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Processes of debris flow formation and the dynamics of glaciers in the Central Caucasus

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ABSTRACT: An analysis of the reconstructed large picture of debris flow events during the last one and a half millennia showed that, with different stages of global glacial dynamics, different mechanisms of debris flow formation prevailed in the periglacial zone. A majority of catastrophic debris flows in the Central Caucasus occurred during the stages of glacial retreat because of outbursts of numerous temporary glacial lakes near the edges of retreating valley glaciers; and from the thermal erosion of small glaciers. With the present glacial retreat in the Central Caucasus, the potential exists for increasing debris flow activity related to thermal erosion destruction of small glaciers in the near future.

1 INTRODUCTION

The twentieth century was marked by a high level of debris flows in the periglacial zone of the Central Caucasus. Two tremendous catastrophic debris flows occurred in the Baksan and Genaldon River valleys at the beginning of twenty-first century. They were initiated by the collapse of buried stagnant ice and cirque glaciers. Are such events extraordinary or have similar events happened in the past? What trends in debris flow phenomena can we expect in the near future because of global warming and the continuous glacial retreat in the Central Caucasus? An attempt to answer these questions by an analysis of debris flow chronology during the last 1500 years is presented in this article.

2 STUDY AREA

The study area is located north of the main Caucasus Range, in the center of the huge alpine-type region of Caucasus, named the Bolshoy Caucasus (i.e. "big" in Russian). The Bolshoy Caucasus spreads from the Black to the Caspian Seas through 1100 km and covers an area of 197,000 km^2. The Bolshoy Caucasus is divided into the West, Central and East Caucasus according to the amplitudes of neotectonic uplifts. The boundaries between them are the potentially active volcanoes – Mount Elbrus in the West (5642 m) and Mount Kazbek in the East (5034 m a.s.l.). The Central Caucasus is a district with a well-developed alpine-valley glacial system. Seven hundred fifty-two glaciers cover an area of 590 km^2, or half the total glacial area of the Caucasus (Lurie 2002).

The periglacial zone is a permanent potential source of catastrophic debris flows. One of the most debris-flow prone rivers is the Baksan. This river starts from glaciers on the highest peak in the

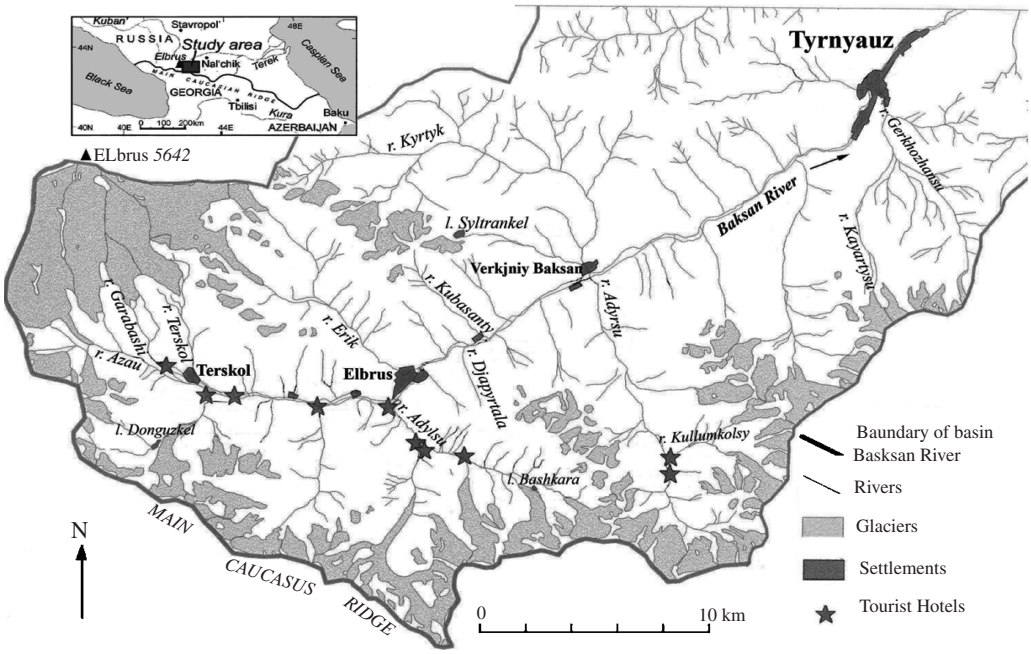

Figure 1. Study area.

Caucasus, Mount Elbrus. The upper part of the Baksan River valley crosses three alpine ridges formed of granitoid bedrock. Here the river is periodically blocked by debris flow deposits originating in tributaries. The total area of tributary basis prone to debris flows in the Baksan River drainage is 858 sq. km, with a glacial area 133 km^2. There are a total of 156 glaciers, of which 85% are small. The active origination sites of modern catastrophic debris flows are associated with small glaciers (Fig. 1).

3 METHODS AND DATA

The evolution of glaciers and debris flows in the Central Caucasus was studied on the basis of long-term monitoring, both terrestrial and with remote sensing (Seinova & Zolotarev 2003). This monitoring was supplemented by analysis of older maps as well as by paleogeographical research, including lichenometry for reconstructing past glacier extent and debris flow hazards. Additionally each case of debris flow after 1960 in the Baksan River valley and each catastrophic event in the entire Central Caucasus region were comprehensively monitored.

Clear trends of changes in debris flow activity and formation processes were found to be related to glacial dynamics over the last 1500 years. The last one and a half millennia contain the full cycle of the last two stages of glaciation (Seinova & Zolotarev 2003) from the beginning of the glacial retreat in the fifth century to the intensive modern retreat (Table 1). In this article we will concentrate mainly on one of the important results – a reconstructed picture of typical debris flow formation processes during different stages of glacial dynamics.

4 ANCIENT DEBRIS FLOWS IN PERIGLACIAL ZONE OF THE CENTRAL CAUCASUS

The oldest of the remaining debris flow sediments in the Baksan River valley belongs to the time of the glacial retreat during the fifth to ninth centuries AD. During this period gigantic debris flows formed in

Table 1. Change of glacially related debris flow activity and prevalent formation processes during the last two stages of glaciation.

Glaciation phase	Glacier dynamics	Dates	Activity*	Prevailing formation processes
Regression	Intensive recession	5th-10th century	High	Collapse of temporary dams in the course of main river formed by debris flows originating in tributaries.
Transgression	Regeneration	12th-13th century	Low	No traces
	Growth	14th-16th century	Low	No traces
Transition from transgression to regression	Fluctuations around maximum glaciation	17th century	Average High only locally in vicinity of volcanoes Elbrus and Kazbek	Rare lake outbursts and collapse of valley glaciers near the ancient lava dams
		18th century		
		1780-1820		
		1830-1850		
Regression	Intensive recession	1850-1920	High	Outburst of temporary lakes formed near the edges of valley glaciers
		1930-1950		Lake outbursts and thermal erosion
	Slow recession	1960-1990	High often mass simultaneous events	Thermokarst & thermal erosion of small glaciers and collapse of temporary dams in the course of main river
	Intensive recession	21st century forecast	High	Same as previous

*Degree of debris flow activity has been determined from rankings of flow frequency and runoff volume for the biggest debris flows on the basis of field observations (Seinova 1991; Seinova & Zolotarev 2001).

the upper part of the Terek River valley itself and on the Terek's large tributaries: Baksan, Chegem, Ardon and Genaldon (Fig. 2). The visible traces of these events have been found both in cuts and on surfaces of ancient river terraces and marked by huge boulders carried into foothills of these river valleys. Coarse-grained deposits of huge debris flows, originating in the periglacial zone in the fifth to seventh centuries filled the bottom of the U-shaped valley near the Baksan River headwaters. Vast fans of debris flow deposits were also formed in the drainages of the Garabashi, Kubasanty, Adyrsu and Gerkhozhansu Rivers.

The typical process of catastrophic debris flow formation during this time most likely had the following steps: The course of Baksan River was dammed by the debris flow sediments from its tributaries, forming the temporary lakes upstream. Later, outburst from these lakes formed catastrophic debris flows in the Baksan River itself. Remnants of these ancient dams are still visible.

During the last part of the glacial retreat of the First Stage, a gradual decrease of debris flow activity in the periglacial zone occurred. In this way in the ninth century big debris flows still formed near the headwaters of Baksan River and its glacial tributaries, but did not reach the main river. Traces of debris flows from the tenth and eleventh centuries have not been found. This indicates that the deposits of any flows that did occur were probably destroyed by later events.

At the beginning of glacial advance of the twelfth and thirteenth centuries (beginning of the Little Ice Age) debris flows also did not leave traces in valleys of rivers originating from glaciers with the

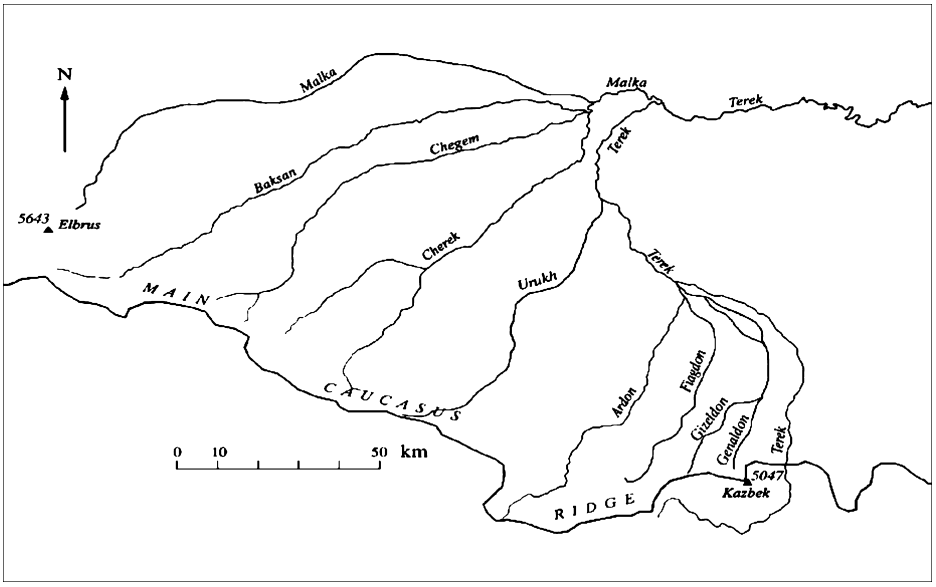

Figure 2. Large tributaries of Terek River.

exception of a huge debris flow that started in the depression of melted cirque glacier near the headwaters of Kullumkolsy River (the tributary of Adyrsy River).

During the intensive stage of glacial advance in the fourteenth to sixteenth centuries the level of debris flow activity in the periglacial zone remained low. It started to increase gradually in the seventeen century. A few traces of huge events from this period have been found in the valleys of the Azau, Terskol and Adyrsy rivers. Catastrophic debris flows in this interval typically formed as a result of lake outbursts. These lakes could have originated from damming by advancing valley glaciers (Kostenko & Seinova 1982).

During the maximum of the Little Ice Age in the eighteenth and nineteenth centuries, debris flow processes occurred at an extraordinary scale. All these processes were strictly located in the tectonic active areas of volcanoes Kazbek and Elbrus. Here the valleys of local rivers were blocked by the lava dams during the last eruption six thousand years ago. The advancing glaciers produced huge ice accumulations with depths of up to 300 m near the lava dams. The mutual destruction of glacial tongues and the lava dams which blocked their farther movement were accompanied by glaciers collapses and the resulting huge debris flows.

Such a phenomenon was first described after the Devdorak Glacier collapsed from the slope of Mount Kazbek on June 19, 1776. A series of following gigantic debris flows formed in a similar manner in 1778, 1785, 1808, 1817 and 1832 (Statkowsky 1879). The biggest collapse occurred on August 15, 1832. The narrow Darial Gorge of the Terek River was completely blocked by a 100 m high ice-rock dam. But the biggest tragedy occurred after the dam collapsed. The main road between Russia and Georgia and fields and settlements up to 60 to 80 m above the river level were destroyed.

Similar processes of debris flow formation occurred in the Baksan River valley near the edges of the Azau and Garabashi glaciers, blocked by lava dams. Glacier collapse produced debris flows in the seventeenth century, during the periods between 1720 to 1750, 1770 to 1780 and 1840 to 1850. These dates were determined by lichenometry. Glacial collapses in the Baksan and Terek valleys ceased after the glaciers retreated from the lava dams.

Such unique processes of debris flow formation during the maximum glacial advance occurred locally only in the vicinity of the volcanoes Elbrus and Kazbek. No traces of the catastrophic debris flows in other Central Caucasus rivers valleys with glaciers during this period have been found.

Table 2. Part of the catalogue of debris-flow basins for the Baksan River tributaries.

River	Morphometric parameters			Chronology of modern debris flows	Max. volume (10^3 m^3)
	Basin area (km^2)	Area of glaciation (km^2)	Source/mouth altitudes (m)		
Kubasanty	11.8	0.66	3660/1680	1880, 1945, 17-18.08.1953, 3.08.1966, 5.08.1967, 28.06.1973, 1-3.07.1974, 9.06.1975, 19.07.1983, 25.07.1984, 18-20.06.1987, 24-26.06.1987, 1.08.1989, 15.07.1995, 08.1998.	1000
Terskol	24.6	8.6	3300/2080	1880, 1900-1910, 1920, 1936, 17-18.06. 1953, 5.08.1967, 31.07.1968, 11.08.1977, 19.07.1983, 24.07.1984, 25.07.1987, 12.08.1995, 07.2000.	500
Garabashi	11.1	2.7	3300/2100	1880, 1895, 1912, 1920, 1936, 1947, 17-18.08.1953, 3.08.1966, 5.08.1967, 19.07.1983, 12.08.1995, 25.07.1996.	1000
Azau (source of the Baksan River)	54.9	32.5	2500/2000	1880-1900, 1930-1940, 1947, 17-18.08.1953, 3.08.1966, 5.08.1967, 15.08.1977, 26.08.1977, 19.07.1978, 25.07.1980, 2.07.1981, 11.09.1981, 19.07.1983, 30.08.1985, 4.09.1985, 10.08.1986, 12.08.1995, 25.07.1996, 31.08.1998.	1000
Adylsu	98.7	21.9	3120/1900	1910, 1930-40, 8.08.1958, 5.08.1959, 3.08.1966, 5.07.1975, 11.08.1977, 26.07.1979, 19.07.1983, 12.08.1995.	1000
Djapyrtala	5.0	–	3260/1560	1890, 08.1934, 07.1943.	500
Adyrsu	103.0	20.5	3100/1500	1880-1900, 1911, 1910-1920, 1936, 1-3.08.1940, 17.08.1953, 27.07. 1958, 08. 1961, 3.08. 1966, 29.07. 1973, 05.07. 1975, 11.08.1977, 26.07. 1979, 29.07. 1980, 19.07. 1983, 25.07. 1996, 19.07.2000.	3000
Gerkhozhansu	78.0	6.2	3200/1270	2.08.1937, 1.08.1960, 14.08.1961, 23.07. 1963, 7.09. 1965, 5.07. 1975, 11.08. 1977, 19.07. 1983, 15.07. 1995, 15.08. 1995, 20.08. 1999, 18-25.07.2000.	6000

5 PROCESSES OF DEBRIS FLOW FORMATION DURING THE MODERN PERIOD OF GLACIAL RETREAT

The modern period of glacial retreat started in the second half of nineteenth century due to sustained climatic warming. The total area of glaciers in the Central Caucasus decreased by 52% from 1887 to 1957 (Panov 1993). The massive system of alpine glaciers was divided into many smaller units such as cirque glaciers and rock glaciers during less than a hundred years. The low edges of valley glaciers typically retreated up to 1-2 km, and the total glacial area in the Baksan valley decreased by 43% (102 km^2). The number of small glaciers increased by 85, and only 14 big valley glaciers remained (Popovnin 1992).

The intensive ice melting created lakes in the sites freed from ice behind glacial moraines, such as U-shaped valleys, cirques and corries (Efremov 2003). Outbursts from these glacial lakes created huge debris flows. In this way in 1881 the settlement of Urusbievo (modern name Verhniy Baksan) was destroyed. This debris flow formed as a result of glacial collapse into a lake (Teptsov 1892). Lakes near the edges of Azau and Garabashi glaciers and on the northern side of Mount Elbrus produced outbursts in 1895, 1909 and 1912 (Ivanov 1902; Gerassimow 1909). Numerous debris flows traces had been found from this period in all the river valleys originating from glaciers (Table 2).

Maximum debris flow activity took place during the warmest part of the twentieth century: 1930-1940. The main processes of glacial-system transformation were accomplished during these years. Small lakes quickly disappeared. The last lake near the Garabashi Glacier produced an outburst in 1947. The big lake near the Bashkara Glacier, which appeared approximately in 1930, produced outbursts twice: in 1958 and in 1959, producing catastrophic debris flows in the Adylsu River. Later, this lake was reestablished and still exists.

Evidence for catastrophic debris flows not related to lake outbursts or glacial collapses first appeared with a flow in 1940. That debris flow originated in the terminal moraine of a cirque glacier near the headwaters of the Adyrsu River. Its formation was provoked by the intensive melting of buried ice accompanied by intensive drainage out of the newly opened internal glacial channels. The flow, which produced several waves of rock and mud, was stimulated initiated by the slide and collapse of blocks of saturated moraine. These waves destroyed two tourist centers on August 1-3, 1940 (Kovalyov 1961).

Thermokarst and thermal erosion processes and the degradation of numerous moraine complexes produced by small glaciers have become the main cause of modern debris flows in the study area (Seinova & Zolotarev 2003). This is evidenced by erosion channels in debris flow origination zones on moraines of many cirque glaciers. The trigger of modern catastrophic debris flows in the periglacial zone usually is ordinary rainfall (30-50 mm/day) after 6-10 days of extremely hot weather. The main peculiarity of typical catastrophic debris flows in the second half of the twentieth century was their simultaneous origin in numerous tributaries of the main rivers, and as a result huge debris flows formed in the main rivers. Such events took place in the upper part of the Terek River valley in 1953 and 1967, in the Ardon River valley in 1958, 1967, 1973, 1986 and 1996, in the Cherek River valley in 1953, 1975, 1983 and 1999, and in the Baksan River valley in 1967, 1977, 1983 and 2000.

The massive, destructive debris flow event of August 6, 1967, originated differently from all other cases in the periglacial zone. It formed as a result of extraordinarily heavy precipitation in the form of rain at this altitude (89 mm of rain at an altitude of 2100 m above see level). Such heavy rain occurred here only once during the period of instrumental measurements. But the probability of the recurrence of such an event is certainly increasing due to global warming. The debris flows of August 6 in the Terek River valley again (as in the nineteenth century) destroyed the main road between Russia and Georgia, debris flow protective structures, two nineteenth century military towers and a new gas delivery structure. At the same time in the Baksan River valley a huge debris flow again (86 years after previous catastrophe) destroyed the settlement of Verhniy Baksan.

Probably the best example of typical catastrophic debris flows events at the end of twentieth century was the massive debris flows in the Baksan, Chegem and Cherek River valleys on July 19, 1983. The debris flows originated in the periglacial zone of 83 tributaries of these rivers. The catastrophic events occurred after 7 days of extremely hot weather at a 0 isotherm level above 4000 m. The intensive

melting of glaciers and buried ice at elevations of 3000 to 3500 m destabilized the permafrost moraine as well as such normally stable deposits as rock glaciers.

Fortunately, a geological expedition was working near the headwaters of Kullumkolsu River (Baksan valley, Adyrsu basin) during that summer. Their alert signal helped to evacuate all tourists from a big lodge, which was completely destroyed by the debris flow two days later. The first signs of debris flow formation process were observed on July 16, 1983 (Zaporozhchenko 1985). The first few micro debris flows formed from a thawing cirque glacier moraine. On this day the surface of the terminal moraine formed a narrow channel with a depth of 4 m with vertical walls cemented by permafrost. The 36.4 mm rain occurred on the night of July 19. The formation of waves of debris flow of increasing volume inside the original channel started at 6 a.m. The first wave reached the lodge at 7:21 a.m., the last wave arrived at 11:38 a.m. The depth and width of the original debris flow channel inside the moraine complex increased to 35-40 m during the two days. The total volume of this debris flow was approximately 1.2 M m^3, which is bigger than the previous catastrophic event of the 13th century in the Kullumkolsu River.

6 DEBRIS FLOW DISASTERS AT THE BEGINNING OF TWENTY FIRST CENTURY

Two extraordinary nature disasters took place at the beginning of twenty first century in the Central Caucasus. A debris flow on July 18-25, 2000, produced the biggest tragedy in the history of the town of Tyrnyauz. A huge wave 30 m high in the Gerkhozhansu River destroyed engineering protective structures, a multi-level apartment building, and blocked the course of the Baksan River. It created a large flood through the town, causing fatalities. The total volume of this debris flow was estimated as about 6 M m^3 (Chernomorets 2005). This was the biggest such event in the Gerkhozhansu River during the last 2000 years and two to ten times bigger than the previous debris flows that reached Tyrnyauz in 1937, 1960, 1961, 1962, 1977, 1983, and 1999.

This phenomenal event was different from all previous events in its process of formation. Extreme hot weather lasted from the end of June. Near the headwaters of the Gerkhozhansu River on a cirque moraine complex of Kayarty Glacier a huge block of dead ice collapsed under the influence of thermal erosion. The whole right side of a previous erosion channel collapsed and exposed the layers of dead ice. The monolith with a volume 100,000 m^3 was divided into 30 pieces, which blocked the course of the stream. From the July 18-25, 2000, 590,000 m^3 of morainic material was transported downstream from the origination site. This increased the length of the original channel from 800 to 970 m, the depth from 20 to 50 m, and the width from 50 to 120 m (Chernomorets 2005). The melting and destruction of collapsed ice blocks and exposed dead ice at the edges of this erosion channel, accompanied by daily small debris flows, continued for the next two seasons after this tragedy happened.

One of the biggest historical debris flow tragedies in the Central Caucasus took place because of the collapse of the cirque glacier Kolka on September 20, 2002. The trigger of this flow of ice, water, and rock was a few failures from the walls of the Kazbek volcanic massif onto the rear part of the Kolka Glacier. The glacier was partially moved out of its bed. The gigantic wave of mainly ice material with a height up to 150 m and width up to 500 m moved down the Genaldon River valley. The total volume of debris accumulated upstream from the natural obstruction in the river course (the escarpment of Rocky Ridge) was estimated as 120 M m^3 (Chernomorets 2005). The melting of these deposits still continues.

Failures of small glaciers at the beginning of the 21st century occurred during an advanced stage of glacial retreat. Such processes may cease to be extraordinary. Fortunately, according to the opinion of Russian glaciologists (Panov 1993; Ilyichev and Solpagarov 2003), the overall picture of small glaciers existence in the Central Caucasus will not change dramatically up to 2050 even with global warming. Together with it, due to gradual glacial retreat, the periglacial zone will spread out and the amount of potential sites for debris flows origination will increase in any case. It could be the result of both thermal erosion channels in the numerous moraine complexes of small glaciers or newly formed lakes near the edges of retreating valley glaciers. Such processes indicate the potential for an increase of glacially related debris flow activity in the Central Caucasus in the near future.

7 CYCLE OF THE DEBRIS FLOW DISASTER FORMATION IN GLACIAL AND PERIGLACIAL ENVIROMENTS

On the basis of long-term research in the Central Caucasus, a new concept for a cycle of disastrous debris flow occurrence has been developed (Chernomorets 2005). The cycle includes four stages: pre-disaster preparation, the disaster, post-disaster adaptation and inter-disaster evolution. It has been demonstrated that a considerable part of the debris flow material is transported not only at the disaster stage, but also at the preparation stage and during the first few years after the disaster.

Using the Gerkhozhansu debris flow disaster (2000) as a case study, we demonstrate that the transformation of debris flow origination sites at the post-disaster adaptation stage is characterized by volumes of the transported material which are only a few times smaller than at the disaster stage. The main processes at the post-disaster stage are: the degradation of ice-rock masses, regression of the banks of debris flow channels, small debris flows and the formation of new lakes. The inter-disaster evolution stage is characterized by disappearance of ice masses with debris flow formation and by the decrease in steepness of slopes of the debris flow channels.

The concept was further validated through the research of the terrain changes after the Genaldon glacial disaster (2002) in the republic of North Ossetia-Alania. A special type of catastrophic ice-water-rock debris flow has been identified. It is shown that by volume and by way of movement of the transported material they differ significantly from ordinary debris flows.

Detailed studies of new pre-disaster and post-disaster lakes in the Caucasus have been also conducted. The pre-disaster preparation stage in the periglacial area by the contemporary retreating glaciers is characterized by the separation of masses of stagnant ice accompanied by formation of lake basins and flat lake-type sites, where the water for future debris flows is accumulated.

The concept has been also applied in other debris flow basins of the Caucasus, including Kullumkolsu (after the debris flow of 1983, which destroyed a mountaineering camp) and Adylsu (where outburst flows partially emptied a lake in 1958 and 1959), etc. The results show that accounting for the stages in a disaster cycle improves the hazard assessment and facilitates the choice of monitoring measures. An original monitoring method has been developed for the Gerkhozhansu basin, which exemplifies the stages of post-disaster adaptation and inter-disaster evolution.

8 CONCLUSIONS

An analysis of the reconstructed large picture of debris flow events during last one and a half millennia shows that at different stages of global glacial dynamics different levels of debris flow activity occurred and that different mechanisms of debris flow formation prevailed in the periglacial zone.

A majority of catastrophic debris flows in the Central Caucasus occurred during the stages of glacial retreat: from the fifth to seventh centuries and again from the end of the nineteenth century to the present. The present scale of modern debris flow catastrophes is comparable to the scale of events of the fifth to seventh centuries.

At the earlier stages of glacial retreat huge debris flows formed usually from outbursts of numerous temporary glacial lakes near the edges of valley glaciers. At the advanced stage of glacial retreat debris flows formed mainly from the thermal erosion of small glaciers, which often created massive simultaneous catastrophic events. In the final stage of glacial degradation debris flow activity in the periglacial zone gradually decreased to a low level.

During glacial advances debris flow activity gradually increased again to a middle level. Rare separate catastrophic debris flows formed usually as a result of lakes outbursts. At the stage of maximum glaciation, extraordinary catastrophic debris flows formed in the vicinity of volcanoes Kazbek and Elbrus as a result of advancing valley glaciers collapsing near ancient lava dams.

At the present modern stage of advance glacial retreat in the Central Caucasus the high level of debris flow activity in the periglacial zone will not decrease until at least the middle of 21st century. There are clear indications of its potential increase in the near future.

Different mountain areas of the World now experience different stages of global glacial dynamics. Successful understanding of the potential trends in debris flow phenomena in a variety of regions possibly can be based on the patterns determined for the Central Caucasus.

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REFERENCES

Chernomorets, S.S. 2005. *Origination Sites of Debris Flow Disasters: Before and After*. Moscow: Nauchny Mir. (in Russian with English summary)

Efremov, Yu.V. 2003. *Ozernyi morfolitogenez na Bolishom Kavkaze* [Lakustrine morphogenes and lithogenesis in the Bolshoy Caucasus], Krasnodar: Kubanskiy Gosudarstvennyi Universitet. (in Russian)

Gerassimow, A.P. 1909. O proryve lednikovogo ozera na NO sklone Elbrusa [About glacial lake outburst at the north-east slope of Mt. Elbrus]. *Izvestiya Geolkoma* 28(7):156-160. (in Russian)

Ilyichov, Yu.G. & Solpagarov, D.S. 2003. *Malye formy oledeneniya. Rasprostranenie, rezhim i dinamika*. [Small glaciers. Distribution, regime and dynamics]. Moscow: NIL Priroda. (in Russian)

Ivanov, M.A. 1902. V ushelje Baksana. [In the valley of Baksan River]. *Izvestiya Kavkazskogo otdeleniya Imperatorskago Russkago geograficheskago obshchestva* 15:7-20. (in Russian)

Kostenko, N.P. & Seinova, I.B. 1982. Vertikalinye klimaticheskie i strukturno-geomorfologicheskie uslovia formirovaniya seley [Vertical climatic and geomorphological condition of debris flows formation]. *Vestnik Moskovskogo Universiteta* Series 4(1):26-32. (in Russian)

Kovalyov, P.V. 1961. O selyah na severnom sklone Tsentralnogo Kavkaza [About debris flows in the northern slope of the Central Caucasus]. *Materialy Kavkazskoy expeditssii po programme MGG.* Har'kov: Izdatelistvo Har'kovskogo Universiteta 3:149-161. (in Russian)

Lurie, P.M. 2002. *Vodnye Resursy I Vodnyi Balans Kavkaza* [Water recourses and water balance of the Caucasus]. Sankt-Petersburg: Gidrometeoizdat. (in Russian)

Panov, V.D. 1993. *Evolutsiya sovremennogo oledeneniya Kavkaza* [Evolution of the modern glaciation in the Caucasus]. Saint-Petersburg: Gidrometeoizdat. (in Russian)

Popovnin, V.V. 1992. Sovremennoe oledenenie v verkhovyakh reki Baksan [Modern glaciation in the upper reaches of the Baksan River]. *Prirodopolzovanie Priel'brus'ya*. Moscow: Izdatelstvo Moskovskogo Universiteta:36-64. (in Russian)

Seinova, I.B. 1991. Past and present changes of mudflow intensity in the Central Caucasus. *Mountain Researches and Development* 11(1):13-17

Seinova, I.B. & Zolotarev, E.A. 2001. *Ledniki i seli Prielbrusya. (Evolutsiya oledenenia I selevoy aktivnosti).* [Glaciers and debris flows in the Elbrus region. (Evolution of glaciation and debris flow activity)]. Moscow: Nauchniy Mir. (in Russian)

Seinova, I.B. & Zolotarev, E.A. 2003. The evolution of glaciers and debris flows in the vicinity of Elbrus, Central Caucasus. In D. Rickenmann & C.L. Chen (eds), *Debris-Flow Hazards Mitigation: Mechanics, Prediction, and Assessment; Proceedings of the 3rd International DFHM Conference*, Davos. Switzerland, September 10-12, 2003:189-198

Statkowsky, B. 1879. *Problemes de la Climatologie du Caucase*. Paris: Gauthier-Villars, Imprimeur-Librarie, Successeur de Mallet-Bachelier

Teptsov, V.Ya. 1892. Po istokam Kubani I Tereka [In a headwaters of Kubany River and Terek River]. *Sbornik materialov dlia opisaniya mestnosti i plemen Kavkaza* 14:59-212. (in Russian)

Zaporozhchenko, E.V. 1985. Neobychnyi sel' na r. Kullumkol-su [The unordinary debris flow in Kullumkol-su River]. *Meteorologiya i gidrologiya* 12:102-108. (in Russian)