THE UPPER VOLGA RIVER IN MIS 2 - EARLY HOLOCENE: RESPONSE TO CLIMATE CHANGES AND ICE SHEET IMPACT

A.Panin[1], D.Baranov[1], P.Moska[2], A.Utkina[1]

[1]*Institute of Geography RAS, Russia, a.v.panin@igras.ru, dm_baranov@igras.ru, utkina@igras.ru*

[2]*Institute of Physics, Silesian University of Technology, Poland, Piotr.Moska@polsl.pl*

The source of the Volga River is located in the marginal zone of the last, Valdai glaciation in the northwest of the East European Plain (Fig. 1). The age of the upper Volga terraces is a controversial issue. Some researchers [4] believed that the upper Volga is a young river formed after the drainage of the system of proglacial lakes at the end of the last Ice Age and, therefore, its upper terrace belongs to MIS 2. Others [7] believed that the Volga valley was formed immediately after the Moscow (MIS 6) glaciation and dated the upper terrace to MIS 5–4. Until recently, the only data on absolute geochronology from the Volga valley were Holocene radiocarbon dates for the floodplain alluvium. Alluvium of older terraces does not contain organic remains, and no direct dates have been obtained on the terraces so far.

To clarify the question of the age and history of the development of the valley, we carried out luminescence (OSL) dating of the alluvium of the terrace staircase on two profiles at the Bolshaya Kosha village and at the Rzhev town, located at a distance of 80 km along the river from each other (Fig. 1). The structure of the river valley in both locations is similar: alluvial levels are represented by floodplain up to 4 - 4.5 m high and four to five steps of above-floodplain terraces, of which the highest terrace is the widest on both profiles. On both profiles, it has the same height of 15 - 17 m and is separated from the lower terraces by a 5 - 7 m high step. 20 OSL dates from terrace deposits were produced in the GADAM Centre, Silesian University of Technology.

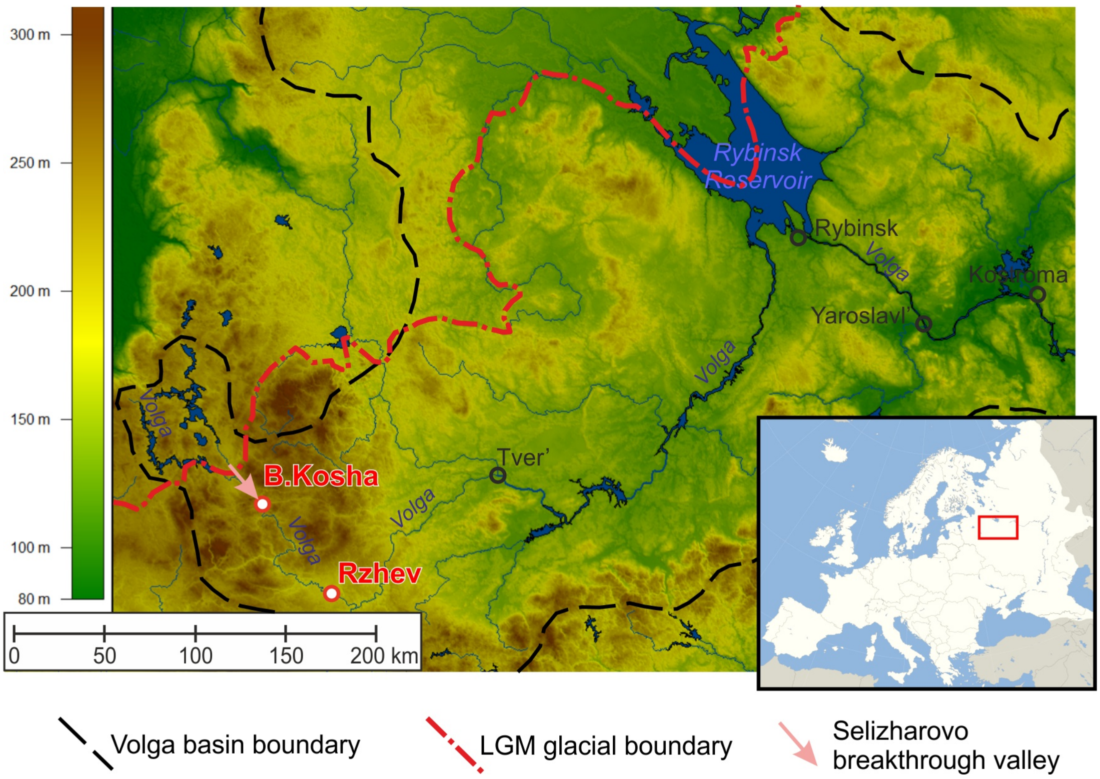

Fig. 1. *Upper Volga River catchment, study area and the last glacial boundary*

The similarity of the terrace staircases at both sites gives grounds to combine the obtained dates for statistical processing into a single array. In contrast to the traditional age-depth models, we have constructed an age-height model using the rBacon software [2]. The analogy between terrace height and depth in a geological section is incomplete, since the age of the terraces grows from bottom to top, and the age of alluvium in each individual section grows from top to bottom. Therefore, the modeling was carried out in two versions. In the first, the height above the river of each individual sample was taken (Fig.2A), in the second, for all samples from one terrace, a single height is taken - the height of this terrace (Fig.2B).

Both models gave similar results. The modeled age of the 15-17-m terrace in the first case is 23±3 ka, in the second - 21±2.5 ka. Age about 19 ka was modeled for the lower 12-13-m terrace. Taking into account the scatter of dates, it cannot be excluded that both terraces are about 19-20 thousand years old. This does not contradict the existing geochronological data on the dynamics of the southeastern edge of the Scandinavian ice sheet: according to [3], the ice sheet entered the upper reaches of the Volga basin about 20 ka BP, reached its maximum at about 19 ka BP and left this part of the Volga basin no later than 18 ka BP. This gives the basis to associate the formation of both highest terraces and the beginning of the incision of the river with the runoff of glacial melt waters through the Volga valley. Judging by the ^{14}C dates from the floodplain, the incision stopped in the middle of the Holocene. The total depth of incision was 12 m, the average rate – 1.2-1.5 m per ka.

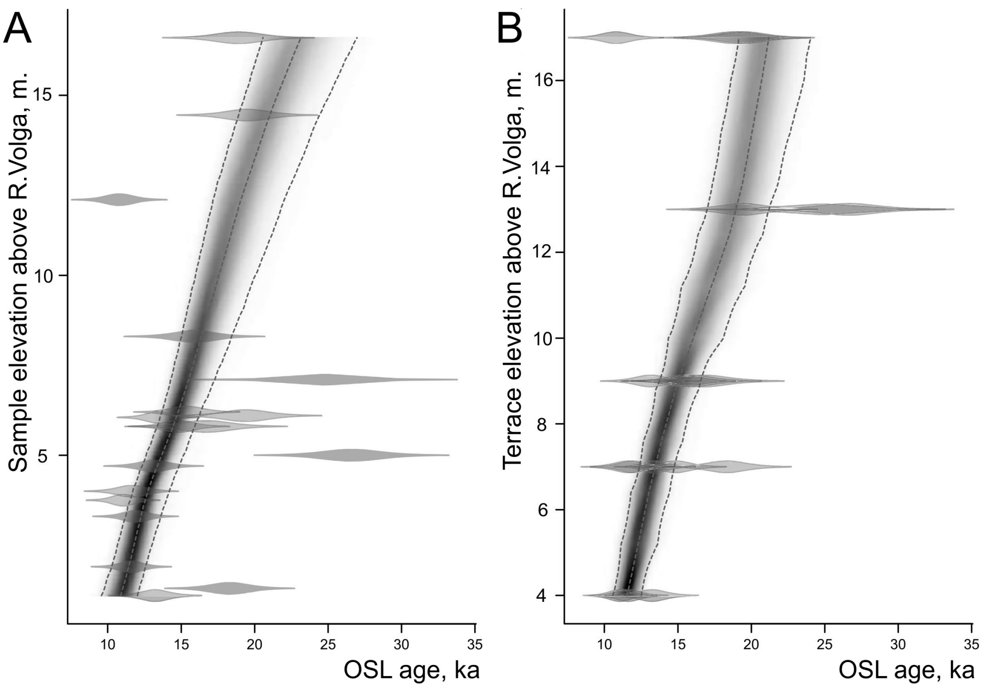

Fig. 2. *Age-Elevation models for alluvial OSL ages from R.Volga terraces (A – elevation of terraces, B – elevation of individual samples).*

Below we discuss three possible reasons for the river incision.

1. Postglacial deformations of the earth's crust as a result of glacioisostatic adjustment (GIA). To estimate the magnitude of deformations of the topographic surface, we used the realization of the ICE-5G Global Glacial Isostasy model [7]. The constructed map of deformations shows that the earth surface sank in a strip 250-300 km wide along the edge of the ice sheet. The magnitude of subsidence at the edge of the glacier was about 150 m. At a distance of 300-800 km from the glacier, there was a glacial forebulge 10-15 m high. All these deformations influenced the longitudinal profile of the upper Volga (Fig. 3).

2. Climatically driven increase in river runoff in the period 18-13 thousand years ago, established earlier for the center and south of the Russian Plain [6].

3. Increase in the Volga runoff due to an increase in the basin area. It is assumed that before the last glaciations, the source of the Volga was the river B. Kosha. A breakthrough valley was formed around the LGM between the Selizharovo town and the B.Kosha village (Fig. 1). This led to the capture by the Volga basin of the entire modern region of the Upper Volga lakes. The increase in the basin area led to an increase in runoff and river incision until a new equilibrium longitudinal profile was formed.

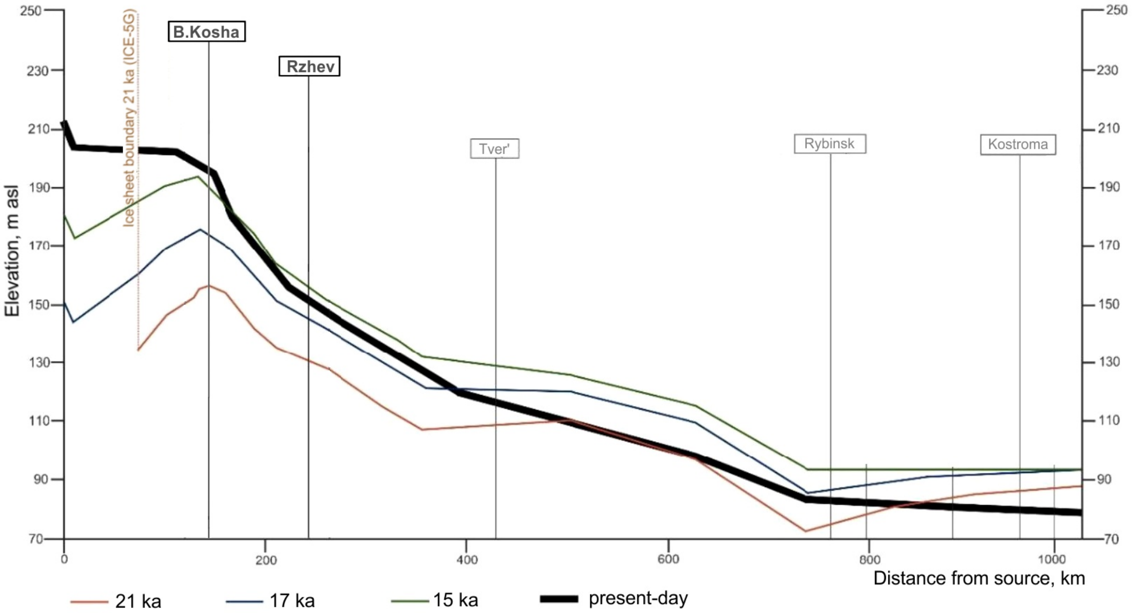

Fig. 3. *Transformation of R.Volga long profile due to glacio-isostatic adjustment, according to the ICE-5G GIA model [7]*

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