STOP 10: Kame terrace in the Upper Daugava depression at Rakuti, near Krāslava

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According to the established deglaciation history of Latvia (Āboltiņš et al. 1972; Meirons et al. 1976; Zelčs and Markots 2004; Zelčs et. al. 2011), the Upper Daugava depression and adjacent glacial uplands were the very first areas to become free of the Fennoscandian ice sheet during the last glacial termination, approximately 16–18 ka BP (Raukas et. al. 1995; Rinterknecht et al. 2006). Consequently, these areas are among those in Latvia which have been exposed to proglacial and non-glacial conditions for the longest period of time. Hence, the geomorphological and geological study of these regions allows reconstruction of the processes and environmental conditions of the events occurring at the end of the Late Pleistocene and beginning of the Early Holocene. In such a context, the possibility of studying the uppermost part of the Late Pleistocene sequence in a number of sections at the Rakuti sand and gravel quarry (Fig. 10.1), with various spatial orientations, permits substantial scientific data to be obtained. The main morphological characteristics and preliminary results of lithological studies from three out of seven studied outcrops (see Fig. 10.1B for location) are demonstrated in this stop description. The quarry covers an area of 4.24 ha and lies 132–134 m a.s.l. During the extraction of sand and gravel the layers of clastic Quaternary sediments are exposed to a depth of up to 12 m.
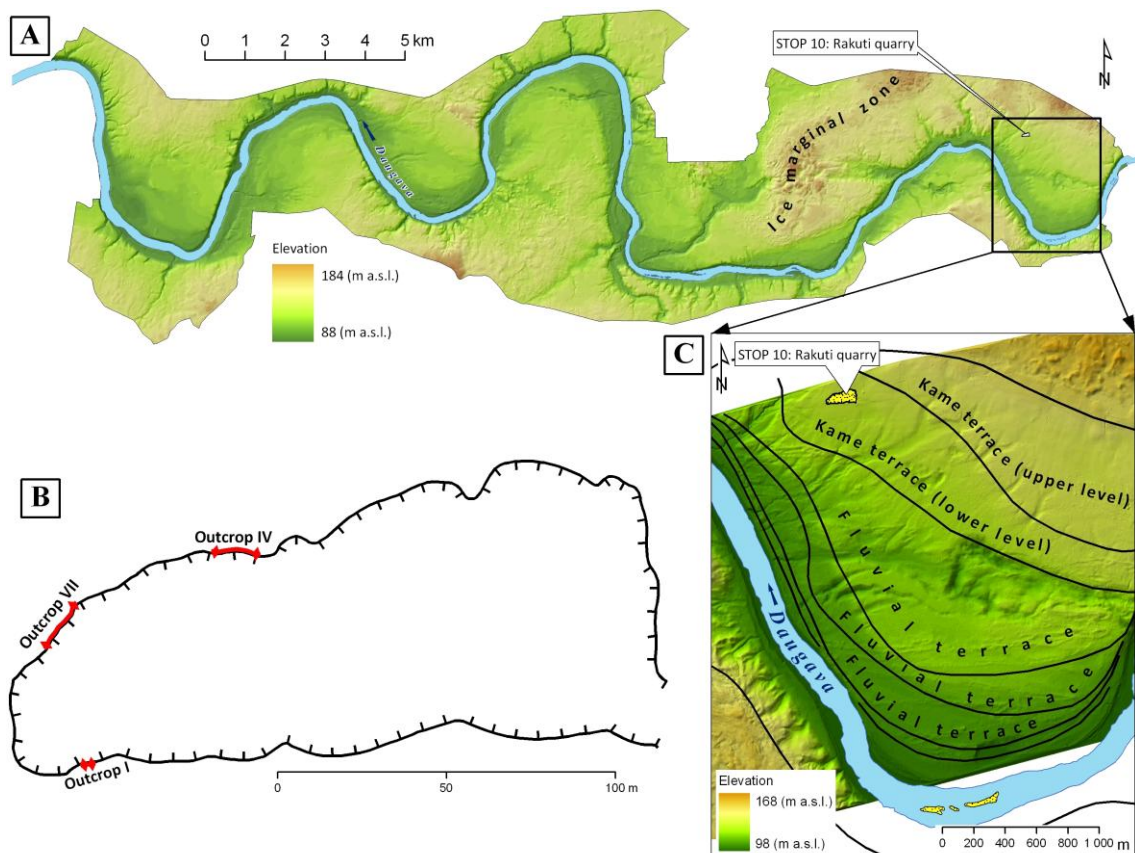

Fig. 10.1. A. Digital elevation model of the Upper Daugava depression and general location of the stop site, distal from the ice-marginal zone. B. Location of the studied outcrops. C. Location of kame and fluvial terraces.

The Rakuti sand and gravel quarry (55°53'51"N, 27°05'30"E) is located on a flat-topped geomorphic surface complicated by dispersed microforms (e.g. erosional features and small kettle holes) and bounded by the riser of the lowermost terrace, presumed to be fluvial (Fig. 10.1C). Eberhards (1972) has mapped this flat-topped landform, which occurs alongside the northern edge of the Upper Daugava depression, west of the town of Krāslava, as the uppermost terrace or Terrace VIII of the East-Latvian terrace spectrum of the River Daugava. Eberhards (ibid., 2013) and later also Āboltiņš (1995) have specified that the terraces (VII to II) were mainly erosional, besides which the terraces of the upper complex (VII–V) were formed by meltwater streams flowing from Lake Polatsk into the Nīcgale ice-dammed lake. However, the course of stream flow during its formation is still an open question, because alongside this terrace the surface slopes slightly to east in the direction of the Polatsk ice-dammed lake, from 132–134 m a.s.l. at the quarry down to 128.5 m a.s.l. for this terrace level, and from 142 m a.sl. to approximately 138 m a.s.l. for the uppermost terrace level, over a distance of about 1000 m. Without completely rejecting the idea of meltwater drainage to east, Eberhards (1972) attempted to explain the upstream inclination of the levels of both above-mentioned terrace treads, opposite to the modern river flow direction, in terms of glacial isostatic adjustment.

The results of the most recent research lead to a different conclusion and reveal that Terrace VIII is not a fluvial erosional terrace but a kame terrace. The terrace micro-relief and internal structure of the underlying sediments also provide evidence of glaciokarst and periglacial processes, the presence of floating dead ice blocks (Fig. 10.2) and substantial temporal and spatial changes in the depositional environment (Fig. 10.3). These are classic features for identification of kame terraces occurring in various glaciated regions, as noted by Klimek (1956), John (1972), Huddart and Lister (1981), de Jong and Rappol (1983), Bitinas et al. (2004), Pisarska-Jamrozy et al. (2010), and Dauškans (2013).
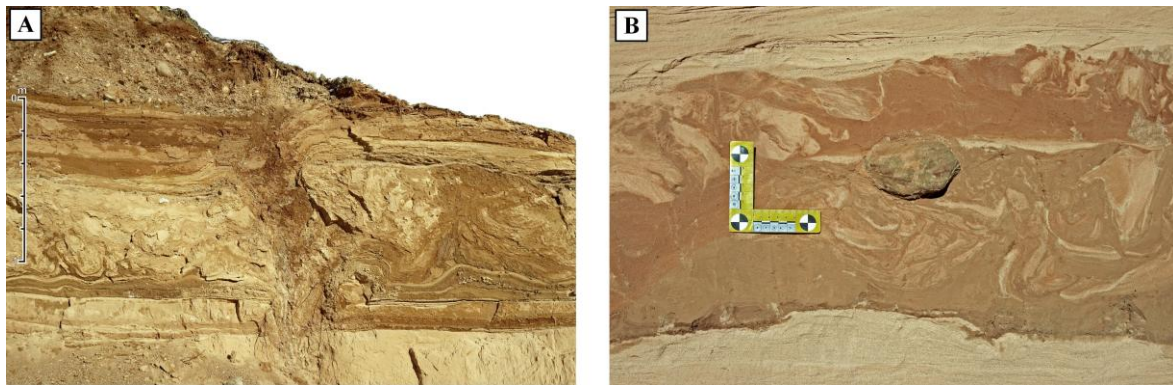

Fig. 10.2. Ice wedge and cryoturbation in horizontally laminated silt and clay interlayered with gravelly sand matrix and occasional cobbles (A) and large dropstone, supposedly, in convoluted and slumped silt and silty sand interlayered with sand (B) in outcrops V and VI located in the NE corner of the Rakuti quarry. Evidently this part was occupied by an ephemeral glaciomarginal lake. The ice wedge and cryoturbation present important evidence of essentially subaerial conditions, which might have been caused by climate deterioration or drainage of this glaciomarginal lake. Besides, occasional carbonate cementation has been observed in the underlying sand. The massively cemented units occur as isolated lenticular patches with a thickness up to 1.5 m.

The kame terrace is located about 20 km W of the highest shoreline (140 m a.s.l.) of the Polatsk ice-dammed lake and 30 km east of the Nīcgale ice-dammed lake. The Rakuti quarry lies in the proximity of the distal slope of an unnamed ice-marginal zone, considered to be somewhat older than the Kaldabruņa ice-marginal position by Meirons et al. (1976), and tentatively assumed to be the Dagda ice marginal zone by Zelčs et al. (2011). According to Zelčs et al. (ibid.), before formation of the Dagda ice marginal features the territory under

consideration was in the coalescence zone between the Lubāns and Polatsk lobes.

The bedrock surface is on average 85–90 m a.s.l. In the neighbouring territory on the bottoms of the buried valleys and narrow bedrock depressions it falls to 46 m b.s.l. The bedrock is Middle Devonian terrigenous sedimentary rock. The thickness of Pleistocene sediments is about 50–60 m, but decreases in the Daugava river valley, reaching 27 m at Krāslava. The Pleistocene superficial sediments are mapped as Upper Weichselian glaciofluvial gravelly sand (Juškevičs and Skrebels 2003). To the north, in the direction of the Latgale Upland, it is replaced by Late Weichselian till.

Investigation of the internal structure of the sediments underlying the terrace utilised field techniques widely used in Quaternary geology and glacial geomorphology (Hubbard and Glasser 2005), i.e. measurements of long axis orientations of 450 elongate pebbles by identification of their dip and its direction. Simultaneously, 100 pebbles in each of the fractions 8–16 mm, 16–32 mm and 32–64 mm were collected by dry sieving material from nine layers. Thereafter the three major axes – a, b and c – of each clast were measured by digital callipers and recorded to estimate the shape of pebbles according to the classification of Sneed and Folk (1958). The data were plotted in triangular diagrams using the *TriPlot* module according to Graham and Midgley (2000).

Outcrop I

Matrix supported massive diamicton interlayered by boulder diamicton and gravelly sand is underlain by silty sand. In the basal part the silty sand becomes coarser and contains gravel. The lower bed consists of planar cross-stratified fine to medium-grained sand, the structure of which is excellently visible in the sections striking perpendicular to this outcrop.
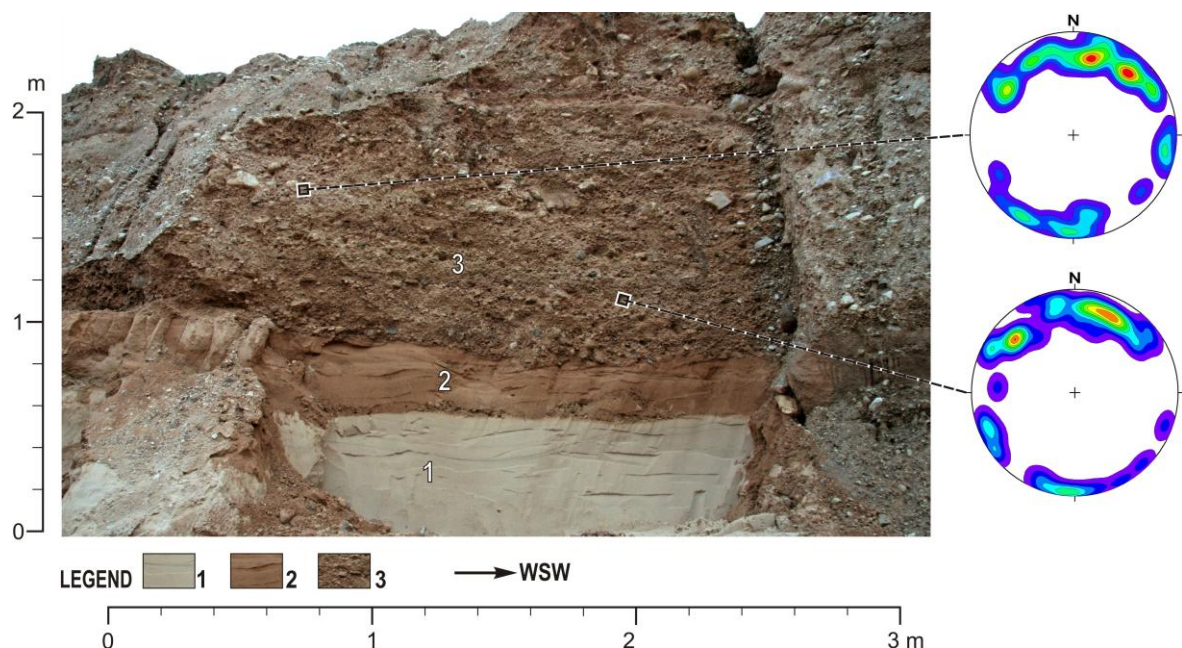

Fig. 10.3. Outcrop I (see Fig. 10.1 for location). Composition of the kame terrace tread underlying sediments is shown in the section subparallel to the terrace stretch. Legend of identified layers: 1 – planar cross-stratified fine to medium-grained sand; 2 – trough cross-stratified silty sand with occasional gravel and gravel lenses in the basal part; 3 – massive, matrix supported clast rich diamicton, interlayered with gravelly sand.

Three-dimensional diagrams of clast orientation are on the lower hemisphere and in equal area projection. Based on 50 elongated clast measurements. Contoured at 0-1-2...6-8 percent areas.

The measurements of the orientation of clasts indicate a relatively weak to moderately strong multimodal azimuth. The dip varies across a wide range. However, it indicates the

gravity flow direction from the melting stagnant ice lobe to the lateral slope. The diamicton is interpreted as flow till re-deposited by dense cohesive flow, whereas the underlying silty sand with an admixture coarse grained particles has perhaps been deposited as fluidised sediment flow, but its structure has been slightly altered by deformation. The lower sedimentary unit represents a delta foreset series.

Outcrop IV

The uppermost part of the exposed section is similar to Outcrop I. For instance, unit 7 can be conditionally correlated with unit 1 of outcrop I (Figs. 10.3 and 10.4). Five beds of diamicton lithofacies can be distinguished in the section. Excluding units 7 and 8, the lower boundaries of other diamicton units with horizontally laminated sand and fines are sharp, presumably erosional, but the boundary between units 5 and 4 is also marked by erosional scours (Fig. 10.4). The results of orientation of the elongated clasts mainly show multimodal azimuth patterns. Only in unit 3 and unit 5 clast linearity is quite strong and indicates flow direction at an oblique angle to the stagnant ice.
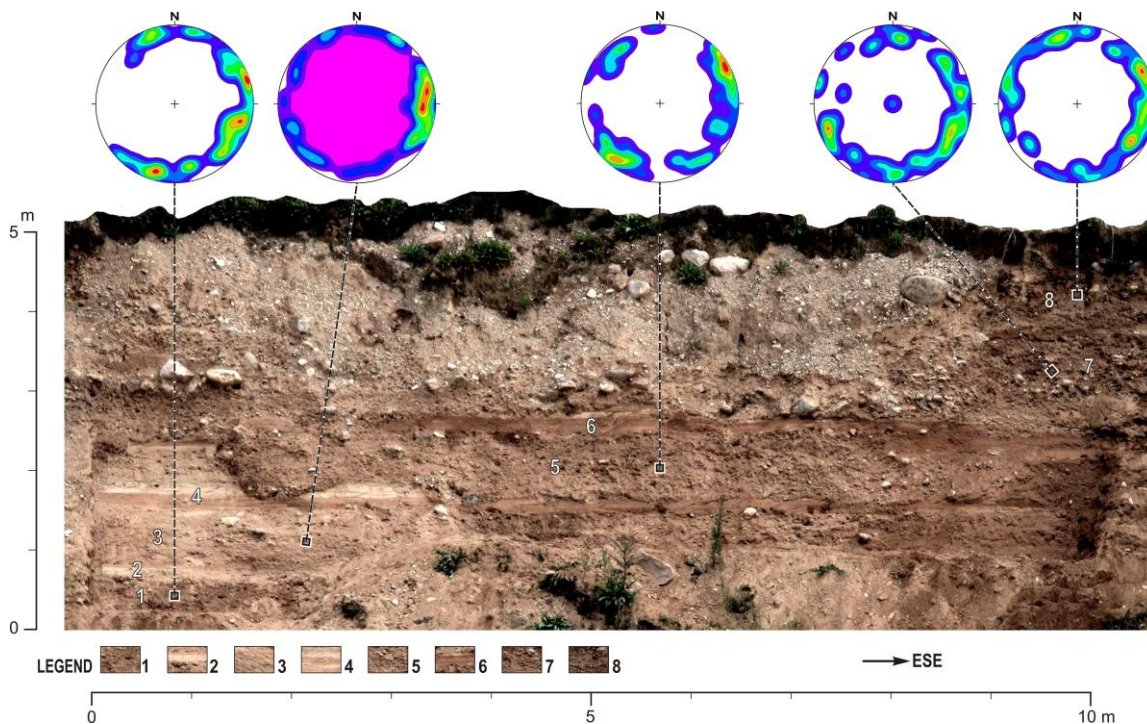

Fig. 10.4. Outcrop IV (see Fig. 10.1 for location). Composition of the sediments underlying the kame terrace tread is shown in the section alongside the terrace stretch. Legend of identified layers: 1 – matrix supported, clast moderate, massive diamicton; 2 – horizontally laminated silty sand; 3 – massive, matrix supported, clast moderate diamicton; 4 – fine sand and sandy silt, horizontally laminated; 5 – massive, matrix supported, clast moderate diamicton; 6 – horizontally laminated fines; 7 – matrix supported, clast rich diamicton with boulder concentration zone; 8 – clast supported diamicton with boulder concentration on the top.

The three-dimensional diagrams of clast orientation are on the lower hemisphere and in equal area projection. Based on 50 elongated clast measurements. Contoured at 0-1-2...6-8 percent areas.

Outcrop VII

This outcrop is situated at the NW corner of the quarry (Fig. 10.1). It displays an alternation of sedimentary units consisting of coarse clastic and finer material (Fig. 10.5). Some of them can be correlated with units occurring in Outcrop IV. The orientation maxima of the elongated clasts are well-expressed. They indicate a debris flow direction parallel or

subparallel to the kame terrace stretch.

Analysis of field study data demonstrate that in the western part of the quarry clastic sediments are dominant and mainly consist of poorly sorted gravel with pebbles, and boulder-size material in places, with a sandy loam matrix (Figs. 10.3, 10.4 and 10.5). The coarse clastic material is interlayered with basin sediments, and underlain by planar cross-stratified fine to medium-grained sand in the western part of the quarry. Eastwards this well-sorted sand is replaced by rippled and horizontally laminated sandy silt, evidently deposited in a shallow lake. The role of basin deposition in the topmost part of the sediment sequence also increases in the same direction.
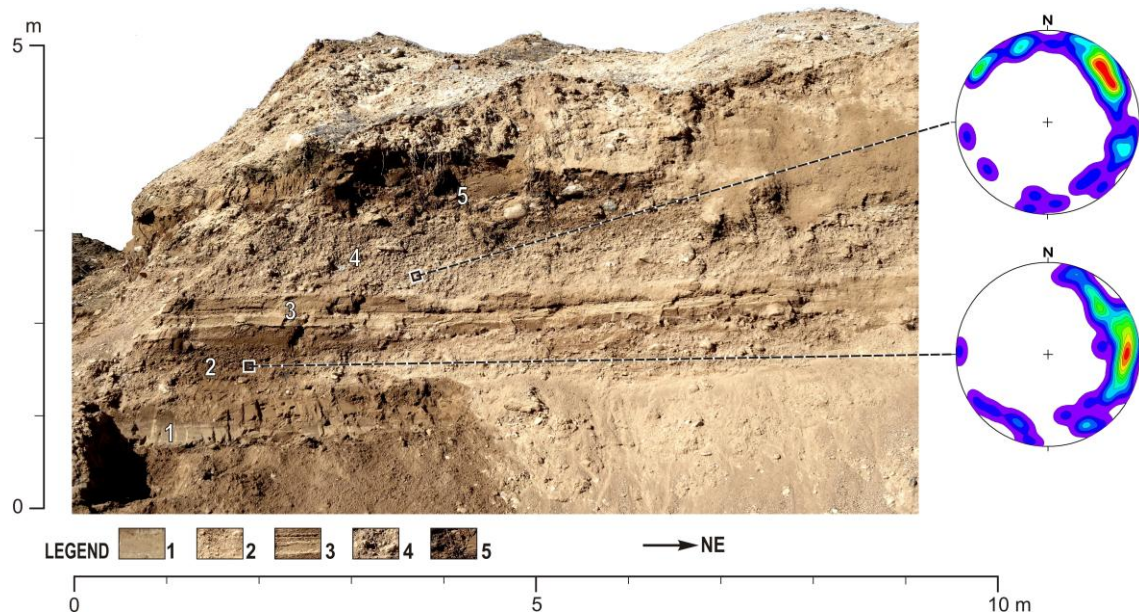

Fig. 10.5. Outcrop IV (see Fig. 10.1 for location). Composition of the sediments underlying the kame terrace tread is shown in the section transverse to the terrace stretch. Legend of identified layers: 1 – horizontally laminated sandy silt (in Fig. 10.4: unit 4); 2 – massive, matrix supported, clast moderate to rich, gravelly diamicton; 3 – horizontally laminated silt and rippled fine sand interlayers; 4 – clast supported diamicton with occasional cobbles and boulder concentration zone (tentatively correlated to unit 7 in Fig. 10.4); 5 – deformed diamicton with admixture of fines and occasional boulders.

Three-dimensional diagrams of clast orientation are on the lower hemisphere and in equal area projection. Based on 50 macrofabric measurements. Contoured at 0-1-2...6-8 percent areas.

Pebble- to boulder-sized clasts are mostly unconsolidated and their roundness varies widely from well-rounded to sub-angular. Clasts of the limestone and dolomite lithological groups dominate in all examined layers of diamicton, the proportion of clasts of carbonate rocks varying from 70% to 82% of the total number of pebbles. Estimation of the shape of pebbles according to the Sneed and Folk (1958) classification indicates that compact-bladed and bladed clasts are dominant; however, such a shape is not typical for glacial sediments. In addition, the analysis of data on the ratio of the shortest to longest axis of pebbles, i.e. c/a-axis ≤0.4 (termed the C_{40} index) according to Graham and Midgley (2000), demonstrates that all values plotted in triangular diagrams are located both above and below the C_{40} index line, although the values of pebbles of crystalline lithology are located mainly above it. Such a distribution of values in triangular diagrams is not typical for subglacially transported sediments, which are usually characterized by a concentration of points above the C_{40} line (Graham and Midgley 2000). A feasible explanation of this finding is that pebbles of carbonate lithology reflect a short transport distance of deposited clastic sediments.

In most cases the clast linearity coincides with the stretch of the kame terrace, indicating

that debris was transported from the ice marginal zone. However, in some cases clasts have been oriented at an oblique angle to the stagnant ice or the lateral slope of the Upper Daugava depression. Such a clast spatial orientation and erosional marks on the lateral slope as well as on the scarp of the upper kame terrace level (Fig. 10.1) suggest that proglacial waters have been produced not only by ice melting but also by extra-glacial waters draining from the already ice-free parts of the Latgale Upland.

It is likely that the kame terraces at Rakuti are located where meltwater flowed between stagnant ice and the lateral slope of the Upper Daugava depression. Deposition from stagnant ice and extraglacial waters, and in an ephemeral glaciomarginal lake has resulted in continuous kame terrace.

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