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Ice–rock avalanche of 2002 in Genaldon River valley, North Caucasus, Russia: consequences and problems

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ABSTRACT

The biggest glacial disaster in the Russian history occurred in September 2002. A huge ice–rock–water flow from the Kolka Glacier went down the Genaldon River valley with a speed of 320 km/h. Having travelled a distance of 18.5 km, it was stopped by the 2 km long narrows of the Rocky Mountain Range and it filled the hollow with 120 m^3 of deposits. The ice–rock–water mass pressed through the narrows forming a debris flow which went down the valley for 10 km devastating all the settlements on the riverbed. As a result, 125 people lost their lives. In 2002, two months before the disaster, a series of collapses from an elevation of about 1000 m at the backside of the glacier had activated the avalanche. The last ice–mass collapse had a volume of 10 million m^3. The material accumulated in the glacier hollow was knocked off and went down the valley. The 100–150 m high ice–rock–water mass (with air also) was moving down the 400–500 m wide valley. The flow on its way down the valley trough was fed by the frontal masses of three huge ancient landslides situated on the left bank. The hazards and risks after 2002 can be attributed mainly to the filling up of the hollow by the ice–rock material, the formation of a dammed lake, and the filling up of the narrows by debris flow and mudflow deposits. Presently the dammed lake is discharging naturally and there is about 0.5 million m^3 of water in it. The future behaviour of the ice–rock dam is not clear and it is difficult to make any forecast due to its melting on the one hand and the formation of underground outflows with sporadic floods on the other hand. In 2002–2004 the debris flow deposits on the riverbed were still unstable and loose. A surge with a discharge of more than 20 m^3/sec and (or) a storm flood of such a magnitude can adversely affect the riverbed processes in the overpopulated foothill areas requiring mitigation and protective measures.

INTRODUCTION

The disaster of September 2002 in the mountains of the Republic of Northern Osetia-Alania is usually described as the Kolka Glacier avalanche. The disaster took by surprise the local population and the State Security Service. Though it is classified as a "rare and devastating", the disaster occurred in the region that had experienced such processes (with different levels of devastation) three times in the last 200 years. According to a scientific forecast made on the basis of Gaussian (linear) trend of distribution, the next "avalanche" was expected by 2040 (Rototaev et al. 1983; Zalikhanov et al. 1999). The scale and the consequences of the 2002 disaster point out to an underestimation of the recurrence period of rare and devastating disasters – the real period turned out to be much shorter and it seems to be corresponding to the distribution trend of extremely great events of a collapse-type (Rodkin 2005). These events developed on a confined high mountain site – on the rear side of the Kolka Glacier and its adjacent steep slopes (up to 1000 m high) – have caused the so-called synergetic effect when the development of an extreme event is causing a further increase in the extent of disaster. Since the causes of the extreme event as well as the description of its magnitude and impact have already been described (Zaporozhchenko 2004), this work focuses on the status of the debris and the riverbed processes (with frequent floods) in the changed (after September 2002) geomorphic and hydrological conditions.

BACKGROUND

The biggest glacial disaster in the Russian history took place on 20 September 2002 when a huge ice–rock–water mass flowed from the Kolka Glacier situated on the Northern slopes of the Main Caucasian Mountain Range (Fig. 1). It went down the Genaldon River valley with a speed of 320 km/h destroying everything on its way. The flow was stopped by the narrows (formed by limestone cliffs) of the Rocky Mountain Range, trending parallel to the Main Caucasian Mountain Range situated at a distance of 18.5 km. The flow filled up the Karmadon hollow flanking the Rocky Mountain Range from the south with 120 million m^3 of deposits. The ice–rock–water mass was pressed through about 2 km long narrows (called the Karmadon Gates) and then it went down the valley as a debris flow for a distance of more than 10 km devastating all the settlements on the riverbed. The ice–rock–water mass as well as the debris flow went down the Karmadon Gates and buried 125 people on its way to the valley. Similar disasters were also experienced in 1834 and 1902. A relatively slow movement of the Kolka

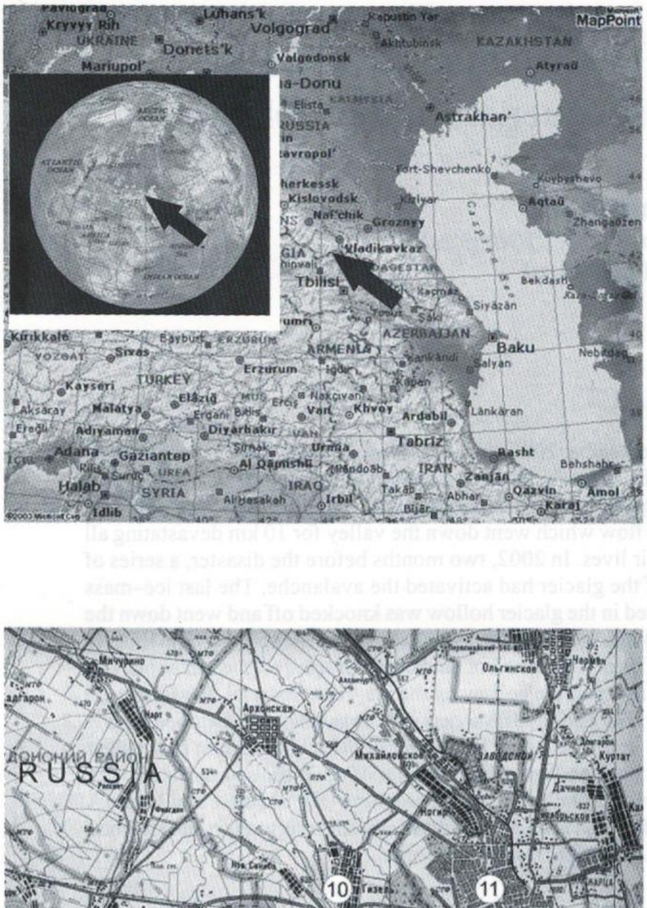

Fig. 1: Location of Genaldon River (main disaster sites of 2002 are numbered from downstream to upstream)

Fig. 2: Water level of dammed lake reaches the basement of XVII century crypt in Gornaya Saniba village. Photo by E. Zaporozhchenko, 17 October 2002

Glacier was also observed in 1969–1970 when it went down the valley for 4.5 km without any serious consequences. There are also some other glaciers in the Kazbek lava massif (viz. Devdorakskiy and Abano) known for their fast movement rates.

In 2002, two months before the disaster, a series of ice–rock mass collapses on the Dzhimarai-Hoh slopes (at altitudes of 4150–4450 m) lying on the rear side of the Kolka Glacier had activated the avalanche. The last disaster preceding the ice–rock mass collapse had a volume of 16 million m^3. It had left behind a 60 m deep glacier hollow and ice–rock splashes. The material from the glacier hollow was knocked out and went down the valley in the form of a debris flow. The 100–150 m high water-ice–rock mass (with air also) was moving down the 400–500 m wide valley splashing from one side to another. The area affected by the ice–rock avalanche from its zone of collapse to the narrows of the Rocky Mountain Range was 12.7 km^2 (which included the collapse zone, the zone of entrainment, the debris flow zone, and the debris accumulation zone in the Karmadon hollow). The ice–rock mass blockage covered 2.1 km^2 (by 6 October 2002), and it was 3.6 km long and 135–140 m wide with an average height of 60 m. The debris flow that went down the narrows of the Rocky Mountain Range (viz. the Karmadon Gates) covered an area of 2.5 km^2. Its initial volume was about 6 million m^3 (with a thickness from 1 to 15 m), but by 2005 it reduced to 4.5 million m^3 due essentially to melting down of ice.

The flow was fed mainly by the collapsed ice–rock masses, the knocked-out material from the Kolka Glacier, and loose till. On its way down the valley trough, it also incorporated slope deposits, especially the frontal masses of three huge ancient landslides (viz. Aktivny, Biterzyksky, and Grokhadagsky with volumes of 5.3, 12, and 22 million m^3 respectively) situated on the left bank . The rapid removal of material from its toe sometimes reactivated the whole landslide mass (e.g. Biterzyksky, lying on the concave turn

Fig. 3: Gornaya Saniba dammed lake and adjacent parts of ice–rock dam. Photo by S. Chernomorets, 9 August 2004

of the valley, moved by 10–15 m towards the riverbed). But, it was unable to dam the river during the disaster or afterwards (up to 2005).

Having hit the Rocky Mountain Range, the main part of the avalanche (about 30% of the debris within a wide size range and about 70% of ice) stopped in the Karmadon valley. Finally the avalanche formed debris flows down the ice–rock mass stopped by the narrows of the Rocky Mountain Range. The debris flow deposits were accumulated in the Genaldon and Gizeldon valleys as well as at the upper Gizel village, and then they were transformed into mudflows further downstream. At the confluence of the Genaldon and Gizeldon Rivers the debris deposits blocked the latter. In the lower reach of the Genaldon River, the debris flow of September 2002 was sloping towards its left bank, as revealed by an elevation difference of 4.3–6.0 m between the high flood marks on two banks. By 3 October 2002, the newly formed lake on the Kauridon River near the Gornaya Saniba village (Fig. 2) had accumulated about 7.5 million m^3 of water. The water level was rising fast enough. In accordance with the forecast made by the "Sevkavgiprovodhoz" (SKGVH) Research Institute, seepage through the dam was observed from 18 October 2002 and when the dam was overtopped on 23 October 2002 the water level finally stopped rising.

After the disaster the attention of researchers was focused mainly on its causes and (or) triggering mechanisms. Presently, it is vital to estimate the flood characteristics (storm floods, outburst floods, and debacles) in the changed conditions after September 2002. It is also necessary to design and implement necessary preventive measures.

The SKGVH Research Institute was asked to estimate the movements in 1969 and to forecast of its further consequences. The institute was involved in the design of engineering measures to protect the land and infrastructures in the Genaldon and Gizeldon valleys from the freshets and floods of 1970 and the following years. These measures were based on the probable movement scenario of the ice masses that had gone down the Genaldon River from an altitude of 3000 m to 2000 m. At that time, their speed varied from 1.5 m/day (end of September 1969) to 215 m/day (beginning of October), and to 0.5 m/day (beginning of January 1970). The SKGVH Institute completed the basic engineering works by June 1970 – the beginning of the freshet period. This project did not take into consideration the disaster scenario and peculiarities of the Genaldon events of 1969–1970 in comparison with those of 1902. For example, the ice–rock masses moved considerably faster (60 to 100 km/h) in 1902 than in 1969 (up to 0.01 km/h); and the ice mass in July 1902 had stopped at the Tmenikau transit while in January 1970 the location of the terminus was about 10 km upstream.

The 1969 motion was forecasted in February 1968 (V. Chomay, "Zarya Vostoka" Newspaper, Georgia): "The glaciers of the Kazbek Mountain are active. They started growing and their growth rate is astonishing. For the last 4 years … the Maili Glacier has extended by 50 m. The snow cap on the Kazbek Mountain has become enlarged and the snowline has descended by 100–300 m… The present glacier growth rate … may trigger landslides and avalanches… " But no one paid attention to it.

The new landslides triggered by the September 2002 event were the Sanibansky Landslide (spring 2003) on the left bank of the dammed lake with a volume of about 20,000 m^3 which has destroyed the settlement of Gornaya Saniba village; and the Kolkinsky Landslide on the left bank upstream of the Genaldon River with an area of 100,000 m^2, a volume of 2 million m^3, and a lateral displacement (without blocking the riverbed) of about 20 m.

HAZARDS AND RISKS

The hazards and risks are due to the following changes in geomorphic and hydrological conditions in the Genaldon valley and to some extent in the Gizeldon valley:

- An increase in slope angle of the Genaldon riverbed between the Kolka Glacier tongue and the Karmadon valley;
- The filling up of the Karmadon hollow by the ice–rock material (i.e. the blockage near the N. Kani village, Fig. 3);
- The formation of a dammed lake near the Gornaya Saniba village; and
- The filling up of the Genaldon valley (down the Karmadon Gates) and the Gizeldon River (down the Genaldon River) by debris (Fig. 4).

Fig. 4: Debris flow deposits in transit accumulation zone near Genaldon River mouth. Photo by S. Chernomorets, 7 October 2002

Considering these factors, the authors infer that such a disaster can recur by 2025 when, according to the estimations, the Kolka Glacier will attain its critical pre-disaster volume (due to the accumulation of ice and snow) of about 100 million m^3. Depending on the ice–rock collapse activity, this pre-disastrous state may develop in various ways: "… With collapses – there can be a recurrence of the 2002 or 1902 scenario whereas without any collapses – there could repeat the 1969 situation. On the other hand, the role of the Kazbek magma chamber on ice ejection from the Kolka cirque is still unknown…" (Petrakov et al. 2005).

Since 2003 the movement of the ancient landslides (Fig. 5) has ceased and there is hardly any probability of landslide dam formation across the Genaldon River. Only an earthquake of magnitude 8 (or larger) on the MSK scale and complete submergence of large (5–6 times bigger than actual) landslide blocks could trigger instability. Such a scenario seems to be quite unreal. The situation with the new low-volume landslides of 2003 and 2004 as well as with the Kolkinsky landslide is the same. The ice–rock debris mass is being rapidly eroded away in the form of slope splashes. The small debris flows and landslides triggered by ice melting have not affected the natural flow regime and the slopes tend to be stabilised.

The situation in the transport zone does not influence the debris flow regime. The mudflow of 11–12 August formed in the three mudflow sites was an ordinary one (Fig. 6). Though it had a volume of 500,000 m^3 (including water) it did not stop in the Karmadon valley (i.e. at the hydrological post located at the toe of the 2002 blockage).

By the beginning of 2005 the volume of ice in the blockage zone has decreased by 60% and undermining of ice by the Genaldon River has been over. The discharge from melting of ice in summer has not exceeded 5 m^3/sec. Hence, the blockage does not pose any risk of water level rise from the storm floods. Furthermore, it drains ordinary floods (of 10 year return period with a 10% probability) and there are no signs of undermining. The ice melting rate has decreased by 4 times in the last 2 years due to the accretion of the rock cap and ice undermining is expected to complete in 7–10 years.

Fig. 5: Close-up view of Activny landslide. Photo by S. Chernomorets, 5 October 2002

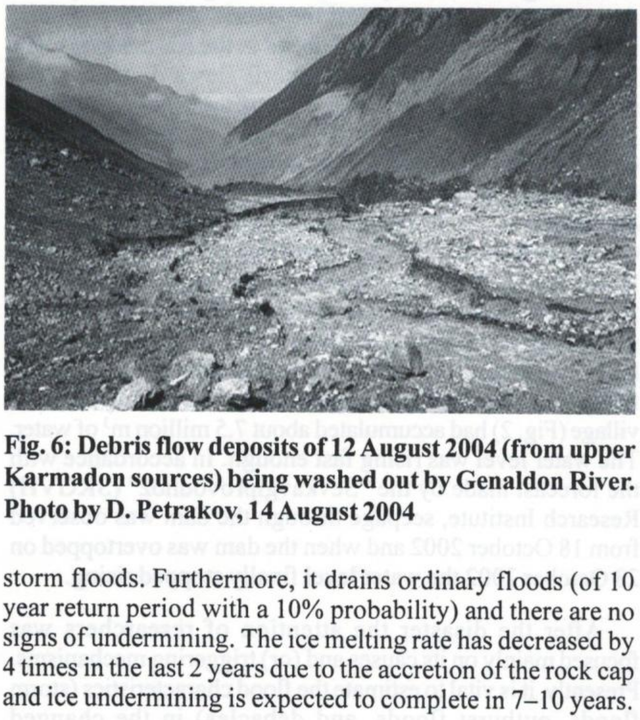

Fig. 6: Debris flow deposits of 12 August 2004 (from upper Karmadon sources) being washed out by Genaldon River. Photo by D. Petrakov, 14 August 2004

The grain size distribution of the ablation moraine on the ice–rock blockage surface at the end of 2004 is given in Table 1. The composition of fractions larger than 10 mm in the ablation moraine is: siltstone – 27.8%, volcanic rocks – 59.6%, granodiorite – 9.6%, diabase – 2.0%, and vein quartz – 1.0%. The fractions smaller than 10 mm constitute: siltstone – 55.8, volcanic rocks – 25.6%, quartz – 7.3%, feldspars – 4.2%, calcite – 3.3%, and argillo-micaceous minerals – 3.8%. The density of ablation moraine material is 2.09 t/m^3 and that of the ice from the blockage zone is 0.96 t/m3 (without taking into consideration its fissures).

The dammed lake which had an initial capacity of 4.9 million m^3 in October 2002 is discharging naturally. There

Table 1: Grain size distribution at ablation moraine surface with large boulders (>500 mm) comprising about 11%

Grain size, mm	Weight %
>200	22.9
200–20	29.1
20–10	8.9
10–5	10.2
5–2	11.0
2–1	6.2
1–0.5	3.1
0.5–0.25	2.4
0.25–0.1	4.7
<0.1	1.5

Fig. 7: Right bank of Gizeldon River down the Genaldon River mouth. Debacle of 16 June 2003 has destroyed the road. Photo by E. Zaporozhchenko

was 0.45–0.5 million m^3 of water remaining in the lake by the end of September 2004. It corresponds to a maximum water level drop of about 19 m in the lake. The future behaviour of the ice–rock dam is not clear since there are many uncertainties such as the rate of compaction of the dam, the formation of subsurface channels, and rare floods (with 1% of occurrence probability). Nonetheless, the dam breaching is possible. The outburst in June 2003 (by 1.5 m drawdown in some hours) caused water-rock freshet downstream the narrows (Q = up to 20–25 m^3/sec) which could not have been carried out by the Genaldon riverbed filled with debris flow deposits without inadmissible erosive consequences (e.g. the piers of two bridges were destroyed and the road was also severely undercut, Fig. 7). At the same time there were some storm floods at this site of the Genaldon riverbed with a discharge of about 100 m^3/sec (i.e. 99.7 m^3/sec in 1953).

Immediately after the formation of the lake behind the blockage and with water level constantly rising, the disintegration of the ice–rock dam and the formation of a debacle were anticipated by many specialists. Only the SKGVH Institute had a different view on the situation. In our document of 3 October 2002 concerning the problem it was mentioned that "... in 15–20 days the dammed lake will start discharging naturally through the cracks of the ice–rock blockage. A disastrous discharge rate increase is not expected... natural processes of stabilisation and discharge... will act faster than any engineering works pursuing the same goal (e.g. construing a channel or a hydromonitor)..."

We do not reject the point that "the forcible draining of the mountain lakes is one of the most effective methods of controlling the critical situation of debacles and glacial debris flows" (Bolov et al. 2003). Historically there are examples of such forcible drawdown. But the very conditions of the situation do not respond to such a measure because of the following considerations.

The devastating floods of June 2002 (which have not been seen here since the last 100 years) in the Genaldon–Gizeldon River system caused the destruction of the Arkhon watershed (Fig. 8), seriously damaged the Gizeldon Hydro-Engineering complex constructed in 1960s (Fig. 9), filled up the Arkhonka and Kizilka riverbeds, and also scoured bridge piers and embankments. At that time, the discharge down the mouth of the Genaldon River was about 230 m^3/sec, which was close to the design discharge (295 m^3/sec) of the Gizel Hydro-Engineering dam. The rate of consolidation of the debris flow deposits by the ice–rock flows from the upper reaches of the Genaldon River is very slow. The debris flow (with ice) filled up the Genaldon and Gizeldon valleys for a distance of 12 km. The debris has also obstructed the machinery access since September 2002 (Fig. 10).

The grain size distribution of the debris flow deposits near the Genaldon River mouth (at the prospecting hole 1 lying 6 km downstream from the Karmadon Gates, with a thickness of more than 4.5 m) and in the Gizeldon river valley (at the prospecting hole 2 situated 9 km downstream, with a thickness of 1.5 m) is presented in Table 2, whereas Table 3 depicts the density of debris.

There was a maximum subsidence (primarily due to melting of ice) of 3.5 m in the debris flow deposits near the mouth of the Genaldon River by the end of 2004 (Cross-section 1; Figs. 11, 12). The entrainment velocities for these deposits lie in the limits of 1.35–1.40 m/sec, while for a discharge of 7 m^3/sec (ordinary summer freshets) the actual velocities are 1.5–1.7 m/sec. Erosion is intense (Fig. 13) in the areas with inclines from 0.02 to 0.04, and re-deposition takes place on the sites with inclines from 0.02 to 0.01 (Fig. 14). The daily average discharge and velocity of the storm floods with a probability of occurrence of 1–3% (for the Genaldon River in the narrows of the Karmadon Gates: $Q_{1.0} = 154$, $Q_{3.0} = 103$ m^3/sec, $V_{1.0} = 4.7$ m and $V_{3.0} = 4.3$ m/sec, respectively; for the Gizeldon River: in the limits of the debris flow development $Q_{1.0} = 172$, $Q_{3.0} = 122$ m^3/sec, $V_{1.0} = 1.8–2.0$, and $V_{3.0} = 1.5–1.6$ m/sec) show a real possibility of river channel shifting.

After the event of 20 September 2002 the riverbed down the Karmadon Gates rose by 7–8 m while it became 2 m high

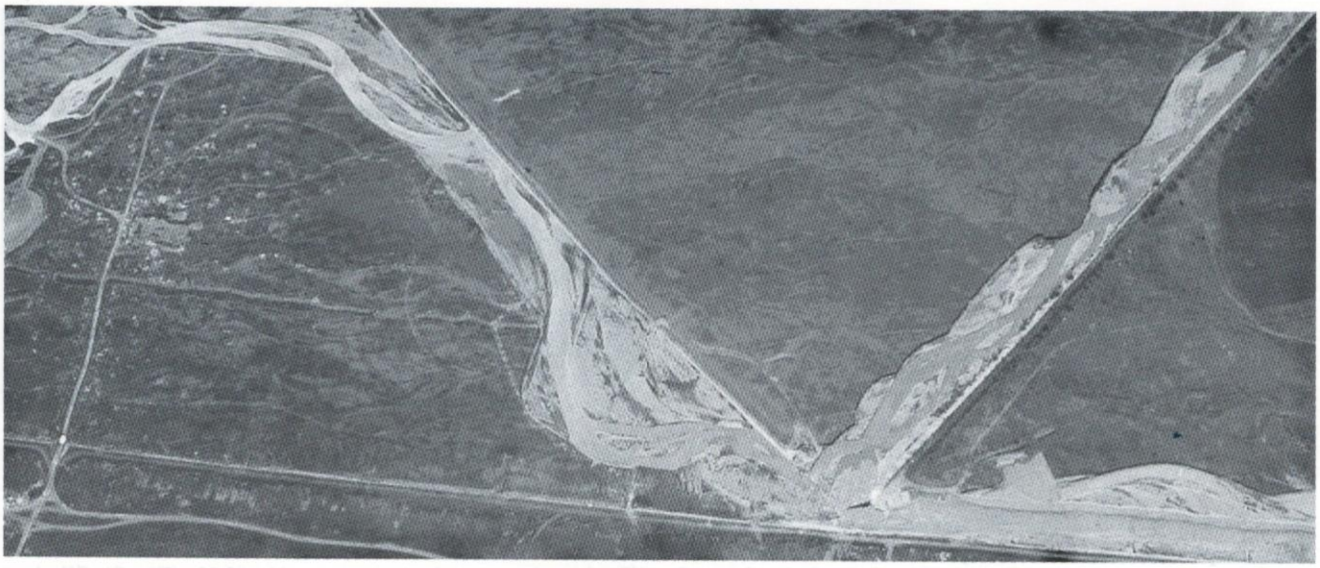

Fig. 8: Arkhon water divider. Photo by I. Galushkin, 30 April 2003

Fig. 9: Flood (with a discharge of about 30 m³/sec) through Gizel Hydro-Engineering complex. Photo by E. Zaporozhchenko, 16 June 2003

about 12 km downstream from the gates. The floodwater in the Gizeldon River after the debris flow was 4 m high and by the end of 2004 it did not exceed 1–1.5 m. This incident did not cause any trouble to the downstream territories.

As the debris flow leaves the narrows of the Karmadon Gates, the velocity of this wave attenuated by the blockage masses in the Karmadon hollow would define the course of the riverbed processes. On 20 September 2002 the discharge of the debris flow down the rocky section (judging by the high wave marks) was about 2000 m³/sec (Zaporozhchenko 2004). This section is the best place for installing a hydrological station (Zaporozhchenko 2005). Besides measuring floods (or debris flows) it is planned to put here an automatic radar sensor and also an alarm system to warn the population in the downstream areas. The alarm system will be triggered by a rising water level (Fig. 15).

Fig. 10: Right bank of Gizeldon River about 1 km down the Genaldon River mouth. The road was washed away by an ordinary summer flood of 10 m³/sec. Photo by E. Zaporozhchenko, 1 June 2004

PREDICTIONS

Even though no eruptions were noted in the Holocene, Kazbek Volcano is a prominent threat. Its possible consequences will depend on the location of the crater and the direction of lava flow. If the lava flows near the cirque of the Kolka Glacier, it will become a source of disastrous lahars in the whole Genaldon valley and downstream. It is neither possible to make any accurate forecast of such an eruption nor estimate the volume of generated flows.

There is a possibility of warming up of the Kolka Glacier by the heat coming from the subsurface magma chamber (the roof is 4 km deep, the bottom is 8 km below sea level) under the Kazbek massif (Gurbanov et al. 2004). There is some evidence of such an effect on the Kolka Glacier before

Table 2: Grain size distribution of debris flow deposits near Genaldon River mouth and in Gizeldon River valley

Distance from Karmadon Gates, km	Sampling interval, m	Fraction size in mm, content in %											Mean diameter (mm)
		>200	200–100	100–80	80–20	20–10	10–5	5–2	2–1	1–0.5	0.5–0.25	<0.25	
New debris flow deposits													
6	0–1.5	13.7	20.4	7.0	14.4	6.4	7.8	7.5	4.0	3.2	2.3	4.9	80.8
6	1.5–3.0	38.0	16.3	4.6	5.5	5.5	6.9	3.9	3.7	2.2	2.7	3.2	121.2
9	0–1.5	4.0	11.0	3.6	10.9	11.0	14.1	8.2	8.3	5.5	4.2	7.4	42.0
Holocene alluvium of Gizeldon River													
9	1.2–3.0	15.8	25.1	5.1	13.1	10.5	3.1	6.6	5.1	2.5	1.0	0.5	91.3
13.5	0–1.0	10.7	12.9	6.3	16.7	12.9	3.5	5.3	5.1	2.5	1.7	1.2	68.0
18	0–4	3.7	19.8	11.7	12.8	10.1	5.3	5.9	4.8	1.5	1.6	1.1	56.5
28	0–2	-	7.0	11.1	29.4	12.9	9.2	3.7	1.6	1.5	1.3	2.2	46.9
31	0–1.5	-	9.1	11.1	14.0	13.4	5.5	0.8	2.3	7.0	3.4	15.0	38.8

Table 3: Debris flow density measured on borehole samples taken in January 2005

Prospecting hole number	1	1	1	1	2	2	2	2
Depth, m	0.2–0.3	0.5–0.6	0.7–0.8	1.8–1.9	0.2–0.3	0.3–0.4	0.7–0.8	1.0–1.1
Density, t/m^3	1.8	1.73	2.18	2.14	1.83	2.18	2.20	2.21

the disaster of 2002 – the concentration of sulphur in the rivulet coming from the former bed of the Kolka Glacier was a thousand times more than usual, there was strong odour, and gas puffs were frequent. The probability of disaster caused by the geothermal effect in the future 20–25 years is not big but it will increase while the Kolka Glacier accumulates the critical ice mass (Muravyev 2004).

Besides a low probability of its occurrence, a large earthquake will affect not just the Genaldon River valley, but the induced debris flows may devastate the settlements in both the Genaldon and Gizeldon River valleys. Hence, the main triggering factor remains to be a heavy precipitation alone.

POST DISASTER SCENARIO OF THE ICE–ROCK FLOW TRANSPORT ZONE

The Kolka cirque (within the Genaldon watershed) with the hollow in the backside of the glacier was already filled up by the summer of 2004. The Kolka Glacier may reach its pre-disaster size in a period of 20–25 years, provided that there are stable climatic conditions (Chernomorets 2005), and its mass is close to the critical value. In case of ice–rock mass collapses from the surrounding slopes and mountain walls, the recurrence of the 1902 or 2002 scenario is possible no sooner than 2025–2030.

The site from the Kolka Glacier to the southern escarp of the Rocky Mountain Range is free of settlements and infrastructures. A typical post-disaster dynamics of exogenous processes is expected here in the near future. Incision and liquefaction have already ceased by 2005. The quickly recovering grass cover on slopes will interrupt and reduce siltation in the Genaldon River to its prior figures and it will also retard the local debris flow activity. Though a relatively large earthquake may destabilise the ancient landslides and may trigger catastrophic flows, there is a probability that the debris disintegrates either up the Karmadon hollow or gets accumulated in it.

There are two potential scenarios due to the formation of the ice–rock blockage: the plugging of the under-ice drain channels of the Genaldon River or outburst of the dammed lake. The natural shifting of under-ice drain channels is normal for any glacier. It can take place several times during the season but usually it does not cause any problems. This fact was also confirmed by the observations of 2003–2004 (the period of the most active endoglacier transformations).

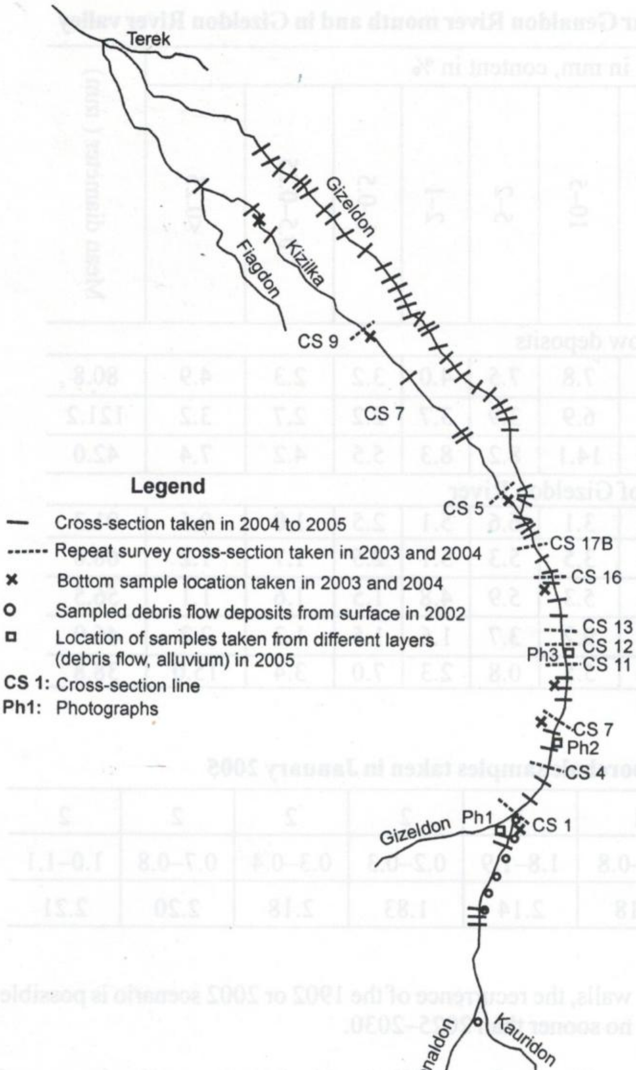

Fig. 11: River sections taken for hydrological monitoring

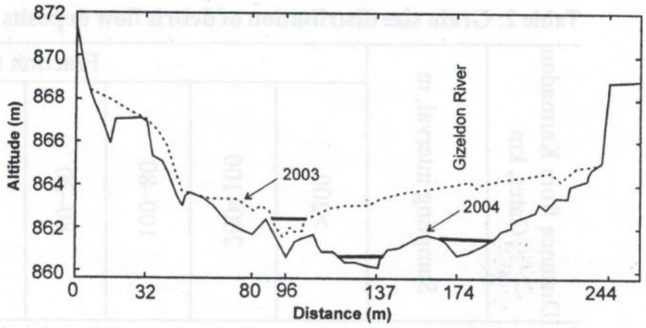

Fig. 12: Changes in river cross-section at CS 1 (see Fig. 11) in 2003 and 2004. Bold lines indicate high flow levels.

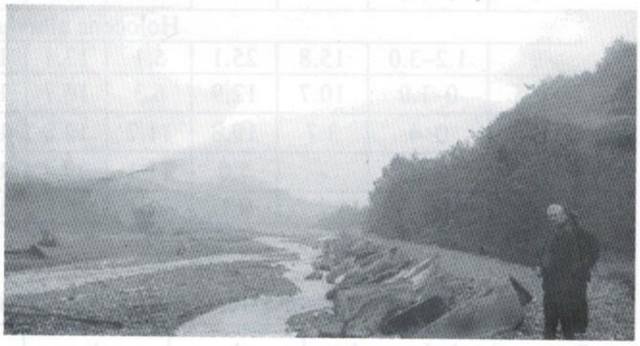

Fig. 13: Right bank of Gizeldon River about 1 km below Genaldon River mouth (Ph1 in Fig. 11). The road was washed away by an ordinary summer flood (10 m^3/sec). Photo by E. Zaporozhchenko, 1 June 2004

The drain channel shifting has not affected the flow rate of the river as it leaves the Karmadon Gates.

The consequences of a lake outburst are diminishing as the lake level falls down. The outburst of 16 June 2003 with a volume of 0.4 million m^3 (it is the approximate amount of the water in the dammed lake by the beginning of 2005) showed that such a flood cannot form a debris flow able to reach the sub-mountain regions (i.e. the Gizel village section). But its erosivity can be destructive for the valley infrastructure and the discharge rate (about 20–25 m^3/sec) a can be critical for the riverbed alteration processes and debris carrying capacity to the downstream Hydro-Engineering complex. The outburst from the dammed lake should not be regarded as an important flood-causing factor.

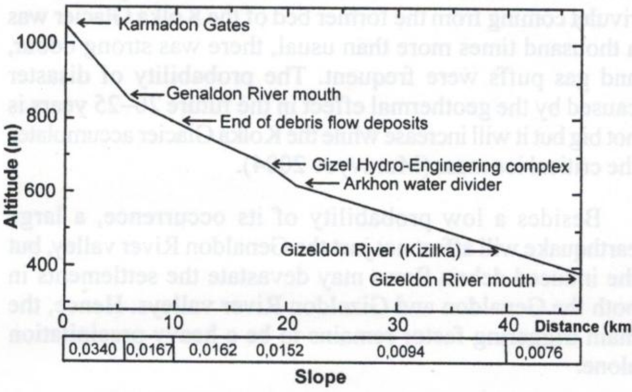

Fig. 14: Longitudinal profile of Genaldon and Gizeldon Rivers between the Karmadon Gate and the Gizeldon River mouth (Fiagdon River), taken in January 2005

The main factor affecting the riverbed processes implies extreme weather pattern – torrential rains accompanied by high temperatures (usually between July and early August). The debris flow of 6 August 196 (with a discharge about 100 m^3/sec, a water volume about 3 million m^3) caused by such rains destroyed the road and bridges in the narrows of the

Fig. 15: Genaldon River immediately downstream from Karmadon Gates where a hydrological station is proposed (Ph2 in Fig. 11). Photo by E. Zaporozhchenko, 25 June 2004

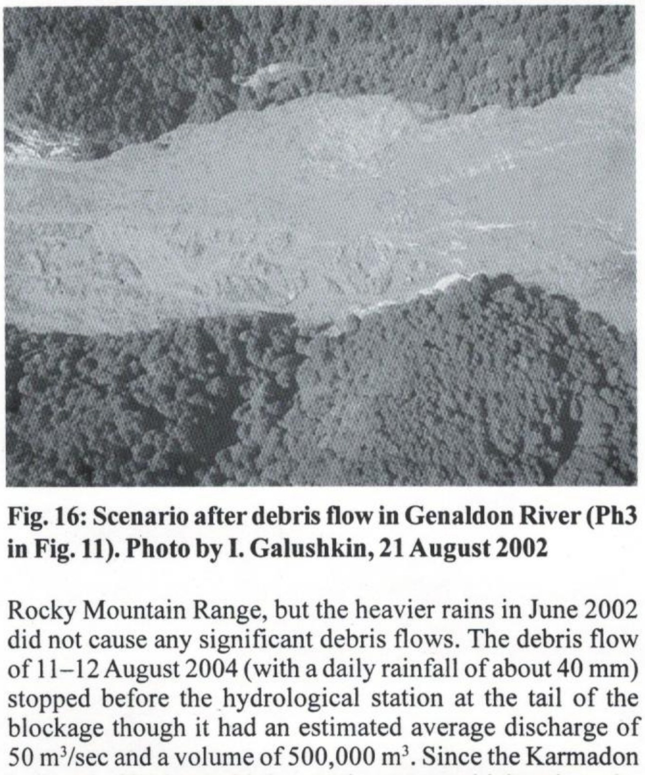

Fig. 16: Scenario after debris flow in Genaldon River (Ph3 in Fig. 11). Photo by I. Galushkin, 21 August 2002

Rocky Mountain Range, but the heavier rains in June 2002 did not cause any significant debris flows. The debris flow of 11–12 August 2004 (with a daily rainfall of about 40 mm) stopped before the hydrological station at the tail of the blockage though it had an estimated average discharge of 50 m^3/sec and a volume of 500,000 m^3. Since the Karmadon hollow is filled up with ice–rock masses which reduce the slope angle and act as an accumulator only a debris flow with a discharge of more than 150 m^3/sec and a volume higher than 4 million m^3 can carry its material to the Karmadon Gates. Such parameters have an occurrence probability of 1%.

The site about 40 km down the narrows of the Rocky Mountain Range is the most critical since the Gizeldon River flows through a densely populated hilly region. There are many infrastructures including a drinking water supply system. The upper part of the Genaldon valley (about 6 km) is filled up with the deposits of the debris flow of 2002. Down the mouth, these deposits cover about 7 km distance of the Gizeldon riverbed. The debris flows of September 2002 (Fig. 16) followed the July 2002 storm floods and the outburst wave of 16 June 2003. Such flows severely hampered the emergency works (clearing, aligning, and bank protection).

CONCLUSIONS

The disasters are not expected till 2025 in the Genaldon valley situated south of the Rocky Mountain Range provided there are no endogenic triggers. The Kolka Glacier will be ready to collapse as soon as its ice mass reaches a critical volume of about 100 million m^3. During the summer, debris flows will be limited to the southern escarp of the Rocky Mountain Range.

The hazards and risks after 2002 can be attributed mainly to: 1) the filling up of the hollow by the ice–rock material, 2) the formation of a dammed lake, and 3) the filling up of the narrows by debris flow and mudflow deposits. Presently the dammed lake is discharging naturally and there is about 0.5 million m^3 of water in it. It is difficult to forecast its future behaviour. In 2002–2004 the debris flow deposits on the riverbed were still unstable and loose. A surge with a discharge of more than 20 m^3/sec and (or) a storm flood of such a magnitude can negatively affect the riverbed processes in the overpopulated foothill areas.

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