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WATER RESOURCES AND THE REGIME OF WATER BODIES

On the Timing of the Epoch of Abundant River Flow in the Volga Basin

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Abstract—Large paleochannels with sizes far greater than the modern ones are widespread on the floodplains and low terraces of rivers in the Volga basin. These are indicators of higher values of river runoff in the end of the latest glacial epoch. The assessment of the time interval of the epoch of abundant runoff requires the determination of the age of large paleochannels. With this in view, drilling of large paleochannels has been carried out all over the Volga basin. Radiocarbon dating of the channel alluvium was carried out. The majority of dates lied within the time interval 14.5–17.0 thousand years ago, which suggests the conclusion that the epoch of abundant river flow approximately coincides in time with the early Khvalynian transgression of the Caspian Sea.

Keywords: large paleochannels, macromeanders, pleniglacial, last glacial period, lateglacial, radiocarbon dating

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INTRODUCTION

The past variations of surface runoff beyond the period of instrumental observations are studied by various methods—by the positions of cultural layers of archeological sites [3, 10, 33, 35, 49, 50], by geomorphological traces of extreme erosion events [21, 39–41], by the data of historical geography [9, 32], by quantitative paleoclimatic reconstructions using the method of modern analogues based on paleofloristic data [2, 29]. Changes in river water discharges in the geological past can be judged by the size of ancient river channels. The sizes of paleochannels in the East European Plain show appreciable variations over time [12, 16, 26, 27, 36, 43], thus suggesting considerable variations of river flow [18, 20]. These changes took place under abrupt temperature variations at the end of the last glacial period. In the period from about 26 to 19 thousand years ago, the so-called global maximum of the last glaciation with the lowest temperature took place. The major portion of the glacial epoch (pleniglacial) continued up to ~14.7 thousand years ago. The Late Glacial period that began after that included two epochs with contrasting temperature—a significant warming, which consisted of two phases—Bølling and Allerød (14.7–12.9 thousand years ago), and a cooling called the Younger Dryas (12.9–11.7 thousand years ago) [30].

Among the ancient river channels, which persisted in the landscapes of the floodplain and low terraces, of particular importance are the so-called large paleochannels, the size of which (the width of the paleochannel, meander wavelength) exceed the parameters of modern rivers by factors of 2–5 and more. Large paleochannels of meandering type are called *large meanders* or *macromeanders* [11]. They are widespread in the river valleys of the East European Plain [6–8, 12, 17, 29, 37, 47, 48] and Western Siberia [19, 46].

In the Volga basin, large paleochannels are practically ubiquitous [23, 47]. Their sizes were used to make quantitative estimates of the runoff depth at the end of the last glacial age, which showed that the annual runoff in different parts of the Volga River system was 1.5–2.5 greater than its present-day value, and that in the outlet section upstream of the Volga delta head was 1.7–2.0 times higher [22, 47]. It is shown that such an increase in the runoff was enough to maintain the shore line of the Caspian Sea at elevation close to the maximal levels of the Early Khvalynian transgression of the Caspian Sea; therefore, to explain this transgression one has not to substantiate the presence of additional water sources, such as glacial melt runoff and overflows between rivers basins [15, 22, 34, 47]. A remaining problem is the time boundaries of this epoch of abundant river runoff—to what extent do they agree with the chronology of Caspian level variations. The time interval of this epoch can be determined by instrumental dating of the time of active formation of large paleochannels. For the center of the

East-European Plain, this time is estimated at 18–13 thousand years ago [42]; however, this estimate for the Volga basin takes into account only few dates [47], which is not enough to give reliable estimates of the age of this epoch in the basin. The objective of this study is to obtain systematic data on the age of large paleochannels in the Volga basin and to use the results to determine the interval of the epoch of abundant river flow in the Late Weichselian epoch.

STUDY OBJECTS

Large paleochannels have different sizes and shapes even in the same rivers. This is due to changes in runoff and water discharges over space and time and the type of channel, depending on them [25]. In addition, the morphological elements of floodplain change and grade, resulting in that some landscape features erode and even disappear. The authors of this article accept the classification of large paleochannels from the study [14]. Overall, six types of large paleochannels are identified: inherited macromeanders, macromeanders–old riverbeds, meander cirques, rectilinear, systems of large meander scarfs, and branched.

The Volga basin contains the largest number of inherited large paleochannels—meanders of the modern river channel, which repeat the outlines of large meanders that have formed earlier under higher river discharge [23]. They are most common in narrow river valleys, where the rivers have less space for channel deformations. Since in such cases the modern rivers repeat the outlines of their ancient channels, we can estimate only the length of the slip-off slope (half of the wavelength) of macromenders and the menders of the present-day channel that have developed against their background (Fig. 1a). The ratio of the ancient and current channel widths cannot be determined by direct measurement. The width of the river in the period of formation of a large paleochannel can be estimated only indirectly based on hydrological-morphological relationships via the meander wavelength. The sizes of inherited macromeanders can be 5–6 times or more larger than the present ones, though the typical ratio in the Volga basin is 3–4 [22]. A large ratio of the meander wavelength of ancient and modern meanders can be also seen in meander cirques (the Tanyp River near Tangatarovo is an example) (Fig. 1c) and in systems of large meander scarfs (the Bol'shoi Irgiz River near Malaya Bykovka) (Fig. 1e), for which it is also impossible to measure the channel width. In other cases, the wavelength can be clearly seen and its width can be obtained by direct measurements, as, for example, in the rivers Sok (many clearly seen old-riverbed macromeanders) (Fig. 1b), Veslyana (a large straight channel near Onyl Village) (Fig. 1d) and Chagodoshcha (traces of a branching channel near the Merezha River inflow) (Fig. 1f).

In the case of inherited macromeanders, their age cannot be definitely assessed as late Weichselian (the last glacial period), especially, if their spurs are occupied by high terraces or even interfluve areas [23]. In addition, to determine the age by radiocarbon (^{14}C) method, we have to find alluvium containing organic materials (wood, plant macroremains, etc.). Because of this, the objects for drilling and further determination of the age were chosen among the macromeanders-old riverbeds, which persisted in the landscapes of floodplains outside of the meander-belt of the present-day river.

METHODS OF STUDY

To determine the time of the active development of a paleochannel, it is necessary to determine the age of its channel alluvium. For this purpose, drilling was carried out in large paleochannels, and the obtained core was separated into types of quaternary sediments, in particular, facial analysis of alluvium was carried out. The major portion of drilling operations was carried out with the use of Pride Mount 80 drilling unit, mounted on UAZ 3303, by an improved rotary drilling. The auger was screwed to 1–2 m with minimal deformation of deposits and next extracted with a core. The deposits were obtained on the surface in a maximally undisturbed state with preserved textures, newly formed structures, inorganic and organic inclusions, which could be studied in situ and sampled for various types of analysis.

The drilling sites were chosen before field expeditions with the use of remote sensing data. Space photographs were used to choose the most representative sites where paleochannels with measurable parameters could be clearly seen. Among the selected sites, optimal sites in terms of transport availability and practical use (no engineering communications) were chosen. The final choice of objects for drilling was carried out on site.

The borehole logs were separated in accordance with the classical concepts regarding the expected series of facies in the paleochannel [28] (from top to bottom): deposit of spring floods (as a rule, loamy, low-thickness, only in well-filled paleochannels), paleochannel filling (gyttja, peat, loam), channel (sand, gravel, pebble—commonly, in accordance with the particle size of the modern alluvium). The age of large paleochannels was determined by ^{14}C-method by organic residues contained in the channel alluvium. The samples for dating were taken at the drilling site from cleaned core. In some rare cases, large samples could be taken with large enough organic matter content in the form of dispersed organic matter or plant remains. Radiocarbon dating of such samples was carried out using the liquid scintillation (LSC) method in the Laboratory of Geomorphological and Paleogeographic Studies of the Polar Regions and the World

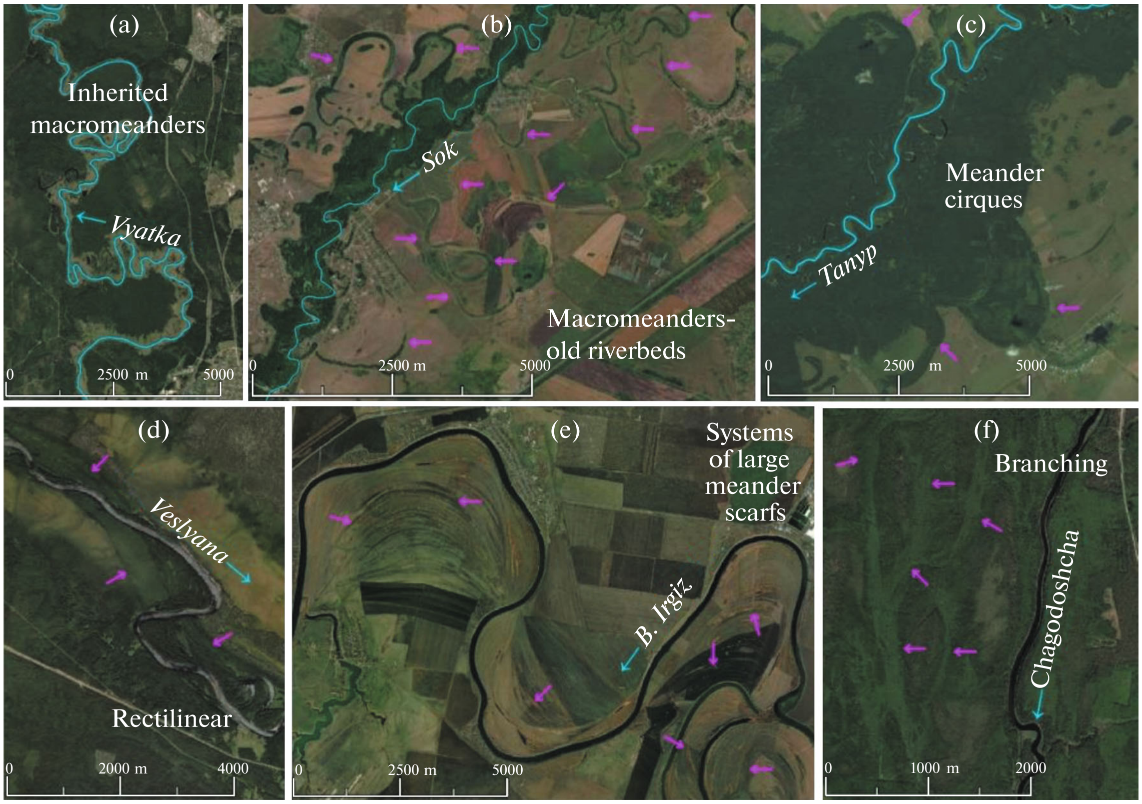

Fig. 1. Geomorphological types of high past river runoff in the river valleys in the Volga Basin.

Ocean, St. Petersburg State University (laboratory index LU). The standard procedure [1] was used. A fraction acceptable for dating was isolated from the sample and purified by successive treating by HCl and NaOH solutes. Next, the isolated fraction was converted through pyrolysis into elemental carbon (coal), from which lithium carbide was obtained through the interaction of coal with metal lithium at 800°C in vacuum. The lithium carbide was decomposed by water to obtain acetylene, which was converted to benzol over a vanadium-alumina silicate catalyst. Scintillators 2.5-diphenyloxazole (PPO) and 1.4-di-[2-(5-phenyloxazolyl)]-benzene (POPOP) were added to the purified benzol. Radiocarbon activity in a benzene sample was determined using a low-background liquid scintillation spectrometer Quantulus 1220. The results of measurements of the sample, background, and the standard were used to calculate the radiocarbon age.

Most often, the core was found to contain only small interlayers of disperse organic matter or plant remains, branches, in which the mass of organic carbon was not enough to measure the age by the LSC method. In such cases, the ^{14}C-age was determined with the use of accelerator mass spectrometry (AMS). Cleaning the samples from foreign impurities, isolating the dating fraction, obtaining graphite and pressing graphite targets for measuring ^{14}C, graphitization of standard samples for measurements were carried out at the Laboratory of Radiocarbon Dating and Electron Microscopy, Institute of Geography, Russian Academy of Sciences (laboratory index $IGAN_{AMS}$). The measurements were carried out at the Center for Applied Isotope Research at the University of Georgia USA).

Once the ^{14}C dates were obtained, they had to be converted to the astronomical time scale (calibrated). The calibration was carried out in the OxCal 4.4 Online [44] using the calibration curve IntCal20 [45]. The calibrated dates were represented as median values of the age (calendar years before present—cal. BP) with a standard deviation.

RESULTS AND DISCUSSION

A total of 11 dates were obtained for the channel alluvium of large paleochannels (Table 1). The date at a depth of 2.9 m in the Pizhma River was rejected as inversion (probably, a result of redeposition of more ancient organic matter). The distribution of the dates over age intervals is given in Fig. 2; in this case, one, more ancient date was taken for each paleochannel. In the plot in Fig. 2, five dates for large paleochannels of the Dubna (15840 ± 80, 15620 ± 100 and 15310 ± 80 cal. BP [13]) and the Upper Volga (16.7 ± 1.5 and 15.4 ± 1.0 cal. kiloyears BP, OSL-dates [38] are added).

Table 1. Radiocarbon dates of large paleochannels alluvium of rivers in the basins of the Volga and Northern Caspian region (TOC is dispersed organic mater or total organic carbon)

Point no., latitude/longitude	River	Depth from the surface, m	Dated material, host deposits	^{14}C age, y. a. (BP)	Calibrated age, y. a. (BP)	Laboratory index
19552, 57.1849° N 36.3356° E	Medvetista (left-bank tr. of the Volga)	1.25	TOC in loam with sand clusters	12805 ± 35	15280 ± 80	$IGAN_{AMS}$ 7353
Mk-19-03, 54.6765° N 41.9288° E	Moksha	3.2–3.3	TOC in interlayering of sand and loam	15075 ± 40	18520 ± 130	$IGAN_{AMS}$ 7719
		5.2–5.3		15410 ± 40	18744 ± 51	$IGAN_{AMS}$ 7720
20903, 54.5392° N 42.0455° E		3.7	TOC in sand with loam interlayers	13680 ± 40	16530 ± 90	$IGAN_{AMS}$ 9336
		4.4		13640 ± 40	16470 ± 80	$IGAN_{AMS}$ 9337
20910, 56.5050° N 53.0385° E	Izh	4.2	Plant macroremains in sand and loam interlayers	12400 ± 40	14530 ± 180	$IGAN_{AMS}$ 9678
20944, 57.7292° N 47.9323° E	Pizhma	2.9	TOC in sand and loam interlayers	13630 ± 50	16460 ± 91	$IGAN_{AMS}$ 9877
		4.35		12765 ± 50	15224 ± 86	$IGAN_{AMS}$ 9878
211041, 53.0011° N 51.2717° E	Samara	6.7–6.9	Plant macroremains in sand	12630 ± 160	14920 ± 330	LU-10550
211046, 53.2775° N 50.7860° E	Bol'shoi Kinel	4.4–4.6	Plant macroremains in sandy loam	13000 ± 250	15560 ± 400	LU-10552
211107, 50.6898° N 47.9882° E	Bol'shoi Uzen	9.0	Plant macroremains in interlayers of loam with silt and fine sand	13860 ± 230	16800 ± 330	LU-10558

According to the obtained data, the age of the channel alluvium in the examined large paleochannels mostly fall within the interval of 14.5–17.0 kiloyears BP. Two dates from the Moksha River paleochannel have an age of ~18.7 kiloyears BP. However, this paleochannel of the Moksha River is not greater than the present-day river, and, therefore, it can reflect the runoff of the river ~19 kiloyears BP, not related with large paleochannels.

According to the literary data generalized in [51], as well as the data on the basins of the upper [7] and middle Don [11, 14], and the upper and middle Dnieper [12, 29, 36, 37], large paleochannels formed in the Central and Eastern Europe 18–13 kiloyears BP. Panin et al. [37], due to earlier dates, attributed the beginning of the phase of high river runoff to an earlier period. Gelfan et al. [31] interpret dates earlier than 18 kiloyears BP (there are two of them) by channel alluvium as an indication to redeposition of organic material in alluvium. The results of this study suggest that the large paleochannels in the Volga basin formed in the period 17.0–14.5 kiloyears BP, i.e., in the late pleniglacial—early late glacial period, and their formation ceased after the beginning of the bölling-allerød warming (Fig. 2). The distribution of dates contains a gap in the interval 16.0–16.5 kiloyears BP; however, the available data are still too small to reliably interpret this as an indication to an interval between the two phases of high runoff. No territorial differences can also be seen between the formation times of large paleochannels: in different ecoregions and in different parts of the Volga basin, the dates show no systematic differences (Fig. 3).

Up to now, practically no attention has been paid to studying large paleochannels of river valleys underflooded by water of the Early Khvalynian basin. Large paleochannels could have formed there only after the retreat of the sea. According to recent data [4], the main phase of transgression with the highest level rise lasted from 17 to 15 kiloyears BP; however, it is still unclear, in what time period, the shoreline lied at an mean sea level (MSL) of ~22 m. According to [5], the maximum of transgression lasted up to 13.5 kiloyears BP, which is somewhat later than the time of cessation

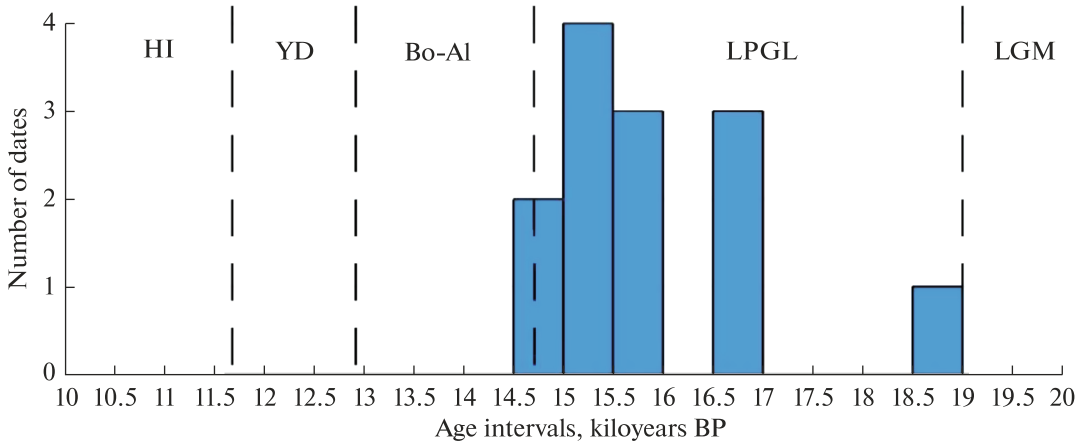

Fig. 2. Histograms of date distribution by channel alluvium of large paleochannels. Main climate epochs of the recent 20 kiloyears BP: before 19 kiloyears BP—last glaciation maximum (LGM), before 14.7—late pleniglacial (LPGL), before 12.9—warming bölling-allerød (Bo–Al), before 11.7—cooling late drias (YD), after 11.7—modern interglacial period (Holocene; Hl) (according to [30]).

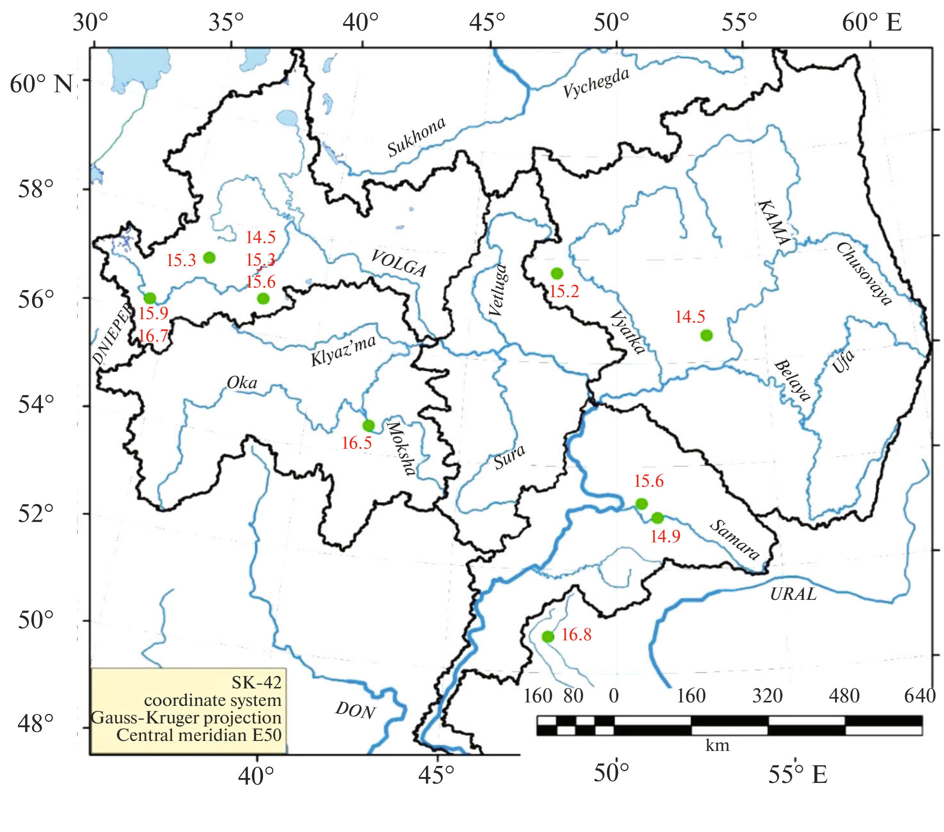

Fig. 3. Spatial positions of the dated large paleochannels in the Volga Basin and the median values of ^{14}C dates by channel alluvium. The green dots are boreholes with dated channel alluvium, the number near it is the age of the channel alluvium (kiloyears BP).

of abundant runoff (the age of the youngest large paleochannels) in the Volga basin. The channel alluvium of the large paleochannel of the Bol'shoi Uzen River, lying at an elevation of +23 m MSL, was analyzed to obtain a ^{14}C-date of ~16.8 kiloyears BP (Table 1), and the dated alluvium of this paleochannel lied at the level of +21 m MSL. The deposits of spring floods of the same river from a level of +24 m MSL yielded a ^{14}C-date of ~16.6 kiloyears BP [24]. These data suggest that the transgression was maximal before

16.5–17 kiloyears BP; however, it is impossible to say this with confidence, because the data obtained so far are limited.

CONCLUSIONS

Large paleochannels in the Volga Basin formed at the end of the Late Pleistocene within the time interval 17.0–14.5 kiloyears BP, i.e., in the late pleniglacial–early interstadial (warming) bölling-allerød. No difference was found between the formation time of large paleochannels all over the Volga basin. The dates by the deposits of channel alluvium in large paleochannels of the Volga basin are in a good agreement with the latest data on the time of the early khvalynian transgression of the Caspian Sea.

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CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

REFERENCES

1. Arslanov, Kh.A., *Radiouglerod: geokhimiya i geokhronologiya* (Radiocarbon: Geochemistry and Geochronology), Leningrad: Izd. Leningrad. Univ., 1987.
2. Borisova, O.K., Landscape and climatic conditions in the central East European Plain in the last 22 thousand years: reconstruction based on paleobotanical data, *Water Resour.*, 2021, vol. 48, no. 6, pp. 886–896. https://doi.org/10.1134/S0097807821060038
3. Karmanov, V.N., Chernov, A.V., Zaretskaya, N.E., Panin, A.V., and Volokitin, A.V., Experience in the application of the data of paleochannel studies in archeology: case study of the Middle Vychegda (Northeastern European Russia), *Arkheol., Etnogr. Antropol. Evrazii.*, 2013, vol. 54, no. 2, pp. 109–119.
4. Kurbanov, R.N., Belyaev, V.R., Svistunov, M.I., Butuzova, E.A., Solodovnikov, D.A., Taratunina, N.A., and Yanina, T.A., New data on the age of the Early Khvalynian transgression of the Caspian Sea, *Izv. RAN. Ser. Geogr.*, 2023, vol. 87, no. 3, pp. 403–419. https://doi.org/10.31857/S2587556623030081
5. Makshaev, R. R. and Tkach, N. T.: Chronology of Khvalynian stage of the Caspian Sea according to radiocarbon dating, *Doklady Earth Sciences,* 2022, vol. 507, S51–S60. https://doi.org/10.1134/S1028334X22601341
6. Matlakhova E.Yu. Macromeanders of the Vorona River as evidences of high river runoff in the Late Glacial., *Lomonosov Geography Journal*, 2021, no. 2, pp. 103–109.
7. Matlakhova E.Yu., Panin A.V., Belyaev V.R., Borisova O.K. The Upper Don river valley evolution in the End of the Late Pleistocene. *Lomonosov Geography Journal*, 2019, no. 3, pp. 83–92.
8. Matlakhova E.Yu., Ukraintsev V.Yu., Panin A.V. The history of the Moksha River valley development in the end of the Late Pleistocene. *Geomorfologiya*, 2021, vol. 52, no. 3, pp. 105–115. https://doi.org/10.31857/S043542812103007X
9. Panin, A.V., Ivanova, N.N., and Golosov, V.N., The river network and the processes of erosion and accumulation in the Upper Don Basin, *Water Resour.*, 1997, vol. 24, no. 6, pp. 609–617.
10. Panin, A.V. and Nefedov, V.S., Analysis of variations in the regime of rivers and lakes in the Upper Volga and Upper Zapadnaya Dvina based on archaeological–geomorphological data, *Water Resour.*, 2010, vol. 37, no. 1, pp. 16–32. https://doi.org/10.1134/S0097807810010021
11. Panin, A.V. and Sidorchuk, A.Yu., Macromeanders ("large meanders"): problems of origin and interpretation, *Vestn. Mosk. Univ.*, Ser. 5, *Geografiya*, 2006, no. 6, pp. 14–22.
12. Panin, A.V., Sidorchuk, A.Yu., Baslerov, S.V., Borisova, O.K., Kovalyukh, N.N., and Sheremetskaya, E.D., The main stages in the history of river valleys in the central Russian Plain in the Late Valdai and Holocene: results of studies in the middle reaches of the Seim River, *Geomorfologiya*, 2001, no. 2, pp. 19–34.
13. Panin, A.V., Sorokin, A.N., Bricheva, S.S., Matasov, V.M., Morozov, V.V., Smirnov, A.L., Solodkov, N.N., and Uspenskaya, O.N., The history of landscape formation in Zabolotskii peat bog in the context of initial colonization of Dubninskaya lowland (Upper Volga basin), *Vestn. Arkheol.*, 2022, vol. 57, no. 2, pp. 85–100. https://doi.org/10.20874/2071-0437-2022-57-2-7
14. Panin, A.V., Sidorchuk, A.Yu., and Vlasov, M.V., Powerful Late-Valdai river runoff in the Don basin, *Izv. RAN. Ser. Geogr.*, 2013, no. 1, pp. 118–129.
15. Panin, A.V., Sidorchuk A.Yu., and Ukraintsev V.Yu., The contribution of glacial melt water to annual runoff of River Volga in the Last Glacial Epoch, *Water Resour.*, 2021, vol. 48, no. 6, pp. 877–886. https://doi.org/10.1134/S0097807821060142
16. Sidorchuk, A.Yu., Borisova, O.K., Kovalyukh, N.N., Panin, A.V., and Chernov, A.V., Paleohydrology of the Lower Vychegda in the Late Glacial and Holocene, *Vestn. Mosk. Univ., Ser. 5, Geografiya*, 1999, no. 5, pp. 34–41.
17. Sidorchuk, A.Yu., Borisova, O.K., and Panin, A.V., Late Valdai paleochannels of rivers in the Russian Plain, *Izv. RAN., Ser. Geogr.*, 2000, no. 6, pp. 73–78.
18. Sidorchuk, A.Yu., Panin, A.V., and Borisova, O.K., Climate-induced changes in surface runoff on the North-Eurasian plains during the Late Glacial and Holocene, *Water Resour.*, 2008, vol. 35, no. 4, pp. 386–396. https://doi.org/10.1134%2FS0097807808040027
19. Sidorchuk, A.Yu., Panin, A.V., and Borisova, O.K., Late Glacial paleochannels of West Siberian rivers, *Izv. RAN, Ser. Geogr.*, 2008, no. 2, pp. 67–75.

20. Sidorchuk, A.Yu., Panin, A.V., and Borisova, O.K., River runoff decrease in North-Eurasian plains during the Holocene Optimum, *Water Resour.*, 2012, vol. 39, no. 1, pp. 69–81. https://doi.org/10.1134/S0097807812010113
21. Sidorchuk, A.Yu., Panin, A.V., Borisova, O.K., and Eremenko, E.A., Geomorphological approaches to evaluating river runoff in the geological past (art. 3. Analysis of the structure of stream network), *Geomorfologiya*, 2018, no. 1, pp. 18–32. https://doi.org/10.7868/S0435428118010029
22. Sidorchuk, A.Yu., Ukraintsev, V.Yu., and Panin, A.V., Estimating annual Volga runoff in the Late Glacial Epoch from the size of river paleochannels, *Water Resour.*, 2021, vol. 48, no. 6, pp. 864–876. https://doi.org/10.1134/S0097807821060178
23. Ukraintsev, V.Y. Geomorphological Evidence of High River Runoff in the Volga Basin during the Late Glacial. *Dokl. Earth Sc.*, 2022, vol. 506 (Suppl. 1), S1–S6. https://doi.org/10.1134/S1028334X2260030X
24. Ukraintsev, V.Yu., Panin, A.V., Zakharov, A.L., Kirillova, I.V., Uspenskaya, O.N., and Yanina, T.A., New data on river valley structures in the Northern Caspian Region, *Issledovaniya prirody i obshchestva v usloviyakh global'nykh transformatsii. Sb. materialov XV vseros. molodezhnoi nauch. shk.-konf. "Meridian"* (Studying Nature and Community under Global Transformations. Proc. XV Russ. Young. Sci. School-Conf. Meridian), Moscow, Institute of Geography, Russian Academy of Sciences, 2023, pp. 240–246.
25. Chalov, R.S., Zavadskii, A.S., and Panin, A.V., *Rechnye izluchiny* (River Bands), Moscow: Mosk. Univ., 2004.
26. Chernov, A.V. Morphology and History of Development of the Moscow River Valley in the Late Glacial and Holocene. *Dokl. Earth Sc.*, 2022, vol. 506 (Suppl. 1), S19–S32. https://doi.org/10.1134/S1028334X22700180
27. Chernov, A.V., Zaretskaya, N.E., and Panin, A.V., Evolution and dynamics of the upper and middle Vychegda in Holocene, *Izv. RGO*, 2015, vol. 147, no. 5, pp. 27–49.
28. Shantser, E.V., Alluvium of lowland rivers and its role in understanding the regularities in the structure and formation of alluvial suites, *Tr. Inst. Geol. Nauk, Akad. Nauk SSSR*, 1951, no. 135.
29. Borisova, O., Sidorchuk, A., and Panin, A., Palaeohydrology of the Seim River basin, Mid-Russian Upland, based on palaeochannel morphology and palynological data, *Catena*, 2006, vol. 66, pp. 53–73. https://doi.org/10.1016/j.catena.2005.07.010
30. Cohen, K. and Gibbard, P., Global chronostratigraphical correlation table for the last 2.7 million years, version 2019 QI-500, *Quaternary Int.*, 2019, vol. 500, pp. 20–31. https://doi.org/10.1016/j.quaint.2019.03.009
31. Gelfan, A., Panin, A., Kalugin, A., Morozova, P., Semenov, V., Sidorchuk, A., Ukraintsev, V., Ushakov, K., Hydroclimatic processes as the primary drivers of the Early Khvalynian transgression of the Caspian Sea: new developments, *Hydrol. Earth System Sci.*, 2024, vol. 28, pp. 241–259. https://doi.org/10.5194/hess-28-241-2024
32. Golosov, V. and Panin, A., Century-scale stream network dynamics in the Russian Plain in response to climate and land use change, *Catena*, 2006, vol. 66, pp. 74–92. https://doi.org/10.1016/j.catena.2005.07.011
33. Karmanov, V., Zaretskaya, N., Panin, A., and Chernov, A., Reconstruction of local environments of ancient population in a changeable river valley landscape (the middle Vychegda River, Northern Russia), *Geochronometria*, 2011, vol. 38, no. 2, pp. 128–137. https://doi.org/10.2478/s13386-011-0018-5
34. Kislov, A., Panin, A., and Toropov, P., Current status and palaeostages of the Caspian Sea as a potential evaluation tool for climate model simulations, *Quaternary Int.*, 2014, vol. 345, pp. 48–55. https://doi.org/10.1016/j.quaint.2014.05.014
35. Lapteva, E., Zaretskaya, N., Lychagina, E., Trofimova, S., Demakov, D., Kopytov, S., and Chernov, A., Holocene vegetation dynamics, river valley evolution and human settlement of the upper Kama valley, Ural region, Russia, *Vegetation History and Archaeobotany*, 2023, vol. 32, pp. 361–385. https://doi.org/10.1007/s00334-023-00913-5
36. Panin, A., Adamiec, G., Arslanov, K., Bronnikova, M., Filippov, V., Sheremetskaya, E., Zaretskaya, N., and Zazovskaya, E., Absolute chronology of fluvial events in the Upper Dnieper river system and its palaeogeographic implications, *Geochronometria*, 2014, vol. 41, no. 3, pp. 278–293. https://doi.org/10.2478/s13386-013-0154-1
37. Panin, A., Adamiec, G., Buylaert, J.-P., Matlakhova, E., Moska, P., and Novenko, E., Two Late Pleistocene climate-driven incision/aggradation rhythms in the middle Dnieper River basin, west-central Russian Plain, *Quaternary Sci. Rev.*, 2017, vol. 166, pp. 266–288. https://doi.org/10.1016/j.quascirev.2016.12.002
38. Panin, A., Baranov, D., and Moska, P., Rates of postglacial incision of the upper Volga river estimated by luminescence dating of the terrace staircase, *Practical Geography and XXI Century Challenges*, Moscow: Inst. Geogr. RAS Publ., 2018, pp. 569–574. https://doi.org/10.15356/IGRAS100CONF_V1
39. Panin, A., Borisova, O., Belyaev, V., Belyaev, Yu., Eremenko, E., Fuzeina, Y., Sheremetskaya, E., and Sidorchuk, A., Evolution of the upper reaches of fluvial systems within the area of the East European Plain glaciated during MIS 6, *Quaternary*, 2022, vol. 5, no. 1, pp. 1–26. https://doi.org/10.3390/quat5010013
40. Panin, A., Borisova, O., Konstantinov, E., Belyaev, Yu., Eremenko, E., Zakharov, A., and Sidorchuk, A., The Late Quaternary evolution of the upper reaches of fluvial systems in the southern East European Plain, *Quaternary*, 2020, no. 4, A. 31. https://doi.org/10.3390/quat3040031
41. Panin, A., Fuzeina, Yu., Karevskaya, I., and Sheremetskaya, E., Mid-Holocene gullying indicating extreme hydroclimatic events in the center of the Russian Plain, *Geographia Polonica*, 2011, vol. 84, pp. 95–115. https://doi.org/10.7163/GPol.2011.1.6

42. Panin A. and Matlakhova, E., Fluvial chronology in the East European Plain over the last 20 ka and its palaeohydrological implications, *Catena*, 2015, vol. 130, pp. 46–61.
https://doi.org/10.1016/j.catena.2014.08.016

43. Panin, A., Sidorchuk, A., and Chernov, A., Historical background to floodplain morphology: Examples from the East European plain, *Floodplains: Interdisciplinary Approaches*, London: Geol. Soc. Special Publ., 1999, vol. 163, pp. 217–229.
https://doi.org/10.1144/GSL.SP.1999.163.01.17

44. Ramsey, C.B., Bayesian analysis of radiocarbon dates. *Radiocarbon*, 2009, vol. 51, no. 1, pp. 337–360.
https://doi.org/10.1017/S0033822200033865

45. Reimer, P.J., Austin, W.E., Bard, E., Bayliss, A., Blackwell, P.G., Ramsey, C.B., Butzin, M., Cheng, H., Edwards, R.L., Friedrich, M., Grootes, P., Guilderson, T., Hajdas, I., Heaton, T., Hogg, A., Hughen, A., Kromer, B., Manning, S., Muscheler, P., Palmer, J., Pearson, C., Plicht, J., Reimer, R., Richards, D., Scott, E., Southon, J., Turney, C., Wacker, L., Adolphi, F., Büntgen, U., Capano, M., Fahrni, S., Fogtmann-Schulz, A., Friedrich, R., Köhler, P., Kudsk, S., Miyake, F., Olsen, J., Reinig, F., Sakamoto, M., Sookdeo, A., Talamo, S., The IntCal20 Northern Hemisphere radiocarbon age calibration curve (0–55 cal kBP), Radiocarbon, 2020, vol. 62, no. 4, pp. 725–757.
https://doi.org/10.1017/RDC.2020.41

46. Sidorchuk, A., The large rivers of the past in West Siberia: unknown hydrological regimen, *Water*, 2023, vol. 15, A. 258.
https://doi.org/10.3390/w15020258

47. Sidorchuk, A., Panin, A., and Borisova, O., Morphology of river channels and surface runoff in the Volga River basin (East European Plain) during the Late Glacial period, *Geomorphology*, 2009, vol. 113, pp. 137–157.
https://doi.org/10.1016/j.geomorph.2009.03.007

48. Sidorchuk, A., Panin, A., and Borisova, O., Surface runoff to the Black Sea from the East European Plain during Last Glacial Maximum–Late Glacial time, *Geology and Geoarchaeology of the Black Sea Region: Beyond the Flood Hypothesis*, Geological Society of America. Special Paper, 2011, pp. 1–25.
https://doi.org/10.1130/2011.2473(01)

49. Syrovatko, A., Panin, A., Troshina, A., and Zaretskaya, N., Magnitude and chronology of extreme floods in the last 2 ka based on the stratigraphy of a riverine archeological site (Schurovo settlement, middle Oka River, Central European Russia), *Quaternary Int.*, 2019, vol. 516, pp. 83–97.
https://doi.org/10.1016/j.quaint.2018.10.002

50. Syrovatko, A., Zaretskaya, N., Troshina, A., and Panin, A., Radiocarbon chronology of the Schurovo burial mound cremation complex (Viking Times, Middle Oka River, Russia), *Radiocarbon*, 2012, vol. 54, no. 3, pp. 771–781.
https://doi.org/10.1017/S0033822200047421

51. Vandenberghe, J. and Sidorchuk, A., Large palaeomeanders in Europe: distribution, formation process, age, environments and significance, *Palaeohydrology. Springer Cham*, 2020, pp. 169–186.
https://doi.org/10.1007/978-3-030-23315-0_9