Climate-induced and local-scale erosion and sedimentation features in small catchments: Holocene history of two small valleys in Central Russia

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Abstract Valleys draining small catchments in Central Russia demonstrate changing incision or aggradation tendencies in the second half of the Holocene. Such changes may reflect regional-scale climate dynamics. Alternatively, some may be only of local importance, resulting from catchment-scale events. A way to distinguish between these two causes is to compare the behaviour of several fluvial landforms within a relatively uniform territory. Two small valleys (catchment area 6.5 and 8.7 km^2) located close to each other were studied in detail in the field. Periods of high fluvial activity in the Middle Holocene (4.5–6 ka BP) and the last millennium, as well as a phase of stabilization during the Sub-Boreal and through to the middle of the Sub-Atlantic, are characteristic for both valleys and thus may be attributed to climate changes. Superimposed on these climate-induced tendencies are signals from local events such as forest fires and lateral shifts of recipient streams. The background for millennium-scale incision–infill cycles is the main tendency of incision over the entire Holocene controlled by a convex shape of long profile in both valleys and relatively erosion-resistant underlying material (the Mid-Quaternary glacial boulder clays).

Key words erosion; Holocene; Russian Plain; sedimentation; small catchments

INTRODUCTION

Investigations of the history of fluvial landform development are very important for better understanding the mechanisms and processes of their evolution. It gives us opportunity to verify our concepts of past environmental conditions, obtained by other palaeogeographical methods. Hence, it also moves us toward more precise long-range forecasts of future changes in drainage networks. Some of the events in a valley's history are characteristic for a certain catchment only, but others are of a regional scale. In order to distinguish between such events it is necessary to compare reconstructions for several valleys of the same region. Most such reconstructions for the Russian Plain have concentrated on small valleys of steppe and forest-steppe zones (Butakov, 1986; Sycheva, 1997; Panin *et al.*, 1998; Sycheva *et al.*, 1998; Hrutskiy *et al.*, 1998), whereas the forest zone has received much less attention. In view of this, for the study presented here we chose two small valleys situated in the south of the forest zone near the Moscow University research station Satino, where detailed investigations of geological and geomorphological structure have been conducted during the last 30 years (Komplexnyi analiz..., 1992; Rychagov, 1996; Panin *et al.*, 1999; Panin & Karevskaya, 2000; Belyaev *et al.*, 2003).

Fig. 1 Location of the case study valleys.

CASE STUDY SITES AND METHODS

The basins of the Cholokhovskaya stream and Yazvitsy stream are situated in the centre of the Russian Plain, about 110 km to the southwest of Moscow (Fig. 1). It is a marginal area of the Middle Pleistocene (Moscow age) glaciation. Modern landscape conditions and relief morphology both make this territory typical of the humid temperate centre of the Russian Plain. The two basins are similar in area (8.7 km^2: Cholokhovskaya, and 6.5 km^2: Yazvitsy) and in position in the drainage network. Both valleys have permanent streams at least in the lower parts.

The morphology of the valleys was studied using 1:5000–1:25 000 topographic maps and during field geomorphological mapping of key areas. Detailed investigations of the geological structure of the valleys were conducted along a number of cross-section profiles, at locations chosen to characterize morphologically different parts of valleys. Fossil organic matter provided a series of radiocarbon dates for alluvial and slope deposits (Table 1). Samples were analysed at the radiocarbon laboratories of the State Centre of Environmental Radiogeochemistry, National Academy of Science of Ukraine (Kiev), Moscow State University (MSU) and Institute of Geography, Russian Academy of Science (IGRAS). All dates cited here are in non-calibrated radiocarbon timescale.

Table 1 Radiocarbon dates of sediments from Cholokhovskaya and Yazvitsy valleys.

Sample	Profile	Pit	Depth (m)	Location	Material	Date
Dates from the Cholokhovskaya valley						
Ki-8411	b	1	0.45	Colluvial sheet base	Charcoal	1290±120
Ki-8412	b	2	0.57–0.58	Flood plain sediment	Charcoal	1940±120
Ki-8413	b	2	1.45	Flood plain sediment	Charcoal	3520±110
Ki-8414	b	4	1.05	Top of basal layer	Charcoal	5170±120
Ki-8415	d	12	0.40	Top of basal layer	Fossil wood	2470±120
Ki-8416	d	13	0.67	Basal layer	Fossil wood	3160±120
Ki-8417	d	16	0.44–0.45	Flood plain sediment	Charcoal	3860±120
Ki-8418	d	17	1.18	Top of basal layer	Charcoal	5125±110
Ki-8419	d	19a	0.51–0.54	Flood plain sediment above buried soil	Charcoal	4670±120
Ki-8420	d	19a	1.74–1.75	Top of basal layer	Charcoal	5830±120
Dates from the Yazvitsy valley						
Ki-5243	a	13	0.95	Colluvial sheet base	Charcoal	635±35
Ki-6441	e	31	1.05	Basal layer	Charcoal	4260±75
Ki-6442	e	31	1.05	Basal layer	Charcoal	4590±80
Ki-6443	e	28a	0.85	Colluvial sheet base	Charcoal	870±60
IGRAS-1643	i	14	0.6	Colluvial sheet base	Charcoal	740±180
MSU-1457	j	51	1.2	Colluvial sheet base	Charcoal	820±60
MSU-1474	e	31	1.05	Basal layer	Charcoal	4735±200
MSU-1475	e	28a	0.85	Colluvial sheet base	Charcoal	1100±60

MORPHOLOGICAL AND GEOLOGICAL STRUCTURE OF VALLEYS

The case study valleys appear to be very similar in both morphology and geological structure. They have convex longitudinal profiles typical for small valleys of this territory and strikingly similar features in their geological cross-sections (Figs 2 and 3).

Upper parts of valleys are incised in Late Pleistocene loessial loams which cover significant portions of interfluve areas in the region (Antonov & Rychagov, 2002). Further downstream, valleys begin to cut in to Middle Pleistocene glacial sediments (Dnieper and Moscow glaciation age boulder clays). The Cholokhovskaya stream valley is also cut into lenses of the Late Pleistocene alluvial-lacustrine sediment (Mikulino interglacial-age clays) in its lower reaches (Rychagov, 1996).

Cross-section profiles of the studied valleys are characterized by the presence of a complex of fluvial terraces, which are easily traced along both valleys (Figs 2 and 3), although their morphology and height above the thalweg vary noticeably. The terraces are composed of relatively thin (no more then 2.0–2.5 m thick) two-layered alluvial sediments. The thin lower layer (20–40 cm thick) is composed of variably sized coarse debris (up to boulders) within a clayey sand or sandy loam matrix, and is referred to as the basal layer. The upper layer is up to 1.0–1.5 m thick and is largely associated with a flood-plain-like sedimentation regime. It consists of finer material—sandy loams, silts or loamy sands—sometimes with prominent lamination. The composition of the alluvium (grain size, and the ratio between the thickness of the basal layer and the flood-plain alluvium) varies between different terraces within each cross-section, as well as within each terrace level along the valley. These changes provide important information about the dynamics of the effective channel-forming discharges and flood activity in the past.

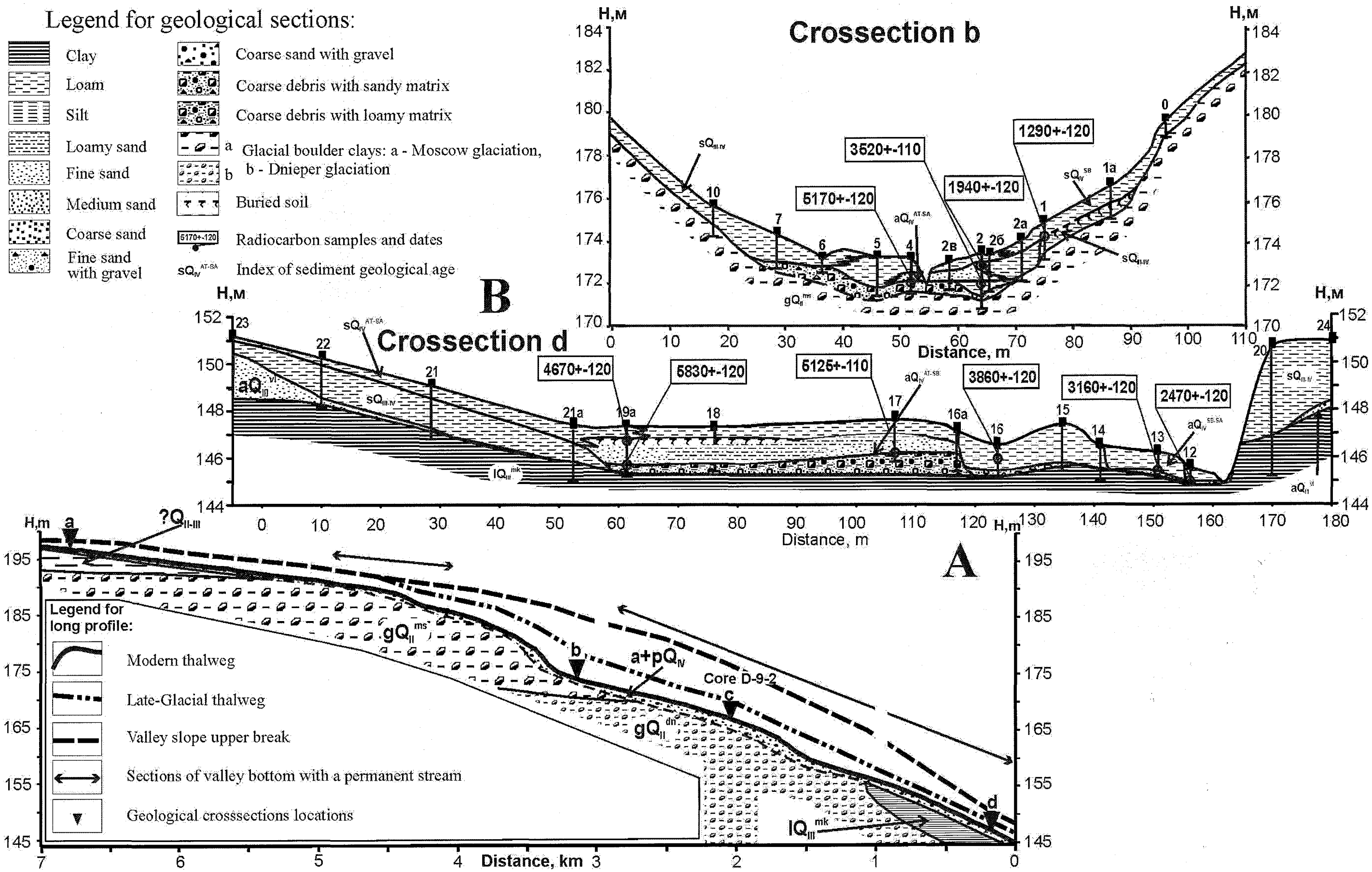

Fig. 2 Long profile (A) and geological cross-sections (B) of the Cholokhovskaya valley.

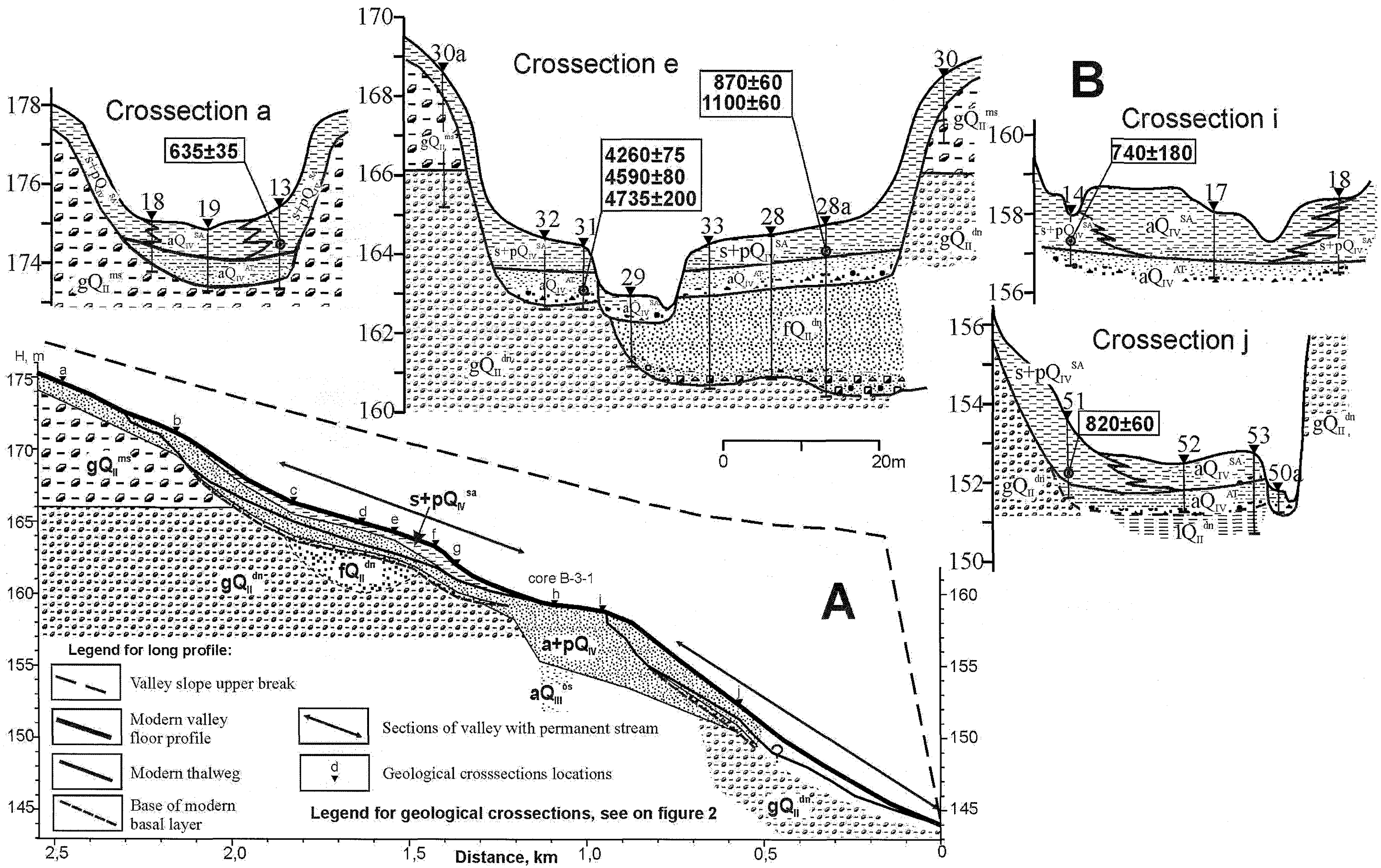

Fig. 3 Long profile (A) and geological cross-sections (B) of the Yazvitsy valley.

Detailed investigation of the geological structure of both valleys showed that there are no Late Quaternary (Valday glaciation age) or Early Holocene (Pre-Boreal and Boreal) sediments in their bottoms. The oldest Holocene alluvial material was found at the base of bottom infill sections in middle parts of both valleys, and in the highest terrace section in the lower part of the Cholokhovskaya stream (Figs 2 and 3). Dates from the top of the basal layer are 5830 ± 120 (Ki-8420), 5125 ± 110 (Ki-8418) and 5170 ± 120 (Ki-8414) from the Cholokhovskaya valley and 4260 ± 75 (Ki-6441), 4590 ± 80 (Ki-6442) and 4735 ± 200 (MSU-1474) from the Yazvitsy valley (Table 1). These dates allow us to associate these oldest alluvial sediments with the second half of the Atlantic period.

In the lower part of the Cholokhovskaya valley the alluvial unit is characterized by relatively large sized debris in the basal layer (up to in excess of 30 cm) and the increased thickness of this layer itself (up to 1 m) (Fig. 2(B), cross-section d). The upper layer of this unit consists of laminated sand, although in the Yazvitsy valley and in the middle part of the Cholokhovskaya valley it has a thinner, loamy composition. Alluvial units of younger age have the same two-layered structure, but they are generally thinner and have a normal ratio between basal and flood plain sediment thickness (i.e. the basal layer is substantially thinner than the overlying flood plain sediment layer). Importantly, the base of every younger alluvial unit lies deeper than that of the older alluvial unit in most of the studied cross-sections of the both valleys, except for upper parts and local zones of recent deposition. This suggests that incision is the main tendency in the history of this valley.

HOLOCENE HISTORY

An absence of Late Quaternary or Early Holocene alluvial sediments in the valley bottoms together with the radiocarbon dates for the oldest alluvial unit (Table 1) make it clear that, at least in the first half of the Holocene, incision was the main tendency in the development of the studied valleys. There may have been some minor aggradation episodes, but no evidence of that has been found, as lateral erosion was also active, widening valley floors and destroying all traces of any older sediment. Such an assumption is verified by other research concerning the intensification of erosion during the transition between glacial and interglacial periods (Sycheva, 1997). Intensive incision, starting in the Late Glacial, most likely occurred almost simultaneously along all the valleys; however, there was regressive erosion too.

For the Cholokhovskaya valley, the depth of the Early Holocene incision in the upper part was about 1.0–1.5 m, in the middle part 3.0–4.0 m and in the lower part, up to 2.0 m (Fig. 2(A)). Such a situation is typical when incision is caused by an increase of water runoff (Makkaveev, 1956). The size of the terrace that was formed and the sharpness of its upper boundaries prove that the valley floor at that period of time was much wider than today and that lateral erosion was very active. The relatively large size of debris in the basal layer and the width of the terrace complex lead us to a conclusion of highly effective channel-forming discharges and flood activity in the Cholokhovskaya and Yazvitsy valleys in the first half of the Holocene. Results of pollen analysis of the Atlantic age alluvium from Yazvitsy valley also confirm our assumption about higher precipitation levels during that period of time (Panin *et al.*, 1999).

In the lower part of the Cholokhovskaya valley intensive incision temporarily stopped about 5800 years ago (Table 1, Ki-8420). Dates and the geological cross-section (Fig. 2(B), cross-section d, Table 1, Ki-8420, Ki-8418) show that the period between 5800 and 5100

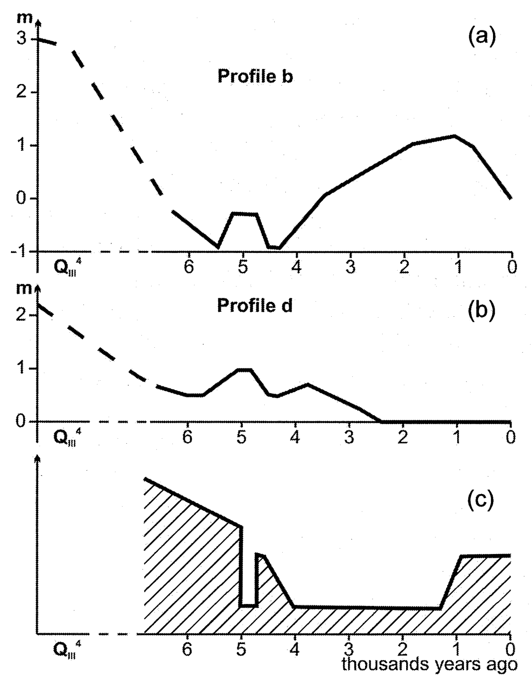

Fig. 4 Generalized tendencies of development (elevation of mean bed level) for (a) the middle reach and (b) the lower reach, and (c) qualitative changes in flood activity of the Cholokhovskaya stream.

years ago was marked by a slight decrease in flood activity (Fig. 4). Flood plain deposits became more clayey (Fig. 2(B), cross-section d, pits 17 and 18 in comparison to pit 19a) and horizontal channel deformation took place simultaneously with a slow and limited aggradation (Fig. 2(B), cross-section d).

Between 5100 and 4700 years ago (Table 1, Ki-8418, Ki-8419) flood activity and channel-forming discharges decreased dramatically (Fig. 4). Most of the floodplain in the lower part of the Cholokhovskaya stream became an unflooded terrace. On the surface of this terrace a fully stratified zonal soil profile was formed (Fig. 2(B), cross-section d).

About 4700 years ago flood activity increased again (Table 1, Ki-8419). The zonal soil was buried (Fig. 2(B), cross-section d) and incision in the lower part of the valley started again. At the beginning of this stage of incision the channel was braided, but most of its branches now exist only as oxbow depressions on the terrace surface. In the middle part of the Cholokhovskaya stream the Early Subboreal incision formed a narrow bottom cut, which is now buried by subsequent deposition (Fig. 2(B), cross-section b). However, the period of active erosion was very short. Dating of the alluvial infill of the bottom cut shows that it happened not later than 3900 years ago in the lower course and 3500 years ago in the middle course (Table 1, Ki-8413, Ki-8417). The same situation occurred in the Yazvitsy valley, where the period of intensive erosion is dated between 4200-4800 years ago (Fig. 3(B), Table 1, Ki-6441, Ki-6442, MSU-1474).

In the lower reach of the Cholokhovskaya stream a modern meandering belt has been formed since the Middle Sub-Boreal (about 3200 years ago). Simultaneously with meander shifts, continuous but slow incision has taken place. It was probably brought about by lateral shift or incision of the recipient stream, resulting in increased channel gradients in the Cholokhovskaya valley lower part. The basal layer here is very thin because receipt of coarse material from upstream was limited. The reason for that is the limited extent of this stage of incision which affected only a short part of the valley close to its mouth. At the same time, in the middle part fine sediment deposition took place, infilling a previously formed bottom cut (Fig. 2(B), cross-section b). The most appropriate explanation of this phenomenon is a decrease in flood activity.

Traces of a significant increase in flood activity—numerous dry channels and the main bottom cut, which still continues to incise or grow regressively in its upper part—are correlated with the Sub-Atlantic period. In the middle part of the Cholokhovskaya valley, the stream incised through a lens of sandy alluvium, the upper part of which is dated as 1940±120 years ago (Fig. 2(B), cross-section b, Table 1, Ki-8412). At the same time, the fact that dry channels situated on the surface of the currently unflooded terrace cut through young slope deposit sheets (Fig. 2(B), cross-section b, pit 6) is evidence that accumulation episodes and this most recent incision may be inter-related. Most probably, intensive incision and deepening of the valley started only after the last episode of slope-derived sediment accumulation. During that episode, thick sheets of slope-derived sediment partly covered valley floors. Abundant charcoal pieces were observed inside these sediment bodies. This suggests that forest fires were the most probable cause of this slope destabilization. Dates from different colluvial sheets are relatively close and vary between 1200 and 600 years ago (Table 1, Ki-5243, Ki-8411, Ki-6443, MSU-1475, MSU-1457, IGRAS-1643). Therefore, the last stage of incision in these two small valleys probably occurred during the last millennium and was caused by an increase of flood activity.

In recent centuries, human activity began to be a serious environmental factor within the study area. Human artefacts prove that agricultural activity already took place here in the 16th and 17th centuries. In the 18th century, the drainage basins of the Cholokhovskaya and Yazvitsy streams were partly cultivated. Later, cultivation ceased, arable fields were abandoned and secondary forests developed. All the artefacts found in fluvial sediments lay near the surface. Hence it is believed that, unlike the forest-steppe and steppe zone valleys (Golosov, 1998), human-induced accumulation in these two valleys was not very intensive.

DISCUSSION

Two main groups of factors are responsible for the trends revealed in the small valleys' development. The first is regional-scale climatic fluctuations, which have common reflections in both of the valleys. The second is a group of local catchment-scale events such as forest fires, human activities, processes of self-regulation in valleys and the influence of recipient streams. Comparison of the histories of the different valleys demonstrates that the most large-scale (in amplitude and duration) erosion or accumulation trends are similar for both valleys and occurred under a similar timeframe. This is verified by a striking similarity in morphology and geology in the two valleys investigated and especially in radiocarbon dates. The main climate-induced stages of the history of the small valleys are identified clearly (Fig. 4). The first is a stage of incision and high flood activity in the first half of the Holocene. The second is a stage of decreased flood activity, valley floor stabilization and limited aggradation in the Sub-Boreal and beginning of the Sub-Atlantic period, interrupted by a short increase of erosion 4700–3900 years ago. The last stage is of a recent increase of flood activity and erosion in the Late Sub-Atlantic. As additional support for such a conclusion, a similar Holocene history has been described for the Protva River, which is the main river of the territory (Panin & Karevskaya, 2000).

The most important of the local events that influenced the history of the two study valleys are forest fires. They caused intensive erosion in basins and accumulation of colluvial material on slopes and the valley bottoms. The influence of the recipient stream caused incision in the lower reach of the Cholokhovskaya stream in the Late Sub-Boreal. Internal fluvial system self-regulation processes (long profile adjustment via passage of regressive and transgressive waves of erosion and deposition) resulted in differences in the dates of interruption of the Early Holocene incision between middle and lower parts of the Cholokhovskaya valley. These waves of erosion and deposition can be clearly identified in the modern pattern of the valley floor morphology.

CONCLUSIONS

The main tendency in the Holocene history of the two studied small valleys is progressive incision. It is controlled by the convex shape of the long profiles and relatively erosion-resistant underlying material (the Mid-Quaternary glacial boulder clays). Three main long-term stages of the Holocene history of both valleys, induced by climatic fluctuations, are similar and can be summarized as follows:

- The Early Holocene – end of the Atlantic (about 5100 years ago). High flood activity. Intensive incision and lateral erosion. Wide valley floors were formed.
- Beginning of the Sub-Boreal – second half of the Sub-Atlantic. Decrease of runoff and channel-forming discharges. Stabilization of valley floor with limited aggradation in middle and upper parts. Between 4700 and 3900 years ago, short period of flood activity increase and incision.
- The Late Sub-Atlantic period (after 1300 years ago). Increase of flood activity and progressive incision.
- The main catchment-scale events influencing development of the study valleys during the Holocene are forest fires.

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