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THE SNOW-ICE-ROCK AVALANCHE ON BASHKARA GLACIER IN THE ADYL-SU VALLEY (CENTRAL CAUCASUS) ON APRIL 24, 2019

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On the basis of the comparative interpretation of Sentinel 2A satellite images on April 23 and 25, 2019, the fact of a collapse from Mt. Bashkara (4162 m) located in the headwaters of the Adyl-Su River (the basin of the Baksan River, Central Caucasus) has been revealed. The initiation zone of the collapse is located on the border of Russia and Georgia; the accumulation zone is located in Russia. The parameters of the collapse have been determined from measurements on the satellite image and the map. The width of the sediment zone is more than 500 m, the runout distance of the avalanche is 3160 m (in projection), the affected area is 0.9 km^2, the approximate volume of deposition is 1.2–1.5 million m^3. According to eyewitnesses, the date of the collapse was April 24, 2019. We compared the survey data from April 30, 2019 and the previous survey data and determined the location of the rock block at the top of Mt. Bashkara and detected a collapse of a hanging glacier with snow cover on an area of about 40,000 m^2, which transformed the rock collapse into a snow-ice-rock avalanche. The main zone of the deposition of the landslide masses is located on a section of the glacier in the altitude zone 2660–2800 m. Remote sensing of the landslides in the Caucasus has demonstrated an increase of their activity in the 21st century. We detected facts of collapses in the high-altitude zone of the northern and southern slopes of the Caucasus: in the cirque of Belalakaya Glacier in the valley of the Amanauz River in 2012, in the cirque of Dzhalovchat Glacier in the valley of the Aksaut River in 2013, 2015 and 2016, in the valley of the Tviberi River in 2017, and in the valleys of the Klych and Nenskra rivers in 2018. In the future, such landslides may occur in other parts of the high-mountainous zone and pose a hazard to the people and the recreational and economic activities in the mountain regions.

Snow-ice-rock avalanche, Bashkara Glacier, satellite image

INTRODUCTION

In the 21th century, rock avalanches in the mountains have become more frequent in the Caucasus due to climate warming [*Dokukin et al., 2015*]. Such events have happened over the recent 20 years in other regions, as well, – in Tibet, Szechuan, Karakoram (Himalaya), St. Elias Mountains, the Alps, and in Alaska [*Shang et al., 2003; Haeussler et al., 2004; Crosta et al., 2006; Dunning et al., 2007; Evans et al., 2007; Huggel et al., 2007; Lipovsky et al., 2008; Wei et al., 2010*]. In [*Legros, 2002; Hewitt, 2009; Deline et al., 2015; Sosio, 2015*] data on rock avalanches and rock-snow-ice avalanches which occurred in the mountainous regions of the world are summarized.

The following collapses (ice-rock avalanches) were found to be the largest in the Caucasus: in 2002, from Kolka Glacier in the glacial cirque of Kolka (Republic of North Ossetia–Alania) [*Kotlyakov et al., 2004; Petrakov et al., 2004; Tutubalina et al., 2005; Evans et al., 2009*], with the total volume of 115 million m^3 and the runout distance of about 20 km, in 2006 on a slope of the Pirikitel Range in the valley of the Khargabakh River, Chechen Republic, with the total volume of about 5 million m^3 and the runout distance of 7.5 km [*Dokukin, Savernyuk, 2010*], in 2014 on a slope of Mt. Kazbek, with the volume varying, according to different sources, from 2 to 6 million m^3 and the runout distance of 10.5 km [*Chernomorets, 2014; Drobyshev et al., 2014; Chernomorets et al., 2016; Tielidze et al., 2019*], as well as collapse after the avalanche from Kolka Glacier in 2002 [*Dokukin et al., 2015*]. In 2003, avalanches moved from Aristova Rocks onto Dzhalovchat Glacier in the valley of the Adyl-Suu River [*Dokukin et al., 2015; Rezepkin, Popovnin, 2018*].

Over the recent years, based on comparative interpretation of Sentinel 2A satellite images (the resolution of 10 m), of the WorldView2 satellite image as of 17.09.2012 and of the materials of audio-visual observation as of 22.08.2013, the events of avalanches were detected in the Western and Eastern Caucasus: in 2012, in the cirque of Belalakaya Glacier in the valley of the Amanauz River [*Dokukin et al., 2015*], in 2013, 2015 and 2016 in the cirque of Dzhalovchat Glacier in the valley of the Aksaut River [https://twitter.com/inrushmd/status/1000776089558503425], in 2015 in the cirque of Shtulu Vostochny Glacier [https://twitter.com/inrushmd/status/1020990870043136000], in 2017, in the valley of the Tviber River [https://twitter.com/inrushmd/status/999363888738111488], in 2018, in the valleys of the Klych River [https://twitter.com/inrushmd/status/1033775971265064961], the Nenskra River [https://twitter.com/inrushmd/status/1123580598172487682], etc. In 2019, the list of events continued: on March 21, a collapse occurred from the slope above Lekzyr Glacier in Svanetia (Georgia) [https://twitter.com/inrushmd/status/1123580598172487682], on April 24, there was a collapse from Mt. Bashkara in the Adyl-Suu Gorge [https://twitter.com/inrushmd/status/1121799921034612736], in early July, there was an avalanche from the slope over Bashil Severny Glacier in the Bashil-Auzu-Su Gorge, in late July, an avalanche collapsed in the velley of the Murkvami River in Svanetia with the runout distance exceeding 4 km [https://twitter.com/inrushmd/status/1159681328297709568].

THE COLLAPSE AND THE SNOW-ICE-ROCK AVALANCHE ON BASHKARA GLACIER ON APRIL 24, 2019

On the 2A Sentinel 2A satellite image of April 25, 2019, one can see the traces of an avalanche on Bashkara Glacier in the upper part of the valley of the Adyl-Suu River (the basin of the Baksan River). On April 23, there was no such an avalanche (Fig. 1).

On April 26, 2019, GIF-animation of the satellite images before and after the avalanche was uploaded in the electronic resource [https://twitter.com/inrushmd/status/1121799921034612736]. On April 30, D. Petley commented the message [*Petley, 2019*]. He compared the Bashkara Glacier event with the rock avalanche from Mt. Haast (Dixon) in New Zealand in 2013 and provided data on the runout distance of the rocks equal to 2.7 km, with the possible volume of the material being 2 million m^3.

After measurements made on the satellite image (EO Browser program) and on a topographic map, we obtained the following parameters of the collapse from Mt. Bashkara: the altitude difference 1500 m (4162–2660 m), the runout distance 3160 m (consid-

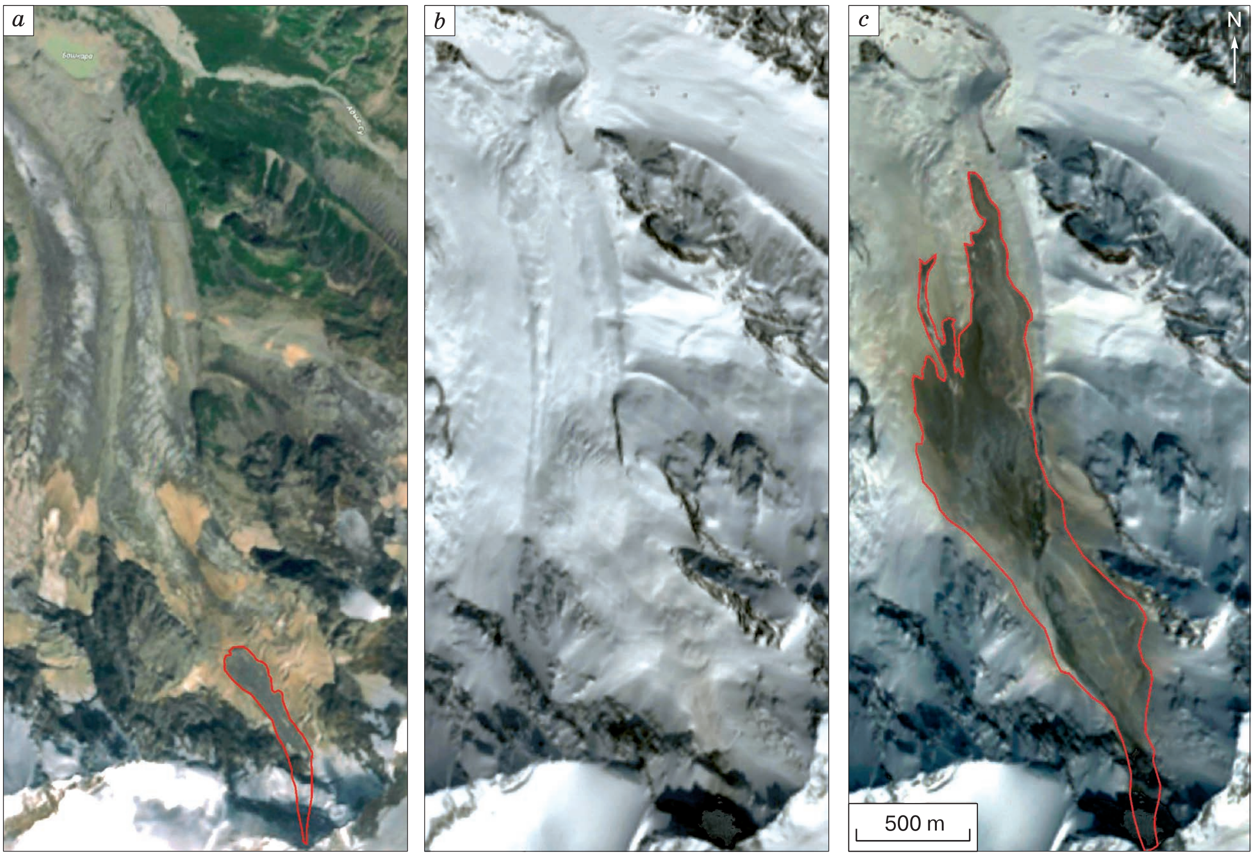

Fig. 1. Traces of collapses from Mt. Bashkara in 2018 and 2019 on Bashkara Glacier.

Sentinel 2A satellite images: *a* – 13.08.2018; *b* – 23.04.2019; *c* – 25.04.2019. Red line – contours of new collapses.

ering the mean inclination angle of the run 25.4° – 3500 m),the affected area (0.90 ± 0.04) km^2, the maximum width of the deposit area 500–510 m, the total area of the deposit zone (0.44 ± 0.03) km^2, the approximate volume of deposits based on the visual estimation of the mean depth (3 m) and the measurement error in measuring the area from the satellite image (0.03 km^2) – 1.2–1.5 million m^3. The measurement error in measuring the area from the satellite image was determined based on the cone perimeter and the 0.5-pixel resolution of the image ($dS_{max} = P \times \zeta$, where dS_{max} – the area error for the collapse contour; P – perimeter of the collapse contour; ζ – half a pixel of the resolution of the satellite image) [*Petrov et al., 2017*].

As a result of the avalanche, the watershed in the area of Mt. Bashkara shifted to the south to the distance of up to 25 m. In 2018, a collapse occurred at the place, its deposits being 8 times less than those in 2019 (Fig. 1). The first collapse occurred before August 13, 2018 (Fig. 1, *a*). The debris covered the glacier surface on the area of (0.052 ± 0.007) km^2.

On April 30, 2019, we examined the collapse area at the site. After the examination and comparison of the site with the materials of 2018, we revealed the specific features of the initiation zone of the collapse, the transit zone and the zone of accumulation of the collapse mass. That allowed us to make a conclusion that the process of the collapse had the signs of a snow-ice-rock avalanche. According to the testimony of the eyewitnesses, the time of the collapse was 10–11 A.M. on April 24, 2019.

Fig. 2. The general view of the collapse area in the upper part of the Adyl-Suu River valley:

1 – Mt. Dzhantugan (4012 m); 2 – Mt. Bashkara (4162 m); 3 – the frontal part of the collapse deposit zone (snow-ice-rock avalanche); 4 – Bashkara Lake; 5 – Bashkara Glacier. The photo was taken by M.D. Dokukin, 30.04.2019.

Fig. 2 demonstrates the general view of the collapse area.

Fragments of the conventional photographs taken on the land (Fig. 3) show contours of rock blocks on top of Mt. Bashkara before the collapses. Compar-

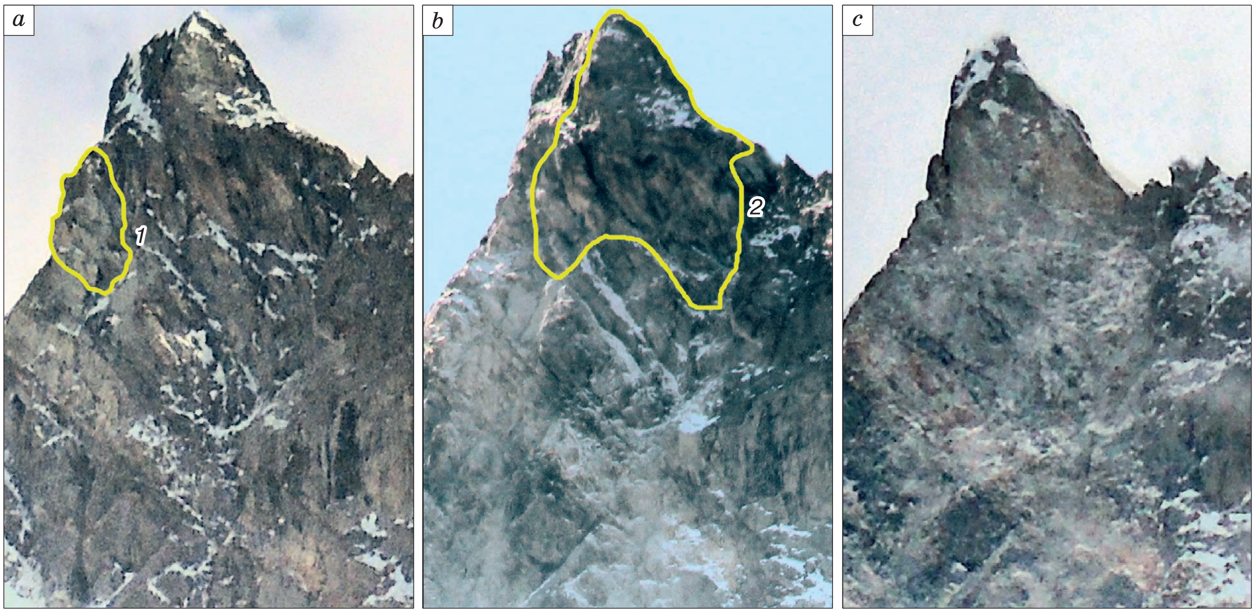

Fig. 3. The top of Mt. Bashkara before and after the collapses:

a – 29.07.2017 (the photo was taken by M.D. Dokukin); *b* – 20.08.2018 (the photo was taken by S.S. Chernomorets); *c* – 30.04.2019 (the photo was taken by M.D. Dokukin). *1* – the contour of the rock block collapsed in August 2018; *2* – the contour of the rock block collapsed on 24.04.2019.

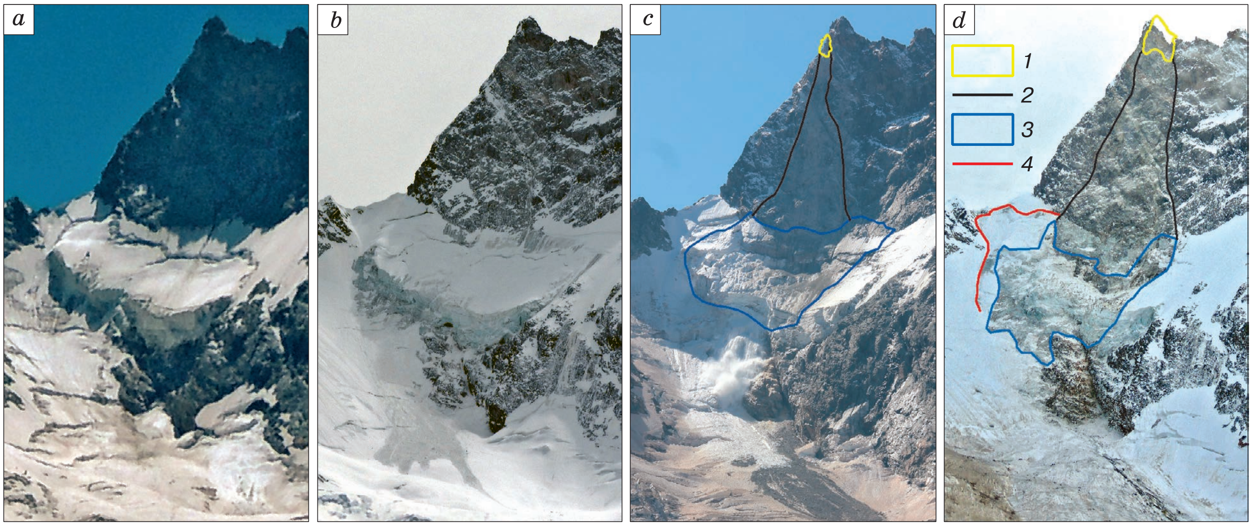

Fig. 4. The slope of Mt. Bashkara before and after collapses:

a – 29.07.2017 (the photo was taken by M.D. Dokukin); *b* – 18.04.2018 (the photo was taken by M.D. Dokukin); *c* – 20.08.2018 (the photo was taken by S.S. Chernomorets); *d* – 30.04.2019 (the photo was taken by M.D. Dokukin). *1* – contours of the collapsed rock blocks; *2* – boundaries of the zone of the rock fall; *3* – boundaries of the zone of hitting and detachment of the ice masses of the hanging glacier; *4* – the detachment line of the snow avalanche.

ison of the land photographs of the slope of Mt. Bashkara before and after the collapses of 2018 and 2019 allowed us to identify the detachment zones of the rock blocks, the dropdown zones of the rock blocks and the zones of hitting and detachment of masses of ice from the hanging glacier (Fig. 4).

Comparison of the photographs resulted in the following conclusions:

1) The summer and spring images made before the collapse of 2018 (Fig. 4, *a*, *b*) show the same contours of the hanging glacier;

2) Resulting from a rather small rock collapse of 2018, a part of the hanging glacier located above the bergschrund collapsed and the upper layer of the hanging glacier was "torn down";

3) More than a week after the rock collapse of 2018, a part of the hanging glacier collapsed (Fig. 4, *c* demonstrates the moment of ice collapse), the deposits of which covered the area of about 0.03 km^2;

4) The ice masses of the hanging glacier and the snow cover on the glacier slope collapsed not only in the zone of the impact of rock fragments but also outside it;

5) The volume of ice and of snow in the collapse mass was much greater than the volume of the collapsed rock fragments. The rock fragments falling from the height of 400 m hit the layer of the snow cover and ice of the hanging glacier on the area of about 0.03 km^2 (determined by the Google Earth measurements).

Fig. 5 demonstrates the other zones of the snow-ice-rock avalanche. Aside from the zone of the fall of the rock fragments, one can see the zone of the origin of the snow avalanche with a clear line of initiation (Fig. 5, *a*).

No deposition of the snow-ice-rock avalanche masses occurred on the steep scarp of the glacier within the range of altitudes of 2800–2880 m (Fig. 5, *b*). Above this scarp at the altitudes of 2880–2940 m there was the first accumulation zone in the glacier area up to 6–8° steep, about 400 m long and having the area of (0.092 ± 0.009) km^2.

The second accumulation zone is situated at the altitudes of 2660–2800 m in the part of the glacier more than 1 km long and 6–8° steep. The deposits are formed by several slides of various width, out of which the right slide was the largest, 70–230 m wide (Fig. 5, *c*). The marginal left slides are rather narrow (in total, up to 40 m wide) and are rather shallow grooves in the snow cover of the glacier, limited by prolonged snow banks (Fig. 5, *d*). The rock material is mostly concentrated in the frontal part of the left-side slides. The total area of the deposits left by the snow-ice-rock avalanche on Bashkara Glacier amounted to (0.44 ± 0.03) km^2.

The snow-ice-rock avalanche stopped at the distance of 450 m from Bashkara Lake (Fig. 2), the rupture of which is described in [*Chernomorets et al., 2018*]. This demonstrates that the risk of the lake rupture not only was due to a catastrophic rainfall or melting of ice or snow but also resulted from the fall of a mass of rocks into the lake. Such a mechanism is considered to have been the main one that caused the rupture of Lake Palcacocha in Peru, which resulted in the death of 5000 people in 1941 [*Carey, 2010*]. Such a possibility should be considered for other lakes, too.

The meteorological conditions of the collapse which occurred on April 24, 2019 were noted for the permanent negative temperatures. According to the data provided by the Cheget meteorological station located at the altitude of 3040 m, the maximum air temperatures in the period of April 17–25 were negative. Moreover, considering the vertical temperature gradient in the detachment zone, the air temperatures remained negative during the entire month. From April 15 to April 21, 53.4 mm of solid precipitation fell.

According to the Geophysical Service of the Russian Academy of Sciences, USGS, online catalogues and maps of earthquakes, seismic activity in the area of the collapse was not observed directly before the event.

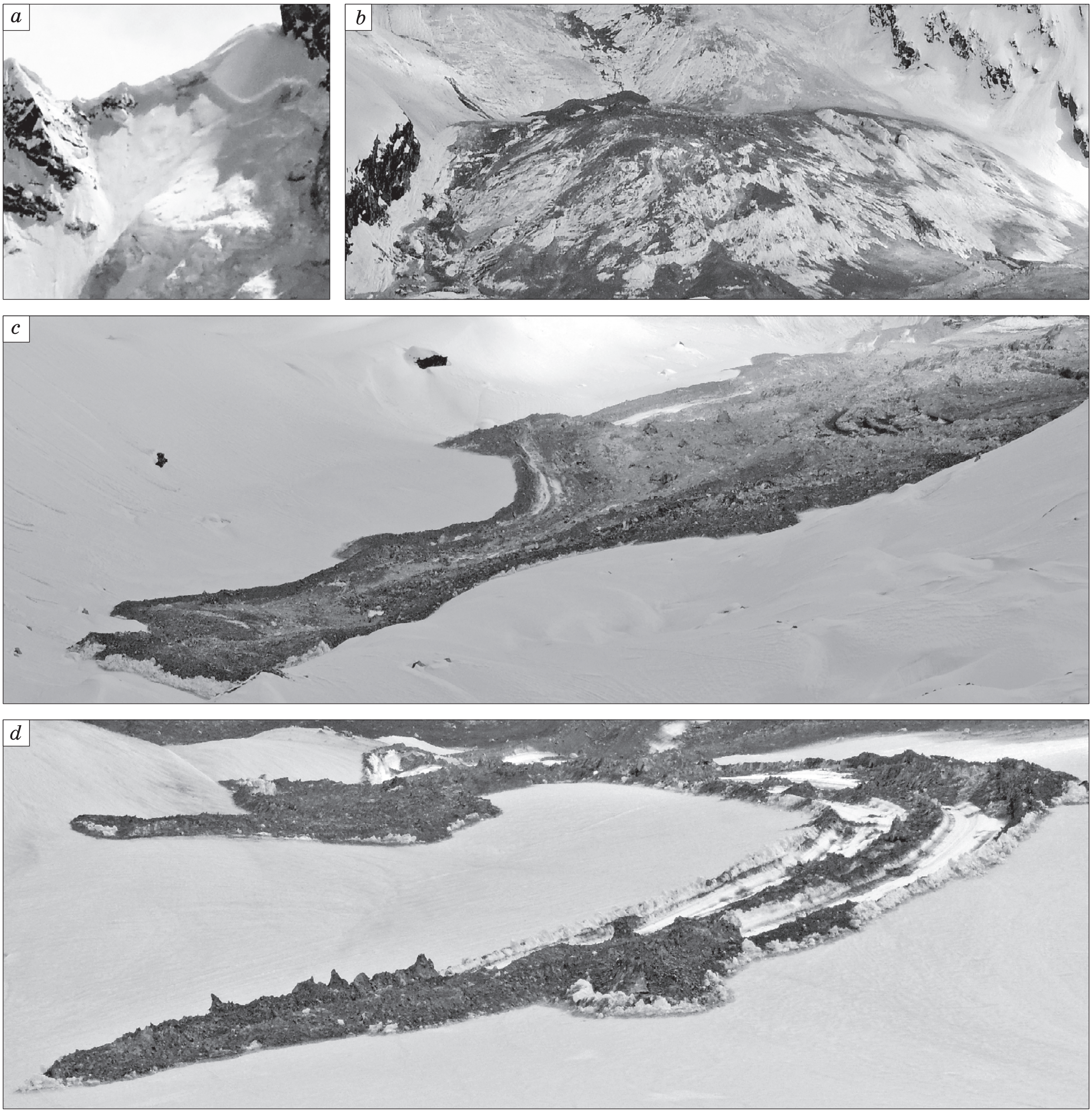

Fig. 5. Dynamic zones of the snow-ice-rock avalanche on Bashkara Glacier:

a – the detachment line of the snow avalanche outside the zone of rock fall; *b* – the transit zone in the area of the steep scarp in the range of altitudes of 2800–2880 m; *c* – the right lobe of the deposit zone; *d* – the left lobe of the deposit zone. The photo was taken by M.D. Dokukin, 30.04.2019.

CONCLUSIONS

1. The satellite monitoring of the alpine zone based on the date obtained from the Sentinel 2A satellite allowed us to detect activation of the avalanche processes in the Western and Central Caucasus over the recent years.

2. The zones of the collapse initiation reach the altitude of 3800–4000 m (a rock block broke away from Mt. Shtavler in Georgia in July 2018 at the altitude of 3830 m).

3. For the runout distance (3500 m), the area of the affected zone (0.90 ± 0.04 km^2) and the volume of the collapse mass (1.2–1.5 million m^3), the collapse on Bashkara Glacier is not the largest but it is greater than average.

4. The characteristic features of collapses in the high-mountain zone are involvement of the ice masses of hanging glaciers into the collapsed masses and transformation of the collapses into ice-rock and snow-ice-rock avalanches.

5. Collapsed deposits may affect the behavior of Bashkara Glacier, hence, the observations of the glacier will continue.

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References

Carey, M., 2010. In the Shadow of Melting Glaciers – Climate Change and Andean Society. U.K., Oxford University Press, Oxford, 273 pp.

Chernomorets, S.S., 2014. New "Kazbek Obstruction" of 17 May 2014. Nature 7, 67–72.

Chernomorets, S.S., Savernyuk, E.A., Petrakov, D.A., et al., 2016. Ice-rock avalanche and consequent debris flow in the Devdorak Gorge (Mt. Kazbek, Caucasus, Georgia) in 2014. In: Debris flows: risks, forecast, protection: Proc. IV Intern. Conf. (Irkutsk; Arshan village, Sept. 6–10, 2016). Institute of Geography SB RAS, Irkutsk, pp. 244–248 (in Russian).

Chernomorets, S.S., Petrakov, D.A., Aleynikov, A.A., et al., 2018. The outburst of Bashkara glacier lake (Central Caucasus, Russia) on September 1, 2017. Earth's Cryosphere XXII (2), 61–70.

Crosta, G.B., Chen, H., Frattini, P., 2006. Forecasting hazard scenarios and implications for the evaluation of countermeasure efficiency for large debris avalanches. Eng. Geology 83, 236–253.

Deline, P., Hewitt, K., Reznichenko, N., Shugar, D., 2015. Rock avalanches onto glaciers. In: Landslide Hazards, Risks, and Disasters. Chap. 9. Elsevier, Amsterdam, pp. 263–319.

Dokukin, M.D., Savernyuk, E.A., 2010. On the possibility of assessing the threat of rock avalanches (by the example of the valley of the Khargabakh River, Chechen Republic). Siberian J. Life Sciences and Agriculture, No. 3–4, 146–151.

Dokukin, M.D., Savernyuk, E.A., Chernomorets, S.S., 2015. Rock avalanches in the Alpine Zone of the Caucasus in the 21th century. Nature 7, 52–62.

Drobyshev, V.N., Torchinov, X.-M.Z., Tutubalina, O.V., Khubaev, H.M., 2014. Basic topogeodetic parameters and kinematics of the Devdorak landslide, May 17, 2014. Vestnik of Vladikavkaz Scientific Centre, No. 4, 30–41.

Dunning, S.A., Mitchell, W.A., Rosser, N.J., Petley, D.N., 2007. The Hattian Bala rock avalanche and associated landslides triggered by the Kashmir earthquake of 8 October 2005. Eng. Geology 93, 130–144.

Evans, S.G., Guthrie, R.H., Roberts, N.J., Bishop, N.F., 2007. The disastrous 17 February 2006 rockslide-debris avalanche on Leyte Island, Philippines: a catastrophic landslide in tropical mountain terrain. Nat. Hazards Earth Syst. Sci. 7, 89–101.

Evans, S.G., Tutubalina, O.V., Drobyshev, V.N., et al., 2009. Catastrophic detachment and high-velocity long-runout flow of Kolka Glacier, Caucasus Mountains, Russia in 2002. Geomorphology 105 (3–4), 314–321.

Haeussler, P.J., Schwartz, D.P., Dawson, T.E., et al., 2004. Surface rupture and slip distribution of the Denali and Totshunda faults in the 3 November 2002 M7.9 earthquake, Alaska. Bull. Seismol. Soc. Amer. 94 (6B), S23–S52.

Hewitt, K., 2009. Rock avalanches that travel onto glaciers and related developments, Karakoram Himalaya, Inner Asia. Geomorphology 103, 66–79.

Huggel, C., Caplan-Auerbach, J., Waythomas, C.F., Wessels, R.L., 2007. Monitoring and modeling ice-rock avalanches from ice-capped volcanoes: A case study of frequent large avalanches on Iliamna Volcano, Alaska. J. Volcanol. and Geotherm. Res. 168, 114–136.

Kotlyakov, V.M., Rototaeva, O.V., Nosenko, G.A., 2004. The September 2002 Kolka glacier catastrophe in North Ossetia, Russian Federation: evidence and analysis. Mountain Res. and Development, No. 24, 78–83.

Legros, F., 2002. The mobility of long-runout landslides. Eng. Geology 63, 301–331.

Lipovsky, P.S., Evans, S.G., Clague, J.J., et al., 2008. The July 2007 rock and ice avalanches at Mount Steele, St. Elias Mountains, Yukon, Canada. Landslides 5, 445–455.

Petley, D., 2019. Bashkara Glacier: a major rock avalanche in the Caucasus last week. – URL: https://blogs.agu.org/landslideblog/2019/04/30/bashkara-glacier-1/ (last visited: 17.05.2019).

Petrakov, D.A., Tutubalina, O.V., Chernomorets, S.S., 2004. The 2002 Genaldon glacial catastrophe: one year later. Kriosfera Zemli (Earth's Cryosphere) VIII (1), 29–39.

Petrov, M.A., Sabitov, T.Y., Tomashevskaya, I.G., et al., 2017. Glacial lake inventory and lake outburst potential in Uzbekistan. Sci. Total Environ. 592, 228–242.

Rezepkin, A.A., Popovnin, V.V., 2018. Influence of the surface moraine on state of Djankuat Glacier (Central Caucasus) by 2025. Led i Sneg (Ice and Snow) 58(3), 307–321.

Shang, Y., Yang, Z., Li, L., et al., 2003. A super-large landslide in Tibet in 2000: background, occurrence, disaster, and origin. Geomorphology 54, 225–243.

Sosio, R., 2015. Rock-snow-ice avalanches. In: Landslide Hazards, Risks, and Disasters. Chap. 7. Elsevier, Amsterdam, pp. 191–240.

Tielidze, L., Kumladze, R.M., Wheate, R., Gamkrelidze, M., 2019. The Devdoraki Glacier Catastrophes, Georgian Caucasus. Hungarian Geograph. Bull. 68 (1), 21–35.

Tutubalina, O.V., Chernomorets, S.S., Petrakov, D.A., 2005. Kolka glacier before the 2002 collapse: new data. Kriosfera Zemli (Earth's Cryosphere) IX (4), 62–71.

Wei, F., Chernomorets, S., Aristov, K., et al., 2010. A seismically triggered landslide in the Niujuan valley near the epicenter of the 2008 Wenchuan earthquake. J. Earth Sci. 21 (6), 901–909.

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