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THE KARMADON ROCK-ICE BLOCKAGE: ITS FORMATION AND DEGRADATION

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INTRODUCTION

Formation of the Karmadon blockage (Northern Ossetia-Alania, Russia) was caused by a rock-ice avalanche on September, 20, 2002. Taking into account that ice-composed features outside the permafrost zone are not a "long-living" in the geological sense, the Karmadon blockage should be considered as a unique natural phenomenon. Only indirect evidences can indicate existence of similar dams in the past due to their rapid destruction.

It is necessary to note that according to the archive data, at least 6 similar ice and ice-rock avalanches fell from the Dovdorak glacier on the Military-Georgian Road that crosses the Great Caucasus Range from North to South during the period from 1775 to 1875. Those that occurred on June 18, 1776 and on August 13, 1832 were the largest. The first one blocked the Terek River for 3 days and was breached catastrophically; the second one was 100 m high and 2 km wide and its breach started after 8 hours. The possibility of similar glacial surges at present can not be excluded too. Therefore the Karmadon ice-rock blockage should be considered as a natural laboratory that allows investigating processes that take place when large-scale ice failure blocks river valley.

REGIONAL ENVIRONMENT

The study area is located in the south of the European part of Russia at the northern slope of the Great Caucasus Range. The annual precipitation here is about 700-900 mm and more. The average annual temperature varies from the negative values up to 5-7ºC depending on the altitude.

The alpine relief is very rugged and can be characterised as an erosional, locally as an erosional-glacial. It was formed at a large extent by the neotectonic movements. Several orographic zones can be selected within the studied area. In the south there is a Kazbek-Dzimara Plateau, which is a part of the Main Caucasus Range. The Kazbek dormant volcano (5033 m) – the second highest peak of the Caucasus, and the Dzimaraihoh Mountain (4780 m) rises above the central part of the Plateau at the Georgian-Russian border. Directly northern and north-eastern slopes of the Kazbek-Dzimara Plateau have abrupt rocky cliffs more than 800 m high and 45-55º steep. Slopes are covered by hanging glaciers, which are fed by ice and snowfield lying above. Northward there are rocky crests divided by the valleys with steep rocky slopes occupied by the Maili and Kolka glaciers up to the elevation of about 2300 m and inclined up to 18-19º. Frontal parts of the glaciers are completely buried by the superficial moraines.

Further to the north, sub-parallel to the main mountainous ridges there is a Rocky Ridge separated from the Kazbek-Dzimara massive by a "shale depression", which corresponds to the Digoro-Osetian structural-formational zone. The deeply incised valleys of the Terek River basin (Fiagdon, Gizeldon, Genaldon, etc.) cross the entire area. They form narrow canyons through the Rocky Range. That one formed by the Genaldon River is named the "Karmadon Gates".

DISPLACEMENT OF THE ROCK-ICE AVALANCHE AND DAMS FORMATION

According to the Northern Ossetia regional monitoring centre, the catastrophic rock-ice avalanche on September, 20, 2002 was caused by the collapse of ice and, possibly of volcanic rocks from the northern cliff of the Kazbek-Dzimara Plateau at the eastern ledge of the Dzimaraihoh Mountain at the elevation of about 4400 m. The collapsed rock-ice mass moved along the steep (~45°) slope for about 2 km and reached the upper part of the Kolka Glacier at the elevation of about 3300 m. It caused the activation and displacement of the section of glacial ice and moraines about 4-km long. Presence of several scarps at the glacier basement on a way of rock-ice avalanche allows assuming that it could move as on an air cushion. This assumption is supported by the very high speed of its motion – 91.5 m/s or 329 km/hour (according to I.M. Vas'kov & G.A. Dolgov estimations)[1].

[1] *However, there is an alternative hypothesis on the Karmadon disaster origin proposed by glaciologists from the Institute of Geography, RAS (Kotliakov, Desinov et alii, 2003). They do not consider the rock (ice) fall from the trough wall, as the direct cause of the Kolka glacier rapid motion. This assumption is based on the information from the mountaineers who visited the are shortly before the catastrophe that these failure occurred not on September 20, but several days before. Thus, the first seismic record corresponds to the impact of the surging glacier on the valley slope and, consequently, the velocity of the rock-ice avalanche should be less than the above mentioned value. According to this hypothesis the disaster could be classified as a regular surge of the Kolka glacier generally similar to those, that have been observed in the past. The extremely high velosity of motion could result from the large amount of melted water accumulated at the glacier basement (Kotliakov et alii, 2003)*

Moving rock-ice avalanche cut off the lower part of the Maili glacier, turned 90° left and rushed into the Genaldon River valley, which is characterised by a straight channel inclined from 3.5° to 8° and without any prominent bends. This motion was accompanied by avalanche swinging from one valley slope to another one. For a very short time the rock-ice avalanche has reached the Lower Karmadon village. The vector of main rock-ice mass impact has been directed towards the Upper Genal village ruins. This settlement was destroyed by the similar avalanche in 1902. As on September 20, 2002, in the 1902 ice-rock avalanche did not reached the Upper Genal village, however it was destroyed by the air wave. After collision with a slope near the Upper Genal village ruins, speed of the rock-ice avalanche, apparently, decreased essentially and it divided into 2 parts. One part rushed towards a narrow canyon of Genaldon River, and the second (smaller) one – towards the Gornaya Saniba village, moving upstream the Saniba River valley. The rock-ice debris could not pass through a narrow canyon and its main portion stopped blocking the canyon.

The total amount of the displaced rock-ice mass is estimated as 110 million m^3. The entire travel distance is about 19.6 km, and the elevation step between the initial ice failures and the distal point of the ice-rock avalanche is 3200 m. Considering the time period of 3 minutes 33 seconds between the first shock recorded by seismic stations and the end of vibrations as the total time of rock avalanche motion its average speed should be 92 m/s or 331 km/hour. There were two sections where the velocity could decrease due to abrupt bends of its travel path (at the upper part of the Kolka glacier and at a distal part of the Maili glacier).

Ice-rock avalanche led to the formation of an ice-rock blockage 4 km long and 500 to 1000 m wide from the Kauridon and Genaldon Rivers junction upstream of the "Karmadon Gates". Average thickness of the deposits ranged from 20-40 m at its proximal part to 160-170 m at the frontal part. Total area covered by the deposits was 3.85 km^2. Its surface was extremely rough. The frontal part initially was light blue, which testify predominance of ice in the debris. 500-600 m from the frontal edge dams' surface became grey and dark grey, indicating significant increase of rock material quantum.

Such internal structure of the blockage (ice in front and ice-rock mixture at the proximal part) proves the above model of Karmadon ice-rock avalanche formation and motion.

Originally, the rock-ice dam was composed of coarse breccia, consisting of acute-angled fragments of ice, firn and rocks. The initial ice/rock ratio was 7/3. Between fragments of ice and rocks there was plenty of thin carbonaceous shale dust whose formation, apparently, is connected with carbonaceous shale shuttering during avalanche motion. Rocks content is various. Andesite volcanic rocks that form the Kazbek-Dzimara Plateau prevail, but there are also siltstone, diabase, granodiorite and, rarely, quartz conglomerate and gravelstone fragments. Petrography and roundness of rock fragments allow to suggest the limited entrainment of an alluvial material in the displaced mass. The blockage stabilisation occurred within several days.

FORMATION OF THE DAMMED LAKES AND THEIR DEVELOPMENT

After dams' formation the Genaldon and Kauridon River valleys started impounding. In September 2002 these rivers had discharge rates of 4-6 m^3/s (400000 m^3/day) and 1.0 m^3/s (85000 m^3/day), correspondingly. Two days after the disaster, on Septenber 22 at 10 h 40 m a.m. water surface of the dammed lake at the Gornaya Saniba village (in the Kauridon River valley) was 5-7 thousands m^2 and that in the Genaldon River valley – up to 75 thousands m^2. Additionally there were several minor lakes with water surface from 1000 to 3000 m^2.

At 3 p.m. on September 22, 2002 water accumulated in the Genaldon River started breaching towards the Gornaya Saniba village where water level raised 1.5-2.0 m/hour. Practically at the same time water started breaching through the main blockage. Such a fast breach, just two days after dam formation and without its overtopping is not typical of the rock avalanche dams. In this case it was caused by the high content of ice in the blockage (up to 70% initially). Analysing possible scenarios of the Karmadon blockage breach we assumed the filtration along the valley slopes or under the blockage body. It was also hypothesised that blockage containing a lot of ice may float-up. Indeed, water accumulated on the blockage and in the dammed lakes flew along the blockage boundaries and filtrate through the dam body where ice prevailed and through the alluvial deposits in the valley bottom. Initially intensive filtration was prevented by ice barrages at the valley slopes but later on they failed.

Consequently, in a year, ice masses intensively thawed and impounded water passed through. The observed rate of thaw was higher than it has been expected initially. At the end of 2003 dam volume decreased significantly, its surface became much darker, more rough and have been crossed by large deep fractures. Dammed lakes almost disappeared and water drained through the dams' body.

The general state of a blockage remains very unstable. Ice is thawing everywhere, both within a blockage body, and on adjoining slopes of a valley. Blockages destruction occurs, basically, by ice thawing due to positive temperatures, and also by the internal erosion caused by draining water.

CONCLUSIONS

Formation of ice and rock-ice slope failures, their transformation in ice and rock-ice avalanches is typical of the central part of the Main Caucasian ridge and is observed with a certain regularity. It can be proved, in particular, by the National epos, which incorporated a long history of development of this territory, and by the real observations during the Military-Georgian Road construction in XVIII century. Recurrence of such phenomena varies significantly for different valleys. In the Genaldon River, on tentative estimations, alongstream ice or rock-ice avalanches occur once in 100 years. Formation of the dammed lakes accompanied by rapid inundation of the upstream parts of river valleys and their catastrophic breach is the important component of the natural hazard estimation aside from high kinetic energy of the catastrophic ice or rock-ice avalanches and their rapid motion. A principal cause of the Karmadon rock-ice blockage and several dammed lakes formation was the abrupt deceleration of the rock-ice avalanche in the narrow Karmadon Gates canyon. Probably, if the Genaldon River valley does not have such a sharp narrowing, rock-ice avalanche could move much further, up to the foothill plain. Thus, the Rocky Ridge played a role of the natural "protective dam".

Results of the performed studies show that high ice content in the Karmadon avalanche deposits that was destroyed by water and positive temperature is the main peculiarity of this feature. Ice is an additional source of water for the dammed lakes and, at the same time, is the weakest component of the dam body. The possibility of the "floating-up" of such a blockage due to low density of ice (if the rocky component is insignificant) should be considered as well.

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