The role of anthropogenic factors in formation of shores of Lake Baikal

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Abstract: The rising water level in Lake Baikal due the construction of Irkutsk Hydro, caused the activation of all shore deteriorating processes: abrasion of accumulative deposits, damage of bars and bay-bars etc. In this respect the Yarki-islands located near the northern shore of Baikal should be specially noted as the area of tourist and recreational interest.

Key words: Lake Baikal, limnology, littoral zone, shore morphology, shore processes.

In recent years much attention is devoted to the problems of recreational use of seashores, especially the shore areas of the inland natural and man-made reservoirs (Recreational..., 1990; Shores..., 1999). In this respect the shore areas of Lake Baikal are considered the national property equally with mineral wealth, forests, waters and other natural resources. The Lake Baikal itself is regarded as a recreational object of international importance (Atlas..., 1993). The outlook for the recreation and tourism in the Baikal zone is not yet sufficiently evaluated; besides, the foreign experts suggest to set up the ecological tourism in the international scale.

At present the problem of Baikal water pollution is the subject of debates in publications. Keeping this in mind we, however, focus on the problems of engineering geology, particularly on different geological processes in the Baikal shores (Fig. 1).

Formation of the shore zone of Lake Baikal lasted for a long time, being associated with development of rift troughs of Baikal type. It was much contributed by neotectonic displacements and variations of Baikal water level due to cyclic, rhythmic and other types of its fluctuations. The Baikal shores developed in the context to these neotectonic, hydrogeological and climate conditions. Despite the differences in dimensions, all rift troughs of Baikal type are characterized by similar morphological features: asymmetry of cross section, oblong shape, considerable steepness of underwater slopes. Lake Baikal as well as its islands and semi-islands are marked by rocky character of shores. The lacustrine accumulations and relatively shoal banks originated in recent stages of evolution; these are confined to the sites of large river outfalls. Baikal is the running-water reservoir, with the level regulated by the outflow of Angara-river.

The shore zone of Baikal developed in the post-glacial time during Holocene, under the no-shelf conditions (in its present concept). The processes of shore formation occurred mainly in the underwater slopes, under the influence of
relatively short-period wind-driven waves. Under these conditions, various accumulative deposits in smaller reservoirs of elongated shape can be formed by the alongshore flows of alluvium in a narrow (width of only several wavelengths) zone. These flows are formed by short steep waves which, being not refracted, reach the bank at a definite angle.

The Lake Baikal with its >2000 km – long shore line is characterized by a wide range of wave regimes which determine the morphology and type of shores. According to theoretical estimations, the waves of Baikal can reach the height of 6 meters (Atlas..., 1971); virtually, however, the observed wave heights do not exceed 3.6 meters. Formation of the modern pattern of shore zone was determined by the history of development of the relief of Baikal depression during Cenozoic. Intensive sinking of the depression bottom in the process of riftogenesis caused the formation of high and steep slopes and development of abrasive shores. About 70% of the Lake’s coast belongs to this type, and only 23% is the accumulative type. In this paper we focus on the latter type of shores, because these are of special importance in terms of their use for recreational, economic and other purposes. Major accumulative forms of shore relief detach “sors” (lagoons) from the Lake’s body, forming the so-called sor-littoral zone of Baikal, marked by peculiar biological community developed during Holocene (the term “sor” is Russian word which means the underwater portion of partly submerged coast) (Rogozin, 1993).

The changing of Baikal water level after the construction of the dam of Irkutsk hydro-power station caused the detrimental technogenic consequences including the activation of different exogenic geological processes (Imetkenov, 1996; Kozhova, Pavlov, 1996). Perhaps, the changes may be not as large as in other inland water reservoirs; however, these should be taken into consideration in view of organization of the intensive tourism in this region.

It is reasonable to recall the history of behavior of water level in the Lake Baikal: construction of the Irkutsk dam in 1958 has created the artificial regime of water level, and since that time the Baikal’s drainage became regulated, depending on both the climatic conditions in the region and the regime of water discharge through the dam’s power units (Verbolov et al., 1992; Sinyukевич, 1993; Kozhova, Pavlov, 1996; Ovchinnikov et al., 2002). This has led to the 1 m-level rise, which in 1962 reached the normal headwater level in the Irkutsk water storage reservoir. The amplitude of annual variations of water level decreased; however, it became larger in the perennial scale. In some periods within the last 200 years, the water level reached the maximum high marks. The water level rise induced the activation of exogenic geological processes and caused the damage of coasts, erosion and intense landslide in the southeastern area of Baikal. These processes were most intensive in the periods of autumn storm weather. In some places the extent of the shore hollow-out reached 6 m. The highest degree of destruction was observed in accumulative forms of shore relief, such as barrier beaches and bay-mouth bars. Many of those disappeared, for example, the bay-bars in the region of Kultuk, the bars detaching the Chikalovo-sor (island Babya Karga) and the Proval-bay (within the period of 1962–1973). In the north area of Baikal the intense destruction of Yarki-island detaching the Angarsky sor currently occurs. The temporary falls of the Baikal water level, particularly within the period of 1971–1972, interrupted the shore abrasion; accordingly, the landslide processes decreased and in some places stopped. These processes activize in the periods of water level rise, reaching the maximum intensity when the level exceeds 0.2–0.3 m the normal head-water mark, stated for the water storage reservoir.

In view of the disastrous situations which may occur during the high level periods and entail the activation of shore processes and flooding of the eastern shore areas of Baikal, the water-level limits have been determined by the Decree of Russian Federation in March 2001, which should be taken into consideration in the industrial and economical ventures in this region: 456 m as the lowest and 457 m as highest level marks. Following these directions has enabled to stabilize to a certain extent the abrasion-landslide processes.

During the relatively low water level in Baikal in summer 2003, the abrasion-landslide processes developed with the intensity similar to that of the former natural conditions. However, another problem arose.
Historically, the low water level in Baikal since 1996 caused the complete draw-down of persistent water reserves of the Lake; by May 8, 2003 the level draw-down reached the mark of 456.2 m, i.e. the actual minimum level, determined in 2001 by the Decree of Russian Federation. A critical situation arose in many settlements concerning water supply, particularly in the Angara-river valley, including the town Angarsk and Usolye; in addition, the navigation problems arose in the Angara-river section between Irkutsk and the Bratsk reservoir, as well as in the Angara downstream. The forecasts do not promise any replenishment of water reserves in that year. It was necessary, therefore, to increase the water discharge through the power units of the hydro-power stations, and in first instance, through the dam of Irkutsk Hydro, which caused lowering of the Baikal water level. It should be noted that the design of Irkutsk Hydro and water storage reservoir provided for the minimum water level mark as 455.54 m.

The variation of Baikal water level associated with the need for generation of definite amounts of electric power by the Angara cascade of hydro-power stations, impede the stabilization of processes of abrasion-accumulation and landslide (Fig. 1).

Formerly we reported the destruction and disappearing of a number of accumulative forms of the shore area relief (Fig. 1). These forms, or their remnants, are at present submerged, their washing-out continues till the water layer over them during the low water level will exceed the value of a half wave length. In this case, the remnants of washed-out accumulative forms will not be affected by wave impacts, unlike the bay-bars detaching the lagoons in the regions of Kultuk, Cherkalovo-sor and Proval-bay (Fig. 1). The Posolsky-bars and Yarki-island detaching the Angarsky-sor, are in the stage of intensive destruction.

The area of Yarki-island as one of supposed places of tourist interest, should be specially described, because it presents a striking example of negative effects of human activity on the Baikal environment (Rogozin, Trzhtsinsky, 1993). The water level rise and wave impacts contribute to the hollow-out of shores of Yarki-island. The amplitude of water level variations at the 1 m-rise of the level and perennially regulated runoff increased; this caused activation of abrasion, especially during the maximum and minimum cycles. The bars consist of the groups of sandy hills of different heights; among them there are flat areas of different extensions, which are the remnants of Yarki-island damaged by waves long ago during the rhythmic rises of water level in Baikal. This could occur one or two thousands years ago during in the periods of water abundance in rivers and water increased water discharge into the Lake Baikal.

In 1990s the top phase of a due-cycle of fluctuations of water level coincided with the sharp level rise after the construction of the Irkutsk dam. The of the bar of Yarki-island is more than 14 km-long, its width varies from 50 to 300 m at different water levels. Seasonal rises of water level causes the flooding of lower areas of bars. At the thickness of water layer over the bar crest close to 1.5 of the wave height, the spilling breaker occurs, which reached the bar crest at minimum speed. The bar crest material (sand) is transported onto the lagoon slopes; this is accompanied by hollow-out of shores. As a result, the bar body shifts to the lagoon; the bar height decreases making it easier to wave overflowing at low water levels.
The dynamics of bar scouring during the water level rise is shown in Figure 2. Similar pattern of bay-bar scouring was observed in the regions of Kultuk, Cherkalov-sor, Proval-bay and the lower areas of Yarki-island. The higher areas of Yarki-island not subjected to the wave overflowing are scoured by edge effect, i.e. by intensive impacts of waves which skirt the Yarki-shores. So, the eastern extremity of Yarki reduced by 20 m during the season of 1989-1990, during 1973-1990 the extent of reduction exceeded 300 m. The distal western extremity of the bar reduced during the similar period by 500 m. During the period of 1962-1990 the total length of the Yarki-island reduced by 25%. The bar transformed into a chain of water-surrounded small islands (edge effect), which intensified the scouring of the Yarki-island. In the middle part of the bar a separate group of higher (about 10 m) areas of Yarki developed, with a total length of about 170 m and the widths from 15 to 20 m. Between the Yarki there were two kaudeirs which later (after 1973). This caused the intensification of the edge effect at high level stands and wave overflowing. The latter occurred only 5 times during the period of 1973-1986; as the consequence, about 10 thousands cubic meters of sandy material were washed off.

Degradation of the Yarki-island was largely contributed by permafrost and eolian phenomena. The dispersion of Yarki-island was accompanied by formation of numerous deflation basins and alluvium. Disintegration of bar into separate hills occurred due to the eolian erosion in the places with damaged vegetation cover. In October 1974 the sand alluvium cones developed in the beach of Yarki-island opposite the deflation basins during 15-20 hours, due to the impact of northern winds of 10-15 m/s speed; one of these cones is 18 m long and 10 m wide, with total volume of 5 cubic meters. In spring periods a certain portion of emerged sandy material is transported by wind onto the bar surface increasing its height, the other portion is washed off during the water level rise adding to the amount of littoral drift material. Besides, there are many other microforms of local deflation in the described area.

The occurrence of cryogenic microrelief forms can a observed here in spring periods (Rogozin, 1993). Defrostation of water-saturated ground in beach areas makes it fluidic which benefits to its easy washing off during the seasonal water level rise. The ramparts composed of different materials (particularly, of peat) are formed on the lagoon shores under the pressure of ice blocks. The runoff scours of about 1.0 m width and 0.5 m depth, formed as a result of thawing of ice hummocks, range from the higher part of Yarki-island to the lagoon.

Destruction of Yarki-island entailed the changing of water exchange in the detached lagoon, i.e. in the Angara-sor; the changes touch the chemical composition of water, temperature and hydrobiological regime, microclimatic conditions in the adjacent territory, including Nizhneangarsk and other settlements near the Baikal-Amur railway. All these conditions influence negatively the use of the territory for recreational and fishery purposes; in the northern area of Baikal the places of waterfoul nesting disappear. All above mentioned concerns also other sors which have become (or will soon become) the bays of Lake Baikal.
The technogenic rise of water level in Lake Baikal caused troubles for the exploitation of the Transsiberian railway which is laid on the south eastern shore of Baikal; this part of the shore is composed of Neogene argillaceous rocks affected by the landslide deformations, confined to places marked by the 5-80 m elevation of bedrock base above the level of the Lake (The problems..., 1993). Before the construction of the Irkutsk dam the main reason of landslide development was abrasion; to control this phenomenon, the bulkheads and breakwaters were constructed. The 1.2 m-rise of water level disturbed the labile equilibrium and renewed the intensive landslide process.

In the north-western shore of the Olkhon-island composed of frozen sandy-argillaceous and scree-clay deposits of Neogene and Quaternary the solifluction landslides activated. The thickness of frozen layers is 30-75 m, with the depth of seasonal thawing varying from 1.2 to 2.5 m. The total length of landslide-affected shore is > 5 km. The deformed slopes have the pronounced cirques with scarps of up to 2 m height. Dimensions of some landslide amphitheatres vary from 70 to 500 m in width and from 70 to 360 m in height. It should be noted that before 1959 these landslides were also in the stage of slow permanent flow. The changed hydrogeological conditions caused the pulsating displacement: during the high water level (457 m) and intensive abrasion the abrupt shifts of soil occur, large amounts of soil (up to several thousands cubic meters) being transported to the beach; this is accompanied by expansion of landslide cirques. During recent 309 years, for example, the Sasa-landslide body doubled in size (Fig. 3).

The rise of Baikal water level due to the dam of Irkutsk Hydro produces the permanent headwater level in the mouths of rivers which inflow the Lake; this is the reason of swamping of these areas, swampy plains occur in the adjacent territories. It is likely, that further existence of dam will increase the high level stands by 50%, entailing the intensification of shores hollow-out.

Thus, the sor-littoral zone of Lake Baikal which was naturally developing during thousands years, can be damaged under the technogenic influence during several decades.
**References**


**Streszczenie**

Podniesienie zwierciadła wody jeziora Bajkał o 1.2 m związane z wybudowaniem i funkcjonowaniem irkuckiej hydroelektrowni doprowadziło do aktywizacji procesów brzegowych. Szczególnie niekorzystne zmiany ekologiczne wystąpiły w obrębie brzegów akumulacyj-
nych – procesem abrazyjnym poddane zostały kosy, wały brzegowe i odsypiska oddzielające zatoki o charakterze lagun. Największe nasilenie tych procesów wystąpiło w obrębie wyspy Jarki znajdującej się w sąsiedztwie północnego obrzeża jeziora, czyli części akwenu przeznaczonej do turystycznego zagospodarowania.