Paleomeanders of the Belaya River (the Upper Angara region)

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Abstract. The article presents data on the existence of fragments of the ancient river network in the Belaya River valley (the Angara River basin). We characterize the modern floodplain-terrace complex of the Belaya River, namely the structure of modern floodplains and low terraces, the heights of their basement and morphology, as well as describe the structure of the ancient part of the Belaya River channel. The estimated fragment of the ancient valley of the Belaya River, with a length of 13.6 km, is a macro-bend. The morphometric parameters of the incised meanders of the ancient valley almost two times exceed the modern meanders of free type but are close in their morphometric parameters to modern incised meanders. Based on the morphometric parameters of fragments of the ancient river channel, we calculated the velocities of the paleo-Belaya and compared them with the actual values for the Belaya River. The calculated water flow rates of the ancient channel are 3.7 to 4.5 times higher than the modern parameters. However, these parameters are close to the maximum values during the summer floods. At the next stage of research, we plan to reconstruct the ancient river network of the area by analyzing basal surface maps.

1. Introduction

The problems of the relict river network and related issues of restructuring the river network and changing the direction of runoff within the Baikal region are widely covered in the literature and associated mainly with paleopathological reconstructions of the Baikal Rift Zone [1-6]. Such studies in the Upper Angara region are few [7, 8].

This paper aims to study the morphology and structure of an ancient valley fragment in the lower part of the Belaya River basin. This fragment is located within Irkutsk-Cheremkhovo plain characterized by weak neotectonic activity. Nevertheless, the study area is heterogeneous in structure, and against the general background of uplifts, there are several depressions. The largest of them in the Belaya River basin are Belsk-Alar, Haita-Bulay, Kholmushino-Taiturka, Malta, and Ust-Belsk depressions that are associated with the Bulaysk anticline structure [9, 10]. The Belaya River valley has various morphodynamic types of the channel due to the presence of faults and discontinuities as well as to the heterogeneity of the lithological composition of the rocks. There is a combination of wide-flooded, adapted, and incised types of channels represented here for a short distance.

The lower part of the Belaya River basin is composed of Cambrian dolomites and limestones, Jurassic sandstones, gravelites, and clays. In the extended sections of the valley, there are fragments of the Holocene-Pleistocene river terraces composed of pebbles, sands, and clays.
2. Materials and methods

The works of the Russian fluvial geomorphology school were the theoretical basis for the research of modern morphology and dynamics of floodplain-riverbed complexes [11-16]. In particular, we used the principles of mapping fluvial processes, morphology, and morphodynamics of bends, including the embedded meanders of N.I. Makkaveev [11] and R.S. Chalov [12]. The paleohydrological reconstructions were carried out according to the ideas of A.V. Panin, A.Yu. Sidorchuk and A.V. Chernov [17-19], N.B. Baryshnikova et al. [20] as well as to achievements of the laboratory of experimental geomorphology at Moscow State University [21].

3. Results and discussions

Structure of the floodplain-terrace complex of the Belaya River.

The Belaya River arises from the confluence of the Malaya and Bolshaya Belaya Rivers and has a length of 79 km. It has predominantly adapted and incised channel types, in which the width of the floodplains is either equal to the width of the channel, or two-three times wider. Areas of the adapted channel type (40 km (50.5%)) occupy most of the studied valley section. The wide-floodplain channel type is developed within the Kholmushinsko-Taiturka depression (26 km (33%)). In the remaining areas, the incised channel type is widespread (13 km (16.5%)). Floodplains are also rather diverse due to the differences in the dynamic types of channels. The floodplains belong to the segmented flat and segmental-riged type. We also observed floodplains of the skeletal type. The floodplain complex is divided into three elevation levels (low, medium, and high floodplains). Such a structure of the floodplain indicates the processes of modern river incision.

River terraces are well expressed throughout the valley. They are the most preserved either in the spurs of adapted bends or depressions. A distinctive feature of the low terraces is their small width. High terraces are much less pronounced and have subdued ledges. The first terrace reaches a height of 7-8 m; the second terrace is 9-11 m (up to 500 m wide), and the third terrace has heights of 14-17 m. Its width varies from 100 to 200 m. The primary floodplain landforms are often preserved on the surfaces of low river terraces. The surface of higher terraces is often changed by non-fluvial landform processes (karst, aeolian processes, and relict cryogenesis). The complex of middle terraces with elevations of 18-19 and 21-22 m is relatively well expressed. Surfaces of 35, 42-43, 46-47 m, 62-65, and 65-70 m are distinguished. The surfaces of the terraces are strongly disturbed by the modern erosion network, whose thalweg has a predominantly northwestern direction.

The tectonic and geological features of the area determine the structure of the Belaya River terraces. Low terraces are predominantly accumulative and widely represented in the lake-shaped extensions of the valley. Erosion-accumulative terraces are observed in areas of intensive river incision corresponding to narrow valley sections. Basement terraces and a high floodplain usually represent them, where the ratio of the basement and loose sedimentary cover is approximately the same. For example, below in the text, we describe a section of loose deposits of the first floodplain terrace near the Michelevka section. The description is given from top to bottom of the section:

- humus horizon of Luvic Phaeozem – 0-25 cm;
- sandy loam is lightly layered. Border with overlying horizon uneven in color – 25-40 cm;
- interbedding of layers of light gray fine-grained sand and brown sandy loam. The thickness of sand layers varies between 1-5 cm, the thickness of sandy loam layers is within 2-7 cm. The thickness of the layers is not maintained in the upper part of the layer (40-50 cm). The layering is horizontally wavy (floodplain facies of alluvial deposits) – 40-115 cm;
- densely packed pebbles with dark gray sand. Pebbles show unstable orientation with inclusions of small boulders (15-20 cm). The roundness of pebbles vary from 2 to 5 points (channel facies (core subfacies) of alluvial deposits) – 115-205 cm;
- pebbles with coarse fragments of bedrock and medium brown sand mixed with dolomite fine-earth (the result of destruction and abrasion of the basement). Deposits result from intensive river incision into the underlying rocks. Pebbles of various orientations included into the
basement and standing vertically indicate the high flow rate – 205-255 cm. Down to a depth of 4.5 m, bedrocks (dolomites of the Belsk Formation of Cambrian age) were exposed.

The loose sedimentary cover often slides along the rocky base, masking the ledges of such terraces. The data on the structure of low terraces and floodplains can explain the weak expression of higher terrace levels in the areas of incised and adapted channel type of development. Their low expression is due to the insignificant thickness of the loose alluvial deposits, the high intensity of gravity-slope, and other processes that change the surface. Moreover, for reconstruction, it is necessary to take into account the significant variability of the basement height of the terraces relative to the modern level of water. According to the G.G. Litvintsev and G.I. Tarakanova [8], the basement of the 10-12 m terrace (the Malta site) is 2-5 m below the water level. The basement of the high floodplain is 1-2 m above the water level, and the 6-meter terrace basement is 4 m above the level of water (Michelevka section). These data can sufficiently illustrate the heterogeneity of the surface of the pre-Quaternary deposits. Thus, insignificant alluvium thickness, narrow floodplain and terrace areas as well as significant variations in the height of the terrace basement and floodplains are common features of the river valleys in the study area.

The study site is located at the confluence of the left tributary of the Belaya River, the Bulayka River (figure 1). Most likely, the Bulayka River occupies a fragment of the ancient channel represented by a system of incised meanders that form a well-distinguished macrobend at altitudes of 480-425 m. Floodplains 1-1.5 m high and 15-30 m wide are formed in the upper part of this river valley with alluvial deposits of the second terrace of the modern Belaya River. The valley is up to 500 m wide and marshy; the height of the slopes from the bottom reaches 65 m in the upper part of the Bulayka River valley.

![Figure 1](image.png)

**Figure 1.** Geomorphology of the study area. Table of symbols: 1 – low floodplain and valleys of small rivers, 2 – high floodplain, 3 – first terraces, 4 – second terraces, 5 – high terraces, 6 – gentle slopes, 7 – steep slopes, 8 – watershed, 9 – water objects, 10 – study area.

The total length of the paleovalley is 13 km. A macroradial 10 km long with a step of 1.8 km is well manifested, being represented by the following elements (in the direction from northwest to southeast): bend 1, bend 2, straight section, and bend 3. Table 1 shows the values of the morphometric parameters of the paleo-radiation, modern adapted and incised meanders, and free meandering bends are given.
Table 1. Morphometric parameters of ancient and modern channel elements of the Belaya River.

| Number of section | Channel element | Length (l), km | Bend step (L), km | Radius of curvature of the bend (r), km | The ratio of the development curves (l/L) km | Bend deflection (h), km | Channel width (b), km | Floodplain width (B), km |
|------------------|-----------------|---------------|-----------------|----------------------------------------|--------------------------------------------|------------------------|-------------------|-----------------------|
| 1                | Adapt meander   | 5.35          | 1.23            | 0.89                                   | 4.35                                       | 1.66                   | 0.16~0.66         | 0.56                  |
| 2                | Inscribed meander | 7.73         | 3.64            | 1.5                                    | 2.12                                       | 2.67                   | 0.16~0.66         | 0.56                  |
| 3                | Incised meander | 3.26          | 2.18            | 0.8                                    | 1.49                                       | 1.24                   | 0.16~0.66         | 0.56                  |
| 4                | Sinusoidal meander | 3.1          | 1.1             | 0.6                                    | 2.8                                        | 1.3                    | 0.2               | 2.8                   |
| 5                | Loop meander    | 4.6           | 2.1             | 0.8                                    | 2.2                                        | 1.8                    | 0.2~0.3           | 2.5                   |
| 6                | Sinusoidal meander | 1.7          | 0.8             | 0.5                                    | 2.1                                        | 1.2                    | 0.2~0.3           | 1.5                   |
| 7                | Segmented meander | 2.8          | 1.9             | 0.4                                    | 1.5                                        | 1.3                    | 0.3               | 1.1                   |
| 8                | Segmented meander | 1.8          | 1.2             | 1.5                                    | 1.5                                        | 1.5                    | 0.3               | 1.1                   |
| 9                | Incised meander (1) | 3.5          | 2.5             | 1.2                                    | 1.4                                        | 2.4                    | 0.5               | –                     |
| 10               | Straightforward inset | 0.7          | –               | –                                      | –                                          | –                      | 0.3               | –                     |
| 11               | Incised meander (2) | 3.5          | 1.9             | 0.8                                    | 1.8                                        | 1.5                    | 0.4               | –                     |
| 12               | Incised meander (3) | 5.9          | 3.1             | 1.55                                   | 1.9                                        | 1.8                    | 0.5               | –                     |

The macro-radiation becomes much less manifested at the point 52°55’04.9259”N 103°08’36.8728”E and is almost unexpressed in topography at 52°56’26.8799”N 103°06’15.3551”E. The width of the ancient valley bottom is 300-500 m; the average radius of the incised bends is ca. 1.16 km, which is 2.5 times higher than the average radius of free bends within the Kholmushino-Tayturka depression. The width of the modern bottom of the valley within the development of the incised channel is 200-400 m. The morphology and structure of the paleomeander and the modern adapted bend indicate the system of tectonic disturbances in the basement. The structure of the valleys of the Belaya River tributaries also evidences this.

Currently, the orientation of the bend upper parts, including the free meandering bends, has a northwest-southeast direction at the site of the village of Uzkiy Lug to the estuary of the Belaya River. On the contrary, the upper parts of the bends in the Belsk-Uzkiy Lug section are oriented in the northeast-southwestward direction. At the same time, it is worth noting the general orientation of the watersheds in the northwestward direction that corresponds to the general direction of the Main Sayan fault and the Prisayansk Depression. Thus, on the Belsk-Uzkiy Lug section, the elements of the river network (including the Malaya Belaya River valley) are subordinate to the geological structures of the northeastern direction.
Based on the equations describing the dependence of the radius of the bends on the intensity of the water flow [21], the ratio of the radius of the incised paleomeanders and free river bends indicates a 5-5.5-fold excess of the ancient water flow rate relative to the modern one. At the same time, the sizes of modern and incised paleoradiations are close (table 1), which indicates the close water flow rates of the stream flowing in the segment of the paleovalley and the modern Belaya River. The method of hydraulic reconstructions was applied [19] to clarify the flow rates of the fragment of the paleo-bend. The equations are as follow:

\[ Q = W \times V, V = n^{-1} \times H^{1/6} \times I \times H^{0.5} \]  

(1)

where \( Q \) is water consumption; \( W \) is cross-sectional area; \( V \) is flow rate; \( n \) is roughness coefficient; \( H \) is average depth, \( I \) is a hydraulic slope.

Since there is no actual data on the morphometric parameters of the paleo-bend channel, the calculations used a correlation with modern indicators of the Belaya River bed on the Belsk-Michelevka site. Since no channel and floodplain sections were distinguished for the paleovalley, flow rates were calculated by the equation:

\[ V = \left( \frac{H^2}{I} \right)^{1/3} n \]  

(2)

proposed by N.A. Baryshnikov and coauthors [20]. The equations presented allowed us to obtain close values of the flow rates. They indicate the concentration of the channel and floodplain flows of the ancient river channel and correlate with the conditions and characteristics of the modern incised channel of the Belaya River (table 2).

**Table 2. Hydrological characteristics of modern channel and paleochannel of the Belaya River.**

| Valley          | \( V(1)^a \) (m/s) | \( V(2)^b \) (m/s) | \( V_{\text{mean}}^c \) (m/s) | \( Q \) (m³/s) | \( Q_{\text{mean}}^c \) (m³/s) | \( Q_{\text{max}}^c \) (m³/s) |
|-----------------|--------------------|--------------------|------------------------------|--------------|-----------------------------|-----------------------------|
| Ancient valley  | 2.34               | 2.33               | –                            | 1210.36      | –                           | –                           |
| Modern channel  | 0.63               | 0.63               | 0.9                          | 219.47       | 271                         | 1261                        |

\(^a\) \( V(1) \) – stream rates calculated by equation (1).  
\(^b\) \( V(2) \) – stream rates calculated by equation (2).  
\(^c\) \( V_{\text{mean}}, Q_{\text{mean}} \) and \( Q_{\text{max}} \) were taken from [22, 23].

Width of the modern channel of the Belaya River was taken along the profile of the Belaya River near the Michelevka site. Morphometric parameters for the reconstruction of the width of the paleovalley were elevated relative to the ratio of the width of the modern river channel and the width of the paleomeander. The calculated data on the current water consumption turned out to be 1.2 times lower than those obtained by long-term measurements [22, 23]. The calculated velocity and flow rate of the ancient water flow was respectively 3.7 and 4.46 times higher than the modern ones. However, these parameters close to the maximum values observed during the summer flood (table 2).

4. Conclusion

According to the analysis of the topography [10], we suppose that the zones of northeastern faults in the Middle Pleistocene had a through development. Such faults were superimposed in the northwestern Sayan directions. Consequently, the isometric Kitoy depression and the basin of the Belaya River (QII) were formed.

Taking into account this concept of the relief evolution, we can conclude that the restructuring of the river network within the Belsk-Uzky Lug section took place in the Middle Pleistocene. Therefore, the elements of the modern and ancient valley have a northeastern direction here, i.e. they are subordinate to local faults.
However, river terraces up to 45 meters in height are formed within this area [10], which indicates the continuation of the valley development since the Middle Pleistocene. The existence of terraces up to 65 meters (Lower Pleistocene) in the Khomlunshino section and downstream indirectly makes the restructuring of the river network within the Bulay section even more ancient. An additional argument for the existence of fragments of the paleo-Belaya valley in the Belsk-Mishelevka section and the interpretation of this object as a relic of the former river network was the analysis of basal surface maps.

Reconstruction of the river network on the baseline surfaces of the sixth order showed that the main water flow that was functioning at that time was the Pra-Belaya. Its valley corresponded to the valleys of the modern Alar – Bolshaya Belaya – Belaya rivers. At the same time, in some areas, its channel was displaced somewhat north of the current position of the valley. Therefore, the Bulaysky paleomeander located 5-6 km to the north of the modern river channel may be a fragment of the Pra-Belaya River that presumably existed before the Pleistocene.

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