping landform with a great number of kettle-holes on its surface. The glaciofluvial deposits of the eskers are mostly coarse-grained (pebble and gravel) and rich (65-90%) in carbonate material derived from local bedrock (Raukas et al., 1971). In some places melt-out till can be observed on surface of eskers, giving the proof of englacial formation of eskers. In depressions, around the lakes, peatlands came into being as a result of filling up of shallow water zone. 4 m thick peat layer underlain by another 4 m of glaciolacustrine clayey silts and sands was established in borehole, located in one of the depressions.

12. PORKUNI QUARRY AND LIMESTONE MUSEUM

Tiia Kurvits (adopted from Nestor, 1990)

In an abandoned quarry located on the western slope of the river valley by the Tamsalu - Kullenga road 1 km west of Lake Porkuni, Upper Ordovician skeletal and reef limestones are exposed. The outcrop is as a stratotype of the Porkuni Stage, the youngest regional stage of the East Baltic Ordovician. A very rich assemblage of fossils has been established here including more than 150 species, among them at least 45 holotypes. In the middle of the western quarry wall, the following sequence is exposed (description adopted from Nestor, 1990; thicknesses of the beds indicated in brackets).

Porkuni Stage. Ärina Formation. *Tõrevere Member* (1.0 m +). Light-grey indistinctly wave-bedded to massive coral- stromatoporoid limestone with microcrystalline matrix. The rock contains abundant stromatoporoids, tabulate

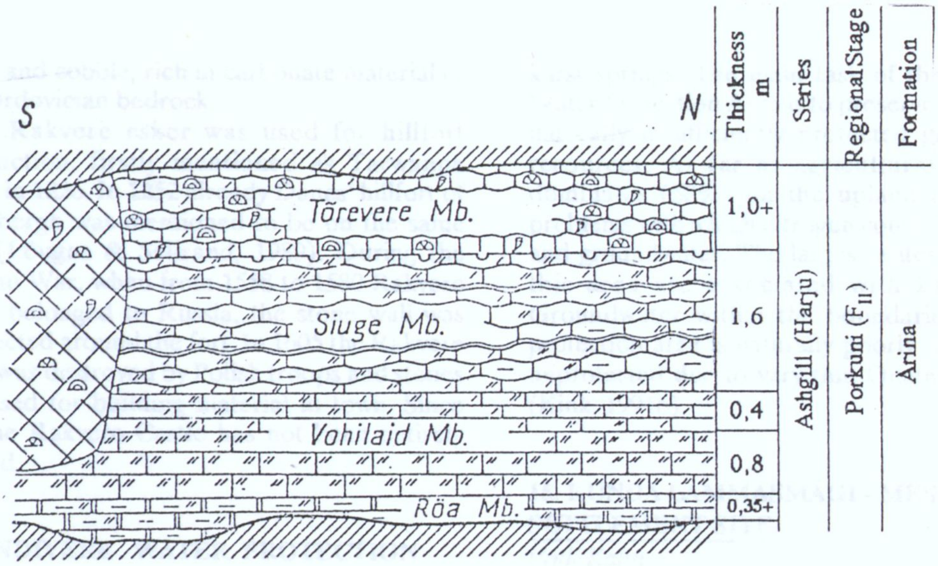


Fig. 12. Upper Ordovician sequence in the Porkuni quarry.

and rugose corals. The lower boundary of the layer is represented by an indistinct hardground. *Siuge Member* (2.0 m). Yellowish-grey lenticular-nodular or horizontal-bedded finegrained skeletal packstone. This level has yielded a great part of ostracodes, gastropods, trilobites and fragments of pelmatozoans, brachiopods, bryozoans and algae as well.
Vohilaid Member (0.8 m). Light-grey thick-bedded to massive skeletal grainstone, mostly composed of the fragments of pelmatozoans, bryozoans and brachiopods.
Röa Member. (0.35 m +). Light-grey massive fine-porous argillaceous dolomite with partly preserved crinoid columnals.

In the southern wall of the quarry a bioherm is exposed. The thickness of the bioherm is over 3 m, the visible horizontal section exceeds 6 m. The frame is composed of corals, stromatoporoids, bryozoans.

Lithologically the Ärina Formation of the Porkuni Stage differs considerably from the underlying Ordovician stages, represented by open-shelf nodular packstones and wackestones of quiet-water genesis. The appearance of skeletal crinoidal grainstone of the Vohilaid Member marks abrupt lowering of the sea level, in the result of witch the area fell into the agitated-water environment.

Limestone Museum. Near the quarry, the Limestone Museum opened in 1992. Limestone is the main natural rock type, used in buildings in West and North Estonia. In the Museum, various types of limestone are exposed, e.g., so-called "marble of Vasalemma" - the bedded skeletal grainstone, "marble of Saaremaa" - the microbedded dolomite from Kaarma, Saaremaa, and "ring rock" - the limestone containing abundantly columnals of crinoids from Kaugatuma, Saaremaa.

13. RAKVERE ESKER AND CASTLE

Volli Kalm

The Pahnimäe - Rakvere - Koeravere chain of radial eskers consists of four single esker ridges, the highest (relative height 26 m) being the Rakvere esker. A characteristic feature of the chain of eskers is the decreasing relative height (3-5 m) towards the distal (southern) end of the chain (Raukas, et al., 1971). The Rakvere esker, 2 km in length and up to 300 m in width, consists of coarse grained glaciofluvial sand, gravel,

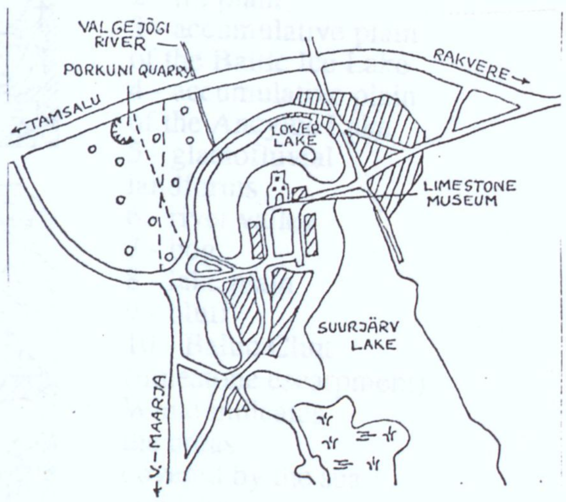


Fig. 13. Location of Porkuni quarry and Limestone Museum.

pebble and cobble, rich in carbonate material of local Ordovician bedrock.

The Rakvere esker was used for hillfort construction, firstly mentioned as Tarwanpe hillfort in 1226. In 1252 already Danes' hillfort of Wesenbergh was mentioned to be on the same place (Lõugas & Selirand, 1989). During the Livonian War, when from 1558 to 1580 Rakvere hillfort belonged to Russia, the stone wall was constructed around the fort. In 1605 the Rakvere Castle was destroyed by Polish troops and stones were used for building material in town. Since then the Rakvere Castle has not been entirely restored.

14. PANDIVERE WATER PROTECTION AREA

Hella Kink

Water protection area covers the central part of Pandivere Upland. The territory of the water protection area is 350,000 hectares, of which 135,000 hectares, or 38% are under forest. Bedrock in water protection area consists of Ordovician and Silurian limestones, dolomites and marls in which the karst phenomena have developed. Karst lakes and springs are very common in this area. The majority of North-Estonian rivers take their beginning from karst springs. The main task of the Pandivere Water Protection Area is to preserve and protect naturally insufficiently protected groundwater resources. As far as agricultural landscape dominates (58%) on the upland there are a problems with a high nitrogen content in surface- and groundwater. The largest water supplies in this area are associated with karst zones. Groundwater within the boundaries of water protection area is naturally poorly protected or unprotected due to very thin Quaternary cover (Kink, 1991b).

15. KUNDA LAMMASMÄGI - MESOLITHIC SETTLEMENT SITE

Volli Kalm

The first traces of human settlement in Estonian territory belong to the middle of the 8th millenium B.C. (10th millenium B.P., the Preboreal climatic period). At that time, a settlement existed near the village of Pulli on the right bank of the Pärnu River. The site of Kunda in northern Estonia which has given its name to the Mesolithic culture of Estonia is one thousand years younger than the Pulli settlement. At Kunda the settlement was situated on an island (Lammasmägi) of a former lake, which became separated from the sea early in the Yoldia period.

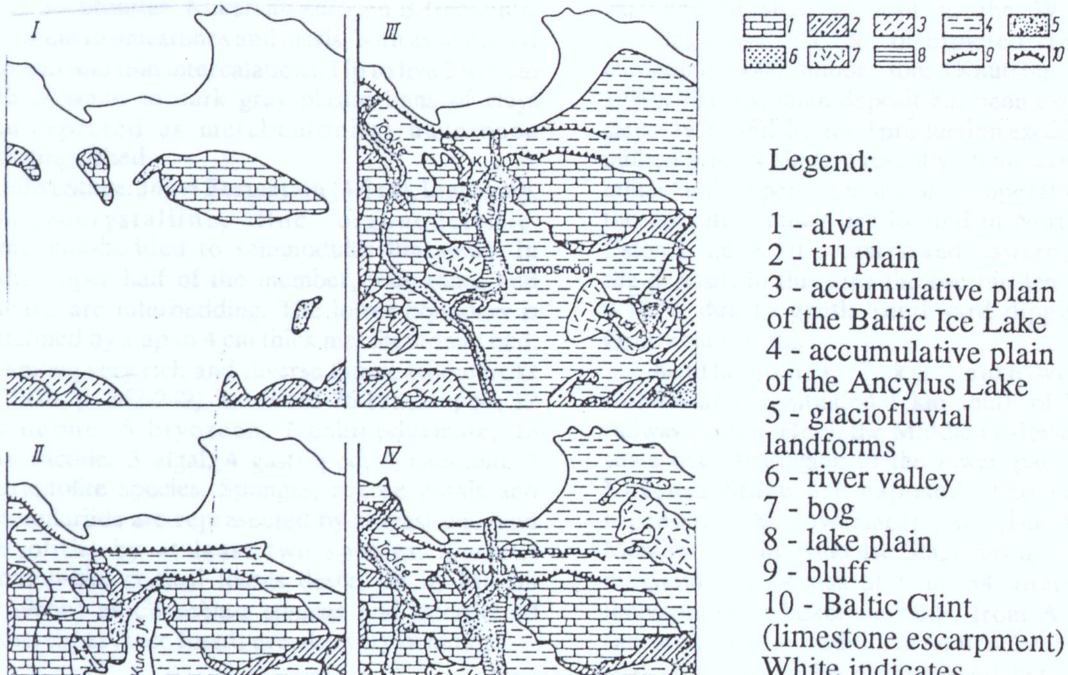


Fig. 14. Geological history of the surroundings of the Kunda settlement from the Pleistocene to pesent: I - end of the Pleistocene, the Baltic Ice Lake stage, 10,500 B.P.; II - Ancylus Lake stage, 8,600 B.P.; III - Litorina Sea transgression, 7,000 B.P.; IV - at present.

The lake dried out in about the 5th millenium B.C. The archaeological material recovered from the site is very rich in bone and horne artefacts, whereas stone implements are less common. No traces of foundation of hopuses have been found, although this dwelling site was used over a long period of time (Lang, 1992).

16. ALUVERE QUARRY. MIDDLE ORDOVICIAN.

Ivar Puura (mostly after Põlma & Hints, 1984)

In Aluvere quarry, 90 km East of Tallinn by Tallinn-Narva highway, Middle Ordovician limestones of Jõhvi and Idavere stages are exposed. The carbonate rocks of Aluvere quarry have been referred to open shelf deposits of medium depths, related to the stabilization stage of the basin. Limestones from Aluvere have been serving as a raw material for cement production in Kunda cement factory. A thorough list of fossils has been published by Rõõmusoks (1970), and the descriptions of the section by Põlma & Hints (1984) and Sarv, et al. (1989). The following description is adopted from Põlma & Hints (1984); the names of stratigraphic units are followed by their thickness in brackets.

Idavere Stage. Vasavere Formation (2.2 m +). Thin and medium scale interbedding of argillaceous limestones, marls and metabentonites. Kukersite kerogen is frequently present in limestones and marls, both as scattered grains and thin intercalations. Up to five 2 to 5 cm thick white to dark gray plastic bans of clays interpreted as metabentonites have been distinguished.

Jõhvi Stage. Jõhvi Formation (4.8 m). Light grey, microcrystalline, fine organodetritic, medium-bedded to seminodular limestone. In the upper half of the member, limestones and marls are interbedding. The lower boundary is defined by a up to 4 cm thick metabentonite bed. Among very rich and diverse fauna, Rõõmusoks (1970, p. 242-249) has listed 26 brachiopod, 12 trilobite, 5 bryozoan, 7 echinodermate, 16 ostracode, 3 algal, 4 gastropod, 3 nautiloid, 3 graptolite species. Sponges, rugose corals and conulariids are represented by at least one, and hyoliths by at least two species. Curious onion-like conical fossils described by Männil (1966b) as *Conichnus conicus* and interpreted therein as trace fossils are also very common.

17. OIL SHALE BASIN

Ivar Puura & Heikki Bauert

Estonian oil shale or *kukersite* (named by a rich Kukruse locality) has been formed in a shallow-water sea basin in Middle Ordovician, during Uhaku and Kukruse time, i.e. approximately 450 million years ago. Recent Scanning Electron Microscope studies have revealed that the organic the kerogen of kukersite is composed primarily of algal lumps of the blue green algae *Gloecapsomorpha prisca* (Kõrts, 1992). The kerogen is thought to have possible algal mat origin, derived from tidal flats. It has been suggested that after their destruction, parts of these mats were relocated by currents and deposited forming brown organic rock -- *kukersite* (Puura et al, 1988; Bauert and Puura, 1990). The kukersite seams are intercalating with limestone beds. Both are rich in macro- and microfossils enabling detailed reconstruction of the oil shale basin geology.

The Baltic Oil Shale Basin is situated in the northern part of Estonia and western part of St. Petersburg district of Russia covering an area over 5000 square km. The basin is divided into Estonian and St. Petersburg fields including three large deposits, from which the Estonian and St. Petersburg deposits are exploited, and the Tapa deposit is considered as perspective.

The northern boundary of the Estonian field is erosional, while the western and southern boundaries are drawn by a critical value of organic matter content. The eastern boundary conventionally coincides with the Narva River.

The Estonian field is the largest commercially exploited oil shale deposit in the World. It contains over 60 % of explored reserves exceeding 6600 million tons (Knutson et al., 1989). The Estonian deposit has been exploited since 1916, and its total production exceeds 770 million tons of shale. Presently, 6 underground mines and 3 open pit mines are in operation. All the operating mines are located in North East Estonia, i.e. in the central and eastern part of the deposit. In this area the overburden ranges 0-70 m due to gentle southward dipping of Ordovician strata.

Kohtla quarry, 7 km south-west of Kohtla-Järve is situated 1 km south of Kohtla railway station. Here, the Middle Ordovician oil shale beds belonging to the lower part of the Kukruse Stage are exposed. The section represents the lowermost part (the Kiviõli Member) of **the Kukruse Stage** having here its maximum thickness of 6 m. 34 alternating limestone and kukersite beds, from **A** to $\mathbf{K_2}$ (according to the traditional nomenclature of oil shale seams) can be distinguished here; 14 of them are brownish kukersite beds. The oil shale beds and limestone interbeds are rich in fossils, among them bryozoans, microgastropods, trilobites and brachiopods are very common. The detailed description of the section with the list of fossils is published by Kõrts and Einasto (1990).

18. ENVIRONMENTAL IMPACT OF OIL SHALE INDUSTRY

Erik Puura & Ivar Puura

Air pollution. Major part of the energy produced in Estonia comes from two oil shale burning regional thermal power plants: Eesti and Balti. The most significant environmental impact of these plants are the emission of the combustion gases (SO_x, NO_x, etc.) and dust to the atmosphere and solid waste residuals. From the whole fly ash production (ca. 4 million tons per year) about 5-7% is emitted to the atmosphere.

Many toxic substances are also emanated by chemical industries. In the surroundings of the oil shale chemistry plants, the sedimentation rate of the airborne ions is 350 to 1200 kg/ha (comp. to natural rate 50-90 kg/ha). In the soil, the concentration of sulfate ion exceeds the background (4 mg/m3) ten times. In general, the rain in North-East Estonia is alkaline, because the dust produced by the power plants contains up to 10 % of free CaO, giving to the precipitation alkaline reaction.

Solid residues of power plants and mines. The yearly accumulation of 18 million tons of solid residues by oil shale mines and industry in North East Estonia has resulted in 250 million tons of solid residues covering an area of 2500 ha, with 2000 ha occupied by the ash plateaus of thermal power plants. The other dumps contain solid residues of chemical plants and oil shale enrichment. The latter contain mostly the pieces and dust of carbonate rocks, but also a certain amount of oil shale. For the self-ignition ability of oil shale, the dump hills have been in fire in several occasions causing extra air pollution and other environmental damage.

From the 8 million tons of ash produced by the thermal power plants, a half is airborne, caught by filters. This ash is partly (less than 5 %) used in agriculture for liming acid soils and in construction of roads and buildings. Another 5 million tons of non-airborne ash is washed from the power plants into the sedimentary basins restricted by a wall.

Usually the ash-rich water ("ash soup") is directed by pipelines to sedimentation basins, where the ash settles and later solidifies. After some amount of the sediment has accumulated, the basin is dried by directing the water to secondary sedimentation basin and new, higher walls surrounding the basin are built. This cycle is repeated many times. This process called wet ash extraction results in growing height of the ash "plateaus". For instance, the Estonian Thermal Power Plant plans to grow the height of its 'ash plateau' up to 90 m, to avoid the extension of the occupied area. No promising projects for recycling this non-airborne ash are presently existing, although some technologies have been developed.

Yearly, about 7 to 8 million tons of carbonate rocks are dumped as oil shale enrichment leftovers. In North East Estonia, they have been accumulated to about 30 dump hills. About 3 million tons of polycoke and the enrichment residues are yearly located to the spoil dumps in the nearest neighbourhood of the factories in Kohtla-Järve and Kiviõli. For their relatively high organic content (5-6%), these polycoke hills, washed by rain water are remarkable pollution sources.

Water pollution. About 660 000 cubic metres of water per day is pumped out from the mines. Some of it leaks back through the drill holes and must be pumped out again. Dewatering of mines causes the depletion of the groundwater, reaching 20 m depth in the North and 70 m depth in the South.

Impact to local consumption. Dewatering of mines and quarries has caused the lowering of ground water levels in Quaternary and Ordovician water horizons which have been giving main water supply for the area. Strong depletions are observed in the wells located 2..3 km from the mining areas. Because of the lowering of water quality and water levels, in many areas the wells cannot be used as water sources any more. Thus, many rural areas must use the drinking water transported from remote areas. Another alternative would be the drilling of deeper wells reaching the lowermost, Cambrian-Vendian water horizon, however, with the great risk to spoil the last resource of clean ground water of Estonia. Alongside the mines, oil shale chemistry industries in Kohtla-Järve and Kiviõli are great polluters of surface and groundwater. In the surroundings of the factories, the water of lower wells is contaminated with phenol derivatives. According to the studies of the wells in the rural areas in the surroundings of Kiviõli, from the 173 wells sampled, 91% were contaminated by oil products, 66% by phenol derivatives and 53% did not meet microbiological standards.

Impact to the Gulf of Finland. In North East Estonia, except the background biological pollution, considerable amounts of polluting substances (phenols, oil products) from the oil shale industry reach the gulf. Among the most polluting sources are Purtse, Pühajõgi and Narva rivers, and the waste water pipes at Saka and Sillamäe. Air pollution caused by power plants and oil shale industry contributes to general pollution of the gulf in a great extent.

19. THE BALTIC CLINT AT ONTIKA

Ivar Puura

The transition from the crystalline rocks of Fennoscandia to the Russian Plain proceeds along an arc-shaped line of depressions, bordered at a distance by a terrace - the Baltic Clint. [This version of English term has been suggested by Martinsson (1958) who traced back the origin of this word to the ancient celts; another commonly used form has been a derivation from German *glint*, following Tammekann (1940)]. The clint has developed along the south coast of the Gulf of Finland into a steep and clearly marked coastal terrace. In the eastern areas of Ingria the clint continues as a less distinct land-terrace observable in various points. The same escarpment continues westwards; it has been traced by echo sounding on the sea floor and is exposed along the western coast of Öland island. The clint has been regarded in some earlier studies as a tectonic fault terrace, but, considering the recent geological evidence including drilling data and undersea studies, most of the present authors agree that it is rather a sub-aerial denudation or abrasion terrace. Opinions vary with regard of the age of the clint: Mid-Devonian or Miocene-Pliocene. The age of the rocks exposed in the clint wall ranges from Lower Cambrian to Middle Ordovician, i.e. from about 570 to 470 million years.

Near the Ontika village (15 km from Kohtla-Järve; ca 150 km eastwards from Tallinn) the clint reaches its maximum height: up to 56 m above sea level. The rocks exposed here are of Lower to Middle Ordovician age, i.e. about 500 to 470 million years old. On the cliff wall Lower Ordovician limestone succession of the Kunda, Volhov and Latorp Stages is exposed. The overburden limestones of Middle Ordovician Aseri and Lasnamägi Stages are observed only in artificial excavations on limestone plateau. The lower part of clint is represented by terrigenous Tremadocian and Cambrian rocks that are generally quite poorly exposed. The geology of the lower part of the section can be observed in Saka outcrop, 10 km west from Ontika where the lower rock formations are better accessible (Mägi, 1990). In general terms, the sequence resembles to that in Mäekalda section (site 1).

20. NARVA

Volli Kalm

20.1. Joaorg section, Cambrian to Lower Ordovician

In Narva town, on the left bank of the Narva River, between medieval Herman Castle and Narva waterfall, so called Joaorg outcrop of Cambrian - Lower Ordovician boundary beds and Narva Neolithic dwelling site are located. In lower part of Joaorg section white to gray silt- and sandstones of the Lower Cambrian Tiskre Formation are cropping out. The Cambrian-Ordovician boundary is marked by "basal conglomerate", which consists of cobbles from Tiskre Formation sandstones, cemented by reddish- violet coloured argillite. The Ordovician is represented by glauconitic sandstone and glauconitic limestone, both containing fragments of obolid brachiopods, which are covered by massive dolomitic limestones of Kunda and Aseri Stages (Orviku, 1936). In addition to the described Joaorg section, there are much more continuous outcrops of Cambrian and Ordovician rocks on both banks of Narva River within the boundaries of town Narva.

20.2. Narva Neolithic dwelling site.

Narva Neolithic dwelling site is located also on the left bank of Narva river, on a 4000 m^2 size bedrock headland. This site was repeatedly in use since the Mesolithic Period and the cultural layers are interbedded by alluvial sands (Jaanits et al., 1982). Both the so called "Narva Ceramics" and the Combed Ware Pottery have been described from this dwelling site. The Neolithic Period began and the pottery making started in Estonia at about 3000 BC. (Lang, 1992) which can be roughtly correlated with the transition of atlantic climatic period to subboreal one. "Narva culture" is the oldest cultural level during the Neolithic period in Estonia.

21. SHORELINES AND BEACH AT NARVA-JÕESUU

Volli Kalm

Along the embayed coast of northern Estonia, the effects of sea level oscillations are most prominent in ancient clint bays, cut into bedrock. Only the Litorina Sea transgressive coastal formations (spits, beach ridges, coastal dunes) have survived to our days within the boundaries of Narva Bay. The transgressions of both the Ancylus Lake and Litorina Sea flooded the Narva Bay, and the present coastal plain was then an archipelago of islands of different sizes. As a result of the abrasion of the clint and till plateaus, as well as longshore and cross drift of sediments, spits were formed between the islands. Even if accumulative coastal formations developed during the first (Ancylus) transgression, the succeeding Litorina Sea transgression either destroyed them or they were buried under the dune sands. However, the Litorina Sea transgression is marked by a 25 km long spit with coastal dunes, running parallel to the contemparary shoreline. The arc-shaped accumulative formation of 70-80 beach ridges with an eolian cover in front of the spit testifies to steady sea regression which followed the Litorina Sea transgression (Martin, 1988).

During the past ten years, the shore of Narva Bay has suffered from severe storm damage. One of the main reasons for that is the ever growing deficiency of sediments resulting from the destruction of the cliff and due to decrease in river load. The latter is, in its turn, connected to the construction of a dam in the upper course of the river. On the other hand, storm activity has considerably increased in this area; during last 20 years severe storms have become much more frequent (Orviku, 1988).

22. LAKE PEIPSI

Volli Kalm

Among more than 1400 lakes of Estonia, the largest is Lake Peipsi (3555 km^2) situated at the Russian border in the eastern Estonia. More exactly, the water-body on Estonian-Russian is considered to consist of three parts. The northernmost and the biggest part is Lake Peipsi and the southernmost part is called Lake Pihkva (Pskov). These two main parts are connected by narrow Lake Lämmijärv which is actually a strait. The water table of the lake is about 30 m a.s.l., the water-catchment area covers 47.800 km^2. The Narva River is the only outlet of the lake. Altogether there are 29 islands and islets in the lakes. The maximum depth of the lake (15.3 m) was estimated in Lake Lämmijärv whereas Lake Peipsi is in its large central areas 9 to 10 m deep and Lake Pihkva 3 to 4 m deep (Mäemets, 1977).

The lake depression has been formed mainly as a result of glacial erosion and therefore it has a simple geological structure and a thin cover of Quaternary deposits. In shallow coastal regions sediments are relatively coarse grained (prevailingly sands) whereas in sheltered areas and in deeper central part silts and clays predominate (Raukas & Rähni, 1981).

Lake Peipsi became isolated from the Baltic Ice Lake during the Late Glacial. The basin water level that had dropped at the end of the Late Glacial experienced a rapid rise in the southern and central parts of the lake depression an the second half of the Atlantic period and at the beginning of the Subboreal as a result of the uneven neotectonic uplift. In southern part of the depression the rise of the water level resulted in inundation of the estuaries of rivers, the bottom of which is at present 6-13 m below the lake surface. It is supposed that during the second half of the Atlantic period the water level was 5-6 m higher in the north and 4 m lower in the estuary of the river Suur-Emajõgi than at present (Miidel, 1981).

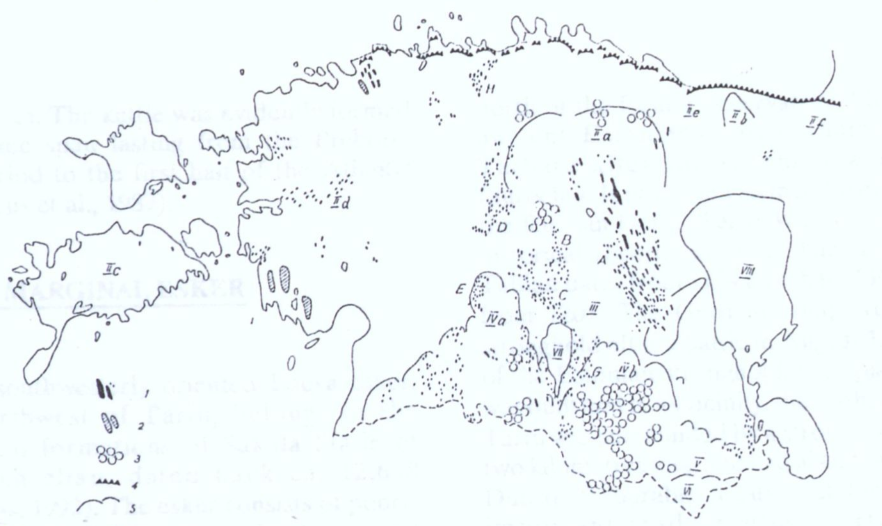
A characteristic feature of Lake Peipsi is that the eastern and northern coasts are opened to the winds at the whole length and sandy beaches are devoid of vegetation. Very steep and short waves are also characteristic of Lake Peipsi. During the high water level periods their effect on the coast is considerable. The profile of equilibrium is formed at the coast by usual winds. When the speed of wind reaches 10-15 m/s the scarps to 50-60 cm in height, festons and small beach ridges are formed on the beach. During the next storm these formes will be smashed and the new balance profile comes into being. Considerable changes take place, when the speed of wind reaches above 20 m/s (Tavast, 1989).

23. VOOREMAA DRUMLIN FIELD

Volli Kalm

The Vooremaa Drumlin Field is the biggest (55x24 km) in Estonia. The drumlin field together with the Pandivere bedrock upland form a huge glacial crag-and-tale. In this area the drumlins are larger than elsewhere in Estonia, reaching 10 km in length, 60 m in heigth and 3 km in width. The thickness of the Quaternary cover is between 30 - 70 m. The drumlins consist mainly of till and glaciofluvial deposits. In few boreholes several different till layers are estimated, whereas the lower part of the sucession is probably of Middle Pleistocene age. This feature is considered to indicate the inherited character of formation of drumlins during several glaciations. The genesis of the drumlin field was closely connected with the Pandivere bedrock upland, serving as an obstacle on the way of moving glacier ice (Rõuk & Raukas, 1989). Alongside the drumlins of Vooremaa, left behind by active continental ice, several other features resulting from the stagnant ice influence and glaciofluvial action, such as kames, kettle-holes, eskers, and marginal meltwater valleys occur. The retreat of the continental ice from the Vooremaa Drumlin Field was accompanied with the high water level of ice-dammed lakes. The higher drumlins formed an archipelago. The present-day elongated lakes between the drumlins are the relicts of the big ice-dammed lake, which have survived in the deepest depressions (Karukäpp, 1992). Raigastvere drumlin with a watch-tower on its highest point belongs to the most elongiated drumlins in this drumlin field.

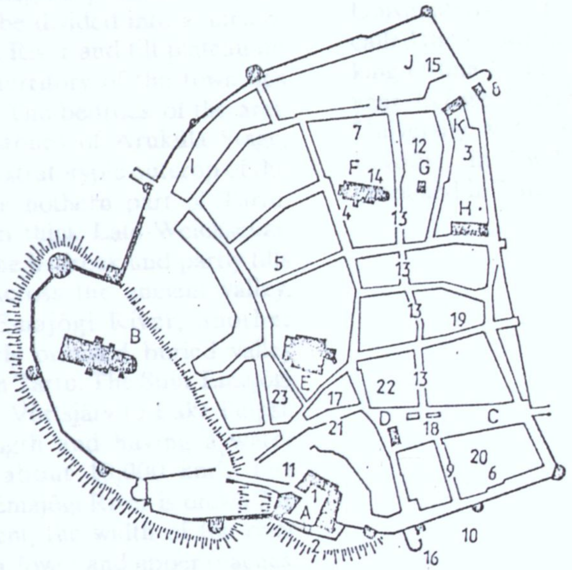
Laiuse drumlin is the biggest drumlin in the Vooremaa Drumlin Field. Its measures are as follows: absolute height 144 m a.s.l., relative height 63 m, length 13 km, and width 3.5 km (Rõuk & Raukas, 1989). The 130 m long and 90 m wide kettle-hole, situated on top of the Laiuse drumlin is of particular interest. The kettle-hole is filled with fen peat which maximum thickness



1 - drumlins and drumline like ridges; 2 - large drumline-like ridges, mainly consisting of glacio-fluvial material or bedrock; 3 - kames and hummocky moraine topography; 4 - North Estonian Glint (escarpment); 5 - proximal slopes of the uplands of the bedrock topography: I - Fore-Glint Lowland; II - North Estonian Plateau with elevations of Pandivere (IIa) and Ahtme (IIb), the East Estonian Archipelago (IIc) and the West Estonian (IId), Ojamaa (IIe) and Narva (IIf) low-lands; III - Central Estonian Lowland; IV - Middle Devonian Plateau with the Sakala (IVa) and Ugandi (IVb) heights; V - Võru-Piusa Lowland; VI - Upper Devonian Plateau; VII - depression of Lake Võrtsjärv; VIII - depression of Lake Peipsi.

The most important drumlin fields: A - Saadjärv; B - Põltsamaa; C - Kolga-Jaani; D - Türi; E - Suure-Jaani; F - Tarvastu; G - Rannu; H - Raasiku.

Fig. 15. The distribution of the drumlins and drumline-like ridges in Estonia (Rõuk & Raukas, 1989).



A - castle; B - cathedral; C - market; D - town hall; E - St. Mary's Church; F - St. John's Church; G - St. Nicolas' Orthodox Church; H - Dominician monastery; I - Cisterian convent; J - St. George's Orthodox Church; K - Holy Spirit Church; L - Lai Street. Excavations: 1 - episcopal castle, 1956-1958; 2 - south side of the episcopal castle, 1979-1980; 3 - Magasini St., 3, 1966; 4 - cemetery to south-west of St. John's Church, 1969; 5 - Munga St., 8, 1970; 6 - Poe St., 1973; 7 - Lai St., 1976; 8 - near the Russian Gate, 1977; 9 - Küüni St., 1979; 10 - Aleksandri St., 1979; 11 - north slope of Toome Hill, 1980; 12 - Magasini St., 12a, 1980; 13 - Rüütli St., 1981, 1988 -1990; 14 - St. John's Church, 1981, 1983, 1988-1990; 15 - Botanical Gardens, 1981, 1982, 1986 -1990; 16 - Barclay Square, 1981; 17 - northern side of Lossi St., 1981, 1985-1990; 18 - Town Hall Square, 1965, 1981; 19 - Hariduse St., 2, 1982; 20 - the block confined by Küüni St., Poe St. and Town Hall Square, 1982; 21 - south side of Lossi St., 1986; 22 - block No. 7, 1988; 23 - east slope of Toome Hill, 1990.

Fig. 16. Archaeological excavations in the area of medieval Tartu (Alttoa & Tamm, 1992).

reaches 11.6 m. The kettle was evidently formed during a time span lasting from the Preborel climatic period to the first half of the Atlantic period (Pirrus et al., 1987).

24. LAEVA MARGINAL ESKER

Volli Kalm

Northeast-southwesterly oriented Laeva esker, 35 km northwest of Tartu, belongs to the ice-marginal formations of Sakala Stade of Late-Weichselian, dated back ca. 12,688 B.P.(Raukas, 1992). The esker consists of poorly sorted pebbly gravel in its proximal part and coarse sand to silt in distal side. Deformation structures, caused by active glacier pressure and as a result of melting out of buried ice, have been described in gravel pit, located in southwestern part of the esker.

25 .TARTU

Volli Kalm & Tõnu Meidla

Geology. From the geological point of view, the territory of Tartu can be divided into a ancient valley of Suur Emajõgi River and till plateau on both sides of it. The territory of the town lies between 33-83 m a.s.l. The bedrock of the area consists of silty sandstones of Aruküla Stage, Middle Devonian. The stratotypic outcrop of the stage is located in the nothern part of Tartu. Reddish brown, 1-2 m thick Late-Weichselian sandy till bed covers the bedrock and partly fills the ancient valley. Across the ancient valley, occupied by Suur Emajõgi River, another northeast-southwesterly oriented buried valley has been established in Tartu. The Suur Emajõgi river flows from Lake Võrtsjärv to Lake Peipsi, being 101 km in length and having a water catchment area of about 10,000 km^2. The gradient of the Suur Emajõgi River is only 3.7 m per 100 km. At present, the width of the river valley is 3-4 km in both, lower and upper reaches, having its minimum (400 m) near by Tartu. The river flat has been bogged up. Continental ice of the last glaciation (Late- Weichselian) retreated from the Tartu region between the Otepää and Sakala Stages, dated back 13,030 and 12,680 B.P., respectively (Raukas, 1992). During the Late Glacial, the Suur Emajõgi River valley served as a meltwater drainage valley, whereas the direction of the flow was opposite to that of now.

Historical record. Archaeological finds from Tartu and its vicinity lead us to believe that as early as in the 3 - 2 millenium B.C. hunters and fishermen used to have settlements at the foot of the present Toome Hill. In about 5th or 6th century A.D. an Estonian stronghold was built on the eastern part of the steep sloped Toome Hill, north of the former observatory. Most probably ancient Estonians called their stronghold Tarbatu after the Estonian word "tarvas" (aurochs). It gave the German form Dorpat and the Russian Derpt. Tartu was first mentioned in historical records in 1030. The first record of Tallinn dates from 1154 and that of Riga (Latvia) from 1201. The German conquerers took the stronghold after a battle in August 1224. In place of the Estonian stronghold, the episcopal castle was built and in its vicinity, the Cathedral Church. Tartu was surrounded by a strong wall which was two kilometres long and had about twenty towers. Due to favourable location at the junction of important trade routes, Tartu acquired recognition as a member of the Hanseatic League. In 1494 the Hansa trading office was closed in Novgorod and transferred to Tartu.

Tartu University. In 1630 a Protestant gymnasium was opened in Tartu on the initiative of Johan Skytte, Governor-General for Livonia. Two years later, in 1632, with the support of King Gustavus II Adolphus of Sweden, the gymnasium was transformed into a university. On June 30, 1632, in a military camp at Nuremberg, Gustavus II Adolphus signed a document instituting the Universitatis Dorpatensis, which came to be also called the Academia Gustaviana in honour of the king (Alma Mater Tartuensis, 1982). In 1699, a year before Northern War (1700-1721) the University was transferred to Pärnu, Western Estonia. In 1802 the Tartu University was reopened in Tartu. The chair of mineralogy, the predecessor of nowadays Institute of Geology, was opened in 1820.

Devonian sandstone outcrop in Tartu. The outcrop in the northern part of Tartu, on the left bank of the Emajõgi River in the vicinity of cementery belongs to the group of stratotype sections of the Aruküla Formation. The outcrop is well accessible and exposes a section typical of the Aruküla Stage. The thickness of the sequence of siltstones, dolomites, domerites and sandstones reaches here 8.5 m.

The following section has been described (Viiding et al., 1981):

Quaternary deposits.
0.10 m – soil;
0.90 m – reddish-brown clayey till;

Middle Devonian. Aruküla Formation.
0.20 m – reddish-brown coarse siltstone; 0.15 m – bluish-grey fine siltstone;
0.25 m – violet-brown domerite, near the contacts yellowishgrey;
0.12 m – yellowish-grey dolomite, with the cubic cristal molds;
0.40 m – violet domerite;
0.25 m – greenish-grey moderately cemented fine siltstone;
1.30 m – reddish-brown fine sandstone, moderately or well (within the upper 0.4 m) cemented;
4.00 m – red to yellowish-brown cross-bedded fine sandstone;
1.85 + m – pink to yellowish-brown, moderately cemented cross- bedded fine sandstone, containing lenses of white mica-rich sandstone with fish fragments, with a thickness of 0.05-0.30 m.

26. TAEVASKOJA:

Volli Kalm

The Devonian sandstone forms the upper part of the bedrock sequence in southern Estonia. Only on a small area in southeasternmost part of Estonia, the Upper Devonian dolomites are overlying the sandstone. There are many Devonian sandstone outcrops on the banks of South Estonian rivers. The Taevaskoja outcrops, up to 22 m high and hundreds of metres long, are among the most attractive ones. Here the quartz (75-95%) rich, predominantly cross-bedded, nearly unconsolidated silty sandstone of the Burtniek Formation crops out (Rõõmusoks, 1983). The thickness of the Burtniek Formation in Estonia ranges from 50-100 m. Sandstone displays different colours - from white to yellow and reddish purple. At Taevaskoja, on the foot of vertical walls of the outcrops, the caves and grottoes have been eroded by the river waters.

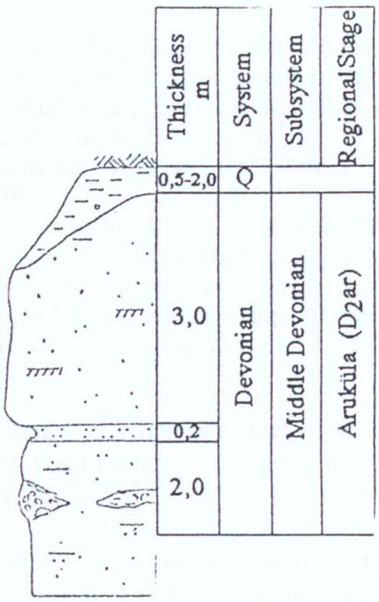
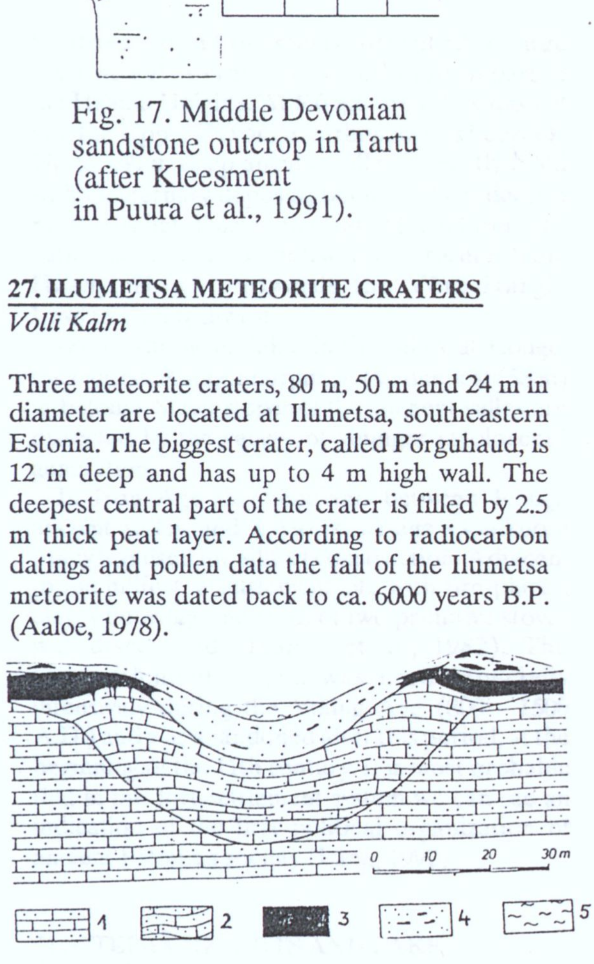


Fig. 17. Middle Devonian sandstone outcrop in Tartu (after Kleesment in Puura et al., 1991).

27. ILUMETSA METEORITE CRATERS

Volli Kalm

Three meteorite craters, 80 m, 50 m and 24 m in diameter are located at Ilumetsa, southeastern Estonia. The biggest crater, called Põrguhaud, is 12 m deep and has up to 4 m high wall. The deepest central part of the crater is filled by 2.5 m thick peat layer. According to radiocarbon datings and pollen data the fall of the Ilumetsa meteorite was dated back to ca. 6000 years B.P. (Aaloe, 1978).



1 - Devonian sandstone
2 - crushed and deformed sandstone
3 - glacial till
4 - glacifluvial sand with till lenses
5 - peat and gyttja

Fig. 18. Cross-section of "Pôrguhaud", the biggest among the Ilumetsa craters (after Aaloe in Raukas, 1988).

28. PIUSA OUTCROP

Tõnu Meidla (mostly after Heinsalu, 1987)

Since the 1920ies the quartz sandstone has been mined at Piusa. In the last decades the exploitation of the deposit has continued in the open-cast pit. For a long time the pure quartz sandstone has been valuable raw material for the Estonian glassworks. All eight underground mines ("caves") at Piusa consist of two crossing sets of parallel mines, leaving thick columns propping the ceiling. The older mines are low, but in newer ones the Upper Devonian sandstone of the Gauja Substage is locally exposed in thickness of 10 m. In the uppermost part of higher caves yellowish- to brownish-grey, horizontally bedded or cross-bedded sandstone with occassional violet or brown clay interlayers is exposed. In the lower part of the sequence the sandstone is light grey or white, cross-bedded (Heinsalu, 1987). Among minerals, quartz is prevailing (94%), with negligible supplement of feldspar (3.6%), mica (1.1%) and heavy minerals (less than 0.25%) (Tamme, 1962). The sandstone of the Gauja Substage in Estonia is probably of deltaic origin (Kleesment, 1991).

29. HAANJA HEIGHTS AND SUUR MUNAMÄGI HILL

Volli Kalm

The Haanja Heights (Upland) belong to the group of accumulative insular heights (with the Otepää Heights) of the ice divide zone between the Baltic and Finnish glacial flows. Haanja Heights covers an area of 2500 km^2, its foot elevation is about 100 m, the highest point (Suur Munamägi Hill) is 318 m a.s.l., being also the highest point in the Baltic states. In general outline the Haanja Heights represents a giant hill, the surface area of which is full of hillocks and depressions, only the north-eastern part of it being a sloping and abraded till plain. The "hills" are mostly up to 25 m high, only few of them exceed 50 m; the relative height of the largest, Vällamägi, is 84 m. The higher central part of the heights represents glaciofluvial or glaciolacustrine kames, having flat tops of a relative height of 20 to 60 m, covered by loamy till (Arold, 1979).

The socle of the Haanja Heights consists of Upper Devonian sandstones of Sventoi and Burtnieck stages and dolomite of the Sargajevo Stage. Tills from five different glaciations have been identified in the Quaternary cover. The considerable thickness of Early and Middle Pleistocene tills and glaciofluvial deposits suggests the inherited character of the formation of Haanja Heights (Raukas, 1978). During all glaciations, the formation of the Haanja and Otepää Heights started with subglacial accumulation of till, followed by the phases of englacial and peripheral marginal deposition, and the formation of the relief under the conditions of "dead" ice (Raukas, Karukäpp, 1979).

In 1939, a 29.1 m high watch-tower was built on the top of the Suur Munamägi hill. In the watch-tower a geological cross-section of the Haanja Heights and till samples from Munamägi drill core are exhibited.

30. RÕUGE ANCIENT VALLEY, LAKES AND HILLFORT

Volli Kalm

Southeast-northwesterly oriented Rõuge Ancient Valley crosses the northwestern part of the Haanja Heights. At Rõuge the valley has cut into the Upper Devonian carbonaceous bedrock. Up to 180 m deep ancient valley is mostly filled with Quaternary deposits, being 30-35 m deep in present relief. During the Late Glacial time the valley served as a meltwaters drainer from Haanja Heights towards the Võru-Hargla Lowland in northwest.

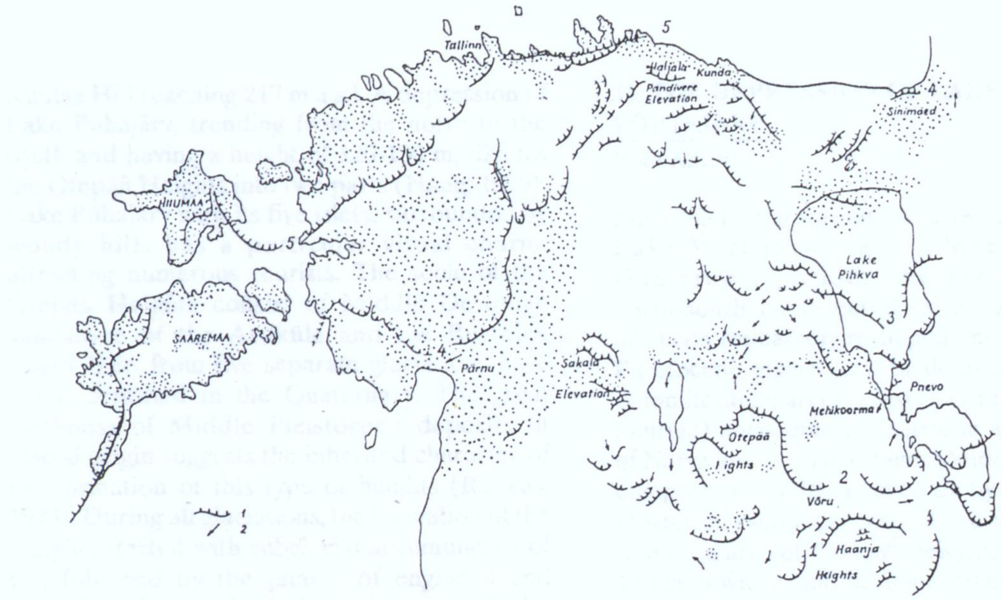
Among the seven lakes in the valley at Rõuge, the biggest, Rõuge Suurjärv, is the deepest (38 m) in Estonia. Steep slopes of the ancient valley are dissected by the valleys of younger (Holocene) generation.

In Iron Age the headland between Rõuge ancient valley and a Holocene-age Ööbikuorg valley was used for hillfort construction. Adjacent to the hillfort, a settlement site with fire-places, clayey floorings and ruins of two primitive stoves was discovered (Jaanits et al., 1982). The fort-settlement system was used especially intensively during the Viking Age (800 - 1500 A.D.) and was abandoned after this period, at the beginning of the 11th century. It is most probable that in this fort-settlement system we can see an indication of the first political organization of ancient Estonian society (Lang, 1992).

31. OTEPÄÄ HEIGHTS AND LAKE PÜHAJÄRV

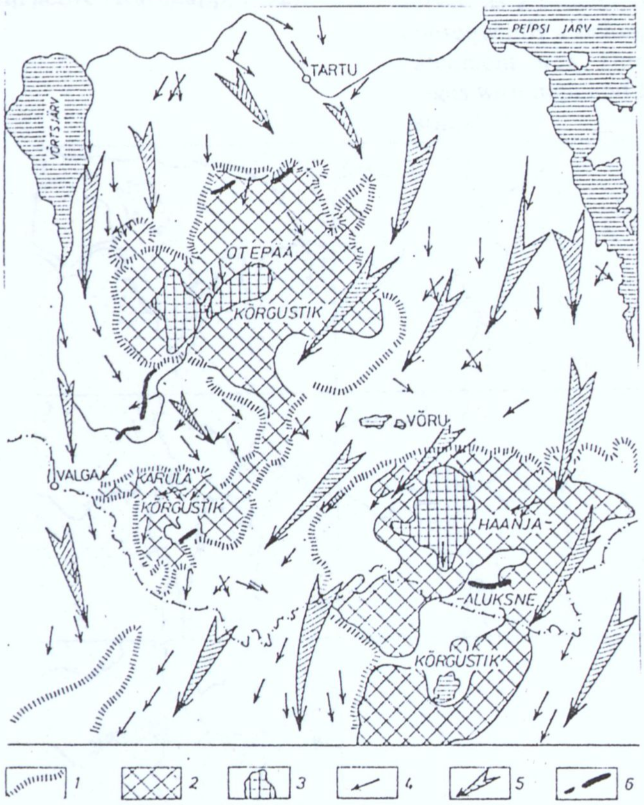
Volli Kalm

The accumulative insular heights, which in Estonia are represented by the Otepää and Haanja Heights, have a bedrock socle, thick Quaternary cover, complicated structure and well developed slopes (Karukäpp, 1992). The total area of the Otepää Heights is 1180 km^2, with its longest range both from north to south and east to west reaching 40 km. The average height of the foot of the upland is 88 m a.s.l. Upland's 19 higher points rise over 200 m a.s.l., the highest,



1 - Haanja (13.430 BP.); 2 - Otepää (13.030 BP.); 3 - Sakala (12.680BP.); 4 - Pandivere (12.480 BP.); 5 - Palivere (11.630 BP.). Arrows show the drainage direction of the meltwater; dotted areas show the distribution of varved clays.

Fig. 19. Main Late-Weichselian glacial marginal belts (Raukas, 1986) and the approximate time of the retreat of ice from these belts (Raukas, 1992).



1 - limit of the heights; 2 - small and medium-size hummocky topography; 3 - hilly topography with plateau-like kames; 4 - orientation of elongiated clasts in till; 5 - direction of the ice movement; 6 - endmoraines.

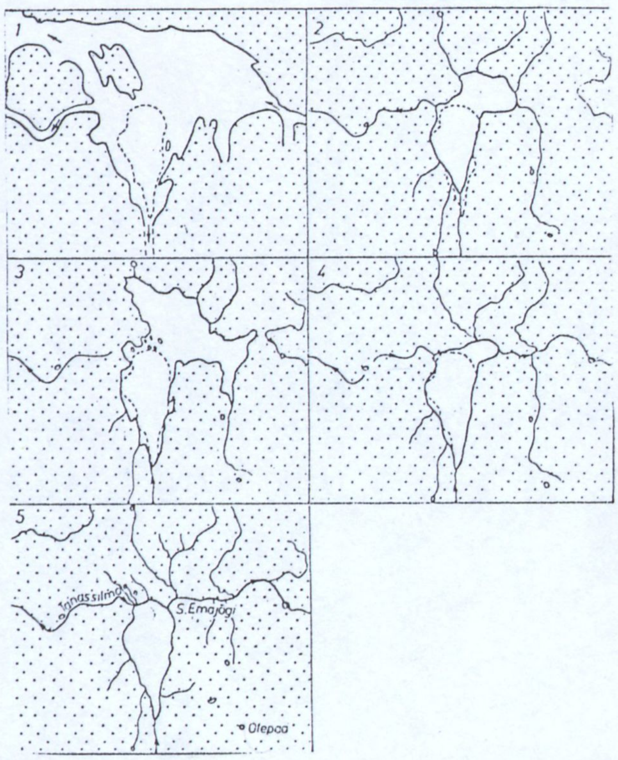
Fig. 20. The formation of the Otepää and Haanja insular heights and the ice lobes dynamics in the end of Late-Weichselian glaciation (after Karukäpp in Raukas & Karukäpp, 1979).

Kuutse Hill reaching 217 m a.s.l. A depression of Lake Pühajärv, trending from the north to the south and having a height of 120-130 m, divides the Otepää Heights into two parts (Hang, 1979). Lake Pühajärv with its five islets, surrounded by woody hills has a particular visual charm, attracting numerous tourists. The socle of the Otepää Heights consist of Middle Devonian sandstone of the Aruküla and the Burtniek stages. Tills from five separate glaciations have been identified in the Quaternary. The great thickness of Middle Pleistocene deposits of glacial origin suggests the inherited character of the formation of this type of heights (Raukas, 1978). During all glaciations, the formation of the Heights started with subglacial accumulation of till, followed by the phases of englacial and peripheral marginal deposition, and the formation of the relief under the conditions of "dead" ice (Raukas & Karukäpp, 1979). The insular heights seem to have promoted the stagnation of large dead ice bodies. At the time, when insular heights (Otepää and Haanja) were covered by stagnant ice, the glacier lobes between the heights were still active (Karukäpp, 1992).

32. THE DEPRESSION OF LAKE VÕRTSJÄRV

Volli Kalm

Most likely, the formation of the depression of Lake Võrtsjärv began a long before the Quaternary period. The pre-Quaternary north-southerly oriented erosional depression has been repeatedly reshaped and deepened by Pleistocene glaciations. In depression area the dolomite and marl of Adavere Formation (Lower Silurian) and domerite, siltstone and sandstone of Narva and Aruküla stages (Middle Devonian) compose the bedrock, overlain by 5- 10 m thick Quaternary sediment cover. Lake Võrtsjärv itself covers an area of 270 km^2, being 35 km in length, 15 km in width, and having average depth 2.8 m (Mäemets, 1977). The only outlet from the lake, Suur-Emajõgi River (101 km in length), dicharges into Lake Peipsi. The water table in Lake Võrtsjärv lies at 33.7 m a.s.l., what is only 3.7 m higher than that in Lake Peipsi. During Late Glacial and Early Holocene time (approximately 12.000-9.000 BP.) the tributaries of Pärnu River served as a drainer of the lake depression and consequently it belonged to the Riga Gulf water catchment area. During the Holocene several stages with high and low water levels have been estimated.



1 - Lake Võrtsjärv after Sakala Stage (~12. 700 BP.) of Late-Weichselian glaciation, 2 - in the beginning of Holocene, 3 - during the second half of Early Holocene (~8500-8000 BP.), 4 - in the beginning of Middle Holocene (~7800-7500 BP.), and 5 - at present.

Fig. 21. The development of Lake Vôrtsjärv during Late Glacial and Holocene (after Orviku in Raukas, 1988).

33. TAMME OUTCROP

Tõnu Meidla (after Kleesment, 1991)

The outcrop near the Tamme village on the eastern bank of the Lake Võrtsjärv represents one of the best sections of the Middle Devonian reddish-brown sandstones of the Aruküla Formation, being among the most important localities of Devonian fishes in Estonia.

The Aruküla Formation contains a diverse vertebrate fauna, containing several species of *Tartuosteus* and *Pycnosteus*, accompanied by *Psammolepis* and many other fishes (Viiding et al., 1981). Small fish fragments abundantly occur in the Tamme sequence also, but greater pieces are scarce. In the southernmost outcrop the sequence reaches the thickness of 5 m (description after Kleesment, 1991):

up to 2 m – reddish-brown to greenish grey mottled clayey till (Quaternary);

up to 2.8 m – brownish-red cross-bedded moderately cemented sandstone;

0.2 m – reddish-yellow cross-bedded weekly cemented fine silty sandstone;

2.0+ m – brownish-red moderately cemented cross-bedded sandstone with yellowish-grey micaceous laminae. A well cemented, up to 2 m thick interbedding of conglomerate occurs within the interval, approximately 1.3 m from the bottom, consisting of abundant fish fragments and occassional clay pebbles at the base.

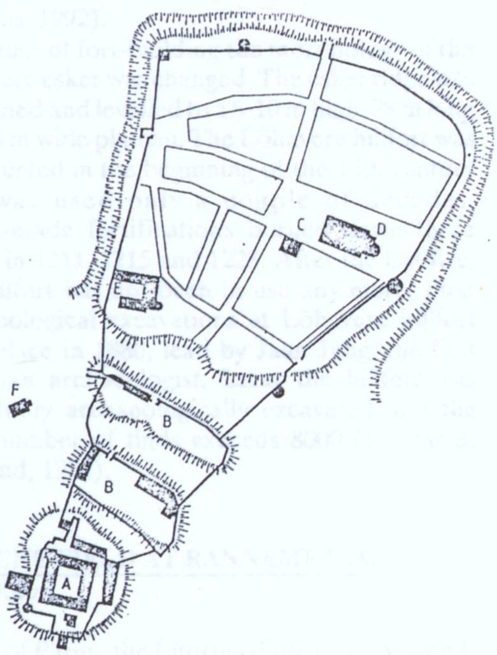


Fig. 22. Medieval Viljandi (Alttoa & Tamm, 1992).
A - castle, B -outer bailies,
C - market square, D - church,
E - Franciscan monastery,
F - St. Catherine's chapel

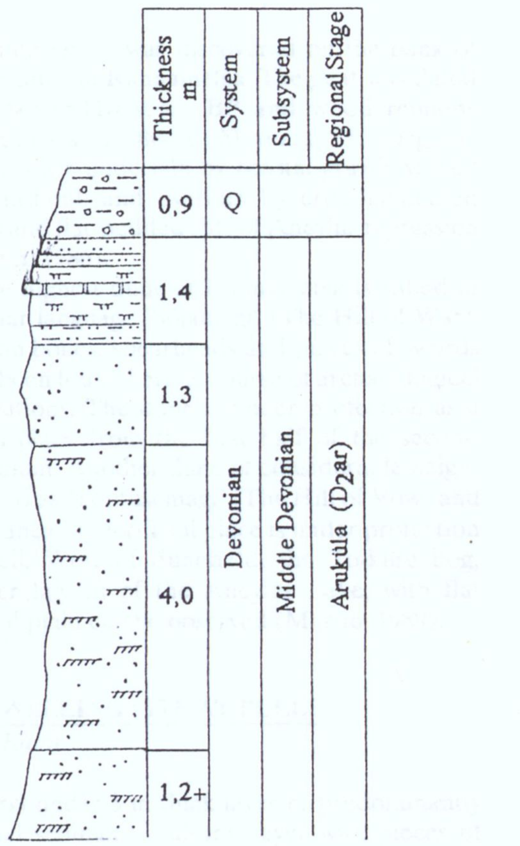


Fig. 23. Middle Devonian sandstones in Tamme outcrop (after Kleesment in Puura et al., 1991).

34. VILJANDI ANCIENT VALLEY, LAKE AND CASTLE HILL

Volli Kalm

Northeast-southwesterly oriented Viljandi Ancient Valley crosses the Sakala Upland and falls into the Abja Ancient Valley. The known maximum depth of the Viljandi Ancient Valley reaches -26 m in vicinity of town Viljandi. In the same region the Devonian sandstone plateau on both sides of the valley is at a height of 53-67 m a.s.l. Consequently, the valley has cut into the Devonian sandstone at least 80-90 m, from which 45-60 m are at present buried by Quaternary deposits (Kalm, 1991). After the glaciers retreat from southern and central part of Sakala Upland the valley served as a meltwaters drainer, whereas the direction of the flow was opposite to that of now, i.e. from Lake Võrtsjärv basin towards the Pärnu Bay drainage area. Now there is a watershed between these two drainage areas few kilometres east of Viljandi. In present day relief the ancient valley shows up as a 30-35 m deep valley with lakes and rivers in it. Lake Viljandi is the biggest within the boundaries of ancient valley, measuring 4.6 km in length, 450 m in width and having the maximum depth 11 m, with water-table at 42 m a.s.l. (Mäemets, 1977). The thickness of lake deposits, undelain by Late Glacial glaciolacustrine clayey silts, ranges usually between 3-4 m. The alteration of lake marl and gyttja layers and the presence of peat interlayer in the upper part of the deposits gives evidence about the water-level changes during the Holocene (Lõokene,1979).

To north-west of Lake Viljandi, on the edge of Devonian sandstone plateau, between small tributary valleys the Viljandi hillfort was constructed and in use in the beginning of 13. century. After several battles, in 1223 the hillfort was finally taken over by German conquerors and the castle-building started at the same place. The castle in its turn was ruined during the Great Northern War in the beginning of 18th century (Lõugas, Selirand, 1989).

35. LÕHAVERE ESKER AND HILLFORT.

Volli Kalm

Lõhavere hillfort is located on the northern slope of Sakala Upland. The fort was built on the northwesternmost short ridge from the Mudiste - Allaküla - Lõhavere system of marginal eskers (Lõokene,1961). This line of eskers was formed a little after the marginal formations of Sakala Stade (Late Weichselian), dated back 12,700 B.P. (Raukas, 1992).

Because of fort-building the morphology of the Lõhavere esker was changed. The esker ridge was shortened and levelled to a 8-10 m high, 78 m long and 44 m wide plateau. The Lõhavere hillfort was constructed in the beginning of the 13th century and was used only a couple of decades. Wood-made fortifications burned down three times, in 1211, 1215 and 1223. After the last fire, the hillfort has not been in use any more. First archaeological excavations at Lõhavere hillfort took place in 1880, lead by Jaan Jung, the first Estonian archaeologist. Later the hillfort was repeatedly archaeologically excavated and the total number of finds exceeds 8000 (Lõugas & Selirand, 1989).

36. DUNE FIELD AT RANNAMETSA.

Volli Kalm

South of Pärnu, the Litorina dune ridge proceeds in parallel with the Pärnu - Riga highway and before Rannametsa village turns into dunefield. Its maximum width is 1.5 km and relative height of dunes reaches 29 m. The characteristic feature of Rannametsa dunes is that both, their down and upwind slopes are similarily steep (25-45°). The 30 cm thick organic containing clayey gyttja with peat interlayers was discovered on the bank of Timm canal at Rannametsa. The peat was dated back 8080±110 years BP and wood remains 8060±110 and 7860±190 years BP. Organic deposits are underlain by coastal gravel, varved clay and till, and overlain by cross-laminated sands and flat-bedded silts of Ancylus regression (Martin, 1986).

The highest dune at Rannametsa is called in popular language "Sõjamägi" (The Hill of War). Human bones, spearheads and pieces of swords have been found here in course of archaeological excavations. The dune is under protection as a burial-place from the first half of the second millenium. Another dune of considerable height is called as "Tõotusemägi" (The Hill of Vow) and as an ancient sacrificial place is under protection as well. West of dunefield, the Tolkuse bog, former lagoon of the Ancylus Lake, with flat coastal plain can be observed (Martin, 1989).

37. DWELLING SITE AT PULLI

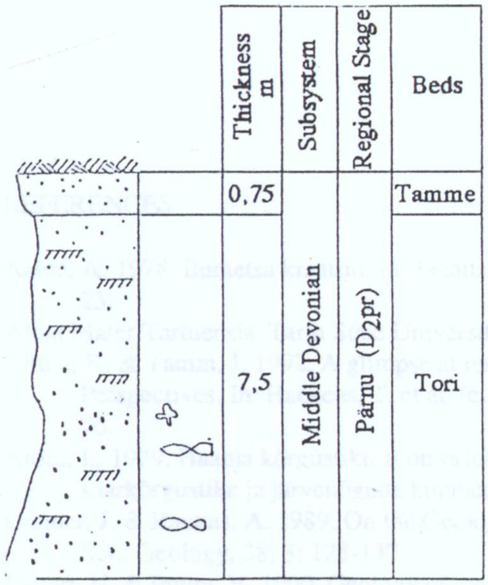
Volli Kalm

In 1968 under 3 m thick layer of predominantly alluvial sediments cultural layer with pieces of coal and animal bones was discovered at Pulli village near Sindi (North of Pärnu). The village was situated on the right bank of the Pärnu River, not far from its influx to the Yoldia Sea. The C^{14} age of the cultural layer was estimated as 9575±115 years BP (Lang, 1992). Only a few hearhts and post-holes were found in the excavated part of this short-lived settlement. Archaeological finds, made from flint, horn and bone, point out the fact that people who lived at Pulli belonged to the same tribes as those who came from the south and had settled at Kunda. As the cultural layer and finds at Pulli are a thousand years older than that at Kunda, which was for a long time considered the oldest settlement site in Estonia, one can assume that Pulli village was the oldest settlement in the Stone Age Estonia (Jaanits et al., 1982; Lang, 1992).

38. TORI SECTION.

Volli Kalm

Tori Põrgu (Tori 'Hell') is the stratotypic outcrop of the Pärnu Formation (Middle Devonian). Both the Tori and Tamme beds are cropping out here. The 250 m long and 7-8 m high outcrop is located on the left bank of Pärnu River, at the Tori village. The name "Põrgu" ("Hell") came after the cave in the foot of the vertical outcrop. The Pärnu Formation is represented by parallel and cross-bedded quartz rich (80-95%) silty sandstones of white to gray colour (Rõõmusoks, 1983; Kleesment, 1991). Of special interest are



Devonian sandstone outcrop at Tori (Tori "Hell").

Fig. 24. Middle Devonian sandstone at Tori, 'Tori Hell' (after Kleesment in Puura et al., 1991).

fossil plants described from the thin clayey interbeds of this outcrop (Thomson, 1940) and nearby Kose (Oore) quarry (Kalamees, 1988).

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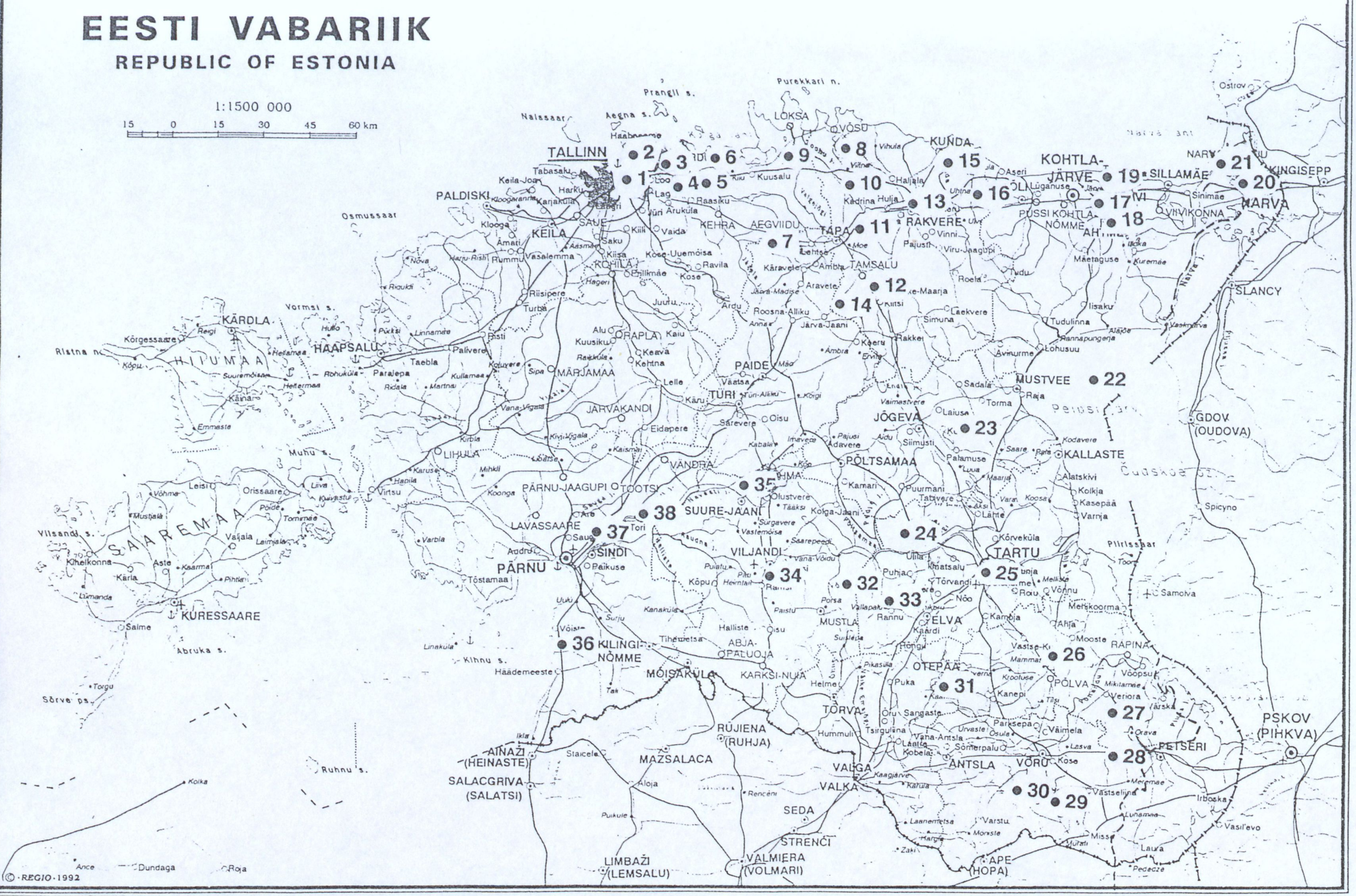
APPENDIX 1. General data about Estonia (from National Report...,1992).

GENERAL INFORMATION

Official name:	THE REPUBLIC OF ESTONIA
State order:	Parliamentarian democracy
Area:	45,215 km^2 (plus another 2000 km^2 currently occupied by Russia)
Geographical latitude:	between 57°30' and 59°49' N
Geographical longitude:	between 21°46' and 28°13' E
Population:	1,574,955 inhabitants (1990), about 70% of them citizens
Density of population:	34.8 persons / km^2
Urban population:	1,124,235 (71.4%)
Ethnic composition:	Estonians 61.5% (963,269), Russians 30.3%, Ukrainians 3.1%, Byelorussians 1.8%, other nationalities 3.3%
Capital:	Tallinn (484,400 inhabitants)
Number of towns:	33
Larger towns:	Tartu (115,400) Narva (82,300) Kohtla-Järve (76,800) Pärnu (54,200)
Administrative division:	15 districts (in Estonian: maakond), and 6 towns outside districts;
local units:	193 communes (vald)
Language:	Estonian (belongs to the Finno-Ugric languages; related to i.a. Finnish and Hungarian)
The main religions:	Lutheran, Orthodox and Baptist
Currency:	Estonian crown (kroon) from summer, 1992, divided into 100 cents (sent)
NATURE	
Air temperature:	Mean annual 4.7°C; in February - 6.6°C; in July + 16.3°C
Mean annual precipitation:	500 to 700 mm
Lakes:	Over 1400 (6.1% of the territory)
Larger ones:	Peipsi (3555 km^2, shared with Russia), Võrtsjärv (270 km^2)
Islands and islets:	Over 1500 (9.2% of the territory)
Larger ones:	Saaremaa (2673 km^2), Hiiumaa (989 $km^{2)}$, Muhu (200 km^2)
Coastline:	3780 km (islands make 2540 km of this)
Agricultural land:	32.5% of the territory
Forests:	40.1% of the territory
Area covered with mires (fens, bogs, swamps):	21.5% of the territory (partly coinciding with forest areas)

APPENDIX 2. Map of Estonia, with the excursion sites included in this guide.



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