History of the channel systems formation of the Kama-Keltma lowland in the Late Pleistocene

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Abstract. The outcome of the research of the geomorphological structure and age of deposited materials, with a particular focus on separate elements of the Kama-Keltma lowland erosive and accumulative relief, indicates the existence of six channel system formation (reorganization) stages in the late Pleistocene-Holocene: 1 – end of the Kalinin stadial; 2 – Mologa-Sheksna interstadial; 3 – Ostashkov stadial; 4 – 18–10 thousand years ago; 5 – 10-2.5 thousand years ago; 6 – 2.5 - 0 thousand years ago. According to the results of the analysis of Landsat-8 satellite images, the best geomorphological expression of the erosion relief was obtained for bands combinations of the SWIR and NIR 7-6-5 (indication of sandy bars and ridges, indication of the moistening degree of upper bog facies) and NIR, SWIR and RED bands –5-6-4 (indication of the vegetation species composition and the moistening degree of floodplain and swamp peat geosystems).

1. Introduction
Studying the history of development and dynamics of Kama-Keltma lowland (KKL) channel systems is important to get insight into the history of the drainage network across the Kama-Vychegda-Pechora watershed, including upstream valleys of the regional principal rivers (figure 1). Although the overall relief and landscape formation in the periglacial zones have already been substantially studied, the spatio-temporal aspects of the riparian channel and lake system formation in the Late Pleistocene age are unresolved issues even today [1–3, 5–9, 12, 13, 15].

2. Material and methods
Unlike Kama floodplain whose absolute age varies from several hundreds of years (the first floodplain generation) to 6–7 ka (the fifth floodplain generation), the absolute age of the first upland fringe within the explored territory has not been officially established. The attempts to establish the period of its formation include several dates fixed after analysing the cliff deposits of the upland fringes of the rivers draining KKL (figure 2). The buried soil discovered under the floodplain facies of the Timsher River upland fringe (a high floodplain) is aged 9890±170 ka (LU-8725) (N60 °28'36.9", E55 °23'47.60")．An oxbow deposit formation consisting of wood residues and mud was exposed in the
erosion scrap of the Southern Keltma. The absolute age of the organic matter is $4790\pm80$ ka (LU-8726) (N60°31'54.9", E55°31'17.80"). Two adjacent cliff cuts of the Pilva River located at distance of 100 m from each other, can be precisely dated: the first one – $11680\pm230$ ka (LU-8727) (N60°30'56.2", E55°43'13.90"), consisting of gray sands lying below the bottom layer of channel facies yellow sands (wood specimen), the second one – $7360\pm170$ ka (LU-8728) (N60°30'55.9", E55°43'15.80"), consisting of the peat buried under floodplain silt (0.6 m).

Figure 1. Map showing the area investigated in the Kama-Pechora-Vychegda watershed, North-Eastern European Russia.

Except the modern channel network and the fragments of valley and channel geosystems defining the location of the Pre-Holocene deposits of the KKL river area, runoff hollows have become common – channel-like swamped lows, the beginning and the end ("entrance" and "exit") of which disappear within bog complexes. Generally, the length of such formations seldom exceeds 1–2 km. An exception is the Great Terraced Hollow (GTH) located in the interstream area of the Southern Keltma and Pilva (N60°30'40.06", E55°36'43.03"). A channel-like low is currently occupied by a moss bog, 6 km long and about 250 m wide. The beginning and the end of the hollow are structurally above the left-bank valley edge of the Southern Keltma and above the level of the Kama first upland fringe.

The analysis of the spectrum of the deposited sporo-pollen that forms the GTH bottom was carried out to the depth of 3.18 m. The structure of the studied formations is as follows: 0-0.6 m – poorly decomposed sphagnum peat; 0.6-2.2 m – partially decomposed peat; 2.2-2.4 - muddy peat (sapropel); 2.4-3.0 m – fine-grained sand; deeper than 3 m – dark-brown mud (sapropel). The results of the sporo-pollen analysis allow distinguishing between four palynozones. The sporo-pollen spectrum of palynozone one characterized by the deposits lying deeper than 2.4 m includes Ephedra pollen – a relict of the periglacial landscapes. Taking into account the composition of pollen found in three other palynozones (0.0-2.4 m), the lowest part of the section belongs to the preboreal time of formation. The
sapropel layer occurring at a depth of 2.2 m and of 2.45 is at the age of 8350 ±80 ka (Spb-2702) and 8433 ±80 ka (Spb-2700), respectively.

Landsat space images of the territory of the Upper Kama depression reveal the formation of several old channel systems within typical marsh natural boundaries [4, 14]. To determine the central channel system (CCS), a blue-specter image was used. The combination of bands 7-6-5 enabled the optimum location of sand low ridges and sand bars delineating the divagation line of the old stream. The combination of NIR, SWIR and RED bands (5-6-4) made it possible to locate the North channel system (NCS) stretching along the North bed-rock of the Upper Kama depression. At the junction point of CCS, NCS and the recently-formed Timsher River floodplain, floodplain terraced complexes interacted through the immersion of younger geosystems into the older ones – the Timsher floodplain immersed into CCS, CCS immersed into NCS. The encroachment line of a joint channel system (JCS) is quite definitely identified through its sandbars with rare vegetation distinguished by pink and crimson colours against the moss bog blue colour.

Figure 2. Lithological logs plotted in metres above sea level and age of the terraces studied: 1 – Sand, 2 – Sandy loam, 3 – Peated sandy loam; 4 – Loam; 5 – Peated loam; 6 – Peat; 7 – Calibrated radiocarbon date.

3. Results and discussion
The analysis of measurement data gathered by the KKL channel system of age analysis is based on the confirmed different times of multi-layer relief formation: the higher the layer level, the older the surface, the lower layer – the younger the surface. The physical properties of the flowing water that
penetrates the lowest relief levels necessitates the use this approach defining the sequence (phasing) of the land surface modelling.

The Kama-Keltma lowland is an ecosystem with a distinctive four-layer vertical structure. The Kama floodplain with its floodplain and channel complexes (floodplain generations) belongs to the first lowest level. An average relative elevation of the floodplain over the encroachment line amounts to 3–6 m. The second level is formed by the Southern Keltma, Timsher and Pilva's upland fringes (with an absolute elevation of ≤ 120 m). The first Kama upland fringe, along with the ecosystems of old channel systems complicating its structure – CCS, NCS, JCS – can be referred to the third level (with an absolute elevation of 122–130 m). The lake terrace of the Kalinin age occupying the major part of the Keltma hollow, and sand (pine-forest) bars elevating over the marsh massifs of the Upper Kama depression (with an absolute elevation of 130–135 m) correspond to the fourth level. Apparently, the same level also includes the bottom of the old channel bending around the sandy massif at the estuary part of the river Chepets (a feeder of the Timsher River) on the North-West. The surface elevation of the boggy Chepets hollow is about 132 m.

Based on the lake-terrace age – the highest relief level within KKL, it becomes possible to determine the GTH formation period. The system which shaped the lake terrace surface, based on the clear-cut delta on the surface of the first upland fringe, had formed during the termination of an active development stage of the previous one. Most likely, this period belongs to the Ostashkov stadial theory according to which watercourse formation from the Northern Keltma could have resulted from glacial- and lake-water inflow from the Vychegda basin. The probability that GTH had formed under periglacial conditions is implicitly confirmed by the results of the research of plant pollen found in the bottom deposit section.

The GTH geomorphological position with regard to the South Keltma, Pilva and Timsher upland fringes allows assuming the age of the GTH formation as the Ostashkov stage of the previous glaciation. Being structurally located several meters lower the GTH bottom level, these terrace surfaces are apparently the fragments of the macromeander bottoms (floodplains). Mass formation of the latter occurred 18–13 thousand years ago during steady and long warming periods and was caused by high water discharge of the rivers [10, 11]. The Pre-Holocene age of the KKL transitional river upland fringes is indicated by the peat formed on their surfaces about 10 thousand years ago occasionally re-occurring as peat formation processes in the Holocene optimums.

Sudden warming followed immediately during the LGM termination and affected the nature and intensity of relief formation in the Kama valley. An increase in sediments due to the rising levels of water in the Pra-Kama basin resulted in a braided channel formation in the lake-shaped opening of the Upper Kama depression – the southern part of the KKL. Today, the erosive marks of two separate late-Pleistocene river branches – CCS and NCS – represent the main pattern of the framework of hydrographic network reorganization in the Upper Kama basin.

4. Conclusion

The geomorphological structure and elemental deposition analysis of the KKL erosive accumulative relief makes it possible to outline six stages of channel system formation. The development of the first stage (the final stage of the Kalinin stadial) points to the Chepets hollow which is, apparently, one of the few fragments of the old hydraulic network remaining after major relief changes in the course of the first upland fringe formation. The third stage includes the period of the GTH formation and functioning – a temporary stream channel whose formation occurred under the periglacial conditions of the Ostashkov stage. It is characterized not only by the almost complete absence of plant pollen in the alluvion that fills the hollow cutting, but also by its high elevation of the structurally lower-located first Kama River upland fringe, the formation of which refers to the second stage (Mologa-Sheksna interstadial) of erosive and accumulative system formation across the region. The subsequent lake terrace surface modelled by the Southern Keltma, Pilva and Timsher's macromeanders, and the first upland fringe surfaces modelled by the Kama braided channel (CCS, NCS, OCS) can be referred to the fourth stage of the channel system formation. This stage includes a
period of 18-10 thousand years, alternating with a relatively short term of warming and cooling periods immediately after the LGM termination. The fifth stage includes the first three quarters of the Holocene self-development of the present riparian floodplain and channel complexes during the periodically recurring dry – damp, warm – cool periods from the Preboreal to the Subboreal stage of development. The sixth and last stage of hydrographic network reorganization within the KKL area is characterized by the process of "straightening" of the Kama riverbed across the Upper Kama depression. What two or three thousand years ago used to be a meandering riverbed running along a wide floodplain of the Kama channel, as suggests the oxbow configuration with a sinuosity coefficient of more than 1.5 during that period, is now characterized by a relatively straightforward channel.

It is our opinion that intensive marsh geosystem formation could have been one of the reasons for changing the orientation of the channel during the subatlantic stage of the KKL channel system reorganization. High bogging rates on the upland fringe surface were followed by the gradually increasing elevation of the peat massif central parts (where peat thickness reaches five and more meters) and at the same time by the development of swamps peripherally approaching the floodplain geosystems thus contributing to the significant decrease of the erosive impact on the banks during the high-water seasons. The formation of local elevated zones along with the rapid expansion of peat massif areas have also led to formation and subsequent preservation throughout the Holocene of the largest lakes and lake systems in the Perm Cis-Ural region.

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