Outlines of the Quaternary geology of Latvia

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Latvia is one of the three south-eastern Baltic countries. It is situated geographically between Estonia and Lithuania. Latvia is bordered by Russia in the east and Belarus along its south-east corner. The territory of Latvia covers an area 64,589 km^2. The Baltic Sea lies along its west side, and the Gulf of Rīga penetrates in the central part from the north.

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 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, where they are replaced by Carboniferous, Permian, Triassic and Jurassic deposits.

Quaternary deposits of various thickness and age cover almost all Latvian territory, with the exception of 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. 1). 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. 1). The greatest thickness of the Quaternary deposits (310 m) occurs in the Aknīste buried valley in southeastern Latvia. Most of the Quaternary deposits are glacial and of the Late Pleistocene age (Zelčs et al. 2011).

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). Lithostratigraphical, biostratigraphical and geochronological information available indicate the occurrence deposits of three Pleistocene interglacials – Cromerian (termed locally as Židiņi), Holsteinian (Pulvernieki) and Eemian (Felicianova), and tills of Elsterian (Lētiža), Saalian (Kurzeme) and Weichselian (Baltija) glacials. In eastern Latvia (Vidzeme, Alūksne, particularly Latgale and Augšzeme) uplands and buried valleys have not only a greater than average Pleistocene sediment thickness (Fig. 1) but also display stratigraphically complex sections. However, on the basis of present knowledge, there is no conclusive evidence to support the presence of tills of the Early Pleistocene (Latgale) glaciation, as it was suggested by Danilāns (1973). Therefore, up to 0.51 m thick diamicton-like material that was encountered in test drilling section No. II (Danilāns et al. 1964), located in south-eastern Latvia between towns of Krāslava and Daugavpils at the base of plaeolake sediment sequence, and recently studied by Kalnina et al. (2013), can most likely be correlated with the Cromerian complex of early Middle Pleistocene.

The internal structure of the Pleistocene sequence has in many places been complicated by glaciotectonic deformation (Āboltiņš and Dreimanis 1995; Dreimanis and Zelčs 1995; Molodkov et al. 1998; 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.

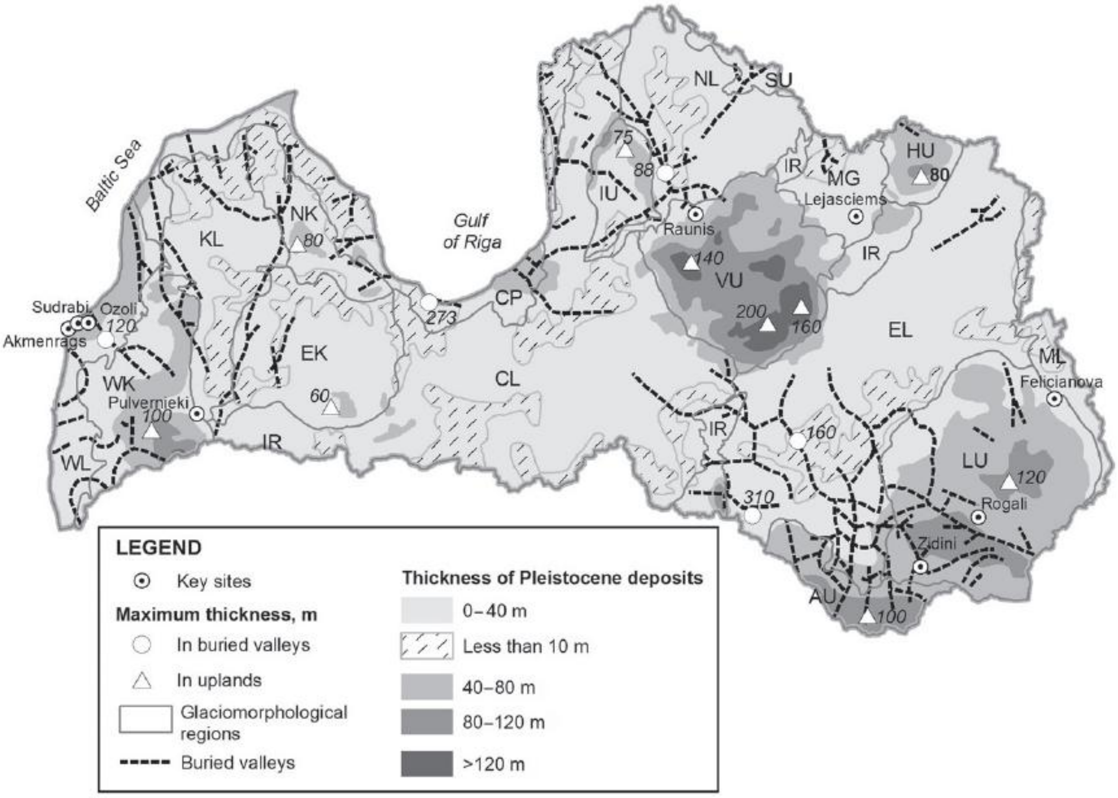

Fig. 1. Thickness of the Quaternary deposits in Latvia (modified after Zelčs et al. 2011).

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.

Glaciotectonic deformation structures are extremely common in the Weichselian deposits and thus complicate their stratigraphical interpretation. 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.

The extent and timing of Pleistocene glaciations, particularly Upper Pleistocene events, in Latvia have traditionally been interpreted on the basis of palynological studies, cross-correlation of lithological data, radiocarbon dates of plant remains from organic and organic-bearing sediments, „sub-fossil" reindeer finds and mammoth tooth enamel samples (e.g. Ukkonen et al. 2006; Arppe and Karhu 2010), and results obtained by TL, OSL (e.g. Zelčs et al. 2011; Saks et al. 2012) and ESR (Molodkov et al. 1998) dating techniques. The chronology of the last deglaciation of the southern sector of the Fennoscandian Ice Sheet, including the territory of Latvia, has also been established following the results of the cosmogenic ^{10}Be determination (Rinterknecht et al. 2006).

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. The highest point is Hill Gaiziņkalns (312 m a.s.l.) in the Vidzeme Upland.

Almost 75% of Latvia lies below 120 m a.s.l., and elevations higher than 200 m are restricted to less than 3% of the territory. 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.

The present-day topography 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. 2). The Last glacial maximum limit is located outside of Latvia.

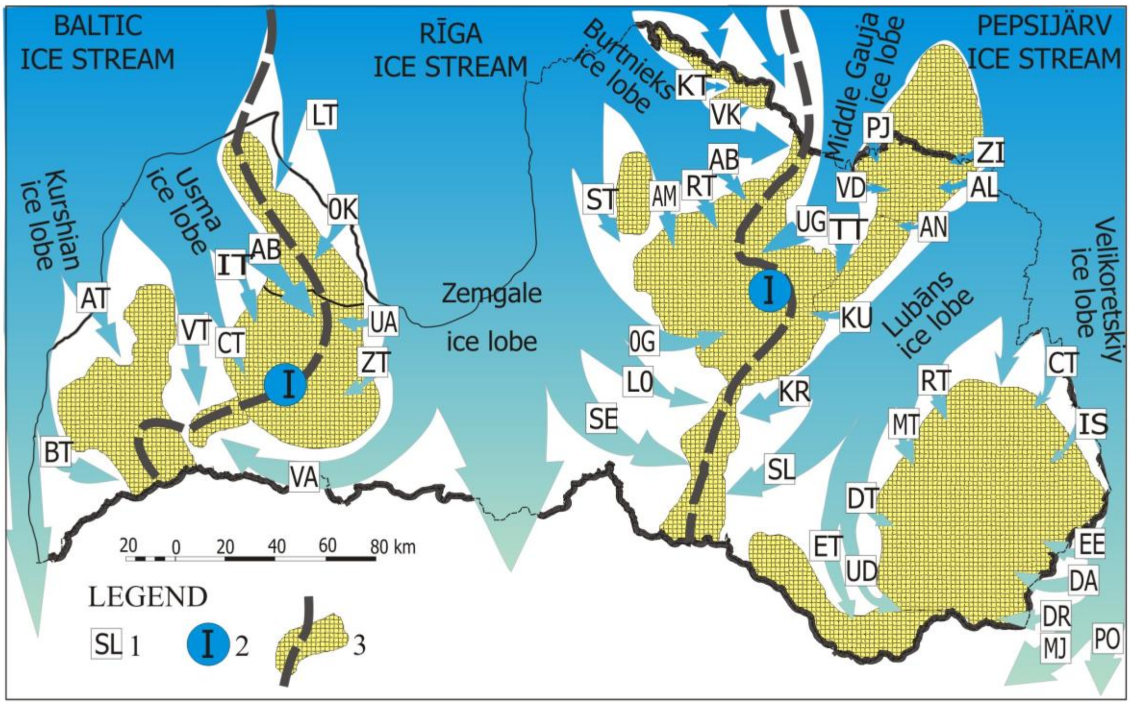

Fig. 2. Lobate structure of the peripheral cover of the Fennoscandian Ice Sheet in Latvia during transgression and decaying of the Late Weichselian glaciation (modified after Zelčs and Markots 2004).

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 and three main types of lowlands can be distinguished in Latvia, based on hypsometric position, thickness and structure of the Pleistocene cover, and glacial topography (Zelčs and Markots 2004). Latvia was located in the inner belt 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, Rīga 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. The insular uplands and interlobate ridges represent zones of convergence of ice lobes 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 the ice thickness decreased. A very complex lobate structure with many small glacier tongues and sub-tongues were existed in the early phases of the deglaciation, so-called 'insular deglaciation stage' by Āboltiņš et al. 1972. Later, during the 'lobate stage' (ibid.), 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 (in order of decreasing age – Dagda, Kaldabruņa, Gulbene, Linkuva and Valdemārpils) can be distinguished in Latvia (Zelčs et al. 2011). These ice marginal zones can be tentatively correlated with Baltija (Pomeranian), South Lithuanian, Middle Lithuanian, North Lithuanian (Otepää) and Pandivere zones in the neighboring part of Estonia and Lithuania (see Guobytė and Satkūnas 2011; Kalm et al. 2011; 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 encompass the hypsometrically highest part of the upland, that is regarded as interlobate moulding. This phase replaces the Indra phase, defined by Āboltiņš et al. (1972), after improved topographical data became available.

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. Further west across the Latvian-Lithuanian border, this marginal zone clearly coincides with the South Lithuanian marginal zone. Both these marginal zones are thought to represent the termination of the Lubāns and Polatsk (both draining from the Peipsi Ice Stream) ice lobes. There is only one ^{10}Be date, which corresponds to this glacial phase, and was taken from the boulder near the Latgale Upland northern margin well within the Kaldabruņa glacial limit (Rinterknecht et al. 2006). This date of 15.5 ka probably provides the minimum age of this phase (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 (Zelčs and Markots 2004; STOP 7: Fig. 7.1 in this volume). During this phase, the lowest marginal landform assemblage of the Latgale Upland was formed, as a termination of Lubāns and Polatsk ice lobes (Zelčs and Markots 2004). In north-eastern Latvia, this phase can be drawn with some difficulties. During this 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.

The ^{10}Be dates from within the Gulbene glaciation stage range from (excluding extremes) 12.6 to 14.0 ka (Rinterknecht et al., 2006), giving the average minimum age of the phase of ca. 13.5 ka. This corresponds rather well to the ^{10}Be dates from the Middle Lithuanian phase in neighbouring Lithuania (Rinterknecht et al. 2008). The minimum OSL age of the Gulbene ice-marginal zone is 14.5 to 15.5 ka, and it can be correlated with the Haanja zone in Estonia (Zelčs et al. 2011; Nartišs, Zelčs 2013). Single ^{10}Be date of a boulder connected with the Gulbene ice-marginal zone in the Alūksne upland has yielded 15.290 ± 980 yrs (Rinterknecht et al. 2006), thus indicating the start of ice retreat from the Gulbene ice-marginal zone into the direction of the Middle Gauja Lowland.

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 (Velikoretsky) 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 glacial lake (see Fig. 3 for location), 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. The ^{10}Be dates from boulders within the margins of the Linkuva phase give a wide distribution of ages (12.0–15.4 ka). Cross-border correlation in central Latvia is straightforward, while in western Latvia, the Linkuva ice-marginal formations are thought to correlate with the Pajūris ice-marginal formation zone (Guobytė and Satkūnas, 2011) but are hard to trace. In Estonia, the Linkuva glacial phase marginal formations can rather be correlated with the Otepää ice-marginal zones but here the cross-border correlation is again difficult.

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 Valdemārpils ice-marginal zone can logically be correlated to the Sakala ice marginal zone in Estonia. There are no reliable dates corresponding to this ice-marginal zone; being located between the Otepää and Pandivere ice-marginal zones, sets the time limits for this stage between 14.5 ka (Lasberg and Kalm 2013) and 14.0 ka (Vassiljev and Saarse 2013).

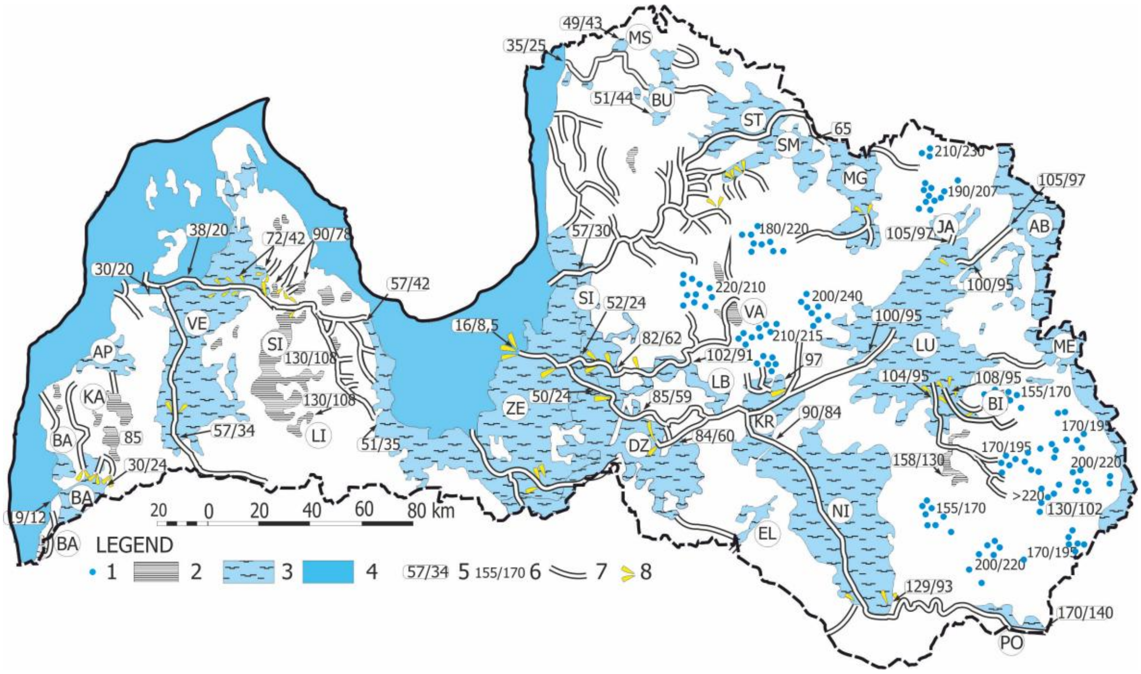

Fig. 3. Distribution of ice-dammed lakes and glaciolacustrine deposition sites in Latvia (modified after Zelčs and Markots 2004).
Legend: 1 – accumulation of glaciolacustrine sediments on hilltops; 2 – ice dammed lakes in glacial uplands: KA – Kalvene, SI – Saldus-Imula, LI – Lielauce, VA – Valole, BI – 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.

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. 3). 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. 3). The width of the largest spillway valleys (e.g., Upper Daugava and Lower Gauja) reaches 2.5-3 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.

The onset of the Late Weichselian glaciation in Latvia has not been reliably dated, but the available OSL dates from western, central and eastern Latvia suggest that ice masses invaded the territory no earlier than 24-25 ka. Deglaciation of the territory was started in Daniglacial time, about 18,000 years BP. The ice sheet finally retreated from Latvia during the Late Weichselian Late-glacial Interstadial, about 14 ka B.P. Therefore the possible duration of the Late Weichselian glaciation of Latvia ranges between ca. 9 and 10 ka (Zelčs et al. 2011). Periglacial conditions persisted until the beginning of the Holocene.

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