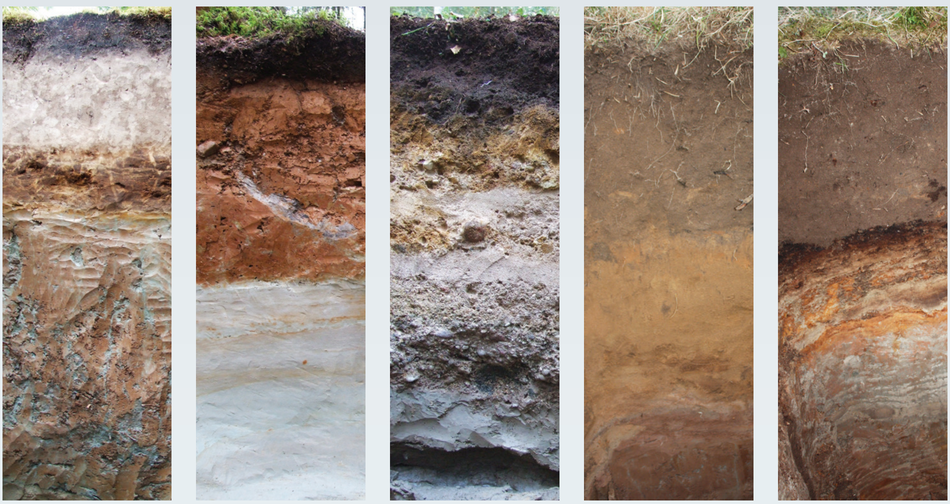
INTERNATIONAL WRB SOIL CLASSIFICATION FIELD WORKSHOP IN LATVIA AND ESTONIA

Guidebook

July 22-27, 2017



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Eesti Maaülikool
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ESSC
EUROPEAN SOCIETY for SOIL CONSERVATION

Latvijas Augsnes zinātnes biedrība
Soil Science Society of Latvia

Soil Science Society of Estonia

International Union of Soil Sciences

International Decade of Soils 2015 - 2024

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Financial support:

IUSS Stimulus Fund

IUSS Division 1

University of Latvia

ISBN 978-9934-18-257-0 (Print)

ISBN 978-9934-18-256-3 (Online)

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FOREWORD

International WRB Soil Classification Field Workshop in Latvia and Estonia is a great opportunity for Soil Scientists to stimulate deep reflections on the strong links between soil classification and soil sustainable management and conservation as well as to develop discussion and WRB approbation in the boreo-nemoral region, where soils are influenced by very complex factors and soil processes.

Soils are developed mainly on Late Weichselian glacial deposits (formed by loamy sand, sandy clay, loam, clay, gravel, sand) and altered to some extent by postglacial aeolian, marine, lacustrine, alluvial and mire sediments, as well as formed on pre-Quaternary sedimentary rocks.

This workshop will look at differently formed automorphous, semihydromorphous and hydromorphous soils (23 soil profiles and according to WRB soil classification – 12 soil groups (Gleysols, Podzols, Cambisols, Luvisols, Calcisols, Planosols, Histosols, Arenosols, Retisols, Fluvisols, Phaeozems and Anthrosols)) in intensively and extensively used agricultural lands and in deciduous and coniferous forest lands. The soils show different organic surface layers: mull, moder, mor, amphi etc.

Raimonds Kasparinskis
President of Soil Science Society of Latvia

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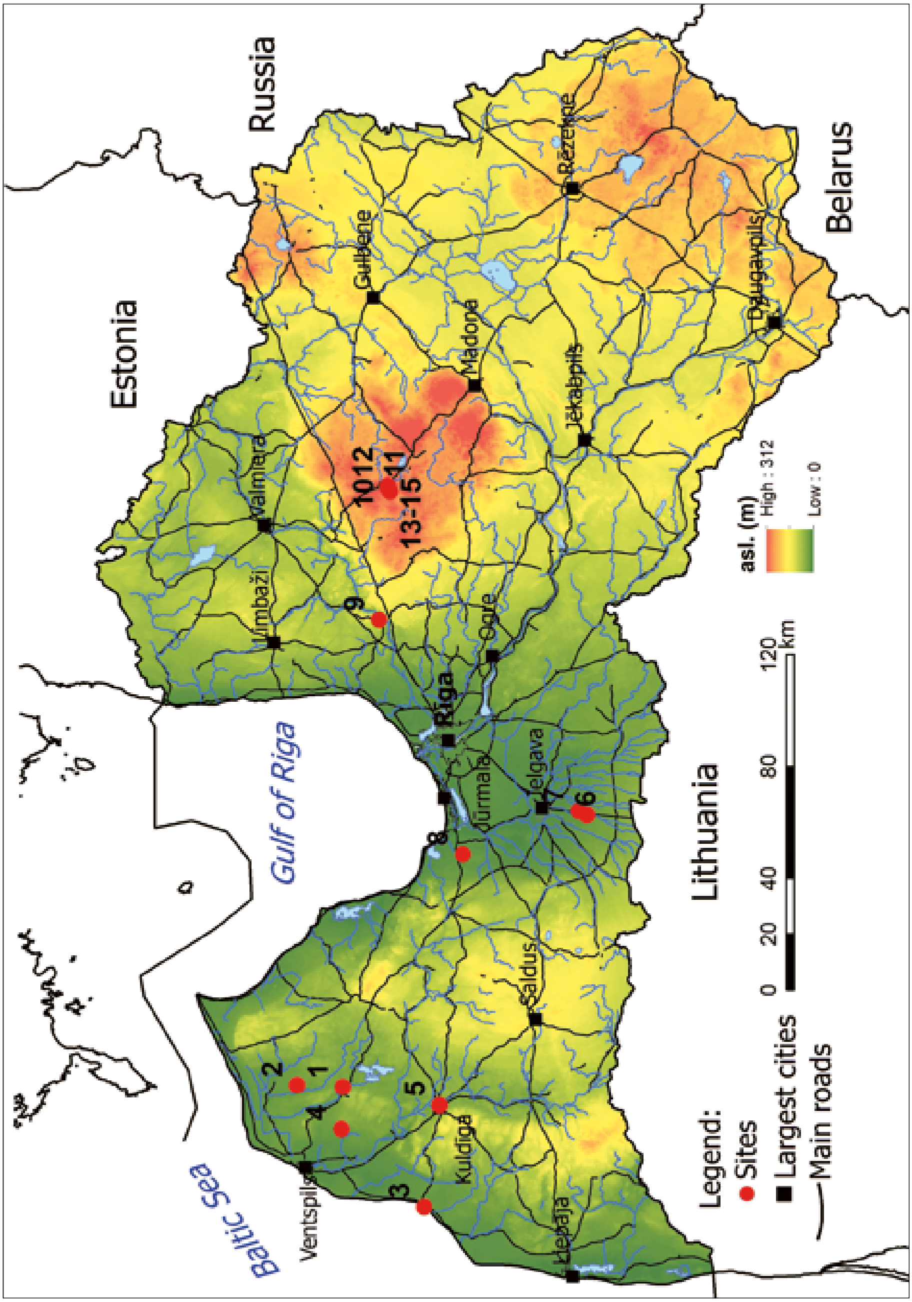

Fig. 1. **Map of site locations in Latvia** (source: SRTM; author: M. Krievāns)

MAP OF SOIL PROFILE LOCATIONS IN ESTONIA

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1. GENERAL INFORMATION ABOUT LATVIA

Latvia is one of the three Baltic states, situated on the eastern shore of the Baltic Sea, between Estonia and Lithuania. The country is also bordered by Russia and Belarus, and it shares maritime borders with Sweden (Fig. 3).

The country area is 64 589 km². Its mostly flat landscape offers a mix of beaches (seacoast length ~494 km), rivers (~12 000), lakes (~3 000) and forests (~55% from area).

The country has a population of 1.95 million people (in 2017), capital and largest city is Riga (Fig. 3).

Fig. 3. **Political map of Latvia** (source: www.nationsonline.org)

After a brief period of independence between the two World Wars, Latvia was annexed by the USSR in 1940. It reestablished its independence in 1991 following the breakup of the Soviet Union.

Although the last Russian troops left in 1994, the status of the Russian minority (some 26% of the population) remains of concern to Moscow. Latvia continues to revamp its economy for eventual integration into various Western European political and economic institutions. Since May 2004 Latvia is a member of the European Union, it joined the euro zone in 2014.

Latvia is a parliamentary republic. Ceremonial Chief of State is the president, he is elected by the Saeima (parliament). Head of Government and commander-in-chief of the armed forces is the Prime Minister, he is appointed by the president with the approval of the Saeima. The Saeima is the unicameral legislative body for the Latvian government.

Major ethnic groups are Latvians 58.5%, Russians 29%, Belarusians 3.9%, Ukrainians 2.6%, Poles 2.5%.

Religions: Lutheran, Orthodox, Roman Catholic.

Official language is latvian, but russian also is spoken by most people.

Natural resources: peat, limestone, dolomite, amber, hydropower, wood, arable land.

Agriculture products: grain, sugar beets, potatoes, vegetables, beef, pork, milk, eggs, fish.

Industries: Automotive industry, railroad cars, agricultural machinery, fertilizers, electronics, synthetic fibers, pharmaceuticals, processed foods, textiles.

Exports – commodities: foodstuffs, wood and wood products, metals, machinery and equipment, textiles.

REFERENCE

www.nationsonline.org

1.1. Land use

Increase of forest area occurred in 20th and 21st century in Latvia and area of agricultural lands significantly decreased from 57% in 1935 till 36% of country area in 2010. However area of forest lands increased from 27% in 1935 till 46% of country area in 2010 (Fig. 4). Furthermore forest area reached 3.2 mlj ha or 51% of country area in 2016.

Forests in Latvia according to soil fertility and moisture conditions are divided into 23 forest growing types. In relation to soil fertility forests are divided into 3 trophic groups: oligotrophic, mesotrophic and eutrophic.

Poor or oligotrophic (low amount of nutrients) forest growing types (*Cladinoso – callunosa*, *Vacciniosa*, *Myrtillosa*, *Callunoso – sphagnosa*, *Vacciniosa – sphagnosa Sphagnosa*, *Callunoso mel.*, *Callunoso turf. mel.*) covers 8,9% of total area of forests in Latvia.

Eutrophic forest growing types (*Oxalidosa*, *Aegopodiosa*, *Myrtillosa polytrichosa*, *Dryopteriosa*, *Filipendulosa*, *Mercurialiosa mel.*, *Oxalidosa turf. mel.*) covers 37,5% of total area of forests in Latvia.

More than half of forest total area (53,9%) is covered by mesotrophic (moderately amount of nutrients), where occurs coniferous (pine, spruce) and deciduous (birch, aspen, oak, black alder) forest stands.

More than half of forests (55,3%) is growing on automorphic soils, however other forests grows on soils with gleyic features or hydromorphic soil conditions – Histosols.

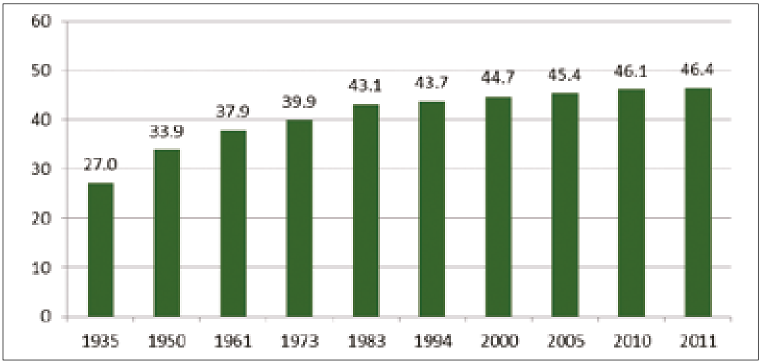

Fig. 4. **Cover of forest lands (% from total area of Latvia)**
(source: State Forest service, 2000-2011)

Pine (*Pinus sylvestris*) and spruce (*Picea abies*) predominates in forests of Latvia and covers about 51,8% from total area of forests, pine – 33,9%, however spruce – 17,9% (Forest state register, 2016).

Dominant tree species in deciduous forests are different, e.g. ash (*Fraxinus excelsior*), oak (*Quercus robur*), elm (*Ulmus glabra*), white elm (*Ulmus laevis*), maple (*Acer platanoides*), lime (*Tillia cordata*) and hornbeam (*Carpinus betulus*). Above mentioned forest stands covers only about 1% from forest total area. Other areas of forests is covered by birch (*Betula pendula*), aspen (*Populus tremula*), and grey alder (*Alnus incana*).

After independence regaining in Latvia, area of agricultural lands significantly decreased to 1930.6 thousands hectares in 2016 (Fig. 5).

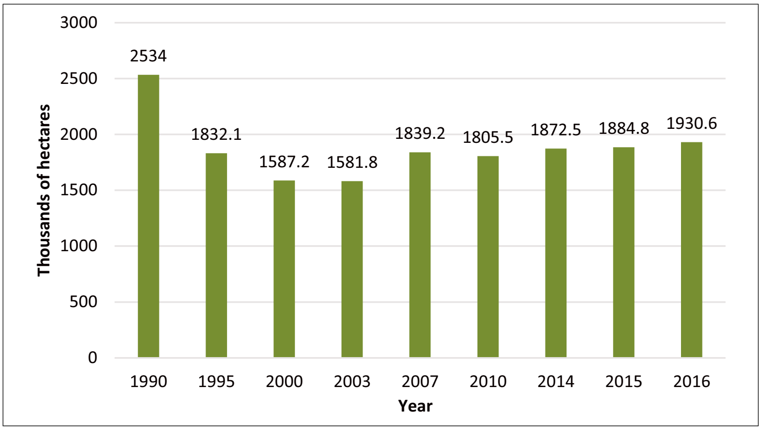

Fig. 5. **Area of agricultural lands in Latvia (thousands of hectares)**
(source: Central Statistical Bureau, 2017)

Nowadays in Latvia non used (abandoned) agricultural lands covers 19.2% (443.8 thousands of hectares) from agricultural land area and is overgrowing by shrubs and trees.

1.2. Climate

Solar radiation, peculiarities of atmosphere circulation as well as the Baltic sea, Gulf of Riga and surface topography influences air temperature regime and distribution (Fig. 6) in Latvia.

Relatively flat surface topography cause conditions that warm and moist marine air masses formed under Atlantic ocean in the reason of planetar flow moves from west to east far into Europe continent. Therefore mean annual air temperature exceeds geographic latitude average temperature of Latvia about 4-6 °C, but during winter about 9 °C. Smaller fluctuations of air temperature are in coastal regions (Kļaviņš et al., 2016).

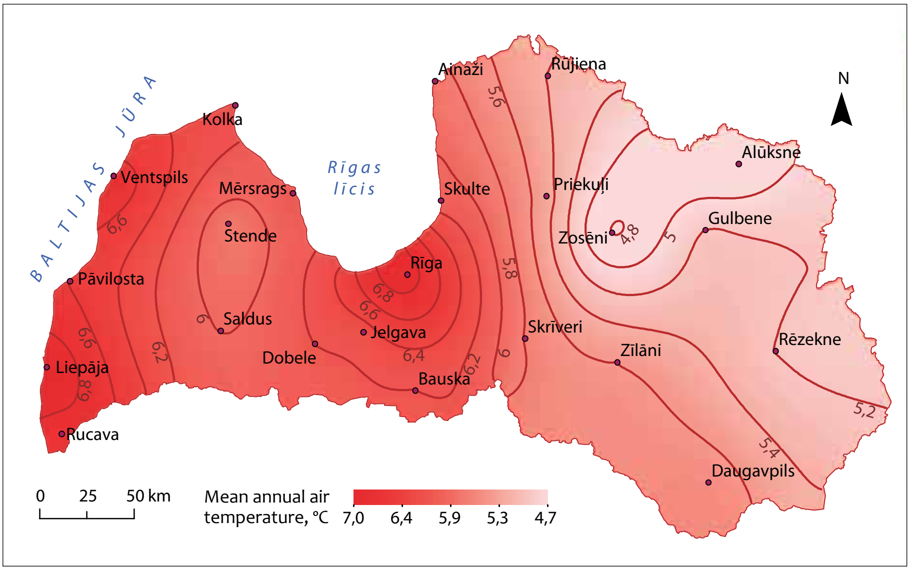

Fig 6. **Mean annual air temperature (°C) in Latvia (1950-2010)**
(source: Klavins et al., 2016)

Mean air temperature in Latvia is 6.0 °C (according to long term observation from 1950-2010), however during last 30 year time period (1981.-2010.) is increased to 6.4 °C.

Highest mean annual air temperature is characteristic to coastal area of Baltic Sea, but lowest mean annual temperature is characteristic to Vidzeme upland and Latgale upland. July is warmer month with mean air temperature 16.9 °C (according to time period: 1950.-2010.), but according to last 30 year time period (1981.-2010.) is increased to 17.4 °C.

Lowest mean air temperature is in february (according to time period: 1950.-2010.). Absolute temperature maximum +37.8 °C is fixed in august 8, 2014. However absolute temperature minimum -43.2 °C is detected in Daugavpils (southeastern part of Latvia) in february 8, 1956. Thus amplitude of extremal air temperatures is about 81.0 °C (Kļaviņš et al., 2016).

Mean amount of precipitation in Latvia is 685 mm (Fig. 7). Surface topography impacts distribution of precipitation in local scale. Highest amount of precipitation (760-870 mm) is characteristic to western parts of Vidzeme upland, Rietumkursa upland, and Latgale upland (Fig. 7) due to predominant west, south-west wind.

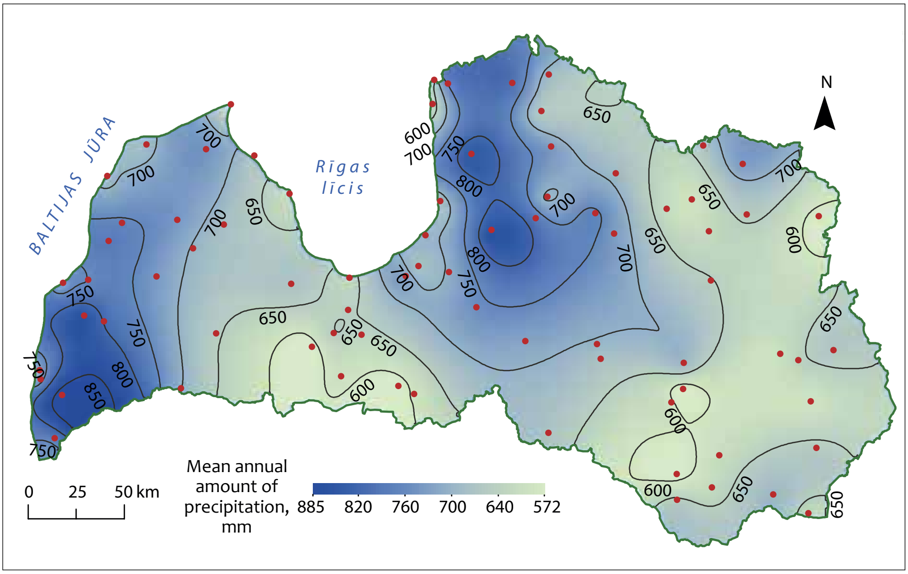

Fig 7. **Mean annual amount (mm) of precipitation in Latvia (1950-2010)**
(source: Klavins et al., 2016)

Smallest amount of precipitation (580 mm) is observed in Zemgale plain, as well as in depression valleys that are located on eastern parts of uplands. Highest amount of precipitation (> 80 mm per month) is observed during summer time, however in winter, amount of precipitation is smaller (~20 per month) (Kļaviņš et al., 2016).

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Kļaviņš, M., Zaļoksnis, J., Blumberga, D., Briede, A., Brizga, J., Dimante, Dž., Kalvāne, G., Melecis, V., Prūse, I., Vincēviča-Gaile, Z., GRID-Arendal, 2016. Klimats un ilgtspējīga attīstība. [Climate and sustainable development]. Rīga: LU Akadēmiskais apgāds, p. 384.

1.3. Surface topography

Latvia is located on the slightly undulating, in places flat northwestern margin of the East European Plain characterised by moderate variations in elevation. The average height is about 87 m (Fig. 8).

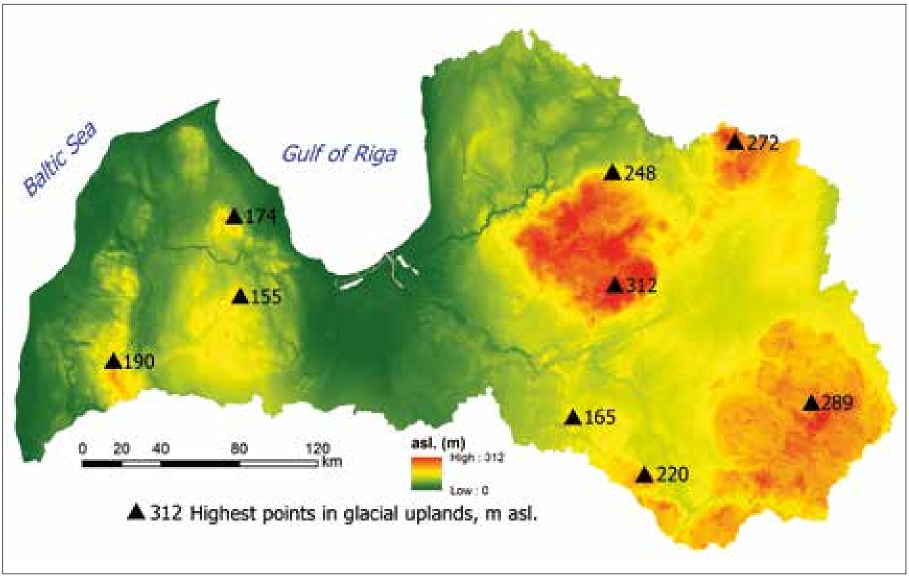

Fig. 8. **Digital elevation model of the Latvia territory** (derived from SRTM)

Almost 75% of Latvia lies below 120 m asl., and elevations higher than 200 m are restricted to less than 3% of the territory. The highest point is Hill Gaiziņkalns (312 m asl.) in the Vidzeme Upland. The average local relief rarely exceeds 10-25 m with a maximum up to 90 m in eastern Latvian glacial uplands, and in some places along proglacial spillways (Zelčs et al., 2011). The landscape of Latvia is dominated by Pleistocene glacial landforms, except for a belt of coastal plains along the Baltic Sea and Gulf of Rīga shore.

1.4. Geological History of Latvia

1.4.1. Glacial dynamics

The present-day topography (Fig. 8.) has largely been formed as a result of Pleistocene glaciations, particularly of the last Weichselian event. Most of the glacigenic landforms were created during oscillatory retreat of the Late Weichselian Fennoscandian Ice Sheet, when it was divided into several more or less independently flowing ice lobes and glacier tongues (Fig. 9). The Last glacial maximum limit is located outside of Latvia.

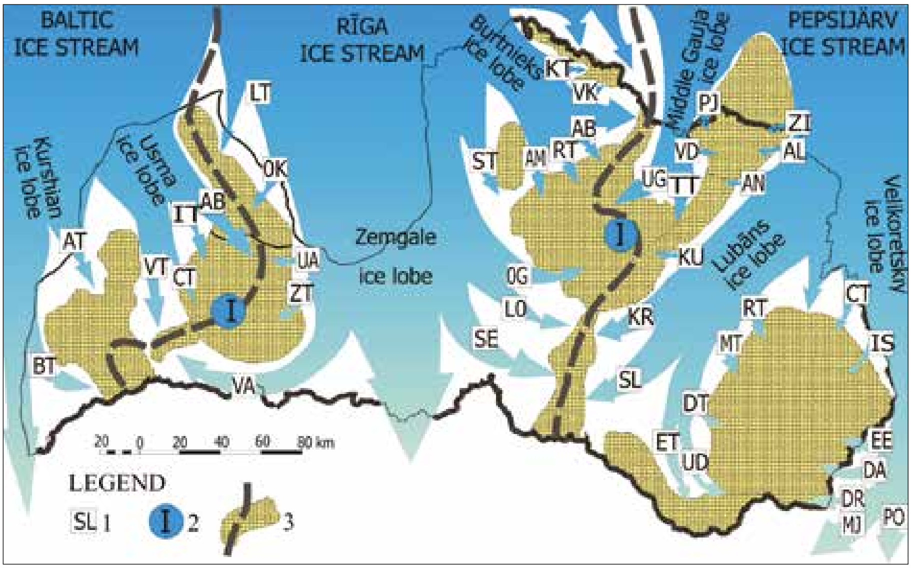

Fig. 9. **Lobate structure of the peripheral cover of the Fennoscandian Ice Sheet in Latvia during transgression and decaying of the Late Weichselian glaciation**
(modified after Zelčs and Markots 2004). Legend: 1 = Ice tongues: BT = Bārta; AT = Apriķi; VT = Venta; CT = Ciecere; AB = Abava; IT = Imula; LT = Laidze; OK = Oksle; UA = Upper Abava; ZT = Zebrus; VA = Vadakste; SE = Sēlian; LO = Lobe; OG = Ogre; ST = Straupe; AM = Amata; RT = Rauna; AB = Abuls; VK = Valka; KT = Kārķi; UG = Upper Gauja; TT = Tirza; VD = Vaidava, PJ = Perlijõgi; ZI = Ziemeri; AL = Alūksne; AN = Anna; KU = Kuja; KR = Krustpils; SL = Slate; ET = Eglaine; UD = Upper Daugava; DT = Dubna; MT = Malta; RT = Rēzekne; CT = Cirma; IS = Istra; EE = Ežezers; DA = Dagda; DR = Druja; MJ = Mjori; PO = Polatsk. 2 = Main interlobate zones: I = Baltic-Rīga; II = Rīga-Peipsijärv. 3 = Interlobate uplands and heights (ridges)

More than 60% are glacial lowlands which occupy large-scale depressions within the sub-Quaternary surface. Most glacial uplands are insular-shaped and bedrock-cored. Uplands and lowlands can be considered as the largest scale or macrorelief glacial landforms. Processes of glacial accumulation, with particular importance of selective glacial erosion, glaciotectonics and proglacial meltwater activity, have resulted in the formation of lowlands, while proglacial and subglacial accumulation and glaciotectonics have dominated in the glacial uplands. Three varieties of glacial uplands (isometric insular, radial insular and marginal uplands) and three main types of lowlands (divergent, convergent and consequent type) can be distinguished in Latvia, based on hypsometric position, thickness and structure of the Pleistocene cover, and glacial topography (Zelčs and Markots 2004).

Latvia occurs at the inner margin of the depositional zone of the Fennoscandian ice sheet where the main features of glacial topography were created by subglacial processes. During the last glaciation, it was affected by the Baltic, Riga and Peipsijärv (Peipsi Lake) ice streams. The ice streams were terminated in lobes and tongues, which merged in areas of the interlobate zones during transgression of the Late Weichselian glaciation (Fig. 8). The insular uplands and interlobate ridges represent zones of collision of ice lobes and glacier tongues moving in different directions and through separate neighbouring lowlands (Zelčs et al., 2011).

The formation and location of ice lobes and glacier tongues, and their dynamics were initially highly controlled by the geological setting of the pre-Quaternary bedrock but during the last glaciation mainly by the pre-Weichselian surface. The influence of the subglacial topography increased particularly during deglaciation, as ice thickness decreased (Zelčs and Markots, 2004).

1.4.2. Ice – marginal formations

A very complex lobate structure with many small glacier tongues and sub-tongues were existed in the early phases of the deglaciation, the ice dynamics were simplified and only the largest radial ice lobes and glacier tongues remained active in the lowlands. The major stillstands of ice terminus or readvances of the ice margin were fixed by ice marginal zones. The reactivation of the ice lobes and glacier tongues was induced not only by climatic and environmental changes but was also caused by the melting and stagnation of the glacier in the adjacent upland areas that improved ice mass balance in the lowlands (Dreimanis and Zelčs 1995). As a result of melting of stagnant ice, a complex of superimposed glacial landforms in upland areas formed simultaneously with the glacial landforms continuum created by active ice fluctuations in lowlands. Later, related to melting of stagnant ice sedimentation and landform processes occurred in lowlands.

Five major ice marginal zones (Fig. 10) can be distinguished in Latvia (Zelčs and Markots, 2004). Starting from the oldest, they are named the Dagda, Kaldabruņa, Gulbene, Linkuva and Valdemārpils ice-marginal zones. These ice marginal zones can be tentatively correlated with Baltija (Pomeranian), South Lithuanian, Middle Lithuanian, North Lithuanian (Otepää and Sakala) and Pandivere zones in the neighboring part of Estonia and Lithuania The onset of the Late Weichselian glaciation in Latvia has not been reliably dated, but the available OSL dates from western Latvia suggest that ice masses invaded the country no earlier than 24-25 ka. Deglaciation of the territory was started in Daniglacial time, about 18,000 years BP. The possible duration of the Late Weichselian glaciation of Latvia ranges between ca. 9 and 10 ka. (Zelčs et al., 2011).

The Dagda phase marginal positions can only be traced in the south-eastern corner of Latvia, in the Latgale Upland. Here, the marginal zone is represented by the composite marginal ridges, which forms the highest part of the upland, and is regarded as interlobate.

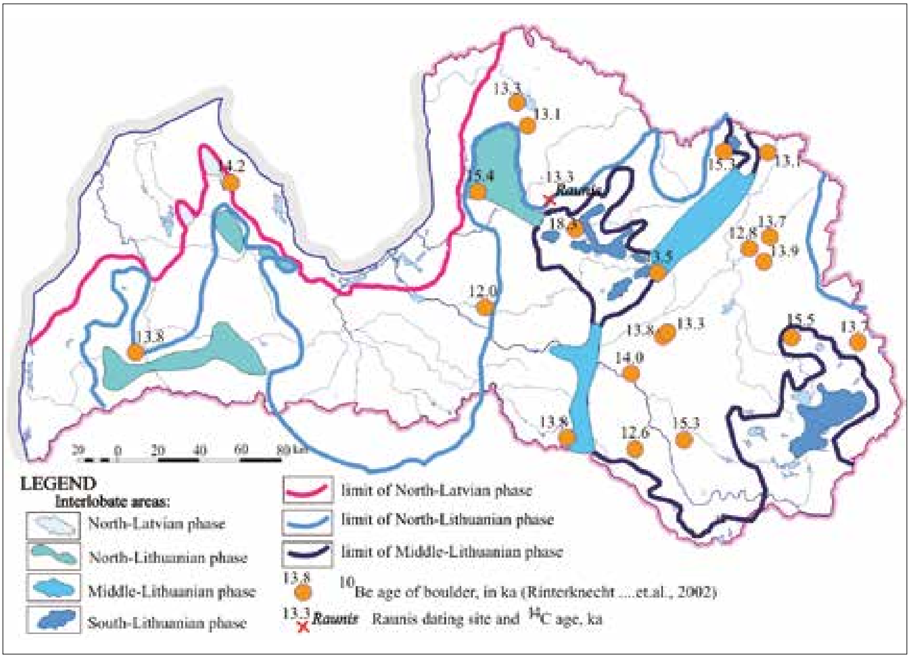

Fig. 10. **Ice marginal positions during deglaciation of the last glaciation**
(modified after Zelčs and Markots, 2004)

The Kaldabruņa marginal zone can be traced in Latgale, Augšzeme and Vidzeme Uplands. In the convergence zone of the ice masses of Zemgale and Lubāns lobes occurs the Sēlija Interlobate rigde. In Latgale and Vidzeme uplands the Kaldabruņa marginal formations are located in the upglacier position from the central, hypsometrically highest zone where large-sized composite hummocks and plateau-like hills are dominant. In the Augšzeme Upland, this zone is composed of rather well-established marginal moraine ridges, eskers and tunnel valleys altered by subareal meltwater drainage (Zelčs et al., 2011).

During the Gulbene glacial phase, most part of the eastern Latvia upland area was ice free or covered by stagnant ice, while in western Latvia, only the southern part of the Western Kursa Upland became deglaciated (Zelčs et al., 2011). During this phase in south-eastern Latvia, the Lubāns ice lobe flowed south-westwards from the territory of Russia. Its termination is marked by the spectacular, up to 70 m high, composite marginal moraine ridge in the East-Latvian Lowland. During this phase, the lowest marginal landform assemblage of the Latgale Upland was formed (Zelčs and Markots, 2004). In north-eastern Latvia, this phase can be drawn with some difficulties. During Gulbene stage, the Vidzeme Upland became ice free, and this phase is traced by the marginal moraine ridges and heavily glaciotectonised composite marginal ridges on its western, northern and north-eastern margins. In central Latvia, during this time, the Zemgale ice lobe was advancing in a highly divergent manner, far into the Middle Lithuanian lowlands (Zelčs et al., 2011).

During the Linkuva phase, glacial ice retreated furthernorth and most of eastern Latvia became ice free (Āboltiņš et al., 1972; Zelčs and Markots, 2004). The Lubāns ice lobe disappeared, and only the Mudava ice lobe was active in the extreme east of the East-Latvia Lowland. The ice-marginal position during this time is marked by the end-moraine chain, esker deltas and some short marginal meltwater valleys. In north-eastern Latvia, during this phase, the Burtnieks drumlin field was formed, terminating in the Veselava end-moraine chain (Āboltiņš et al., 1972). Central Latvia was occupied by the Zemgale ice lobe, producing the well-developed Linkuva end moraine arch in northern Lithuania and partly in Latvia (Āboltinš et al., 1972). During this phase, the western Latvia uplands became active ice free. The Usma ice lobe terminated as a series of glacier tongues, one of which ended in the Venta-Usma glacial lake, therefore, position of the Usma ice lobe margin is very approximate. During this phase, the Baltic Ice Stream in the western Latvia coastal lowlands ceased to exist, and, instead, several ice tongues formed that protruded from west to east, leaving fragmented chains of end moraines on the slopes of the Western Kursa Upland (Zelčs et al., 2011).

The Valdemārpils glacial phase is the latest deglaciation stage of the Fennoscadian Ice Sheet in Latvia, and its limit stretches along the Baltic Ice Lake and modern sea coast. Inland, east and west of the Gulf of Rīga, the Valdemārpils phase is marked by a chain of relatively low-marginal ridges and end moraines. In central and north-western Latvia, tracing this glacial limit is quite problematic because most of the glacial landscape is smoothed or eroded by Late-glacial meltwater basins and Litorina Sea. The ice sheet finally retreated from Latvia during the Late Weichselian Lateglacial Interstadial, about 14-12 ka B.P., but periglacial conditions persisted until the beginning of the Holocene (Zelčs et al., 2011).

In the Latvia the Holocene is represented by shoreline and nearshore deposits of the Ancillus Lake, Littorina Sea and Limnea Sea. Eolian dunes were formed in the sandy coastal and inland areas. Gytia, freshwater lime and limonite were deposited in lakes; peat and bog iron ore in bogs (about 10% of Latvia comprises bog); and travertine at calcareous springs. Some amber and heavy mineral concentrates were deposited along the Baltic shorelines. The main Quaternary economic deposits are gravel, sand, clay and peat. Karst sinkholes were formed over gypsum areas and in some fractured dolostones, and caves in Devonian sandstone (Dreimanis and Kārkliņš, 1997). The territory of Latvia has been inhabited for more than 10,000 years.

1.4.3. Ice – dammed lakes and proglacial fluvial systems

Due to effect of the flat topography and the dominant sloping down of the glacier bed surface towards the retreating ice margin, the meltwater and proglacial waters could not drain freely and flooded relatively large areas of glacial lowlands (Fig. 11). Drainage of these glacial lakes was often gradual, via lateral and/or proglacial meltwater channels, but sometimes during large lake drainage events this release was catastrophic. As a result in watershead areas deeply-incised and wide proglacial spillways were formed (Fig. 11). The width of the largest spillway valleys (e.g., Daugava and Gauja) reaches up to 2.5 to 3 km, the depth is up to 90 m.

Meltwater discharge resulted also in intense deposition of sediments either as deltas in the hipsometrically lower position located lakes or glaciofluvial fans in supra-aquatic environment.

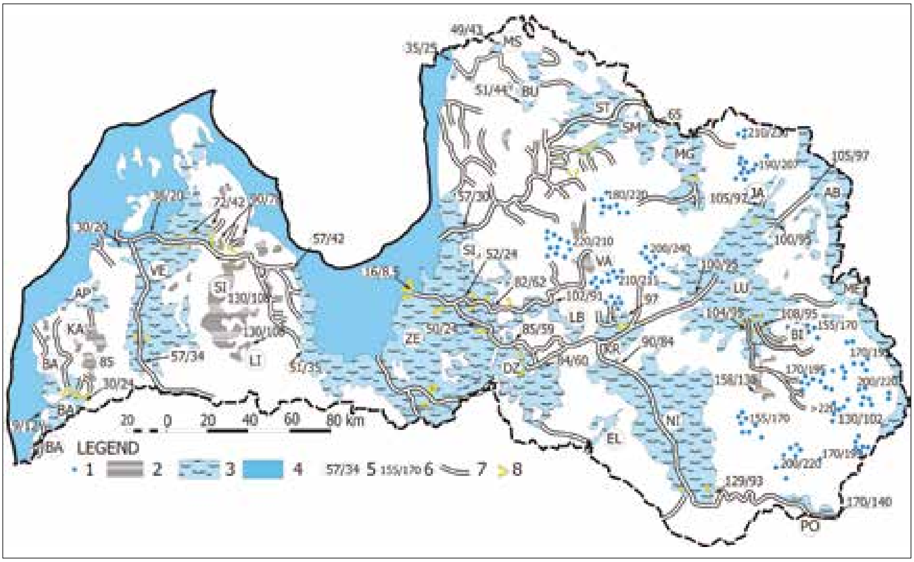

Fig. 11. **Distribution of ice-dammed lakes and glaciolacustrine deposition sites in Latvia** (modified after Zelčs and Markots 2004). Legend: 1 – accumulation of glaciolacustrine sediments on hilltops; 2 – ice dammed lakes in glacial uplands: KA – Kalvene, SI – Saldus-Imula, LI – Lielauce, VA – Valole, BI – Biži; 3 – meltwater basins in glacial lowlands: BA – Bārta, AP – Apriķi, VE – Venta, ZE – Zemgale, SI – Silciems; DZ – Daudzeva, LB – Lobe, EL – Elkšņi, KR – Krustpils, NI – Nīcgale, PO – Polatsk, ME – Mērdzene, LU – Lubāns, JA – Jaunanna, AB – Abrene, MG – Middle Gauja, SM – Smiltene, ST – Strenči, BU – Burtnieks, MS – Middle Salaca, 4 – Baltic Ice Lake; 5 – maximum/minimum shorelines a.s.l.; 6 – elevations of plateau-like hills; 7 – largest meltwater and remnant lake drainage pathways; 8 – ancient deltas

The formation of the proglacial fluvial network in the Baltic countries began after the South Lithuanian phase, some 16000 years ago in southern Lithuania and about 12600 years in northernmost Estonia. In Latvia, a reach of the Daugava River valley, connecting the glacial lakes of Polatsk and Nīcgale (Fig. 11), formed during ice retreat, after the Gulbene stage. Most of the fluvial development however, was related to the retreat of the Linkuva phase ice sheet. Commonly, the Late –glacial terraces of the Latvian rivers, except the uppermost terrace fragments of the Daugava and Jodupe rivers, dip upglacier or towards the Gulf of Riga and Baltic Sea (Zelčs and Markots, 2004).

The first meltwater basins that formed in Latvia were supraglacial lakes. They are assumed to have appeared in depressions of the ice surface initially as slush ponds. These supraglacial lakes were probably small, covering an area 1-2 to 15 km^2. Local glaciolacustrine deposits overlie the uneven base of the glaciotectonic composite hills in the isometric uplands of the interlobate areas of Eastern Latvia (Fig. 11). The lake sequence begins with massive clays or silt and/or varve-like laminated silt and clay. Coarser sandy material, in places with an admixture and intercalation of gravel, occurs at the margins of these dead ice-dammed lakes.

Large ice-dammed lakes covering an area of some thousands of km^2 developed in glacial lowlands. The maximum depth of these lakes was up to 40 m. They were formed during the latest episodes of the Gulbene recession. The formation of younger ice-dammed lakes in the lowlands resulted from drainage of the lakes mentioned above, after the Linkuva reactivation, and they existed up to the Palivere deglaciation phase (12,8-11,7 ka years). The glaciolacustrine sediments are represented by varved clays and other types of laminated and non-laminated sediments (Zelčs and Markots, 2004).

The Baltic Ice Lake covered considerable parts of Latvia (Fig. 8). It existed during the Allerod Interstadial and Younger Dryas Stadial and followed the retreating ice sheet of the Palivere phase (approximately 13,3 and 11,6 cal. ka BP) and in the Baltic depression and adjoining coastal areas (Zelčs and Markots, 2004). In the development of the Baltic Ice Lake, there have been many outlets which appear on the shorelines of the basin profiles. The shorelines of the Baltic Ice Lake stages I (BI), II (BII) and III (BIII) as well as in places the shoreline of maximum Littorina Sea (Lit_a) transgression are well traceable in the Latvia territory. The stages BI and BII are featured as transgressive but BIII with BIIIa, BIIIb, BIIIc phase regressive formation (Veinbergs, 1979).

Its waves and currents abraded the offshore glacial plains, including lower parts of marginal formations of the Valdemārpils phase (Veinbergs, 1979). Abrasion scarps, bars, spits, accumulative terraces and other coastal landforms allow the reconstruction of several shorelines at hypsometric levels from 5 to 55 m (Grīnbergs, 1957; Veinbergs 1964). All these Baltic Ice Lake shorelines are tilted northwestwards because of the glacioisostatic uplift. The best developed shorelines are those of Baltic Ice Lake phase BII and BIIIb (Zelčs and Markots, 2004).

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1.5. Bedrocks, the Quaternary deposits and soil cover

1.5.1. Bedrocks

Structurally, the territory of Latvia is located on the western side of the East European Platform. The platform is bordered on the north by the southern slope of the Baltic Shield. In the subsurface, the Precambrian basement of crystalline rocks and succeeding Upper Proterozoic and Palaeozoic sedimentary rocks underlie the territory of Latvia. The total thickness of sedimentary bedrock is increases from less than 0.5 km in the north-east borderland up to about 2 km in the south-west (Dreimanis and Kārkliņš, 1997).

The crystalline basement is composed of folded Proterozoic metamorphic and igneous rocks such as gneisses, migmatites, granites, anorthosites. It lays in depth of 380-1900 m. Active development of the basement took place approximately 1,93-1,8 billion years ago, (Kirs et al., 2009). The surface of the crystalline basement is covered, in ascending stratigraphic order, by Ediacaran, Cambrian, Ordovician, Silurian, Devonian, Carboniferous, Permian, Triassic and Jurassic deposits. The Devonian sedimentary rocks lie in the shallow depth and compose the topmost part of the pre-Quaternary sequence in all area of Latvia with exception of its south-western part (Fig. 12).

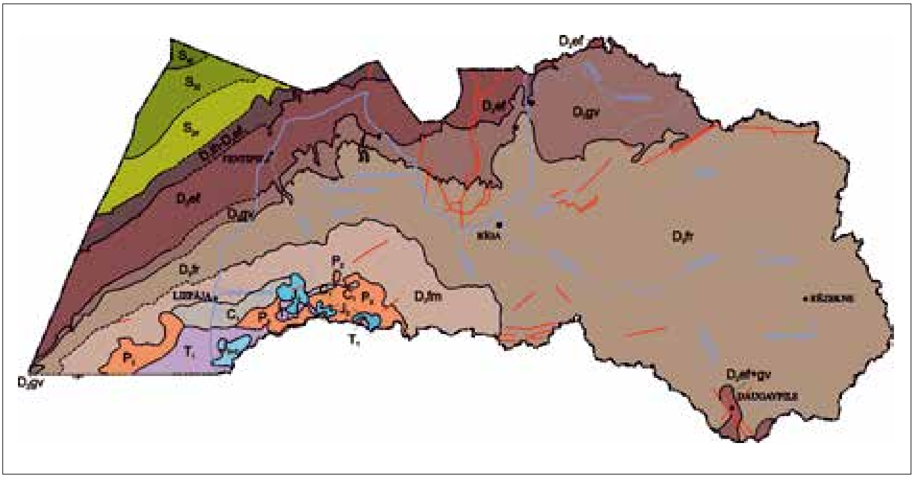

Fig. 12. **Schematic map of pre-Quaternary bedrock in Latvia** (composed in the State Geological Survey of Latvia): S_w – Silurian, Wenlock; S_{ld} – Silurian, Ludlow; S_{pr} – Silurian, Pridoli; D_1lh-ef1 – Lower Devonian, Lochkovian – Emsian; D_2ef – Middle Devonian, Eifelian; D_2gv – Middle Devonian, Givetian; D_2ef-gv – Middle Devonian, Eifelian and Givetian; D_3fr – Upper Devonian, Frasnian (in this map the Gauja and Amata fms are included in Frasnian); D_3fm – Upper Devonian Famennian; C_1 – Carboniferos, Mississippian; P_2 – Permian, Guadalupian; T_1 – Lower Triassic; J_2 – Middle Jurassic; J_{2-3} – Middle to Upper Jurassic

The Phanerozoic deposits accumulated in shallow epeiric sea, sometimes also in continental environment, except the Ordovician and Silurian deposits, which formed in epeiric and pericontinental seas. After the Jurassic period, a continental environment developed in Latvia, therefore the Cretaceous, Paleogene and Neogene deposits are not preserved (Brangulis et al., 1998).

1.5.2. The Quaternary deposits

Quaternary deposits of various thickness and age cover almost all Latvian territory, except for restricted bedrock outcrop areas – mainly erosional plains of the Baltic Ice Lake in the north of Latvia, along and in river valleys. The average thickness of the Quaternary deposits is 5-20 m in the lowlands and 40-60 m in the uplands (Fig. 6). Locally, along the southern, south-western and south-eastern sides of the bedrock elevations, e.g. in the Vidzeme Upland, and in east-central Latvia, between the towns of Cēsis and Madona the thickness of the Quaternary deposits may reach up to 200 m (Fig. 13). The greatest thickness of the Quaternary deposits (310 m) occurs in the Aknīste buried valley in southeaster Latvia. Most of the Quaternary deposits are glacial and of the Late Pleistocene age (Zelčs et al., 2011). The main landscape forms were built during last two glaciations, and commonly the cores of positive landforms consist of glaciotectonically deformed sediments (Dreimanis and Kārkliņš, 1997).

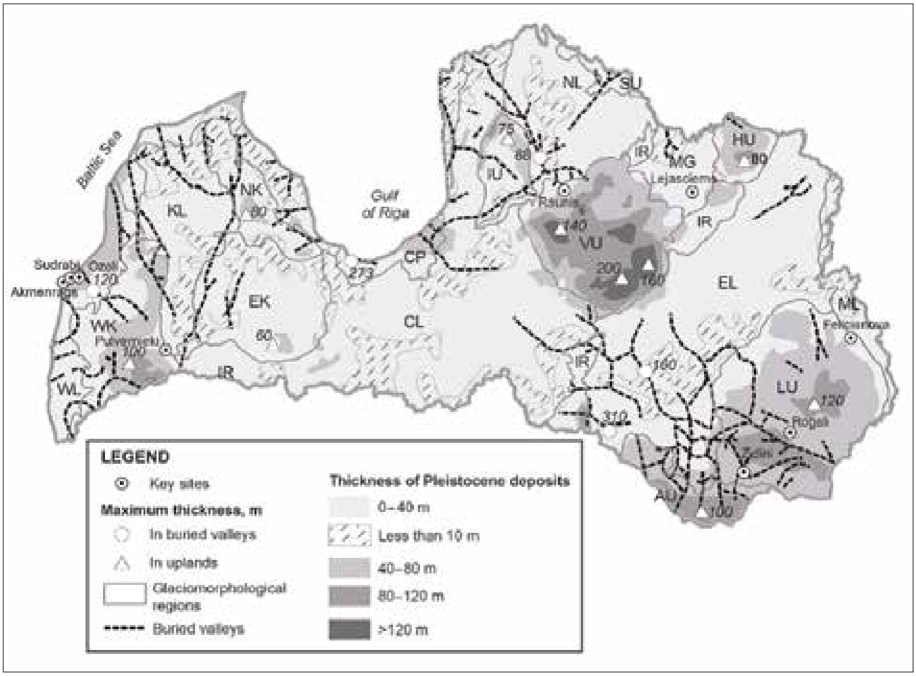

Fig. 13. **Thickness of the Quaternary deposits in Latvia** (modified after Zelčs et al. 2011). Glacial lowlands: WL – Western Latvian, KL – Kursa, CL – Central Latvian, NL – Northern Latvian, MG – Middle Gauja, EL – East-Latvian, ML – Mudava (Velikoretsky). Glacial uplands: WK – Western Kursa, NK – Northern Kursa, EK – Eastern Kursa, IU – Idumeja, VU – Vidzeme, HU – Alūksne-Haanja, LU – Latgale, AU – Augšzeme, IR – Interlobate ridges

Latvia is located within the area of the Fennoscandian Ice Sheet, and so the sediments of previous interglacials are rarely found in the Quaternary cover (Dreimanis and Zelčs, 1995). Newest available geological information indicates the occurrence of three tills deposits – Pleistocene interglacials – Cromerian (termed locally as Židiņi), Holsteinian (Pulvernieki) and Eemian (Felicianova), and tills of Elsterian (Lētiža), Saalian (Kurzeme) and Weichselian (Baltija) glacials (Zelčs et al., 2011).

The internal structure of the Pleistocene sequence has in many places been complicated by glaciotectonic deformation (Āboltiņš and Dreimanis, 1995; Dreimanis and Zelčs 1995; Saks et al., 2012). Older sediments have been emplaced above younger ones as megablocks, or as overthrusts and complex folds (Āboltiņš, 1989; Zelčs and Dreimanis, 1997). As a result of glaciotectonism and glacial erosion the Pleistocene sequence has also undergone large-scale sediment redistribution and remarkable complication of its structure (Zelčs et al., 2011). Only deposits of the Late Weichselian glaciation are present throughout almost all of Latvia. These deposits have a dominant role in the Pleistocene sequence of the glacial uplands and lowlands. The Late Weichselian non-deformed and glaciotectonised till and stratified deposits are also the main landforming material.

1.5.3. Soil cover

Soils of Latvia are relatively young due to its development during Holocene in the evolution process after the deglaciation of the territory. Absolute age of soils generally makes less than 10 000 years. The youngest soils can be found along the rivers and on the Baltic Sea terraces and dunes (Kārkliņš et al., 2009). The Quaternary deposits are the main parent material of soil formation, and glacial tills (moraines) prevail among them. Others are glaciolacustrine, glaciofluvial, aeolian, marine, lacustrine (limnic) and organic deposits. Two-membered deposits, which consists of tills (or other deposits) underneath and different Holocene formations, are quite common. The seasonal stagnation of perched water in clayey till and / or at the contiguity of different texture layers is on of the widespread pedogenetic features (Kārkliņš et al., 2009).

Mild and wet climatic conditions are favourable for intensive chemical and biological weathering of minerals and rocks, for nutrient cycling and for formation of mobile soil humus. Due to the favorable chemical composition of Quaternary deposits, various species and rather high biomass productivity represents virgin vegetation. Spruce and mixed forests dominante on till landscapes, whereas pine stands prevail on sands.

Development of Latvia soils is greatly influenced by **human activities and changes in land use**. ***Firstly***, changes in the vegetation occurred, e.g. most of forests are replanted, marginal agricultural lands are abandoned and natural afforestation occurs, however on fertile soils in central Latvia lowland – intensive agricultural farming prevails. Slash and burn agriculture or fire-fallow cultivation until 17th century were predominant in wide areas of Latvia for agricultural production. These evidences can be observed in all area of Latvia in forest lands as well as in agricultural lands. Amount of carbon and nutrients decreased in the result of slash and burn agriculture, as well as mineral horizons of topsoil were mixed. Therefore secondary podzolization, characterized by E horizon above A horizon is observed in many places in Latvia. Soil factor was most important for land use after slash and burn agriculture. Fertile soils were used in agriculture, however natural afforestation occurred under relatively poor soils (Fescenko et all., 2014). Abandonment of agricultural lands and natural afforestation is ongoing nowadays in Latvia. Also in this case, soil factor (soil texture, amount of nutrients and moisture conditions) is one of the important factors that determine overgrowing of agricultural lands (Ruskule et al., 2016). Studies in Latvia (Nikodemus et al., 2013) showed, that after abandonment of agricultural lands and natural afforestation by trees, changes in soil morphology within glacial till loamy sand deposits, can be observed after 60 years.

Secondly, management of the surface and ground water regime has influenced natural hydrological conditions. Currently, about 64% of agricultural land and 48% of forests have been drained. Also other water management activities like construction of water reservoirs for power plants, dams, road dikes and polders, as well as dredging and modification of water courses, etc., have substantially influenced anthropogenic and natural ecosystems, including soils.

Thirdly other human activities related to farming and agricultural production, such as amelioration (expansion of field contours and changes in field configuration, removal of stones and trees, modification of land surface, subsoiling, etc.), lime application, use of fertilizers, and soil tillage, have influenced the land and soil quality.

These activities were very intensive within the period from 1960 up to 1990 and considerably influenced soil properties, especially for arable land. Agricultural activities have experienced some decline since 1990, which also, to some extent, has influenced the soil processes. Deterioration of water management systems and improper attention to their maintenance, orvergrowing of farmland with bushes and deep-rooted weeds (especially on marginal lands), dramatic decrease in fertilizer and manure use and lime application, long-lasting repeated cropping of cash-crops, etc., are the main features of the present farming situation in general. They have periodically changed the soil moisture, oxidation-reduction, humus formation, nutrient turnover and other regimes, biodiversity, as well as have mechanically mixed not only the topsoil layers but also deeper soil horizonts. Therefore the natural soil development equilibrium has been disturbed periodically. This has resulted in the formation of specific soil profile features, has caused high spatial variability of soil properties, as well as has increased the diversity of soil cover (Fig. 14).

Formation of Podzols and Luvisols is related to predominant soil formation processes (podzolization, lessivage, leaching) in soil evolution due to the fact that Latvia is located in boreal climate moisture European-westsiberian soil region, where amount of precipitation exceeds evaporation. Podzols are widespread in Piejūra lowland and inland dune areas, where predominates sediments of different development stages of the Baltic Sea or aeolian deposits.

Distribution of Luvisols is related to glacial till (uplands) and glaciolacustrine deposits (lowlands). Glacial till and glaciolacustrine clay and loam deposits interfere water infiltration and therefore in uplands of glacial till and lowlands of glaciolacustrine deposits frequently stagnogleyization is observed, that is confirmed by reductimorphic properties and stagnic colour pattern. Therefore Stagnosols or other soils with stagnic properties are prevailing in such conditions

Flat topography with disturbed natural drainage and relatively high ground water table in uplands and depression valleys is important precondition for the development of gleyization process. Gleysols develops in such conditions. Histosols forms due to the accumulation of peat in depression valleys of topography. Disturbed natural runoff and drainage in plains is one of the factors in formation of the raised bogs, therefore Histosols predominates in lowlands (Piejūras lowland, Austrumlatvijas lowland).

Lithological discontinuity is precondition for distribution of Planosols, therefore Planosols frequently occurs within glaciolacustrine deposits. Studies in Latvia shows (Kasparinskis and Nikodemus, 2012) that high diversity in geological deposits and moisture conditions is precondition for soil diversity in Latvia.

According to **WRB classification** (2014) in central Latvia lowland (Zemgales plain) most of soils corresponds to Phaeozems or Stagnosols. However in uplands

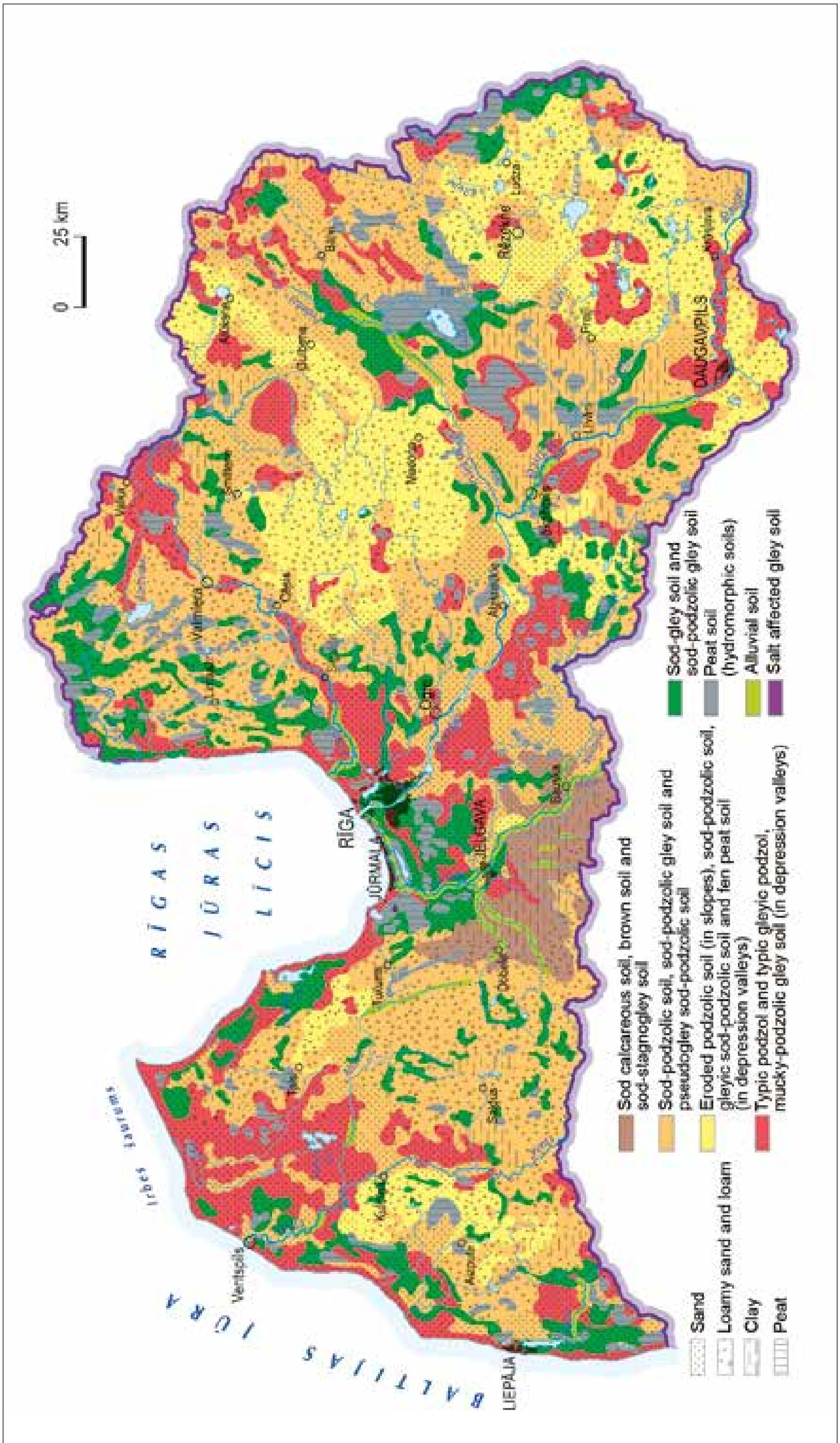

Fig. 14. **Soil map of Latvia (according to genetic soil classification of Latvia)**
(source: Jāņa Sēta, author: O. Nikodemus)

predominates Luvisols, Cambisols, Gleysols and Histosols. In pine *Pinus sylvestris* forests widely distributed are Arenosols and Podzols, however in spruce *P. Abies* and deciduous forest stands – Umbrisols, Stagnosols, Albeluvisols and Cambisols. Due to changes in soil texture and moisture conditions, as well as undulated topography in uplands soil contours are relatively small in Latvia. Therefore for characterization of soil distribution in many cases is used soil complexes. Characteristic soil complex in glacial tillu pland is following: Luvisols, Arenosols, Stagnosols in slopes and crest of topography, but in lower part of slopes – *Gleysols* and in depression valleys – Histosols. In dunes soil complex is formed by Arenosols, Cambisols, Podzols and Histosols. In central Latvia lowland (Zemgales plain) distributed are Phaeozems or Stagnosols as well as Cambisols and Luvisols.

1.5.4. Latvian soil classification

The scheme of latvian soil classification includes three dependent (hierarchical) levels: classes, types, and subtypes. On the highest categorical level (class), the main criterion is hydromorphism. On the second level, the criteria are different features, such as depth of carbonates, evidence of certain processes of soil genesis (lessivage, podzolization, and reductimorphic and oximorphic processes), and profile development, but for hydromorphic soils – type and decomposition rate of organic soil materials.

Automorphic soils – developed on the relatively highest part of landscape with a deep groundwater tabele. Soil profile is water-saturated only for a short period within a year. This soil class comprises 6 soil types with 22 subtypes:

- Sod calcareous soils – well developed A horizon, and carbonates in soil profile within 0-60 cm from the surface.
- Brown soils – clay accumulation in B horizon *in situ* or by illuviation, and carbonates deeper than 60 cm.
- Podzolic soils – soils with some features of podzolization (bleached E horizon).
- Podzols – soils with distinct features of podzolization (well expressed E and Bs / Bhs horizonts).
- Weakly developed soils – young and noticeably eroded soils with weaklu developed or truncated genetic horizonts.
- Anthrosols – development of soils is considerably influenced by a man. Includes the soils strongly altered by cultivation, as well as recultivated, technogenic and also buried soils.

Semihydromorphic soils – developed in planes or depressions on fine-textured parent material. Soil profile is water-saturated for a long period within a year including the growing season. Gleyic and / or stagnic properties are clearly distinguished. This soil class comprises 3 soil types with 24 subtypes:

- Gley soils – sod calcareous or brown soils with distinct gleyic and / or stagnic properties.

- Podzolic-gley soils – podzolic soils or podzols with gleyic and / or stagnic properties.
- Alluvial soils – developed on alluvial sediments.

Hydromorphic soils – organic soils: mires, peatlands, naturally water-saturated soils. This soil class comprises 3 soil types with 10 subtypes:

- Fen peat soils – organic soils from highly decomposed grass vegetation.
- Transitional mire soils – intermediate stage between fen and raised bog development.
- Raised bog soils – organic soils with considerable amounts of recognizable plant tissue.

On the third level, soil types are divided into subtypes according to additional properties: organic matter content in surface horizonts and their thickness, as well as development of genetic horizonts.

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2. EXCURSIONS TO SITES IN LATVIA

2.1. Kurzeme region and soil profiles (No 1, 2, 3)

Sites in Kurzeme region (Fig. 15) and soil profiles located in the Coastal Lowland and in the Kursas Lowlands. Quaternary deposits cover relatively articulated surface of Devonian period Burtnieki and Gauja Formations terrigenous rocks directly below quaternary deposits. Pre-Quaternary surface lies in a depth of 1-25 m asl., gently sloping from SE to NW. Major characteristics of Pre-Quaternary landscaper are not know in details because for major part of the area continental denudation and sedimentation prevail from late Devonian.

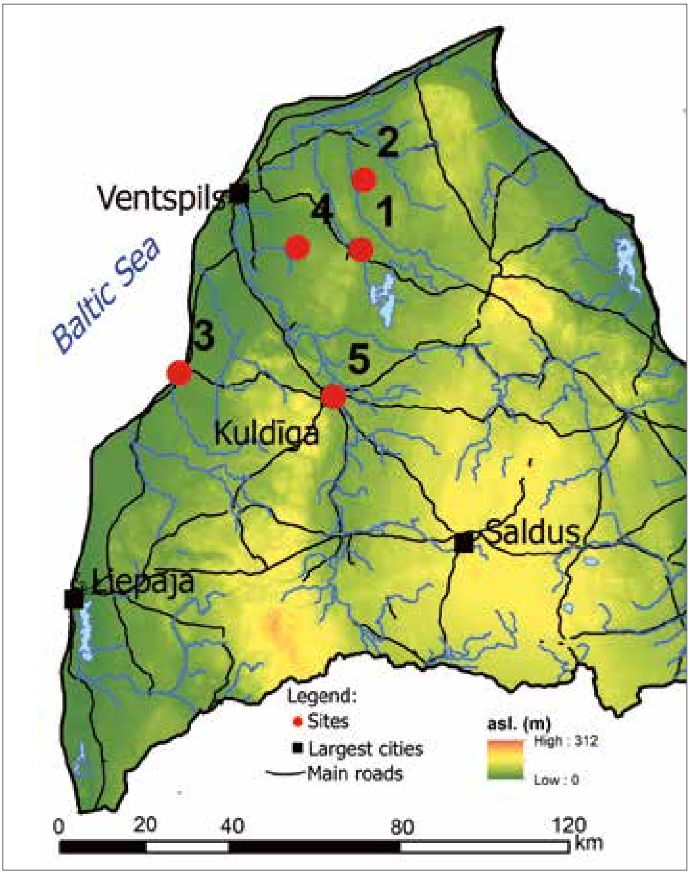

Fig. 15. **Map of site locations and soil profiles in Kurzeme region**
(source: SRTM; author: M. Krievāns)

There are several areas, where the Devonian sedimentary rocks are exposed at outcrops (Juškevičs et al., 1998). Western Kurzeme several times was under the pressure of Quaternary glaciations. Thickness of Quaternary deposits in the western part of Latvia is very variable and reflected specifics of Pre-Quaternary formations landscape surface particularities, glacial exaration and accumulation specifics and modern relief general regularities.

The Quaternary cover is mostly composed of Late glacial glaciolacustrine deposits which are represented by clayey sediments of the Baltic Ice Lake, and silt, fine-grained sand of the Litorina Sea. The clayey deposits of the Baltic Ice Lake are underlain by Weichselian till with rafted bedrock blocks, interlayers and lenses of glaciofluvial deposits (Veinbergs, 1964). The older Middle Pleistocene Saalian till, possibly also Elsterian till, and intertill deposits have been observed only in the pre-Quaternary valley like depressions incised in a Devonian sedimentary rocks (Juškevičs et al., 1998).

The area of the development of the old Baltic Sea formation widespread on the land, is represented by sandy plain located between the internal, hypsometrically higher, elevated areas of the accumulative, glacial topography of Latvia and the present sea shore. The width of the coastal plain varies from several kilometres to 40-50 km. Number of old shorelines of the Baltic Sea basin can be traced. Sandy, coastal, accumulative formations and dunes of the Litorina stage are nearest to the present shore. On the coast of the Baltic Sea, near the cities of Liepāja and Ventspils and thehead of the Gulf of Rīga, these formations separate the low parts of old lagoons, which lowest parts are occupied by lakes, such and Liepājas, Engures, Babītes, etc. from the sea. Landward from the coastal forms of the Litorina Sea in the north of the Kurzeme peninsula up to the Piltene-Roja aggradation terraces, abrasion scarps and other coastal formations of the Ancylus Lake may be traced. The coastal forms of different stages of the Baltic Ice Lake constitute borderline of the coast and the area where glacial drift occurred. The shore formations of Baltic Ice Lake stages mainly are represented by abrasion scarps, splits, bars accumulative terraces, separate ridge-like dunes and some others (Veinbergs, 1979).

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Soil profile No 1

WRB 2015 soil classification: Stagnic Folic Albic **Podzols** (Abruptic, Arenic, Siltic)
Latvian soil classification: Stagnogley sod-podzolic soil

Geological deposits: Baltic Ice lake sands (top)/Glaciolacustrine (bottom)
Land use: Spruce *P. Abies* forest
Location: Ugāle, plain
Coordinates: 57,281499°; 22,071700°

Table 1. Texture and colour

Horizon	Depth [cm]	Percentage share of fraction [mm]			Textural class	Colour
		Clay < 0.002	Silt 0.002-0.063	Sand 0.063-2.0		
O	0-10	—	—	—	—	10YR 2/1
Ah	10-18	8.3	11.8	80.0	MS	10YR 4/2
E	18-48	3.1	9.7	87.2	MS	10YR 7/2
Bs	48-71	0.7	6.0	93.3	FS	7.5YR 2.5/3
Bg	71-164	45.0	25.0	30.0	C	7.5YR 4/4
Cr	164-175	0.7	52.7	46.6	SiL	5Y 5/2

Table 2. Chemical properties

Horizon	Depth [cm]	$C_{org.}$ [%]	$N_{tot.}$ [g·kg^{-1}]	C/N	Extractable P [mg·kg^{-1}]	$CaCO_3$ [g·kg^{-1}]	Al_o	Fe_o
							[mg·kg^{-1}]	
O	0-10	9.2	1.1	8.4	678.6	—	452.8	818.5
Ah	10-18	3.9	0.5	7.8	42.6	—	127.3	34.2
E	18-48	0.1	—	—	—	—	84.0	0.0
Bs	48-71	0.1	—	—	—	—	468.0	249.0
Bg	71-164	0.1	—	—	—	6	756.0	1109.7
Cr	164-175	0.4	—	—	—	29	—	—

Table 3. Sorption properties

Horizon	Depth [cm]	pH value		Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	Al^{3+}	Fe^{2+}	EA	CEC	BS
		pH_{CaCl2}	pH_{H2O}	[mg·kg^{-1}]						[cmol(+)·kg^{-1}]		[%]
O	0-10	5.5	4.2	8.28	0.76	2.12	0.52	1.59	0.01	1.68	37.1	78
Ah	10-18	6.6	4.7	0.27	0.09	0.02	0.16	0.61	0.04	1.21	25.2	87
E	18-48	7.1	5.3	0.10	0.03	0.01	0.13	0.05	0.01	0.65	4.4	50
Bs	48-71	7.0	6.2	0.26	0.07	0.02	0.12	0.07	0.01	0.67	3.5	40
Bg	71-164	7.9	6.5	0.37	0.09	0.01	0.14	0.12	0.00	0.72	45.3	97
Cr	164-175	7.9	—	—	—	—	—	—	—	—	49.9	98

Soil profile No 2

WRB 2015 soil classification: Stagnic Gleyic Abruptic **Luvisols** (Siltic, Fluvic)
Latvian soil classification: Sod –stagnogley soil

Geological deposits: Glaciolacustrine and Glacial till (top) / Devonian sandstone (bottom)
Land use: Coniferous (pine *Pinus sylvestris*/spruce *P. Abies*) forest
Location: Ance, plain
Coordinates: 57,428800°; 22,073600°

Table 4. Texture and colour

Horizon	Depth [cm]	Percentage share of fraction [mm]			Textural class	Colour
		Clay < 0.002	Silt 0.002-0.063	Sand 0.063-2.0		
O	0-5	—	—	—	—	10YR 3/3
Ah	5-9	—	—	—	MS	7.5YR 3/4
B	9-25	33.3	44.6	22.0	SCL	7.5YR 4/6
Btg	25-72	44.6	52.2	3.2	CL	5YR 5/6
CRr1	72-100	1.5	6.4	92.1	FS	5Y 7/2
CRr2	100-122	5.0	13.5	81.5	VFS	Gley1 6/10Y
CRr3	122-143	1.5	4.8	93.7	VFS	5Y 6/2

Table 5. Chemical properties

Horizon	Depth [cm]	$C_{org.}$ [%]	$N_{tot.}$ [g·kg^{-1}]	C/N	Extractable P [mg·kg^{-1}]	$CaCO_3$ [g·kg^{-1}]	Al_o	Fe_o
							[mg·kg^{-1}]	
O	0-5	32.9	1.3	25.3	666.9	1.3	723.1	1031.2
Ah	5-9	21.4	0.5	42.8	68.9	0.5	1006.7	494.2
B	9-25	1.6	—	—	—	0.08	1027.2	589.9
Btg	25-72	0.4	—	—	—	0.05	736.3	372.7
CRr1	72-100	0.1	—	—	—	0.005	687.8	617.5
CRr2	100-122	0.1	—	—	—	0.008	—	—
CRr3	122-143	0.0	—	—	—	0.004	—	—

Table 6. Sorption properties

Horizon	Depth [cm]	pH value		Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	Al^{3+}	Fe^{2+}	EA	CEC	BS
		pH_{CaCl2}	pH_{H2O}	[mg·kg^{-1}]						[cmol(+)·kg^{-1}]		[%]
O	0-5	4.0	2.7	6.13	2.05	1.03	0.34	1.59	0.00	2.81	—	—
Ah	5-9	4.6	2.8	0.30	0.13	0.01	0.12	2.90	0.03	3.18	63.9	14
B	9-25	5.3	3.7	0.37	0.19	0.02	0.10	1.58	0.03	1.86	40.1	27
Btg	25-72	5.3	3.7	0.16	0.09	0.02	0.14	0.93	0.04	1.21	39.8	32
CRr1	72-100	5.9	4.3	0.58	0.33	0.04	0.10	0.69	0.04	0.97	11.8	65
CRr2	100-122	—	4.2	—	—	—	—	—	—	—	16.4	53
CRr3	122-143	—	4.3	—	—	—	—	—	—	—	10.8	78

Soil profile No 3

WRB 2015 soil classification: Skeletic Cambic Fluvic Endogleyic **Phaeozems**
Latvian soil classification: Sod – podzolic gley soil

Geological deposits: Baltic Ice lake sand and gravel (top)/Glaciolacustrine (bottom)
Land use: Spruce *P. Abies* forest
Location: Jūrkalne, plain
Coordinates: 57,007200°; 21,378000°

Table 7. Texture and colour

Horizon	Depth [cm]	Percentage share of fraction [mm]			Textural class	Colour
		Clay < 0.002	Silt 0.002-0.063	Sand 0.063-2.0		
O	0-10				—	10YR 2/2
Ah	10-20	1.7	10.0	88.3	FS	7.5YR 2.51/1
B	20-42	3.6	4.0	92.5	MS	10YR 5/6
BCk	42-67	1.7	1.3	97.0	FS	10YR 6/3
Ck	67-76	2.4	2.0	95.6	US	2.5Y 6/3
Clk	76-90	0.2	3.7	96.1	US	2.5Y 5/3
Crk	90-120	11.2	19.6	69.2	LS	2.5Y 5/2

Table 8. Chemical properties

Horizon	Depth [cm]	$C_{org.}$ [%]	$N_{tot.}$ [$g \cdot kg^{-1}$]	C/N	Extractable P [$mg \cdot kg^{-1}$]	$CaCO_3$ [$g \cdot kg^{-1}$]	Al_o	Fe_o
							[$mg \cdot kg^{-1}$]	
O	0-10	39.7	2.5	15.88	780.8	—	655.1	779.6
Ah	10-20	8.9	0.6	14.83	185.6	—	960.8	491.1
B	20-42	0.2	—	—	—	2	489.0	473.1
BCk	42-67	0.3	—	—	—	13	378.0	702.6
Ck	67-76	1.3	—	—	—	21	126.0	153.9
Clk	76-90	0.1	—	—	—	22	—	—
Crk	90-120	0.4	—	—	—	19	—	—

Table 9. Sorption properties

Horizon	Depth [cm]	pH value		Ca^{2+}	Mg^{2+}	K^+	Na^+	Al^{3+}	Fe^{2+}	EA	CEC	BS
		pH_{CaCl2}	pH_{H2O}	[$mg \cdot kg^{-1}$]						[cmol(+)$\cdot kg^{-1}$]		[%]
O	0-10	4.4	3.9	18.90	0.83	0.60	0.34	1.56	0.01	1.76	—	—
Ah	10-20	6.2	5.5	3.03	0.19	0.09	0.27	0.18	0.00	2.87	43.9	72
B	20-42	6.7	7.0	0.88	0.06	0.01	0.14	0.02	0.00	0.98	34.0	95
BCk	42-67	7.9	7.7	1.54	0.08	0.02	0.15	0.03	0.01	0.27	49.5	98
Ck	67-76	8.0	7.7	0.82	0.14	0.04	0.16	0.05	0.00	0.29	49.9	98
Clk	76-90	—	7.8	—	—	—	—	—		—	49.5	98
Crk	90-120	—	7.8	—	—	—	—	—		—	50.2	98

2.2. Baltic Sea Coast, Jūrkalne seashore bluffs and coastal erosion in Latvia

The total length of the Latvian coastal zone is 496.5 km. It mainly consists of sandy beaches and dunes. Gravel, pebble or boulder covered beaches are more rare and there are hardly any steep coasts. In the areas of sand accumulation beyond the beach, 1-4 m high predunes with typical vegetation have formed. Beyond these, there is typically a belt of grey dunes and forest-covered coastal dunes dominated by pine trees. There is little urban development along the coast due to restrictions in the Soviet period; the developed area closer than 500 m from the shore is about 11% (Tonisson et al., 2013).

Studies made in Latvia demonstrate that over the past 100 years land areas in some places have extended by 50-200 m (in Irbe Strait from Luzna to Mikeltornis), however in most cases, the territories of land have receded and the width of the washed off coastal belt is 50-150 m (in Nida, Bernatu Dune, in the section of Ulmale-Jurkalne bluff at the Baltic Sea coast (Fig. 16, 17), also in the Gulf of Riga in the coastal area of Kolka, Engure, Bigaunciems). By the end of 1970s, the erosion rate of the coast was 0.5-1 m, at some locations 1.5 m per annum, however during the past decades the erosion rate has increased 2-5 times (Ministry of the Environment of the Republic of Latvia, 2006)).

Fig. 16. **Jūrkalne Seashore Bluffs and Coastal Erosion**
(author: R. Kasparinskis)

Fig. 17. **Baltic Sea Coast, Jūrkalne Seashore Bluffs and Coastal Erosion**
(author: R. Kasparinskis)

From 1992-2011, some 120 km of the coastline has been affected by erosion; for some 60 km erosion rate is >0.5 m/year. Over the last decades, there has been a sharp reduction in sea ice duration time (Meier et al., 2004; Tonisson et al., 2013) as a result of which ice is not acting as a natural 'protective barrier' during winter storms. The most intensive erosion is near Kurzeme coast (near Bernāti and Jūrkalne) where the coast during the year may step back by up to 20-30 metres. Seriously endangered is also the western coast of Riga Bay because of the concentration of housing in historical villages of fishermen. Observations show that in the last 50-60 years the average wash-off of coasts in approximately 30% of total length of the coastal belt of Latvia reached 30-50 m, the maximal wash-off being 100-200 m (Ministry of Environmental Protection and Regional Development of Latvia, 2001).

In the past 20-30 years, the force of devastating autumn and winter storms in Latvia (as observed also elsewhere in Europe and globally) is increasing and the drifts of wind born water mass in the coastal area are getting higher. At the same time, winters are getting warmer – without coastal ice in the shallow sea zone and freezing of soil. As a result, erosion of the coast increases (Ministry of the Environment of the Republic of Latvia, 2006)).

As 62% of the 496.5 km long coastal line (corresponding to 27% of the total border length) in Latvia is considered as an area of increased risk from erosion, every year the monitoring of the geological processes on the sea coast is carried out within the scope of the National Environmental Monitoring Program. The low sandy coasts with dunes (the Baltic Sea coast from Pape to Jurmalciems and around the furthest point on the western coast of Latvia) are most vulnerable to erosion (Ministry of the Environment of the Republic of Latvia, 2006)).

2.3. Kuldīga old town and the Venta waterfall (the widest waterfall in Europe)

The historical centre of Kuldīga started developing as far back as the 13th century and has preserved urban planning elements dating back to periods from the 13th to the 19th century. At present, the old town of Kuldīga and the red-brick bridge across the river Venta are candidates for inclusion in the UNESCO List of World Cultural Heritage. The town is also famous for the widest waterfall in Europe. Narrow streets, peculiar one-storey houses with a chimney in the middle, and red roof tiles are still preserved in the historical centre. The historical buildings of the town and its nature create a unique, harmonious ensemble, incomparable to anything found in Latvia or elsewhere in Europe.

The Alekšupīte River flows directly along the walls of many buildings which is why Kuldīga has been called the Venice of Latvia. Initially the buildings of the town centre were constructed as the suburb of Kuldīga.

The Venta Rapid is the widest waterfall in Europe (Fig. 18), which in spring and autumn offers a view on flying fish. The width of the waterfall is around 100-110 metres, while its height is 1.8-2 metres. The waterfall can be viewed along its entire length from both the sides of the river, as well as from the old brick bridge across the Venta, which is located 200 m downstream from the waterfall. Each autumn and spring one can see an exciting phenomenon here, as the fish try to clear the rapid by jumping over it. About 300 years ago, Jacob, the Duke of Courland, invented a way to catch with baskets placed along the rapid the fish that came upstream to breed and jumped across the rapid. Due to these fishing devices invented by Duke Jacob, Kuldīga used to be called to be a town where you can catch salmon in the air. One could catch as many as 80-100 salmon a day.

The old brick bridge across the Venta river (Fig. 19) was built in 1874 and is the longest bridge of this kind of road bridge in Europe – 164 m. These were restored in 1926, but concrete was used instead of bricks. In 1958 the cobbled road was covered with tarmac, but the old-style lamp-posts were restored in 2005. The bridge has been often used in shooting films. The brick bridge across the Venta has been serving the people of Kuldīga since 1874. It was according to 19th century standards. The 164 metre long arched bridge with seven spans of brick arches with boulder abutments was not only the largest and most ornate in the territory of Latvia, but also one of the most modern in Europe.

The bridge was lit by lamps on 6 ornate cast iron lampposts with fish-shaped bases. The width of the bridge was a sure sign of achievements in bridge construction since it was wide enough to allow two carriages going into the opposite directions to pass each other.

REFERENCE:

Source: http://www.latvia.travel/en/sight/historical-centre-kuldiga

Fig. 18. **The Venta Waterfall (the widest waterfall in Europe)** (author: O. Nikodemus)

Fig.19. **The old brick bridge across the Venta river** (author: R. Kasparinskis)

2.4. Central Latvia lowland and soil profiles (No 4 and 5)

Central Latvian Lowland (Fig. 20) is a glaciodepression of divergent type, and it is located also at the major Central Latvian bedrock depression (Zelčs, 1993). The glacial topography generally, was formed during the Linkuva glacial phases of the Late Weischelian glaciation by the activation of the Zemgale Ice Lobe of the Riga Ice Stream. The re-activation of the Zemgale Lobe was asynchronous during the deglaciation of the Fennoscandian Ice Sheet. This lobe expressed explicitly divergent flow character as suggested by the orientation of streamlined landforms (Lamsters and Zelčs, 2015). The maximum extent of the Zemgale Lobe during the Linkuva glacial phase is marked by the Linkuva end moraine (Āboltiņš, 1970).

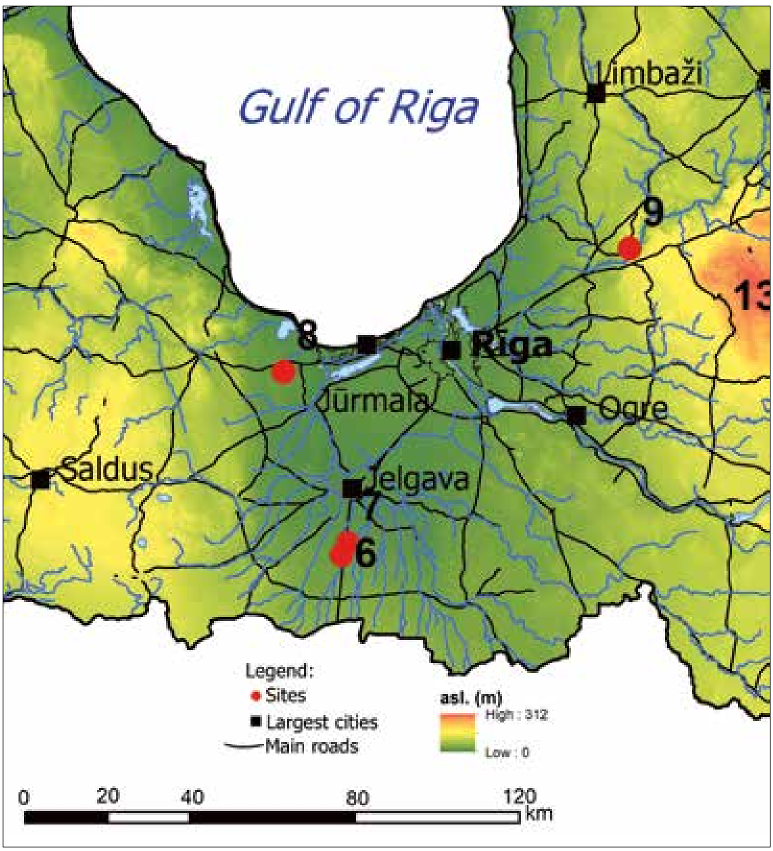

Fig. 20. **Map of site locations and soil profiles in Central Latvia lowland** (source: SRTM; author: M. Krievāns)

Present-day terrain in the Central Latvian Lowland is dominated by radial and transverse subglacial bedforms – mostly drumlins and ribbed moraines (Zelčs, 1993, Lamsters and Zelčs, 2015). The greatest part of eskers in the Central Latvian Lowland, are concentrated between Viļķene and Bārbele or up-ice from the ice-marginal formations of the Linkuva glacial phase.

The thickness of Quaternary sediments in is relatively small, on average it is around 10-20 m, and reaches 20-40 m only at the highest points of the glacial topography. In the northern-east, part of the Central Latvian Lowland Quaternary sediments are only 2-8 m thick. Quaternary sediments in the study area mainly consist of heterogeneous Late Weichselian till with interlayers of sorted sediments. Till sediments does not form a continuous cover. Their bedding together with intra-till sorted sediments in subglacial bedforms is often disturbed and complicated (Zelčs and Dreimanis, 1998).

The upper Late Weichselian till bed is covered with an average of 2-3 m thick glaciolacustrine sediments of the Zemgale ice-dammed lake in south and east parts of the Central Latvian Lowland. On average 5-6 m thick glaciolacustrine sediments of the Baltic Ice Lake comprises the upper Pleistocene sequence in the north and north-east territory, whose maximum thickness reaches up to 18 m, while a 10-15 m thick clay and silt sediments cover the bottom of the Gulf of Riga (Lamsters, 2015). 3-8 m thick glaciolacustrine sediments of the Daudzeva Proglacial Lake are distributed in southern-eastern part (Meirons et al., 2002). Sandy sediments build up the area of inland dunes in the separate parts of the Central Latvia Lowland (W part of the Ropaži Plain, NW parts of the Upmale and Taurkalne plains).

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Soil profile No 4

WRB 2015 soil classification: Endocalcaric **Luvisol** (Aric, Amphiclayic, Cutanic, Hypereutric, Ochric, Katoprotostagnic)
Latvian soil classification: Leached sod-calcareous soil

Geological deposits: Glaciolacustrine deposits
Land use: Agricultural land, crop rotation
Location: Jelgava, Pēterlauki
Coordinates: 56,537300°; 23,718299°

Table 10. Texture and colour

Horizon	Depth [cm]	Percentage share of fraction [mm]			Textural class	Colour
		Clay < 0.002	Silt 0.002-0.063	Sand 0.063-2.0		
Ap	0-20	31.75	59.08	9.18	SiCL	7.5YR 4/2
AE	20-35	52.23	39.94	7.83	C	7.5YR 5/3
Btk1	35-58	59.36	39.83	0.81	C	2.5YR 4/4
Btk2	58-92	67.32	31.47	1.20	C	2.5YR 4/4
Bkg1	92-139	25.57	70.19	4.24	SiL	7.5YR 5/4
Bkg2	139-200	24.09	75.35	0.56	SiL	7.5YR 5/4
Ckg1	200-245	40.32	57.61	2.07	SiC	7.5YR 5/4
Ckl2	245-270	52.16	42.35	5.49	SiC	7.5YR 5/2
Ckl2	270-300	37.31	38.31	24.38	CL	10YR 5/1
2Ck	300-345	13.01	17.73	69.26	SL	10YR 5/4

Table 11. Chemical properties

Horizon	Depth [cm]	Humus [%]	$CaCO_3$ [%]	pH value		CEC_s
				pH_{KCl}	pH_{H2O}	[cmol(+)·kg^{-1}]
Ap	0-20	1.53	3.16	8.11	7.38	15.30
AE	20-35	0.86	1.23	8.16	7.31	13.56
Btk1	35-58	0.40	15.32	8.45	7.47	12.33
Btk2	58-92	0.08	19.59	8.54	7.61	11.03
Bkg1	92-139	0.00	23.09	8.54	7.68	7.90
Bkg2	139-200	0.00	28.73	8.45	7.88	5.05
Ckg1	200-245	0.00	23.56	8.43	7.66	6.10
Ckl2	245-270	0.00	22.94	8.40	7.75	7.36
Ckl2	270-300	0.00	28.33	8.42	8.02	6.30
2Ck	300-345	0.00	26.52	8.47	8.41	4.01

Soil profile No 5

WRB 2015 soil classification: Cambic **Calcisol** (Aric, Bathyluvic, Ochric, Anosiltic, Protostagnic)
Latvian soil classification: Sod-stagnogley soil

Geological deposits: Glaciolacustrine deposits (top)/glacial till (bottom)
Land use: Agricultural land, crop rotation
Location: Jelgava, Poķi
Coordinates: 56,5109999°; 23,692999°

Table 12. Texture and colour

Horizon	Depth [cm]	Percentage share of fraction [mm]			Textural class	Colour
		Clay < 0.002	Silt 0.002-0.063	Sand 0.063-2.0		
Ap	0-33	20.32	64.12	15.56	SiL	10YR 4/3
Bw	33-46	22.19	58.34	19.47	SiL	7.5YR 5/3
Bkg1	46-77	24.00	50.70	25.30	SiL	7.5YR 6/3
Bkg2	77-116	26.06	42.50	31.44	L	7.5YR 5/3
2C	116-124	3.91	7.80	88.29	MS	7.5YR 5/4
3Bkg	124-138	11.04	43.16	45.80	L	7.5YR 5/3
3C1	138-151	6.53	6.75	86.72	LS	10YR 6/4
3C2	151-175	17.66	20.40	61.94	FSL	7.5YR 5/4
3C2	175-235	11.25	30.05	58.70	FSL	7.5YR 5/4

Table 13. Chemical properties

Horizon	Depth [cm]	Humus [%]	$CaCO_3$ [%]	pH value		CEC_s
				pH_{KCl}	pH_{H2O}	[cmol(+)·kg^{-1}]
Ap	0-33	1.69	2.04	7.33	7.98	16.34
Bw	33-46	0.41	31.35	7.60	8.40	18.46
Bkl1	46-77	0.17	36.42	7.79	8.59	17.22
Bkl2	77-116	0.00	36.39	7.82	8.54	9.31
2C	116-124	0.00	16.47	8.49	8.75	13.54
3Bkl	124-138	0.00	32.34	7.93	8.63	8.97
3C1	138-151	0.00	20.32	8.59	8.78	15.34
3C2	151-175	0.00	29.07	8.11	8.69	11.97
3C2	175-235	0.00	29.38	8.09	8.69	10.67

2.5. Peatlands in Latvia and the raised great bog of Ķemeri

At present approximately 10% of Latvia is covered by raised bogs, fens and transitional peatlands, which are irregularly distributed throughout the country (Lācis, 2010). Peatlands in Latvia have developed within negative relief landforms that were created mainly during the last, Weichselian glaciation and deglaciation, and under the impact of its meltwaters, which shaped the main landscape macroforms (Zelčs and Markots, 2004). In the coastal areas the landscape was formed following the retreat of the Late Weichselian Fennoscandian Ice Sheet, when the area was significantly influenced by the waterlevel changes associated with the Baltic Sea evolution, primarily by the Baltic Ice Lake and the Littorina Sea stages (Veinbergs, 1979; Zelčs and Markots, 2004). The most extensive peatland formation has taken place in lowlands with a gentle, slightly undulating relief, where the substrate consists of till, glaciolacustrine clays and silts. These factors, and the excess of precipitation over evaporation, have promoted peatland-formation processes. At present the number of peatlands in Latvia exceeds 9600 and they are unevenly distributed between the various physiographic regions of the country (Kalniņa et al., 2015).

The development of the oldest peatlands generally began with a fen stage at the beginning of the Early Holocene, approximately 11,600 cal. BP (Kalniņa, 2007; Kalniņa et al., 2012). Intensive peat accumulation took place at the end of the Early Holocene (8500-8200 cal. BP), due to the onset of a milder, more humid climate, when raised bogs formed on the largest peatland complexes.

Fig. 21. **The Raised Great Bog of Ķemeri** (author: O. Nikodemus)

The youngest peatlands developed in interdune depressions, and in shallow lakes originating from Littorina Sea lagoons at the end of the Middle Holocene (8200-4200 cal. BP) and the beginning of the Late Holocene, 4200-3000 cal. BP (Kalniņa et al., 2012). The most intensive accumulation of peat has occurred over the last 2500 years, suggesting a cool, humid climate during this period. The currently existing peatland complexes are complicated dynamic systems, growing intensively both in the vertical and horizontal directions, and exerting a considerable effect on landscape dynamics (Kalniņa et al., 2015).

The raised great bog of Ķemeri (Fig. 21) is one of the largest raised bogs in Latvia. It covers a 6192 ha large area in the Tīreļi marshy plain that is the north-westernmost part of the Central Latvian Lowland. Since 1977 the largest part of the mire (5762 ha) is a conservancy area under protection, but since 1997 it is included in the Ķemeri National Park.

The largest part of the mire, covering more than 6000 ha, is occupied by raised bog peat. Territory of raised bog is rich in small lakes and bog pools, some of which reach just 2 ha in area. Only along of the north and west edges of the raised bog transitional type deposits occur. Fen peat is formed only at the southern part of the mire. Along the east edge and inside of the mire there are several ridges of dryhills (dunes) are common. The relative height of the bog dome (or cupola) is about 8 m and it is just 18 asl. The average thickness of peat layer is 4.8 m, but in the marginal parts it is only 2-3 m thick, while in the central part the depth of the raised bog reaches up to 8.5 m. The Mire of Ķemeru Lielais tīrelis formed in the area that was covered by the Baltic Ice Lake (Kalniņa and Markots, 2004).

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2.6. Gauja National park and lower Gauja spillway valley at Sigulda

Between Valmiera town and Murjāņi village the River Gauja valley span (Fig. 22), known as the Gauja spillway according to Āboltiņš (1971), is about 110 km long. The spillway is confined to an ancient buried valley incised into Middle and Upper Devonian sedimentary rock (Pērkons 1947) (Fig. 23). The oversized river valley is 1-2.5 km wide and reaches a depth of 25 m near Valmiera, 35-40 m in the vicinity of Cēsis and 85 m at Sigulda. The floor of the bedrock within the valley lies at 17-18 m a.s.l. near Valmiera, 12 m b.s.l. in the vicinity of Cēsis and more than 50 m b.s.l. at Sigulda. It is significant that downstream of Cēsis the ancient valley is carved into weakly-cemented and/or soft Devonian terrigenous rock that runs along the lithological boundary with carbonate rock.

The valley has asymmetrical cross-sectional profiles with prevalence of erosional terraces (Āboltiņš et al. 2011).

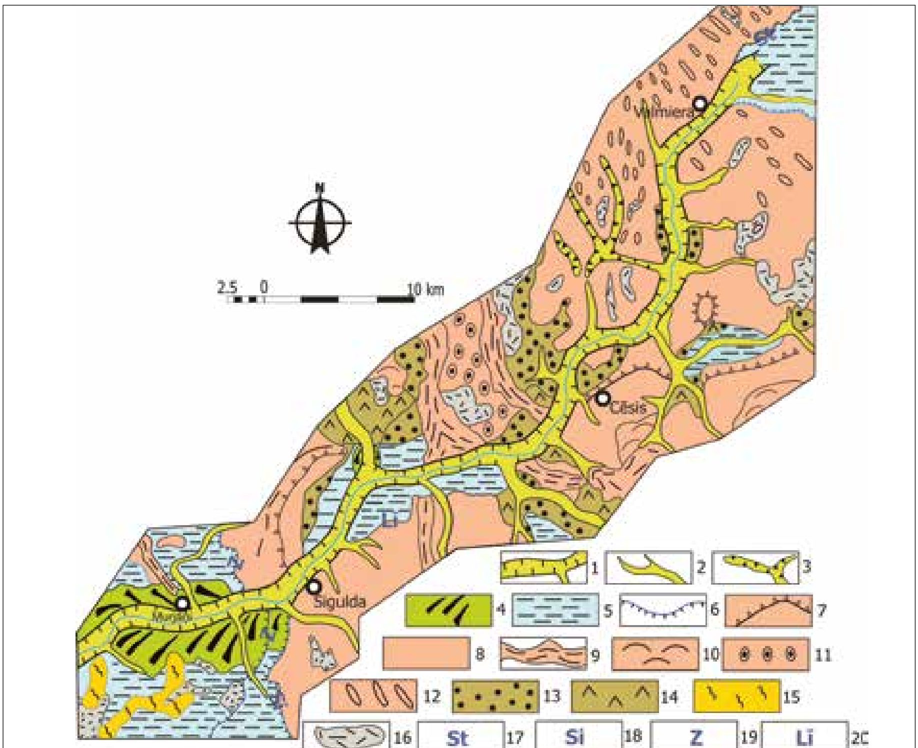

Fig. 22. **Geomorphological map of the River Gauja valley and the adjacent area between Valmiera town and Murjāņi village.** 1 – Lower Gauja spillway valley; 2 – valleys of tributaries; 3 – largest gullies; 4 – late-glacial delta plains; 5 – glaciolacustrine plains; 6 – ancient shorelines of glacial lakes; 7 – ice-contact and bedrock scarps; 8 – till plains; 9 – ice marginal ridges; 10 – morainic hills; 11 – cupola-like hills; 12 – drumlins; 13 – glaciofluvial plains; 14 – kames; 15 – inland dunes; 16 – mires; 17 – Strenči proglacial lake; 18 – Silciems ice-dammed lake; 19 – Zemgale ice-dammed lake; 20 – Līgatne ice-dammed lake

Fig. 23. **Devonian sandstone outcrop and Gutman's cave in the river Gauja valley at victinity of Sigulda** (author: O. Nikodemus)

These terraces represent the Sigulda terrace spectrum of the River Gauja valley. On the basis of geomorphological and geological investigations Āboltiņš (1971) has distinguished seven terrace levels at the town of Sigulda. Formation of the River Gauja spillway began after ice retreat from marginal zone of the North Lithuania phase at least about 15.2 cal. ka B.P. (Āboltiņš et al. 2011).

Terraces VII to IV apparently are formed before Allerød. Terraces VII and VI were formed by meltwater streams which flowed from melting dead ice and small proglacial basins located adjacent to the upper reaches of the spillway into the Silciems ice-dammed lake. Terraces V and IV were produced as a result of the water drainage from the Strenči meltwater basin into the Zemgale ice-dammed lake. Terraces III and II are formed during Allerød and Younger Dryas. They relate to levels of stage Bgl II and phase Bgl IIIb of the Baltic Ice Lake. Terrace I is aggradational and conjugated with the Littorina Sea phase Lit a level. The lower part of the river valley is occupied by an aggradational flood plain (Āboltiņš et al. 2011).

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2.7. Vidzeme upland and soil profiles in catena (No 6, 7, 8, 9, 10, 11)

The Vidzeme Upland is the second largest (area 6,500 sq. km) insular interlobate macroform in Latvia (Fig. 24). The upland is moderately hilly (Fig. 25). A relative height ranges from 5-10 to about 70 m and its elevation ranges from 120 m in the outer area to 311.5 m at Gaiziņkalns, the highest point in Latvia. The upland is located on a spacious rise in the pre-Quaternary surface. The bedrock elevation ranges from 110-120 m in the south and central portions of the rise, to 144 m in the northern part (Āboltiņš, 1995).

The bedrock is covered by a 160-180 m thick blanket of Quaternary deposits that make up a large portion of the Vidzeme Upland. The Quaternary cover is mostly composed of glaciogenic deposits which are represented by Upper Pleistocene basal and deformation tills, with a thickness of up to 80 m (Āboltiņš et al., 1975). In places meltwater deposits cover the till. The Vidzeme Upland can be divided into definite central and peripheral zones. The extensive central zone is characterized by glaciostructural accumulative landforms (Āboltiņš, 1989).

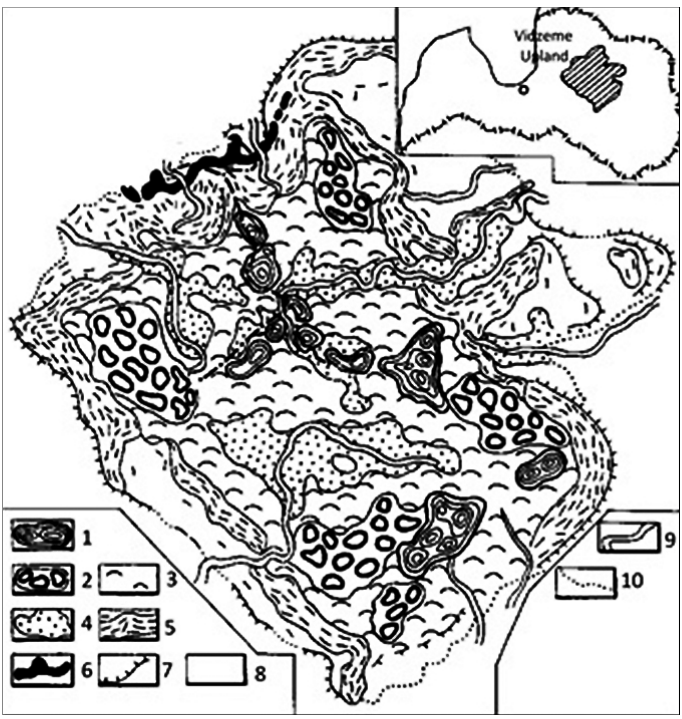

Fig. 24. **Simplified geomorphologic map of the Vidzeme Upland.** Legend: 1 –primary massifs; 2 –plateau-like hills; 3 –hills of various types (which prevalence of moraine hills); 4 –largest depressions in the central zone; 5 –oriented marginal relief of the peripheral zone; 6 –end interlobate moraines in the peripheral zone; 7 –marginal slopes; 8 –rolling plains containing genetically different kinds of hills in the plain peripheral zone; 9 –largest river valleys; 10 –outline of the Vidzeme Upland (Āboltiņš, 1995)

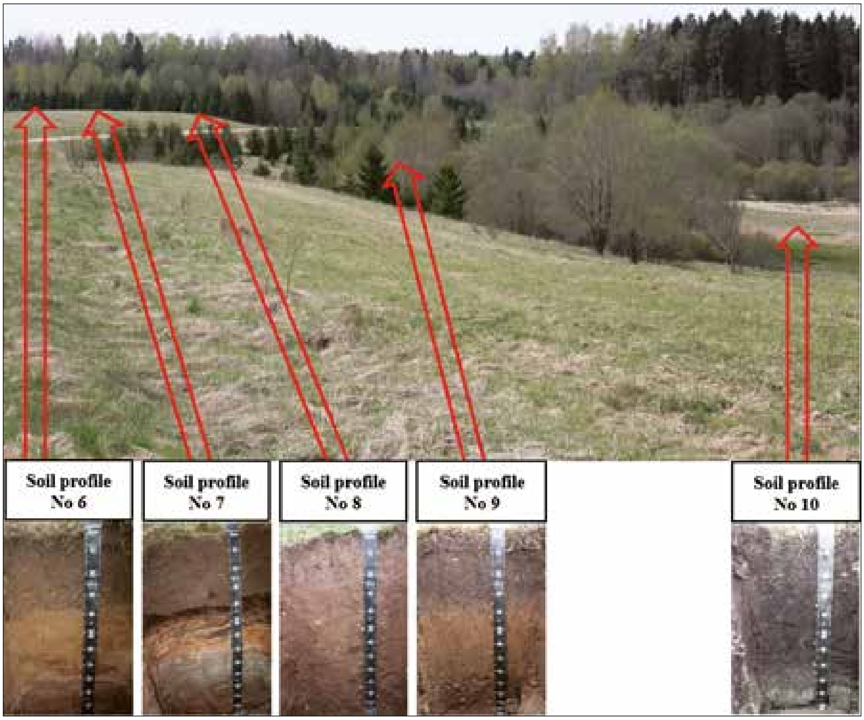

Fig. 25. **Soil profiles in catena of undulated topography in Vidzeme upland**
(author: R. Kasparinskis)

The largest of these forms are primary massifs, plateau-like hills, which a cover of glaciolacustrine sediment, dome-shaped hills and morainic hills. Kames occur less than morainic hills, and they are mainly associated with the largest depressions, such as the headwaters of the rivers of Gauja, Amata and Ogre.

The central zone of the Upland is almost entirely surrounded by a peripheral zone (Āboltiņš, 1995), characterized by marginal relief elements including small ridges, hilly ridges, systems of oriented hills, ramparts etc. All of these forms and the depressions between them, strike roughly parallel to one another. This hilly relief of the peripheral zone is composed of glaciotectonically dislocated and deformed sediment complexes (Āboltiņš, 1989). The proximal side of the peripheral zone often consists of ice contact slopes, where sediments are intensely dislocated.

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Soil profile No 6

WRB 2015 soil classification: Epidystric Endoeutric **Planosols** (Arenic)
Latvian soil classification: Sod – podzolic soil

Geological deposits: Outwashed glacial till
Land use: Catena, crest, abandoned former agricultural land, grassland
Location: Taurene, Jaņi
Coordinates: 57,140400°; 25,633000°

Table 14. Texture and colour

Horizon	Depth [cm]	Percentage share of fraction [mm]			Textural class	Colour
		Clay < 0.002	Silt 0.002-0.063	Sand 0.063-2.0		
Ap	0-37	0.2	1.1	98.1	FS	10YR 3/4
B	37-70	0.1	1.0	98.3	FS	10YR 5/6
BC	70-79	1.2	1.1	97.1	FS	10YR 4/6
BCg	79-90	25.2	9.8	65.0	SCL	7,5YR 4/4
Cg	90-110	38.9	0.8	60.7	SC	7,5YR 4/6

Table 15. Chemical properties

Horizon	Depth [cm]	$C_{tot.}$ [%]	$N_{tot.}$ [%]	C/N	P_2O_5 [mg·kg⁻¹]	$CaCO_3$ [g·kg⁻¹]	Al_o	Fe_o	Al_d	Fe_d
							[mg·kg⁻¹]			
Ap	0-37	0.7	0.08	9	31.5	-	-	-	-	-
B	37-70	-	-	-	-	-	1100	813	468	861
BC	70-79	-	-	-	-	-	883	708	364	677
BCg	79-90	-	-	-	-	-	683	1811	577	3506
Cg	90-110	-	-	-	-	-	812	2412	402	2474

Table 16. Sorption properties

Horizon	Depth [cm]	pH value			Ca^{2+}	Mg^{2+}	K^+	Na^+	Al^{3+}	Fe^{2+}	Mn^{2+}
		pH_{KCl}	pH_{BaCl2}	pH_{H2O}	[mg·kg⁻¹]						
Ap	0-37	5.4	5.5	6.4	433.84	25.7	18.56	1.45	2.8	0.46	2.54
B	37-70	5.3	5.4	6.7	154.5	7.9	8.5	3.14	3.7	0.23	0.57
BC	70-79	5.4	5.6	6.6	262.2	28.6	17.6	0.38	1.6	0.13	0.54
BCg	79-90	5.4	5.6	6.5	824.6	116.3	48.1	3.94	1.2	0.27	0.92
Cg	90-110	5.6	5.9	6.6	2259.1	291.5	83.4	8.8	0.8	0.09	2.91

Table 17. Sorption properties

Horizon	Depth [cm]	TEB	CEC	BS
		[cmol(+)·kg⁻¹]		[%]
Ap	0-37	2.41	2.44	98.74
B	37-70	0.83	0.87	95.49
BC	70-79	1.58	1.60	98.90
BCg	79-90	5.22	5.23	99.75
Cg	90-110	13.97	13.98	99.94

Soil profile No 7

WRB 2015 soil classification: Stagnic **Podzols** (Endoeutric, Lamellic, Novic)
Latvian soil classification: Pseidogley sod – podzolic soil

Geological deposits: Outwashed glacial till
Land use: Catena, crest, abandoned former agricultural land, natural afforestation by pine *Pinus sylvestris*
Location: Taurene, Jaņi
Coordinates: 57,140899°; 25,632600°

Table 18. Texture and colour

Horizon	Depth [cm]	Percentage share of fraction [mm]			Textural class	Colour
		Clay < 0.002	Silt 0.002-0.063	Sand 0.063-2.0		
Ap	0-40	0.3	0.8	98.0	FS	10YR 5/2
Bsh	40-45	0.7	1.3	97.0	FS	10YR 4/3
BEsg	45-53	1.9	2.7	94.5	FS	10YR 6/3
Bgh	53-60	0.2	1.5	97.6	FS	10YR 6/4
Bs	60-64	2.3	3.8	92.8	FS	7.5YR 6/4
Bg1	64-76	2.9	3.6	92.3	FS	7.5YR 6/3
Bg2	76-95	0.8	2.9	95.2	FS	10YR 6/3
Cg1	95-112	3.6	3.6	91.3	FS	10YR 5/3
Cg2	112-125	2.6	3.4	92.9	FS	7.5YR 5/3

Table 19. Chemical properties

Horizon	Depth [cm]	$C_{tot.}$ [%]	$N_{tot.}$ [%]	C/N	P_2O_5 [mg·kg^{-1}]	$CaCO_3$ [g·kg^{-1}]	Al_o	Fe_o	Al_d	Fe_d
							[mg·kg^{-1}]			
Ap	0-40	1.2	0.09	13	24.0	-	-	-	-	-
Bsh	40-45	-	-	-	-	-	3576	1922	3670	1992
BEsg	45-53	-	-	-	-	-	3074	4278	2836	4816
Bgh	53-60	-	-	-	-	-	1003	607	749	467
Bs	60-64	-	-	-	-	-	802	4646	509	5565
Bg1	64-76	-	-	-	-	-	855	606	319	376
Bg2	76-95	-	-	-	-	-	281	139	42	297
Cg1	95-112	-	-	-	-	-	542	1812	177	1761
Cg2	112-125	-	-	-	-	-	419	2018	91	2105

Table 20. Sorption properties

Horizon	Depth [cm]	pH value			Ca^{2+}	Mg^{2+}	K^+	Na^+	Al^{3+}	Fe^{2+}	Mn^{2+}	TEB	CEC	BS
		pH_{KCl}	pH_{BaCl2}	pH_{H2O}	[mg·kg^{-1}]							[cmol(+)·kg^{-1}]		[%]
Ap	0-40	5.7	5.7	6.7	878	88	41	0.7	0.8	0.8	0.8	5.23	5.2	99
Bsh	40-45	4.3	4.2	6.1	450	93	42	3.3	245	9.4	0.6	0.42	3.1	53
BEsg	45-53	4.3	4.3	6.0	154	32	35	1.8	254	2.8	0.4	0.03	1.1	28
Bgh	53-60	4.7	4.6	6.2	84	15	16	1.6	77	1.2	0.1	0.07	0.6	40
Bs	60-64	4.6	4.6	6.1	722	163	89	6.5	61	0.7	0.7	4.54	5.2	88
Bg1	64-76	4.7	4.8	6.5	1135	245	111	7.1	23	0.3	1.1	7.78	8.0	96
Bg2	76-95	5.7	5.9	6.6	481	95	36	4.0	1.5	0.2	0.2	3.29	3.31	99
Cg1	95-112	6.0	6.3	6.8	2102	400	113	7.6	1.5	0.2	0.3	14.15	14.2	99
Cg2	112-125	6.7	6.7	7.0	1683	333	85	4.5	0.8	0.2	0.3	11.43	11.4	99

Soil profile No 8

WRB 2015 soil classification: Haplic **Luvisols**
Latvian soil classification: Eroded sod – podzolic soil

Geological deposits: Glacial till
Land use: Catena, crest, abandoned former agricultural land, natural afforestation by spruce *P. Abies*
Location: Taurene, Jaņi
Coordinates: 57,141399°; 25,632800°

Table 21. Texture and colour

Horizon	Depth [cm]	Percentage share of fraction [mm]			Textural class	Colour
		Clay < 0.002	Silt 0.002-0.063	Sand 0.063-2.0		
Bt(Ap)	0-24	18.2	13.6	68.2	L	7.7YR 4/6
Bt	24-53	26.9	15.0	58.1	SCL	7.5YR 4/6
Btk1	53-75	19.3	14.2	66.5	L	7.5YR 4/6
Btk2	75-94	23.5	13.3	63.2	SiL	7.5YR 4/6
Btk3	94-120	20.2	15.8	64	SL	7.5YR 4/6

Table 22. Chemical properties

Horizon	Depth [cm]	$C_{tot.}$ [%]	$N_{tot.}$ [%]	C/N	P_2O_5 [$mg \cdot kg^{-1}$]	$CaCO_3$ [$g \cdot kg^{-1}$]	Al_o	Fe_o	Al_d	Fe_d
							[$mg \cdot kg^{-1}$]			
Bt(Ap)	0-24	1.2	0.12	10	13.2	-	-	-	-	-
Bt	24-53	-	-	-	-	-	921	1337	507	5853
Btk1	53-75	-	-	-	-	+	804	1162	354	4178
Btk2	75-94	-	-	-	-	+	672	1020	348	3419
Btk3	94-120	-	-	-	-	+	393	794	255	3909

Table 23. Sorption properties

Horizon	Depth [cm]	pH value			Ca^{2+}	Mg^{2+}	K^+	Na^+	Al^{3+}	Fe^{2+}	Mn^{2+}
		pH_{KCl}	pH_{BaCl2}	pH_{H2O}	[$mg \cdot kg^{-1}$]						
Bt(Ap)	0-24	5.9	6.4	6.9	3021.9	401.8	55.8	7.7	0.8	0.09	2.04
Bt	24-53	6.3	6.4	6.9	2933.9	397.9	38.13	4.95	1.3	0.36	1.23
Btk1	53-75	7.4	6.9	7.4	4111.4	370.25	46.4	5.97	0.9	0.22	0.18
Btk2	75-94	7.4	7.2	7.5	4086.6	368.8	50.9	7.11	0.9	0.15	0.22
Btk3	94-120	7.5	7.4	7.5	1838.3	208.2	43.4	5.06	1.3	0.20	0.14

Table 24. Sorption properties

Horizon	Depth [cm]	TEB	CEC	BS
		[$cmol(+) \cdot kg^{-1}$]		[%]
Bt(Ap)	0-24	18.62	18.63	100
Bt	24-53	18.09	18.10	100
Btk1	53-75	23.78	23.79	100
Btk2	75-94	23.66	23.67	100
Btk3	94-120	11.05	11.06	100

Soil profile No 9

WRB 2015 soil classification: Endostagnic **Luvisols**
Latvian soil classification: Sod podzolic soil

Geological deposits: Glacial till
Land use: Catena, slope, abandoned former agricultural land, natural afforestation by spruce *P. Abies*
Location: Taurene, Jaņi
Coordinates: 57,142300°; 25,632100°

Table 25. Texture and colour

Horizon	Depth [cm]	Percentage share of fraction [mm]			Textural class	Colour
		Clay < 0.002	Silt 0.002-0.063	Sand 0.063-2.0		
Ap	0-32	6.8	6.5	84.6	LS	10YR 4/4
Bt	32-75	15.2	10.8	80.0	SL	7,5YR 5/4
Btgk	75-105	22.4	14.9	57.6	SCL	7,5YR 4/4
Ck	105-125	18.4	11.6	70.0	SL	7,5YR 5/6

Table 26. Chemical properties

Horizon	Depth [cm]	$C_{tot.}$ [%]	$N_{tot.}$ [%]	C/N	P_2O_5 [mg·kg^{-1}]	$CaCO_3$ [g·kg^{-1}]	Al_o	Fe_o	Al_d	Fe_d
							[mg·kg^{-1}]			
Ap	0-32	2.1	0.18	12	18.4	-	-	-	-	-
Bt	32-75	-	-	-	-	-	1619	2895	811	7671
Btgk	75-105	-	-	-	-	+	992	1563	559	7705
Ck	105-125	-	-	-	-	+	314	647	193	2873

Table 27. Sorption properties

Horizon	Depth [cm]	pH value			Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	Al^{3+}	Fe^{2+}	Mn^{2+}
		pH_{KCl}	pH_{BaCl2}	pH_{H2O}	[mg·kg^{-1}]						
Ap	0-32	6.1	6.3	6.7	2280.6	206.3	98.7	4.11	0.8	0.13	5.83
Bt	32-75	5.9	6.3	6.6	3490.7	432.2	75.85	16.08	0.8	0.33	5.88
Btgk	75-105	7.5	7.8	7.5	5582.0	436.6	197.1	8.5	1.4	0.08	0.38
Ck	105-125	7.8	7.5	7.6	1382.5	120.8	21.8	3.70	0.8	0.08	0.15

Table 28. Sorption properties

Horizon	Depth [cm]	TEB	CEC	BS
		[cmol(+)·kg^{-1}]		[%]
Ap	0-32	13.38	13.39	100
Bt	32-75	21.31	21.32	100
Btgk	75-105	32.08	32.1	100
Ck	105-125	7.98	7.99	100

Soil profile No 10

WRB 2015 soil classification: Eutric Rheic Murshic Sapric **Histosols** (Limnic)
Latvian soil classification: Fen peat humic soil

Geological deposits: Peat (top)/lacustrine (bottom)
Land use: Catena, bottom, grassland
Location: Taurene, Jaņi
Coordinates: 57,142800°; 25,631299°

Table 29. Texture and colour

Horizon	Depth [cm]	Percentage share of fraction [mm]			Textural class	Colour
		Clay < 0.002	Silt 0.002-0.063	Sand 0.063-2.0		
H1	0-34	-	-	-	-	10YR 2/1
H2	34-56	-	-	-	-	10YR 2/1
H3	56-69	-	-	-	-	10YR 2/1
L1	69-75	-	-	-	-	10YR 2/2
L2	75-87	-	-	-	-	10YR 3/1
Cr	87-105	17.0	17.0	69.9	L	GLEY1 7/10y

Table 30. Chemical properties

Horizon	Depth [cm]	$C_{tot.}$ [%]	$N_{tot.}$ [%]	C/N	P_2O_5 [$mg \cdot kg^{-1}$]	$CaCO_3$ [$g \cdot kg^{-1}$]	Al_o	Fe_o	Al_d	Fe_d
							[$mg \cdot kg^{-1}$]			
H_1	0-34	19.6	1.20	16	11.9	-	-	-	-	-
H_2	34-56	-	-	-	-	-	-	-	-	-
H_3	56-69	-	-	-	-	-	-	-	-	-
Bh_1	69-75	-	-	-	-	-	6760	9965	3537	10558
L	75-87	-	-	-	-	-	-	-	-	-
Cr	87-105	-	-	-	-	-	1470	6849	394	4564

Table 31. Sorption properties

Horizon	Depth [cm]	pH value			Ca^{2+}	Mg^{2+}	K^+	Na^+	Al^{3+}	Fe^{2+}	Mn^{2+}
		pH_{KCl}	pH_{BaCl2}	pH_{H2O}	[$mg \cdot kg^{-1}$]						
H_1	0-34	6.8	6.3	7.1	12710.6	1068.5	146.2	48.98	0.8	0.77	0.11
H_2	34-56	6.7	6.3	7.0	14636.4	1303.5	104.1	68.7	0.8	0.10	0.11
H_3	56-69	6.5	6.2	6.9	15675.9	1474.4	78.1	74.7	0.8	0.28	0.19
Bh_1	69-75	6.5	6.3	6.9	14181.9	1430.7	112.6	65.38	1.0	0.19	0.80
L	75-87	-	-	-	-	-	-	-	-	-	-
Cr	87-105	6.8	6.3	6.9	2874.1	312.2	73.8	12.72	1.0	0.44	1.50

Table 32. Sorption properties

Horizon	Depth [cm]	TEB	CEC	BS
		[$cmol(+) \cdot kg^{-1}$]		[%]
H_1	0-34	73.04	73.05	99.99
H_2	34-56	84.60	84.61	99.99
H_3	56-69	91.18	91.19	99.99
Bh_1	69-75	83.40	83.41	99.99
L	75-87	-	-	-
Cr	87-105	17.21	17.22	99.94

Soil profile No 11

WRB 2015 soil classification: Hortic? Pretic? **Anthrosols** (Endoeutric, Epidystric, Arenic, Novic, Spodic)
Latvian soil classification: Sod podzolic soil

Geological deposits: Glaciofluvial deposits
Land use: Spruce *P. Abies* forest on former agricultural land (specific land use history)
Location: Taurene, Bānūži
Coordinates: 57,133700°; 25,603399°

Table 33. Texture and colour

Horizon	Depth [cm]	Percentage share of fraction [mm]			Textural class	Colour
		Clay < 0.002	Silt 0.002-0.063	Sand 0.063-2.0		
O	0-1	0.26	0.51	98.0	FS	7.5YR3/3
AE1	1-7	1.40	0.75	98.0	FS	10YR5/3
AE2	7-20	0.11	0.78	98.0	FS	2.5YR4/2
AE3	20-40	0.76	0.68	98.0	FS	10YR5/2
EA	40-52	0.10	0.54	98.0	FS	10YR4/2
A	52-55	0.05	0.58	98.0	FS	10YR3/2
EB	55-60	0.11	0.57	98.0	FS	10YR4/6
Bsl	60-70	0.30	0.57	98.0	FS	10YR4/6
Bs2	70-90	0.30	0.60	98.0	FS	10YR4/6
Bs3	90-100	0.72	0.47	98.0	FS	10YR3/6
BgC1	100-110	0.51	0.86	98.0	FS	7.5YR5/6
BsC	110-120	0.43	0.14	99.0	FS	10YR5/6
BgC2	120-140	0.21	0.29	99.0	FS	7.5YR5/6

Table 34. Chemical properties

Horizon	Depth [cm]	$C_{tot.}$ [%]	$N_{tot.}$ [%]	C/N	P_2O_5 [$mg \cdot kg^{-1}$]	$CaCO_3$ [$g \cdot kg^{-1}$]	Al_o	Fe_o	Al_d	Fe_d
							[$mg \cdot kg^{-1}$]			
O	0-1	12.6	0.5	27	-	-	-	-	-	-
AE1	1-7	2.3	0.12	18	4.42	-	1029	478	599	1277
AE2	7-20	1.4	0.06	21	3.31	-	1131	624	821	1314
AE3	20-40	1.2	0.05	23	-	-	431	465	580	593
EA	40-52	1.0	0.04	23	-	-	804	654	766	994
A	52-55	1.7	0.07	26	-	-	821	688	895	1039
EB	55-60	0.7	0.04	15	-	-	1680	1347	1914	1759
Bsl	60-70	-	-	-	-	-	3248	2936	4641	3741
Bs2	70-90	-	-	-	-	-	2325	1953	4453	2925
Bs3	90-100	-	-	-	-	-	1707	1641	4187	3612
BgC1	100-110	-	-	-	-	-	1017	373	427	2328
BsC	110-120	-	-	-	-	-	512	145	283	767
BgC2	120-140	-	-	-	-	-	751	286	353	1751

Table 35. Sorption properties

Horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	Al^{3+}	Fe^{2+}	Mn^{2+}
		[mg·kg^{-1}]						
O	0-1	5583.9	485.2	195.3	14.6	7.9	1.8	56.5
AE1	1-7	258.7	25.9	33.9	2.5	160.7	22.0	1.3
AE2	7-20	90.62	7.8	20.0	2.2	181.9	14.0	2.1
AE3	20-40	691.6	1.2	8.45	4.8	168.4	10.7	0.7
EA	40-52	14.06	3.0	3.57	2.4	113.8	5.0	0.3
A	52-55	88.7	9.0	10.46	1.8	207.5	9.1	0.6
EB	55-60	6.84	3.48	13.7	9.6	73.7	2.7	0.7
Bsl	60-70	671.1	44.5	11.8	5.0	2.7	1.1	0.3
Bs2	70-90	1041.1	59.36	14.6	13.4	0	0.2	0.3
Bs3	90-100	1421.7	109.2	15.1	7.0	0.46	0.5	0.4
BgC1	100-110	765.4	99.9	18.7	4.0	1.0	0.6	0.8
BsC	110-120	277.3	32.2	5.3	1.9	0.16	0.2	0.4
BgC2	120-140	555.8	75.0	20.0	0.5	0.8	0.7	0.5

Table 36. Sorption properties

Horizon	Depth [cm]	pH value			TEB	CEC	BS
		pH_{KCl}	pH_{BaCl2}	pH_{H2O}	[cmol(+)·kg^{-1}]		[%]
O	0-1	4.9	4.1	5.5	65.85	65.94	99.9
AE1	1-7	3.9	3.3	5.3	5.77	7.56	80.9
AE2	7-20	4.0	3.6	5.3	3.98	6.00	74.8
AE3	20-40	4.2	3.8	5.3	12.79	14.66	88.7
EA	40-52	4.4	4.0	5.4	4.38	5.64	81.7
A	52-55	4.0	3.7	5.3	2.81	5.12	68.9
EB	55-60	4.7	4.3	5.4	21.44	22.26	96.5
Bsl	60-70	5.7	4.7	6.0	17.49	17.52	99.8
Bs2	70-90	6.3	5.2	6.4	36.62	36.62	100.0
Bs3	90-100	6.8	5.8	6.8	28.74	28.75	100.0
BgC1	100-110	6.0	5.7	6.6	16.38	16.39	99.9
BsC	110-120	6.5	5.8	6.5	6.01	6.01	99.7
BgC2	120-140	6.1	5.7	6.5	4.28	4.28	99.6

3. GENERAL INFORMATION ABOUT ESTONIA

Estonia area is 45 227 km^2, from which 9.2% is taken up by islands and 4.6% is under inland bodies of water. Estonia's neighbors are Russia in the East, Latvia in the South, Sweden in the West and Finland in the North. Its land border is 645 km long, with half of it running along rivers and lakes. The northernmost point of Estonia is Vaindloo Island (59°49'17" N; on the mainland – Purekkari Peninsula, 59°40'27" N) and the southernmost point lies near Naha village (57°30'32" N). The extreme points in the West and in the East are, respectively, Nootamaa Island (21°46'06" E; on the mainland – Ramsi Peninsula, 23°24'28" E) and Narva (28°12'33" E). The greatest distances by road reach 400 km. Approximately 50% of the territory is covered by forests and agricultural land and mires cover a further fifth of the territory.

REFERENCE:

Estonica. Encyclopedia about Estonia (http://www.estonica.org/en/)

3.1. Climate

Estonia is located in the northwestern part of the East-European Plain, i.e. within a transition zone from maritime to continental climate. The main factor influencing the climate of Estonia is the Atlantic Ocean (in particular the North-Atlantic Stream), which influences the climate in the whole of Europe. The active cyclonic activity occurring in the northern part of the Atlantic Ocean (the Icelandic minimum) determines a very high variability of the weather in Estonia and causes strong winds, high precipitation and abrupt fluctuations in temperature.

The annual amount of sunshine hours varies between 1600 and 1900, being higher on the coast and on the islands, and lower on the uplands. This amounts to less than half the maximum possible duration of sunshine. The annual average temperature in Estonia is between 4.3 °C and 6.5 °C, being lower on the uplands and higher on the western coast of the islands. The average air temperature in January is -6° to -7 °C in Central and East Estonia and -2° to -4 °C in the West-Estonian Archipelago. The coldest month is February. The average temperature in July varies between 16.0 °C and 17.4 °C. The vegetation period lasts for 180-195 days and the frost-free period 110-190 days. Both are longer on the coast.

The annual average wind speed in the inland parts of Estonia is less than 4 m/s; on the coasts of the open seas it is more than 6 m/s. Bigger still are the differences in the frequency of storm winds. In the inland, storm winds (more than 15 m/s) are rare, occurring only a few times a year, while on the coast and islands of the open seas the frequency of storm winds reaches 30-45 days/year.

Estonia is located in a region of humid climate, where the amount of precipitation exceeds the total evaporation. The annual average of the relative air humidity is 80-83%. It is higher in winter and at its lowest in May, being 70% on average. The annual average precipitation varies between 550 and 800 mm. As a rule, the coastal zone receives less rainfall than the inland areas. It is particularly dry on the coast in spring and in the first half of summer. Areas with the highest precipitation are located on the uplands and at a distance of 30-60 km from the western coast. The latter zone receives a comparatively large amount of precipitation in autumn and early winter.

The snow cover in Estonia is characterized by large territorial and temporal variations. The average duration of snow cover during winter is 75-135 days. Snow cover remains for the shortest time on the small islands near the western coast of Saaremaa Island and for the longest time on the Haanja and Pandivere Uplands.

3.2. Surface topography

As a part of the East European Plain, Estonia is a flat territory, where uplands and plateau-like areas alternate with lowlands, depressions and valleys. These land forms, alongside with the coastal cliffs in northern and western Estonia, are the larger features of Estonian topography.

The bases of the uplands of Estonia are usually 75-100 m above sea level (a.s.l.). The highest point in Estonia and the Baltic States, Suur Munamägi Hill (317 m a.s.l.), is located in the middle part of the Haanja Upland. Erosional uplands are mostly flat. Their appearance depends largely on the bedrock topography. These uplands have a relatively thin Quaternary cover and the relief is dominated by moraine plains. The two erosional uplands in Estonia are The Pandivere Upland (the highest point: Emumägi Hill, 166 m a.s.l.) and The Sakala Upland (the highest point: Rutu Hill, 146 m a.s.l.). The accumulative uplands have hilly topography. Their appearance is not dependent on the bedrock topography. Their relief is dominated by hills and valleys, built up of Quaternary sediments. The three accumulative uplands in Estonia are The Haanja Upland (the highest point: Suur Munamägi Hill, 317 m a.s.l.), The Otepää Upland (the highest point: Kuutse Hill, 217 m a.s.l.) and The Karula Upland (the highest point: Rebasejärve Tornimägi Hill, 137 m a.s.l.). Other elevations include the Saadjärve Drumlin Field reaching 144 m a.s.l., the West-Saaremaa elevation (54 m a.s.l.) and the Ahtme or Jõhvi elevation (81 m a.s.l.).

Higher areas include also the plateaus. The Harju and Viru plateaus are located in northern Estonia and bordered on the north by the steep escarpment of the Baltic Klint. Both plateaus are about 30-70 m above sea level. The flat surface of the plateaus is occasionally cut through by river valleys and karst features. The erosion of the Harju Plateau has left some separate flat plateau-like hills: Toompea Hill and Viimsi Lubjamägi Hill in Tallinn and the Pakri islands. The relief of the Viru Plateau is formed by artificial features – oil shale pits and waste rock and ash hills. The Ugandi Plateau (40-100 m a.s.l.) in southern Estonia is a sandstone plateau, cut by ancient valleys and bordered by high escarpments:

the Tamme outcrop near Lake Võrtsjärv in the west and, the Kallaste outcrop on the beach of Lake Peipsi. Other relatively high areas are the Central-Estonian Plain (60-80 m a.s.l.) and Kõrvemaa (50-90 m a.s.l.).

The Lowlands are the plains reaching less than 50 m above sea level that have been flooded by the Baltic Sea, ancient Lake Peipsi and ancient Lake Võrtsjärv. The lowlands cover nearly half of the Estonian territory. The largest lowlands are located in western Estonia. The West Estonian Lowland is a swampy plateau, with up to 20 m high limestone hills (Kirbla Hill, Mihkli Salumägi Hill, Salevere Salumägi Hill, etc.). The Pärnu Lowland is also swampy. Its bedrock is composed of Devonian sandstones. Its western margin at the sea coast is bordered by the highest dunes in Estonia. The West Estonian Lowland extends to the West Estonian Archipelago. The relief is mostly flat and reaches 20 m a.s.l., except for the higher areas, including the West-Saaremaa elevation and its southern extension in the Sõrve Peninsula. The northern coast of Muhu and Saaremaa Islands is steep, up to 21 m at the Panga Cliff.

The North-Estonian Coastal Plain includes a narrow belt of land between the Gulf of Finland and the Baltic Klint. Its width is from a few metres to 20 km. The area includes several peninsulas and bays, and the islands of the Gulf of Finland. Low and swampy lowlands also occur west and north of the Lake Peipsi depression and in the Lake Võrtsjärv depression. The Alutaguse Lowland is situated north of Lake Peipsi.

Depressions and valleys are large features of relief, easily distinguished in South Estonia, where they separate the uplands. The Valga depression, 40-80 m a.s.l., is located between the Sakala and Karula Uplands and the Otepää Heights. The Väike-Emajõgi Valley, reaching Lake Võrtsjärv, is its northen extension. The Hargla depression, 70-100 m a.s.l., is located between the Haanja Heights and the Karula Upland. The Võru Valley is its extension, separating the Haanja and Otepää heights.

The Baltic Klint, also known as the North Estonian Klint in Estonia, is a remarkable feature of topography. It is one of the longest erosional escarpments in northern Europe, extending from Öland Island in Sweden to Lake Ladoga in Russia. In North-West and North-East Estonia, the Klint is often exposed as a coastal cliff of the Gulf of Finland. At Ontika, the highest point of the North Estonian Klint reaches 56 m a.s.l.

In most of the Estonian territory, the Palaeozoic sedimentary rocks are covered by Quaternary sediments. Most of the Palaeozoic bedrock outcrops occur in coastal cliffs near the sea and the larger lakes and in river valleys. All these outcrops have been formed by the erosive power of lakes, seas or rivers during the Pleistocene glaciation.

The present-day topography is largely a reflection of the bedrock geology. The deepening of the sea floor of the Gulf of Finland from Finland towards Estonia corresponds to the deepening of the crystalline basement. The rise of the sea floor towards the North Estonian limestone plateau corresponds to the erosional boundary of the Palaeozoic rocks under the sea. Another valley, in Central

Estonia, oriented in the East-West direction, corresponds to the contact of hard Silurian limestones and soft Devonian sandstones.

About 12 000 years ago, most of Estonia was covered by the Baltic Ice Lake. About 7000 years ago, the predecessor of the Baltic Sea, the Litorina Sea, covered the coastal areas of the present northern and western Estonia. As the ice margin retreated, the uplands of Estonia, including the Pandivere Upland and the Haanja, Otepää and Sakala heights became free from ice as terrestrial areas. The lowlands, however, were abraded. The deposition of thin sequences of varved clays and sands in lowlands made the surface topography even flatter.

The topography after the Ice Age is very different from that before the Ice Age. Since before the Ice Age, the sea level has risen more than 100 m, covering former land areas and forming the Baltic Sea and its bays. The escarpments (the klints) have lost two thirds of their height. Heavy glaciers pushed the surface several hundreds of meters deeper, as compared to the position before the Ice Ages. After the ice retreated, a compensatory land rise began. It continues today in NW Estonia, reaching 2-3 mm per year. This has resulted in a slow, but steady growth of the land area. New islets have formed in the Väinameri area and elsewhere near Hiiumaa and Saaremaa Islands.

Mires have also contributed to the flattening of the surface topography. The oldest mire deposits in Estonia are about 8000 years old. The most intense peat formation in bogs has taken place during the past 2000 years. The mire lowlands cover more than 1/5 of the Estonian territory.

3.3. Geology

In Estonia, bedrock complexes range in age from Palaeoproterozoic to Late Devonian. Quaternary deposits cover more than 95% of the territory, their thickness varying between some tens of centimeters (alvars) and one hundred and fifty meters (in buried valleys and the uplands in South Estonia). In Estonia the geological section consists of two principal elements: the Precambrian crystalline basement and the sedimentary cover.

The crystalline basement has a complicated block structure and is characterised by different complexes of metamorphic and intrusive rocks of Palaeo- and Mesoproterozoic age (1900-1400 Ma). The sedimentary cover consists of rocks belonging to the Ediacaran (upper Vendian), Cambrian, Ordovician, Silurian and Devonian systems. The cover is thin or absent in North Estonia and adjacent parts of the Baltic Sea but reaches up to more than 800 m in thickness in southwestern Estonia.

The Ediacaran (upper Vendian) System (630-542 Ma) is represented by clay-, silt- and sandstones, reaching up to 120 m in thickness in the surroundings of Narva. The Cambrian System (542-488 Ma) is represented mostly by its lower series (thickness 100-140 m), which consists of clay-, silt- and sandstones. The Cambrian succession crops out in northern Estonia on the foot of the Baltic Klint and includes ca 540 Ma old blue clay.

The Ordovician System (488-444 Ma), covering more than 30% of Estonian territory, is represented mostly by limestones, dolostones and marls. Sandstones (glauconitic sandstone, Obolus sandstone), graptolite argillite (Dictyonema shale) and siltstones make up only the Lower Ordovician Series, which has limited thickness and crops out only in northern Estonia. The Middle and Upper Ordovician rocks, up to 200 m in thickness, are found in northern and central Estonia, on the island Hiiumaa and on the seabed at the same latitude. The most impressive outcrops occur in association with the Baltic Klint and along the northern coast of Estonia. The Silurian System (444-416 Ma), occurring over less than 30% of the territory, consists exclusively of limestones, dolostones and marls and reaches a maximum thickness of 455 m on Ruhnu Island (Gulf of Riga). The main outcrops of Silurian rocks are connected with the Silurian Klint (or Gotland-Saaremaa Klint), running along the northern coast of Saaremaa and Muhu islands up to the mainland of southwestern Estonia. The Devonian System (416-359 Ma) is represented mostly by sand- and siltstones, clays and marls occurring in southern Estonia and covering ca 40% of the territory. Devonian deposits crop out mostly on the banks of rivers (Ahja, Piusa, Võhandu, etc.) in southern Estonia. The youngest Devonian rocks comprising lime- and dolostone and dolomitic marl belong to the Frasnian Stage and occur only in the southeastern corner of Estonia.

The Precambrian crystalline basement has been subjected to intense denudation and is covered by a weathering crust. Monoclinal Neoproterozoic and early Palaeozoic sedimentary rocks overlie the crystalline basement. On the mainland, the thickness of the sedimentary cover varies from 100 m in northern Estonia up to ca 800 m on Ruhnu Island (Gulf of Riga).

In addition to the Estonian Monocline, two major structural elements should be mentioned: the northern slope of the Baltic Syneclise in southwestern Estonia, and the Valmiera-Lokno Uplift in the southern Estonia border area. In addition to these large-scale structures, there are also smaller ones such as uplift structures in northeastern Estonia (Uljaste, Sonda, Assamalla), and uplifts connected with Cambrian blue clay deposits at Vaivara (northeastern Estonia). The bedding in the sedimentary cover is close to horizontal (on average, dipping south at 3 m per km), but there are numerous (ca 40) linear dislocations from 10 to 100 km in length and up to 1 km in width. Circular faults surround the ca 535 Ma old Neugrund and 455 Ma old Kärdla meteorite craters (diameters 20-21 km and 12-15 km, respectively) and the Märjamaa rapakivi granite massif.

3.4. The Quaternary deposits and soil cover

The Quaternary cover (Fig. 26) largely determines the features the outlook of Estonian landscapes. It is the primary origin of the soil cover and an important factor influencing the water condtitions and the chemical composition of waters. The Quaternary cover of Estonia, covering the bedrock (Fig. 27), was formed during and after the last glaciation.

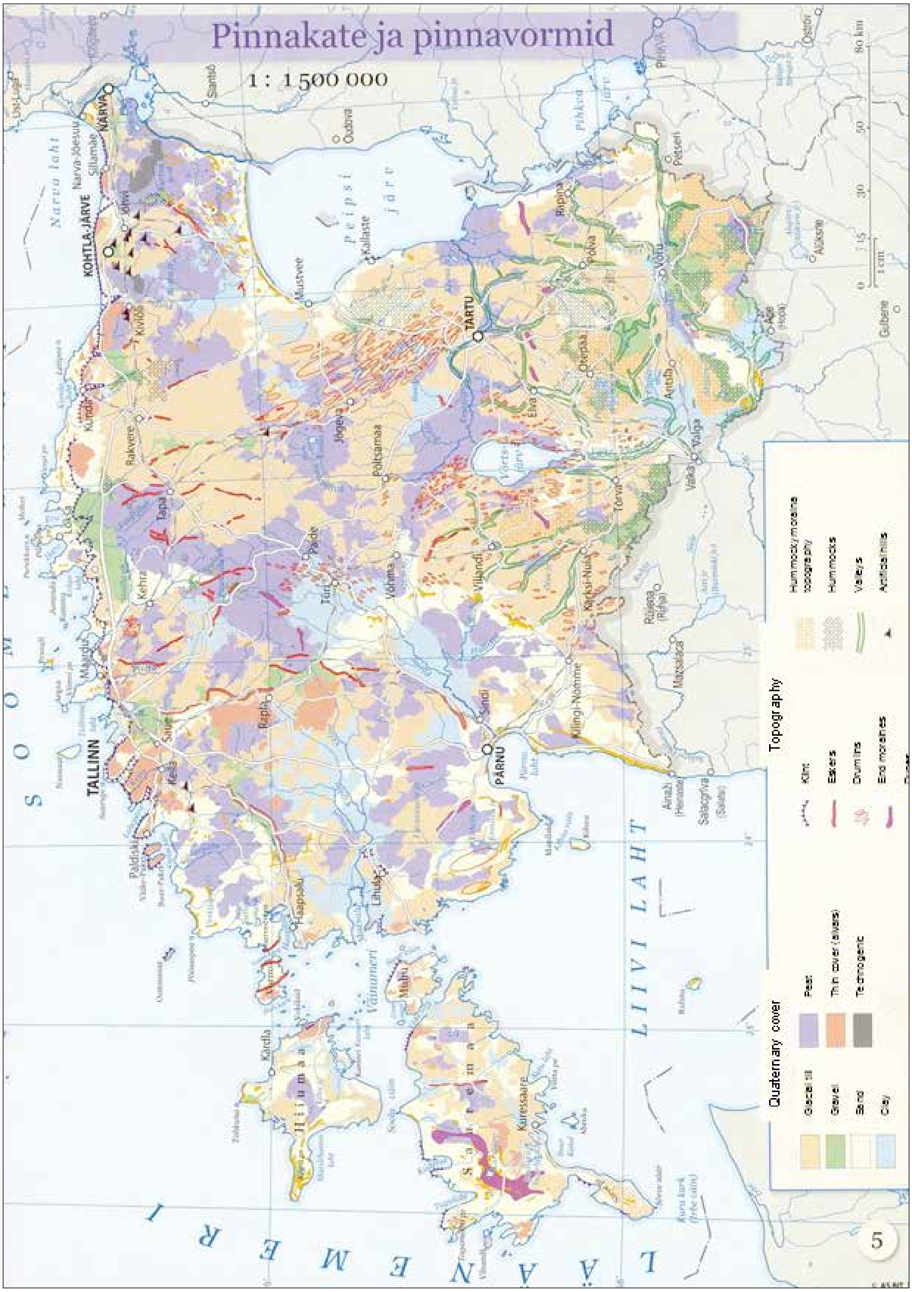
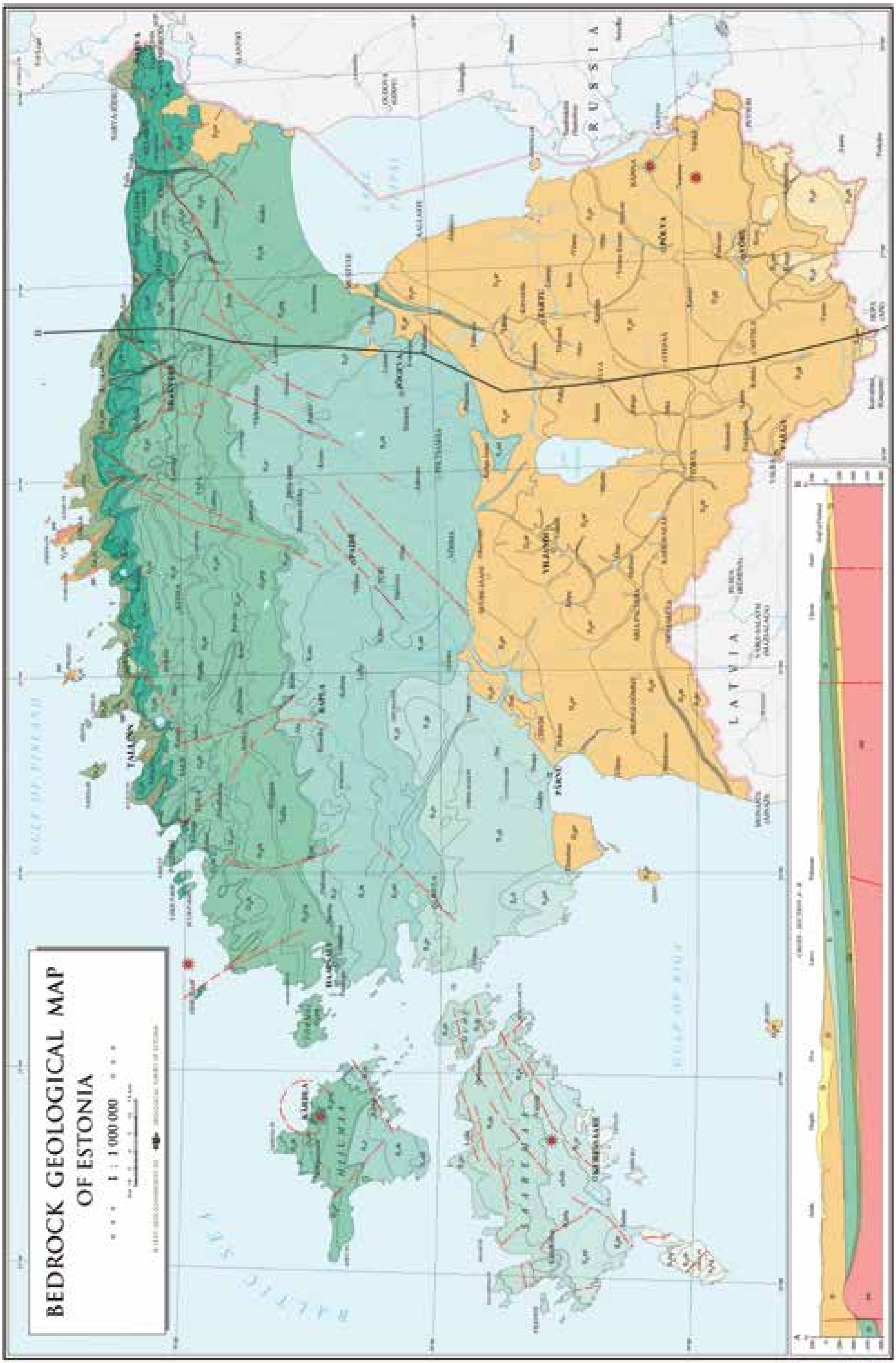


Fig. 26. **Quaternary cover and topography of Estonia**
(Eesti Atlas. 2004. Koost. R. Aunap)


BEDROCK GEOLOGICAL MAP
OF ESTONIA
1 : 1 000 000
RUSSIA
LATVIA

LEGEND

GLOBAL STRATIGRAPHY

System	Series	Stage
NEOGENE		
DEVONIAN	Upper Devonian	Frasnian
	Middle Devonian	Givetian
		Eifelian
SILURIAN	Pridoli	
	Ludlow	Ludfordian
		Gorstian
	Wenlock	Homerian
		Shein-woodian
	Llandovery	Telychian
		Aeronian
		Rhuddanian
ORDOVICIAN	Upper Ordovician	Hirnantian
		Katian
		Sandbian
	Middle Ordovician	Darriwilian
		Dapingian
	L. Ord.	Trem. + Floian
CAMBRIAN	Furong.	
	Series 1-3	
NEOPROTEROZOIC		
MESOPROTEROZOIC		
PALEOPROTEROZOIC		

REGIONAL STRATIGRAPHY

Series	Stage	INDEX	MAIN ROCK TYPES
QUATERNARY		Q	*Sand, gravel, till, clay, peat (only in cross-section)*
Upper Devonian	DAUGAVA	D_3dg	*Limestone, dolostone*
	DUBNIKI	D_3db	*Dolomitic marl, dolostone*
	PLAVINASE	D_3pl	*Dolostone, limestone, dolomitic marl*
Middle Devonian	AMATA	D_2am	*Siltstone, breccia-like sandstone*
	GAUJA	D_2gj	*Sandstone, siltstone*
	BURTNIEKI	D_2br	*Sandstone, siltstone*
	ARUKÜLA	D_2ar	*Sandstone, siltstone*
	NARVA	D_2nr	*Dolomitic marl, siltstone, sandstone with breccia layers*
	PÄRNU	D_2pr	*Sandstone, siltstone, dolomitic marl*
Upper Silurian	OHESAARE	S_2oh	*Dolomitic marl, limestone, siltstone*
	KAUGATUMA	S_2kg	*Limestone, marl, crinoidal limestone*
	KURESSAARE	S_2kr	*Argillaceous limestone, marl*
	PAADLA	S_2pd	*Argillaceous limestone, dolostone, marl*
Lower Silurian	ROOTSIKÜLA	S_1rt	*Argillaceous dolostone, argillaceous limestone*
	JAAGARAHU	S_1jg	*Limestone, marl, dolostone, biohermal dolostone*
	JAANI	S_1jn	*Marl, argillaceous limestone, dolostone*
	ADAVERE	S_1ad	*Marl, limestone*
	RAIKKÜLA	S_1rk	*Limestone, dolostone, argillaceous limestone*
	JUURU	S_1jr	*Argillaceous limestone, marl, dolostone*
Harju	PORKUNI	O_3pr	*Limestone, dolostone, marl, calcareous sandstone*
	PIRGU	O_3prg	*Limestone, marl*
	VORMSI	O_3vr	*Limestone, marl, argillite*
	NABALA	O_3nb	*Argillaceous and cryptocrystalline limestone*
Viru	RAKVERE	O_3rk	*Cryptocrystalline limestone*
	OANDU	O_3on	*Argillaceous and biohermal limestone, marl*
	KEILA	O_3kl	*Argillaceous and biohermal limestone, marl, K-bentonite*
	HALJALA	O_3hl	*Argillaceous limestone, marl, K-bentonite, impact breccia*
	KUKRUSE	O_3kk	*Argillaceous limestone, kukersite, marl*
	UHAKU	O_2uh	*Argillaceous limestone, marl, kukersite*
	LASNAMÄGI	O_2ls	*Limestone, argillaceous limestone*
	ASERI	O_2as	*Limestone with Fe-ooliths*
Öland	KUNDA	O_2kn	*Limestone, sandy limestone, kerogenous limestone, glauconitic limestone, limestone with Fe-ooliths*
	Undifferented[1]	O_1pk-O_2vl	*Sandstone, graptolite argillite, glauconitic silt-, sand- and limestone, limestone*
	Undifferented[2]	Ca_{2-3}	*Sandstone, siltstone, claystone*
	DOMINOPOL	Ca_1dm	*Sand- and siltstone, claystone*
	LONTOVA	Ca_1ln	*Claystone, siltstone, sandstone*
	KOTLIN	V_2kt	*Sandstone, siltstone, silty claystone*
		MP	*Rapakivi granite, porphyrite, quartz-porphyry*
		PP	*Complex of metamorphosed rocks: gneisses, crystalline schists, amphibolites etc.*

a b *Fault zone: a) proved, b) supposed* *Meteorite crater* A B *Cross-section line*

Fig. 27. **Bedrock geological map of Estonia** (www.egeos.ee)
(Modifed after K. Suuroja, 1997 by T. Kalberg, S. Suuroja, A. Põldvere and O. Hints.
Global stratigraphy and colour codes after ICS, 2007 (www.stratigraphy.org).

The usual thickness of the Quaternary cover in the plateaus of North and Central Estonia is 2-3 m, in South Estonia 5-10 m. Parts of the limestone plateaus, where the Quaternary cover is absent or only a few centimetres thick, are called alvars. The maximum thickness of the Quaternary cover, exceeding 100 m, occurs in ancient valleys and in the accumulative heights in southern Estonia. The main constituent of the Quaternary cover is till. The limestone in North and North-West Estonia is covered by a gray till, rich in boulders. The sandstone in South Estonia is covered by a brown till, rich in clay and poor in boulders. Except for tills, the Quaternary cover includes sediments of gravel, sand, varved clay, peat and mud. The fluvioglacial sediments are usually composed of cross-bedded gravel and sand, used in road and building construction. The fine-grained limnoglacial sediments include varved clays, used as a raw material for bricks, drainage pipes and roof stones. After the retreat of the ice margin, the Quaternary cover in the lowlands of Estonia was largely formed by the sea. In the uplands, untouched by the sea and large lakes, the Quaternary cover was formed by the erosion and accumulation caused by temporary water currents, weathering and wind. The sediments formed after the glaciation are of different origin. The sand, gravel and pebbles are of marine origin. The lake sediments include lake mud, sand and lacustrine lime; the river sediments, gravel, sand and clay. The occurrences of travertine are rare.

The soil cover (Fig. 28) of Estonia is characterised by high diversity due to the varied composition of parent material and diverse water conditions, a large share of peatland and peaty soils (ca 50%), abundance of calcareous soils (especially in North and West Estonia), and the high rock content of soils. About ten types of soil are distinguished in Estonia, differing from one another in their distribution, structure, properties and the ways they are used.

Limestone rendzinas (Rendzic Leptosols) on alvars occur in North and West Estonia, where limestone bedrock lies close to the land surface. These soils have a high humus and nutrient content but are very stony and sensitive to drought. Therefore attempts are made to be maintain these soils under natural vegetation instead of tilling them. The most common natural vegetation types on such soils are alvar forests and alvar meadows.

yhk and pebble rendzinas (Rendzic Leptosols and Calcaric Regosols) on calcareous sceletal till can also be found mainly in North and West Estonia, although in areas of thicker quaternary cover. Such soils are characterised by a high humus and nutrient content and a high content of sharp-edged pieces of weathered limestone (ryhk). These soils have been largely cultivated. In places where natural vegetation still remains, these soils are covered with species-rich wooded meadows and fresh boreo-nemoral forests.

Brown typical and lessive soils (Cambisols and Luvisols) occur mainly on the till plains of Central Estonian and Pandivere Uplands. These are the most productive agricultural soils in Estonia and their area of distribution therefore coincides with the main agricultural regions.

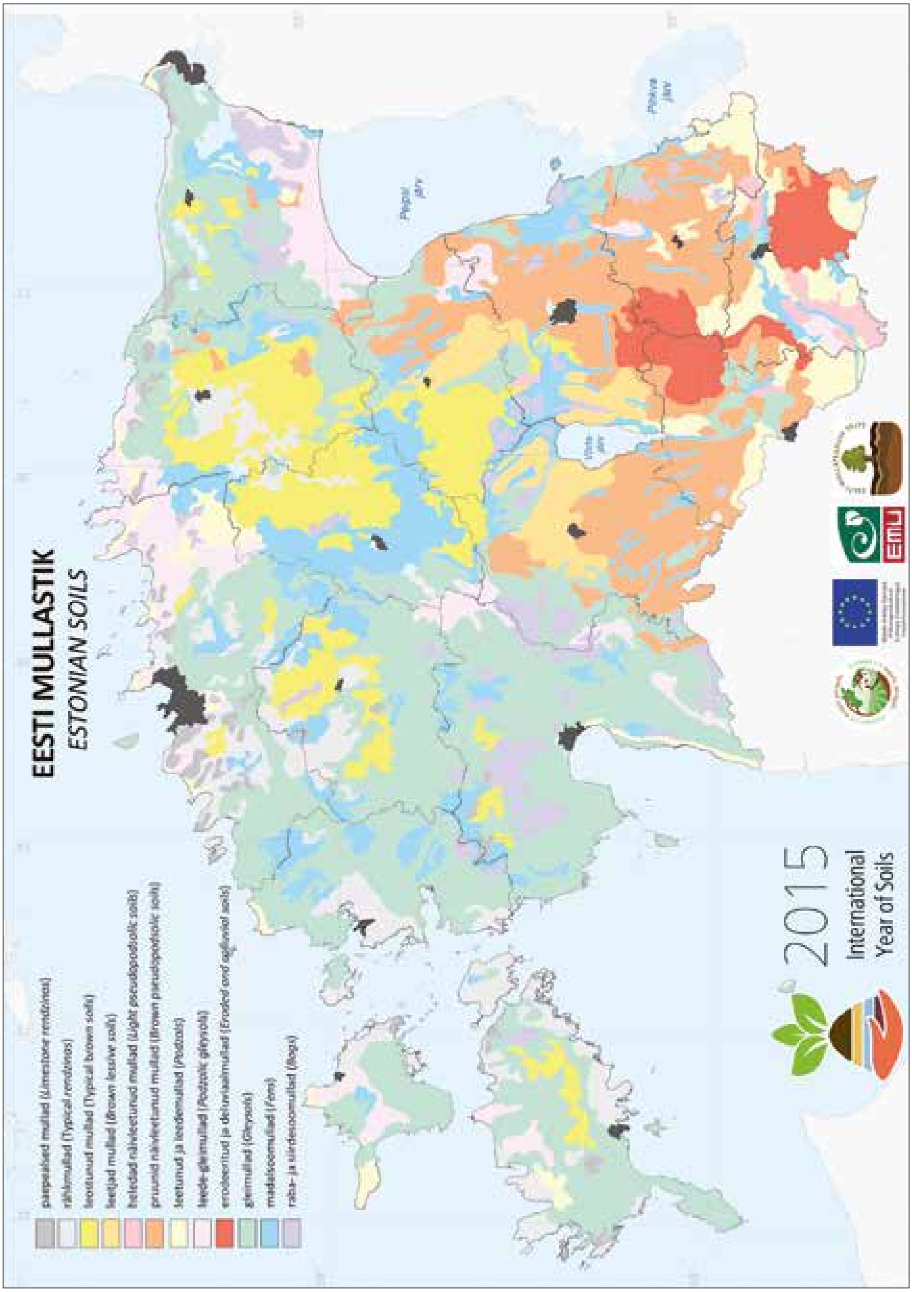


Fig. 28. **Soil map of Estonia**

Sod-podzolic soils and podzols (Podzols) have formed primarily in areas of sandy quaternary cover. Podzols usually occur under pine forests without herbaceous vegetation. No humus horizon forms in such soils. Sod-podzolic soils have formed on a relatively richer parent material, which supports herbaceous vegetation whose decomposition yields a thin humus horizon in the soil profile. A common feature of both soils is the existence of a greyish-white eluvial horizon, beneath which there is a reddish-brown illuvial horizon rich in mobile humus substances, aluminium and iron.

Pseudopodzolic soils (Stagnic Luvisols and Planosols) occur on the till plains of South and Central Estonia. Their formation is conditioned on the presence of a clayey or two-layered parent material, where a compact layer with low permeability underlies the upper layer. Seasonal stagnation of perched water is characteristic of these soils, especially in spring, resulting in the formation of a whitish layer resembling a podzolic horizon in the soil profile. Pseudopodzolic soils are, for example, South Estonian soils of medium humus content, which have largely been cultivated. Where the natural vegetation still remains, fresh boreo-nemoral and boreal forests grow on such soils.

Sod-gley soils (Gleysols) represent a large association of waterlogged soils with highly variable composition and properties. They prevail in the soil cover of Estonia. The common feature of Gleysols is a bluish-grey or greenish-grey gley horizon formed in the conditions of either high ground water level or prolonged surface and perched water. Their surface horizon consists of only partly transformed organic matter – raw humus. Some sod-gley sandy soils may have undergone podzolisation. Paludified pine forests grow on such soils. Sod-gley soils, formed in a calcareous environment, support paludified deciduous forests. In West Estonia, cultivated grasslands and fields can often be found on sod-gley soils.

Peatland soils (Histosols) occupy about one-fourth of the territory of Estonia and are divided into lowland mires (Terric Histosols), transitional and raised bogs (Fibric Histosols). These soils are characterised by an at least 30-cm peat layer with underlying gleyic and podzolic profiles, respectively.

Alluvial soils (Fluvisols) form in the bank and shore zones of inland water bodies in conditions of periodic floods. Relatively few of them have been preserved in Estonia, as the frequency and scope of floods have considerably decreased due to dredging and damming of rivers and drainage. On low seacoasts, in the influence zone of saline seawater, slightly saline littoral soils (Salic Fluvisols) occur. These are, as a rule, young soils still in their developing stage.

South Estonian uplands with a hillocky relief host soil communities typical of eroded areas. The slopes and tops of hills are covered with eroded soils where the humus horizon has thinned significantly due to erosion, or is entirely absent. At the foot of hillocks, however, deluvial soils with an extremely thick (up to 1 m) humus horizon accumulate. Such soil communities can be found in cultivated areas exposed to rain-water erosion. In exhausted open pits, artificial soils can be found.

4. EXCURSIONS TO SITES IN ESTONIA

4.1. Polli soil profiles (No 12, 13 and 14)

The Polli research institute for horticulture was founded in 1945 by the decree of the ministry of agriculture. Long time it belonged to the Estonian Institute of Agriculture and Land Reclamation as the department of fruit growing. Since 1994 it was included to the Estonian Agricultural University in rights to institute. Polli has a suitable site with characteristic soil and climate in South Estonia which belongs to one of the best region for fruit growing in the republic.

Bedrock: Devonian sandstones, aleurolits.

Quaternary cover: reddish brown till with various limnoglacial materials (gravel, sand) and organic deposits.

Main ladform: Sakala Upland – the flat topped sandstone bedrock upland in South Estonia.

Topography:

- rolling plateau with reddish-brown till cover, intersected by deep primeval valleys;
- in the middle moraine mounds;
- on the edges drumlins and sills;
- lakes in the denudational depressions;
- rivers and streams flowing in primeval valleys;
- mired flat old river valleys;

Denudations of light Burtniek sandstone stratum.

Highly productive spruce forests, birch forests.

Area of ancient settlement and land cultivation.

Soil profile No 12

WRB 2015 soil classification: Pantocalcaric **Arenosol** (Aric, Humic)

Land use: horticulture – fruit trees
Location: Polli
Coordinates: 58,134166°; 25,540000°
Elevation: 85.5 m

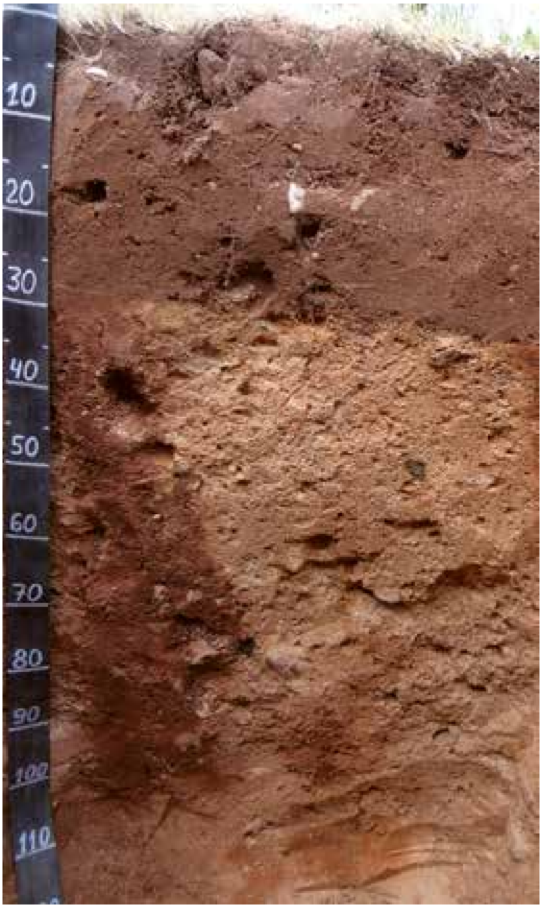


Table 37. Texture and colour

Horizon	Depth	Main colour	Texture
Ap	0-25(30)	7.5YR 4/3	CS
BC	30-45(50)	7.5YR 5/6 (5YR 3/4)	CS
C	50-100	7.5YR 7/4	CS
2C	100-120+	5YR 5/6	FS

Table 38. Chemical properties

Horizon	Depth	pH_{KCl}	pH_{H2O}	Corg %	Ntot %	Carbonates	P (Olsen) mg/kg
Ap	0-25(30)	7,41	7,67	1,65	0,10	Yes	32
BC	30-45(50)	7,77	8,13	0,29	0,001	Yes	36
C	50-100					Yes	
2C	100-120+					No	

Table 39. Particle size distribution, %

Horizon	Depth	Very coarse+coarse sand	Medium sand	Very fine + fine sand	Sand, total	Silt	Clay
Ap	0-25(30)	15,45	23,95	45,40	84,8	9,9	5,3
BC	30-45(50)	27,66	30,40	31,79	89,9	5,3	4,8
C	50-100	27,66	30,40	31,79	89,9	5,3	4,8

Soil profile No 13

WRB 2015 soil classification: Endocalcaric **Luvisol** (Loamic, Aric, Epydystric, Humic)

Land use: horticulture – fruit trees
Location: Polli
Coordinates: 58,134100°; 25.538799°
Elevation: 85 m

Table 40. Texture and colour

Horizon	Depth, cm	Main colour	Texture
Ap	0-35(40)	10YR 3/4	SL
E	35-40(50)	10YR 7/6	SL
Bt	40-80	7.5YR 5/4	SL
2BC	80-110	2.5YR 4/4	SL
2C	110+	5YR 5/4	

Table 41. Chemical properties

Horizon	Depth, cm	pH_{KCl}	pH_{H2O}	C_{org} %	N_{tot} %	Carbonates	P (Olsen) mg/kg
Ap	0-35(40)	5,6	6,7	0,94	0,06	No	63
E	35-40(50)	5,63	6,8	0,40	0,01	No	28
Bt	40-80	6,56	6,92	0,09	0,002	No	33
2BC	80-110	6,36	6,8	0,14	0,005	Yes	9
2C	110+					Yes	

Table 42. Particle size distribution, %

Horizon	Depth	Very coarse+coarse sand	Medium sand	Very fine + fine sand	Sand, total	Silt	Clay
Ap	0-35(40)	6,72	13,09	49,07	68,9	23,8	7,3
E	35-40(50)	7,33	13,11	57,04	77,5	18,4	4,2
Bt	40-80	7,70	18,51	56,25	82,5	13,7	3,8
2BC	80-110	6,92	13,53	47,75	68,2	21,0	10,8

Soil profile No 14

WRB 2015 soil classification: Eutric Rheic Drainic Amphisapric **Histosol** (Endocalcaric, Fluvic, Epiloamic)

Land use: grassland (drained)
Location: Polli
Coordinates: 58,130999°; 25,530799°
Elevation: 64.5 m

Table 43. Texture and colour

Horizon	Depth, cm	Main colour	Texture
Ah	0-40	Gley 2 2.5/1	SL
Ta	40-90		peat
L1l	90-100		SL
L2l	100-110+		SL

Table 44. Chemical properties

Horizon	Depth, cm	pH_{KCl}	pH_{H2O}	Corg %	Ntot %	Carbonates	P (Olsen) mg/kg
Ah	0-40	7,14	7,49	12,19	0,91	No	1
Ta	40-90	7,1	7,53	13,97	0,91	No	6
L1l	90-100	6,94	7,27	17,04	1,064	Yes	33
L2l	100-110+	7,19	7,4	5,49	0,322	Yes	32

Table 45. Particle size distribution, %

Horizon	Depth	Very coarse+coarse sand	Medium sand	Very fine + fine sand	Sand, total	Silt	Clay
Ah	0-40	3,48	7,14	46,39	57,0	33,9	9,1
Ta	40-90	2,50	8,68	39,99	51,2	36,8	12,1
L1l	90-100	2,13	7,50	32,84	42,5	36,5	21,0
L2l	100-110+	3,05	9,11	48,03	60,2	26,9	12,9

4.2. Kaara soil profile (No 15)

Bedrock: Devonian sandstones, aleurolits, clays.

Quaternary cover: reddish brown till with various limnoglacial materials (gravel, sand) and organic deposits.

Main ladform: Valga depression.

Located between Otepää, Karula and Sakala uplands. After the ice retreat a solid ice strip remained to the present-day Valga depression.

After the retreat of the ice strip till moraine and sands were left behind, kame fields, rolling landscape.

The valley of the Väike Emajõgi river, intersecting to the morain plain; forests

Large flooded areas, floodplain mires.

Large drained and cultivated floodplains (during the Soviet time).

Arable land on moraine plains.

Soil profile No 15

WRB 2015 soil classification: Endocalcaric Stagnic Mollic **Gleysol** (Aric, Clayic, Drainic)

Land use: arable land, drained
Location: Kaara
Coordinates: 57,87299998104572296°; 26,20839997194707394°
Elevation: 48 m

Table 46. Texture and colour

Horizon	Depth, cm	Main colour	Texture
Ap	0-20	10YR 3/1	CL
Ah	20-30	10 YR 4/2	CL
Bwg	30-55	10YR 6/4	SiC
Cl	55-75+	10YR 6/6 (Gley2 8/1)	SiC

Table 47. Chemical properties

Horizon	Depth, cm	pH_{KCl}	pH_{H2O}	Corg %	Ntot %	Carbonates	P (Olsen) mg/kg
Ap	0-20	6,44	7,11	5,02	0,46	No	82
Ah	20-30	6,23	6,96	4,46	0,35	No	46
Bwg	30-55	6,95	7,77	0,59	0,045	No	16
Cl	55-75+	7,13	8,2	0,11	0,009	Yes	17

Table 48. Particle size distribution, %

Horizon	Depth	Very coarse+coarse sand	Medium sand	Very fine + fine sand	Sand, total	Silt	Clay
Ap	0-20	3,79	6,68	17,61	28,1	37,7	34,2
Ah	20-30	3,84	6,33	15,14	25,3	41,4	33,3
Bwg	30-55	0,70	0,80	2,49	4,0	52,0	44,0
Cl	55-75+	0,53	0,29	0,87	1,7	50,4	47,9

4.3. Tartu area and soil profiles (No 16, 17, 18 and 19)

Bedrock: Devonian sandstones, aleurolits.

Quaternary cover: reddish brown till with various limnoglacial materials (gravel, sand) and organic deposits.

Main ladform: Ugandi Plateau.

Plains with reddish-brown non-calcareous moraine, easily abrading sandstones.

Devonian sandstone denudations at Kallaste near Peipsi lake and at Tamme near Võrtsjärve lake; also on the river banks of the Ahja and Võhandu primeval valleys.

Deep buried primeval valleys, filled with Quaternary sediments, their valley beds below the sea level.

In partly buried valleys there are rivers (the Emajõgi, Ahja, Elva, Alatskivi, Kavilda rivers) or lakes (Verevi, Viisjaagu, Vissi)

Moraine plains with rolling hilly landscape near Elva-Vitipalu, Vara, Rannu and Valguta.

Drumlins on the east coast of Võrtsjärve lake. Hilly kame fields near Vellavere and Kambja. The highest form of kame fields is Vooremägi hill of 123 m at Haaslava. Mires in valleys and in abrasional basins of glaciers. Moraine landscapes mostly cultivated.

Spruce forests in valleys and on plains (in the east), pine forests on sandy soils.

Floodplain communities.

Soil profile No 16

Soil profile No 16

WRB 2015 soil classification: Calcaric **Cambisol** (Aric, Loamic, Humic)

Land use: arable land
Location: Rõhu
Coordinates: 58,356500°; 26,524699°
Elevation: 52.5 m

Table 49. Texture and colour

Horizon	Depth, cm	Main colour	Texture
A	0-30	7.5 YR 3/2	SL
A	30-50	7.5 YR 4/2	SL
Bw	50-62	7.5YR 5/6	SL
BC	62-80	5YR/5/4	SL
C1	80-100	5YR 5/6	LS
C2	100+		SL

Table 50. Chemical properties

Horizon	Depth, cm	pH_{KCl}	pH_{H2O}	Corg %	Ntot %	Carbonates	P extr mg/kg	CEC cmol/kg	BS %
A	0-30	6,6	7,3	2,50	0,26	No	28	10,5	100
A	30-50	6,2	7,1	0,65	0,08	No	28	10,5	100
Bw	50-62	6,6	7,6	0,17	0,049	Yes	2	6,8	100
BC	62-80	7	7,9			Yes		2,5	100
C1	80-100	7,4	7,9			Yes			100
C2	100+	7,3	7,9			Yes			100

Table 51. Particle size distribution, %

Horizon	Depth	Sand	Silt	Clay
A	0-30	57	30	13
A	30-50	56	34	10
Bw	50-62	70	14	16
BC	62-80	66	22	13
C1	80-100	86	6	8
C2	100+	61	23	16

Soil profile No 17

WRB 2015 soil classification: Eutric **Retisol** (Aric, Cutanic, Loamic, Humic)

Land use: arable land
Location: Eerika
Coordinates: 58,371700°; 26,665500°
Elevation: 60 m

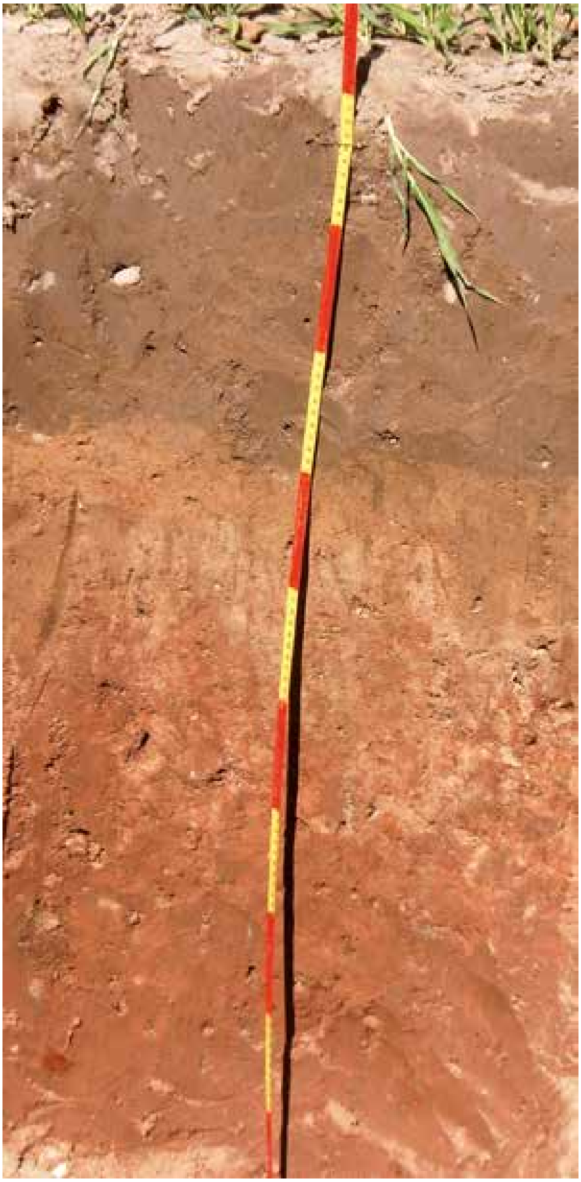


Table 52. Texture and colour

Horizon	Depth, cm	Main colour	Mottles	Texture
Ap	0-25	10YR 4/3		SL
E	25-58	7.5YR 5/4	10YR 6/4	SL
Bt	58-86	5YR 4/4	10 YR 5/3	SL
C	86-100	5YR 4/4	7.5YR 4/4	SL

Table 53. Chemical properties

Horizon	Depth, cm	pH_{KCl}	pH_{H2O}	Corg %	Ntot %	Carbonates	P extr mg/kg	CEC cmol/ kg	BS %
Ap	0-25	6	6,5	1,08	0,13	No	57	6,9	97
E	25-58	5,6	6,9	0,19	0,05	No	42	2,9	79
Bt	58-86	5,2	6,9	0,10	0,036	No	17	5,3	89
C	86-100	4,9	6,5	0,08	0,039	No	18	5	96

Table 54. Particle size distribution, %

Horizon	Depth	Sand	Silt	Clay
Ap	0-25	59	32	9
E	25-58	62	30	8
Bt	58-86	57	27	17
C	86-100	60	23	17

Soil profile No 18

WRB 2015 soil classification: Dystric Ombric Drainic Episapric Fibric **Histosol** (Hyperorganic)

Land use: abandoned/recultivated peat excavation area
Location: Ilmatsalu
Coordinates: 58,386100°; 26,520499°
Elevation: 33 m

Table 55. Soil description

Horizon	Depth, cm	Material	pH_{KCl}	Carbonates
Ha	0-15	peat	4,6	No
He	15-25	peat	3,4	No
Hi	25-60+	peat	3,36	No

Soil profile No 19

WRB 2015 soil classification: Gleic Folic Albic **Podzol** (Arenic, Densic)

Land use: forest
Location: Tiksoja
Coordinates: 58,394500°; 26,664399°
Elevation: 50.5 m

Table 56. Texture and colour

Horizon	Depth, cm	Main colour	Texture
O	5-0		
Ah	0-15	10YR 2/1	S
Ea	15-35	7.5YR 7/2	S
Bhs	35-65	7.5YR 3/2	S
Bhsl	65-85	7.5YR 4/4	S

Table 57. Particle size distribution, %

Horizon	Depth	Sand	Silt	Clay
O	5-0			
Ah	0-15	97	2	1
Ea	15-35	96	3	1
Bhs	35-65	98	2	1
Bhsl	65-85	99	1	0

Table 58 Chemical properties

Horizon	Depth, cm	pH_{KCl}	Corg %	Ntot %	Carbonates	CEC cmol/kg	BS %
O	5-0	3,64	49,30	0,57	No	25,9	64
Ah	0-15	3,64	1,00	0,04	No	1,22	18
Ea	15-35	3,49	0,97	0,030	No	1,87	19
Bhs	35-65	4,59	1,57	0,040	No	0,66	18
Bhsl	65-85	4,53	1,01	0,02	No	0,58	19

4.4. Porkuni soil profile (No 20)

Bedrock: Silurian limestones and dolomites

Quaternary cover: yellowish grey carbonatic till with various limnoglacial materials (gravel, sand) and organic deposits.

Main ladform: Pandivere Upland

The Pandivere Upland is the highest bedrock upland in Estonia. Its bedrock is represented by Middle and Upper Ordovician and Lower Silurian limestones.

The Quaternary cover of the upland is only a few metres thick. The largest Quaternary landforms — the Ebavere (146 m a.s.l.), Kellavere (156 a.s.l.) and Emumägi (166 m a.s.l) hills are located on the southern slope of the upland. Other well-known Quaternary landforms on the slopes of the upland are the Porkuni-Neeruti hills and the Rakvere Vallimägi, Pähnimägi, and Võlumägi hills.

The Quaternary cover is composed of calcareous clayey till. It has moderate water-bearing capacity and is a favourable source rock for fertile soils that are common in the Pandivere region. Agricultural landscapes dominate here. Small stands of forest are reminders of the times when the area was covered with diverse broad-leaved forests.

In the Pandivere Upland, the limestones are near the surface and topographically higher than in the surrounding area. This causes intense filtration and karst processes in the vault of the upland: above 100 m a.s.l. in an area of 1300 square km, lakes and rivers are almost non-existent. At about 80-90 m a.s.l., the base of the upland is marked by a circle of springs, from where many rivers and rivulets begin. Well-known springs include Norra-Oostriku, Kihme, Jäneda, Imastu, Lavi, Kulina and Simuna.

Soil profile No 20

WRB 2015 soil classification: Calcaric Gleyic Amphihistic **Fluvisol** (Geoabruptic, Endoarenic, Episiltic, Humic)

Land use: grassland
Location: Porkuni
Coordinates: 59,195388°; 26,177000°
Elevation: 102 m

Table 59. Texture and colour

Horizon	Depth, cm	Main colour	Texture
Ah	0-30	10YR 1/1	L
C	30-35	10YR 7/2	SiL
BG	35-65	10YR 5/6	LS
Ta	65-80	Gley1 2.5/black	peat
2Cl	80-100	2.5Y 7/2	LS

Table 60. Chemical properties

Horizon	Depth, cm	pH_{KCl}	pH_{H2O}	Corg %	Ntot %	Carbonates	P (Olsen) mg/kg
Ah	0-30	7,19	7,58	13,9	1,0	Yes	1
C	30-35	7,28	7,52	9,5	0,4	Yes	10
BG	35-65	7,39	7,8	11,6	0,8	Yes	11
Ta	65-80	7,39	7,9	14,6	0,9	Yes	8
2Cl	80-100	7,89	8,02	8,4	0,1	Yes	0

Table 61. Particle size distribution, %

Horizon	Depth	Very coarse+coarse sand	Medium sand	Very fine + fine sand	Sand, total	Silt	Clay
Ah	0-30	8	9	17	34	41	25
C	30-35	2	3	5	9	73	17
BG	35-65	62	6	5	73	23	4
Ta	65-80				0		
2Cl	80-100	17	23	47	86	12	1

4.5. Kurgla soil profiles (No 21, 22 and 23)

Bedrock: Ordovician limestones and dolomites.

Quaternary cover: white carbonatic till with various limnoglacial materials (gravel, sand) and organic deposits.

Main landform: Harju plateau.

Plateau of limestone bedrock in North-West Estonia, bordered by the klint and including the Väike-Pakri, Suur-Pakri and Osmussaar islands.

Thin Quarternary cover, almost exposing the abraded tectonically fissured limestone bedrock.

Bedrock layers visible on the lower courses of the rivers on the klint terraces.

Alvar communities, moraine plains with deciduous forests, moraine arable fields.

Troughs (synclinal valleys) intersect the plateau into smaller units.

In abraded depressions there are mires as a result of the overgrowth of old lakes – 20.5% of the plateau area, e.g. Mahtra mire system and Harku, Pääsküla, Valdeku and Rae bogs around Tallinn.

Numerous karst features: Tuhala, Kostivere, Kuimetsa.

Most of the rivers start from the mires, flowing in troughs and forming falls, cascades or rapids on the klint: the Jägala, Jõelähtme, Pirita, Vääna, Keila rivers.

The hidden 2-km Kuivajõgi river (a tributary of the Pirita river).

Sae-Paunküla channel to link the Pirita and Jägala rivers; Vaskjala channel to link the Pirita river and Ülemiste lake.

Only a few lakes: Ülemiste (985 ha), Maardu and Klooga lakes.

Soil profile No 21

WRB 2015 soil classification: Eutric Rheic Drainic Sapric **Histosol** (Endocalcaric, Endosiltic, Aric)

Land use: grassland
Location: Kurgla
Coordinates: 59,377499°; 25,084499°
Elevation: 39 m

Table 62. Material and colour

Horizon	Depth, cm	Main colour	Material and texture
Tap	0-25		peat
Ta	25-60		peat
Cl1	60-80	Gley1 6/1	SiCL
Cl2	80-100	Gley1 6/1	LS

Table 63. Chemical properties

Horizon	Depth, cm	pH_{KCl}	pH_{H2O}	Corg %	Ntot %	Carbonates	P (Olsen) mg/kg
Tap	0-25	5,97	6,73	22,0	1,8	No	47
Ta	25-60	6,31	6,86	34,3	2,0	No	161
Cl1	60-80	5,24	6,03			Yes	79
Cl2	80-100	7,49	7,9			Yes	0

Table 64. Particle size distribution, %

Horizon	Depth	Very coarse+coarse sand	Medium sand	Very fine + fine sand	Sand, total	Silt	Clay
Tap	0-25						
Ta	25-60						
Cl1	60-80	5	4	5	13	47	39
Cl2	80-100	54	26	9	90	3	7

Soil profile No 22

WRB 2015 soil classification: Eutric Drainic Episapric Endohemic **Histosol** (Aric)

Land use: grassland
Location: Kurgla
Coordinates: 59,375399°; 25,088100°
Elevation: 38.5 m

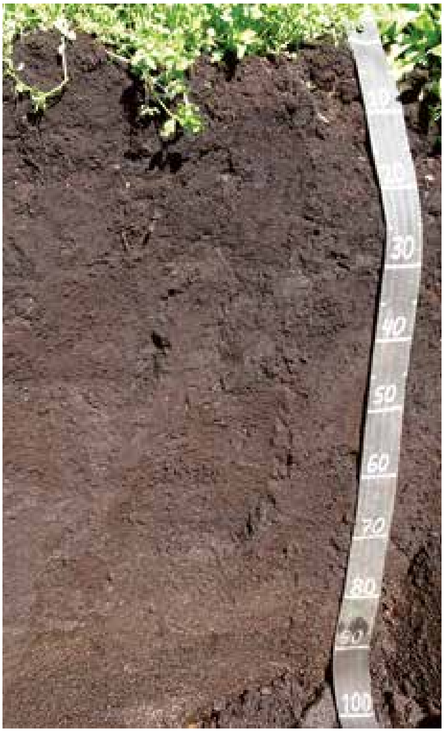


Table 65. Soil description

Horizon	Depth, cm	Material
Tap	0-25	peat
Ta	25-80	peat
Te	80-100+	peat

Table 66. Chemical properties

Horizon	Depth, cm	pH_{KCl}	pH_{H2O}	Corg %	Ntot %	Carbonates	P (Olsen) mg/kg
Tap	0-25	5,78	6,07	24,8	1,7	No	21
Ta	25-80	6,04	6,59	27,5	1,4	No	5
Te	80-100+	6,04	6,63	32,4	1,4	No	12

Soil profile No 23

WRB 2015 soil classification: Calcaric Mollic **Gleysol** (Aric, Drainic, Aric, Endosceletic)

Land use: grassland
Location: Kurgla
Coordinates: 59,377699°; 25,083400°
Elevation: 40 m

Table 67. Texture and colour

Horizon	Depth, cm	Main colour	Texture
Ahp	0-30	7.5YR 2.1/1	SiL
BCl	30-45	2.5YR 7/3 (2.5YR 7/6)	SL
Cl	45-100	2.5YR 7/3	SL

Table 68. Chemical properties

Horizon	Depth, cm	pH_{KCl}	pH_{H2O}	Corg %	Ntot %	Carbonates	P (Olsen) mg/kg
Ahp	0-30	6,72	7,15	13,1	1,0	Yes	84
BCl	30-45	6,46	7,9			Yes	7
Cl	45-100	6,46	7,9			Yes	

Table 69. Particle size distribution, %

Horizon	Depth	Very coarse+coarse sand	Medium sand	Very fine + fine sand	Sand, total	Silt	Clay
Ahp	0-30	13	9	14	36	53	12
BCl	30-45	20	12	27	59	29	12
Cl	45-100	20	12	27	59	29	12

Annex

Soil profiles compiled after the WRB Workshop

(by Peter Schad and participants of the WRB Workshop)

Soil profile No 2

WRB 2015 soil classification: Endoeutric Dystric Amphialic Retic Epialbic Folic **Planosol** (Chromic, Amphiclayic, Drainic, Nechic, Ochric, Amphiraptic, Bathyarenic, Bathygleyic)

Soil profile No 5

WRB 2015 soil classification: Luvic Katostagnic **Phaeozem** (Aric, Endoprotocalcic, Endoraptic, Anosiltic, Bathycalcaric, Bathyloamic)

Soil profile No 6

WRB 2015 soil classification: Hypereutric Endoluvic **Planosol** (Anoarenic, Aric, Ochric, Endoraptic, Bathyclayic)

Soil profile No 8

WRB 2015 soil classification: Haplic **Luvisol** (Endoprotocalcic, Cutanic, Hypereutric, Pantoloamic, Protostagnic)

Soil profile No 9

WRB 2015 soil classification: Amphiluvic Katostagnic **Phaeozem** (Aric, Pantoloamic, Endoraptic, Bathycalcaric)

Soil profile No 10

WRB 2015 soil classification: Eutric Rheic Murshic Sapric **Histosol** (Bathylimnic)

Soil profile No 11

WRB 2015 soil classification: Terric **Anthrosol** (Pantoarenic, Eutric, Endorelictigleyic, Bathystagnic)

Soil profile No 12

WRB 2015 soil classification: Lamellic **Luvisol** (Arenic, Aric, Cutanic, Differentic, Hypereutric, Humic, Epiraptic, Relictiturbic)

Soil profile No 13

WRB 2015 soil classification: Albic Katostagnic Abruptic **Luvisol** (Anoarenic, Aric, Neocambic, Cutanic, Hypereutric, Ochric, Endoraptic, Relictiturbic)

Soil profile No 14

WRB 2015 soil classification: Calcaric Mollic **Gleysol** (Drainic, Hyperhumic, Loamic, Epiraptic, Thaptohistic)

Soil profile No 15

WRB 2015 soil classification: Hypereutric Amphiluvic Mollic **Stagnosol** (Aric, Endoprotocalcic, Katoclayic, Drainic, Humic, Epiloamic, Endoraptic)

Soil profile No 16

WRB 2015 soil classification: Dolomitic Aphicambic Endoluvic **Phaeozem** (Aric, Anoloamic, Endoraptic)

Soil profile No 17

WRB 2015 soil classification: Endochromic **Luvisol** (Aric, Cutanic, Differentic, Hypereutric, Pantoloamic, Ochric, Bathycalcaric)

Soil profile No 18

WRB 2015 soil classification: Dystric Ombric Drainic Hemic **Histosol**

Soil profile No 20

WRB 2015 soil classification: Calcaric Endofluvic Mollic **Gleysol** (Aric, Drainic, Hyperhumic, Loamic, Amphiraptic, Thaptohistic)

Soil profile No 21

WRB 2015 soil classification: Hypereutric Rheic Murshic Sapric Endorockic **Histosol** (Aric)

Soil profile No 22

WRB 2015 soil classification: Eutric Rheic Anomurshic Sapric **Histosol** (Bathyfibric)

Soil profile No 23

WRB 2015 soil classification: Calcaric Oxygleyic Mollic **Gleysol** (Aric, Protocalcic, Drainic, Hyperhumic, Katoloamic, Episiltic, Uterquic)

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ISBN 978-9934-18-257-0
9 789934 182570