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LANDSLIDE BLOCKAGES IN TADJIKISTAN MOUNTAINS (GISSAR-ALLAI & PAMIRS): THEIR ORIGIN AND DEVELOPMENT

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INTRODUCTION

Mountainous regions of Tadjikistan have been very active from the seismo-tectonic point of view during the last 1.0-1.5 millions years. Geological processes in the alpine, seismically active regions are characterised by their scale and high activity and very often their manifestations can be considerd as natural catastrophes. It is especially typical of the outburst floods and debris flows associated with the dams' breaches. In Tadjikistan blocking of the deeply incised river valleys is a common phenomenon.

About 40 blockages in the Piandj River valley along the Pamirs-Afghanistan border, 16 blockages in the Gissar-Alai region in the Zeravshan, Fan-Daria and Shing River valleys (Southern Tien Shan), 18 blockages in the Murgab, Kudara, Tanymas and Bartang River valleys (Western Pamirs) and about 20 complete or partial blockages in the Shakhdara River in the South-Western Pamirs have been identified by the analysis of different maps, space and aerial images. Though each of them is a unique phenomenon, some general characteristic features of such natural dams can be proposed.

There are several main problems related to the landslide/rockslide dams:

- Where do such blockages occur most often?
- How are they formed – conditions and causes of their origin?
- What is the longevity of rivers damming?
- What are the causes and character of the dams' breach or erosion?
- What measures are necessary to undertake in the entire region or in the specific river valley?

WHERE DO ROCKSLIDE BLOCKAGES OCCUR?

Rockslide blockages of river valleys took place, as a rule, within the epicentral zones of the strong modern earthquakes and of the past (Q_{III-IV}) earthquakes identified by paleoseismological data. Spatial distribution of such events is controlled by large seismically active faults, mainly. The main fault planes are usually accompanied by the systems of sub-parallel secondary faults and their structure (within the studied region) can be characterised as a thrust zones with several blocks. Non-uniform uplift of the neotectonic structures leads to the blocks warping, which, in tern, affects the development of the drainage system and active erosional-gravitational transformation of the slopes. The most deeply incised valleys often coincide with the transverse uplifts with tectonically fractured slopes. These areas are characterised by high seismicity as well.

Typical paragenesis of seismically active structures and seismic dislocations can be observed in the central-lower part of the Kudara River valley and at the Kudara-Murgab watershed (the Sarez Lake area). Study of the river valleys' history within this area indicates that they were blocked by rockslide dams repeatedly during the entire Quaternary period. 6 complete and 4 partial blockages in the lower part of the Kudara River valley, the Usoi dam, 5 assumed blockages of the Murgab River valley, which are now submerged by the Sarez Lake, and 3 partial blockages of the Bartang River valley were identified. All of them, with the exception of the Usoi dam, are prehistoric and their conventional ages vary from Q_{III} to Q_{IV2}.

Similar, though much smaller relative to the Sarez case seismogenic structures have been identified in Tadjikistan in the central part of the Zeravshan Range (the Chimtarga "knot"), along the Gissar-Kokshaal and the Main Gissar faults (Ziddy, Khait, Faisabad, Karateg and Garm areas), at the Gissar-Alai – Pamirs junction zone (Peter-1 and Zaalai Ranges), at the Pamir-Afghan seismic zone. It shows that areas located at the intersections of the main longitudinal seismogenerating zones and transverse arch uplifts undergo intensive seismic destruction. In the Sarez Lake basin it takes place at the intersection of the east-west trending fault zones at the junction of the Central-Pamirs and Southern-Pamirs regions with the Zulumart-Kyzyldan arch uplift that belongs to the Academy of Sciences Range system.

HOW DID THEY FORM – CONDITIONS AND CAUSES OF THEIR ORIGIN?

Most of blockages occurred due to strong earthquakes with intensity not less than IX points of the MSK-64 (MM) scale. High intensity of these events is testified by:

- volume of the displaced rock mass (from $2×10^8$ to $1\text{-}2×10^9$ m^3);
- presence of seismic ruptures along the scars;
- high extent of rock crushing of both the displaced rock massifs and of rocks at the adjacent slopes (sackung features, zones of fracturing on the slopes).

There are clear relationships between the blockages' origin and the geological conditions, neotectonics and the history of the glacial-erosional processes of valley formation. They were studied in details in the valleys of Western Pamirs and in the Zeravshan River valley in the Gissar-Alai region.

The first group of factors favourable for the blockages formation is the lithological heterogeneity of rocks, their weathering and intensive fracturing, seismic discontinuities and fold-blocky structure of slopes.

The second group of such factors – the intensive neotectonic uplift and effect of glaciation. They determine high rate of the slopes height increase and deep valley incision. Relatively flat Pliocene relief formed by the sheet glaciation was deeply incised and at the upper parts of the slopes wide benches of the Early Pleistocene half-sheet glaciers and younger valley glaciers remain. Such slopes are unstable in the seismically active regions even when they have rather low general inclination (up to 20 -30º). It is supported by rock massifs softening up to the significant depth due to high glacial loading (up to 10-12 MPa) and subsequent unloading, undercutting of slopes feet and their erosion during the Late Pleistocene over-incision that was 50 m or more deeper than the present-day valley's level. The general slope disruption is governed by the deep-seated seismotectonic and seismogravitational structures, while the tendency of its further transformation – by the superficial seismic ruptures. Slope height increase and complication of its profile led to the stress field changes and caused rock slope failures just at the remnants of the stepped slopes where giant Late Pleistocene rockslides had been formed. Due to neotectonically active blocks it caused complex undulation of river valleys and formation of numerous rockslide dams.

According to Fedorenko *et alii* (1981) three variants of the stepped slope formed by the glacial and water erosion transformation are typical: those that affect only upper step, those that affect only lower step and those that affect the entire slope.

The first variant means that only that part of the weathered rock massif fails that is located above the slope formed by the erosion. Such type of failure is also supported by the "erosional forks" undercutting the slope. They form the local lowering on the slope and the free space where a block displacing first can accelerate. At a system of such "forks" large displacement near one of them can cause the cascade slope failure in case of the earthquake. It can be assumed that just this mechanism worked during the formation of rockslides on high slopes of the Sarez Lake basin. Perhaps this process took place during the formation of the Mantaro rockslide in Peru in 1974. Similar slope failures accompanied by river blockages are typical of the contemporary glacial zones (Gunt, Shakhdara, Shing and other River valleys).

Those rock slope failures that affect lower steps only can be classified as seismogenic and aseismic rockslides with volumes up to 250×10^8 m^3, that reach valleys bottoms but block only their narrowest parts or tributary valleys.

Seismogenic rockslides that affect the entire slopes are characterised by the maximal volumes. They are typical of the Middle-Pleistocene or Late-Pleistocene epochs of rockslides formation, which took place after maximal incision of river valleys. In the Central and Soth-Western Tajikistan such incision accompanied intensive tectonic deformations and was the main factor supporting formation of giant seismotectonic translational rockslides that blocked large sections of river valleys (Obi Garm).

In the narrow river gorges incised by the intensive erosion, blockages are formed basically by rockslides and rock avalanches (Usoi, Shidz, Timur-Dara, Shing, Yagnob, Iskanderkul). In contrast, wide valleys formed by glaciers are blocked by rock avalanches that generated in the tributary valleys and enter the main valley or by large seismotectonic translational rockslides (Khait, Liabidjoi, Surkhob – Figure 1, several blockages in the Shakhdara river valley). In the valleys of the South-Western Tajikistan where thick loess-like loam deposits are widely developed, blockages are caused by translational landslides that convert into earthflows and mudflows (Figure 2).

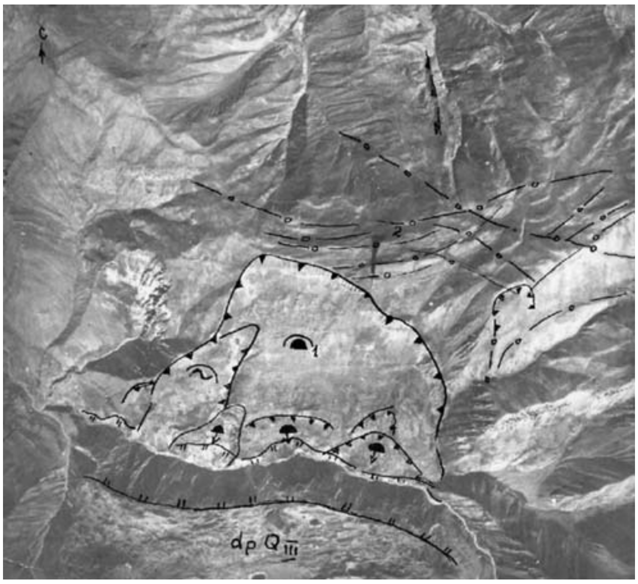

Figure 1 - Seismotectonic destruction of the block and rockslide damming the tributary of the Surkhob River

Depending on the amount of the displaced material and valleys morphology, blockages can be classified as complete, near-slope and partial (Figure 3).

Rockslide and rock avalanche blockages in the Central Asia, Caucasus and other regions can be divided into two large groups. The first one includes long-living blockages that are incised slowly by the rivers, without partial or complete breach. Usually they are large natural dams composed of angular boulders, large blocks and rock massifs. Those blockages composed of loamy material and intensively shattered rock debris can be ascribed to the second group. When they block large rivers, their uncontrolled breach begin shortly after and there are just few days to undertake emergency measures.

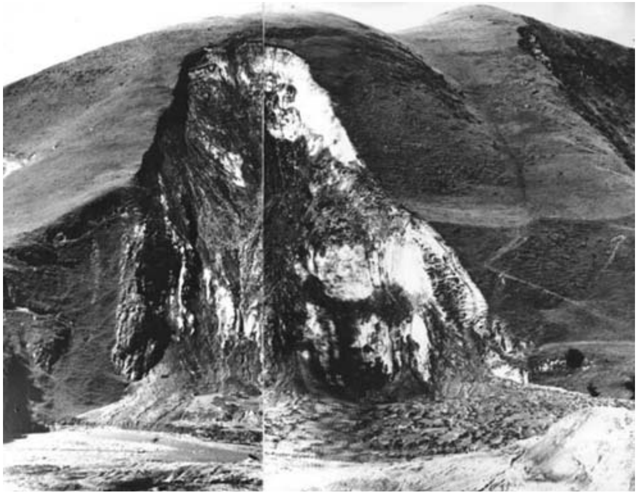

Figure 2 - The Gudara landslide, damming the Kyzil-Suu River channel and flood-plain

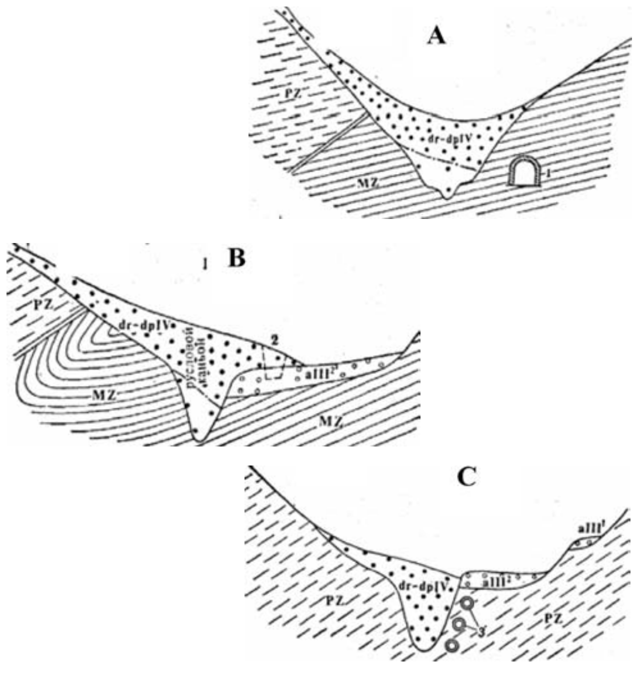

Figure 3 - The complete (A), near-slope (B) and partial (C) blockages and related types of spillways

Each type of blockages requires a specific complex of both preventive and emergency measures to reduce hazardous consequences of such phenomena. Those blockages, which dam narrow deep canyons are most hazardous. Due to rapid impounding the spillways should be constructed immediately, mainly by blasting.

The two best known ancient blockages in the West Pamirs valleys, namely the Kudara (Pasor) at the lower reaches of the Kudara River valley and the Shidz in the Piandj River valley are described hereafter.

The Kudara blockage was formed 17 km upstream from the Murgab-Kudara Rivers junction by a rock avalanche 750×10^6 m^3. The 110-m high dam is composed by fragments of variable size with fine and medium-size fractions predominating. Thus it is significantly different from the Usoi dam. This blockage can be classified as the near-slope type, since it collapsed in the wide glacial valley.

The Shidz blockage is located at the latitudinal section of the Pianj River valley, 28 km downstream from the Rushan village. It was formed by the seismogenic rock avalanche about 1 billion m^3 in volume that descended from the left slope of the river valley. It blocked the valley completely. Dam up to 450 m high is composed of giant angular boulders of the Cretaceous-Palaeogene biotite granite up to several dozens meters in size. Cliffs composed of such blocks are well retained in the incised gorge. Its seismic origin is proved by the presence of crushed rocks in the scar and of the numerous recent faults and papeoseismic dislocations at the surrounding slopes. Rock avalanche overlap high Late Pleistocene terraces on both banks of the river. The dammed lake extended for more than 70 km along the Pianj River valley. However, absence of the alluvial fans of the same age at the tributaries' mouths and weakly developed lacustrain deposits indicate that the dam was breached shortly after its formation.

CAUSES AND STYLE OF THE NATURAL DAMS BREACH OR INCISION

Most of the natural rockslide dams, both modern and ancient have been breached or incised with rare exceptions that can be exemplified by the Usoi dam. There is one characteristic features typical of all of them – breach or incision always occur at their proximal parts.

Style of such erosion practically has not been studied. There was an attempt to reconstruct the Kudara blockage breach. Such reconstruction and back analysis showed that this dam was eroded at its proximal part stage by stage in the form of alternating overtopping until it was completely dissected and the present day river channel was formed. Due to the presence of the levees that overlay the Upper Pleistocene and Holocene depositional terraces of the Kudara River 40-50, 18-25 and 5-8 m high. These levees can be traced up to the Kudara River mouth. The blockage was incised up to 60 m.

Though breaching levees of the Shidz blockage have not been studied in details, field observation allow to identify two breaching events divided by long period of the gradual incision. Two breaching levees are clearly identified - the upper one (main) up to 70 m high and 17 km long and the second one up to 12 m kigh and 40 km long.

The dam was incised at a depth of about 230 m. Its remaining part forms 3-km long rapids between the upstream limit of the dam near Shidz village and its downstream edge where the riverbed is 150 m lower.

Our investigations show that overtopping of such blockages began when dammed lakes were infilled and sometimes led to dams breach. Direct causes of the breaches have not been determined, though, according to the situation at the Lake Sarez area and general analysis the list of such causes is typical and rather diverse:

- Lake overfilling due to lacustrain deposits accumulation;
- Change of the filtration streams;
- Back erosion of the canyon on the downstream slope;
- Failure of large landslides into the lake (it was found at three sites in the Shidz Lake) and formation of the wave that affects the dam;
- Effect of earthquakes;
- Each rockslide blockage has its specific features of both origin and incision.

Observations performed at the Kudara and Shidz dissected blockages, at the existing West-Pshart blockage, and data on the blockages of the Gissar-Alai region (Toktobeksai, Akterek, Kararel and Karavshan) prove that the zone of rather surgeless overflow forms at the beginning of the incision of all dams types. Its dimensions depend on the ratio of the hydraulic parameters of the stream and grain-size composition and erodability of debris. As can be judged from the hydraulic perfection of the overflow zones they must be formed for a long time.

BLOCKAGES LIFETIME

The problems of the lifetime of all prehistoric dams of the style of their destruction and of those consequences remain unsolved. However, they are crucial for the solution of the Sarez Lake problems.

Practically all blockages at the Western Pamirs occurred at the end of Late Pleistocene or in the Early Holocene. For several dammed lakes such as the Kudara and some lakes in the Pianj and Shakhdara River valleys their longevity was determined as 3000 to 6000 years on an average by the lacustrain deposits thickness. In many lakes there are expressive lake terraces that mark stages of rapid discharging.

CONCLUSIONS: WHAT SHOULD BE UNDERTAKEN WITHIN THE REGION AND AT A SPECIFIC VALLEY?

Study of the specific features of the natural dams formation, “life” and “death” is very important since they form grounds of the design solutions, of the dam material mechanical and filtration design parameters of the methods of structures strengthening and environmental protection.

Since just seismotectonics is the main factor governing rockslide dammed lakes formation and development in Tajikistan, therefore, study of the seismic regime of the whole Quaternary period, estimation of the existing blockages’ stability and selection of the seismogenic rockslide-prone sites seems to most important problems.

The main tasks of the related investigations are:

- Rockslides formation prediction and estimation of the probability, types and scale of the phenomena in question with due regard to the different combinations of natural conditions.
- Seismic microzonation and determination of the slope stability criteria under seismic loading.
- Seismic monitoring at the selected sections of each seismogenerating zone and reconstruction of seismic conditions. Varity of seismic structures will help to find the analogous structures for the existing (Usoim Shidz, Kudara, etc.) and expected blockages.
- Detailed study of the natural analogues of the existing (Usoi, Drumkul) and dissected (Shidz, Shakhdara) blockages.
- Reconstruction of the rockslide-prone slopes and river valleys sections.

It is still impossible to predict time of the catastrophic failure. However, as E.P. Emelianova noted “… in the seismically active regions for the practical purpose it is easier to bear with uncertainty of the time of the event rather than with the uncertainty of its location”.

It is important to estimate approximately the type of the slope failure and related blockage, its possible volume by analogy with the similar slopes, basing on the geological data and on the deformational monitoring data. It is necessary since the type, complexity and cost of the protective measures depend on the slope failure type, on the mechanism and rate of debris motion downslope and along the valley, on the extant of valley damming.

Since breach and incision of the blockages are always hazardous and affect large areas as exemplified by the study of the Kudara and Shidz blockages breach traces, now in Tajikistan high priority is given to the scientific research and to elaboration of the social aspects of population protection rather than to the expensive construction measures:

- Selection of the most unstable natural dams and slopes in the course of regional engineering-geological studies;
- Assessment of the areas expected vulnerability and risk of the population and economics;
- Organisation of the monitoring of the most unstable slopes as the basis of the early warning systems;
- Development of the early warning systems;
- Organisation of the local emergency teams;
- Development of the state emergency system;
- Infrastructure planning and reconstruction;
- Training of the local population of the risky areas for the emergency situation.

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