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The mechanism of formation and degradation of the Chuya-Kuray ice-dammed lake

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ABSTRACT. The results of the study of the stratigraphic structure, granulometric composition of the sediments of the ridge relief, the heights of shorelines and the water balance of the Chuya-Kuray ice-dammed paleolake (Altai Mountains) are presented. It is established that the ridge relief is an alluvial fan of fluvioglacial temporary watercourses. The magnitude of floods during the drainage of the paleolake reached 800-2160 m^3/s.

Keywords: ice-dammed lake, giant current ripples, Altai Mountains, paleoshoreline

1. Introduction

Among the Neo-Pleistocene ice-dammed paleolakes studied by researchers that existed in North America and Eurasia, the most famous are the Columbia River basin paleolakes – Missoula, Spokane, Bonneville, etc. (O'Connor et al., 2020), Lake Vitim (Margold et al., 2018). As a rule, ice-dammed paleolakes occupied intermountain depressions, within which various lacustrine geomorphological relics were preserved. Such relics include *ancient shoreline*, the cover of *lacustrine sediments, dropstones and* fields of *ridge relief* at the bottom of depressions, the origin of which causes debate among researchers. Anomalously high river terraces downstream are indicated more full-flowing conditions in the past. The formation of ice-dammed paleolakes is mainly associated with the growth of mountain-valley and cover glaciers during the Pleistocene glaciations and subsequent damming of draining valleys (O'Connor et al., 2020).

One of the notable examples of Neo-Pleistocene paleolakes is the Chuya-Kuray ice-dammed lake located in the southeastern part of the Altai Mountains. In the course of a long history of studying this territory, researchers have been discussing many aspects of the evolution of the Chuya-Kuray ice-dammed lake. The most discussed issue is the problem of estimating the rate of drainage of the paleolake and the parameters of floods during the destruction of the ice dam. Currently, there are two main views on this issue:

1. according to the researches (Baker et al., 1993), upon reaching the maximum level of filling of the lakes, the erosion of the ice dam began, lead to catastrophic drainage of a large volume of water within a few days or weeks. Thus, the observed geomorphological relics within the basins and downstream river valleys, by analogy with the territory of the Missoula paleolake, represent a *scabland* – a territory exposed to a catastrophic flood, the accumulative formations of which are composed of *diluvium*. The main argument in favor of this hypothesis, the authors cite the presence of ridge relief fields at the bottom of the depressions – a *giant current ripples*, which is considered an analogue of river dunes at the bottom of river flows (Baker et al., 1993). Based on this interpretation, numerical parameters of megafloods were estimated in further studies (Agatova et. al., 2020). According to the latest of them (Bohorquez et al., 2019), water flows were characterized by discharge of up to 10.5 million m^3/s and a flow rate of up to 40 m/s, which lasted 33.8 hours.
2. the hypothesis of a catastrophic flood was criticized (Okishev and Borodavko, 2001; Pozdnyakov and Khon, 2001) in a number of other studies. In these researches, the authors point out the essential contradictions of the catastrophic hypothesis to the hydrodynamic laws. These contradictions are connected with the impossibility of simultaneous formation of conjugate landforms in a rapid water flow - channel ridges at the bottom of basins and lacustrine shoreline on the slopes of basins. This contradiction is eliminated if we accept

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an alternative interpretation of the genesis and mechanism of formation of ridge relief. In addition, the very presence of a series of lacustrine shorelines indicates a slower and gradual nature of the drainage of the lake.

Thus, the aim of the study is the systematic interpretation of geomorphological relics in the Chuya and Kuray basins and the revelation of the mechanism of formation and degradation of the paleolake. The key objectives of the study are: to determine the genesis of the ridge relief of the Kuray basin and estimation possible magnitude water flows of tributaries and sources of the paleolake.

2. Materials and methods

To determine the genesis of the ridge relief, transverse and longitudinal profiles, stratigraphic and lithological structure of deposits of morphologically typical ridges were studied using pits and channels. In our work, we focused on the study of the granulometric composition deposits (*d*) and the calculation of the hydraulic size of debris (ω). The hydraulic size of sediments is the rate of particle fall in standing water. A ratio of hydraulic size to flow rate shows the resistance to erosion and the hydrodynamic environment of transportation of sediments. The hydraulic size of debris was calculated using the equation (Altschul et al., 1977):

$$\omega = \sqrt{\frac{4}{3} g} \cdot \sqrt{\frac{d\left(\rho_d - \rho_w\right)}{C_\partial \rho_w}}, \quad (1)$$

where *g* is the acceleration of gravity, *d* is the size of grains (cm), ρ_d is the density of the debris; ρ_w is the density of water; C_∂ is the coefficient of resistance (for spherical debris – 0.45, for rectangular debris – 2).

Quantitative estimation of the volumes of water released during the drainage of the paleolake is possible by analyzing the distribution of heights of shorelines. It is obvious that the absolute height of the shoreline corresponds to the former level of the water area. Since the formation of one shoreline could only occur during the warm season of the year, equal to 3 months in periglacial conditions, the difference between the height of neighboring shorelines allows us to find the height of the lowering of the water level ΔY (2):

$$\Delta Y = (Y_n - Y_{n-1}), \quad (2)$$

where Y_n is the absolute height of the shoreline and, respectively, the lake level in the initial period, and Y_{n-1} is the absolute height of the shoreline in the subsequent one. To determine the heights of the shorelines, instrumental measurement of the slopes of the basins was carried out, as well as the decoding of satellite images. The volume of water ΔVn is determined by the equation (2) with a known area S(Y) of the lake's water area at the corresponding level of absolute height and a known height of lowering the level ΔY:

$$\Delta V = S_n \cdot \Delta Y_n \quad (3)$$

Thus, knowing the duration of the lowering of the level *t*, it is possible to obtain the magnitude of floods Q_{out}:

$$Q_{out} = \Delta V_n / t \quad (4)$$

The determination of the hydrological parameters of the paleolake was carried out in the ArcGIS 10.6 software using the SRTM DEM.

3. Results and discussion

According to the conducted studies, the ridges are composed of two heterogeneous sediment strata. In the base of the ridges lies a layer of rolled boulders, pebbles and gravel with coarse-grained sand aggregate. Boulder-pebble deposits is not differentiated granulometrically, the hydraulic size varies widely – there are both boulders $d \geq 15$-50 cm ($\omega = 2.7$-5 m/s) and gravel with sand $d = 0.03$-1 cm ($\omega = 0.12$-0.7 m/s), which characterizes the variability of the hydrodynamic situation typical for fluvioglacial flows with a flood regime. The boulder-pebble layer is covered by packs of thin-layered dense clays and siltstones of brown and light gray color (d = from 0.005 mm to 0.05 mm; $\omega \leq 0.15$ m/s), clearly indicating on their lacustrine origin.

According to the results of the research, 201 shorelines were identified in the range of abs. heights of 1531-2133 meters, the height between which varies from 1-2 meters to 4-9 m. At the maximum filling level of 2133 meters, the depth of the Chuya-Kuray Lake reached 673 meters, the volume of water – 753 km^3, and the area of the water area reached 3054 km^2 (Pozdnyakov and Pupyshev, 2020). Currently, it is assumed (Okishev and Borodavko, 2001; Agatova et al., 2020) that the formation of the lake is associated with the blocking of the flow of the basins by the Maashey glacier, but only a glacial dam would not be enough to restrain the water column over 600 m due to the presence of cracks in the glacial body. An ice dam formed by layer-by-layer freezing of ice (Pozdnyakov, 2019) would be restrain water and resistant to long-term gradual erosion. The length of such a dam was over 40 km, and the area exceeded 350 km^2; the total volume of ice was 68 km^3. The freezing of the ice dam was facilitated by a short warm season and low water flow due to the fact that most of the river valleys were occupied by glaciers.

The study of relative heights of shorelines (Pozdnyakov and Pupyshev, 2020) shows that the drainage of the lake was characterized by a flood regime. In the initial period of drainage, when the water area was maximum (3000-3050 km^2), and the lowering of the level was 1-2 m/year, the water flow was 370-730 m^3/s. Periodic peak flood water flow rates at levels with an absolute height of 2100-1700 m were 800-2120 m^3/s, and taking into account the melting of dam ice (68 km^3), floods reached 2160 m^3/s. In general, the drainage of the lake occurred unevenly and with gradual attenuation for about 200 years (Pozdnyakov and Pupyshev, 2020).

4. Conclusions

The presence of a cover of lacustrine clays within the fields of the ridge relief of the Kuray basin suggests that it began to form in the pre-lake period in the form of fluvioglacial fan. The drainage of the paleolake occurred by overflow and erosion of the ice dam with a synchronous lowering of the water area level.

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Conflict of interest

The authors declare no conflict of interest.

References

Agatova A.R., Nepop R.K., Carling P.A. et al. 2020. Last ice-dammed lake in the Kuray basin, Russian Altai: new results from multidisciplinary research. Earth-Science Reviews 205: 103183. DOI: 10.1016/j.earscirev.2020.103183

Altschul A.D., Kalitsun V.I., Mayranovsky F.G. et al. 1977. Primery raschetov po gidravlike [Examples of calculations for hydraulics]. Moscow: Stroyizdat. (in Russian)

Baker V.R., Benito G., Rudoy A.N. 1993. Paleohydrology of late Pleistocene Superflooding, Altay Mountains, Siberia. Science 259: 348-350. DOI: 10.1126/science.259.5093.348

Bohorquez P., Jimenez-Ruiz P.J., Carling P.A. 2019. Revisiting the dynamics of catastrophic late Pleistocene glacial-lake drainage, Altai Mountains, central Asia. Earth-Science Reviews 197: 102892. DOI: 10.1016/j.earscirev.2019.102892

Margold M., Jansen J.D., Codilean A.T. et al. 2018. Repeated megafloods from glacial Lake Vitim, Siberia, to the Arctic Ocean over the past 60,000 years. Quaternary Science Reviews 187: 41-61. DOI: 10.1016/J.QUASCIREV.2018.03.005

O'Connor J.E., Baker V.R., Waitt R.B. et al. 2020. The Missoula and Bonneville floods-a review of ice-age megafloods in the Columbia River basin. Earth-Science Reviews 208: 103181. DOI: 10.1016/j.earscirev.2020.103181

Okishev P.A., Borodavko P.S. 2001. Reconstructions of "fluvial catastrophes" in the mountains of Southern Siberia and their parameters. Vestnik Tomskogo Gosudarstvennogo Universiteta [Bulletin of Tomsk State University] 274: 3-13. (in Russian)

Pozdnyakov A.V. 2019. Self-Freezing of the Ice Dam: The Self-Regulation Algorithm. Geography and Natural Resources. 40 (2). 180-186. DOI: 10.1134/S1875372819020112.

Pozdnyakov A.V. Khon, A.V. 2001. About the genesis of "giant ripple bars" in Kuray basin, Altai Mountains. Bull. Tomsk State Univ. 274. 24–33. (in Russian)

Pozdnyakov A.V. Pupyshev, Y. S. 2020. Continuous discrete mode of degradation of the Chuya-Kuray ice-dammed lake. Geoshere Research. 1. 56-65. (in Russian) DOI 10.17223/25421379/14/4