SCIENTIFIC JUSTIFICATION OF THE NATURE OF ULTRAMUDFLOW DISASTER

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Abstract. Based on the research and analysis of numerous publications about the Genaldon disaster, the authors propose an ingenious, scientifically grounded approach to understanding the nature of the process. It is shown that the mechanism of displacement of large ice-water-rock (moraine-ice) masses has a complicated pattern and represents an ultramudflow displacement. Initially, several mechanisms were implemented in the process: 1) impact; 2) vibration and 3) water hammer. At the beginning, this led to the breakaway of the glacier, its movement, disintegration, and then the gliding mechanism turned on and caused stretching of the moving mass, its rocking and powerful blows against the sides of the valley in the Karmadon Gorge, then its compaction, squeezing and stopping at the Karmadon Gate. Below is the zone of low-power water-soil mass accumulation.

1 Introduction

The study is aimed at substantiating the nature of ultramudflow disasters using the example of the Genaldon glacial disaster that occurred in 2002 in the Caucasus in the Republic of North Ossetia (RSO-Alania).

Algorithms of the origination, formation and behavior of ultramudflow ice disasters, including the Genaldon disaster, have been studied by many domestic and foreign experts. Among them are Malneva I.V., Chernomorets S.S., Zaporozhchenko E.V., Vaskov I.M., Gevorkyan S.D., Poznanin V.L., Egorin S.V. and many others. When studying such catastrophes, Egorin S.V. attached the greatest importance to fracture tectonics. He analyzed a series of previous disasters in the Genaldon Gorge and collected a great deal of facts and data. In his photograph taken back in October 1997, long-lived cracks marking the fault are traced. The opening of this fault led to the formation of two sections of ice cliffs (about 300m and 250m long) by the morning of 20th September 2002, which were traced during the comparison with the space images. Later on, along with other factors, it triggered the disaster. Vaskov I.M. proposed a hypothesis on the origination of ultramudflow catastrophes as a result of the combined effects of endogenous and exogenous processes. The most detailed study of the mudflow formation and movement is provided in the works by Vinogradov Yu.B. and Panov V.D., where the tendency to generalize the ways of

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mudflow origination is clearly traced. In later research by Perov V.F. and Sidorova T.L. three mechanisms of the mudflow origination have already been identified, although this idea was diclosed by Vinogradov Yu.B. earlier, back in 1976. He put forward and substantiated somewhat different mechanisms than his predecessors: erosive — erosive-shear—shear. The ideas by Vinogradov Yu.B. turned out to be very long-lived, since he was only one step away from the idea of the unified shear mechanism. Poznanin V.L. and Gevorkyan S.D. suggested the idea of the gliding movement of the Kolka Glacier, which is partly adhered to and to some extent supported by the authors of this article. However, along with it, some other aspects of hypotheses are supported and developed, which describe and prove essentially a single multidimensional mechanism of ultramudflow of this kind. By an ultramudflow (UMF), the authors mean an ice-water-rock mudflow of huge size, with volumes of ice, water and mudstone debris averaging 100 million m3 or more.

2 Materials and methods

The information and data of the field study performed by one of the authors shortly after the Genaldon disaster laid the basis for the research. They were collected along the routes mapped upwards the gorge of the Kolka River from the Gornaya Saniba village. To identify the nature of ultramudflow disasters, the researcher applied generally accepted in engineering geology methods, techniques and models, which are based on the laws of physics and mostly related to mechanics. In addition, space images from the QuickBird and Landsat 7 satellites were interpreted and analyzed. The Argis software was used for data processing.

The glaciers of the Genaldon basin are glaciers that form a part of the Kazbek-Jimarai glaciation node of the Greater Caucasus. The Kolka Glacier is the second after the Miley Glacier in terms of the area of distribution and volume of ice (at least 125-130 million m3, as of 2001, according to its main parameters (as per the data of the RSO-Alania Hydrometcentre). Kolka is a valley glacier that occupies the valley of the same name, which has a sub-latitudinal strike that coincides with the strike of the main tectonic structures of the Caucasus. That is why, with its modern high activity, the glacier is pulsating and has powerful surface and internal moraine deposits. As E.L. Shteber wrote back in 1902, due to the frequent movements of rock blocks along tectonic cracks, the entire surface of the glacier is covered with fragments of black Paleozoic shales, which over time were apparently processed into the material that makes up most of the surfacial and inner moraine.

The Kolka mudflow has a classic three-membered structure, but it is characterized by a rather complex structure of the formation zone and a two-stage accumulation zone. The formation zone of UMF-2002 consists of 5 very specific sites [1] (Figure 1).

Moreover, sites 1-3 are characterized by long-term ‘maturing’ of the disaster. While sites 4 and 5, on the contrary, characterize the rapid process of combining ice, rocks and water into an ice-water-rock mudflow, or UMF.

Fig. 1. Mudflow zones in the Genaldon River basin and the specific sites in the formation zone
1 – landslide sites; 2 – impact mudflow source; 3 – Kolka Glacier; 4 – glacier acceleration site, a – inertial discharge of the envelope flow from the glacier; 5 – section of the sliding impact of the water-ice mass and the formation of an ultramudflow; 6 – transit zone; 7 – ice accumulation zone; 8 – upper part of the water-soil accumulation zone

3 Results and discussion

Based on field observations and as a result of space image interpretation, it was found that rock and ice collapses of up to 8 million m3 occurred on site 1 (Figure 1) for two months, which led to the formation of a basic mudflow source (site 2). They caused a change in the state of the ice in the rear part – at the contact point of the glacier's adhesion with the bed (3) and the filling of the area with the formed water. This was made possible by the influence of several mechanisms: 1) impact; 2) vibration and 3) water hammer. This was followed by a collapse of the glacier and its rapid movement along site 4 with partial disintegration. On site 5, the fourth mechanism turns on – gliding, and the UMF consolidates again and continues moving through the transit zone (6). Here, active rocking of the mudflow occurs. Due to hitting against the sides of the valley, the frontal parts of the UMF slow down and at this time it is 'caught up' by the succeeding parts of the flow and its mass is compacted in the accumulation zone (7). The UMF's break through a narrow rocky gorge led to the squeezing of its water-ice component and below, on site (8), it got accumulated into a water-soil mass to a great extent.

So, it has been determined that such disasters should be considered as a synthesis of several components. Let us look at each of them separately and their interaction as a whole.

The impact mechanism. This term should be understood not only as an impact process, but also as a process of dense indentation, or imprinting – in this case, of large ice and rock blocks from the peaks bordering the glacier, mainly of the Jimarai-Khokh mountain.

As is known, impacts have peculiar properties of high-speed compression and ultra-high pressure on the base for a short period of time. The manifestations of this phenomenon can be seen in the Landsat 7 ETM+ image dated 19 August 2002, where avalanche plumes are noted, spilling over the entire Kolka Glacier and its left coastal moraine. In the same image, powerful ice collapses are visible (Figure 2).

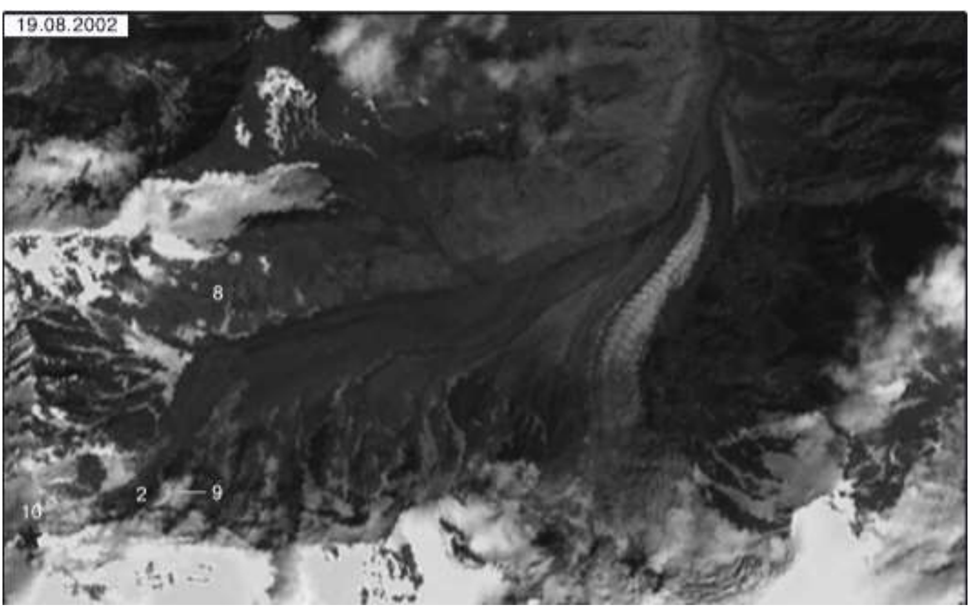

Fig. 2. The Kolka Glacier's circus a month prior to the disaster on 20 September 2002 in satellite images of Landsat 7 ETM+
2 –zone of collapsed rocks; 8 – a collapse plume of rocks on 19 August; 9 – a hanging glacier, later completely collapsed; 10 – Jimarai-Khokh Mtn (according to S.S. Chernomorets)

Thus, it was established that large rock and ice collapses began between 28 July and 19 August 2002. The accumulation of collapse material and the expansion of the boundaries of the collapses continued in the subsequent days. The image dated 20 September 2002 shows a very large rock fall lying on top of fresh snow, with an area of (0.17 ± 0.02) km2 (see the Table 1 (according to S.S. Chernomorets [2]).

Table 1. Area of collapsed sites calculated using the Landsat 7 ETM+ space image

Date (local time)	Site	Area, km2
20 September 2002	Fan of rock	0.20 ± 0.03
20 September 2002	Rock accumulation	0.17 ± 0.02*
19 August 2002	Fan of rock	0.13 ± 0.02
19 August 2002	Rock accumulation	0.36 ± 0.03
19 August 2002	Ice accumulation	0.19 ±0.03
* Fresh plume of collapsed rock on top of the snow cover		

By 20 September 2002, collapses of the hanging glaciers on Kolka had almost ended, which is confirmed by comparing the ETM+ image dated 20 September 2002 with a fragment of the QuickBird image of September 25th, published in Huggel et al., 2005. The total area of the collapsed ice was 0.34 km2. Moreover, the bulk of the ice collapsed from 19 August to 20 September 2002. (It should be noted that the rock collapses continued after the disaster).

Then, the second mechanism of UMF formation is activated, i.e. shock-and-vibration, since release of a huge amount of energy caused changes in the structure of the surface part of the ice, turning its parts (ice) into a liquid crystalline state, and filling the underlying site (3) with water (Fig. 1), which further led to a loss of adhesion and, ultimately, caused the collapse of the body of the Kolka Glacier.

Data on impact and shock-and-vibration effects (disaster preparation) are reflected in the same satellite image taken 8.5 hours before the Genaldon disaster, the magnification of which makes visible some holes in the rear of the glacier, bulges of bubbly ice around them and traces of water splashes (Fig. 3).

To substantiate the hydraulic shock mechanism during the UMF formation and its effect on the glacier's breakdown, it is necessary to justify where a sufficient volume of water came from. According to calculations, the amount of kinetic energy released during the fall of rock debris and ice, taking into account its conversion into heat generated when interacting with the glacier body, is not sufficient, even though their volume is gigantic [3]. Here it is necessary to take into account the amount of runoff from the firn slopes of the lateral glaciers, as well as the amount of internal feed of the lateral glaciers and the Kolka Glacier itself. Given the gigantic volume of rockfall (see the Table), it is necessary to take into account the amount of trapped air, which releases a lot of heat during adiabatic compression. According to the calculations by Poznanin V.L., the amount of heat released was sufficient to melt 0.1 million tons of ice. Thus, according to the total volume of accumulated water in the area of the impact point was 6.6 million m3. Besides, a porous layer of ice and accumulated fine-grained soil on the glacial bed with a volume of about 35 million m3 have a capability to be passed through by an additional considerable volume of water.

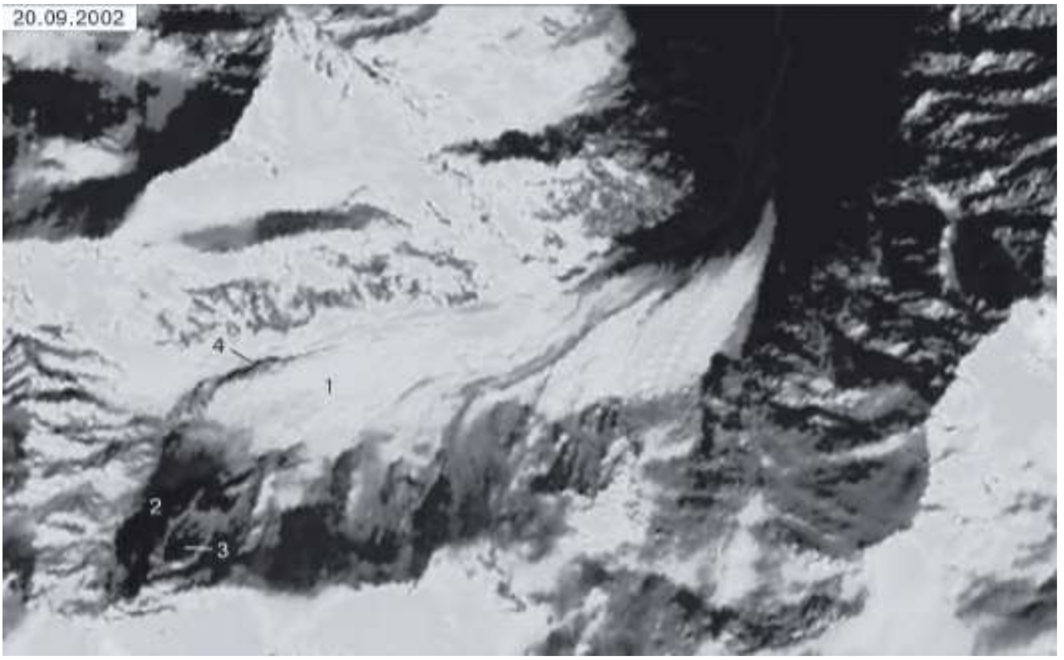

Fig. 3. The Kolka Glacier's circus 8.5 hours before the disaster on 20 September 2002 on satellite images Landsat 7 ETM+
1 – The Kolka Glacier; 2 – the zone of collapsed rocks; 3 – the place of the hanging glacier, which collapsed in the period from 19 August to20 September 2002; 4 – the shadow of the ledge of the glacier surface

The fact that the water hammer mechanism was in place is evidenced by the earth surface seismic shocks recorded by seismic stations in North Ossetia (RSO-Alania) on 20 September 2002, the first of which occurred at 19 hours 43 minutes. Other shocks followed. The interval between them decreased at first, and then, having reached a minimum, began increasing again. This, according to Poznanin V.L. and some other experts in the field of geodynamics, is a sign of the disaster's outbreak. [4-11].

It really was the crucial point – the actual collapse of the glacier, followed by its rapid movement.

Then, the rotation mechanism of sliding off the collapsed part of the glacier along the mass of the porous water-saturated layer in the right-to-left-down direction is activated with axial rotation until the impact on the left lateral moraine (Figure 4) and the formation of a breakthrough wave on the surface of the accelerating glacier.

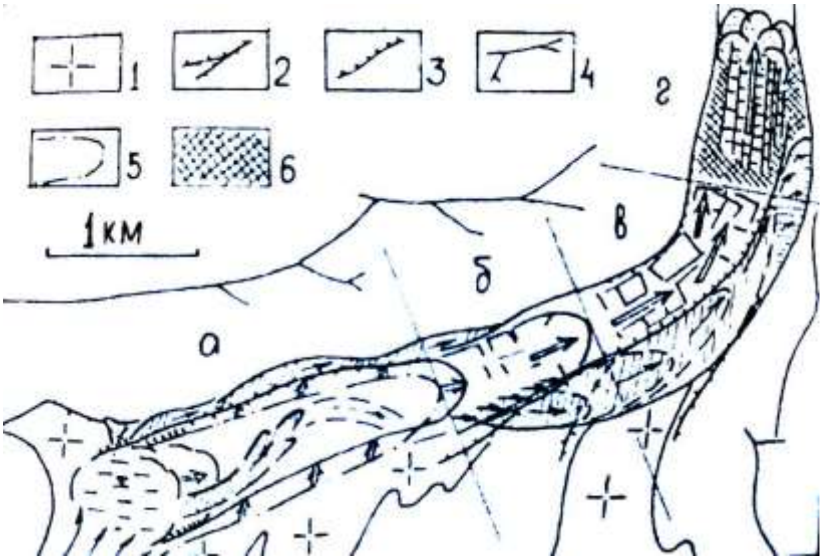

Fig. 4. Plan view of the zones of the mudflow disaster formation in the upper reaches of the Kolka Glacier: the zone of initial displacement of the glacier and emptying of the reservoir of the impactsource (a); the zone of glacier acceleration and inertial discharge of flows through the moraine triangle (б) and the Miley Glacier; the zone of crushing glacial blocks and lateral water capture of the envelope flow (в); the zone of high-speed interaction of ice, water, soil and air – the formation of an inversion flow structure with a gliding mechanism of mudflow movement (г). 1 – rock scree and moraine; 2 – snow and firn; 3 – accumulation of water; 4 – stages of collapse development; 5 – contour of the glacier at the moment of detachment; 6 – mudflow mud-stone mass.

The actual acceleration of the glacier took place in the form of gliding along the mudflow mass that drew ahead of the glacier. The main link in the mechanism of the ultramudflow formation is its dynamic restructuring into a single body with a sliding impact after collapsing from the rock ridge. Such a structure is capable of preserving the gliding mechanism of high-speed movement.

4 Conclusions

As a result of the research, the nature of the formation, development and dynamics of the Kazbek-type ultramudflow was substantiated using the Genaldon disaster as an example. The following conclusions were drawn:

- disasters of this type result from of several mechanisms in action, some of which are cumulative in nature, others are extremely rapid and act like a hurricane;
- the Kolka Glacier ultramudflow has a classic three-membered structure, while it is characterized by a rather complex formation zone and a two-stage accumulation zone;
- such disasters should be considered as a synthesis of several components or mechanisms, such as impact, vibration and hydraulic shock in the formation zone, as well as rotation and gliding in the transit and accumulation zones.

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