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THE SPECIFIC FEATURES OF THE BEHAVIOR OF GLACIAL LAKES WITH UNDERGROUND DRAIN CHANNELS (ANALYSIS OF MULTITEMPORAL AEROSPACE INFORMATION)

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Data on the dynamics of glacial lakes located in the territory of the River Malka, Baksan, Chegem, Cherek (KabardinoBalkar Republic, Central Caucasus) basins and other mountain areas are reported. The glacial lakes with underground drain channels were investigated. They are notable for significant water level fluctuations up to total disappearance of the lakes in the winter season and for manifestations of debris flows of varying scale.

Glacier, glacial lake, underground drainage, satellite images, lake level fluctuations, lake outburst, debris flow, earthflow

INTRODUCTION

The term "glacial lake" stands for a lake the kettle of which was formed as a result of accumulative and (or) exarative activity of a glacier.

Glacial lakes are a great hazard due to the threat of forming outburst floods and debris flows. The numerous facts of catastrophic lake outbursts are shown in [*Vinogradov, 1977; Reynolds, 2003; Petrakov, 2008*]. A disaster was the flow of debris as a result of an outburst, which occurred in 1941 in Lake Palkakocha in the Peruvian Andes, which carried away over 4,000 lives and destroyed part of the town of Huaraz [*Reynolds, 2003*]. The lethal statistics of the outbursts of glacial lakes is continuing to grow.

On July 8, 1998, an outburst of a glacial lake destroyed the settlement of Shakhimardan (Uzbekistan), with 116 people killed [*Eugster et al., 2008*].

On August 7, 2002, an outburst-caused debris flow in Roshtkalinsky district of Gorno-Badakhshan autonomous region (Tajikistan) destroyed a significant part of the settlement of Dasht, with 540 left homeless and 24 persons killed [*Yablokov, 2009*].

On June 17, 2013, a debris flow caused by an outburst of Lake Chorabari (Gandhi Sarovar) destroyed the settlement of Kedarnath (state Uttarakhand, India). The number of casualties exceeded 120 people [*FirstPost..., 2013*].

For glacial lakes with moraine and glacial-moraine kettles, the probability of an outburst increases when there is underground drainage in the lake, and the water level becomes unstable. The water level fluctuations may exceed 10 m (12 m Lake KakhabRosona, Dagestan [*Poznanin, 1979*], 16 m Lake Manshuk Mametova, Kazakhstan [*Kasatkin, 2011*]).

Observations over lake dynamics allow a possibility of forecasting the coming threat. Fast filling of the kettle of Lake No. 16 which had been empty for a long time in the river basin of River Kaskelen (Kazakhstan) served as grounds for organizing observation over it, which resulted in forecasting a lake outburst and a debris flow, the volume of which was about 800,000 m^3 [*Markov et al., 1981*].

In this paper, the authors have tried to reveal the specific features of the behavior of glacial lakes in different mountainous areas, having used both modern satellite images and aerial photos of the past years, and to trace down their connection with debris flow cases.

The following materials were used in the study: aerial photos taken from the flights carried out in the years of 1957, 1974, 1975, 1978, 1980, 1982, 1983, 1987, 1988, 1997, satellite images IRS (© 2003–2007 ANTRIX, © 2007–2009 ANTRIX, © 2006 National Remote Sensing Centre, Department of Space, Government of India), SPOT 5 (© SPOT Image), EROS A (© 2007 ImageSat International N.V.), GeoEye (© GeoEye Inc.), provided by ScanEx engineering and technology center as part of international tenders activity; satellite images QuickBird, IKONOS, GeoEye, WorldView2 from the public resources of companies Google, Bing, and Yandex; a satellite image

RISAT1 from Dave Petley's blog, the website of the American Geophysical Union "AGU Blogosphere" [*Petley, 2013*]; helicopter photos of the Chief Department of the Ministry of RF for Emergencies relating to the KabardinoBalkar Republic, Moscow State University; photos provided by users from the websites "Yandex.Photki", "Photosite", "Caucatalog", "Altay Photo", "Panoramio", "Flickr", etc.; and the materials of our own field and helicopter observations.

THE BEHAVIOR OF GLACIAL LAKES BY THE DATA OF SATELLITE IMAGES AND AERIAL PHOTOS

The aerial photos, satellite and helicopter images taken at different times were connected by reference points in the ArcGIS software program in the system of coordinates WGS 84 in the UTM projection, using topographic maps and satellite images SPOT 5, connected by orbital data and satellite image mosaics.

After a preview and processing of the photo materials of different mountainous areas (Caucasus, Altay, Zaili Alatau, Himalayas), lakes were selected to analyze the dynamics of their development, for which there were photos taken at different times and for which the facts of significant fluctuations of water levels and traces of debris flow manifestations were established in the interpretation process. The chart of location of "dynamic" lakes in the high mountains of the KabardinoBalkar Republic (Central Caucasus) is shown in Fig. 1.

In comparing the satellite images of July, August and September of 2004, 2007, 2011 and 2012 with the satellite images of April, October, November and December of 2012, it was first established that by November 23 and December 12, 2012, a whole number of the lakes essentially got reduced in their area, with some having disappeared completely, while the kettles of the lakes which existed in the summer of 2012 had been empty earlier in April (Table 1, Fig. 2). The images WorldView2 (Bing Maps) taken on April 21, 2012 demonstrate the absence of Lake Balyk (Table 1, No. 2; Fig. 1) in the circus below Mount Balyksubashi (3,932 m) in the head of River Kara-Kaya-Su (River Malka), and the images taken on April 11, 2012 showed the absence of Lake Manshuk Mametova (Table 1, No. 12; Fig. 1; Fig. 2, *i*, *j*).

The fact that the lakes disappear in winter is supported by the data of other years, for example, on November 11, 2004 the kettle of Lake Brno was already empty (the satellite image QuickBird from Google Earth).

The beginning phase of filling the kettle of the lake is almost not recorded by photos or observations. There are some data of different years for the lakes, the kettles of which have not yet been filled. A helicopter photo of June 4, 2012 recorded that the kettle of Lake Giybashkel was 60 % filled. Fig. 2, *m*, *n* demonstrates rapid filling of the kettle of Lake Maashey after winter emptiness. Within six days (May 24–30, 2002), the lake area increased from 10,000 to 186,000 m^2, to amount to 60 % of the maximum area.

Satellite images of slightly different timing allow the decrease rate of the water level in the lakes to be estimated. There are almost no images taken at different times for one season of individual lakes. Only for one lake the beginning of drainage was recorded. The beginning of drainage of Lake Maloye Sakashilskoye (Fig. 2, *g*, *h*) was recorded on the image of October 26, 2012, whereas on December 12, 2012 there was a residual lake with a diameter up to 15 meters on the bottom of the kettle.

The authors tried to assess the duration of the period during which the lake was completely emptied, using the air temperature measurement data collected at Cheget meteo station, located at the altitude

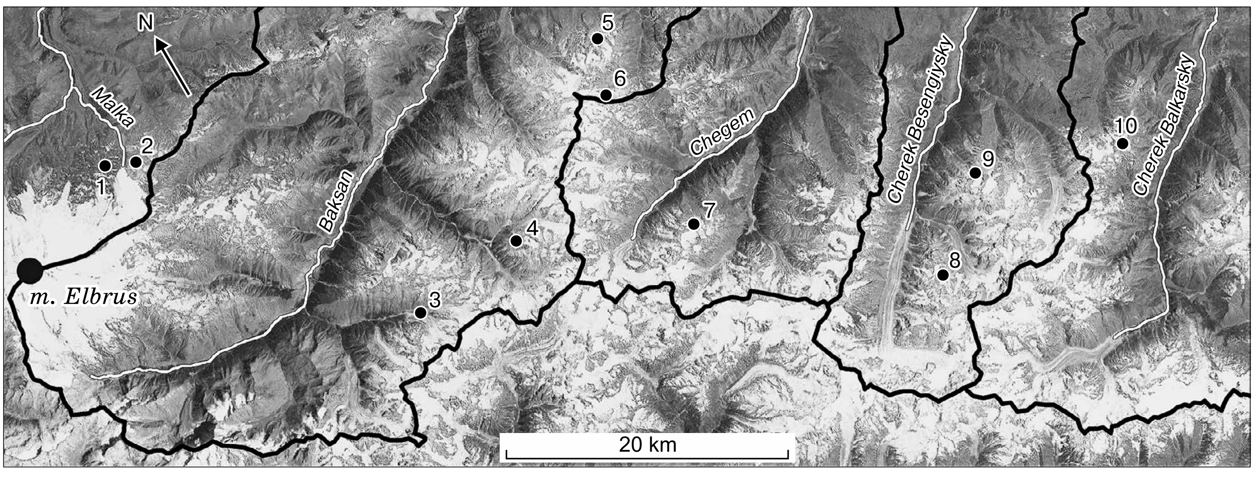

Fig. 1. Location plan of the glacier lakes in the high mountainous areas of the KabardinoBalkar Republic.
The location plan was composed on the basis of the satellite images mosaic, Google Earth. The lake numbers are given in Table 1.

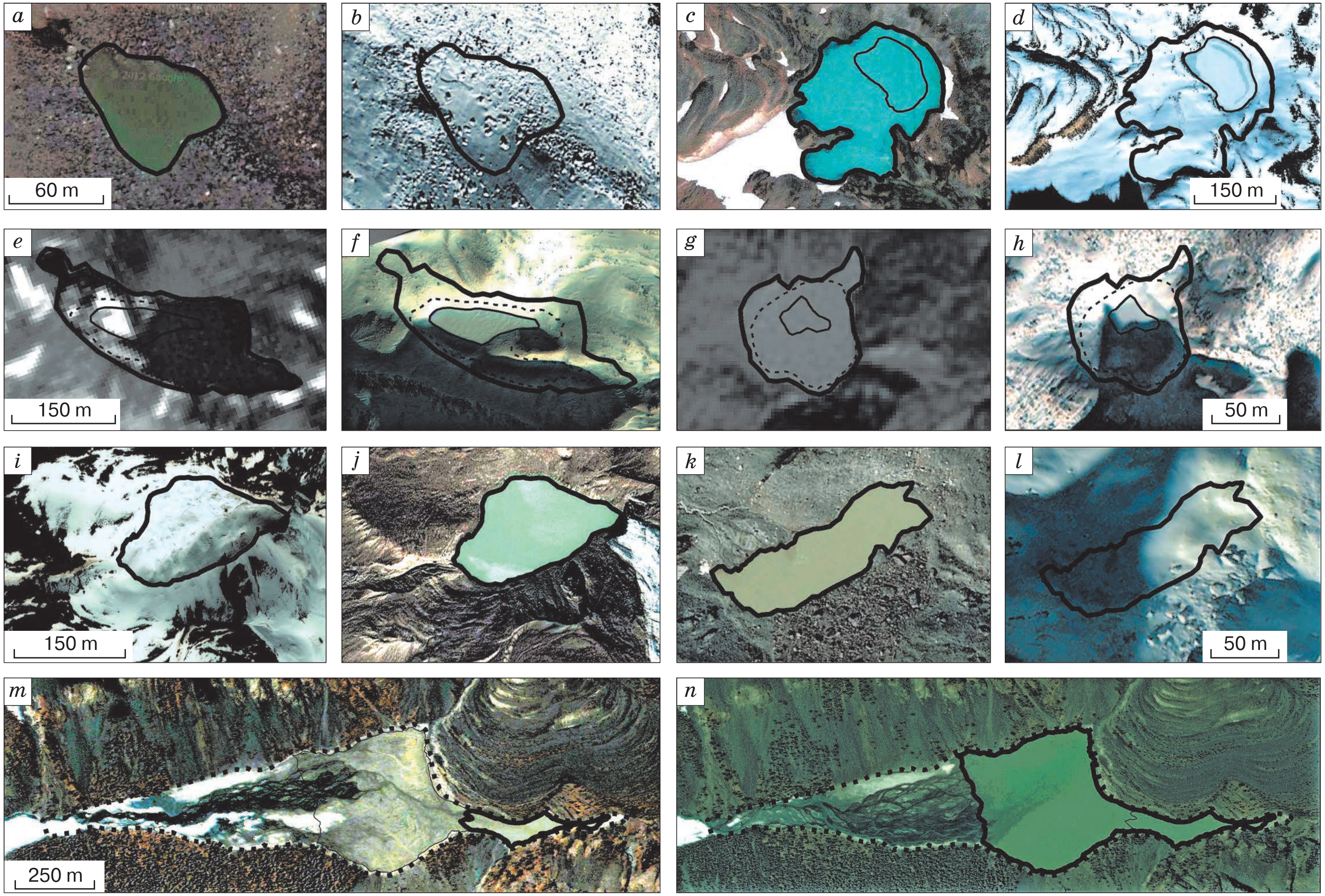

Fig. 2. Behavior of the lakes with partial or complete water outflow from the kettles in the winter period.

a – Lake Brno, 21.07.2011, a WorldView2 satellite image (Google Earth, the other images, too); *b* – Lake Brno, 23.11.2012, GeoEye1; *c* – Lake Giybashkel, 17.08.2004, QuickBird; *d* – Lake Giybashkel, 23.11.2012, GeoEye1; *e* – Lake Sarynskoye, 31.07.2007, IRS1C/1D (provided by ScanEx); *f* – Lake Sarynskoye, 16.12.2012, IKONOS, dashed contour – 29.08.2009, IRS P5 (provided by ScanEx); *g* – Lake Maloye Sakashilskoye, 21.09.2011, SPOT 5 (provided by ScanEx); *h* – Lake Maloye Sakashilskoye, 16.12.2012, IKONOS, dashed contour – 26.10.2012 r., GeoEye1; *i* – Lake Manshuk Mametova, 11.04.2012, WorldView2 (Bing Maps); *j* – Lake Manshuk Mametova, 09.08.2012, GeoEye1; *k* – Lake Boldoshke, 31.08.2010, WorldView2 (Bing Maps); *l* – Lake Boldoshke, 16.12.2012, IKONOS; *m* – Lake Maashey, 24.05.2002, IKONOS; *n* – Lake Maashey, 30.05.2002, IKONOS, dashed contour – the lake's coastline with the kettle filled to the maximum).

Table 1. **Characteristics of glacial lakes with underground drainage channels**

Lake	Number in Fig. 1 and in the text	River basin	Altitude, meters above sea level	Glacier area, km^2	Lake area, thousand m^2; date	
					max	min
Lake Severnoye Chungurchat	1	Malka (Birjaly-Su)	3,249 (3,244)	Not determined	25.1 09.09.1980	0.0 28.09.1987
Lake Balyk	2	Malka (Kara-Kaya-Su)	3,256	0.03	4.2 11.08.2006	0.0 21.04.2012
Lake Bashkara	3	Baksan (Adyl-Su)	2,568	2.10	90.6 July 2008 [*Kidyaeva, 2011*]	40.1 29.03.2006
Azot	4	Baksan (Adyr-Su)	3,197	0.52	22.7 04.09.2010	7.7 16.08.1957
Maloye Sakashilskoye	5	Baksan (Gerhozhan-Su)	3,227	0.38	8.9 27.07.1988	0.6 16.12.2012
Sarynskoye	6	Chegem (SarynSu)	3,590	0.09	38.8 31.07.2007	7.3 16.12.2012
Boldoshke	7	Chegem (Bashil-Ausu-Su)	3,260	0.66	6.3 31.08.2010	0.0 16.12.2012
Brno (a lake near Kursantskiye Nochevki (Cadets' Sleepovers))	8	Cherek Besengiysky (Mizhirgi)	3,400	0.31	4.6 21.07.2011	0.0 23.11.2012
Zhirishki	9	Cherek Besengiysky (Zhirishki-Su)	3,242	0.58	7.7 17.08.2004	1.4 23.11.2012
Giybashkel	10	Cherek Balkarsky (Suldur-Su)	3,145	0.04	48.0 17.08.2004	9.8 23.11.2012
Maashey (Altay)	11	Chuya (Mazhoy)	1,984	37.48	286.0 (established by the coastline)	0.0 15.07.2012
Manshuk Mametova (Trans-Ili Alatau)	12	Kishi Almaty (Kazakhstan)	3,620	0.34	25.2 02.08.2010 [*Kasatkin, 2011*]	0.0 11.04.2012
Chorabari (Gandhi Sarovar) (Himalayas)	13	Mandakini (India)	3,960	0.27 (part of the glacier water flows may get into the lake)	~66.7 (established by the level in the passage area)	0.0 17.06.2013

Note. The names of lakes No. 1, 2, and 6–9 were offered by the authors considering the toponymy of the neighboring glaciers, mountain peaks and rivers. For Lakes Bashkara, Maloye Sakashilskoye, Sarynskoye, and Boldoshke, the glacier areas from which the ice water comes to the lakes were determined using satellite images of 2011.

of 3.043 m, as well as the facts of emptying of certain lake kettles by November 23 (Table 1).

In accordance with the Cheget meteo station data, in 2012 the positive average daily temperatures got established on April 25. Approximately at about this time, the kettle of Lake Balyk remained empty.

The transition of air temperatures from positive to negative values occurred on November 1, 2012 and on November 3 in 2004. Hence, if the fact of the absence of Lake Brno was confirmed by the satellite image of November 11, 2004, one can assume that with the same air temperatures in 2012, the drainage of Lake Maloye Sakhashilskoye, which started in the third decade of October, finished in mid-November to last about two weeks.

Several states were traced down for several lakes for different years and months, including the winter of 2012, for example, Lake Sarynskoye (Fig. 2, *e, f*). Increase in the amount of lake water was observed in the 60s–70s of the 20th century due to expansion of the kettle caused by retreat of the glacier and by melting of dead ice.

The maximum area of Lake Sarynskoye was recorded on a satellite image in late July 2007 (Fig. 2, *e*) in the period of the maximum air temperatures. Nearly the same lake area was recorded on the aerial photo of August 9, 1978. On all the images of the lake taken in late August and in September, the lake area was much less. Based on these data, one can make a conclusion regarding direct connection between the area (level) of the lake and the air temperature.

The Landsat images (the materials provided by *M. Pelto* [*2013*]), photos from tourist websites and topographic maps showed that Lake Chorabari (Gandhi Sarovar) (Table 1, No. 13) in the valley of River Mandakini (Himalayas) existed for over 50 years (it is present on the maps of 1962) and had the area of about 36,000 m^2 (assessed by the coastline shown on a satellite image WorldView2 (Bing Maps) of November 9, 2011). The lake was fed with water coming from rains and melting snow. A small part of the drainage flow from a small glacier is likely to enter the lake's kettle. By winter, the lake got drained by filtration channels. Its maximum level was recorded in the photo of July 15, 2008. The existence of the lake is confirmed by the photos of September 4, 2011 and of October 17, 2008. The empty kettle was shown on the photos taken by N. Zverev on September 2, 2009 (Panoramio) and on the satellite image WorldView2 (Bing Maps) of November 9, 2011. As the lake behavior was determined by the precipitation behavior, its emergence, maximum filling and disappearance occurred at different times.

THE CAUSES OF WATER LEVEL FLUCTUATIONS OF LAKE BASHKARA

Researchers of the Moscow State University conducted on-site observations on Lake Bashkara. They found out as a result that the maximum water levels of Lake Bashkara were recorded in June. "By the end of June (when the period of maximum glacier ablation begins – *the authors' note*), the water levels go down to be quasi-stable during the summer; a more expressed decline in the water level begins after August 20–September 1, with the minimum water levels being at the end of the observation season (September–October)" [*Chernomorets et al., 2007; Petrakov et al., 2009*].

The authors suggest the following explanation of the unusual fact of water level reduction in Lake Bashkara in the period of maximum glacier ablation.

Just as the above listed lakes, Lake Bashkara does not have over-the-surface flows. The data of a helicopter image taken in late March 2006 (Fig. 3) show the minimum values of the water level in the lake practically to coincide with the stable water level of Lake Bashkara in the early 1980s.

At that time, the flow from the lake in the area of the moraine boulder train in the northwestern corner of the kettle was over-the-surface. Resulting from the advance of glacier Bashkara in the 90ies of the 20th century, a push moraine was formed in the area (Fig. 4, *a*) [*Dokukin and Savernyuk, 2012*]. As this boulder train emerged, the flow of water from the lake started to proceed from the underground filtration channels, while its water level began to be exposed to significant seasonal fluctuations.

The lower level of the filtration channels corresponds to the level of the over-the-surface water flow from the lake before the advancement of the glacier in the 1990s. It is likely that the dam below the minimum lake level is water-proof and composed of bedding rocks, as, if filtration had occurred across the entire lake depth, it would have disappeared in the winter season.

In the winter season, the water entrance areas of the filtration channels get frozen. According to [*Volodicheva et al., 2010*], seasonal freezing of ground in the near-Elbrus area may go down to the depth of 1.5–2.0 m.

In spring and in early summer, while the filtration channels remain to be frozen, the water level in

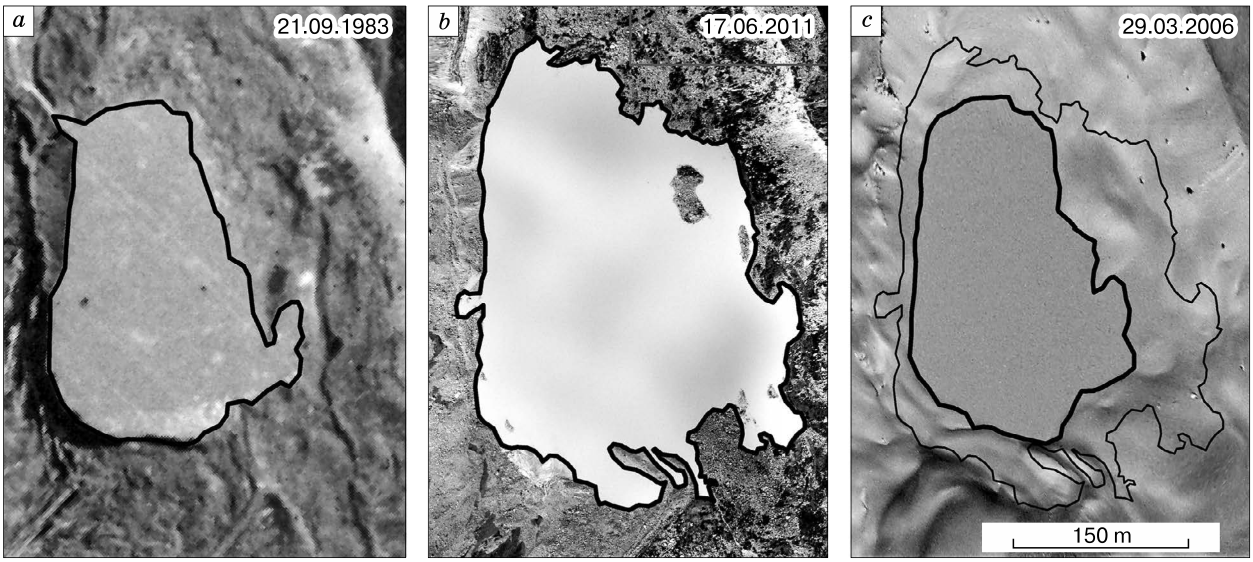

Fig. 3. The condition of Lake Bashkara in autumn, in early summer and in spring in different years.

a – an aerial photo; *b*, *c* – helicopter photos taken by the Ministry of RF for Emergencies, Chief Department in the KabardinoBalkar Republic.

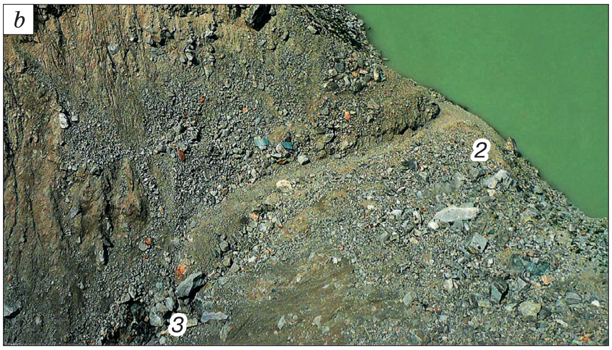

Fig. 4. A section of the drainage flow from Lake Bashkara.

a – a lateral view of the northwestern part of the lake: *1* – a push moraine ridge, 1990s (photos taken by the Ministry of RF for Emergencies, Chief Department in the KabardinoBalkar Republic, 29.09.2006); *b* – a top view of a part of a moraine dam: *2* – a ditch in a moraine dam, *3* – an outflow of drainage water to the surface (photo taken by Dokukin, M.D. on 23.07.2009).

the lake rises to the annual maximum values due to the inflow of melted water to the kettle. Then, exposed to the thermal impact of the lake water, the filtration channels melt, and their drainage ability recovers to reach the maximum value. As a result, the water level in the lake goes down to the average annual values.

By the wintertime, when the inflow of melted water into the lake decreases and stops, the underground flow channels do not get frozen yet and preserve their carrying capacity. The flow of water from the lake continues, and the water level decreases to the minimum.

In July 2008, there was an anomalous rise in the water level, and water overflew over the moraine dam. Compared to the maximum levels of July in 2005 and 2009, the exceeded height was 4.5 m (according to the plots presented by [*Kidyayeva, 2011*]). In [*Khadjiyev et al., 2009*] a conclusion was made that the rise in the water level was caused by the showers of July 15 and 18 (according to the findings of Cheget meteo station, on July 15 there was 57 mm rainfall, and on July 18 the rainfall amounted to 53.4 mm). Over the period of observations, the maximum precipitation was recorded on July 8–9, 2001 – 62 mm in total; on July 20–21, 2002 – 61 mm; on July 28–29, 2003 – 63.9 mm; on July 12, 2004 – 48.7 mm; on July 15–16, 2007 – 59 mm. On those days, no excess of the water level was recorded.

As the water level started to rise before the showers (in early July the excess of the water level over the annual maximum values already was 1.5 m), and the air temperature conditions of 2008 were not maximum, the authors supposed that, besides the precipitation, the cause of the anomalous rise of the water level could be transformation of the drainage system of glacier Bashkara, during which a large part of the glacier runoff got into the lake, although previously is had passed by the lake.

In order to prevent further sharp rise in the water level, works were conducted under the supervision and with the participation of the specialists of the Ministry of Emergencies of Russia in Kabardino-Balkar Republic and of the specialists of the High Mountain Geophysical Institute (HMGI) to make a dredge cut across the moraine dam 20 m long and 2.5–3.0 m deep (Fig. 4, *b*). Thus, the possibly hazardous water amount in the lake was reduced by 180,000–200,000 m^3.

DEBRIS FLOW MANIFESTATIONS RELATED TO THE LAKES HAVING UDERGROUND DRAINAGE

The numerously repeating processes of water outflow and water filling in the lakes result in the fact that the underground flow channels become stable to function for tens and hundreds of years. According to the aerial photos of 1957, the lakes under study (Table 1) have existed for over 50 years, with the exception of Lake Severnoye Chungurchat, which disappeared in the 1980s, after glacier water stopped coming into it.

Over the long period of the lakes' existence, the carrying capacity of the flow channels comes into agreement with the annual maximum inflow of water into the kettles. Such agreement is observed both for lakes with feeding glaciers with the area of dozens of square kilometers and for small lakes fed by small glaciers with the area of several hectares.

Lake Maashey (Fig. 2, *m*, *n*) received water flow from glaciers with the total area of over 37 km^2 (the data borrowed from the report of Yu.K. Narozhny, Tomsk University, 2004) (Table 1), while Lake Giybashkel (Fig. 2, *e*, *f*) received water from a rock glacier and a small glacier with the area of 0.04 km^2.

The outburst of Lake Maashey, which had existed for over 100 years [*Nikolayev et al., 2012*] on

July 15, 2012, that for the lakes with underground drainage channels there is a potential hazard of an outburst, despite the lengthy period of stability.

Lake outbursts occur as a result of deformation of underground drainage channels, connected with the processes of permafrost degradation of ice debris moraine and periglacial masses (rock and armoured glaciers, buried ice, according to the defined types of glaciers [*Dokukin, 1988*]). Outbursts may be both underground outbursts with erosion-landslide niches formed on the slopes of frontal moraine shelves, rock and armoured glaciers, and surface outbursts, with passages in the dam bodies and erosion channels formed.

Comparative interpretation of the aerial photos taken in the 1970–1980s revealed several underground outbursts of Lake Severnoye Chungurchat in the area of the frontal ridge of the armoured glacier (Fig. 5) [*Bagov et al., 2009*], which were accompanied by debris drifts of DzylySu mineral springs. The length of the underground channels where the outbursts of Lake Severnoye Chungurchat occurred varied from 30 to 90 m.

It was seen from a QuickBird image taken on 31.08.2008 (Google Earth) of the lake in the upper flows of River Dasht (Tajikistan) and the erosion landslide niche on the lateral border of the rock glacier from which traces of a catastrophic mudslide begin were separated by an area with an underground flow about 200 m long.

Examples of lake outbursts with underground drainage channels up to 500 m long are Lakes Kakhab-Rosona (Dagestan) [*Poznanin, 1979*], Lake Maashey (Altay) and Maloye Sakashilskoye (Fig. 2, *g*, *h*). It is likely that the debris flow of 1977 along the River Sakashil-Su is related to an underground outburst of Lake Maloye Sakashilskoye, as on the frontal shelves of the armoured glacier, in the back zone of which the lake is situated, the earthflow occurred of the volume amounting to 15,000–20,000 m^3 (Fig. 6, *a*, *b*). Further development of the lake's kettle resulted in dulling of the flank moraine with the area reaching 1,500 m^2 and with the accumulation of deposits at its foot and a surface flow channel formed (Fig. 6, *c*, *d*). Due to the small size of the earthflow and only slightly sloping zone of the earth accumulation, the process did not cause a debris flow.

Based on the erosion landslide niches below the lakes seen on the aerial photos and satellite images, the following outbursts were recorded: Lake Balyk – between 1957 and 1978, Lake Sarynskoye – after 1957 (according to *I.B. Seinova* – 1958), Lake Boldoshke – before 1957, Lake Zhirishki – after 1957 (according to [*Cadastre..., 2001*] – 1967).

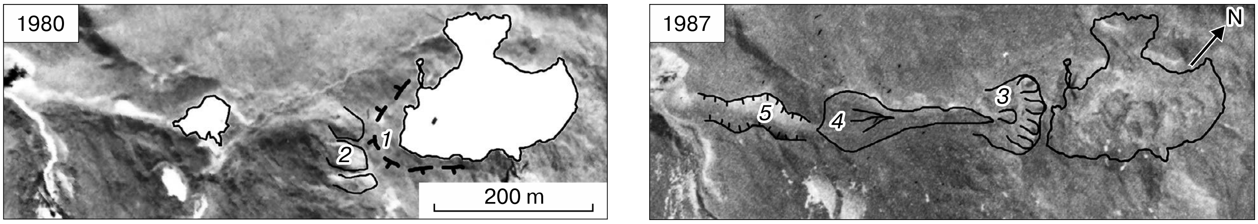

Fig. 5. Passage traces of Lake Severnoye Chungurchat in aerial photographs.

1 – a shelf edge of a frontal moraine wall; *2* – old earth flow niches (1970s); *3* – earth flow niches formed in early 1980s; *4* – debris flow deposits; *5* – crests of a debris flow channel.

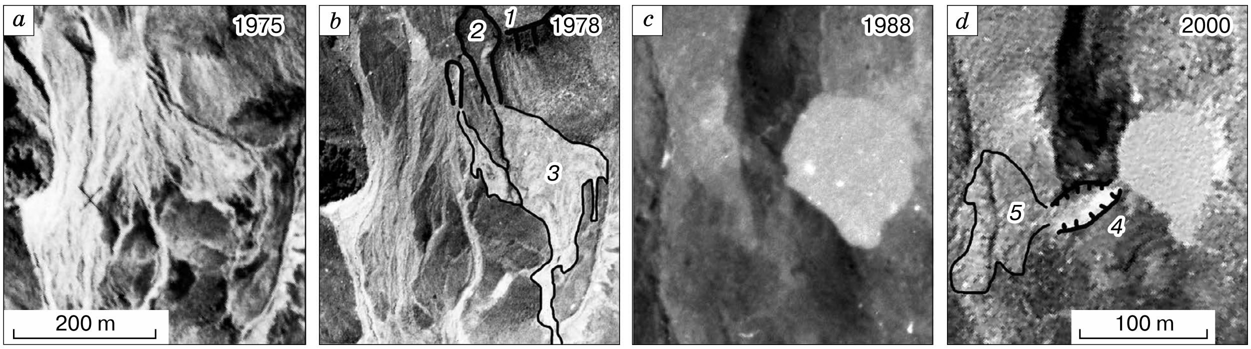

Fig. 6. Behavior of the frontal shelf edge of an armoured glacier and Lake Maloye Sakashilskoye in aerial photos.

a–*c* – aerial photos; *d* – a helicopter photo taken by M.Yu. Nikitin; *b*: *1* – a frontal shelf edge, *2* – erosion-landslide niches of the earth flows, *3* – debris flow deposits of 1977; *d*: *4* – a passage in the lake's kettle, *5* – deposits of a dulled moraine block.

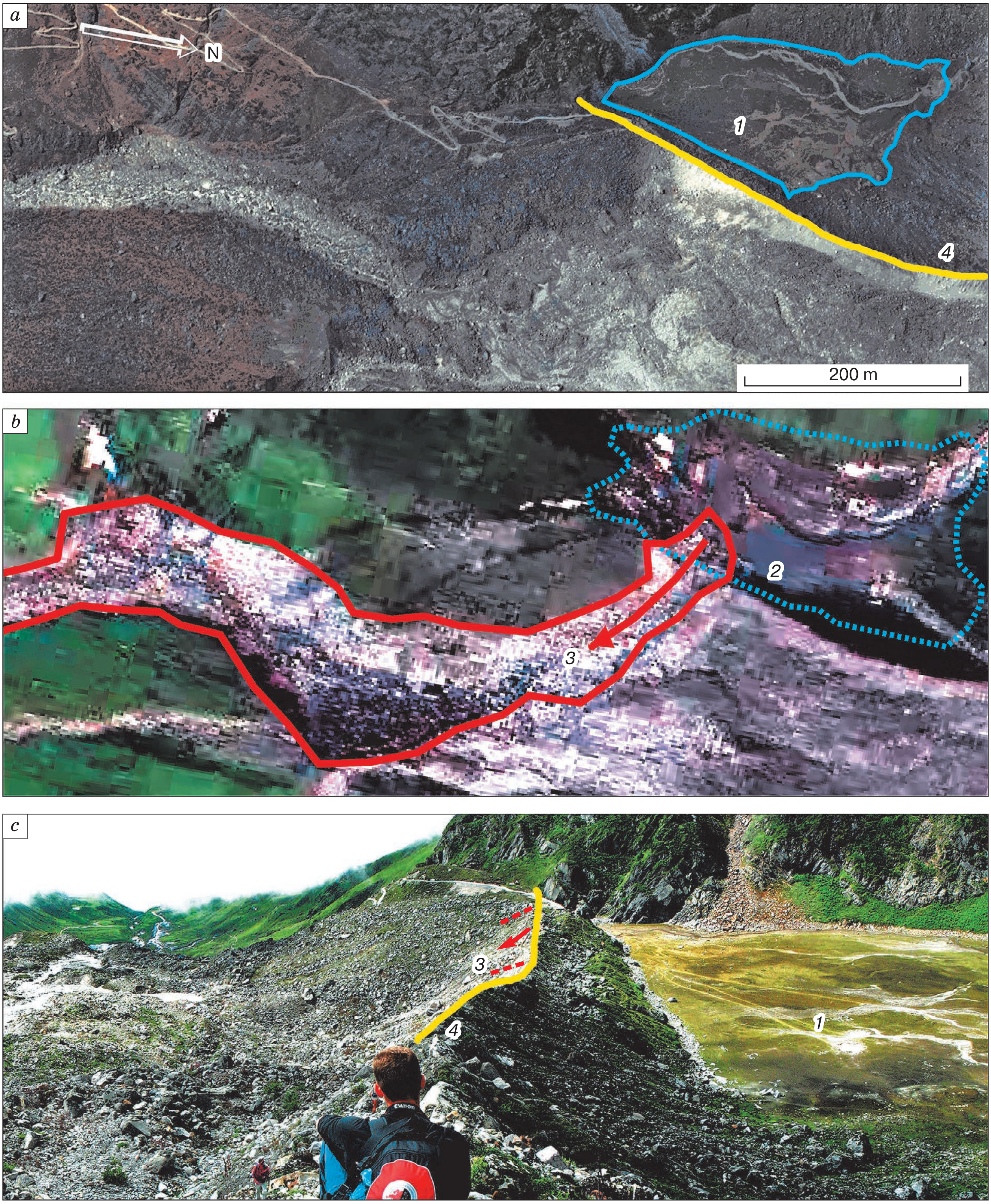

Fig. 7. An area of flood formation resulting from an outburst of Lake Chorabari (Gandhi Sarovar) in the valley of the River Mandakini (state Uttarakhand, India).

a – a fragment of a WorldView2 satellite image (Bing Maps) of 09.11.2011: *1* – the lake contour with the kettle filled in summer, *4* – an edge of a coast moraine; *b* – a fragment of a RISAT1 satellite image of 23.06.2013 [*Petley, 2013*]: *2* – an estimated lake contour before the outburst of June 17, 2013 г., *3* – a passage and an erosion channel after the lake outburst; *в* – a fragment of N. Zverev's photo of 02.09.2009: *1* – the lake's kettle bottom, *3* – the area of the would-be passage, *4* – an edge of a coast moraine.

In [*Seinova, 2001*] a conclusion was made that the outbursts of Lake Azot took place before 1930ies and were related to the existence of a glacial dam. According to the description made by *P.V. Kovalev* [*1961*], catastrophic outbursts of Lake Bashkara in 1958 and 1959 occurred in the area of the existence of an ice dam in the early period of lake formation.

Lake outbursts with underground drainage flow channels may be triggered by excessively affluent rains and glacial floods, caused by the outbursts of englacial waters or change of direction of the englacial flow channels. As a result, such amounts of water get into the lake, with which the underground drainage channels cannot cope. A surface flow is formed to start an erosion process, sometimes coinciding with thawing of the permafrost rocks in the underground drainage areas.

For example, before the outburst of Lake Maashey, there had been showers tripling the regular precipitation amount. Overfilling of the kettle of Lake Chorabari (Gandhi Sarovar) and its outburst were caused by the rains with the daily rainfall of 325 mm [*Dobhal et al., 2013; Petley, 2013*]. According to the eyewitnesses, the researchers of Wadia Institute of Himalayan Geology (WIHG) [*Dobhal et al., 2013*], the outflow of Lake Chorabari lasted about 5–10 minutes. During this time, about 600,000 m^3 of water flew out of the lake, with the average flood rate exceeding 1,000 m^3/s. The outburst flood was called the “Himalayan tsunami”. Such a fast outflow of water occurred due to the moraine dam, as the edge of the flank moraine literally dropped. It can be seen on Fig. 7, *c* that the area of the would-be passage is characterized by the smallest width and the height of the edge (the chine is 12 m elevated over the kettle bottom). Shown in Fig. 7, *b* is an estimated lake contour for maximum filling of the kettle. The lake area before the outburst was about 67,000 m^2.

The example of Lake Chorabari demonstrates that it is necessary to keep a record of the lakes with kettles partially filled or empty, which exist for dozens and hundreds of years. When anomalous rainfalls or glacier floods occur, the kettles of the lakes are likely to be overfilled and outburst flows may occur.

CONCLUSIONS

A large amount of information on the behavior of glacier lakes and of other natural bodies can now be obtained from different internet resources (satellite images of different years, photos from tourist websites, event descriptions and discussions, etc.).

The numerous facts of lake outflows at the beginning of the winter season may be considered a characteristic feature of the lakes with underground drainage flow channels.

The use of satellite images and helicopter photos showing the condition of the lakes in winter allows the researchers to identify lakes with underground drainage flow channels and to reveal the maximum levels of the drainage zone. Complete image coverage of the periods of filling the kettles of the lakes and their discharge will allow, given the bathymetric observation data, the carrying capacity of the underground channels and their condition to be estimated.

The examples of lake outbursts in the other mountainous areas show that there is much in common in the patterns of lake outbursts and in the types of kettles. The study of the evolution of the lakes and their kettles, with aerial photographs and satellite images used, allows their condition to be assessed and the development phase and the relation between the different outburst mechanisms and certain morphogenetic types of moraine and periglacial complexes to be identified.

The above materials on the behavior of lakes having underground drainage allow us to consider them potentially outburst-hazardous, despite the comparatively rare cases of their outbursts and the lengthy periods of stability.

In organizing monitoring of the glacier lakes, it is reasonable to use the numerous materials of satellite imaging and of aerial photography available in the internet, to order lake images and photos in the periods in question, and to make helicopter surveys in the spring and winter seasons.

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