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Geological and geomorphological background of cataclysmic debris flooding in the Altai mountain rivers

Abstract: Article discusses effects of catastrophic floods on the rivers in the Altai Mountains. The whole complex of floodplain terraces of the main rivers – the Biya and Katun was formed by insertion of these rivers in the loose deposits, that was formed as the one-act occurrence associated with glacial-dammed lakes – the Prateletskie and Chui-Kuraipaleovodoema. This conclusion is confirmed by a series of radiocarbon age determinations of sediments and opto-luminescence dating.

Keywords: Altai Mountains, above the floodplain terrace, glacier, moraine, alluvium, catastrophic flooding, radiocarbon dating.

Floods in the Altai Mountains were largely determined by the climatic conditions of the region, that in the past was related to the increase in temperature and intensive deglaciation, with subsequent formation of ice-marginal lakes and their outflow through the arterial rivers. These were catastrophic flooding phenomena. At the present day the most important triggering factor for floods is abundant precipitation in the mountains succeeded by the spring overflow which used to happen a lotthe last decade.

The background of cataclysmic debris flooding in the valleys of Altai arterial rivers is strongly linked with the geological–geomorphological structure of the territory. The majority of researchers exploring Altai Mountains (e.g. Nekhoroshev, 1932; Moskvitin, 1946; Ivanovskiy, 1962; Adamenko, 1976; Rakovetz, 1979) argue for a uniform stationary character of a regional river network that was formed at the boundary between the Tertiary and Quaternary period. However there is some controversy. B.F. Speranskiy (1937) and later on M.S. Kaletzkaya (1948) proved and spoke up for a flexible and changeable potential of the rivers in South-Eastern and Central Altai.

Hence, previous investigations show two opposite approaches to this issue, nonetheless the two sides are evenly matched and neither has sufficient evidential data.

Today there is much obtained actual data on the terrace sediments in the Upper Priob'ye region. Numerous studies of terraces quantity and their age based on common geomorphological observations, groundwater bore data, palynological and paleocarpological materials, small mammal fauna justification, molluscan shells, a number of radiocarbon dates interpreted as organic deposits of alluvial sediments in the Ob river, lead to contradictory conclusions.

Current available information gives the basis to outline the structure, quantity and age of the Upper Biya and Upper Katun fluvial terraces, and enables us to discover the nature of the Biya – Katun valley system development.

As noted before (Baryshnikov, Panychev, 1987), the Biya river valley is marked by diverse tectonic zones, which to some extent predetermine distinct outflow direction.

Geological structures of the Proterozoic, Middle Cambrian, Ordovician, and Devonian, oriented, as a rule, perpendicularly to the valley, played no significant role. The reach downstream is rather well developed valley of considerable width. The reach upstream, running from Lake Teletskoye to Turachak village, has mountain river character.

Geomorphological maps of the Biya river valley indicate a floodplain, five fluvial terraces and one debris flow terrace. The relative elevation of each terrace increases in the direction upstream to the river outflow (Table 1). It is indicative that a large-scale geologic and environmental mechanism is responsible for terrace formation at high elevations.

Table 1. Height of fluvial terraces at different locations in the Biya river valley

Number	Biysk city	Dmitrievka village	Turachak village	Kebezen village
Floodplain	1,5-5,0	3	1-4	1-4
I	8-12	3-5	5-8	10-13
II	20-23	12-15	13-17	20-25
III	30-35	20-25	25-30	30
IV	40-45	-	35-40	40
V	60-80	-	55	60-80

It has been recognized that Upper Neopleistocene in the Altai Mountains is the period of glacial advance, initiating global cold climate change. Glaciers pre- existing in the central part of the Altai Mountains out flowed into the river valleys. The glacier moving through the meridional section of the Teletskoye Lake took up debris scattered on the terrace edges. Then in the Lake's most latitudinal reach the glacier provided considerable increase of sediment production with the side moraine sedimentary sections. It was a distinctive rock glacier landform and its lower cone lies in the Upper Biya valley.

Valley glacier dammed some tributary valleys including Yogach river valley. In this case tributaries downstream Yogach have been dammed, as a result of sandy-gravel accumulations deposited along the side moraine. Water level increased in the dammed valley up to on average 100 m versus the current river bed. It was evidenced by lacustrine sediments in the Yogach valley (Figure 1).

Figure 1. Lacustrine sediments in the Yogach valley

To determine the numerical ages of deposits we examined lacustrine deposit samples applying the optically stimulated luminescence (OSL) technique. OSL dates obtained from bottom parts of the exposure were dated at 82.6±7.0 ka (GdTL-1715), at the upper parts of the exposure dated at 50.2±3.3 ka(GdTL-1716) (Baryshnikov *et al.*, 2015).

Moraine dam constraining Lake Teletskoye glacial melt-waters prior assessed at 80 km^3 (currently at 40 km3) broke down inducing giant Biya Debris Flow (Figure 2).

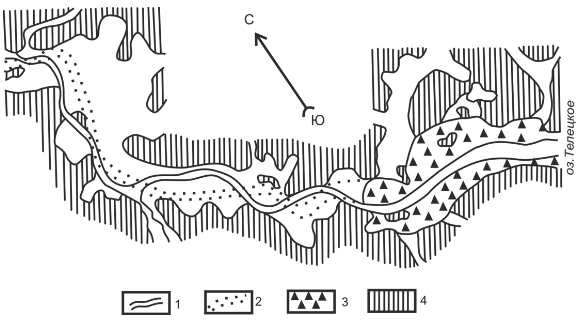

Figure 2. Reconstruction of the catastrophic Biya Debris Flow caused by failure of the moraine dam and outburst of Lake Teletskoye (after Baryshnikov, 1992): 1 – modern Biya River channel; 2 – track of Biya Debris Flow; 3 – moraine; 4 – rocks

Eroded material from the morainic dam was redeposited downstream and dammed tributary valleys, forming the terrace staircase composed of clayey deposits, and sandy gravels with parallel bedding. A number of radiocarbon dates were obtained for these lacustrine clays – 16,120±80 BP (SOAN-1864) and 15,270±60 BP (SOAN-2017) in the left-hand tributary of Biya – Pyzha River valley (Baryshnikov, 1992). Subsequent formation of the Biya river terraces occurred due to river incision into bedrock.

Rapid rise of the bottom of the trunk valley caused by aggradation of the fan resulted in damming of tributary valleys and formation of valley lakes in their lower courses. The lakes outflowed rapidly. The traces of debris flood movement are marked with specific ridged-micro-relief (“giant current ripples”) on the fourth and fifth Biya fluvial terraces upstream the Pyzha river near Kebezen village and Wolf Tooth (Volchiy Zub) mountain (Baryshnikov, 1979).

The Biya river terraces were being formed in a short period of time. Geochronology of the Upper Biya valley is estimated at 20 thousand years as evidenced by our monitoring observations done in the foothills section of Altai (Baryshnikov, 1984).

About 80 thousand years ago terminal moraine was formed in the Upper Biya valley constraining glacial melt-watersand creating conditions for lacustrine sediments accumulation downstream the Yogach River. Within the interval of 20-16 thousand years terminal moraine eroded and destruction of the morainic dam was followed by a huge mud and debris flow previously carried alongby a glacier now splashed out to the Biya river. Lacustrine sediments were being accumulated in the river tributary valleys.Release of large amount of water initiated the formation of a series of fluvial terraces: the fifth and the fourth terraces being formed during the subsequent 1, 0-1, 5 thousand years, the third and the second terraces within the same interval,the first terrace at the boundary between the Upper Neopleistocene and the Holocene, and a floodplain formed 2 thousand years ago.

Numerous studies have focused on the low section of the Katun River system, a number of scholars were studying this question: Ivanovskiy (1956, 1962, 1978), Schukina (1960), Dubinkin (1961), Kryukov (1963), Adamenko and Dubinkin (1968), Maloletko *et al.* (1970), Adamenko (1974), Okishev (1974), Rakovetz and Bogachkin (1974), Borisov and Minina (1979), Panychev (1979), Maloletko (1980) and others.

Much attention has been paid to the existence of the valley glacier in the foothills of the Russian Altai, in particular to the origin of the so-called “Mayminskaya Dam”. Disputable question arises – is it the fragment of lateral moraine or alluvial deposits in high fluvial terrace of the Katun River? Scholars express different opinions on this issue.

Reviewing the recognition of ground ice genesis in Altai Mountains, number of workers hypothesized that the Mayminskaya Dam has nonglacial origin (Martynov, 1961; Dubinkin 1961; Dubinkin and Adamenko, 1968; Seliverstov, 1966; Maloletko, 1980). L.N. Ivanovsky (1967) rejected his former hypothesis as well. It generated controversy on the mechanism of redeposition of multi-tongranite--dioriteblocks; nevertheless there was no denial of alluvial genesis of the Mayminskaya Dam deposits.

In 1984 a series of geological surveyswas carried out, in the location of Mayminskaya Dam PMK-1105, and a number of pits were dug of up to 10 m in depth. Bone remains of mammoth fauna have been discovered among horizontally layered fine sand with small patchy areas of well-rounded gravels. The upper five-kilometers of the section are represented by finepale greysand intercalated with silts. The latter are granite-diorite blocks.

V.A. Panychev (1979) considered that the burial of bone remains dates back to 28,730+995 BP (SOAN-2301). We suggest that the fragment of the fifth fluvial terrace, unique and distinctive the Mayminskaya Dam, is the part of the terrace staircase, which was formed prior to catastrophic outburst floods from glacial lakes in the Central Altai. The fifth fluvial terrace sediments are deposited irregularly in a mountainous area, while here the terrace was composed ofgravel-sandy mixturewith rare boulders. This peculiar feature is applicable to the Biya River valley as well.

To reconstruct formation and evolution of high terraces in the low section of the Katun River system, it is necessary to remodel terrace formation taking account of a new data. Terrace formation has been ascribed to acatastrophic debris flow there, the same as in the Biya River valley. As noted by M.G. Grosswald (1987), for the first time in the Russian Altai, evidence has been recognized of past catastrophic glacial lake outburst floods. Giant current ripples were found in the Altai in valleys of: the Biya River (Baryshnikov, 1979), the Bashkaus river, the Chulyshman river, the Chuya river, the Katun river and in the Kurai Basin (Butvilovsky, 1982, 1985; Okishev, 1982; Rudoy, 1984) and resulted from water flowing from glacial lakes in the Altai. Existenceof these topographic forms has been viewed as the strong evidence for massive catastrophes in Neo-Pleistocene in the Altai.

Later, other evidence of outbursts from glacial lakes was recognized, such as spillways and distant transportation of giant rocks torn from valley sides.Until recently these giant rocks in the river valleys were attributed to the glacier activity. A number of dates obtained by A.N. Rudoy (1984) reveal that massive floods and debris flowed at 14–20 m s^{-1} through the valley gate with discharges that exceed 1 million m^3s^{-1}. Estimated velocities resulted from surface elevation change (of up to 1500 meters a.s.l.) in the Chuya-Kurai paleolake bed above river valley level in entrants in the mountain sides, as well as from the width of channel runoff inside the valley. That was crucial for hydrological regime of runoff and greatly affected the entire process.

M. G. Grosswald (1987) suggests that all the above events occurred in a short time span, within 10-15 days. Nonetheless indicated discharges at those short intervals are impressive.Thus with the destruction of the moraine dam in a present-daymoraine glacier lake – Lake Merzbacher in the Tien Shan Mountains, maximum discharge can be up to 1000 m^3s^{-1}, in Lake George in Alaska discharges exceed 10000 m^3s^{-1}.

In the process of deglaciation, water stock in the ice-dammed lakes was huge and made not less than 1000 km^3 in the Chuya and Kurai systems (Rudoy, 1984). Those large amounts of water was enough for producing giant runoffs of high velocity in the channel and with enormous reserves of energy, strongly affecting valley morphology, causing rock erosion, redepositing alluvial gravel, cobbles, silty boulders, and finally providing conditions for damming of lateral tributary valleys.

It is clear that river valleys have no straight channels. Bending and meandering the runoff, of catastrophic origin as well, reducesits velocity in some sections while in others it continues to peak to its full capacity. Often enough, technical drawing of the river bed and its tributaries indicates that meanders and valley curves are lined up with one another. Consequently a huge mud and debris flow spreads for many tens of kilometers downstream and splashes out to the tributary valleys thus leading to destructions (Baryshnikov, 1990).

For example, among the effusive bedrock, a ridge like solid mass of limestone blocks stretching across the Tytkesken' creek bed has been discovered at the mouth of that creek flowing to the Katun River from the left near Elanda village. Residual islands of the ridge can still be found on the right-hand bank and partially on the left side. With the immense destructive power of the runoff, the ridge was rapidly eroded away, and broken off blocks interlayered with alluvial gravel were transported downstream with rapid deepening of the creek. Studying terrace composition in a natural exposure we discovered no large accumulation of limestone blocks downstream the bedrock exposure, whereas upstreamthere are plenty of them. The remote transportation of debris andgiant rocks by running water proves high-velocity (high-energy)-scale cataclysmic debris flooding.

The Katun River valley has many sections – stretches with widths of up to 3-4 km alternate with narrow sections, some localized stretches, whose profile is often limited to 300 m ravine. At the valley deepening section a staircase of terraces is being formed as a rule. Such a beaded shape of the river valley was a key factor at the time of out bursts from glacial lakes, so far as narrow sections served as natural "hydraulic locking" system, capable to blow off high velocity of the runoff after frontal shock-wave run.

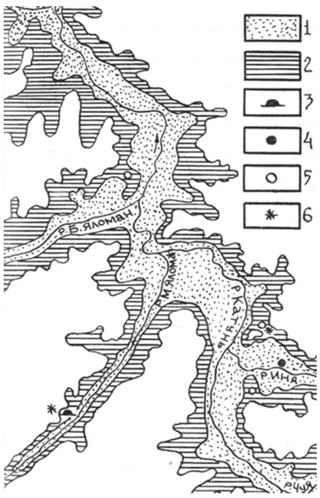

Figure 3. Reconstruction of the dammed lake in the Katun River System near Yaloman village: 1 – present--day river valley; 2 – profile contours of the reconstructed dammedwater reservoir; 3 – Maloyalomanskaya cave; 4 – sampling points for radiocarbon dating (C14); 5 – sites of wave-cut denudation in the basin; 6 – sites of sheetrock (gazha).

The deposition of finer sediment from the sediment plume generated during debris flow occurred further downstream.The results of flood wave are seen in the occurrence of gravels preserved at the steep slopes in the vicinity of Inya, Yaloman, Kupchegen villages (Figure 3, Figure 4).

Figure 4. Lake-dammed sediments in the valley of Katun

The uppermost gravel section has its maximum elevation at 1050 m a.s.l., that is above the present-day level – 300 m a.s.l. at the mouth of the Chuya River, 350 m a.s.l. in the vicinity of Inya village, and 400 m a.s.l. at the mouth of the Bolshoi Il'gumen River. So called "short-lived" lake was formed both by the natural "hydraulic locking" system activity, downstream Bolshoi Il'gumen River estuary, where the valley is extremely narrow, and accelerated erosion rate, as evidenced by wave-cut marks. Such marks (Figure 5) were discovered on the left slope of the Bolshoi Yaloman River at an elevation of 350 m a.s.l., where horizontally-oriented line of washout basins was formed on bedrock in the exposures of coarse-grained and medium-grained granites.The basin could reach up to 30-50 cm and even 1 m in diameter, with the erosion rate of 10-15 cm. Massive limestone blocks can also be found at the same elevation near Inya village and at the watershed in Khrustalny city.

Critical water velocity related erosion is evidenced by the boulders exposed in the fluvial alluvium at the confluence of the Bolshoi Il'gumen River and Katun River (Figure 6). The image clearly illustrates wave-cut denudation in the basin and furrow erosion.

Figure 5. Wave-cut marks of paleolake activity on the bedrock exposure of granite on the left slope of the Bolshoi Yaloman River

Figure 6. Washout basin with the granite in watercourse alluvium at the confluence of the Bolshoi Il'gumen and Katun River

If present-day water velocity related erosion occurs at such rate, consequently it supports the occurrence of paleolake and granite erosion caused by wave-cut activity in the past (Figure 4). After the rapid water drop, accumulated sediments erode intensively. Stabilization of the critical process parameters occurred only when water edge reached and caught up with the water level of the similar section downstream at an elevation of 180-200, 140-160 m a.s.l. and lower sections.

Therefore a series of terraces found in the mountainous area is the result of large arterial rivers incision into bedrock and unconsolidated deposits, accumulated in the course of one-act outburst flood.

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