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Development of the Vychegda-Vyatka-Kama drainage basin and changes in the outflow directions related to the Late-Glacial morphological conditions (North-Eastern European Russia)

Abstract: The paper describes the features of the drainage system development in the upper Kama basin. Two buried river valleys were identified within the Kama-Pechora-Vychegda watershed. The upper courses of the Kama, the Vychegda, the Pechora and their tributaries likely belonged either to the White Sea basin, or the Caspian Basin. The southern direction of the outflow corresponded to the location of the palaeovalleys of the Pra-Kolva and the Pra-Vishera. The northern direction corresponded to the location of ancient hollows in the present valleys of the tributaries of the Kama. It is believed that the upper Kama was connected with the Vychegda basin. The geological structure of the palaeovalley has recorded a long period of joint development of the hydrosystems of the Kama and the Vyatka. The basins were divided only in the Late Neo-Pleistocene. The rivers regenerated in the Middle and Late Neo-Pleistocene after the lakes had flowed into the Kolva-Vishera basin in the east and into the Pra-Vyatka basin in the west.
Keywords: drainage system, upper Kama, Vyatka, Keltma hollow, ice-dammed lakes, palaeovalleys, Neo-Pleistocene

1. Introduction

In the Middle Neo-Pleistocene, the northern part of the Kama region (Fig. 1) represented a plain open to the Pechora lowland in the north. The pattern of the river network and the flow direction differed from the current situation (Aprodov, 1948). Two river valleys were identified based on cores samples of sediments that fill the ancient deep valleys of the Kama-Pechora-Vychegda watershed. During different periods, upper courses of the Kama, the Vychegda, the Pechora and their tributaries likely belonged either to the White Sea basin, or to the Caspian Basin. The southern direction corresponded to the location of the palaeovalleys of the Pra-Kolva (with tributaries) and the Pra-Vishera (lower course). The northern direction corresponded to the location of ancient hollows in the present valleys of the tributaries of the Kama (the Urolka, the Sumych, the Timsher). It is believed that the upper Kama was connected to the Vychegda basin through the

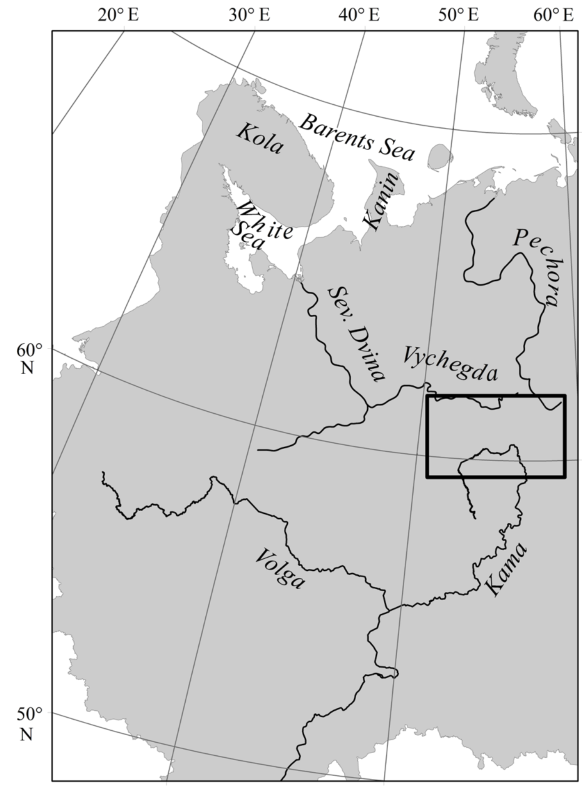

Figure 1. Overview map, North-Eastern European Russia. The investigated area shown in Fig. 2 is indicated

Keltma hollow after the Veslyana river merged with the Kosa river (Krasnov, 1948). The beginning of the glaciation led to the termination of the river flow in the northern direction. As a result, the upper courses of the Pechora and the Vychegda sent their flow to the southern Vyatka basin through the Keltma hollow, the Kama valley and the Vyatka-Kama watershed (Krasnov, 1948; Krotov, 1879; Dedkov and Sturman, 1992; Lavrov and Potapenko, 2005; Grosswald, 2009).

A number of researchers believe that the upper Kama basin represented a single drainage system in the Neo-Pleistocene. The Kama was the main river and its channel from the source to the Vishera mouth was uninterrupted. According to the latest data (Nazarov, 2017), this scheme of the upper Kama basin development describes general stages of the change in the direction and the scale of the development of channel processes in the Middle Neo-Pleistocene. The history of the geomorphological development of the valleys of the Kama tributaries remains poorly studied. These rivers were independent watercourses in the periglacial zone.

2. Materials and methods

Details of the drainage system of the Vychegda-Vyatka-Kama watershed were studied through the interpretation of satellite images, morphological and morphometric review of large-scale topographic maps. The remote-sensing data used included medium to high spatial resolution satellite images for various water-regime phases: Landsat-8, 15 m spatial resolution; SPOT-5, 2.5 m (panchromatic range) and 10 m (spectral channels) spatial resolution; SPOT-6, 2 m (panchromatic channel) and 8 m (spectral channels) spatial resolution. Riverbed features and fluvial depositional features were identified in satellite images using the following details: image hue variation and identification of channels and deltas of perennial and ephemeral streams.

3. Results

The uppermost section of the Kama (from the source to the Veslyana mouth) details the process of the channel network fragmentation at individual stages of the entire basin development. Detailed research on sand and gravel, and alluvial gold was carried in the Kirsa district of the Kirov region in the 1960s and the 1970s. The research provided quite comprehensive information on the structure of the Kirsa palaeovalley. Geological and geomorphological research on this old form and the Kama valley led to the conclusion about the existence of the Kirsa river in the Early and Middle Neo-Pleistocene (Dedkov and Sturman, 1992). The Kama was connected with the Vyatka valley through the Kirsa palaeovalley. On the right, a tributary flowed into the Kama. The source of the tributary was "... somewhere between Kay and Gainy" and had a reverse direction in relation to the current of the present Kama (Dedkov and Sturman, 1992, p. 53). These conclusions are confirmed by the left-sided asymmetry of the Kama valley (right-sided for the north-eastern tributary of the Pleistocene Kama) and the results of numerous measurements of the cross bedding of the Early Pleistocene (socle terraces) and Middle Pleistocene (Likhvinian interglacial) alluvium. The magnetic azimuths of the bed inclination was found to be in the intervals of 223–310° and 185–353°. The results showed that the flow at that time was in the western and south-western direction, towards the Vyatka. According to the researchers, such reorganisation of the river network could be connected with the fragmentation of the Dnieper glacier tongue. However, the neotectonic factor was not excluded as the primary cause of the separation of the upper Kama from the other parts of the basin (Dedkov and Sturman, 1992).

The history of the Upper Kama basin formation in the Middle Neo-Pleistocene has not been sufficiently studied today. This does not allow us to detail the problem until we understand the sequence of disturbances in the channel processes. The results of a comparative analysis of Quaternary deposit maps at different scales (Dubeikovskiy, 1979; Semenova, 2017; Chumakov et al., 1999) confirm these conclusions. The structure of alluvial complexes indirectly indicates a different direction of surface runoff during certain periods of the present Kama valley formation below and above its connection with the Kirsa palaeovalley. The development of the lacustrine-alluvial sediments of the Likhvinian interglacial bed (MIS 11) is characteristic of the northern section (palaeovalley – Kay). These complexes are recorded on the Kama valley slopes. Further, they extend to the Vyatka valley and the valleys of its tributaries through the Kirsa palaeovalley. As a result, a clear trace of the watercourse flow direction from the northeast to the southwest is visible. The Likhvinian interglacial alluvium is not mapped within the southern part of the valley of the present-day Kama (south of the Kirsa palaeovalley towards the source) (Dubeikovskiy, 1979). This fact indicates a relatively passive development of this section of the Kama valley in the Likhvinian interglacial.

According to this scheme of the river network formation, the upper Pra-Kama courses belonged to the Pra-Vyatka basin in the Early and Middle Neo-Pleistocene. The main river in the Veslyana-Kosa-Urolka basin (north of the source of the Kirsa river) is the Pra-Kosa. The long distance from the edge of the Moscow glacier, compared to the Pra-Veslyana, suggests a longer period of development as a permanent watercourse. During the Likhvinian interglacial, the Pra-Kosa (not the Pra-Kama) receiving the Pra-Veslyana as a left-bank tributary, and the Pra-Urolka downstream as a right-bank tributary, channelled its waters to the Vychegda basin through the Keltma hollow (Fig. 2A).

The periods of ice-dammed lakes formation in the Vychegda basin had a great impact on the relief and river valleys formation in the Upper Kama depression. The Upper Kama lacustrine

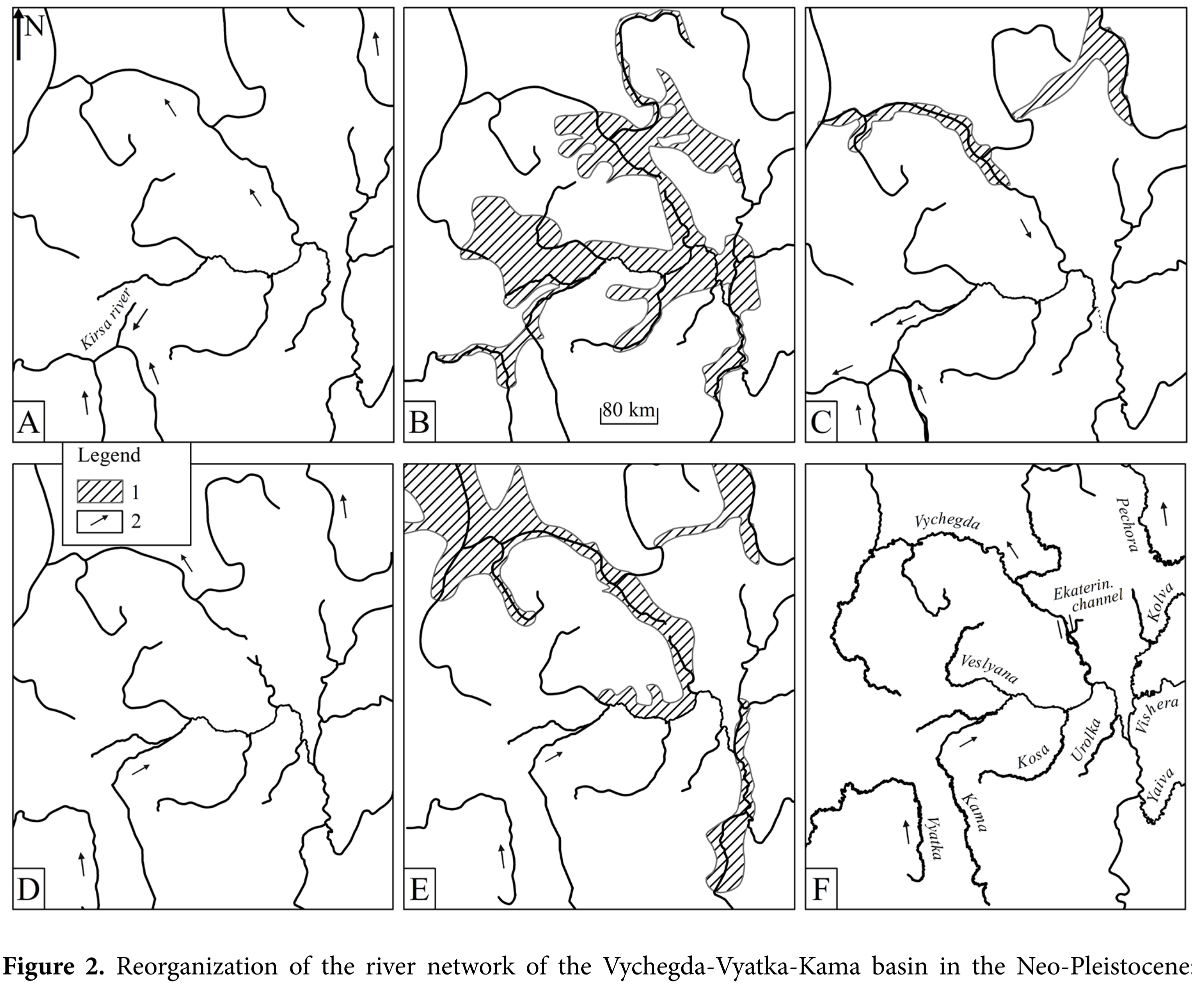

Figure 2. Reorganization of the river network of the Vychegda-Vyatka-Kama basin in the Neo-Pleistocene: A – River network in the Likhvinian interglacial (MIS 11); B – Middle Pleistocene ice-dammed lake (MIS 6); C – River network in the final stage of the Middle Pleistocene glacier termination (MIS 5 – MIS 4); D – River network in the Mikulino interglacial (MIS 4 – MIS 3); E – Late Pleistocene ice-dammed lake (MIS 3 – MIS 2); F – Modern river network (MIS 2 – MIS 1); 1 – Contour of ice-dammed lakes, 2 – Stream course

terrace with an elevation of 160–180 m and the Oziag terrace with an elevation of 130–135 m were formed as a result of the arrival of glacial waters through the Keltma spillway in the Middle and Late Neo-Pleistocene (Lavrov and Potapenko, 2005; Lysa et al., 2011).

The outflow of the rivers was restored after the disappearance of the lakes in the Middle and Late Neo-Pleistocene. The formation of watercourses was associated with the rate and duration of the processes of adaptation of river valleys to the relief of drained lake bottoms and depended on the direction of water discharge (in the east – into the Kolva-Vishera basin, in the west – into the Pra-Vyatka basin). At the end of the Moscow glaciation, the Pra-Kama was part of the Vyatka basin system and the Upper Kama depression received waters of the Vychegda and the Pechora through the Keltma spillway. During this period, the Urolka valley became a depression due to the drainage of glacial-lake water and flow of this large amount of water in the direction of the Vishera. The volume of the glacial water outflow at relatively low river flows during the stable glaciation (MIS 6) period did not significantly increase the newly formed valley until the very beginning of the termination period (Fig. 2B). The situation has changed radically as a result of rapid climate warming. The collapse of the glacier began and melting glacier waters fed the Upper Kama depression in a much larger volume through the Keltma hollow and through the depressions in the relief of the Veslyana-Lokchim watershed. Due to its small width and limited drainage capacity, the eastern pre-Vishera could not prevent the rise of the water level in the reservoir. This led to the formation of another palaeovalley in its western periphery. This initiated a long-term process of lake disappearance through the water outflow towards the Vyatka. The restoration of the Early Pleistocene Pra-Kama valley occurred southwest of the modern mouth of the Veslyana. As a result, the Kirsa river valley expanded. The process of the continuous flow of glacial water from the Vychegda basin left clear traces on the surface of the Upper Kama depression at the end of the Moscow glaciation (partly including the Mikulino interglacial). Drop-shaped bars were formed by a braided channel. This form of relief is up to 1-3 km long and up to 200 m wide. These ridges show contours of the channel of the watercourse with the western direction of the current in the area from the mouth of the Keltma hollow to the Gainy village. According to some researchers, the sharp end of a ridge shows the direction of the river (Zaretskaya, 2014; Chernov, 1983). At present, the ancient riverbed depression in some areas is used by the rivers Bortom and Chepets. The system of bar-shaped forms can be traced in the northern marshes (Oshlobskoe, Dzhurich-Nyur). This fact also indicates the existence of a water flow from the Vychegda basin (Fig. 2C).

The flow of water from the ice-dammed lake in the Vychegda basin through the upper Kama depression to the Vyatka basin (MIS 5 – MIS 4) explains the presence of the second (Late Weichselian) terrace above the floodplain in the Kirsa palaeovalley (Dubeikovskiy, 1979). The terrace is represented by layered fine-grained quartz sands with interlayers of loam and clay. The relative elevation of the terrace is 12–15 m within the palaeovalley. This is higher than its elevation in the valleys of the Kama (up to 12 m) and the Porysh (up to 8 m). The alluvium thickness is 18 m. The geological structure of the palaeovalley records a fairly long period of joint development of the hydrosystems of the Kama and the Vyatka. The division of the basins occurred only in the Late Neo-Pleistocene (Figs 2D, 2E). The cessation of the flow of the northern waters through the Keltma spillway and the restoration of the Kama riverbed in the area between the Kirsa palaeovalley and the Veslyana caused this disconnection. Thus, the main features of the upper Kama basin were formed only in the Late Valdai. Moreover, the Kama has since become the main river connecting its basin with the Vishera basin (Fig. 2F).

4. Conclusions

In the period from the Early to Late Neo-Pleistocene, the upper Pra-Kama basin was quickly incorporated into the drainage systems of the Pra-Vyatka and the Pra-Vychegda. The glacier terminus position was the first factor affecting the periodical changes in the drainage directions within the catchment area (cutting off the upper course of the Pra-Kama and redirecting the flow to the Pra-Vyatka basin). The formation of ice-dammed lakes was the second factor of river reorganization (discharge of "excess" water from the Pra-Vychegda basin into the Pra-Kama basin through the Keltma hollow). The present-day form of the upper Kama basin developed only at the end of the Late Neo-Pleistocene and since then the Kama has become the main river of the basin, connected with the Vishera basin.

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