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СТРОЕНИЕ ПОЙМЫ РЕКИ МОКШИ КАК КЛЮЧ К ПОЗДНЕПЛЕЙСТОЦЕНОВОЙ ИСТОРИИ РАЗВИТИЯ ДОЛИНЫ

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Геоморфологической особенностью изученного участка долины р. Мокши (бассейн средней Оки) является проявление в рельефе поймы многочисленных крупных палеорусел (макроизлучин), являющихся свидетельствами мощного речного стока во время их формирования. Для установления истории развития долины р. Мокши был изучен ключевой участок в ее нижнем течении от устья р. Цны до устья р. Мокши. Основываясь на результатах бурения, геоморфологического и литологического анализа, радиоуглеродного AMS-датирования отложений, были выделены следующие стадии развития долины р. Мокши в позднем плейстоцене. 1) Около 40–30 тыс. л. н. увеличение речного стока, обусловленное климатическими изменениями, привело к врезанию реки глубже современного уровня. 2) После этого сильное иссушение климата и снижение водности реки привели к заполнению долины (наиболее сильное иссушение климата и соответствовавшая ему аккумуляция относятся ко времени LGM, около 23–20 тыс. л. н.). 3) Новое увеличение водности реки 18.5–12 тыс. л. н. привело к образованию больших палеорусел (макроизлучин) и значительному расширению днища долины. 4) В голоцене речной сток снова уменьшился, а параметры русла стали близки к современным.

Ключевые слова: макроизлучины (большие палеорусла), история развития речных долин, палеогеография плейстоцена, флювиальная геоморфология

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1. INTRODUCTION

Large paleochannels (macromeanders) are widespread on floodplains and low terraces in the river valleys of the East European Plain (Sidorchuk et al., 2000; Sidorchuk et al., 2011). The parameters of macromeanders are several times bigger than the characteristics of the modern rivers. As previous studies show such large paleochannels were formed over the periglacial zone of the Last Glaciation. These periglacial rivers were formed under conditions of high spring runoff. Formation of large paleochannels is usually associated with the Late Glacial (the end of MIS 2) (Panin et al., 2013).

The occurrence of macromeanders also characterizes the Moksha River valley in its lower part. Probably, the lower part of the Moksha river valley between the Tsna River confluence and the mouth of the Moksha River seems the best place to study macromeanders all over the Oka Basin. A great number of paleochannels are well preserved at the key site (fig. 1). Paleochannels of the Moksha River may be divided into two groups by their size: small paleochannels have the same parameters as the modern river channel, large paleochannels (macromeanders) are several times bigger.

We studied both large and small paleochannels to reconstruct palaeohydrology and history of the Moksha River valley development in the Late Pleistocene. Large paleochannels correspond to the time of high river runoff. The oldest ones of small paleochannels were studied to know the time of lowering of the river runoff.

The dating of the deposits from the paleochannels and the river valley bottom made it possible to reconstruct the Late Pleistocene history of the Moksha River valley development and to estimate changes in the river runoff during this period.

2. METHODS

In our study we used field and laboratory methods. Boreholes in large and small paleochannels were made during fieldwork in August-September 2019 and September 2020. Detailed lithological description was

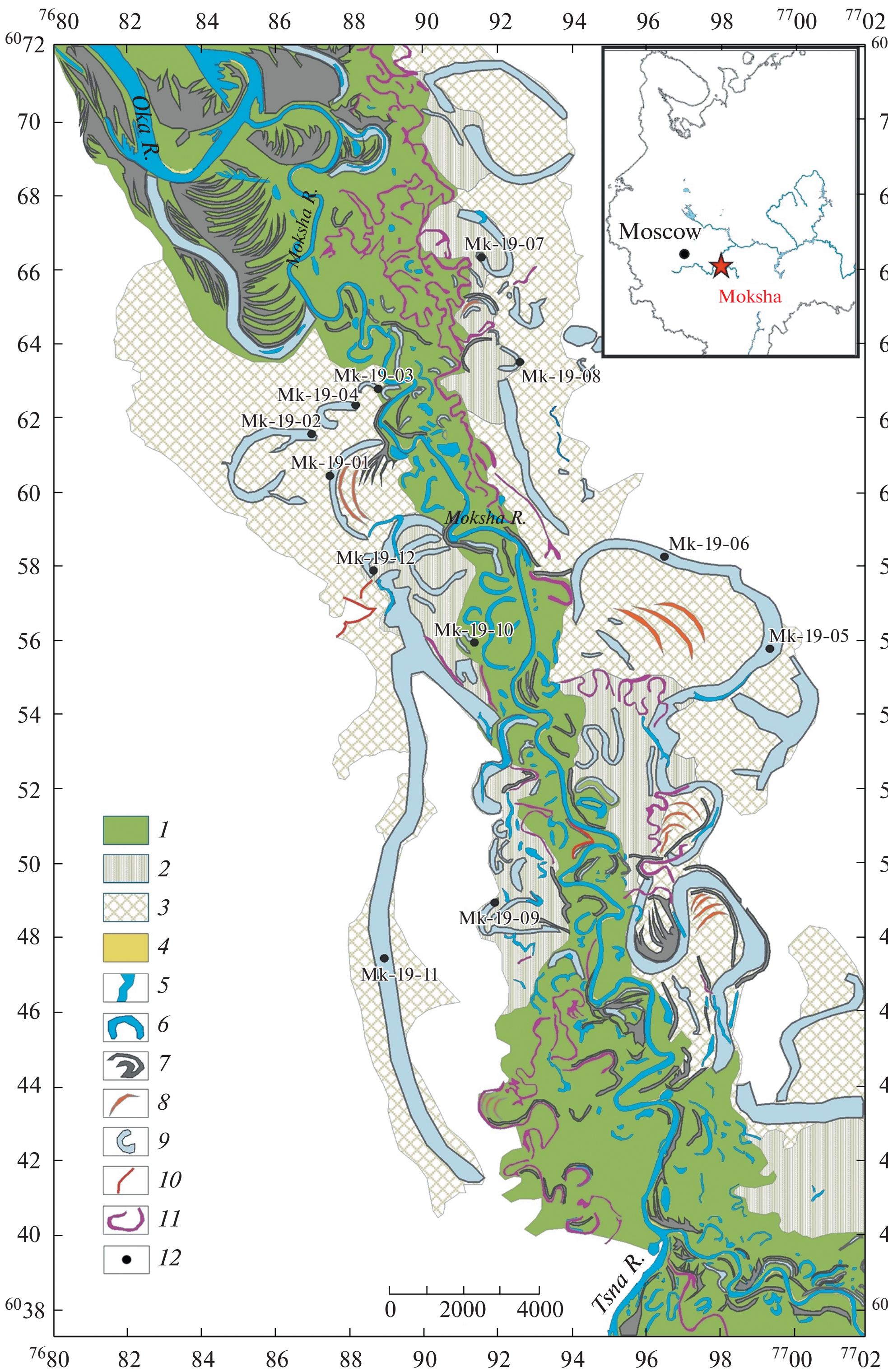

Fig. 1. Geomorphological map of the Moksha River floodplain.

Floodplain: 1 – Late Holocene, *2* – Early Holocene, *3* – Late Pleistocene high; *4* – point bars; *5* – modern river channel; *6* – oxbow lakes; *7* – natural levees; *8* – scroll bars; *9* – palaeochannels; *10* – cut banks; *11* – floodplain channels; *12* – location of boreholes.

Рис. 1. Геоморфологическая карта ключевого участка поймы р. Мокши.

Пойма: 1 – позднеголоценовая, *2* – раннеголоценовая, *3* – позднеплейстоценовая; *4* – прирусловые отмели; *5* – современное русло реки; *6* – старицы; *7* – прирусловые валы; *8* – гривы; *9* – палеорусла; *10* – эрозионные уступы; *11* – русла пойменных проток; *12* – положение скважин.

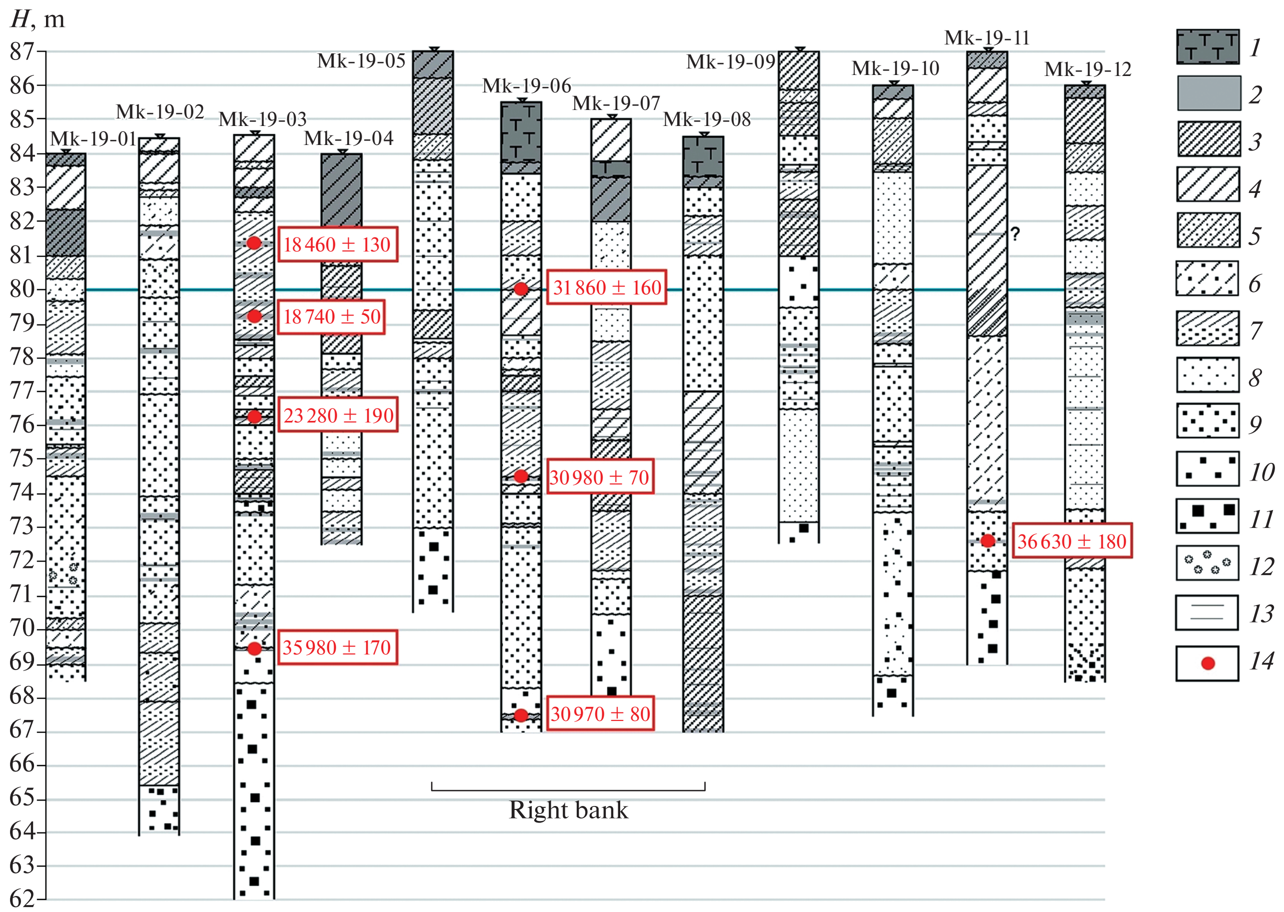

Fig. 2. Lithological structure of the boreholes in the Moksha River valley.

1 – peat; *2* – peat content, organic interlayers; *loam: 3* – heavy, *4* – medium, light loam, *5* – sandy interlayers; *sand: 6* – silted, sandy loam, *7* – interlayering of sand and loam, *8* – fine, *9* – fine-medium, *10* – medium-coarse, *11* – coarse with inclusions of gravel; *12* – large carbonate concretions; *13* – interlayers of sand in loam, loam in sand; *14* – radiocarbon dates (calibrated). The blue line is the current low water level.

Рис. 2. Литологические колонки скважин в долине р. Мокши.

1 – торф; *2* – оторфованность, прослои, богатые органикой; *суглинок: 3* – тяжелый, *4* – средний, легкий, *5* – опесчаненный; *песок: 6* – заиленный, супесь, *7* – переслаивание песка и суглинка, *8* – тонкозернистый, *9* – мелко-среднезернистый, *10* – средне-крупнозернистый, *11* – крупно-грубозернистый, с включениями гравия и гальки; *12* – крупные карбонатные конкреции; *13* – прослои песка в суглинке, суглинка в песке; *14* – радиоуглеродные даты (калиброванные). Голубой линией показан современный меженный урез воды в реке.

made for all boreholes in field. Organic material from alluvium of the river valley bottom was sampled to make radiocarbon (AMS) dating to find the time of river incision and aggradation, paleochannels' formation and infilling.

Radiocarbon (AMS) dating was done in the Laboratory of Radiocarbon Dating and Electronic Microscopy of the Institute of Geography (Russian Academy of Sciences, Moscow). Radiocarbon dates were calibrated (IntCal20) (Reimer et al., 2020) using the online version of OxCal 4.4 program (Bronk Ramsey, 2009).

3. RESULTS AND DISCUSSION

In our research we got data about morphology, geological structure and age of alluvial sediments from the infilling of the Moksha River valley bottom on the key site.

Summarizing the geomorphological data from the Moksha River valley the geomorphological map of the floodplain of the studied part of the valley was completed (fig. 1). Lithology of the studied boreholes can be found on the fig. 2.

3.1. Morphology of the Moksha River valley on the key site. Wide floodplain and two levels of terraces are present in the studied reach of the Moksha River valley. The height of the floodplain is from 1 to 6 m, of the first terrace – about 9–11 m, of the second terrace – 18–22 m. The width of the valley in the study area is about 14–16 km, but sometimes it can reach 20–22 km and more. The width of the floodplain is about 12–14 km.

Table 1. Dates of alluvium from the Moksha River valley infilling
Таблица 1. Даты по аллювию из заполнения долины р. Мокши

Laboratory number	Borehole	Depth, m	^{14}C Age*, years BP	Calibrated Age, years BP
IGAN-7719	Mk-19-03	3.20–3.30	15075 ± 40	18460 ± 130
IGAN-7720	Mk-19-03	5.20–5.30	15410 ± 40	18740 ± 50
IGAN-7723	Mk-19-03	8.35–8.40	19320 ± 55	23280 ± 190
IGAN-7728	Mk-19-03	15.50–15.60	31630 ± 120	35980 ± 170
IGAN-7721	Mk-19-06	5.40–5.45	27950 ± 90	31860 ± 160
IGAN-7724	Mk-19-06	10.60–10.70	26690 ± 80	30980 ± 70
IGAN-7729	Mk-19-06	18.00–18.10	26660 ± 80	30970 ± 80
IGAN-7727	Mk-19-11	14.40–14.45	32320 ± 135	36630 ± 180

Note: * – all dates were made by total organic carbon (TOC).

Moksha has a meandering channel. At the studies site, the Moksha River has a wide floodplain with large and small paleochannels on its surface. Small paleochannels have the same parameters as the modern river channel: their width is about 100–150 m, wavelength is between 300–400 and 600–700 m. Large paleochannels' parameters are few times bigger: their width is about 250–300 m, wavelength is about 1500–2000 m (fig. 1).

3.2. Geological structure of the paleochannels of the Moksha River valley on the key site. The sediment infill of the Moksha River paleochannels is usually presented by the alternation of sands and loams, underlaid by medium and coarse sands (presumably, channel alluvium) (fig. 2). Usually under these channel alluvial sands one can find the continuing alternation of sands and loams, and only under this alternation – clear coarse channel sands. Apparently, all these sediments are different age generations of alluvial infilling of the valley (or infilling of paleochannels of different age). So, mostly it is unclear where the borders between different by age alluvial layers are situated.

Visual interpretation of the structure of the boreholes can also be difficult due to the sandy nature of the underlying pre-Quaternary deposits (Geologocheskaya..., 1998). Sometimes the contact with underlying marine sediments can be unclear.

Thereby, the following dating strategy was chosen. Instead of analyzing single samples in each borehole we decided to study in detail one borehole in a large paleochannel (Mk-19-06) and one borehole in a small paleochannel (Mk-19-03). We supposed that the results would make it possible to determine the borders between different alluvial units and the thickness of paleochannels' infilling. In addition we analyzed one more borehole in a big hollow between two fragments of the low terrace on the left bank of the Moksha River (Mk-19-11).

3.3. Geochronology of the alluvial infilling of the Moksha River valley on the key site. The borehole Mk-19-03 was situated in a small (modern-size) paleochannel (fig. 1). It seems that the infilling of this small paleochannel has thickness of less than 3 m and its age was not determined (because the upper part of this infilling did not contain the material suitable for dating). Up to the depth 2.3 m the infilling was represented mostly by loamy sediments, in the lower part – by interlayering of sand and loam. The deposits at the depth 3.2–3.3 m were dated 18460 ± 130 cal years BP, at the depth 5.2–5.3 m – 18740 ± 50 cal years BP (fig. 2, tabl. 1). These two dates correspond to the previous stage of the Moksha River valley development. Both dates were obtained from total organic carbon; dated layer (up to the depth of 5.9 m) is pure fine sand with interlayers of loam.

Below 5.9 m there were mostly medium sands with interlayers of loam and below 10.5 m the sands became coarse and the number of loam interlayers became much less. The alluvial sediments from the depth 8.4 and 15.5 m were dated to 23280 ± 190 and 35980 ± ± 170 cal years BP respectively.

The borehole Mk-19-06 was situated in a large paleochannel (macromeander) on the right bank of the Moksha River. The upper 1.7 m of the deposits were presented by peat, then up to the depth of 5.1 m the paleochannel's infilling was presented by medium and fine-medium sand with interlayers of loam. It seems that the infilling of this large paleochannel was not dated because there was no organic material in the upper 5 m (except for the peat layer in the top part of the paleochannel, but this peat is definitely much younger than the time of the paleochannel formation).

Below 5.1 m the next alluvial layer started. This layer was presented by loam with interlayers of sand or by sandy loam. Downwards the thickness of sandy interlayers increased and at the depth of 11 m sands started to prevail. Between 11 and 17 m sands from fine in the upper part of the strata become medium and then medium-coarse at the lower part (at depth about 17 m). These alluvial deposits were dated at the depths of 5.4, 10.6 and 18 m and showed very close ages:

31860 ± 160, 30980 ± 70 и 30970 ± 80 cal years BP respectively.

According to the topography and morphology of the valley at the key site the borehole Mk-19–11 was situated in a paleochannel of the Moksha River, or (more likely) in a paleo-valley of the Moksha tributary Tsna River. The second interpretation is supported by the large width of the hollow, much more than width of the large paleochannels of the Moksha River, and also by the rectilinear shape of the hollow, not typical for macromeanders of Moksha.

The structure of the borehole Mk-19-11 was the following. The upper 3.3 m were presented by interlayering of sandy loam, loam and fine sand. Then from 3.3 m to 8.3 m the thick layer of medium loam was described that changed to heavy loam in the lower part of the layer. From the depth of 8.3 m fine sand started, from 13.5 m it changed to medium sand and from 15.2 m – coarse sand with inclusions of gravel. The deposits on the depth 14.4 m were dated to 36630 ± ± 180 cal years BP. From the depth of 17 m another layer of loam with sand and gravel started; apparently this was bedrock underlying alluvial sediments.

4. DISCUSSION

4.1. Interpretation of geomorphological, lithostratigraphical and geochronological data. If we summarize all the data about structure and age of sediments of the valley infilling we can make the following interpretation. The results of dating may be divided into three groups: about 30–35 ka, about 23 ka and about 18–19 ka BP.

The alluvial sediments with the age 30–35 (40) ka BP (the end of MIS 3) were found at depths from 5.5 to 18 m in all three dated boreholes. That allows us to suggest that during this period the river was incised by more than 10–12 m relative to the modern river. This incision was probably driven by the increase of the river runoff associated with climatic changes as was established in the neighboring middle Dnieper basin (Panin et al., 2017). At the end of this epoch about 30 ka ago the infilling of the valley started, and continued in MIS 2 till the end of Late Glacial Maximum (20–23 ka ago).

The date from the borehole Mk-19-11 in the big hollow between two fragments of the low terrace shows that this hollow also was formed in that time. Presumably this hollow is the paleo-valley of Moksha's tributary Tsna that now flows into Moksha few km upstream.

The alluvial sediments dated to 23–23.5 ka BP from the depth of 8.4 m in the borehole Mk-19-03 correspond to the time of the valley infilling. Data from the other river valleys of the East European Plain show that the LGM time was characterized by intensive accumulation in the river valleys. In some valleys not only alluvial but also aeolian deposits were accumulated. These aeolian deposits formed aeolian covers and aprons on the river terraces (Matlakhova, Panin, 2015; et al.). However, such aeolian covers have not been found in the Moksha valley yet.

The next group of dates of about 18–18.5 ka BP from the borehole Mk-19-03 corresponds to the time of the macromeanders (large paleochannels) formation. Position of these dates compared to the others show that the incision of the river was not so deep as it was at the end of MIS 3. It's obvious that these dated sediments correspond to the time of the large paleochannels meandering, but the upper part of paleochannel's infilling was reworked by small (modern-size) paleochannels in the Holocene. This explains the presence of the small paleochannel on the surface of the floodplain here.

The ages of large paleochannels starting from about 18.5 ka BP were established in many river valleys of the East European Plain (Panin et al., 2001; Panin et al., 2011; Sidorchuk et al., 2011, Panin et al., 2013; Panin et al., 2017). For example our previous studies in Don River basin (in Upper Don, Khoper and Vorona river valleys) showed the ages of large paleochannels formation between 18.5 and 12 ka ago (Panin et al., 2013, Matlakhova et al., 2019; et al.).

The presence on macromeanders in the river valleys of the temperate climate zone of the Northern Hemisphere is an important paleohydrological phenomenon that was studied actively all over the world for the last few decades (Dury, 1964; Starkel, 1995; Vandenberghe, 2002; Sidorchuk et al., 2008; Panin et al., 2013; Vandenberghe, Sidorchuk, 2020; et al.). According to the existing ideas such macromeanders formed in the periglacial zone of the Last Glaciation under conditions of extremely high spring runoff. These macromeanders are several times larger than the modern river channels. This is explained by the specific hydrological regime of that time. It is considered that the river runoff was very uneven during the year. The predominance of winter precipitation led to high spring floods, and permafrost prevented filtration of the water that led to the increase of the surface runoff. The parameters of the large channels formed at this time were determined by the maximal spring runoff of that period (Sidorchuk et al., 2008).

Thus, big paleochannels of the Moksha River correspond to the period of high river runoff between 18.5 and 12 ka BP, which is typical for the East-European Plain (Panin et al., 2001; Panin et al., 2011). Small (modern-size) paleochannels formed in Holocene and changed the previous topography of the floodplain (also sometimes overlaying macromeanders). The lowest runoff and formation of smallest meanders in the rivers of central Russian Plain occurred in the Mid Holocene (Sidorchuk et al., 2012; Panin et al., 2014). Significant variations of river runoff were detected in the last Millennium (Golosov, Panin, 2006), but they are not exposed in the morphology of the Moksha valley.

4.2. Late Pleistocene History of the Moksha River valley development. Data analysis allowed us to make the following reconstructions.

In the interval between 40–30 ka ago, the river incised deeper than the present level. It is confirmed by dates of the alluvial sediments from the valley infilling. The tectonic situation in the region was stable during the analyzed period, so we can be sure that the incision of the river was connected with the increase of the river runoff associated with climatic changes.

Then the incision was replaced by the filling of the valley caused by the drying up of the climate and a lowering of the river runoff, which was more significant on the period of the Last Glacial Maximum (LGM, 23–20 ka ago). The previous studies in the river valleys of the central part of the East European Plain show that in some river valleys of the region aeolian covers and aprons on the river terraces' surfaces were formed.

Starting from 18.5 ka ago there was again a significant increase of the river runoff, which led to the formation of macromeanders and widening of the valley bottom. Modern wide high floodplain was formed at that time. Large paleochannels are well preserved in the topography of the floodplain on the key site of the Moksha River valley. Such macromeanders are widespread on the floodplains and low terraces in the river valleys of the East European Plain (Sidorchuk et al., 2000; Sidorchuk et al., 2011; Matlakhova, Panin, 2015; et al.) and are usually dated Late Glacial time (Panin et al., 2013; Matlakhova et al., 2019; et al.).

The Holocene was characterized by a decrease in runoff and channel parameters (width and wavelength) and narrowing of the meandering belt of the river. Despite this fact the Moksha River meanders actively nowadays, that is confirmed by the topography of the modern floodplain.

5. CONCLUSIONS

Summarizing all the data we can conclude the following.

The alternation of high and low river runoff was typical for the Moksha River valley in the end of the Late Pleistocene. This led to the alternation of river incision and aggradation in the valley.

High river runoff and incision of the river were characteristic features for periods 40–30 ka ago and 18.5–12 ka ago. At the second of these periods (18.5–12 ka ago) large paleochannels (macromeanders) were formed. These macromeanders prove the fact of a significant increase in the river runoff at this time.

Low river runoff and aggradation in river valleys were characteristic features for the period between ~30 and 18.5 ka ago. The most significant decrease in the river runoff was related to cryoarydic conditions of the LGM time (23–20 ka ago). The Holocene was also characterized by a decrease in runoff parameters in general. The river runoff in the Holocene was not constant too, but the fluctuations and the runoff in general were lower than in Late Pleistocene.

THE STRUCTURE OF THE MOKSHA RIVER FLOODPLAIN AS A KEY TO THE LATE PLEISTOCENE HISTORY OF THE VALLEY DEVELOPMENT

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The noticeable geomorphic feature of the Moksha River valley (middle Oka River basin) is the occurrence of numerous large palaeomeanders that evidence a several fold rise of river discharges. To establish the history of valley development, the key study in the lower part of the Moksha River valley was organized between the mouth of the Tsna River and the mouth of the Moksha River. Based on the results of mechanical coring, geomorphological and lithological analysis, and radiocarbon AMS-dating we reconstructed the following main stages of the Moksha River valley development in the end of the Late Pleistocene. 1) About 40–30 ka ago the increase of the river runoff associated with climatic changes led to the river incision deeper than the present level. 2) After that the drying up of the climate and a lowering of the river runoff led to the filling of the valley (the strongest drying was in LGM time, about 23–20 ka ago). 3) Between 18.5–12 ka ago the river runoff increased and caused macromeanders formation and widening of the valley bottom. 4) In the Holocene runoff decreased again and the channel parameters became close to the modern ones.

Keywords: macromeanders (large paleochannels), the history of river valleys development, Pleistocene paleogeography, fluvial geomorphology

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