BACK

EVOLUTION OF BORISOGLEBSK UPLAND INTERFLUVES OVER LAST 150,000 YEARS (MARGINAL ZONE OF MOSCOW GLACIATION, CENTRAL PART OF RUSSIAN PLAIN)

E. Garankina[1], V. Belyaev[1], I. Shorkunov[2], P. Andreev[3], T. Verlova[3], Y. Shishkina[1], A. Bondar[1]

[1] Lomonosov Moscow State University, Moscow, Russia, evgarankina@gmail.com

[2] Institute of Geography, RAS, Moscow, Russia

[3] Institute of Earth Sciences, St. Petersburg, Russia

The Upper Volga region is one of the main stratigraphic references for reconstructing geomorphic evolution of northern part of the Russian Plain since termination of the last Middle Pleistocene glaciation (Moscow – Saalian, MIS6) thanks to a large number (>20) of reference sections described in details (Razrezyi..., 1977; Oledeneniya…, 2001). At the same time, interpretation and correlation of these numerous sections still remains controversial for the two main reasons: i) different backgrounds and basic concepts adopted by research groups studying the same set of sections (Novskiy 1975; Kvasov 1975; Gey et al. 2001; Sudakova 2012; Rusakov et al. 2015; Astakhov et al. 2016 etc.); ii) lack of absolute dating. It is generally accepted that since the Moscow glaciation degradation, prominent geomorphological events at its marginal zone have concentrated largely within the fluvial network. Hence, most of the landscape development reconstructions have been strongly biased towards understanding the fluvial landforms, sediment sequences and corresponding incision-widening-infill cycles (Panin et al. 2009). However, thorough understanding of clearly notable fluvial activity cycles creating the existing complex hydrographic network does not shed sufficient light on much slower and lower-amplitude evolution of interfluves characterized by a variety of genetic and morphological types (i.e. typical moraine ridges or hills, dead-ice moraine knob-and-kettle topography, glacial melt-water channels and outwash plains, glaciolacustrine depressions, etc.). The latter for a long time have remained poorly investigated.

The case study area of the Borisoglebsk Upland adjoins long-existing tectonic depression with inherited subsidence trend since Pre-Quaternary (Fig 1). Its central part is occupied by the Nero Lake providing continuous and prolonged sedimentary record for the basin area. The existing palaeolandscape reconstructions for the surroundings are based entirely on integration of the lake sedimentary sequence, valley infills and correlated geoarcheological sites (Novskiy 1975; Gey et al. 2001; Sudakova 2014; Rusakov et al. 2015), reflecting local confined conditions. However, deciphering another part of the environmental change history carved into the interfluve morphology and surface sediments (Eyles 1979, Kaszycki 1987) has a great potential to support reliable extrapolation to regional-scale generalizations. In addition, in most of the studies interfluve surfaces are considered as relatively simply arranged geomorphic, lithogenic and pedogenic background. Nevertheless relic components such as remnants of periglacial microtopgraphic features and ancient fluvial network are observed almost everywhere in the landscape and soil cover structure (Eremenko et al. 2010; Novskiy 1975; Clayton 1964; Andrieux et al. 2016), testifying presence of fundamentally different environmental conditions during their formation. Origin of texturally differentiated sod-podzolic soils (albeluvisols, or retisols) of the region is also a matter of ongoing debate (Glushankova 2008). Contribution and relative importance of surface gleyization, lessivage and podzolization, on one hand, and sedimentation features, on the other, into their formation and evolution has not yet been determined (Targulian 1974).

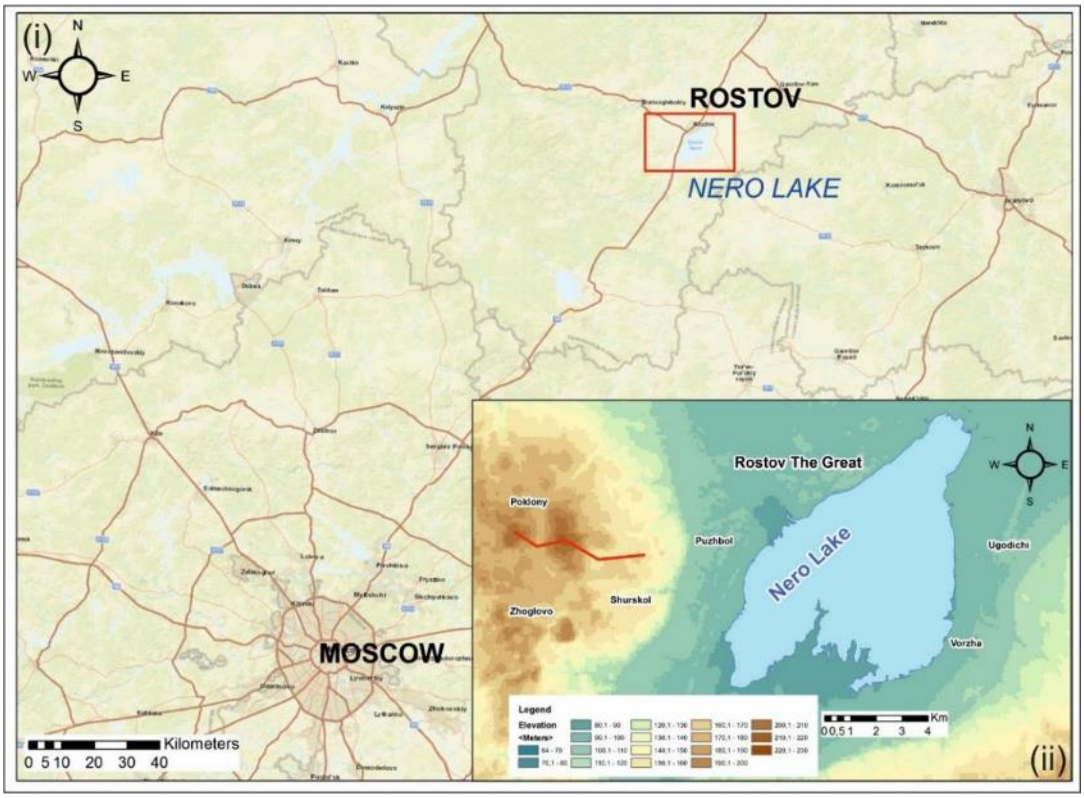

Fig. 1. (i) Case study area at central part of the Russian Plain (source: Google global topography, infrustructure and settlements); (ii) the Lake Nero depression and eastern slope of the Borisoglebsk Upland. Red line marks transect along the main reference sections and cores (source: ALOS 3D 30 m)

In order to decipher this natural archive, almost devoid of traditional palaeoenvironmental proxies, interdisciplinary research of interfluve surfaces and slopes geomorphic structure, lithology, textures and pedogenic properties of surface sediments has been carried out. It involved combination of several independent approaches including detailed geomorphic descriptions, DGPS-profiling, topographic maps and remote sensing data analysis (open source satellite imagery, global satellite DEMs, aerial photography using unmanned aerial vehicle), thorough description and sampling of one open geological section on the hilltop (4 m deep) and more than 20 cores up to 9 m deep along the selected transects. Integrating the available results, we propose a detailed scenario of the interfluve landscape evolution over the last ca. 150 ka for the Moscow glaciation marginal zone. It includes stages of ice cover degradation and successive glaciofluvial-glaciolacustrine transformation during the end of the

Middle Pleistocene, morpholithogenic evolution with continuous polygenic soil formation and superimposed cryogenic periods during the Late Pleistocene and Holocene.

Main morphologically distinctive types of interfluves can be determined considering the Borisoglebsk Upland general ridge-hilly glacial topography (Fig 2). Large (up to 1-2 km wide at base) elevated (214-160 m ASL, 25-50 m relative) flat-topped hills with several steps on comparatively steep (up to 15-20°) slopes dominate upper interfluve level of the area. The lower level (160-140 m ASL) is represented by less prominent but much more widespread smaller isometric typical moraine hills (relative elevation about 10 m, base diameter up to 500 m).

Fig 2. Two main types of interfluves of Borisoglebsk Upland: i) large elevated flat-topped hills and ii) less prominent smaller typical moraine hills

The two highest neighboring hills separated by deep dry valley headwaters have been investigated directly by cores and one large open geological section. Both hills expose similar geological composition with the Moscow till core overlain by thick (4->9 m) glaciolacustrine deposits. Relatively flat surface of the moraine at about 195-200 m ASL is overlain by 1->6 m stratified unit represented by thick (0.5-1 m) silty-sandy loams interbedded with thin stripes (3-15 cm) of fine sands. Upward, it is gradually replaced by 1-1.2-m layer of finely laminated silts and loams. The lower unit corresponds to accumulation in glacial lake environment with highly contrast sedimentary conditions. The upper unit reflects a shift to less dynamic sedimentary environment, most likely in shallow residual lakes with significant aeolian sediment input.

Comparative analyses and geological correlation based on detailed description, grain size analysis and DGPS-topography survey data led us to conclusion that glaciolacustrine unit topping both hills represent a remnant of a supraglacial (and probably transformed later into dammed proglacial) lake 4-4.5x2 km formed during the early stages of Moscow deglaciation.

Its bottom deposits were superimposed on the till surface during the non-uniform ice melting and thermokarst.

Several more or less distinctive leveled surfaces are found on the interfluve hillsides below 200 m ASL. Wider flattened fragments are covered by well-sorted glaciofluvial sands while gently inclined ones are presumably cut directly into the glacial deposits and reveal evidences of dominant erosion. Both types of interfluves are separated by gently outlined linear (open) or more isometric (closed) depressions apparently inherited from the glacial meltwater channels (the former) or dead-ice moraine kettles (the latter), later infilled by lacustrine, alluvial and colluvial deposits.

Moraine knob-and-kettle topography and sequences of distinctive leveled units at different elevations on interfluve hillsides (Fig 3) suggest that large blocks of dead-ice were likely to survive in the terrain depressions during the Moscow glacier ongoing degradation. Promoting formation of ice-dammed proglacial lakes and temporary base levels for local erosion (i.e. meltwater channels) they either slowly melted or caused sudden outbursts. These processes in general led to leveling of the landscape, though at places also left several over-deepened (>10 m) depressions at the foothills. Lake outbursts caused formation of the primarily melt-water channels network. It has the greatest extent, stretches mostly from N toS and from W to E and displays clear evidences of several headwaters interceptions. Nowadays it is partly inherited by the modern small river valleys. Incisions of smaller and steeper radial hollows on the upper interfluve hillsides was associated with less intensive erosion under conditions of surface runoff base levels relatively stabilized on higher levels than the present valley and depression bottoms. Thus, fans of those former gullies are bound to the differently elevated base levels (marking the stages of water-table decline) and now are hanging on sides of the later infilled depressions. As a result, the modern fluvial network generally inheriting the ancient one is clearly separated into two parts with upper reaches practically disconnected from the main fluvial network by the infilled lake or dead-ice depressions.

Such a tentative reconstruction of events makes it unnecessary to involve the unrealistic hypothesis of dramatic rise of the Middle Pleistocene Nero Lake level up to 190-140 m (100 m above its present level) to explain formation of high terrace-like surfaces. Such an extreme stage of the Nero Lake evolution was proposed by several authors (Trudyi... 1958; Kvasov 1975) as a part of the great glacial lake chain supposedly developed in the Middle-Late Pleistocene in the entire Upper Volga River basin as a combination of a series of moraine dams and glacioisostatic uplift. However, careful estimations of the available water sources and dam sizes do not support such enormous waterbody existence. The ultimate decay of glacial ice within the Nero depression was immediately followed by the first and deepest fluvial incision stage (up to 25 m) at the end of the Late Moscow glacial (MIS6). The successive prolonged period of landscape stability was mainly marked by pedogenesis which left fragments of texturally differentiated soil profile (presumably of the Early Mikulino – Early Eemian – age, MIS5e) found in cores on top of the eroded Moscow till surface.

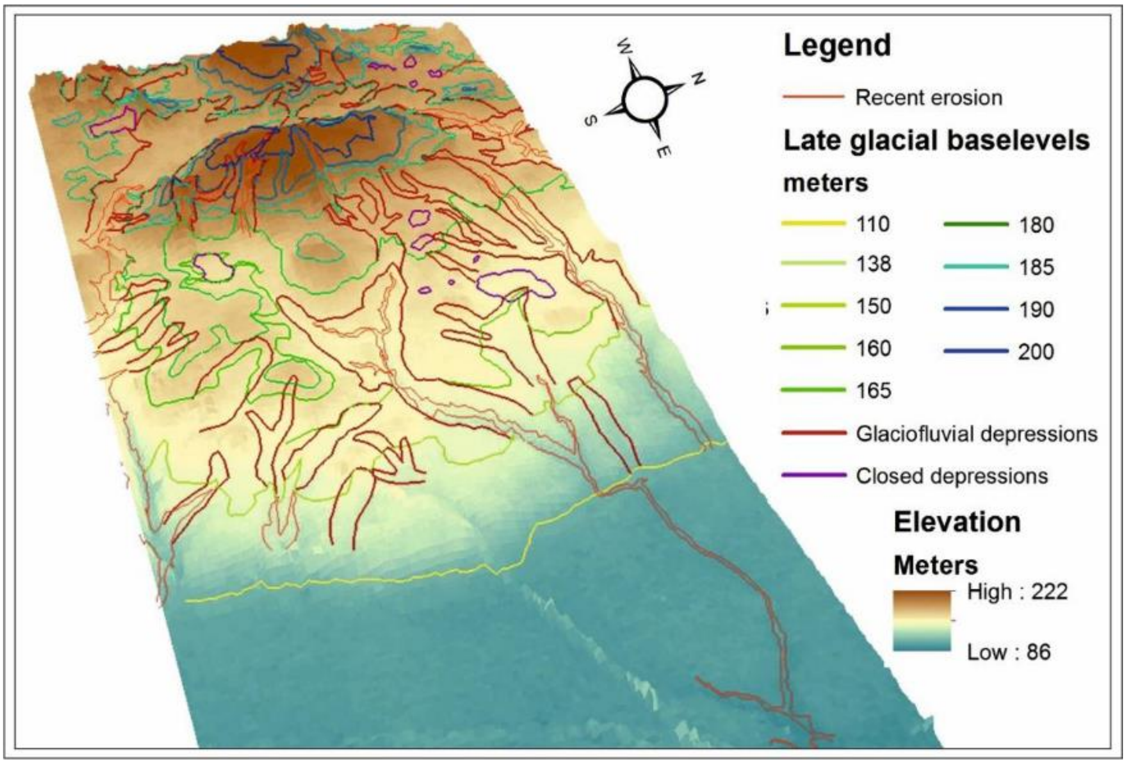

Fig 3. Late Pleistocene relict geomorphic features in the modern landscapes of case study area, the eastern slope of Borisoglebsk Upland (source: ALOS 3D 30 m).

Summits and slopes of both upper and lower interfluve levels are overlain by relatively thin (2.1-3.2 m) heterogenic cover of non-laminated mantle loams possessing strong traces of complex reworking by cryogenic, pedogenic and slope processes. Cryogenic textures have been found in several layers from small-scale cryoturbations along the upper contact of glaciolacustrine units to large (>2 m) frost mound and ice wedge formations involving both lake (or glaciofluvial) and mantle loams and superimposed small-scale polygonal nets in the upper part of cover loams only. This sequence of cryogenic deformations most likely reflects gradual drying trend of hilltops conditions probably due to draining of watershed lakes and puddles and generally lower moisture content of surface sediments towards the end of Late Pleistocene. Pedogenic features show, at least, two generations of texturally differentiated soils developed on surfaces of various ages and elevations. Structural and grain size properties also suggest that the two layers of cover loams can be distinguished. The lower one has complex structure and is characterized by more sandy composition and limited presence in cores and outcrops. The upper one is homogenous and covers not only all the interfluve surfaces and slopes but also the Nero Lake terraces higher levels. Therefore, we consider the lower layer to be deposited during the final stages of Moscow deglaciation (MIS6) and serve as a parent material for the Mikulino pedogenesis (MIS5e). It was substantially disturbed during one of the successive Late Pleistocene cold periods, presumably Early-Middle Valdai periglacial (Weichselian). Thus, the Middle Valdai period (MIS3) could be associated with formation of frost mounds landscapes in warmer, wetter, but yet relatively cool conditions. Those were followed by one of the coldest periods of Quaternary history – the Late Valdai periglacial (Last Glacial Maximum – MIS2) – when the upper stratum of mantle loams have emerged due to the aeolian deposition and was cracked by the polygonal nets due to permafrost development under extremely dry conditions. Afterwards texturally differentiated sod-podzolic soil have developed superimposed on those sediments and cryostructures over the Holocene.

The present-day fluvial network often inherits the ancient meltwater channels of the Late Moscow age, but does not penetrate as far into the most elevated parts of interfluves (Fig 3). However, cores obtained from the Late Pleistocene infills of glacial depressions (up to 7-8 m thick) show a number of alluvial layers (from coarse sands to laminated loams with humic layers) above or within thick lake sediments (silts and silty loams with peat lenses). It indicates that fluvial incision and infill of more limited amplitude have been active here at least once during the Late Pleistocene (probably in MIS3) and were interrupted or slowly shifted to stagnant waterlogged basin conditions by increasing colluvial sedimentation (transition to MIS2). The overlying loamy deposits show patterns typical for colluvial material corresponding to the widespread permafrost with apparently thick active layer during the LGM and end of the Late Pleistocene (second part of MIS2, probably correlated to the time of polygonal net formation on the hilltops). The main Early Holocene fluvial incision stage and the following minor erosion episodes have not spread further up than the lower interfluve level. Only a few of small radial gullies drainig the upper interfluve hillsides exhibit noticeable signs of modern incision whereas the larger ones in the main modern valleys headwaters presently remain complitely stable. Most likely it can be explained by combination of insufficient runoff discharges and domination of generally forested catchments.

It can be concluded that the interfluve landscapes and environmental conditions at the Moscow glaciation marginal zone have experienced distinctive evolutionary changes over the last ca. 150 ka. Several stages of ice cover decay and consequential glaciofluvial-glaciolacustrine transformation could be distinguished during the end of the Middle Pleistocene when initially supraglacial and later moraine-dammed proglacial lakes and dead-ice masses strongly controlled rates and distribution of erosion and sedimentation. Later on, those were followed by relatively slow morpholithogenic evolution of the hilltops with continuous polygenic soil formation and superimposed cryogenic disturbances periods. Simultaneously, upper parts of glacial depressions (meltwater channels and dead-ice moraine kettles) have been gradually incised, infilled and flattened by lacustrine, alluvial and colluvial deposits with at least one distinctive period of fluvial incision during the Late Pleistocene. The present-day fluvial network takes over the ancient meltwater paths only at the lower interfluve level, leaving the Late Pleistocene exterior of the higher elevated parts almost unchanged.

The study was funded by RFBR project № 18-05-01118 and GM AAAA-A16-11632810089-5.

Keywords: Interfluves evolution, glaciation, Pleistocene, pedogenic, cryogenic.

REFERENCES

Astakhov V et al. (2016). Glaciomorphological Map of the Russian Federation. Quaternary International, 420, pp. 4-14.

Andrieux E, Bertran P et al. (2016). Database of Pleistocene Periglacial Features in France: Description of the Online Version. *Quaternaire*, **27** (4), pp. 329-339.

Clayton L (1964) Karst Topography on Stagnant Glaciers. Journal of Glaciology. 5 (37), pp. 107-112.

Glushankova NI (2008). Paleopedogenez i prirodnaya sreda Vostochnoy Evropyi v pleystotsene (Paleopedogenesis and Natural Environment of Eastern Europe in Pleistocene). Smolensk: Madzhenta Publ., 348 p.

Eremenko EA, Panin AV and Karevskaya IA (2010). Poslelednikovaya transformatsiya flyuvioglyatsialnyih lozhbin v kraevoy zone moskovskogo oledeneniya (Postglacial Transformation of Glaciofluvial