PERIBALTIC GROUP
INQUA SUBCOMMISSION ON GLACIATION
FRIENDS OF BALTIC QUATERNARY
UNIVERSITY OF LATVIA

INTERNATIONAL FIELD SYMPOSIUM ON QUATERNARY GEOLOGY AND MODERN TERRESTRIAL PROCESSES

WESTERN LATVIA, SEPTEMBER 12-17, 2004

ABSTRACTS OF PAPERS AND POSTERS

RĪGA 2004

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DEDICATED TO THE 90TH BIRTHDAY OF
PROFESSOR ALEKSIS DREIMANIS

ABSTRACTS OF PAPERS
AND POSTERS

RĪGA 2004

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In 746

SYMPOSIUM PROGRAMME

Day 1 (Monday, September 13)	Stops 1-4, Northern Kursa
Day 2 (Tuesday, September 14)	Paper and poster session, Rojupe Hotel
Day 3 (Wednesday, September 15)	Stops 5-7, Central and Western Kursa
Day 4 (Thursday, September 16)	Stops 8-11, Western and Southern Kursa
Day 5 (Friday, September 17)	Stops 12-13, North Eastern Zemgale

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ALEKSIS DREIMANIS

ONE OF THE GREATEST QUATERNARY GEOLOGISTS OF THE XX CENTURY

ALEKSIS DREIMANIS – A LIVING LEGEND OF THE QUATERNARY

Anto Raukas[1] and Vitālijs Zelčs[2]
(1) Institute of Geology, Tallinn University of Technology, Estonia Avenue 7, Tallinn, Estonia, e-mail: raukas@gi.ee; (2) Department of Geography, University of Latvia, Rainis Blvd. 19, LV-1586, Rīga, Latvia, e-mail: Vitalijs.Zelchs@lu.lv

Aleksis Dreimanis, born and grown up in Latvia, belongs to the Quaternary community of the world, being one of its leaders whose ideas have been included in numerous textbooks. Much can be said about his scientific career, but still more about his personality. Even during the very hard days of World War II and heavy Soviet occupation in Latvia, he stayed optimistic and was sure that one day Latvia will be free from totalitarianism. His optimism and passion have inspired not only his students but also his colleagues of different generations. We are both his apprentices and admirers of his talent. Scientific sharpness and detailed field studies, supplemented by laboratory analyses, have always been in the focus of all his scientific conclusions. With Aleksis one can agree or disagree – and still be good friends. He is a noble man and true scholar. His enthusiasm, energy and diplomacy are well combined with multi-lingual knowledge, so rare in the scientific community nowadays.

At the age of 21 he published his first scientific paper and now his career has spanned already seven decades. It is not easy to find out which is the most important topic in his long-term studies, but probably it is the establishment of quantitative relationship between the bedrock and till lithology that allowed him to find out the details of till formation and stratigraphy. Already as a schoolboy he studied the banks of the River Daugava near his father's farmhouse, where he discovered several till beds and complicated glaciotectonic structures and understood the complexities of glacial sedimentation. In 1935, as a third year student, he published his findings under the guidance of his teacher, Professor Ernst Kraus, an alpine structural geologist. This paper was the first Latvian publication on glaciotectonics and one of the first studies in the world where glaciotectonic deformations were combined with stratigraphy. Later, as a professor at the University of Western Ontario in Canada, he saw similar sections in the bluffs of lakes Erie and Ontario and developed the well-known classical stratigraphic schemes of the last glaciation in the Great Lakes region of Northern America.

Professor Dreimanis became world-renowned through the INQUA Commission on Genesis and Lithology of Glacial Deposits (Hicock and Menzies, 2000), which among the specialists was known better as the commission of Aleksis. He invited representatives from 32 countries to work at the Commission. Being aware of the advanced studies of glacial deposits in the Baltic region, he appointed Peribaltic scientists as leaders of the work groups. He loved to organize international meetings and excursions wishing to see the sites where the samples for the laboratory treatment and scientific papers actually came from, encouraging new discussions. Most of the meetings organized by him have been of extremely great importance for the development of international projects and concepts. He has participated in all the last Baltic meetings of the "Friends of Quaternary" and during the field excursion in Latvia in 1998 he demonstrated in Latvian sections how complicated three-dimensional kineto-architectural constructions could assist in the determination of ice movement. He is one of the founders of kinetostratigraphy in the Quaternary.

In his famous till studies he has always used multiple criteria (lithology, mineralogy, till fabric, glacial tectonics, chemistry, granulometry, etc.), which he put into practice already in his first student competition project. He was invited to solve litostratigraphic problems even abroad. In Estonia he established clear differences in the fine gravel fraction between upper and lower tills in the interglacial sections at Rõngu and Karuküla. In 1939, he published a method for lithologic investigation of the 0.5-1.0 mm fraction of tills and gravels for stratigraphical purposes, later known in the Soviet literature as the method of Dreimanis.

As a schoolboy and student Aleksis enjoyed writing poetry, taking landscape photographs, and archaeology; he often visited the locations of Latvian ancient castles. In one of them he discovered a bronze ring, now known as the national symbol of Latvia – "King Namey's ring". In his thirties he was a classical naturalist, a good combination of past and present, being at the same time geologist, botanist, malacologist and archeologist, a true Linnean scholar and true "Quaternarist", able to do palynological analyses himself. Beginning with 1938 Dreimanis started palynological investigations and in 1942 he taught palynology at the Institute of Geology and Paleontology of Latvian University. Several of his palynological studies were published, dealing, for instance, with the Late glacial section at the Biržu Audzes farm-house (1939) and Elster-Saalian deposits at Rucava (1943). He also used his palynological knowledge in dating of the Sārnate archeological site (1947). Unfortunately, most of his pollen diagrams were lost during wartime. He was in charge of Quaternary mapping of western and central Latvia, and completed the first detailed map sheet in a scale of 1:25,000. He compiled a map of Quaternary mineral resources in a scale of 1:300,000, accompanied by a description of 444 industrially economic deposits (Dreimanis, 1944).

Dreimanis was the first to increase the number of Pleistocene glaciations in Latvia (1943). When Latvia regained independence, he resumed participation in Pleistocene research in Latvia, writing together with local geologists several overview papers and reports (Āboltiņš and Dreimanis, 1995; Dreimanis and Zelčs, 1995; Zelčs and Dreimanis, 1997 a.o.) including the Latvian chapter to the "Encyclopedia of European and Asian Regional Geology" (Dreimanis and Kārkliņš, 1997). In exile he published a long overview "Geology and Economic Deposits of Latvia" (1967). As a great patriot of Latvia he actively participated in the compilation of the Latvian Encyclopedia, writing about 60 entries in "Latvju Enciklopedija" published in Stockholm in 1950-1955 and 35 entries in "Latvju Enciklopedija" 1962-1982 and 1989, published in the USA. Latvian-English-German geologic terminology was published by Dreimanis and Kārkliņš (1986) in the "Dictionary of Latvian Technical Terminology" and related glacigenic terms in Latvian and 20 other languages in the Appendix C of Dreimanis (1989).

Aleksis Dreimanis is among the greatest Latvians of the XX century. He was a military geologist in the Latvian Legion during 1944-45, and volunteered to fight in the front lines during Christmas of 1944. During 1946-48 he was teaching at the Baltic University in Hamburg and Pinneberg. Since 1948 up to the present, he has done much for the study of the Quaternary geology of his second homeland, Canada, teaching hundreds of young geologists and geographers in the University of Western Ontario. He has supervised 28 graduate students and 15 postdoctoral fellows, produced over 200 publications in a wide range of topics. For his brilliant work he has received many awards. He was elected Foreign Member of Latvian Academy of Sciences (1990) and Honorary Doctor of Latvian University (1991), the University of Waterloo (1969), and the University of Western Ontario (1980). He became Honorary member the Geographical Society of Latvia (1990), the Association of Geologists of Latvia (1991) and the Latvian Association for Quaternary Research (1998), a Distinguished Fellow of the Geological Association of Canada (1995), Fellow of the Royal Society of Canada (1979), and Honorary Member of INQUA (1985). He received the University of Helsinki Medal (1990), Logan`s Medal (Geological Association of Canada), Albrecht Penck Medal (DEUQUA), W.A. Johnston Medal (CANQUA) , the Three-Star Order of Latvia (2003), and many other awards.

Aleksis comes from a family of long-lived persons. His grandfather Matvejs passed away at the age of 106, his father Pēteris died in 1971 at the age of 91, his mother Marta passed away in 1992 at the age of 101. Congratulating Aleksis on his ninetieth jubilee we are sure that during the many happy years ahead, he will not only enjoy traveling and gardening and the company of his beloved wife Anita, daughters Māra and Aija, grandchildren Maia, Matthew, Marcis and Andrew, but he will do much for the Latvian community and the "big science". We know that he has many new ideas and numerous not-yet-finished papers on his work table.

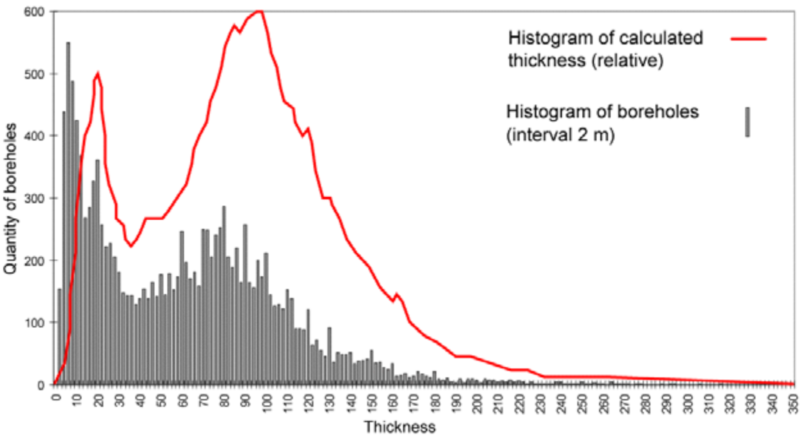
Reference:

Hicock, S. H., Menzies, J., 2000. Aleksis Dreimanis: a legacy in Quaternary science. *Quaternary Science Reviews*, 19 (2000), 1665-1676.

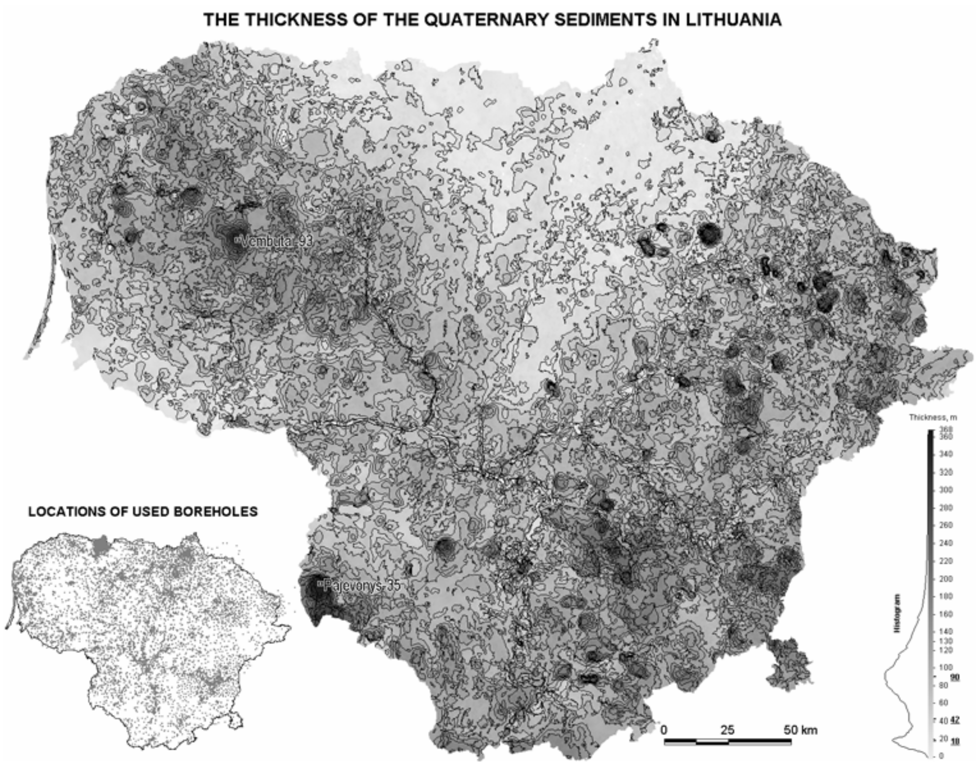
THE THICKNESS OF THE QUATERNARY SEDIMENTS IN LITHUANIA

Paulius Aleksa and Rimantė Guobytė
Geological Survey of Lithuania, S.Konarskio 35, LT-2600, Vilnius, Lithuania, e-mails: paulius@lgt.lt, rimante@lgt.lt

It has been a long time since the last publication on the thickness of Quaternary deposits in Lithuania. Only a few published their works on this subject (Čepulytė, 1959; Vaitiekūnas, 1959; Gaigalas, 1967; Malinauskas, 1991; Vonsavičius, 1994). Maps of two surfaces were used to make a new Quaternary deposits thickness scheme. A Sub-quaternary surface was made from 13737 borehole data using the Mapinfo and Vertical Mapper software. The other surface map is a Digital Terrain Model (DTM) obtained from NASA, Shuttle Radar Topography Mission (SRTM). The scheme of Quaternary deposits thickness was obtained by subtracting the subquaternary surface from the SRTM DEM.



A histogram of the thickness shows a bimodal distribution. The first peak (0-30 m) with a maximum of 18 m is related to plains. An intermediate area (30-70 m) with a minimum of 42 m is related to slopes of uplands and big river valleys. The second peak (70-160 m) with a maximum of 90 m is related to uplands, and the highest thickness (160-368 m) is related to ancient incisions and zones of very intensive glacial accumulation. The histogram derived from the borehole data shows a similar distribution, only the peaks are of different intensity.



The thickest Quaternary deposits are found in the Pajevonys-35 borehole (348.5 m), but the age of the interval from 181.5 to 348.5 may be misinterpreted. The second thickest deposits were found in the borehole Vembutai-93. The thickness registered there is 314.2 m, but the borehole did not reach Pre-quaternary rocks, so the actual thickness remained unknown.

Lowlands were dominated by glacial erosion. They make up 15 % of all the territory. Uplands were an area of predominating accumulation during all glaciations in the territory of Lithuania. They compose 85 % of all the territory.

GLACIOTECTONICS OF SELECTED REGIONS OF POLAND

Andrzej Ber
Polish Geological Institute, 00-975 Warsaw, Rakowiecka 4, Poland, e-mail: andrzej.ber@pgi.gov.pl

This presentation is prepared on the base results of detailed and reviewed geological mapping, published and archival data, as well as explanations and symbols elaborated for a Glaciotectonic map of Poland in a scale of 1:1,000,000 (Ber *et al*., 2004).

Within the territory of Poland subdivided into the following regions: North-Western (West-Pomeranian Lakeland), North (Kaszuby Coast), North-Eastern (Suwałki-Augustów Lakeland), Western, Middle and Southern, glaciotectonically disturbed landforms and sediments, either expressed in recent relief or buried (stated in borings or in exposures), were described. The distribution of glaciotectonic features over the territory of Poland is related primarily to the presence of younger glaciations and thicknesses of the deformable substratum.

Generally, the landforms and sediments were deformed by active ice sheets through the horizontal and vertical thrusts of the ice masses, as well as by the vertical stress of the stagnant ice masses. During the Pleistocene, starting from the oldest Narevian (Menapian) Glaciation, advancing ice sheets were activated by loading (glacial periods) and unloading (interglacial periods), faults and particular tectonic blocks. They influenced limits and retreat standstills of the ice sheet, directly acted on the development of till features with glaciotectonically deformed structure. They also delimited individual ice streams, among others due to varied mobility of individual tectonic blocks (Ber, 2000).

The present landscape, especially of the northern and middle part of Poland, has developed due to glaciotectonic deformations during the Vistulian (Weichselian) Glaciation.

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Ber, A., 2000 – Pleistocene of north-eastern Poland and neighbouring areas against crystalline and sedimentary basement. *Prace Państwowego Instytutu Geologicznego*, ***170***, 89 pp.

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BOULDER ACCUMULATIONS IN THE KALTENE-ROJA AREA, ALONG THE WESTERN SIDE OF THE GULF OF RĪGA, LATVIA

Aleksis Dreimanis[1], Ivars Strautnieks[2] and Vitālijs Zelčs[2]
(1) Department of Earth Sciences, University of Western Ontario, London, Ontario N6A 5B7, Canada, e-mail: aija@csd.uwo.ca; (2) Department of Geography, University of Latvia, Rainis Blvd. 19, LV-1586, Rīga, Latvia, e-mails: Ivars.Strautnieks@lu.lv, Vitalijs.Zelchs@lu.lv

The boulder accumulations of the Kaltene-Roja area occur on the Late Glacial abrasion plain of the Baltic Ice Lake along the W side of the Gulf of Rīga. They appear in a 9 km long and 3-4 km wide belt in a forested area nearly parallel to the coastline, and according to Juškevičs and Talpas (1997), also extend eastward below modern sea level. The boulder accumulations form the surface part of the thin (1-8 m) Quaternary sediment cover over the gently NE sloping Middle Devonian sandstone and clay bedrock surface.

The spectacular boulder accumulations had attracted attention since ancient times, blaming the Devil for their formation. They were noted by the regional study of Buchards (1935) and investigated in more detail by at least a dozen geologists during the last 70 years, proposing a variety of explanations for their origin: as wave washed-out various glacial landforms, or as storm water ice-thrusted ridges with or without the participation of tectonic displacement of bedrock.

Three types of boulder accumulations may be distinguished (Dreimanis, 1943): (1) boulder ridges, (2) boulder pavements, and (3) boulder fields with abundance of scattered boulders.

Boulder ridges are 1.5-6 m high, up to 1 km long, and 20-200 m wide. They consist of several layers of boulders and are asymmetrical in cross-section. The pavements consist of one or two layers of boulders. Most ridges and pavements, including the largest ones, are combined in several NNW-SSE wide belts trending up to 0.5 km, nearly parallel with the coastline. The WSW side of these ridges is steeper, but along the SSE side the ridges are higher and with a wider slope. Another set of shorter ridges and pavements trend WSW-ENE, fanning out towards the W and SW. The E side of these ridges is steeper. Some ridges in both systems are curved. In the NNW-SSE trending ridges most curvatures are convex westward. Commonly the highest parts of the boulder ridges occur at the intersection of both sets.

In the upper parts of higher ridges the gaps between boulders are empty, but the lower ones are filled with sandy gravel and pebbles, or even with sandy till in some of them near their base. Crushed pebbles or cobbles of metamorphic rocks are common inside the ridges. The lowermost boulders are underlain by sand, gravel, sandy till or bedrock. Till also covers the lower edges of boulder ridges, but in depressions till is overlain by sand, scattered boulders and peat.

The NNW-SSE trending ridges were formed by glacial deformation stress from ENE, as indicated by the orientation of elongated pebbles and boulders, overturned folds and scale-like till sheets on their upper limbs, measured in the underlying sediments on the E side of the ridges. The NNW-SSE trending ridge at the Paegļi farmhouse has also an anticlinal fold in its core with long axes of pebbles parallel to the crest of the ridge. The orientation of elongated boulders is parallel or perpendicular to the coastal line on the seaward sides and the tops of both sets of the ridges and in the boulder fields.

All morphological, structural and fabric evidence suggests that the westward fanning system of ENE-WSW trending ridges and pavements were originally drumlin-like radial landforms. At the time when the retreating glacial lobe became thinner, NNW-SSE trending morainic ridges were formed along the boundaries of passive and active ice. After the complete glacial retreat the area became flooded by nearshore shallow waters of the Baltic Ice Lake, and waves washed out both sets of glacially deposited ridges, carrying away the finer material and leaving the boulders as boulder ridges, boulder pavements or boulder fields. The orientation of long axes of elongated boulders in boulder fields and on the seaward parts of the ridges, being related to the coastline, suggests that wind-driven ice masses of the Baltic Ice Lake may have played an important role in displacing and moving the boulders.

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Juškevičs, V. & Talpas, A., 1997. Explanatory note to the map (scale 1:200,000). In: Segliņš, V. & Kajak, K. (eds.), *The map of the Quaternary deposits of the Gulf of Rīga*. Rīga, 39 p.

PALYNOLOGICAL STUDY OF OXBOW LAKE DEPOSITS AT KHOLSTOVO SECTION, EASTERN BELARUS

Yelena N. Drozd
Institute of Geological Sciences NASB, Kuprevich str.7, Minsk, 220141, Belarus, e-mail: drozd@ns.igs.ac.by

A large amount of palynological research of the Holocene sediments has been carried out in Belarus. Traditionally scientists pay more attention to the study of lake and mire sediments. They are characterized by stable conditions of sedimentation that allow with certainty to reconstruct the history of climate and vegetation development. However, alluvial deposits are not less informative. As a rule, they comprise riverbed, floodplain and oxbow lake facies. The example of such deposits is the section Kholstovo, which is located to the S of the village of Kholstovo (Bykhov district, Mogilev region). The next sequence of deposits is exposed (from the top, depth in meters):

1.	Soil	0.00-0.05
2.	Peat dark, friable, mineralized, with layers of sand, remnants of plants roots, lower boundary distinct	0.05-0.20
3.	Loam grey, gleyey, with vertical rusty-ochric flows and pebble basal layer at the lower boundary	0.20-0.30
4.	Sand light-grey, medium grained, gleyey, with rusty-ochric and humic flows, plant remnants	0.30-0.41
5.	Sand pale-yellow, medium grained, with rusty-ochric ledges, from depth 53-54 cm water-bearing	0.41-0.54
6.	Sand pale-yellow, coarse grained, with gravel and pebbles	0.54-0.85

Ten samples have been subjected to palynological analysis; two of them do not contain plant microfossils. According to obtained palynological data, 7 palynocomplexes have been recognized in the pollen succession, reflecting vegetation changes during sedimentation at the depth of 0.00-0.54 m.

Palynocomplex 1 (layer 5) is characterized by a large amount of herb pollen grains (16-40%) and spores (5-20%), however, with a prevalence of pollen of wood species (40-79%) in a general structural spectrum. They are represented by *Pinus sylvestris* (50-53%), *Picea sect. Eupicea* (7%), *Betula sect. Albae* (25-27%), *Alnus* (25%), *Quercetum mixtum* (12%); *Tilia cordata* (6%), *Ulmus laevis* (6%). The herb pollen are composed of Polygonaceae, *Polygonum scabrum,* Cichoriaceae, *Myriophillum spicatum*. Spores are represented by *Lycopodium clavatum*. The mean content of plant microfossils in a sample is 10-19 pollen grains. The results of pollen analysis allow to suppose that the deposits were accumulated in the Subboreal time (SB-2). At that time the moderately warm and dry climate conditions led to the development of pine forests including birch, linden, broad-leave species and abundant ferns. The soil surface was covered by lycopods.

Palynocomplex 2 **(**layer 4) is characterized by less contents of wood species pollen (59%) and spores (37%) with a small amount of herb pollen (4%). An increase of *Betula sect. Albae* (85%) and a decrease of *Pinus sylvestris* (15%) is distinguished. The content of plant microfossils in a sample increase up to 71 grains. Such features are typical for Subatlantic time (SA-1) and could be considered as an evidence of climate cooling. Birch-pine forests were developed in the surrounding area.

Palynocomplex 3 (layer 3) illustrates a domination of spores (77%). The contents of herb pollen (4%) and pollen of wood species (19%) is insignificant. In the wood species group, the small amount of pollen grains of *Pinus sylvestris, Picea sect. Eupicea, Belula sect. Albae* is recognized. The grasses were represented by *Polygonum scabrum, Polygonum persicaria,* Cichoriaceae*,* Ranunculaceaea and Poaceaea; only Cyperaceae grains were found from aquatic plants*. Lycopodium clavatum* (68%) dominates among spores together with Polypodiaceae (23%), *Pteridium* (2%), *Sphagnum* (7%). The content of plant microfossils in a sample is 216 grains. According to these data, the deposits of the layer were accumulated at the SA-2a. Insignificant climate warming stimulated the development of pine forests with admixture of birch and spruce with well developed grass cover represented by ferns. The soil surface was covered by mosses.

Palynocomplexes 4-6 (layer 2) is characterized by a domination of wood pollen (41-72%) and spores (20-55%). The values of herb pollen (4-10%) are low. In the group of wood species *Pinus sylvestris* (84-91%), *Picea sect. Eupicea* (3-9%), *Betula sect. Albae* (3-6%), *Alnus* (1-6%), *Quercetum mixtum* (1%; *Tilia cordata* (1%), rare *Quercus*) are recognized. The herbs were represented by Polygonaceae, *Polygonum scabrum, Polygonum persicaria,* Cichoriaceae, Ranunculaceaea, Poaceaea, Brassicaceae, Artemisia, Chenopodiaceae, Cariophyllaceae and among aquatic plants Cyperaceae, Phragmites, Sparganiaceae were found. Polypodiaceae (48-54%), *Lycopodium clavatum* (8-18%), *L. complanatum* (1-3%), *Sphagnum* (14-42%), *Pteridium* (1-12%), *Hypnum* (1%) dominate among spores. The content of plant microfossils in a sample is 156-4160 grains. The results allow to conclude that the deposits were accumulated at the SA-2b-3b. The continuation of warming was peculiar to that time, pine forests with an admixture of birch and spruce developed, with grass cover formed by ferns. The soil surface was covered by mosses.

Palynocomplex 7 (layer 1) is characterized by the domination of pollen wood species (78%). The values of herb pollen (5%) and spores (17 %) are low. *Pinus sylvestris* (84%), *Picea sect. Eupicea* (11%), *Betula sect. Albae* (4%), *Alnus* (1%) are recognized. The ground grasses were represented by *Polygonaceae, Chenopodiaceae, Cariophyllaceae,* among aquatic forms Cyperaceae were found. Polypodiaceae (55%), *Lycopodium clavatum* (13%), *L. complanatum* (13%), *Sphagnum* (18%), *Pteridium* (1%) were dominant among spores. The contents of plant microfossils in a sample are 4992 grains.

The obtained results allow to reconstruct the time interval and features of sedimentation in the Dnieper river valley. Sand deposition at the layers 4-6 indicate the existence of fluvial conditions of sedimentation; the presence of loam in layer 3 allow to suppose that stream energy decreased in the Subboreal time due to the ox-bow lake formation. The peat formation (layer 2) illustrates the swamping of oxbow lake in the Subatlantic time.

DATABASE AND MAP OF LATE WEICHSELIAN DIRECTIONAL ICE-FLOW FEATURES OF LATVIA

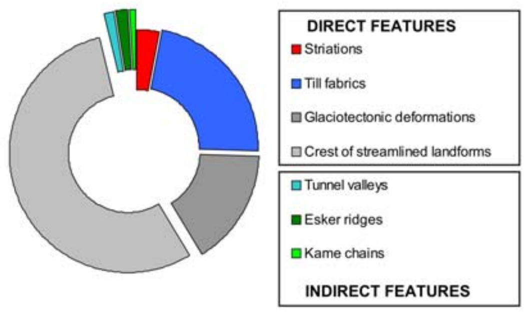
Jānis Dzelzītis, Aivars Markots and Vitālijs Zelčs
Department of Geography, University of Latvia, Rainis Blvd. 19, LV-1586, Rīga, Latvia, e-mails: jdz@envirotech.lv; Aivars.Markots@lu.lv; Vitalijs.Zelchs@lu.lv

The database and map of Late Weichselian directional ice-flow features of Latvia are an integral part of the INQUA Commission on Glaciation project “Ice Flow Directions in the Peribaltic Area during the Weichselian Glaciation”. Directional ice-flow features in the Latvian database and on the map were classified according to the legend worked out for the map of the entire Central and Eastern European area. The Latvian map and database were constructed using the ArcInfo system during the period of 1999-2003. The map is supported by supplementary maps showing the lobate structure of the peripheral cover of the Scandinavian ice sheet with major interlobate zones, main features of the topography, bedrock surface, glaciotectonic features, topographic lineations, and ice marginal positions during deglaciation of the last glaciation.

Numerous directional ice-flow features have been studied, and many directional data have been collected in Latvia starting from 1861. Almost 20 individuals have contributed to the Latvian part of the project. The database and map of directional ice flow features were constructed using the ArcInfo system during the period of 1999-2003. V. Zelčs served as the co-ordinator of the project, J. Dzelzītis and A. Markots were the other primary compilers. Ice-flow directions were reconstructed from glacial striation, till fabric, major glaciotectonic structures, streamlined subglacial landforms, transverse glacial topographic lineations, glacial tunnel valleys, radial eskers and kame chains. Currently the database contains 3623 direct features, including 1562 measurements of striation and till fabric, directions of local glaciotectonic deformation and 2061 crests of streamlined glacigenic landforms (Table). The total number of indirect features is 141.

Table. Classification and estimated number of directional ice flow features in Latvia.

Directional ice flow features	Occurrence	
	Number	%
DIRECT FEATURES	3633	96.2
Striations	116	3.0
Till fabrics	848	22.5
Glaciotectonic deformations	598	15.9
Crest of streamlined landforms	2061	54.8
INDIRECT FEATURES	141	3.8
Tunnel valleys	49	1.4
Esker ridges	65	1.7
Kame chains	27	0.7
TOTAL	3774	100.0



The direct streamlined and indirect features were digitised from 1:50,000 and/or 1:75,000 topographic maps, detected from interpretation of satellite imageries and digital maps, and derived from papers, unpublished reports and personal communications. The geographic base was compiled from the satellite map of Latvia on a scale of 1:50,000 and consists of multiple coverages that include basic geography.

Obviously, streamlined landforms and land-forming glaciotectonic structures are the strongest and constant directional indicators of ice flow. They could be considered as megascale ice flow directional features, which indicate the direction of regional ice movement. Only when the till fabric, glacial striae and small glaciotectonic structures were formed under extensional longitudinal flow regime, they indicate the final local direction of glacial movement. In other cases these features reflect direction of the local secondary stresses that differ from the direction of glacial movement (Dreimanis, 1999).

Superimposed sets of radial and transverse glacial topographic lineation formed beneath margin of the retreating ice lobes and indirect features complicate the ice-flow mosaic. However, near parallel mega-scale lineations with latest cross-cutting features are common for glacial lowlands with longitudinal extensional or compressional flow. The diverging pattern of ice-flow appears in glacial lowlands widening downglacier, while converging lineations occur in lowlands narrowing downglacier or along the western side of the Vidzeme, Western Kursa and Eastern Kursa interlobate uplands. In the interlobate upland areas where transverse and isometric topographic features are dominant reconstruction of ice flow direction could be based mainly upon indirect features, for instance, tunnel valleys, esker-like (‘Aufpressungs-Oser’), and/or till fabric lineation.

This study was supported by the Latvian Science Council (Grant No. 01.0300). We are deeply indebted to Leszek Marks, Volli Kalm, Rimante Guobitė, Irina Pavlovskaya and Hans-Jürgen Stephan for valuable discussions during our joint activities.

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INVESTIGATION OF SCANDINAVIAN ERRATICS FROM TILLS IN THE INTERLOBATE ZONE, IŁAWA REGION, NORTHERN POLAND

Dariusz Gałązka
Polish Geological Institute, 00-975 Warsaw, Rakowiecka 4, Poland, e-mail: dgal@pgi.waw.pl

Quaternary glacial till carries a sequence of important stratigraphic and palaeogeographical data. Indicator erratics (Lüttig, 1958, Schulz, 2003) allow to decipher the history of glacial material, beginning in the source regions in Scandinavia, through transport and finally its deposition. In the test-area (south-western Mazury Lakeland, northern Poland) there are only 2 tills (T1, T2) available in small outcrops (Fig. 1), characterised by differing petrographic composition of boulders and gravel. This differentiation probably results from glacial erosion of different parts of Fennoscandia during the Pleistocene. Two tills in tested outcrops belong to different glacial advances. Each advance should have received material (boulders and gravel) from a different part of Fennoscandia.

Indicator (trace) erratics were grouped into ten petrographic provinces: Bornholm, Bohuslän, Småland, Dalarna, Uppland, Ångermanland, Central Baltic, Åland, SW Finland and SE Finland.

Petrographic analysis of about 5000 erratics from 6 outcrops in this area points out a unique petrographic composition (Table 1) of the two youngest tills due to their position in two ice streams: Vistulian and Mazurian during the last glaciation (Leszno-Poznań and Pomeranian Phases).

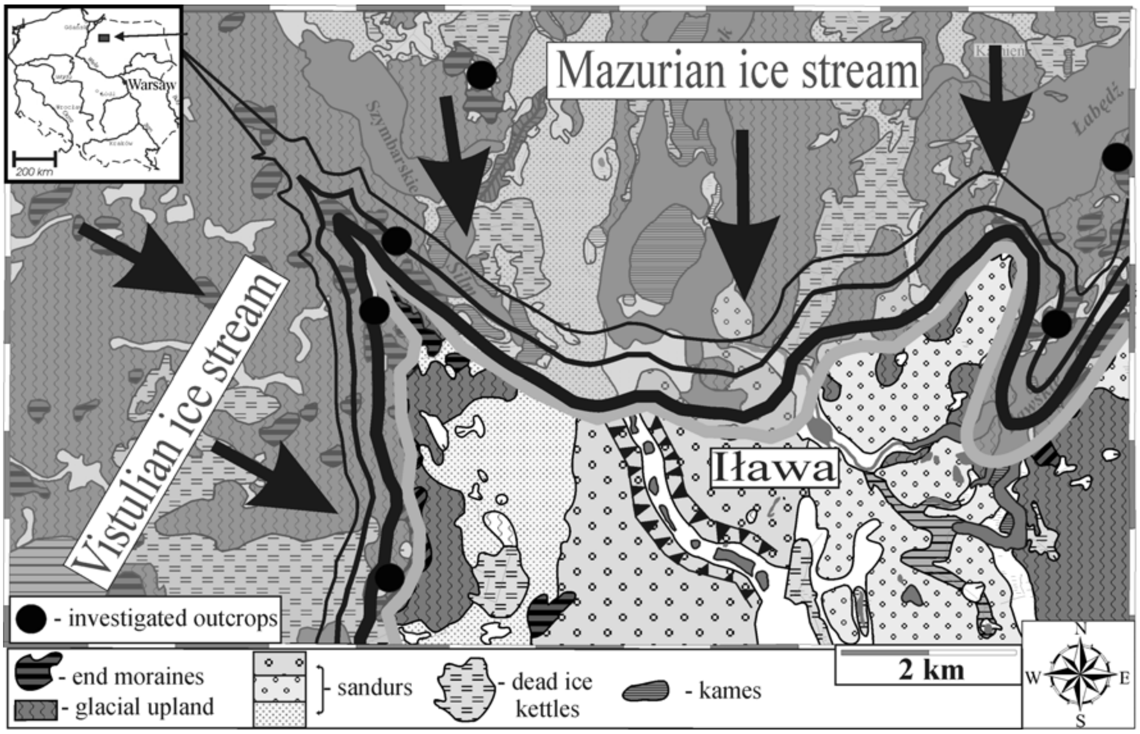

Fig. 1. Geomorphological sketch of the interlobate zone between Vistulian and Mazurian ice streams in the vicinity of Iława, Northern Poland.

In the petrographic composition of gravel we can observe a slight variability of petrographic features – this means variability in content of main petrographic groups (Kr – crystalline rocks; Wp - limestone Dp - dolomite; Pp- sandstone; Qp - quartz; Lp - shale and additional: M1 – Palaeogene mudstone – local rock) and values of the so-called petrographic coefficients (mathematical ratio between sum of petrographic groups): O/K; K/W; A/B, where:

$$O = Wp + Dp + Pp; \quad K = Kr + Qp; \quad W = Wp + Dp;$$
$$A = Wp + Dp + Lp; \quad B = Kr + Pp + Qp$$

Values of each petrographic feature (for gravel and boulders) have a normal distribution with a characteristic dominant. In most cases each till is characterised by a different distribution described by mean and standard deviation. These differences have statistical meanings. A considerably stronger differentiation of petrographic features is observed in perpendicular profile (between two tills) than lateral within one till in the same glacial lobe, but additionally there is also a petrographic difference (with statistic meanings) between tills of the same age investigated in different glacial lobes.

Both methods applied enable to put these tills into several lithostratigraphical units and then, based on regional stratigraphic correlation in the SW Mazury Lakeland, to correlate them with chronostratigraphical units (Table 1).

Table 1

Till (Lithostratigraphy)	Features		Chronostratigraphy
	Erratic boulders main differences	Gravel main differences	
T2 - Mazurian lobe	Åland + Dalarna	Wp+Dp	Weichselian: Pomeranian Phase
T2 – Vistulian lobe	Småland	Kr+Qp	
T1 – Mazurian lobe	Åland	Wp+Dp+M1	Weichselian: Leszno-Poznań Phase
T1 – Vistulian lobe	Småland + Uppland	Kr+Pp+Qp	

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THE DEPOSITS OF THE MIDDLE WEICHSELIAN IN NORTHERN LITHUANIA

Alma Grigienė and Asta Jusienė
Geological Survey of Lithuania, S.Konarskio 35, LT-2600, Vilnius, Lithuania, e-mails: alma.grigiene@lgt.lt, asta.jusiene@lgt.lt

According to the governmental programme "Geology for Society", in the period 2000-2003, the Quaternary geological mapping of the Mažeikiai area (northern Lithuania) was carried out in a scale of 1:50,000.

The lacustrine sediments of the Middle Nemunas (Middle Weichselian) were discovered in the Venta - Viekšniai locality. According to data of several boreholes it was established, that these sediments are covered by till accumulated during the Last Glaciation. The layer of 3-5 m thick glaciolacustrine sediments was observed somewhere on the till. In some areas the glaciolacustrine sand is blown by wind and forms undeveloped continental dunes. The terraced river valley of the Venta cuts the till plane.

The thickness of the Upper Nemunas (Upper Weichselian) glacial deposits is 5-10 m. The till is yellowish-brown and dust-colour, sandy with pebbles and gravel up to 10%. The Middle Nemunas deposits are overlying the Medininkai (Saalian) till, which thickness is 15-20 m. The Žemaitija (Middle Pleistocene) till (thickness reaches up to 25 m) occurs under the Medininkai till and is lying on the rough pre-Quaternary surface. The thickness of the Quaternary deposits in the above mentioned area varies from 25 up to 60 m.

The top of the Middle Nemunas deposits occurs at 50-60 m a.s.l. The thickness of lacustrine sediments reaches up to 13 m. The sediments contain clay, silt, fine and very fine grained sand, they are brown, yellow-grey and black with greenish colour. There are many micro interlayers of organic matter in the silt. Gravel in diameter of 1-2 cm is found in the sediments. The sample of greenish grey silt was dated 19,450 ± 430 conventional ^{14}C years B.P. That means that sediments accumulated in the very end of the Middle Nemunas. The pollen analyses from some boreholes confirm the same age of the sediments.

One of the borehole pollen analyses results are described below. The 31 sample for pollen and spores analyses were taken from silty sediments from borehole No.11. The pollen diagram is characterized by a low percentage of tree pollen, with continuous *Pinus*, *Betula* and *Alnus* curves. Also *Betula nana* is common. Herbs are represented by Cyperceae, *Artemisia*, Poaceae, *Thalictrum*. The characteristics of pollen spectra allow to distinguish three local pollen assemblage zones (LPAZ).

I zone - Pinus - Cyperaceae: *Pinus* pollen increases up to 60% in the lower part of the zone. Cyperaceae with high percentage values is dominant among herbs. Small peaks of Caryophyllaceae and Polygonaceae are noted.

II zone - Betula nana - Artemisia: This zone is marked by an increase in *Betula nana* and *Artemisia* pollen.

III zone - Cyperaceae - *Artemisia*: The pollen spectra are characterized by high values of herbs *e.g*. Cyperaceae, *Artemisia*, Chenopodiaceae and *Thalitrum*.

The pollen flora indicates unfavorable Periglacial climatic conditions.

FIRST DISCOVERY OF ICELANDIC TEPHRA IN HOLOCENE PEAT DEPOSITS OF ESTONIA

Tiit Hang[1], Stefan Wastegård[2], Siim Veski[3] and Atko Heinsalu[3]

(1) Institute of Geology, Tartu University, Vanemuise 46, EE-51014, Tartu, Estonia, e-mail: Tiit.Hang@ut.ee; (2) Department of Physical Geography and Quaternary Geology, Stockholm University, S-106 91, Stockholm, Sweden, e-mail: Stefan.Wastegard@geo.su.se; (3) Institute of Geology, Tallinn Technical University, Estonia Avenue 7, E-10143, Tallinn e-mails: Veski@gi.ee, Heinsalu@gi.ee

Recent advances in the detection of cryptotephra horizons (horizons of very low concentration of shards, invisible to the naked eye) has led to the discovery of previously undetected tephra horizons (e.g. the Borrobol Tephra) and have also extended the known limits of individual Icelandic ash plumes into areas much more distant from the source than was previously known. This includes areas such as the British Isles (Turney et al., 1997 Mackie et al., 2002)), southern and central Sweden (Wastegård et al., 2000a; Zillén et al., 2002; Davies et al., 2003), western Russia (Wastegård et al., 2000b) and northern Germany (van den Bogaard & Schmincke, 2002). As the relatively small-scale 1947 eruption of Hekla deposited tephra along the south coast of Finland (Salmi, 1948) and the stratigraphically important Vedde Ash, from the last glacial-interglacial transition, was reported in two lakes on the Karelian Isthmus, north-western Russia (Wastegård et al., 2000b), it is not unreasonable that tephra from other Icelandic eruptions may have dispersed in the eastern Baltic Sea area.

Here we report the first discovery of middle Holocene cryptotephra from a peat sequence in Estonia. Two sequences, Mustjärve and Parika located 110 km apart, were earlier analysed for fossil pollen (Veski, 1998; Niinemets et al., 2002). Peat accumulation in both localities started at the beginning of the Holocene and continued with changing increments until the present. The radiocarbon dated intervals between 2000 and 5000 14C yrs. BP were in both cases chosen for this pilot study. From the Mustjärve sequence colourless rhyolitic tephra shards were identified at 3.12-3.16 m level while no tephra was found at the equivalent interval at Parika. Electron microprobe analysis of shards from the Mustjärve sequence suggest a correlation with the initial phase of the Hekla-4 eruption (ca 4260 cal yrs. BP; Pilcher et al., 1995), e.g. FeOT total contents between 1.9 and 2.1% and MgO contents between 0 and 0.05%. Hekla-4 has previously been found throughout middle Sweden (Wastegård, in press) and northern Germany (van den Bogaard & Schmincke, 2002). Small concentrations of tephra at 2.60-2.70 m in the Mustjärve sequence might be the Hekla-3 tephra (ca 3000 cal yrs. BP; van den Bogaard & Schmincke, 2002), but geochemical analysis was not possible. The extremely low concentration and small size of the tephra particles indicate that Estonian bogs probably are on the border at which tephrochronology is possible in north-western Europe. Further studies of full Holocene sequences are needed in order to discover traces of other ash plumes.

These new findings may play an important role in developing and extending the known tephra framework in north-western Europe and open new perspectives into studies of late Quaternary chronology in the eastern Baltic. It will also open a possibility to exactly correlate and compare climate shifts recorded in Estonian peat bogs with other areas where the Hekla-4 tephra has been recorded, for example the British Isles, Scandinavia and Northern Germany.

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ESKER SYSTEMS OF DIFFERENT AGES IN EASTERN FINNISH LAPLAND

Peter Johansson
Geological Survey of Finland, Box 77, FIN-96101 Rovaniemi, Finland, e-mail: peter.johansson@gtk.fi

At least three crossing esker systems of different ages exist in the ice divide zone, in eastern Finnish Lapland. It appears that the glacial erosion and deposition processes were exceptionally weak in this area. As a result a number of till units are also found and in several places interbedded with organic layers. By aerial photo interpretation, geomorphological and stratigraphical studies it was possible to determine esker systems and the age relations between them. The results were checked by OSL datings and compared with results of coring carried out at Sokli, in the northeastern part of the area. The coring penetrated deposits from the Weichselian to the Eem Interglacial. Sokli is so far the first site found in Finnish Lapland where interglacial and interstadial deposits separated by till units occur in the same sequence.

The eskers without a till cover have been deposited in subglacial meltwater systems flowing from west-northwest towards east-southeast. Their trend reflects the last direction of ice recession which is approximately equal to the last flow direction of the Late Weichselian ice sheet. The esker systems consist of consecutive sharp crested ridges, 10-25 m in height and often separated by distinct erosional features, e.g. gorges and channels, where the meltwater action has eroded all surficial deposits away from the bedrock. The glaciofluvial sediment is loosely packed and the walls of the gravel pits collapse readily. These esker systems are the youngest ones, because they and the associated proglacial meltwater systems cross-cut the other esker systems.

The esker systems in the area trending north-south or northwest-southeast are till-covered and they predate the latest deglaciation. The till cover is about 40-70 cm thick, and was formed either during the latest glaciation or during the previous one. The eskers that were deposited from the northern direction are small, only 5–15 m high, generally continuous ridges, exhibiting ice-contact landforms, kettles and parallel ridges. Erosional landforms are gently sloping, elongated depressions, however frequently covered by a thin layer of younger deposits. They occur in the same area as till deposited by ice flowing from the north. An OSL age of 65±13 ka has been obtained for the sand that covers the glaciofluvial material. The north-south trending eskers were possibly deposited during the Middle-Weichselian deglaciation. It preceded an interstadial, from which glaciolacustrine sediments (^{14}C AMS age 42 ka) have been found at Sokli.

The till-covered eskers deposited from northwest to southeast consist of massive, over 25 m high erosional remnants of formerly coherent esker ridges. They are clearly deformed by following glaciations and covered by tills deposited during these. The glaciofluvial material is compacted and coarser than that in younger eskers. The erosional landforms connecting the separate ridges are gentle and visible in the field as elongated depressions.

The till-covered eskers deposited from the northwest are no doubt the oldest ones. However, they can not be considered to be of the same age. Age-wise they fall into two groups of so far unknown size. One part of the eskers was probably formed during the Early Weichselian deglaciation, as the ice was receding towards the northwest. The OSL datings (81±6 ka and 85±10 ka) show that their formation would be related to a deglaciation stage before the second stadial of the Early Weichselian. Results from Sokli show that the ice covered the area for the first time during the second stadial and that the area was still ice-free during the first stadial. Deposits from the Eem Interglacial have also been found between glaciofluvial material and a covering layer of till in one esker trending northwest-southeast. This, as well as OSL dates obtained from sand covering glaciofluvial material (129 ± 6 ka) suggest that there are also eskers which may have been formed during the Late-Saalian deglaciation.

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LATE PLEISTOCENE STRATIGRAPHY AND DEGLACIATION IN NORTHWESTERN ESTONIA

Ene Kadastik
Institute of Ecology at Tallinn Pedagogical University, Kevade 2, EE-10137 Tallinn, Estonia, e-mail: ene@eco.edu.ee

As the Quaternary cover is relatively thin in northwestern Estonia, the bio- and chronostratigraphical data are rare, or they are scientifically insufficiently grounded (Karukäpp & Raukas, 1997). Therefore sedimentology and fabrics petrography of differently coloured diamictons are the main methods for distinguishing or correlating till units in the area with few interglacial or interstadial sections. The northwesternmost part of Estonia has turned out be a key area for solving the Late-Pleistocene palaeogeographical problems, related to the deglaciation of the Gulf of Finland. The most remarkable ice marginal zones of Palivere Stadial of Late-Weichselian glaciation were formed in this area before the ice recession into the Gulf of Finland and Salpausselkä marginal zone.

The stratigraphical level where the interglacial Eemian sediments underlie Late-Pleistocene deposits, is determined in detail in northwestern Estonia and in the Gulf of Finland. Eemian interglacial sediments have been found and studied at two sites – at Juminda and Põhja-Uhtju, and correlated with other sites in the region (Kadastik, *et al*., 2003; Miettinen, *et al.,* 2002). Till deposits of Late-Pleistocene glaciations are common in Estonia. The majority of the Upper-Pleistocene sediments in northwestern Estonia are of Late-Weichselian age.

During the Late-Weichselian deglaciation mostly lodgement and melt-out tills were deposited (Kadastik & Kalm, 1998; Kalm & Kadastik, 2001). In some sections they are separated from each other by sorted glaciolacustrine sediments. The key finding of the study was distinguishing the different diamicton units which were correlated event-stratigraphically to the last – Pandivere and Palivere ice advances of the most recent (Late-Weichselian) glaciation and included into the Võrtsjärve Subformation according to Estonian stratigraphic nomenclature (Kadastik & Kalm, 1998). The correlatives of the Palivere and Pandivere Tills in Southern Finland, south of Salpausselkä I, are thought to be the Espoo and Siuntio Tills, respectively. Between the Palivere and Pandivere Stadial tills the interstadial deposits were determined at Kõpu Peninsula, Sõrve and Mõntu.

The detailed sedimentological investigations in northern Estonia and islands of the Gulf of Finland enabled to explain paleoenvironmental conditions during the last, Eemian interglacial and the following Late-Pleistocene glaciation. Several oscillations of the ice margin also occurred during the Late-Weichselian glaciation and deglaciation. After the Pandivere Stadial the ice margin had to retreat northward and the occurrence of buried interstadial deposits at Kõpu site proves that Kõpu Peninsula had to be ice-free during Pandivere/Palivere interstadial.

After the initial Palivere ice readvance, the general recession of the ice sheet slowed down, and the ice margin stopped at Tahkuna-Audevälja line, followed by a standstill or minor oscillation at Tahkuna. The Tahkuna-Audevälja ice marginal zone is almost subparallel to the Palivere zone and located about 20–30 km northward of the latter (Kadastik & Ploom, 2000). Well-sorted delta deposits in front of the glacier margin refer to an existence of a periglacial body of water in northwestern Estonia during the Tahkuna-Audevälja phase.

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PLEISTOCENE CHRONOSTRATIGRAPHY IN ESTONIA

Volli Kalm
Institute of Geology, University of Tartu, Vanemuise 46, EE-51014, Tartu, Estonia e-mail: volli.kalm@ut.ee

Pleistocene chronostratigraphy in Estonia is based on 60 radiocarbon (^{14}C, ^{14}C AMS) and 37 TL/OSL datings available from 29 studied sites/sections that cover a timespan from approximately 200 Ky BP to the Pleistocene–Holocene chronostratigraphic boundary, and a local clay-varve chronology for Eastern Estonia which enables tentative correlations of LG events to Finnish and Swedish varve chronologies. Analysis of existing and new unpublished data was used to review the current Pleistocene chronostratigraphy and particularly the history of Weichselian Cold Stage in Estonia.

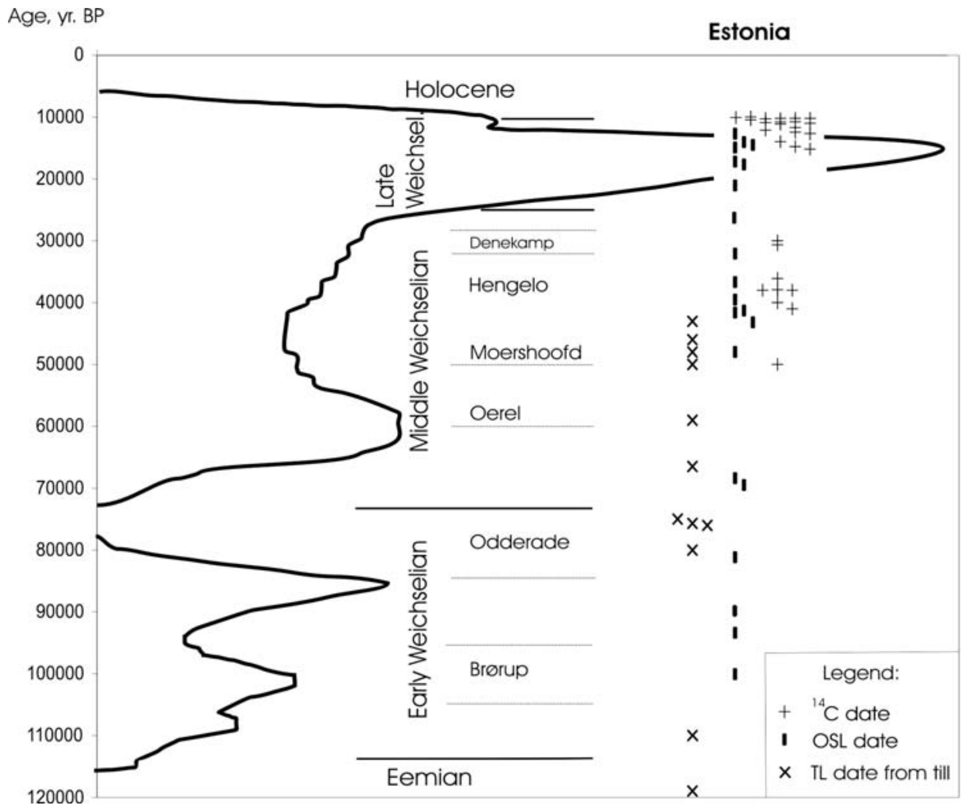

Fig. 1. Late Pleistocene datings from Estonia against the "distance from datum" evolution model of the European ice sheet through the last glacial cycle, modified from Boulton et al., 2001. The Late Pleistocene stratigraphy of Scandinavia and ages follow Donner 1995.

OSL datings from fluvial deposits that included the Kõrveküla (Holsteinian) or Rõngu (Eemian) continental interglacial deposits revealed that the pre-Weichselian interglacial deposits were re-located during the Weichselian. Available OSL and ^{14}C datings and new ^{14}C AMS ages of mammoth bones show ice-free conditions between 105-68 Ky BP and comparatively mild Middle Weichselian between 40-21 Ky BP (Fig. 1). The Late Glacial (LG) chronology (Fig. 2) indicates in general rapid (1650 ^{14}C or 1725 varve years) deglaciation of the territory (average 130 m/yr). The duration of the last glaciation in Estonia ranged between 7.8 and 10.6 Ky.

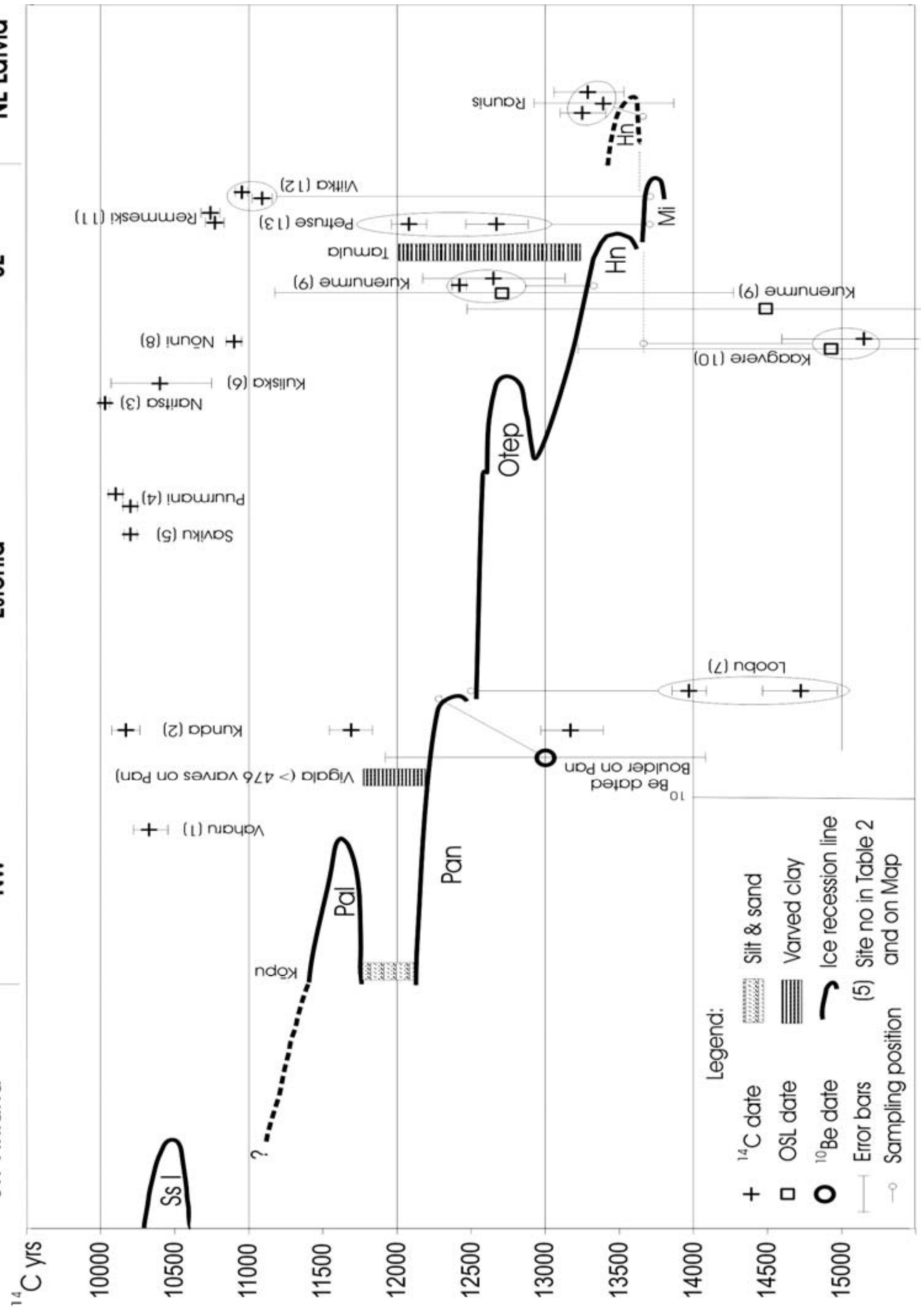

Fig. 2. Modelled decay of the Late-Weichselian ice in Estonia.

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SEQUENCE OF LATE PLEISTOCENE DEPOSITS AT SATIĶI, WESTERN PART OF THE EASTERN KURSA UPLAND

Laimdota Kalniņa[1], Ivars Strautnieks[1], Aija Ceriņa[2], and Zigurds Meirons[3]
(1) Department of Geography, University of Latvia, Rainis Blvd. 19, LV-1586, Rīga, Latvia, e-mails: Laimdota.Kalnina@lu.lv, Ivars.Strautnieks@lu.lv; (2) Institute of Geology, University of Latvia, Rainis Bvld. 19, LV-1586, Rīga, Latvia, e-mail: caija@inbox.lv; (3) State Geological Survey, Eksporta Str. 5, LV-1010, Rīga, Latvia

In the western part of the Eastern Kursa Upland a thickness of Pleistocene deposits is on average only 10-15 m, but the maximum reaches up to 30 m. Due to this interglacial sediments occur occasionally only in places where the Pleistocene cover is thicker than that which commonly relates to bedrock depressions.

In 1977 during geological exploring of the sand-gravel deposit near the Kreceri farmhouse at Satiķi geologist J. Klišāns found gyttja, silt and clay deposits rich in organic matter, including plant macroscopic remains covered by Late Weichselian till (Meirons, Straume, 1979). These deposits occur in the territory of an undulated till plain, close to the Imula River valley. The elevation ranges from 105 to 110 m. In 1980-1982 test drillings were performed, aimed to detect the contour of the ancient palaeobasin. According to the boreholes data, Meirons and Mūrniece (1982) concluded that the basin sediments were accumulated in the buried valley-like depression. Some later lithological and biostratigraphical analyses were done to estimate the age and environmental conditions of the palaeobasin.

According to pollen analyses from three boreholes (Nos. 13, 15, 20), eight pollen zones have been distinguished in the intertill deposits. Palynological data indicate the existence of interglacial conditions during formation of the sediments. Pollen composition, the character of pollen curve changes and the presence of indicator species reflect a vegetation dynamic common for Felicianovian (Eemian) Interglacial (Meirons, Straume, 1979; Kalniņa, Juskevičs, 1998). Interglacial forest succession began with a dominance of *Betula* and some *Picea* and *Pinus* admixture (pollen zone SAT1), gradually being replaced by the dominance of *Pinus* (SAT2). Distribution of broad-leaved forest trees began very early with the appearance of *Quercus* and *Ulmus* already in the *Pinus* zone (SAT2). Upwards, in the pollen zone SAT3 *Quercus* and *Corylus* reach their maxima. The high position of *Alnus* and *Corylus* pollen curves suggests wide distribution during the middle part of the climatic optimum (SAT4). Some increase of *Ulmus* had already started before, but its peak occurred just in the latter part of the climatic optimum, together with maxima of *Tilia* or *Carpinus* and contemporary occurrence of *Hedera, Vitis, Sambucus nigra, Brasenia sp.* and *Viscum* (SAT5).

A high percentage of *Tilia* is common in pollen zone SAT5 of Satiķi pollen diagrams. Such a feature is rather typical for the second part of the Last Interglacial climatic optimum in Latvia. Pollen of *Tilia tomentosa* and *T. platyphyllos* in the Satiķi pollen diagrams are accompanied by pollen of *Sambucus nigra*, and *Brasenia sp*. and spores of *Osmunda cinnamomea*.

Alnus pollen was abundant during the middle and late parts of the interglacial. As *Alnus glutinosa* is associated with wet biotopes, its abundance was probably related to the fill-in processes close to the basin shores.

Carpinus pollen appears in the second part of the interglacial (pollen zone SAT6), just before the retreat of coniferous, which were almost absent in the area since the distribution of broad-leaved forests with admixture of alder and hazel.

According to pollen data, coniferous forests dominated for the first time during the entire interglacial after the climatic optimum in pollen zone SAT7. The pollen curve of *Picea* having a high position, suggests wide distribution of spruce forests and initial changes in the vegetation composition and climate. *Picea* was replaced by *Pinus* with some *Alnus* and *Betula* in the last pollen zone of interglacial (SAT8). Pollen diagrams from all three sections reveal vegetation dynamics and composition characteristic of the Felicianovian (Eemian) interglacial.

Plant macroscopic remains were studied by A. Ceriņa. A number of warm demanding plant remains have been found in gyttja, for instnce *Carpinus betulus* L., *Tilia tomentosa* Moench., *T.*

sf. *platyphyllos* Scbp., *Corylus avellana* L. Large amount of aquatic plant, such as *Najas marina* L., *Nymphaea alba* L., *Nuphar lutea* (L.) Smith., *Salvinia natans* (L.) All., *Brasenia* sp., *Trapa* sp., and lot of different species of *Potamogeton* remains have been found.

The results of lithological and biostratigraphical studies allow to conclude that from a 3,2 up to a 14,8 m thick layer of gyttja, silt and clay had been deposited south-easterly from the gravel pit at Satiki during the Felicianovian (Eemian) interglacial. These sediments are overlain by 2.5-5.5 m thick glacial deposits.

The latest investigation of internal structure of interglacial and glacial deposits in outcrops along the northern edge of the abandoned gravel pit arouses suspicion on the former interpretation of test drilling data. For example, the ccurrence of bedrock in boreholes has been misunderstood as the position of sub-Quaternary surface. Our observation reveals that bedrock interpreted previously as a slope of the buried pre-Quaternary valley in reality represents rafted blocks translocated and altered to some extent. The thickness of the blocks varies from 1.5 to 4 m and they stretch for a distance of 2-6 m, even 10-30 m, along the outcrop. Glaciotectonically rafted and deformed, in places also brecciated Upper Devonian sandstone, siltstone, clay and dolomite are overlain by glacial deposits, including local till of thickness from some ten centimetres up to a few metres.

Palaeobasin sediments of the Felicianovian Interglacial do not occur in any outcrop of the gravel pit. According to Meirons and Mūrniece (1982), the surface of these sediments is located at a depth of 1,5-6 m south-easterly and east-south-easterly from the gravel pit. According to our re-interpretation, the width of this lens-like deposit varies from 100-200 m, but the thickness is less than 15 m. Glaciotectonic deformations of the Late Pleistocene deposits in the outcrops of gravel pit and geological sections compiled by S. Mūrniece from boreholes data indicate that basin sediments can also be deformed and may be altered to some extent. Therefore the results of paleobotanical investigations should be used very cautiously for paleogeographical reconstructions of palaeoenvironmental conditions.

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TILL MICROMORPHOLOGY AND MICROFABRIC IN THE SENSALA OUTCROP, WESTERN LATVIA

Andis Kalvāns and Tomas Saks
Faculty of Geography and Earth Sciences, University of Latvia, Rainis Blvd. 19, Rīga, LV-1586, Latvia, e-mails: andis@spic.lv, tomas@modlab.lv

The Sensala outcrop is a more than 1.5 km long section of Pleistocene and Holocene sediments at a Western Latvia Baltic Sea cliff, some 10 km south from the town of Ventspils. Several lithofacies are exposed in the Sensala outcrop: (1) dark olive grey (marine) silt; (2) fine grained glaciolacustrine sand and silt; (3) sandy waterlain till (lower till); (4) glaciofluvial sand and gravel; (5) upper basal till; and entire sequence is covered by (6) postglacial aeolian and marine sand and gravel. Sediments underlying the upper till are usually extensively deformed. Glaciofluvial sand and gravel and dark grey silt sediments usually occur in the central part of the outcrop. Glaciolacustrine sandy and silty sediments are usually encountered at the margins or at the base of the outcrop and form gentle folds up to several tens of meters wide.

In previous studies two dominant directions of local glacial stress have been identified. One glaciodynamic dominant stress direction is from northeast to southwest and associates with folding of subglacial sediments. The other glaciodynamic dominant stress is oriented from west to east and coincides with the upper till fabric. It is suggested that both structural units have to be attributed to different events during the same glaciation.

In this study micromorphology of glacial sediments at the Sensala site was examined. One or several sets of three mutually perpendicular thin sections of major sediment facies, except sand and gravel, were prepared; micromorphology and microfabric (or microlineation) were investigated.

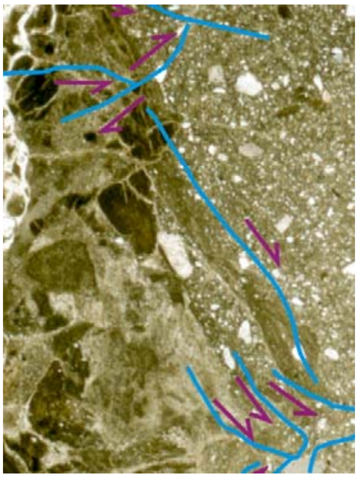

Fig. 1. Fragment of thin section No. 088-H. Contact between diamicton and silt sediments is shown. Several micro faults (*A*) are cutting a A trail of silt dragged along shear plane into diamicton (*B*) Width of the figure ~6 mm.

Dark grey silt forms diapir-like folds. A set of three thin sections is prepared from the interface of silt and diamicton in melange-type sediments (Fig. 1). The silt has a breccia-like microscale structure with angular to subrounded dark silt domains resting in a lighter matrix. In contrast, diamicton has a massive structure and has only some inclusions of angular silt fragments. The silt and diamicton interface is a discrete zone of shearing. It is supposed that initially well-consolidated silt was brecciated due to dynamic glacial stress. Through newly formed fractures high pressure pore water from the subglacial environment penetrated into the silt unit and weakened its structure. Due to deformation the fluid silt phase or matrix formed and enhanced further destruction of breccia grains during the formation of diapir.

In microscale lower waterlain till has 1-3 mm large spherical diamicton inclusions of different composition, banded structure, microlineation in plane of bedding and galaxy type rotation structures indicating that material has undergone flow deformation. Supposedly till units have formed partly by the process of mass gravity flow and partly by deposition in a proglacial lake from floating glacial ice.

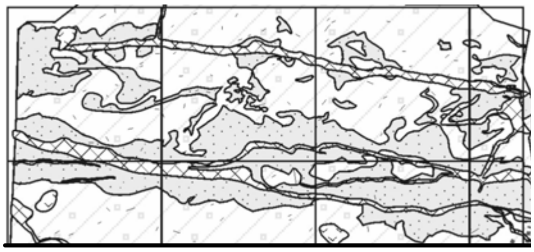

Fig. 2. Fragment of thin section Nr. 072-1: morphology of the silt band in upper till. Lower boundary of silt band is slightly undulating, suggesting formation of echelon type joints on the contact between diamicton and silt; in contrast, upper boundary is uneven, with some disrupted small pieces of silt sediments intruded into diamicton. Width of the figure is 3,3 cm.

Characteristic macroscale structures of upper till are distinct zones of microlineation and bands of sand or silt. Occasionally in the upper part of upper till, interbedding of fine sand and diamicton bands has been observed. Lower surfaces of fine sand or silt bands are step-like or undulating (Fig. 2). Dip directions of step-like structure facies occasionally coincide with the dip direction of zones of distinct microlineation. Probably they formed under shear stress as local shear bands or so-called Riedel shears. The upper surface of the same silt band is mixed with diamicton, suggesting plastic deformation due to shear and associated rotation (Fig. 2).

Fig. 3. Fragment of thin section 054. The boudin like structure of diamicton bands in banded till is visible. Width of figure is ~3cm.

In some places the uppermost part of upper till has a markedly banded structure. In microscale bands of diamicton form boudin-like structures resting in a matrix of fine sand and silt (Fig.3) Banded till probably formed in the phase of glacial retreat, when high gradients of pore water forced intrusions of sub-till matter into the ice-bed interaction zone. Intrusions could locally reduce glacial bed shear strength and permit shearing that in turn formed banded till.

GEOLOGICAL, GEOMORPHOLOGICAL AND HYDROGEOLOGICAL HERITAGE IN LITHUANIA

Bronislavas Karmaza
Institute of Geology and Geography, T. Ševčenkos str. 13, LT 03223, Vilnius, Lithuania, e-mail: karmaza@geo.lt

The term "geological monuments" (in its broad sense) applies to picturesque, unique and rare or typical geological objects that have scientific, educational, cultural, historical or esthetical value. As it is Lithuania has many legally declared objects of natural heritage. Some of them have been given the status of natural monument. The official list of legally protected geological, hydrogeological and geomorphological monuments of Lithuania contains 183 objects now: 122 of them are geological, 32 hydrogeological and 29 geomorphological. The objects of geological heritage in the territory of Lithuania can be divided into a few groups (Table).

Table. Main types of protected objects.

				All objects	Nature monuments
GEOLOGICAL OBJECTS				***122***	***72***
	Boulders			93	47
	Outcrops			25	21
		Quaternary		17	14
		Pre-Quaternary		8	7
			Devonian system	5	4
			Jurassic system	1	1
			Neogene system	1	1
			Devonian and Neogene system	1	1
	Depressions			4	4
		Karst funnels		3	3
		Glaciokarstic holes		1	1
HYDROGEOLOGICAL OBJECTS				***32***	***19***
	Springs			32	19
		Ascending		12	11
		Descending		20	8
GEOMORPHOLOGICAL OBJECTS				***29***	***28***
	Cirques			1	1
	Depressions			1	1
	Ravines			1	1
	Ridges			1	1
	Hills			5	5
	Horns			21	2
	Bluffs			5	5
	Dunes			5	5
	Eskers			5	4
	Hill-ridges			1	1
	Offspurs of hills			2	2

Most of the objects of geological heritage are represented by large size, interesting composition and otherwise valuable boulders: Puokės (Skuodas district), Vozgeliai (Utena district), Vištytis (Vilkaviškis district) boulders, Banioniai stone (Panevėžys district), "Gaidys" stone (Jonava district), etc. The Puokės stone is the largest erratic boulder known so far in

Lithuania. Its height is 3,6 m, length – 13,3 m, width 7,5 m, and perimeter – 32 m. Some of the boulders are known and valued for their connections with famous persons (A. Mickevičius's stone in Kaunas, Napoleon's stone in Zarasai district), for mythological implications (Puntukas stone in Anykščiai district, Laumės stone in Šiauliai district), or as relict attributes of heather worship (stones "Stabo kūlis" and "Šilalės kūlis" in Skuodas district).

The list of geological objects contains by far fewer outcrops of interesting geological composition with fragments of typical and rarer rocks and layers of different age. Seventeen outcrops have sections of purely Quaternary sediments. Outcrop investigations are very informative about moraines of various glaciation layers, their composition and formation conditions, interlayers of interglacial lake, bog and river sediments, their formation conditions (Snaigupėlė outcrop in Lazdijai district, Liškiava outcrop in Varėna district), unique interglacial weathering crust developed on till (Alovė outrop in Alytus district, Škėvonys outcrop in Prienai district), dislocations (Pūčkoriai outcrop in Vilnius, Pilsupiai outcrop in Kėdainiai district), and activity of glacier melt water flows and character of bottom sediments in periglacial lakes (Balbieriškis outcrop in Alytus district, Rokai outcrop in Kaunas district). Older than Quaternary deposits (dolomite, gypsum, marl, limestones) can be observed in 8 other outcrops with rocks of Devonian, Jurassic and Neogene systems. The Papilė outcrop is one of the most famous outcrops. It has been known to scientists since 1825. Collections of fossils from the Papilė outcrop are available to many European universities.

The list of geological objects also includes three deep karst sinkholes. They appeared after gypsum dissolution and formation of ample cavities in the layers of the Devonian system ("Karvės ola", "Jaronio ola", "Velniapilio ola" in Biržai district). One more sinkhole can be found in the Trakai district – "Devil's Hole". Scientists have not developed any common opinion as to the origin of this hole.

The geomorphological objects established in Lithuania are designed to preserve localities with typical or rare forms of relief bearing great scientific and educational value. These objects are mostly mounts – 5, dunes – 5, eskers – 5 and steep slopes - 5.

The geological objects also include 32 springs. Visitors have an opportunity to observe fresh underground water springs ("Šmito" spring in Skuodas district, "Karalienės liūnas" in Anykščiai district, "Ūlos akis" in Varėna district) and sources, where freshwater carbonates are precipitating (Kavarskas tuff springs in Anykščiai district), or mineral underground water springs with salty water (Balbieriškis mineral springs, the Nemunaitis mineral spring in Alytus district).

In addition, 10 geological (6 – bouders, 4 – outcrops of Pre-Quaternary rocks) and 40 geomorphological reserves have been established for the conservation of assemblages of erratic boulders, outcrops and fossiliferous sites, particular landforms and landscapes. The geological reserves are designed for the preservation of unique, rare or typical components of the geological environment that represent a particular value and importance for science, education, culture and the economy. Twenty geological reserves had been established in Lithuania before 1998 including 10 boulder terrains, 6 areas with pre-Quaternary rock outcrops and 3 areas of active karst processes. One reserve was designed for the preservation of groundwater resources. On January 1, 1998 the number of geological reserves reduced to 10: 6 boulder terrains and 4 areas with pre-Quaternary outcrops. Nine areas, which used to have the status of individual geological reserves, have been included into the territories of state parks or otherwise in the schemes of functional zones and planning. Yet it should be pointed out that declassification of their status of geological reserves is a disputable question.

The ongoing geological investigations enrich the knowledge about geological and geomorphologic objects and reveal new valuable elements of the geological environment and complexes. For this reason the list of the objects of natural heritage is supplemented.

THE GEOLOGY OF KAUNAS CITY

Danguolė Karmazienė
Geological Survey of Lithuania, S. Konarskio 35, LT-2600 Vilnius, Lithuania, e-mail: danguole.karmaziene@lgt.lt

The uppermost part of the Earth's crust, the Quaternary system, is the most important geological environment for land use management. Due to this reason the upper part of Quaternary was the main object of geological mapping of Kaunas City, in a scale of 1:10,000, has been completed in 2003. On the presented poster the Quaternary geological map of Kaunas City with geological cross-sections is represented in a scale of 1:50,000.

The glacial deposits of different thicknesses are widespread in Kaunas City and its environs. The thickest cover of Quaternary is linked with deep palaeodepressions and palaeoincisions, while the thinnest Quaternary cover is related with elevations of sub-Quaternary relief. The thickness of Quaternary varies from 20 to 140 meters. Five complexes of glacial deposits are distinguished in the Quaternary thickness: Dainava (Elsterian), Žemaitija (Saalian) and Medininkai (Warthanian) Formations of the Middle Pleistocene and Upper Nemunas (Upper Weichselian) Formation of the Upper Pleistocene. The deposits of the last formation were separated into the Grūda and Baltija sub-Formations.

There are a number of buried palaeovalleys and palaeoincisions in the Kaunas City and adjacent area. Very often they coincide with present-day valleys of the Nemunas and Neris rivers. The deepest palaeo incisions (up to 55 meters) are detected in the Pažaislis and Kaniūkai environs and filled by glaciofluvial deposits of the Žemaitija Formation. The biggest watering places of Kaunas City are connected with these deposits.

Kaunas City was established at the junction of the Nemunas and Neris rivers and first noticed in the chronicles of the Crusader Order in 1316. However, the first people started to live here about 9000 BP. At the present time Kaunas City is spread out far from the valleys of the Neris and Nemunas rivers. According to the Quaternary geological map the deposits of different genesis are extended in the territory of Kaunas City. The glaciolacustrine sediment and basal till prevail among them. The Grūda till lying on the 6th terrace above the floodplain is the oldest among deposits laying on the present day surface.

A significant part of Kaunas City is situated on the sediments of the 1st and 2nd terraces above the floodplain. The last one occupies the essential part of the Nemunas Valley. The sediments of the 1st terrace have been dated by the optically stimulated luminescence (OSL) method. The preliminary results of three samples from the Panemunė outcrop (at a depth 1.7-1.8, 2.9-3.1 and 3.7-3.9 m) are very close: from 2640±200, 2930±210 to 3570±250 BP. This age of sediments indicate that the 1st terrace was formed during the Subatlantic and Subboreal interval.

The Quaternary geological map of Kaunas City at a scale of 1:10,000 is a background for different future geological investigations, and for engineering-geological mapping most of all.

LATE GLACIAL ICE STREAMS IN SOUTHERN ESTONIA AND NORTHERN LATVIA

Reet Karukäpp and Anto Raukas
Institute of Geology at Tallinn University of Technology, Estonia Avenue 7, EE-10143, Estonia, e-mails: karukapp@gi.ee, raukas@gi.ee

The glacially formed landscapes of southern Estonia and northern Latvia are the associations of lobe depressions (North-Western Vidzeme, Central Gauja, Eastern Latvia, Võru-Hargla and Võrtsjärv lobe) and interlobate uplands: Otepää, Haanja-Alūksne and Vidzeme insular accumulative heights (or otepeas) and Sakala erosional plinth upland. The topographic lineations interpreted as a flow-parallel pattern indicate the tendency of convergent movement relating to the centres of the otepeas. The well known geological structure of otepeas indicate enhanced glacial accumulation and limited erosion during the glaciations. We suppose that preservation of the deposits of several glaciations and specific structures of the glacial pressure in the deposits can be explained with local frozen-bed conditions of glacier ice on these specific heights. Locally these conditions excluded the basal flow of the glacier (Kleman, 1994).

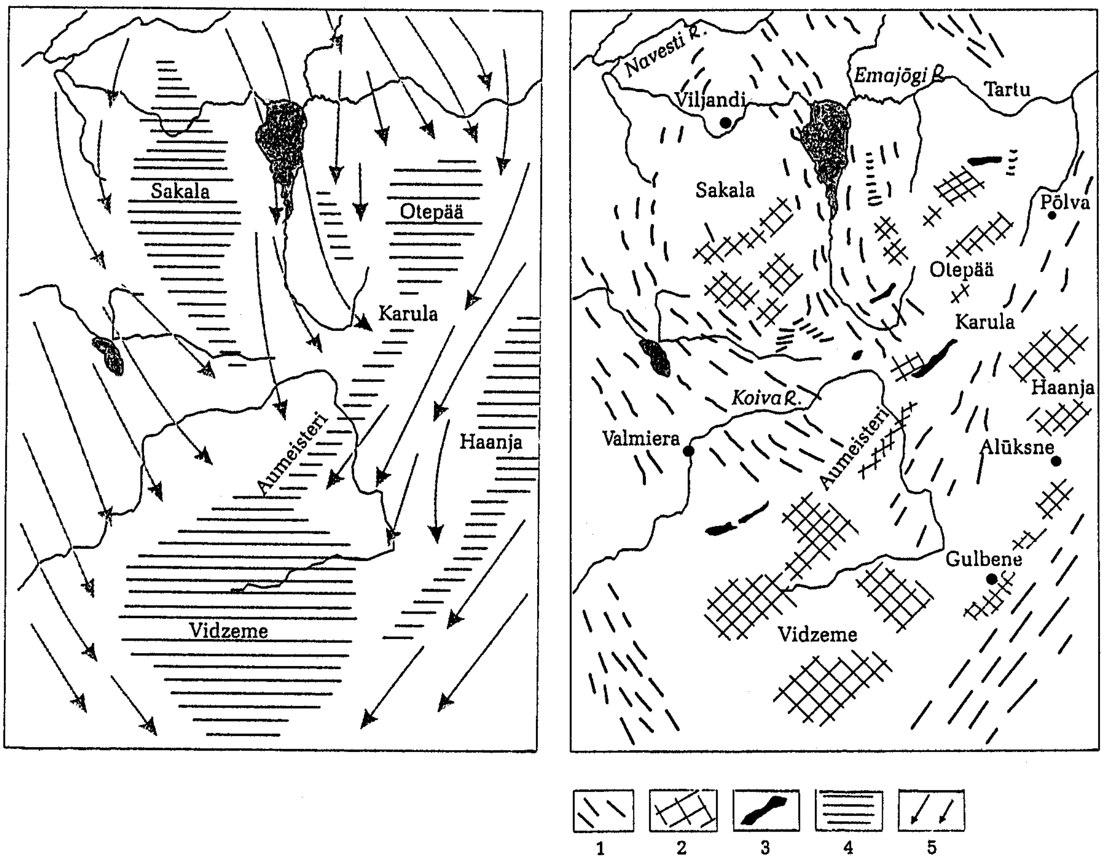

Fig. Reconstruction of palaeo-ice streams (A) of Late Glacial age based on topographic lineations and orientation of clasts in till (B): 1 – drumlins and drumlinized surfaces ; 2 – extensive hummocky areas; 3 – end moraines; 4 – slowly moving or stagnated areas of the glacier; 5 – main directions of the ice streams.

Glacial erosion and transfer of the till in the conditions of thaw-bed prevailed in the areas of the divergent ice movement, typical for lobe depressions and plinth uplands.

In the Võrtsjärv Lowland the glacial topography of the lowland and slopes of Sakala Upland and Otepää Heights was analysed recently. The generalized schemes of deglaciations drawn more or less as sub parallel lines of marginal formations could not explain the complicated palaeogeographic situation of the area (Karukäpp, Moora, 2003). The streamlined landscapes were compared and correlated with those further south. In an area of about 15,000 km^2 (Fig.) there are only a few real end moraines (Koobassaare, Sangaste).

The heights are connected with each other by interlobate hummocky belts of NE – SW direction. The location of the extensive hummocky belts (Karula-Aumeisteri) between lobe depressions indicates spatial, and probably also temporal changes in the glacial dynamics.

The flow-parallel pattern of both sides of this belt indicates:

1) spatially different directions of the glacier movement which caused subglacial and inglacial accumulation and/or;

2) Temporal changes of the moving direction, where the SW directions (a) preceded (were older than), or (b) were more powerful than the SE ones.

One of the most topical problems is the age of glacially formed landscapes and deposits. As the real end moraines in the area are missing, direct correlation of the glacial formations with those in neighbouring areas is complicated. We do not know anything about the synchronicity or asynchronicity of the movement of different ice lobes and their stagnation either. We can indicate only a probable C age of some intertill deposits, pollen data and fragmentary varve chronology diagrams. In the year 2000 on the initiative of P. U. Clark and V. R. Rinterknecht of Oregon State University, we sampled boulders for surface exposure dating with the cosmogenic nuclide ^{10}Be. The results obtained fluctuated from 11,000 to 13,500 years, and indicate the time when boulders melted out from the glacier ice of the uplands. According to the varve chronology, the accumulation in the Tamula glacial lake (between the Otepää and Haanja heights) started 14,400 yrs BP (Hang, 1997).

The area in consideration provides important information on the directions of glacier movement. Nevertheless, we are not able to reconstruct the traditional scheme of the deglaciation stages (stadials), based on geomorphological, lithological or chronological data.

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FAST FLOW OF THE LAKE MICHIGAN LOBE, SOUTHWESTERN MICHIGAN, USA

Alan E. Kehew[1], Brian C. Bird, Andrew L. Kozlowski and Christopher J. Schmidt
(1) Department of Geosciences, Western Michigan University, Kalamazoo, MI, USA 49008, e-mail: alan.kehew@wmich.edu

A rapid readvance of the Lake Michigan lobe from the Lake Michigan basin into southwestern Michigan between 14 and 15.5 ka BP driven by high basal pore pressures is interpreted from sediment—landform associations and exposures of deformed subglacial sediment. This advance involved west to east flow of all or perhaps only a segment of the eastern margin of the lobe, transverse to the dominantly southward movement of the lobe in the Lake Michigan basin, into a lowland along the eastern margin. High basal pore pressures were caused or facilitated by advance into a proglacial lake dammed between the ice margin and higher ground to the east.

A narrow, N-S oriented band of drumlins ~10 km wide was produced during the readvance at a distance of approximately 40 km from the Kalamazoo Moraine, the terminal moraine located at the limit of the advance. These drumlins, which trend east-west to northwest-southeast, occur on the distal edge of the Valparaiso upland, a ridge previously interpreted as a terminal moraine. The Kalamazoo Moraine is a prominent ridge that contains parallel ridges interpreted as imbricate thrust sheets and large areas of hummocky topography underlain by thick sand and gravel sequences. Large glaciofluvial fans head at the moraine at the ends of valleys interpreted as tunnel valleys and form a broad outwash-filled lowland to the east.

The substrate over which the ice advanced consisted of lacustrine sediments deposited in the proglacial lake(s) that existed along this margin. Exposures in several pits show a 5 to 10 m interval of deformed lacustrine sediment composed of alternating beds of silt/clay and sand/gravel immediately below the diamicton deposited during the advance. Deformation consists of tight, asymmetric to recumbent folds with fold axes both parallel and perpendicular to the direction of ice advance. The deformed lacustrine beds are sharply truncated by the contact with the overlying diamicton. Thin, sandy stringers and pods in the diamicton may indicate that it was not pervasively deforming at the time of deposition. These relationships suggest that the ice was partially decoupled and rapidly sliding on its bed facilitated by high pore pressures. The folds may have been produced before or after the most rapid period of sliding, when the ice was exerting more pressure on the bed. The association of drumlins and glaciotectonic deformation suggest that the advance of the lobe to the Kalamazoo moraine was rapid and that high subglacial pore pressures were a factor in this advance. Fast flow of the ice could have been stable, but surge behavior is also possible. The release of high pore pressures by subglacial meltwater flow to the margin via tunnel valleys and deposition of extensive outwash at the Kalamazoo moraine may have terminated the advance.

MINERALOGICAL-PETROGRAPHICAL DIVERSITY OF CONTEMPORANEOUSLY DEPOSITED TILLS IN THE POLISH LOWLAND, POLAND

Krystyna Kenig
Polish Geological Institute, 00-975 Warsaw, Rakowiecka 4, Poland, e-mail: krystyna.kenig@pgi.gov.pl

Petrographic and mineralogical diversity of tills from the regions of Pila (NW Poland), Olsztyn (NE Poland) and Siedlce (E Poland) was studied. Lithostratigraphic zonation is introduced, based on petrographic coefficient values (O/K, K/W and A/B) calculated from petrographical composition of 5-10 mm gravels found in the till.

For the Detailed Geological Map of Poland in scale 1:50,000 64 documentary sections were investigated, where 218 till beds were identified.

Eight (I-VIII) lithostratigraphic units were distinguished in the Pila region. Based on petrographical criterion, they can be subdivided into two complexes (Fig. 1). The lower complex includes horizons I and II. The upper one consists of horizons III, V, VI and VII (excluding horizon IV with only one measuring value). A boundary in the trend of changes in value intervals of petrographic coefficients between the older (I and II) and younger (III-VII) horizons can be observed.

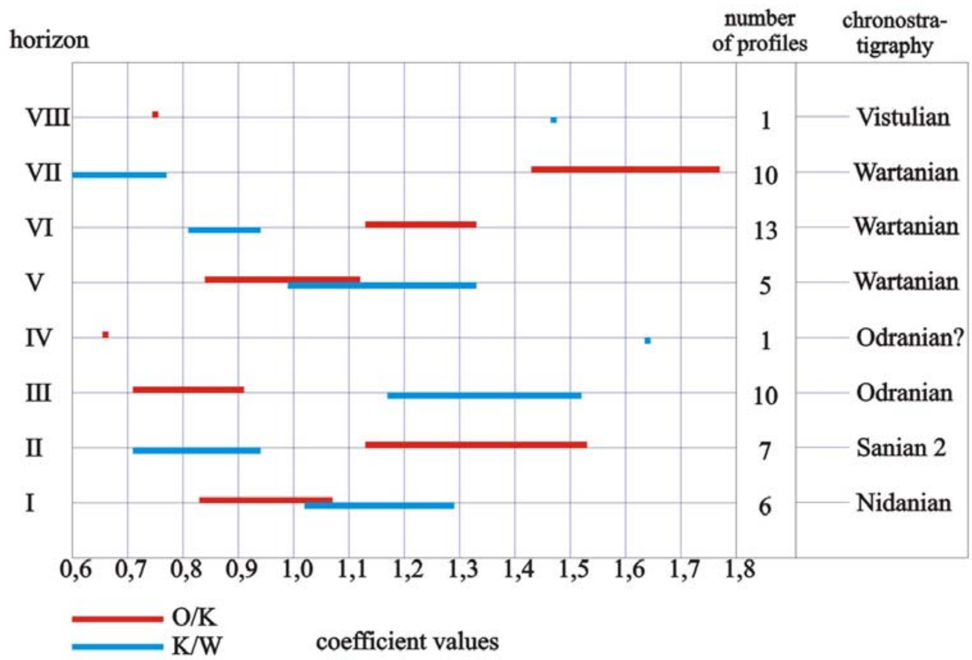

Fig. 1. Intervals of the petrographics coefficient O/K and K/W in tills of different lithostratigraphic units in the Pila region.

In the Olsztyn region, the tills represent nine lithostratigraphic horizons grouped into two complexes. The lower complex includes horizons I and IV, whereas the upper one – horizons from V to IX (Fig. 2).

As evidenced by interval values of petrographic coefficients shown in Fig. 2, the O/K coefficient values increase starting from horizons IV through horizon IX. This is due to increasing content of northern carbonate rocks. Like in the Pila region, the ice sheet centre is claimed to have migrated eastwards during deposition from successive ice sheets also in the Olsztyn region.

The significant difference between individual geographic horizons of the Siedlce region is the presence of only one lithostratigraphic horizon of the petrographically documented Odranian Glatiation in the South Podlasie Lowland. In the North Podlasie Lowland two lithostratigraphic horizons can be identified corresponding to the Odranian and Wartanian Glatiations (Kenig, 1998, 2004).

Petrographic parameters and heavy minerals composition of the tills differ from area to area. Tills from the Pila region contain more resistant minerals (49.6-1.2%) than non-resistant ones (21.9-46.2%), while similar characteristics are typical only of the lower beds in the Olsztyn area.

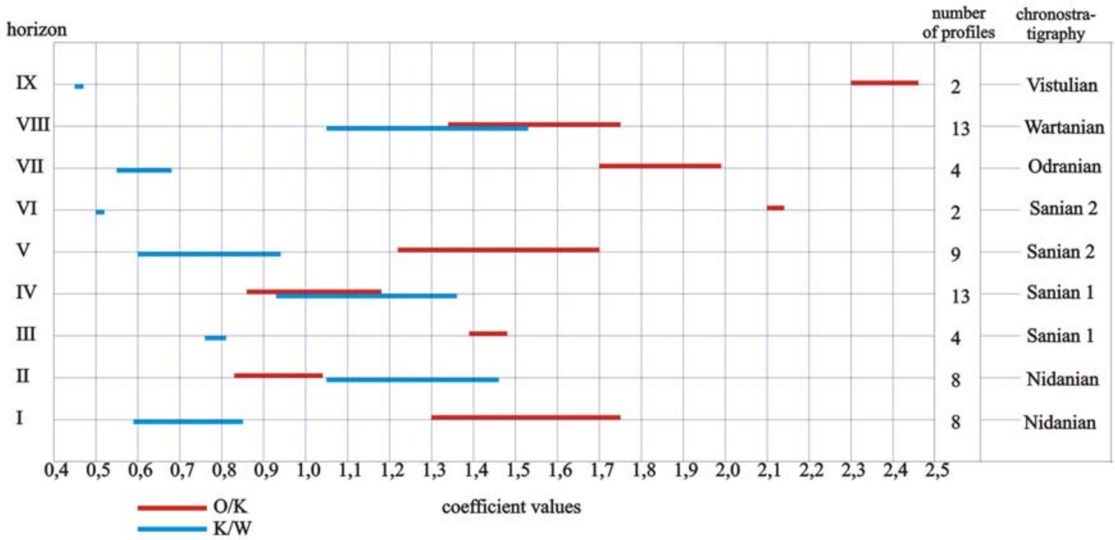

Fig. 2. Intervals of the petrographics coefficient O/K and K/W in tills of different lithostratigraphic units in the Olsztyn region.

Distinct regional quantitative differences are observed with respect to glauconite content. In the Piła region, all the till horizons contain minimal amounts of glauconite (up to 0.6%), whereas in the Olsztyn region, glauconite is much more common (up to 6%).

The carbonate minerals are more abundant in the Olsztyn region (2.2-23.2%) than in the Piła area (1.3-7.1%). In all the lithostratigraphic horizons of the Olsztyn region, the transparent minerals predominate over the opaque minerals. This tendency is less obvious in the Pila region (except for two horizons).

In both of the areas under study, complexes of lithostratigraphic horizons can be distinguished on the basis of glauconite, carbonate minerals and resistant minerals content. In the Pila region, these are horizons I-IV which correspond to the Nidanian, Sanian 2 and Odranian Glaciations. Horizons V-VIII correspond to the 3 successive Wartanian ice-sheet advances and one Vistulian ice-sheet advance. Thus, the boundary between these complexes runs between horizons IV and V, i.e. above the Odranian level. In the Olsztyn region, the lower complex, comprising horizons I-IV, corresponds to the Nidanian and Sanian 1 levels, whereas horizons V-VIII compose the upper complex. The boundary is between horizons IV and V. The latter horizon is included in the Sanian 2 level. This trend in mineralogical composition changes is confirmed by a trend in changes of petrographic coefficients values (Kenig 2004).

It can be suggested that there were ice-sheet mega-lobes in the same stratigraphic level from different areas of E and W Poland, which deposited tills of various mineralogical and petrographical features. Comparison of lithological features of tills from eastern and western parts of the Polish Lowland suggests that the directions of ice-sheet movement and source areas have a greater influence on petrographical and mineralogical variability of tills, than basement mobility has (Kenig 2004).

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POSTGLACIAL GLACIO-ISOSTATIC MOVEMENT OF THE KOLA REGION, RUSSIA

Vasili V. Kolka[1], Vladimir Ya.Yevzerov[1], Jakob J. Møller[2] and Geoffrey D. Corner[2]

(1) Geological Institute, Kola Science Centre, RAS, 14 Fersman St., 184200 Apatity, Russia, e-mails: kolka@geoksc.apatity.ru, yevzerov@geoksc.apatity.ru; (2) University of Tromsø, N-9037 Tromsø, Norway; mails: jakobm@imv.uit, Geoff.Corner@ibg.uit.no

The relative sea-level change of the Barents and White seas coastal line during the Late Pleistocene and Holocene was studied for the estimation of glacio-isostatic emergence of the Kola region. Reconstruction of sea-level change has been made for different parts of the region using the relative sea-level (RSL) curves.

The three RSL curves for the Barents coast (Snyder *et al.*, 1996, Corner *et al.,* 1999, 2001) show a pattern of uplift which conforms predictably with the position of each site relative to the margin of the retreating Fennoscandian ice sheet.

The form of RSL curves of the Barents Sea coast testifies to the following. During the period between 10000 and 9000 years ago, the rapid relative emergence (4-5 cm per year^{-}) of territory took place. The still stand or relative sea-level rise from 8000 to 6000 years BP correlates with the regional Tapes transgression. During the last 6000 years the territory emerged with moderate (<0.5 cm year^{-}) velocity.

The two RSL curves have been derived for the White Sea coast (Kolka *et al*., 1998, 2000). The form of RSL curves for Lesozavod area (SW coast of the Kandalaksha bay) testifies about the high velocity (4-5 cm per year^{-}) of a relative emergence of coast during the period from 10000 up to 9000 years BP and about moderate velocity (~1 cm per year^{-}) of an emergence during the younger period of geological history.

The RSL curve for Umba area (Tersky Coast of the White Sea) shows the relative sea-level rise between ~ 11,000 and ~10,000 years BP. However, at present the time frameworks of late-glacial transgression are outlined only and the late-glacial transgression maximum is not established. In Holocene the Umba section of the White Sea coast emerged with moderate (~1 cm per year) velocity.

On the basis of the analysis of RSL curves of the Barents and White seas and the position of isobases for the Holocene, a transgression maximum is concluded, that in late-glacial and in Holocene time the coasts of Kola Peninsula have possibly endured the fading of glacio-isostatic emergence in time. The last one had most likely a dome-shaped form. It occurred simultaneously with eustatic rising of the Ocean level and, usually, exceeded it in velocity. The position of the coastal line of the Barents and White seas in each particular site of coast is caused by a difference in velocities of glacio-isostatic and eustatic risings. These differences depend, probably, on the rate of glacial loading and intensity of melted water inflow to the Ocean.

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LATE PLEISTOCENE INTERGLACIAL MARINE SEQUENCES IN WHITE SEA DEPRESSION (KOLA PENINSULA, NW RUSSIA): TIMING, STRATIGRAPHIC POSITION AND CONDITIONS OF FORMATION

Olga P. Korsakova[1], Anatoly N. Molodkov[2] and Vasili V.Kolka[1]

(1) Geological Institute, Kola Science Centre, RAS, 14 Fersman St., 184200, Apatity, Russia; e-mails: korsak@geoksc.apatity.ru; kolka@geoksc.apatity.ru; (2) Institute of Geology, Tallinn Technical University, Estonia Avenue 7, EE-10143, Tallinn, Estonia; e-mail: molodkov@gi.ee

The till of Saalian glaciation and two tills and glaciofluvial sediments of Weichselian glaciation, interbedded by marine deposits, were established in the SE Kola Peninsula. The marine deposits are represented by three stratigraphically unconformable formations of different ages. Seven interglacial marine sequences were studied.

The lowest marine formation (Ponoj strata) was formed during the first part of the Boreal transgression and is remarkable for abundant macro- and micro fauna, and diatoms; according to the datings obtained on the Kola Peninsula the age of the formation ranges from 130-120 to 105-100 ka BP.

The overlying formation (Strel'na strata) is represented by shallow coastal sediments and is poor in organic remains. Previously, the formation of Strel'na strata was related to the Middle Weichselian (*s. stricto*) transgression, corresponding to oxygen isotope stage (OIS) 3 (e.g. Gudina, Evzerov, 1973). But, as derived from the recent studies on the structure and texture of the strata and from the ESR-ages of subfossil mollusk shells and OSL-ages of sediments, at least two subsequent phases of the Boreal transgression can be distinguished. The amplitudes of these transgressive phases, which occurred in the southern Kola Peninsula between about 100 and 80 ka, were smaller than the amplitude of the previous transgression. Transgressive phases alternated with regressive ones and were accompanied by marine erosion during the cold substages. Stratigraphic position of the formation in the studied sequences indicates that the marine regime in the southern Kola Peninsula was not disturbed during the whole period, corresponding to oxygen isotope stage 5. The coastal line migrated transgressively-regressively in the range of 50-100 m above the present sea level. According to the palaeontological data (Grave *et al*., 1969; Gudina, Evzerov, 1973), the relatively warm climate was repeatedly interrupted by several rather cool periods. At the end of OIS 5 and the beginning of OIS 4 the cooling was much more pronounced, which is evident from the glacial and glaciofluviall sediments in the sequences of the SE Kola Peninsula.

Overlying is the third marine formation. Its interstadial character is evident from the geological data and the presence of various fossils - diatoms, mollusks, foraminifera, spores and pollen, etc. According to the ESR age determinations (about 55 ka BP), it corresponds to the very beginning of OIS 3. These marine sediments are overlain by Late Weichselian till and glaciofluvial sediments.

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MODERN COASTAL PROCESSES AT THE CAPE OF KOLKA

Jānis Lapinskis

Department of Environmental Science, University of Latvia, Rainis Blvd. 19, LV-1586, Rīga, Latvia, e-mail: janisl@lanet.lv

The Cape of Kolka is located at the top of the Kurzeme Peninsula. It is formed on a spit of the Litorina Sea. The configuration of the Cape during transgressions and regressions of the Litorina Sea has changed many times. During transition from the Litorina Sea to the modern Baltic Sea stage about 2,800 years ago, very significant erosion of both sides of the Cape Kolka took place (Ulsts, 1998). After the stabilization of sea level, the intensity of coastal processes decreased remarkably along the entire coastline (Knaps, 1966). Consequently the amount of incoming sand decreased too. Thenceforth the Cape of Kolka has been gradually changing its shape and position. From 1890 till 1993 the coastline in the northern part of the Cape has retreated some 140 meters and more than 300 meters in the eastern part (Ulsts, 1998). Critical hydrological circumstances in the Cape area are made by storm currents from the Irbe strait which combine with Irbe Strait-Gulf of Riga water exchange currents. The Cape of Kolka as a major foreland represents a partial barrier to alongshore sediment drift (Eberhards, 2003).

In order to assess possible trends on both sides of the Cape of Kolka where sediment dynamics are determined mainly by natural conditions, coastal processes monitoring data were analysed for the period from 1992 up to 2004. Levelling measurements using an optical level on an annual basis, with one-year interruptions at particular transects, were taken along three fixed transects on the eastern side of the Cape where a narrow sandy beach with a relatively wide back beach and embryonic foredunes are present. Transects are located 200, 500 and 800 metres south from the top of the cape. Measurements of the beach and active aeolian landforms volume have been taken since 2000. A total of 58 ordinary measuring transects were used, located in two model sections of the coast of the northern side of the Cape, where a low sandy bluff is present. The first model section (Kolka VII) covers 180 metres of coastline and begins 30 metres from the top of the Cape. The second model section (Kolka I) covers 980 metres of coastline and begins 350 metres from the top of the Cape. Measurements of a bluff retreat rate have been taken since 1992 and 1999 after storm events. The distance between transects within model sections of the coast varied between 10 and 30 metres. The data are available at the Laboratory of Coastal Monitoring of the Department of Environmental Science, University of Latvia. A total of four beach forming sediment samples were collected 0.1, 2.1, 4.1 and 6.1 kilometres to the west from the top of the Cape and analysed for size in 2002 to compare with sediment samples from 1984.

The relief of all shore slopes tends to adapt to the prevailing wave conditions and the amount of available sediment. The profile of the shore slope is very poorly adapted for storm conditions, when wave energy considerably exceeds the mean level, and so it rapidly obtains a gentler slope, at the expense of material from the upper part of the slope. Erosion vulnerability of the coast on the Cape of Kolka is very high (Eberhards, 2003). The natural protective barrier in front of the coast (beach and active aeolian relief) has less than 40-80 m^3/m of sediment above sea level.

Certain particularly stormy autumn/winter seasons have played a very important role in the fluctuations of sediment volume:

- 1992/1993 (coast of the Baltic Sea and Irbe Strait);
- 1999/2000 (Baltic Sea coast);
- 2001/2002 (coast of the Irbe Strait and the Gulf of Rīga).

After the storm of November 2001, beach recovery was particularly rapid, since in many places west from the Cape of Kolka the foredune had been wave-washed, thus mobilising a considerable amount of material, which had for a brief interval been removed from circulation, contributing to aeolian accretion.

The southern side of the Cape. The volume of beach and active aeolian sediment along the eastern side of the Cape of Kolka transects remains fairly stable in the four-year term. An exception is the northernmost transect which shows significant loss of material after stormy autumn and winter of 2001/2002. Catastrophic erosion of the low, sandy acreational coast occurred only in the first 300 metres south from the Cape with a maximum of 30 m at the Cape point. The last major storm, witch washed an equal or greater volume of sand into the sea from the Kolka Cape, was observed in 1967.

The western side of the Cape. According to stationary measurement data in the storm of 1993, the predominant rate of erosion was 4 - 8 m and it was characteristic that significant bluff erosion took place only in a 1,000-metre long section of coast at the top of the Cape. During the storm of 1999 erosion was insignificant. In the storm of 2001 mean rate of erosion was 3 - 7 m, with a maximum of up to 10 m, and once again bluff erosion occurred only in first 750 metres from cape top. During storm-free periods the profile of coastal slope stabilises with some aeolian accumulation in front of the bluff, but the coastline does not retake its lost position.

Main conclusions:

1. The configuration of the Cape of Kolka is unstable for modern conditions in the coastal system of Northern Kurzeme.
2. During major storm conditions maximum damage occurs close to the top of the Cape.
3. Due to measured accelerated nearshore erosion on the Kolka spit, an increasing rate of coastal erosion up to 20-50 m in the next 20 years might be forecasted.

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MAIN CLIMATIC CHANGES IN THE QUATERNARY OF POLAND, BELARUS AND UKRAINE

Leszek Lindner[1], Leszek Marks[1], Petro Gozhik[2], Yadviga Yelovicheva[3] and Barbara Marciniak[4]

(1) Institute of Geology, Warsaw University, Żwirki i Wigury 93, 02-089 Warszawa, Poland; e-mails: lindner@geo.uw.edu.pl, leszek.marks@pgi.gov.pl; (2) Institute of Geological Sciences, National Academy of Sciences of Ukraine, Gonchara 55b, 01054 Kiev 54, Ukraine; e-mail: igndir@igs.org.ua; (3) Institute of Geological Sciences, National Academy of Sciences of Belarus, Kuprevich 7, 220141 Minsk, Belarus, e-mail: yelovicheva@land.ru; (4) Institute of Geological Sciences, Polish Academy of Sciences, Twarda 51/55, 00-818 Warszawa, Poland; e-mail: bmarcini@twarda.pan.pl

Detailed research in 1970-1980 of main climatic changes during the Quaternary has indicated that in central and eastern Europe occupied by Scandinavian glaciations and vast loess cover, most coolings/glaciations and warmings/interglacials are to be studied in Poland, Belarus and Ukraine. This opinion was confirmed later by new data that enabled the determination of glaciations and interglacials as the main climatostratigraphical units in Europe.

No glacial sediments were deposited in this part of Europe during the Early Pleistocene, the interval that was named Preglacial or Prepleistocene by S.Z. Różycki. In Poland it comprises Różcian, Otwockian, Ponurzycian and Celestynovian: the first and third were cold, the second and fourth were warm. In Belarus there are two cold (Olhovskian and Vselubskian) and two warm (Grushevskian and Yelenynskian) horizons. In Ukraine they correspond to two coolings (Siver and Beresan) and two warmings (Beregovo and Kryzhaniv).

In the Dutch subdivision the Lower Quaternary comprises two coolings (Praetiglian and Eburonian) and two warmings (Tiglian and Waalian). In Germany they respond to the coolings Mulde and Wyra, and warmings Wyra/Mulde and Pleise/Wyra accordingly.

In Poland within the Middle and Late Quaternary, considered as the Pleistocene owing to glaciations, there were 10 glaciations or coolings (Narevian, Augustovian 1/2, Nidanian, Sanian 1, Ferdynandovian 1/2, Sanian 2, Liviecian, Krznanian, Odranian+Wartanian, Vistulian), separated by 9 interglacials or warmings (Augustovian 1, Augustovian 2, Malopolanian, Ferdynandovian 1, Ferdynandovian 2, Mazovian, Zbójnian, Lubavian, Eemian). In Belarus there were 9 glaciations or coolings (Narevian, Servetskian, Belovezhian 1/2, Berezinian, cooling 4, cooling 5, Dnieperian, Sozhian, Poozerian) and 8 interglacials or warmings (Korchevian, Belovezhian 1, Belovezhian 2, Ishkoljdian, Alexandrian, Smolenskian, Shklovian, Muravian). In Ukraine 8 main loess horizons (Ilyichivsk, Priazovsk, Sula, Tiligul, Orel, Dnieper, Tyasmin, Valday) introduced the Middle and Late Quaternary. They were separated by 7 palaeosols (Shirokino, Martonosha, Lubny, Zavadivka, Potagaylivka, Kaydaky, Priluky), among which there were four complexes, composed of 2-3 interglacial soils.

This report presents representative climatostratigraphical subdivisions in Poland, Belarus and Ukraine, and is therefore a new approach to the number and correlation of main climatic units of the Quaternary in Central and Eastern Europe. It is based on previous stratigraphical correlations and numerous sections of glacial sediments, loesses, organic deposits and palaeosols. The main cold and warm stratigraphical units were correlated with oxygen isotope stages in deep-sea sediments and with palaeomagnetic record. 26 climatic oscillations were introduced, including global coolings and warmings, and also consistent correlations of main stratigraphical subdivisions of the Quaternary in Poland, Belarus and Ukraine.

The four oldest intervals (Różcian = Olkhovskian = Siver, Ponurzycian = Grushevskian = Beregovo, Otwockian = Vselubskian = Berezinian and Celestynovian = Yelenynskian = Kryzhaniv) are consistently correlated with the ones from Western Europe. Middle-Late Quaternary comprises 11 glaciations/coolings, subdivided either by glacial deposits or by loesses. These subdivisions are separated from one another by 10 interglacials/warmings and are completed by the Holocene. All of them are represented by buried lake deposits with specific floristic successions, and/or interloessy palaoesols or their complexes. They are to be reasonably correlated with similar subdivisions in western Europe.

Glacial sediments and landforms in Poland, Belarus and Ukraine, give the best correlation for glacial subdivisions. They introduce the glaciations: Vistulian (Poozerian, Valday), Odranian+Wartanian (Dnieperian+Sozhian, Dnieperian 2 = Tyasminian) and Sanian 2 (Berezianian). In Western Europe these glaciations correspond to Weichselian, Drenthe+Warthe and Elster 1. Older glaciations/coolings could be studied mainly on the basis of interglacial lake deposits and their relation to the palaeosols. In this case the best correlation was done with a use of pollen spectra of the interglacials: Eemian (Muravian), Mazovian (Alexandrian), Ferdynandovian 2 (Belovezian 2) and Ferdynandovian 1 (Belovezian 1), analysed also for the palaeosols: Pryluki, Zavadivka, Lubny 1 and Lubny 2.

Analysis of climatic changes during the Middle and Late Quaternary in this area, especially expressed by loesses and palaeosols, has created the basis for their chronology by reference to a palaeomagnetic record. This sequence is expressed by distinct cycles, 110-90 thousand years each, and they fully resemble a rhythm of climatic changes recorded in deposits of the Baikal Lake, in northern Eurasia and in deep sea.

The presented material indicates that in the territory of Poland there are two new stratigraphical units (warm and cold) between Narevian glaciation and Augustovian 1 warming. There are also indications of global coolings (glaciations?) Augustovian 1/2 and

Ferdynandovian 1/2. In Belarus, the occurrence of deposits of a global cooling between Smolensk and Shklov interglacials also seems probable. New data in both areas demonstrate that Odranian (Dnieperian) and Wartanian (Sozhian) correspond to Drenthe and Warta stadials in the Western Europe. Shirokino, Lubny and Zavadivka soil complexes in Ukraine, including 2-3 interglacial soils each, can represent first-rank warmings. They correspond not only to interglacial units in Poland and Belarus, but also to warmings Bavel and Cromer, as well as to Holstein and Reinsdorf interglacials in Western Europe.

Summing up, it seems obvious that Poland and Belarus possess the most composite sequence of glacial deposits, whereas Ukraine has the most complete loess and palaeosoil series. They all constitute a standard for a climatic rhythm of the Quaternary in Europe.

SOURCE AREAS AND CENTRES OF THE PLEISTOCENE GLACIATIONS OF THE SCANDINAVIAN ICE SHEET - RECORD IN TILL FINE-GRAVELLY FRACTIONS OF THE VISTULA DRAINAGE BASIN AREA, POLAND

Stanisław Lisicki
Polish Geological Institute, Rakowiecka 4, PL 00-975 Warszawa, Poland, e-mail: stanislas.lisicki@pgi.gov.pl

On the basis of the fine gravel analyses (grain size 5-10 mm) of Scandinavian (northern) group rocks, 16 stratigraphic lithotypes of tills occurring in the Vistula drainage basin are grouped in three petrographic types. The tills of $\boldsymbol{A_2}$, $\boldsymbol{S_1}$ and $\boldsymbol{S_2}$ (K/W = 1,7-1,0) lithotypes belong to the first petrographic type. Predominance of the gravel of crystalline rocks in comparison to the gravel of carbonate rocks or a balance between both kinds of gravel are common for these tills. The tills of $\boldsymbol{A_1}$, $\boldsymbol{N_2}$, $\boldsymbol{G_1}$, $\boldsymbol{G_2}$, $\boldsymbol{W_1}$ and $\boldsymbol{W_2}$ (K/W = 0,9-0,6) lithotypes form the second petrographic type, with a low prevalence of gravel of carbonate rocks on the gravel of crystalline rocks and sandstone. The tills of $\boldsymbol{N_1}$, $\boldsymbol{C}$, $\boldsymbol{O_1}$, $\boldsymbol{O_2}$, $\boldsymbol{B_1}$, $\boldsymbol{B_2}$ and $\boldsymbol{B_3}$ (K/W = 0,6-0,3) lithotypes correspond to the third petrographic type. These three types of lithotypes were explicitly differentiated by gravelly composition of the Scandinavian (northern) rocks.

The largest part of the Fenoscandinavian region is built by crystalline rocks. The territory where the Palaeozoic carbonate rocks crop out, or are overlain only by a thin cover of Cenozoic deposits, is located southerly from Fenoscandia. The carbonate rocks covered by Quaternary deposits are common in the territory of the Western Baltic trough. Occurrence of outcropping Palaeozoic rocks increases to the east. In the central and eastern territory of the Baltic countries (Lithuania, Latvia and Estonia) they appear over a 500 km wide belt, where these layered rocks dip monoclinally to the south or southwest. Gradual denudation of these rocks did not cause the real diminution of the area of their distribution during the Quaternary. The main direction of the Scandinavian ice sheet drawing on the Vistula drainage basin proceeded from the north to the south for particular glaciations and stadials. This is the reason, as well as the varying width of the area composed by the carbonate rocks in the western and eastern sectors of the Scandinavian ice sheet, that caused differences in rocks transferred by the ice sheet. Therefore, it is possible to calculate theoretically the transfer of the gravel petrographical composition from the three main centres of glacial erosion - the Scandinavian Mountains, the Bothnian Gulf area and the northern part of Finland. It seems that the distinct geological structure of these regions is reflected in the difference of gravel composition in the Vistula drainage basin area.

Perhaps three glacial centres in Scandinavia area can be distinduished. The gravel in the first petrographic type ($\boldsymbol{A_2}$, $\boldsymbol{S_1}$ and ***S2*** lithotypes of tills) came from the ***Swedish petrographical province*** and the gravel-forming material was transported by the ice sheet from the Scandinavian Mountains. The ice sheet, which spread out from the Bothnian Gulf area, was responsible for the rock consumption from the ***Bothnian petrographical province*** and the formation of the tills of $\boldsymbol{A_1}$, $\boldsymbol{N_2}$, $\boldsymbol{G_1}$, $\boldsymbol{G_2}$, $\boldsymbol{W_1}$ and $\boldsymbol{W_2}$ lithotypes. The easternmost ice sheet from the northern part of Finland resulted in the formation of the tills of $\boldsymbol{N_1}$, ***C***, $\boldsymbol{O_1}$, $\boldsymbol{O_2}$, $\boldsymbol{B_1}$, $\boldsymbol{B_2}$ and $\boldsymbol{B_3}$ lithotypopes, in which fine-grained gravel from the ***Finnish petrographical province*** is common.

The directions of ice sheet transgressions of the particular glaciations were shown by the geological data obtained from the petrographical studies of tills in the Vistula drainage basin. Generally, the direction of the shifting of the Pleistocene Scandinavian glaciation centre was confirmed.

LECHATELIERITE-BEARING MICROSPHERULES FROM BURNING OIL-SHALES (KIVIÕLI, ESTONIA): CONTRIBUTION TO THE CONTAMINATION PROBLEM OF NATURAL MICROTEKTITES

François Marini[1] and Anto Raukas[2]

(1) Ecole Nationale Supérieure de Géologie (E.N.S.G.), BP40, 54501 Vandoeuvre lès Nancy Cedex, France, and C.R.P.G.-C.N.R.S., B.P. 20, 54501 Vandoeuvre lès Nancy Cedex France. (2) Institute of Geology at Tallinn University of Technology, Estonia Ave 7, EE-10143 Tallinn, Estonia

INTRODUCTION. Natural microtektites are small glass droplets derived from the melting and quenching of terrestrial rocks during hypervelocity meteorite impacts on the Earth (see Montanari & Koeberl 2000, and refs. therein). Most of these natural glass droplets occur in the form of microspherules ranging in size from 1mm to a few tens of micrometers. However, a variety of industrial processes may also produce broadly similar glassy microspheres, and there are still risks in mistaking man-made products for natural microtektites. Moreover, industrial spherules may contaminate the natural glasses, both at the outcrop and during laboratory treatments (Montanari 1986; Wang & Chatterton, 1993; Marini, 2003).

As an additional risk of confusion, we document the occurrence of glassy microspherules ressembling microtektites in solid residues of oil-shale retorting (semicoke heaps). Surprisingly, these spherules exhibit conspicuous inclusions of lechatelierite (pure SiO2 glass). Such inclusions were previously considered as typical of natural tektites and microtektites, in which they are believed to derive from shock-induced melting of quartz grains from the impacted rocks (Chao, 1963; Glass, 1990). Admittedly, lechatelierite inclusions have been taken as a criterion to distinguish natural glasses related to impacts from most common industrial glasses.

OCCURRENCE & DESCRIPTION. The samples come from the top of the "Old semicoke hill": a large heap towering by 101 m above the surface near the city of Kiviõli, NE Estonia. The semicoke appears as blackish, coarse gravel sand (grain size: ca. 50 mm-10 microns), of high intergranular porosity. It consists mainly of fragments of carbonaceous matter, compound fragments (involving silt-sized admixtures of quartz-, phyllosilicate- and carbon- particles), broken carbonate fossil remnants, calcite and dolomite rhomboedrons, and detrital grains of quartz and feldspar.

The spherule content is comparatively high: over 5 spherules per gram after removal of the largest fragments. We found both opaque (Fe-oxide-)- and transparent (silicate-)- spherules (size range: 50-200 microns). Leaving aside the opaque spherules, and part of the transparent ones (rare colourless spherules of Si-rich silicate glass), we focus here on the dominant type: faint yellow spherules of Ca-Al silicate glass, thereafter quoted as the "Kiviõli spherules".

Most of these spherules broadly resemble microtektites, although some may be distinguished readily by their higher content in gas vesicles. Hollow spheres are infrequent, in contrast to silicate coenospheres commonly found in fly ashes from coal power plants (Diamond, 1981). The main glassy component of the "Kiviõli spherules" falls within the compositional range of melilites, more precisely K-rich- Na-poor- melilites (see Table).

The salient feature of the Kiviõli spherules, however, is the general occurrence of unmixed silica remnants (5-15 microns). These can appear in all intermediate conditions, from unmelted quartz grains adhering to the surface of the spherules, to rounded patches of completely melted silica (now lechatelierite). The same situation can be seen in section, from full quartz- to pure lechatelierite- inclusions (intermediate stages show lechatelierite embedding some relictual quartz). These observations are readily confirmed under electron probe: in stark contrast to the quartz remains, the lechatelierite glass is deeply damaged under focused electron-beam, even at moderate conditions (10 nA, 15kV).

Table.

	Mean wt%	St. Dev.	Melilite Range		Mean wt%	St. Dev.	Melilite Range
SiO_2	***41.76***	2.57	(44.1-37.8)	MgO	***3.50***	1.52	(9.43-3.12)
TiO_2	***0.66***	0.33	(0.66-0.00)	CaO	***32.2***	5.07	(34.9-29.8)
Al_2O_3	***11.30***	1.53	(12.9-5.02)	Na_2O	***0.14***	0.08	(5.27-2.83)
FeOT	***4.98***	1.82	(7.95-0.98)	K_2O	***2.86***	1.07	(1.72-tr.)

Faint yellow glass, from 71 selected WDS analyses. Camebax SX100. FeOT= Tot. Fe as FeO. Melilite range (wt%) from data in Deer et al., 1963.

DISCUSSION: a complete understanding of the origin of the Kiviõli spherules and their lechatelierite inclusions must be based on further precise thermodynamic investigations of the melting and cooling processes. As a preliminary draft, we propose the following scenario:
The observed glassy components - hence their parent melts - are fairly close in composition to the bulk of the semicoke (as reported by Raukas & Teedumäe, 1997). However, silicate melts cannot result directly from the retorting process (Kiviter process), which is operated at comparatively low temperatures (ca. 400°C). It seems that the melts derive from much later self-ignition of the residual organic matter, inside the semicoke heap (mean content: 4-6wt% of organic carbon, see Raukas & Teedumäe, 1997). This may result in spots of high temperature, leading to local and partial melting of the porous aggregate of particles which form the semicoke pile. Surface tension would produce spherules when droplets of such melts are expelled into the pores of the semicoke and then driven suspended in hot gas ascending through this porous medium. Rapid cooling of this gas outside the burning spots would congeal the spherules to the glassy state. This scenario would also explain why glassy spherules can be found between semicoke components which seemingly escaped any high temperature transformation (i.e., carbonate fossil remains, calcite and dolomite rhomboedrons)

CONCLUSION: Our finding of lechatelierite inclusions in glass spherules of obvious industrial provenance might cast serious doubts on the validity of the classical "Lechatelierite Criterion" as a test for impact glasses. This stresses the need to take into account a wider set of indicators from the spherule-bearing samples (i.e., occurrence of shocked materials, diagnostic minerals, and chemical anomalies) when evaluating the impact derivation of glassy spherules of unknown origin.

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MAP OF WEICHSELIAN DIRECTIONAL ICE-FLOW FEATURES OF CENTRAL AND EASTERN EUROPE

Leszek Marks[1], Tomasz Bielecki[1], Waldemar Gogołek[1], Jacek Kocyła[1], Rimante Guobyte[2], Volli Kalm[3], Maris Rattas[3], Irina Pavlovskaya[4], Hans-Jürgen Stephan[5] and Vitālijs Zelčs[6]

(1) Polish Geological Institute, Rakowiecka 4, 00-975 Warsaw, Poland, e-mails: leszek.marks@pgi.gov.pl, tomasz.bielecki@pgi.gov.pl, waldemar.gogolek@pgi.gov.pl, jacek.kocyla@pgi.gov.pl; (2) Geological Survey of Lithuania, Konarskio 35, 2600 Vilnius, Lithuania, e-mail: rimante.guobyte@lgt.lt; (3), Institute of Geology, University of Tartu, Vanemuise 46, 51014 Tartu, Estonia, e-mails: volli.kalm@ut.ee, mrattas@ut.ee; (4) Institute of Geological Sciences, National Academy of Sciences of Belarus, Kuprevich 7, 220 141 Minsk, Belarus, e-mail: ipavl@ns.igs.ac.by; (5) Landesamt für Natur und Umwelt Schleswig-Holstein, Hamburger Chaussee 25, 24220 Flintbek, Germany, e-mail: h-j.stephan@freenet.de; (6) Faculty of Geography and Earth Sciences, University of Latvia, Rainis Blvd. 19, 1586 Riga, Latvia, e-mail: Vitalijs.Zelchs@lu.lv

In the area to the south of the Baltic Basin numerous glacial features have been studied for years and many directional data have been previously collected. The project Ice Flow Directions in the Peribaltic Area during the Weichselian Glaciation was expected to select all published and unpublished data. It was supported by INQUA and by national funds of participating countries.

Ice flow directions can be detected from linear glacial landforms and sediment fabric. They are either direct (striations, till fabric, local glaciotectonic deformations, streamlined landforms) or indirect (glacial tunnel valleys, eskers, kame chains, end moraines) ice-flow features. Their spatial distribution indicates radial structure in the ice sheet terminal zone and location of interlobate zones.

A final result of the project is a database and a set of national maps (in a scale of 1:500,000) of the Last Glacial Maximum area in Belarus, Estonia, Germany, Latvia, Lithuania and Poland. The maps have been constructed since 2000 with the use of the program ArcInfo. The maps are to be put together into a complex map (in a scale of 1:1,000,000) that is to present a unified image of ice flow directions during the Late Weichselian. This map will create a reliable background for a profound palaeoglaciological 3-D modelling of the ice sheet body and dynamics of the last Scandinavian glaciation.

Compositional properties of tills (e.g. erratics, trace elements, glacial rafts, clast petrography) also supply a general sense of ice-flow direction, but should be treated with caution, as they can be affected by the recycling of material during several glacial episodes. Dating of sediments in ice-marginal areas and the mutual relation of different directional features throw new light on time-transgressive ice sheet limits during the Last Glacial Maximum, as well as on timing and persistence of the postulated palaeo-ice streams expanding in this time from the Baltic Basin onto the central and eastern European area.

DISCOVERY AND INVESTIGATION OF A "HOT WATERLAIN TILL" IN SOUTHERN ICELAND

Eva Mätzler, Rolf Tschumper, Christian Schlüchter
Institute of Geological Sciences, University of Bern, Baltzerstrasse 1, CH-3012, Bern, Switzerland, e-mails: eva.m@student.unibe.ch

A field mapping project in Thórsmörk, southern Iceland took place from 1999 to 2003. We discovered a special outcrop of waterlain till. It has a length of about 1km and an average thickness of 10m.

The peculiarities of this tillite express themselves by the following attributes: contraction structures formed along fractures similar to columnar joints in basalts, but in dimensions of a few millimetres to centimetres. The tillite is exceptionally compact and has in some places a peculiar dark colour. Some of the dropstones have a white crust. Further more, the tillite breaks into glassy, chert-like pieces.

All these peculiarities indicate heating of the glacial material during or after deposition.

The area of Thórsmörk has been developed and modelled by continuous interaction of glacial and volcanic activity. Hence, we assume the waterlain till was heated by volcanic eruption(s), possibly by a pyroclastic flow. Laboratory investigations are still ongoing.

A NEW WEICHSELIAN SITE IN NORTHEAST ESTONIA: EXPECTATIONS INDUCED BY POLLEN AND ESR PALAEOENVIRONMENTAL RECORDS FROM NORTHERN EURASIA

Anatoly N. Molodkov[1], Nataliya S. Bolikhovskaya[2]
(1) Institute of Geology, Tallinn University of Technology, Estonia Avenue 7, 10143 Tallinn, Estonia, e-mail: molodkov@gi.ee; (2) Department of Geography, Moscow State University, 119899 Moscow, Russia, e-mail: nbolikh@geogr.msu.ru

A time span covering the last interglacial-glacial cycle has been marked by many large-scale global and regional climate changes, between warmer and cooler conditions. At the same time, long and continuous terrestrial proxy climate records through this time interval are scarce in the Baltic region. As a result different stratigraphic schemes and palaeo environmental interpretations for the Last Interglacial and Last Ice Age have been proposed for this region during the last decades. The attempts to correlate them with the global oxygen isotope-based reference levels were not always successful. This can be explained either by the absence of some palaeo environmental episodes in the Late Pleistocene history of the Baltic States or by the circumstance that the relevant deposits have not yet been recognised here. The latter explanation seems more reasonable because glacial erosion could have been very intensive on the territories of the Baltic States, especially in Estonia and Latvia, on the one hand, and the lack of geochronological data beyond the ^{14}C dating range in these two countries, on the other.

The exposures recently revealed at the Voka site, NE Estonia, seem to have great potential for providing a unique archive of natural palaeoenvironmental changes that occurred there during the last interglacial-glacial cycle. It is hoped that many palaeo environmental aspects can be resolved by a multidisciplinary study of the stratigraphic sequences of this promising new Late Pleistocene section. At the same time, it is obvious that stratigraphic sequences, even of the relatively complete section, cannot be considered outside the regional and global context. Therefore, local stratigraphic, geochronological and palaeo environmental data should be compared with those obtained on neighbouring territories and in the rest of Europe.

To develop a palynochronostratigraphic framework for the last interglacial-glacial cycle, we have attempted to link marine mollusc-based age analysis from this time interval with the palaeoclimatic data derived from the pollen-based vegetation signals of the terrestrial environment from the East European loess province (Fig. 1). The linkage of these two independent climatic records has provided us better insight into palaeoenvironmental changes during the last interglacial-glacial periods, where radiometrically dateable materials typically are scarce both in terrestrial and marine sediments.

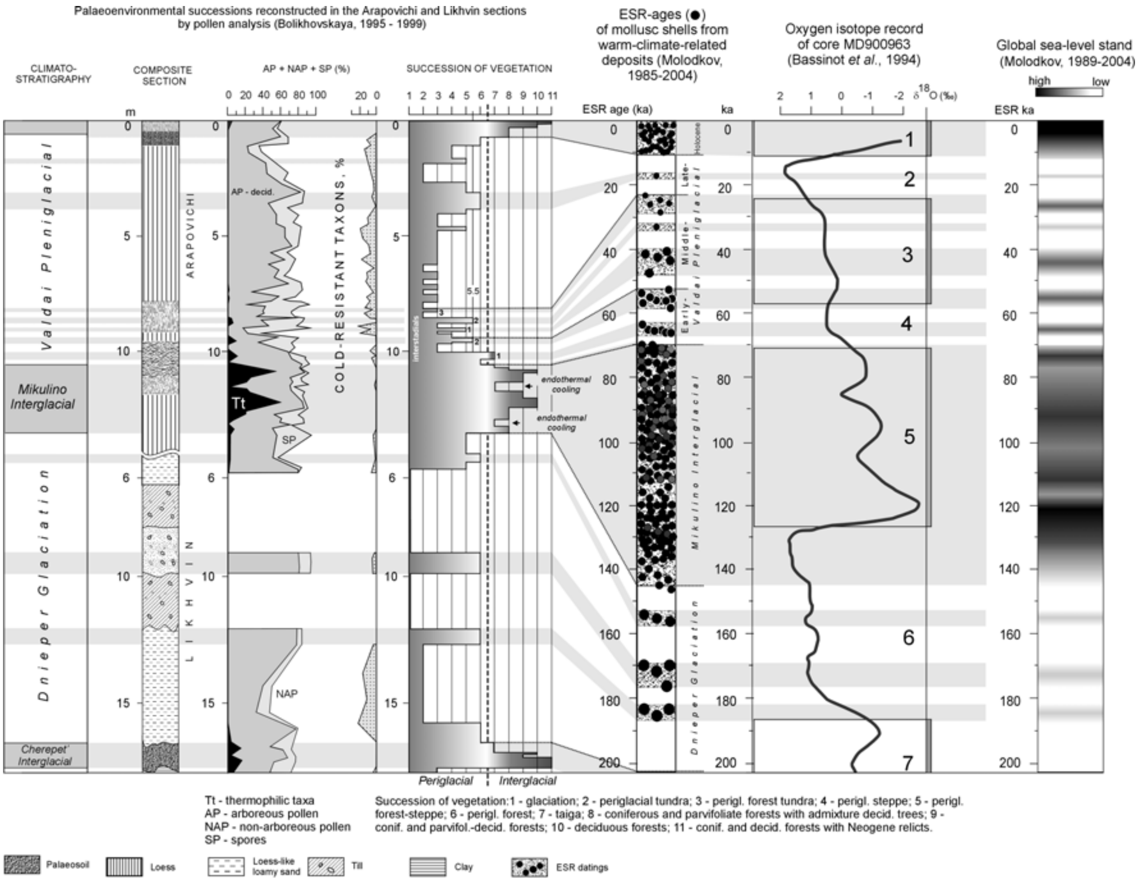

Fig. 1. Palaeoenvironmental changes over the last glacial/interglacial cycles reconstructed from pollen evidence and mollusc-based chronostratigraphy in Northern Eurasia.

The data obtained demonstrate that the last interglacial event in Northern Eurasia may have been long lasting, correlating most likely with the whole of isotope stage 5 and the final phase of stage 6 rather than substage 5e only. During most of the period the vegetation cover has evidently been of interglacial character in Eastern Europe. At the same time, pollen and ESR records suggest that this interglacial was variable rather than stable in nature. During this interglacial period the warm climate was repeatedly interrupted by endothermal coolings.

Weichselian/Valdai Pleniglacial we correlate with isotopic stages 4 to 2. In many areas studied this time interval was characterised by a non-glacial palaeo environment and rather severe palaeo climatic conditions. According to our data, at least six interstadials are distinguished within these isotopic stages ESR-dated at about 65, 56, 44, 32, 26 and 17 KA.

A multidisciplinary study aimed at elucidating the presence of these palaeo climatic events in the Baltic sphere is currently in progress on the basis of the new Late Pleistocene sections at the Voka site, in Northeast Estonia.

TILL STRATIGRAPHY AND PROBLEMS WITH CONCRETE-LIKE TILL IN THE HAUKIPUDAS AREA, NORTH OF OULU CITY

Jari Nenonen
Geological Survey of Finland P.O. Box 77, FIN 96101 Rovaniemi, Finland; e-mail: jari.nenonen@gsf.fi

The purpose of this study is to describe the conditions related to the occurrence of the concrete-like till in terms of stratigraphy, mineral composition and relationship to land uplift, and to clarify the factors which cause such a phenomenon in till. The data for this study were collected in connection with ore prospecting work by the Geological Survey of Finland (GTK) in the study area. The structure and stratigraphic sequence of the Quaternary deposits were studied in pits dug by excavator. The study area is situated on a low-lying coastal area of relatively level topography near the village Haukipudas about 20 km north of the town of Oulu.

The study area is a part of the schist zone of northern Pohjanmaa, which extends in a NW-SE direction from Haukipudas to Utajärvi. The area is characterized by extensive fine- and medium-grained turbiditic metasediments with locally occurring coarse-grained, conglomeratic intercalations. Other rock types typical of the schist zone are sulphide-bearing black schists and related basic volcanites. To the north and east the schist zone is bounded by Archaean basal gneisses. To the south are younger granitoids and the Muhos claystone formation.

The latest flow direction of the continental ice sheet was WNW-ESE. The direction of flow is representative of the late Weichelian stage of glaciation. During the early Weichelian flow stage the direction of glacial flow was NW-SE. At the end of the late Weichelian stage the margin of the continental ice sheet retreated from the study area towards the northwest.

The Quaternary deposits of Haukipudas consist mainly of basal till. Two different ice-flow directions and corresponding till units of different ages have been observed in this area. They can be distinguished by till fabric and also from physical properties, such as colour and lithological composition.

The lower till bed is unstructured, sandy, generally grey basal till. The elongated clasts of the till are clearly oriented, showing that the till was deposited from a direction of 320^{o}-345^{o}. Its lithological composition is similar to that of the bedrock in the surrounding area. The formation of the till is related to the Early Weichselian flow stage of the ice sheet.

The upper till unit is a generally brownish grey sandy basal till containing stripes of brown precipitate. The interface between the upper till and the grey, compact till underlying it is gradual but clearly distinguishable as a change in compactness of the till. In terms of lithological composition the upper till is more heterogeneous. The till was laid down by the ice sheet as it flowed from a direction of 280˚-290˚ during the last glaciation stage, i.e., the younger Weichselian.Extremely compact and hard, concrete-like basal till occurs in places in the Haukipudas area. The reason for its cementation is not the age of the till, but the composition of the underlying rock. This consists of pyrrhotite- and pyrite-bearing black schist, from which abundant rock material was released into the overlying basal till during intense erosion under the ice sheet. Especially during the last ice flow stage, erosion was further enhanced by the parallel directions of ice flow and the orientation of the schist belt. Rapid oxidation of sulphide grains in the till began after the area was uplifted above sea level. Sulphide turned into sulphate and ferrous iron into ferric iron, which precipitated in the form of ferric hydroxide. During its formation, the gel-like ferric hydroxide, which contained abundant water, surrounded the till clasts and mineral grains. As it lost water, it hardened and cemented the till into a concrete-like mass.

The cementation of the surface part of till is quite young for a geological process. It has been going on only during the last 2000 years, while the area has been above the surface of the Baltic Sea. It is probable that due to land uplift, the cementation is still in process at the western end of the schist belt, at the coast of Haukipudas, where the land is now emerging from the sea.

The hardness of the cemented till increases construction costs in areas where this type of till occurs. Ordinary excavators are not powerful enough to dig and move this till. The only alternatives are blasting or, where necessary, avoiding the area with hard till.

MAXIMUM EXTENT, STRUCTURE AND DEGLACIATION PHASES OF THE LAST ICE SHEET IN BELARUS

Irina E. Pavlovskaya
Institute of Geological Sciences, Kuprevich St. 7, 220141, Minsk, Belarus, e-mail: ipavl@ns.igs.ac.by

The maximum extent of the last (Poozerian) ice sheet in Belarus corresponds to the Late Weichselian time that has been argued by geological, biostratigraphical and radiocarbon data. The extent has been traced on the basis of litho-, biostratigraphical and geomorphological evidence. During the Poozerian Glaciation the Svir, Braslav, Nevel, Gorodok, Vitebsk and Orsha glacial highlands were formed. Similarly, large glacial lakes such as the Polotsk, Surazh and Luchosa lakes came into existence as a result of blocked southward melt water drainage. The Poozerian ice sheet extended furthest south within the Vilia, Berezina and Luchosa drainage basins.

New data obtained in the past few years for NW and N Belarus has resulted in a partial revision of the previously-mapped glacial limits and maximum extent of the last glaciation. The limits of phases of the Poozerian Glaciation are based on geomorphological analysis of glacial landform complexes, taking into account the results of geological investigations.

The maximum extent of the Poozerian (Weichselian) Glaciation in north-western Belarus was formerly traced according to morphological features. In this area, the biostratigraphical substantiation of the Poozerian extent is rather impossible due to the lack of interglacial Muravian (Eemian) sediments *in situ*. According to a detailed study of distribution, geomorphological position, mineralogical and pethrographical composition of the Poozerian till, the last glacier in north-western Belarus extended further south than that which was confirmed previously. The outermost limit of the last ice sheet in NW Belarus lay south of the Vilia valley where several glaciofluvial deltas and outwash cones have been recognised in aerial photographs. This position lies 10 km (in some places 20 km) farther to the south than previously assumed. It corresponds well with the equivalent limit in Lithuania (Guobyte, 2002).

The maximum extent of the last ice sheet in western Belarus has been discussed lively in the last years. T. Krzywicki (2002) places it in the Grodno area much farther to the south in comparison with its position supposed by most Belarusian geologists. R. Guobyte (2002) suggests that this limit was located northerly, beyond the Grodno area. In this area, an occurrence of many sections with interglacial Muravian (Eemian) sediments in situ not covered by till may rather support the last opinion but the question is still under discussion.

On the basis of the results of recent investigations, the glacial structure in Belarus was more complicated than previously thought. Three ice streams (Rīga, Peipsi and Lovat) and five main lobes have been recognised for the maximum advance of the Poozerian ice sheet. These were the Neman and Vilia lobes belonging to the Rīga ice stream, Disna and Dvina lobes of the Peipsi ice stream and the Usviacha lobe of the Lovat ice stream, each of them consisted of several tongues.

The glaciodynamic evidence suggests that ice flow directions and ice sheet structure was almost constant during the ice sheet recession until the Braslav (Pomeranian) phase. The relatively passive regime of glaciodynamics changed during the Braslav phase. As it results from measurements of glaciodislocation axial planes, there were several short periods of ice advance, occurring probably as surges.

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MAPPING OF QUATERNARY GEOLOGY IN FINLAND AT 1:20,000 AND 1:50,000

Jouni Pihlaja
Geological Survey of Finland, Rovaniemi Unit, P.O. Box 77, FIN-96101 Rovaniemi, Finland, e-mail: jouni.pihlaja@gtk.fi

Surveys of Finland's Quaternary geology are conducted at scales of 1:20 000 and 1:50 000 to produce basic data about the Quaternary deposits, their composition and the raw materials they contain. The most important element of this work is the production of increasingly accurate numerical observational data. These data can then be used to create maps, map sheet explanations, and various applications related to the management of raw material resources, scientific research, construction, planning, environmental management and other purposes. Some data can also be used to ensure that tourism is developed sustainably in sensitive areas. Surveys have been carried out at these scales in Finland since 1972. The areas that have been surveyed so far are shown on the map in Fig. 1.

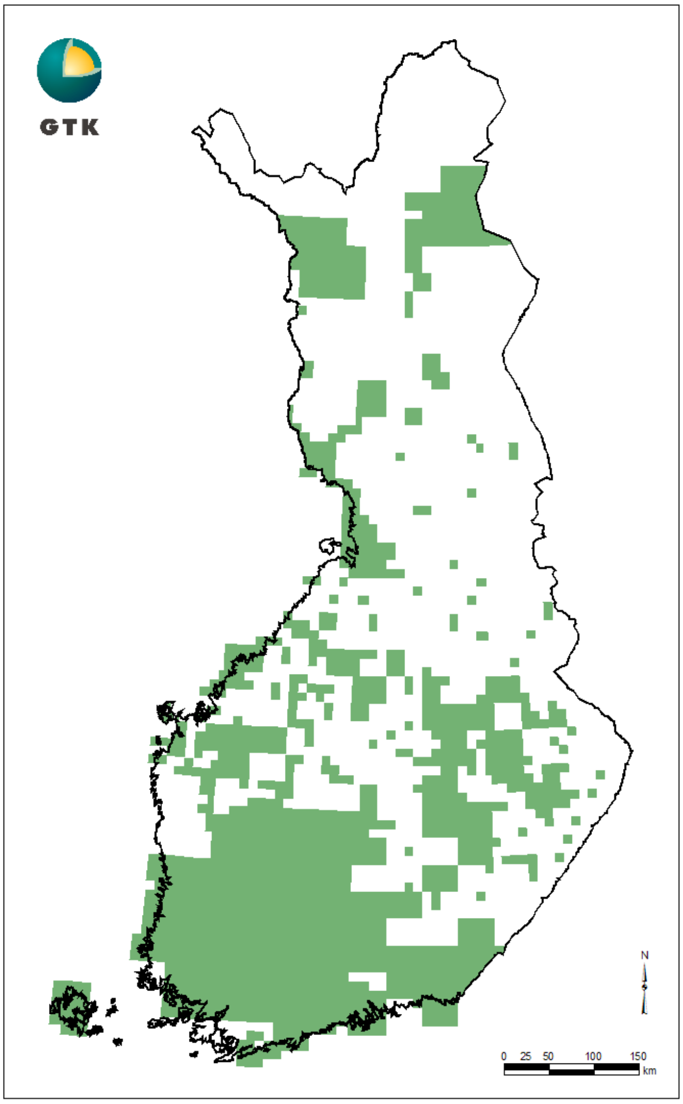

Fig. 1. Areas of Finland already covered by mapping of Quaternary deposits.

Fieldwork surveys involve the collection of observational data, which must then be examined together with information from any previous geological surveys and research records that cover the same area. Accurate digitalised aerial photographs of the survey area can be assessed at the desired scale in 3-D with stereoscopic equipment. On a normal computer screen or on paper this can be done by using a special computer programme to create anaglyphic images in different colours that can be viewed in combination as a single 3-D image.

Aerial photographs and maps of the survey area are then interpreted preliminarily with regard to data obtained from samples collected and analysed beforehand to provide information about the soil and rock types present in the area. At this stage various existing numerical data such as the research data produced by the Geological Survey of Finland on peat and rock types can be viewed simultaneously on top of the aerial photographs on a computer screen.

Soil surveys are then carried out in the field using a soil sampler and a spade. Observations on soil types are then analysed together with further interpretations of aerial photographs and maps conducted in the field to define the boundaries of geomorphological landforms and soil type distributions. By using special portable field computers with colour displays and enough capacity to use geographical information systems, these delineations and the sample data from boreholes can nowadays be directly stored in digitall format. Efficient data transfer systems allow the data collected in the field to be put straight into the relevant database, eliminating the risk of any error during the manual storage of data. Field locations are checked using GPS, which can nowadays be easily used in the field, allowing the locations of sample points and the delineations of features to be defined more accurately than ever before.

Soil samples that are difficult to identify in the field are assessed in the laboratory. The bores and soundings carried out in connection with soil surveys to determine the quality and thickness of the soil also help in the final delineation of landforms. In areas where survey data are particularly difficult to analyse, test excavations may also be carried out where necessary, using mechanical diggers.

On the basis of the data compiled during the fieldwork season, digitally produced Quaternary maps are prepared for publication. The accuracy of these maps is checked according to the quality control system of the Geological Survey of Finland. Published maps are freely available on the internet at *http://geokartta.gsf.fi*. Other important cartographic products today, in addition to the basic Quaternary maps, include various thematic maps such as the popular geological outdoor maps.

THE ORIGIN AND AGE OF CLAY DEPOSITS IN ARUMETSA, ESTONIA

Maris Rattas, Kati Tänavsuu and Kalle Kirsimäe
Institute of Geology, University of Tartu, Vanemuise 46, 51014 Tartu, Estonia; e-mails: maris.rattas@ut.ee, kati.tanavsuu@ut.ee, kalle.kirsimae@ut.ee

Arumetsa clay deposit and pit are situated in the southwestern Estonia, next to Häädemeeste (Fig. 1). The clay deposit is located in a N-S oriented 1.5 km long, 300 m wide and up to 90 m deep depression that is cut into the reddish-brown weakly cemented sand and siltstone of the Middle Devonian Aruküla Regional Stage. Lithological contacts between the Devonian rocks and brownish clayey sediments are sharp and discordant. The thickness of the clayey sediments reaches up to 80 m within the limits of the depression, and they are overlain by up to 1 m thick till or Holocene marine deposits. The clay complex is divided into two parts (Fig. 1):

(1) upper complex – yellowish-brown silty clay and clayey silt with finely laminated interbeds of fine sand and silt in thickness of 0.5–10 m;

(2) lower complex – brownish silty clay which downward grades into homogenous clay, which fills most of the depression.

The whole sequence in the pit is strongly deformed. The orientations of folds and fractures in the upper part of the section suggest deformation from the north. Most of the small faults and shear planes are traced in finely laminated sandy-silty layers within the massive brownish clay (Rattas, Kalm, 2004). The lower part of the section also contains numerous sedimentary deformation structures (slumping, rolling) that indicate mudflows and water saturated sediment slides from the depression sides. The clay deposit has been traditionally interpreted as a synsedimentogenetic clay lens within the Middle Devonian reddish-brown silt- and sandstones of the Aruküla Regional Stage, or as a river valley of the Aruküla Age that is filled with clays of the Middle Devonian Burtnieki Age. This viewpoint is officially accepted up to today.

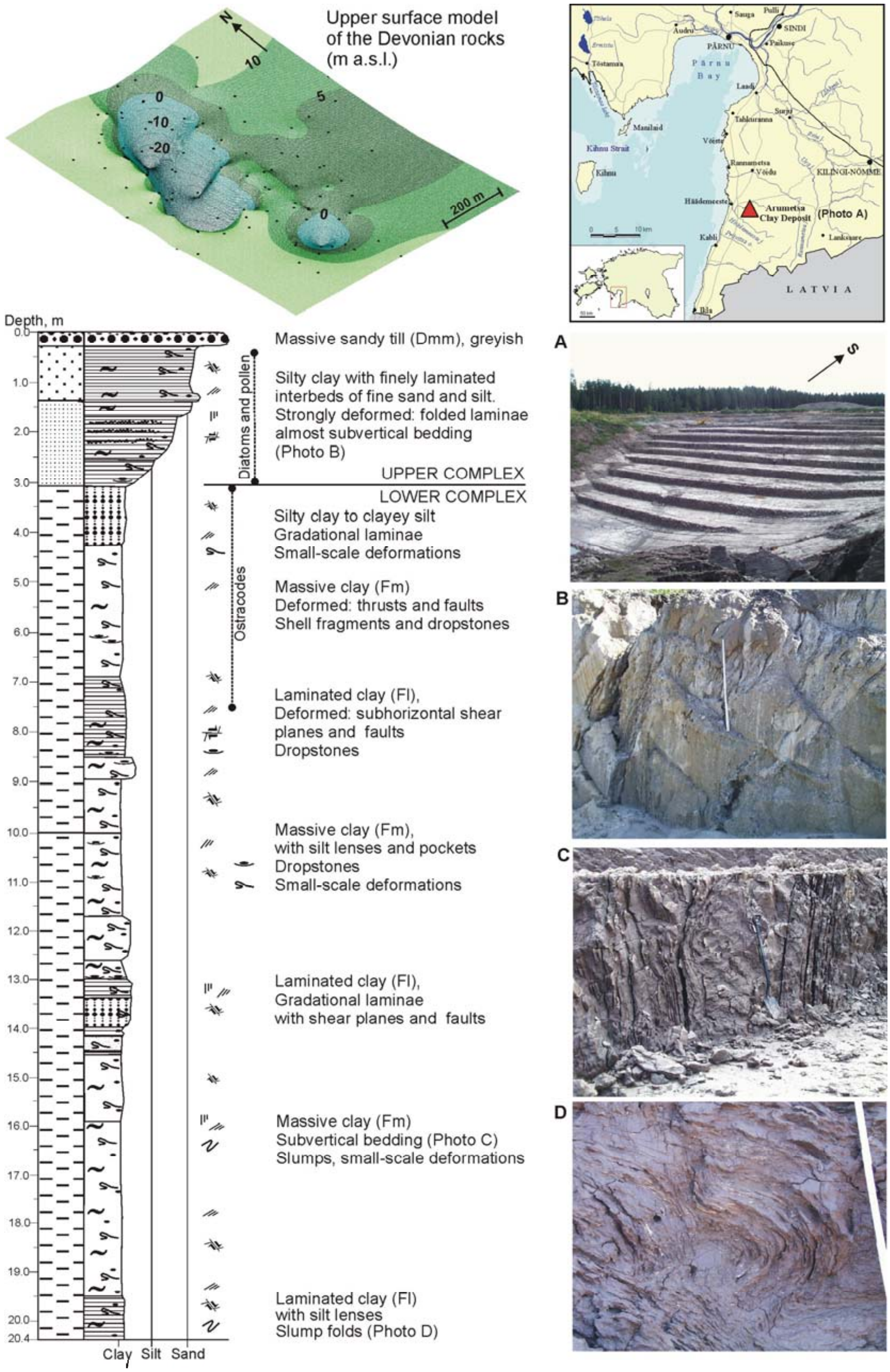

Fig 1. The Arumetsa depression cut into the Middle Devonian sand- and siltstones, and the vertical profile through the upper part (up to 20.4 m) of the Arumetsa clay deposits opened in the pit.

However, paleontological and palynological studies have not confirmed the Devonian age of the sediment. First, two ostracode species *(Cytherissa lacustris* and *Ilyocypris bradyi)* were found in the samples of brownish clay complex in the depth interval of 3–7.5 m (Rattas *et al.*, 2001). The stratigraphic range of these species is Pliocene and Pleistocene to recent. The diatom flora was found in the uppermost part (up to 3 m) of the varvegated greyish-brown clay. All the diatoms noted are typical Quaternary freshwater oligohalobes in character, and their composition is mainly represented by planktonic species *Aulacoseira islandica, Aulacoseira granulata* and *Stephanodiscus astraea* (Tänavsuu, 2002). Palynological material was also recognized only in the uppermost variegated clayey complex. According to E. Liivrand, the palynological composition of investigated samples resembles the Holstenian pollen assemblage. Also, mineralogical composition and the strongly deformed structure of the sediments, including the occurrence of the possible dropstones, differs remarkably from the Middle Devonian Aruküla and Burtnieki sediments.

The structure, mineral and paleontological composition of the sediment proves that the Arumetsa deposit is not of Devonian, but of Quaternary age. Deformations of probably glacial origin and the palynological signatures suggest pre-Weichselian, probably as old as Holstenian age of the deposits. A sedimentological interpretation suggests that the lower clayey complex that in part resembles varved clays with drop stones was evidently deposited in periglacial conditions. The upper complex was deposited probably in a freshwater lake during the interglacial conditions.

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EVOLUTION OF THE WEICHSELIAN GLACIATION CURVE IN LATVIA

Vilnis Stelle and Alexander Savvaitov

Institute of Geology, University of Latvia, Rainis Blvd. 19, LV-1586, Rīga, Latvia, e-mail: geolinst@lanet.lv

The architecture of proposed model, showing glacial advances and retreats during the Weichselian (Latvian) Glaciation of Latvia, is discussed and illustrated in detail in Fig. 1. Here original material of the authors are used, and as well as available data of other researchers.

The glacial advances, which first reached and recovered the area of Latvia during the Middle Latvian time, had not been distributed in the Eastern Baltic further south. According to Gaigalas and Melešitė (1999) the ice-sheet had not reached southeastern Lithuania during this interval. In the Southern Baltic the Middle Weichselian glacial advances reached the area of the Lower Vistula valley in Poland, where the Middle Vistulian tills spread (Marks, 1997).

The common recession of the Latvian major glacial advance had been characterized by a series of ice readvances and retreats, which were connected with different stadials (stages) and interstadials. The first interstadial fixed in Latvia during the recession of a major glacial advance is the Gaiziņkalns Interstadial. The Raunis Interstadial interval of the Late Glacial is recognized in different places of the Eastern Baltic Region. The radiocarbon date obtained from the gyttja at the Mančiagirė outcrop in the region of the Ūla River is 13,430±140 BP (Blažauskas *et al.*, 1998). The Kammeri interstadial of Estonia is the equivalent of the Raunis Interstadial of Latvia. (Liivrand, Kadastik and Kalm, 1999). The curve of advances and retreats of the ice margin during the Latvia Glaciation in Latvia is correlated with the palaeotemperature curve from the ice core from the Greenland ice sheet used by Dreimanis for correlation glacial events in North America in 1972 (Dreimanis and Karrow, 1972; Dansgaard *et. al.*, 1971).

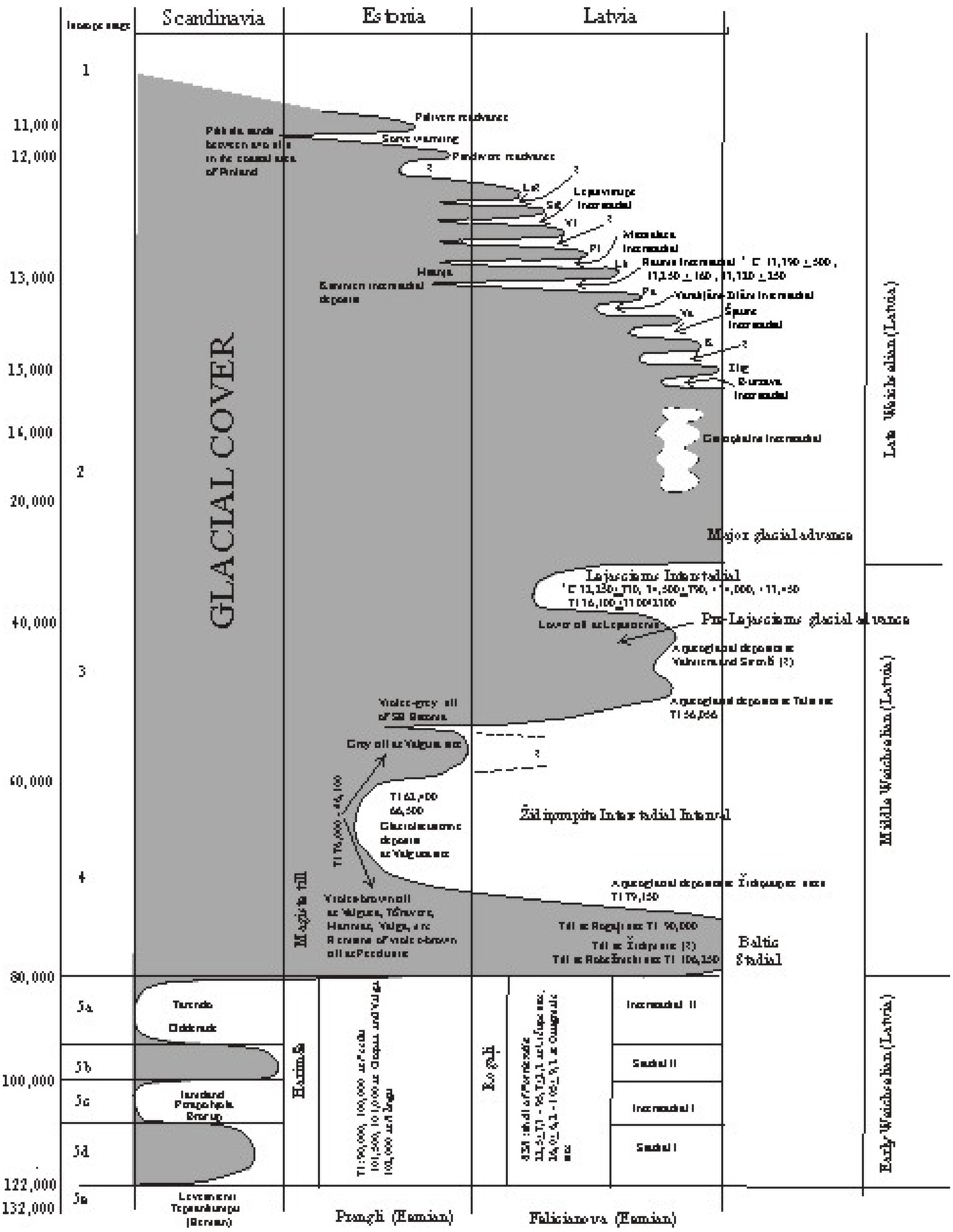

Fig. 1. The Weichselian Glaciation curve in Latvia – advances and retreats of glacial margin and possible correlation with Estonia: Zltg = Ziemeļlatgale Stage, K = Kaldabruņa Stage, Va = Vaiņode-Gulbene Stages, Pa = Pampāļi-Ranka Stage, Lk = Linkuva Stage, Pl = Plieņi Stage, Vl = Valdemārpils Stage, St = Staicele Stage, Ls - Lejassalaca Stage.

The model of the evolution of the Latvian Glaciation passed in the review broadens and complements the ideas represented before by Meirons (1992) and Dreimanis and Zelčs (1995) and will promote reading Latvian Glaciation history.

OCCURRENCE AND HAZARD OF LANDSLIDES IN WESTERN ESTONIA

Peeter Talviste, Marko Kohv, Tiit Hang, Volli Kalm and Alar Rosentau
Institute of Geology, Tartu University, Vanemuise 46, Tartu 51014, Estonia, e-mails: Peeter@geotehnika.ee, ghostx@ut.ee, Tiit.Hang@ut.ee, Volli.Kalm@ut.ee, Alar.Rosentau@ut.ee

The occurrence of landslides during the past few years has been mapped in the lower reaches of four main rivers in Pärnu County, western Estonia. The altitude of slightly undulating recent terrain in the area seldom exceeds 20 m. Geological settings are simple: bedrock is Devonian sandstone, which is covered by loamy till of the Weichselian age. The latter is followed by up to 20 m thick glaciolacustrine varved clay and silt. The Holocene marine sand covers these deposits. Due to alternating transgressions and regressions in the Holocene shore displacement of the Baltic, buried organic layers are common within the marine deposits. The thickness of marine sand reaches in its maximum up to 10m and is only locally absent. Selected geotechnical parameters of most common deposits in the area are presented in Table 1. Owing to the low shear strength, the glacial varved clay is considered as a less stable soil type in the area.

Table 1. Selected geotechnical properties of most common deposits in the study area.

Sediment	Cohesion *c'* (kPa)	Internal friction φ' (°)	Unit weight γ (kN/m^3)
Till	25-100	35-45	20-22
Varved clay	0-25	25-30	15-18,5
Sand	0-10	30-40	18-20
Silt	0-25	30-35	18-21

Small scale landslides in the area are connected with the banks of river valleys and with the areas of outcropping glacial varved clay and silt. Three different types of slides were surveyed (out of 8 individual occurrences). Slides in the silty sand (A) occurred with the critical slope angle 15-20° due to additional shear stress generated by groundwater flow in the slope. Slides in the clayey soils (B) occurred with the critical slope angle 5-7°. The triggering mechanism of this type of landslide remains still unclear and requires additional study. The third type includes small scale slides in the clay (C) occurring only on the banks of river channel due to river erosion (Table 2). Those slides have a direct effect in triggering larger scale (B) slides. The mechanics of landslides was described, critical slope angles and the morphology of the slip surface was found through the limited equilibrium method (Janbu corrected method, Connolly, 1997). Groundwater flow in the slope was described using the finite element method.

Table 2. Location and the main morphological characteristics of the investigated landslides.

Slide	Coordinates	Width (m)	Height (m)	Distance from river min/max (m)	Time	Type
Audru 1	E:24°20,09` N:58°25,26`	75	36	0/33	February 2002	A
Audru 2	E:24°19,89` N:58°25,28`	3,5	8,4	0/3,5	spring 2002	C
Audru 3	E:24°19,89` N:58°25,28`	4,3	16,2	0,3/4,7	spring 2002	C
Sauga 1	E:24°26,41` N:58°25,72`	7	9,3	3,7/11,5	spring 2002	A
Pärnu 1	E:24°36,29` N:58°22,70`	202,5	337	0/135	April 2002	A
Reiu 1	E:24°36,21` N:58°21,60`	22	32	0/32	2000	A
Reiu 2	E:24°37,09` N:58°21,21`	28,8	47,5	0/28,8	February 2002	B
Reiu 3	E:24°36.93` N:58°19,39`	21,8	10	3/25,1	2000	B

A digital elevation model with grid size 4x4m was generated on the base of a topographic map on a scale of 1:10,000 (contour interval 0,5, additional elevation points were considered). Slope angles from the model were combined with the geological data and critical slope angles from slope stability analysis in order to create a landslide hazard zonation map (Fig.1).

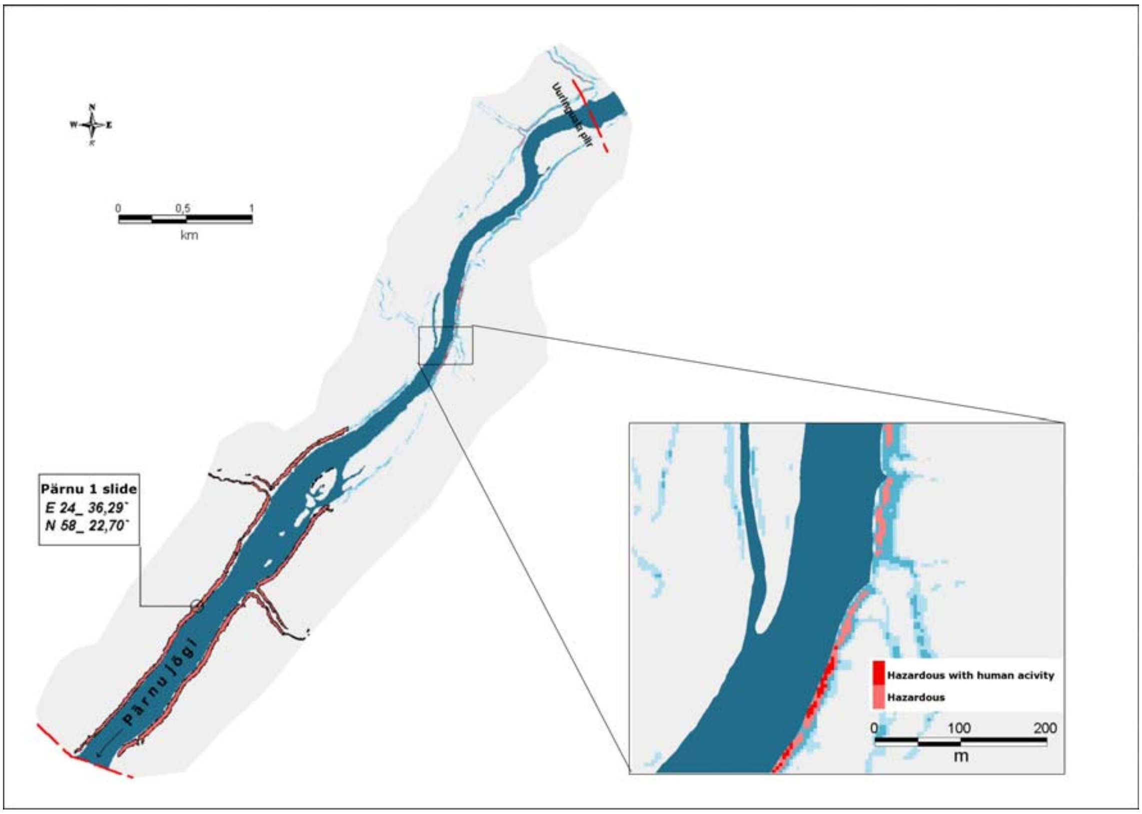

Fig. 1. An example of a landslide hazard zonation map from the Pärnu River valley, West Estonia.

Examples of the geology and morphology of selected landslides and corresponding slope stability calculations together with the hazard zonation map will be presented.

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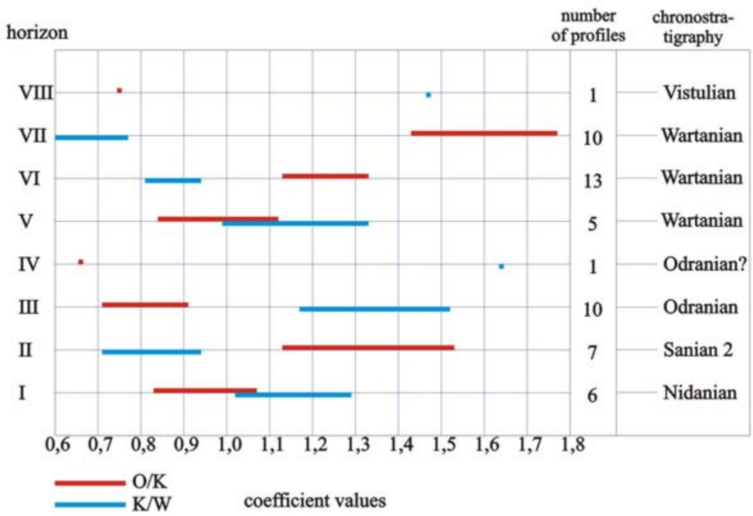
THE PLEISTOCENE LAKELAND IN THE SOUTHERN MAZOVIAN LOWLAND AND ITS IMPORTANCE FOR STRATIGRAPHY

Marcin Żarski
Polish Geological Institute, 00-975 Warsaw, Rakowiecka 4, Poland, e-mail: mzar@pgi.waw.pl

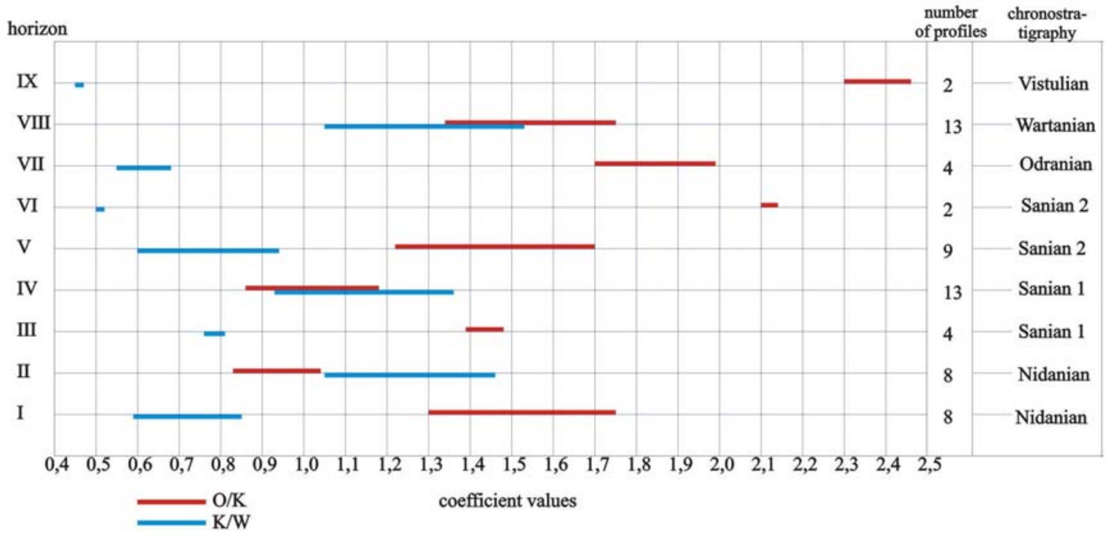
The study area is situated in the Southern Podlasian Lowland, about 100 km south-east of Warsaw. This region was covered by ice sheets of the South Poland (Elsterian) glaciation: Nidanian, Sanian 1 and Sanian 2 (Glacial A, Elsterian I, Elsterian II), Middle Poland (Saalian) glaciation: Odranian and Wartanian (Saalian I and Saalian II). The oldest glaciations: Narevian (Menapian) and Vistulian did not cover this area.

Deposits of glaciations are represented by tills, glaciofluvial sands and gravels, marginal lake clays and silts and fluvial sands. The Quaternary sequence is 30-60 m thick. Tills are very important for stratigraphic correlations. The lacustrine deposits of the Ferdynandovian (Cromerian), Mazovian (Holsteinian) and Eemian interglacials were discovered at many places at Żelechów Plateau and Łuków Plain. These lacustrine deposits were investigated by palynological analyses. The Ferdynandovian, Mazovian and Eemian Lakeland testify to deglaciations of ice sheets. Lakes were usually formed at moraine plateaus. The relief with lakes is characteristic for postglacial landscape.

Clays, silts and sands were accumulated in lakes in the cold climate, after deglaciation. Peats, gyttias, silts and sands with organic material were accumulated in lakes during interglacial periods. Ferdynandovian lakes, at Ferdynandów, Budziska, Kosiorki and Łuków, were formed after deglaciation of the Sanian 1 (Elsterian 1). The maximum ice sheet limit during the Sanian 1 was in Southern Poland. Tills of Sanian 1 (Elsterian 1) occur under lacustrine and marginal lake deposits. These tills have similar petrographic coefficients: Ferdynandów - 0.44-2.78-0.33, Budziska 1.25-0.89- 0.89, Kosiorki 0.63-2.21-0.51. The first value is the ratio between Scandinavian sedimentary and crystalline rocks, the second value is the ratio between crystalline and carbonate rocks, and the third value is the ratio between non-resistant and resistant rocks. Deposits of the Ferdynandovian interglacial occur about 25-30 m under ground level. Sediments of the Ferdynandovian Interglacial are very important for stratigraphic correlations of the older Pleistocene sediments.



Mazovian lakes at Wylezin, Gózd, Adamów, Poznań, Kasyldów and Wola Okrzejska were formed after deglaciation of the Sanian 2 (Elsterian 2) at moraine plateau. The maximum ice sheet limit during the Sanian 2 was about 180 km to the south. Sediments of the Mazovian interglacial occur about 8-15 m under the ground level. Tills of the Sanian 2 occur under Mazovian lacustrine deposits. Petrographic coefficients from tills are the following: 1.40-0.80-1.12 - Wylezin, 1.35-0.79-1 - Gózd, 1.4-0.8-1.2 - Poznań. Sediments of the Middle Poland Glaciation (Saalian) occur above Mazovian deposits.



Eemian lakes were developed in the study area, after deglaciation of the Wartanian ice sheet (younger Middle Poland Glaciation). The ice-sheet of the Wartanian Glaciation reached the recent Wieprz river valley, which was a marginal valley. The Eemian sites are located at a moraine plateau only north of the Wieprz valley. The sites, which are located south of the Wieprz valley, are situated in small river valleys. Eemian lakes, which are located at a moraine plateau, testify to deglaciation of the Wartanian ice sheet. Eemian deposits occur about 2-3 m under the ground level and cover the Wartanian deposits: tills, clays and sands. Eemian sites are situated at Kontrowers, Kletnia Stara, Wola Okrzejska, Szczepanie and other places. Petrographic coefficients from the Wartanian tills are: 1.6-0.6-1.2.

Sites with lake interglacial deposits, located in moraine plateau, are important for delimitation of maximum range of ice sheets and are the basis for investigations of the Pleistocene stratigraphy.

LIST OF PARTICIPANTS

ĀBOLTIŅŠ, Ojārs
Department of Geography
University of Latvia
Raina Bvld. 19
LV-1586, Rīga, Latvia
E-mail: zeme@lanet.lv
Phone: +371 733 2566

ALEKSA Paulius
Geological Survey of Lithuania
S. Konarskio 35
LT 2600, Vilnius
Lithuania
E-mail: paulius.aleksa@lgt.lt
Phone: +3705 213 9053

Prof. BER, Andrzej
Polish Geological Institute
4 Rakowiecka Str.
PL 00-975, Warszawa
Poland
E-mail: aber@pgi.waw.pl
Phone: 482 249 5351

BRUJ, Małgorzata
Polish Geological Institute
4 Rakowiecka Str.
PL 00-975, Warszawa
Poland
E-mail: dgal@pgi.waw.pl
Phone: +482 249 5351

CERIŅA, Aija
Institute of Geology
University of Latvia
Raina Bvld. 19
LV-1586, Rīga, Latvia
E-mail: caija@inbox.lv
Phone: 371 722 2975

DREIMANIS, Aleksis
Department of Earth Sciences
Geological and Biological Building
University of Western Ontario
N6A 5B7, London, Ontario, Canada
E mail: aija@csd.uwo.ca
Phone: 519 661 3197

DZELZĪTIS Jānis
Department of Geography
University of Latvia
Raina Bvld. 19
LV-1586, Rīga, Latvia
E-mail: jdz@envirotech.lv
Phone: +371 733 2566

EBERHARDS, Guntis
Department of Environmental Science
University of Latvia
Raina Bvld. 19
LV-1586, Rīga, Latvia
E-mail: guntise@apollo.lv
Phone: +371 733 1766

GRIGIENE Alma
Geological Survey of Lithuania
S. Konarskio 35
LT 2600, Vilnius
Lithuania
E-mail: alma.grigiene@lgt.lt
Phone: +3705 213 9053

GUOBYTE, Rimante
Geological Survey of Lithuania
S. Konarskio 35
LT 2600, Vilnius
Lithuania
E-mail: rimante.guobyte@lgt.lt
Phone: +3705 213 9055

HANG, Tiit
Institute of Geology
University of Tartu
Vanemuine 46
EE-2400, Tartu, Estonia
E-mail: tiit.hang@math.ut.ee
Phone: +372 746 5821

JENNINGS, Steven
Dept. of Geography and Environmental Studies
University of Colorado at Colorado Springs
1420 Austin Bluffs Parkway
CO80933-7150, Colorado Springs, USA
E-mail: sjenning@uccs.edu
Phone: + 719 262 4056

JOHANSSON, Peter
Geological Survey of Finland
P.O. Box 77, FIN 96101
Rovaniemi
Finland
E mail: peter.johansson@gsf.fi
Phone: +358 20 550 4302

JUSIENE, Asta
Geological Survey of Lithuania
S. Konarskio 35
LT 2600, Vilnius
Lithuania
E-mail: asta.jusiene@lgt.lt
Phone: +3705 213 9053

KADASTIK, Ene
Institute of Ecology
Tallinn University of Educational Science
Kevade St. 2, EE-10137, Tallinn
Estonia
E-mail: ene@eco.edu.ee
Phone: +372 645 4654

KALM, Volli
Institute of Geology
University of Tartu
Vanemuine 46
EE-2400, Tartu, Estonia
E-mail: vkalm@ut.ee
Phone: +372 746 5821

KALNIŅA, Laimdota
Department of Gegraphy
University of Latvia
Raina Bvld. 19
LV-1586, Rīga, Latvia
E-mail: Laimdota.Kalnina@lu.lv
Phone: +371 733 6373

KALVĀNS, Andis
Department of Geology
University of Latvia
Raina Bvld. 19
LV-1586, Rīga, Latvia
E-mail: andis@spc.lv
Phone: +371 733 1766

KARMAZIENĖ, Danguolė
Geological Survey of Lithuania
S. Konarskio 35
LT 2600, Vilnius
Lithuania
E-mail: danguole.karmaziene@lgt.lt
Phone: +370 223 9044

KARUKÄPP, Reet
Institute of Geology of
Tallin Technical University
Estonia Ave 7
EE-0001, Tallinn, Estonia
E-mail: Reet.Karukapp@gi.ee
Phone: +372 645 4654

KEHEW, Alan
Department of Geosciences
Western Michigan University
MI 49008, Kalamazoo
USA
E-mail: alan.kehew@wmich.edu
Phone: +269 387 5495

Dr. Hab. KENIG, Krystyna
Polish Geological Institute
4, Rakowiecka Str.
PL 00-975, Warszawa
Poland
E-mail: kken@pgi.waw.pl
Phone: +482 249 5351

KOLKA, Vasily
Geological Institute at Kola Science Centre
Russian Academy of Sciences
14 Fersman Str.
184200 Apatity, Russia
E-mail: kolka@geoksc.apatity.ru
Phone: +007 81555 79575

LAPINSKIS, Jānis
Department of Environmental Science
University of Latvia
Raina Bvld. 19
LV-1586, Rīga, Latvia
E-mail: Janis.Lapinskis@lu.lv
Phone: +371 733 1766

LIIVRAND, Elsbet
Alliku 6-40
EE-76610,
Keila
Estonia
E-mail: aivar@keila.ee
Phone: +372 604 5921

LISICKI, Stanisław
Polish Geological Institute
4, Rakowiecka Str.
PL 00-975, Warszawa
Poland
E-mail: slis@pgi.waw.pl
Phone: +482 249 5351

MARINI, Francois
Ecole Nationale Superieure de Geologie
Institut National Polytechnique de Lorraine
Rue du Doyen M. Roubault, BP40
54501Vandoeuvre-les-Nancy Cedex, France
E-mail: Francois.Marini@ensg.inpl-nancy.fr
Phone: +33 383 59 64 15

MARKOTS, Aivars
Department of Geography
University of Latvia
Raina Bvld. 19
LV-1586, Rīga, Latvia
E-mail: Aivars.Markots@lu.lv
Phone: +371 733 4050

MARKS, Leszek
Polish Geological Institute
4 Rakowiecka Str.
PL 00-975, Warszawa
Poland
E-mail: lmarks@pgi.waw.pl
Phone: +4822 849 5096

MÄTZLER, Eva
Institute of Geological Sciences
University of Bern
Baltzerstrasse 1, CH-3012
Bern, Switzerland
E-mail: eva.m@student.unibe.ch
Phone: +41 31 631 8763

NARTIŠS, Māris
Department of Geography
University of Latvia
Raina Bvld. 19
LV-1586, Rīga, Latvia
E-mail: marisn@e118.lv
Phone: +371 733 4050

NENONEN, Jari
Geological Survey of Finland
P.O. Box 77, FIN 96101
Rovaniemi
Finland
E mail: jari.nenonen@gsf.fi
Phone: +358 20 550 4300

PAVLOVSKAYA, Irina
Institute of Geological Sciences
NAS of Belarus
Kuprevich Str. 7
220 141, Minsk, Belarus
E-mail: ipavl@ns.igs.ac.by
Phone: +375 172 639 704

PIHLAJA, Jouni
Geological Survey of Finland
P.O. Box 77, FIN 96101
Rovaniemi
Finland
E mail: jouni.pihlaja@gsf.fi
Phone: +358 40 824 3117

RATTAS, Maris
Institute of Geology
University of Tartu
Vanemuine 46
EE-2400, Tartu, Estonia
E-mail: mrattas@ut.ee
Phone: +372 746 5821

RAUKAS, Anto
Institute of Geology of
Tallinn Technical University
Estonia Ave 7
EE 0001, Tallinn, Estonia
E-mail: Raukas@gi.ee
Phone: 372 645 4659

SAKS, Tomas
Department of Geography
University of Latvia
Raina Bvld. 19
LV-1586, Rīga, Latvia
E-mail: tomas@modlab.lv
Phone: +371 733 4050

SAULĪTE, Anita
The Natural History Museum of Latvia
K.Barona Str. 10,
LV-1712, Rīga
Latvia
E-mail: anita.saulite@dabasmuzejs.gov.lv
Phone: +371 7356046

SEGLIŅŠ, Valdis
Department of Geology
University of Latvia
Raina Bvld. 19
LV-1586, Rīga, Latvia
E mail: valdis.s@parks.lv
Phone: 371 733 1766

STRAUTNIEKS, Ivars
Department of Geography
University of Latvia
Raina Bvld. 19
LV-1586, Rīga, Latvia
E mail: Ivars.Strautnieks@lu.lv
Phone: 371 733 2566

ZELČS, Vitālijs
Department of Geography
University of Latvia
Raina Bvld. 19
LV-1586, Rīga, Latvia
E mail: Vitalijs.Zelchs@lu.lv
Phone: 371 733 2566

ŹARSKI, Marcin
Polish Geological Institute
4 Rakowiecka Str.
PL 00-975, Warszawa
Poland
E-mail: mzar@pgi.waw.pl
Phone: +849 535 1118

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