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RECENT GLACIER SURGES IN THE WESTERN PARTS OF PETER THE FIRST RIDGE (PAMIR)

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Analysis of the glacier surges during 2015–2020 in the western parts of Peter the First Ridge, Pamir, is carried out based on the interpretation of images taken from the International Space Station, as well from Landsat, RapidEye and Sentinel satellites. It is established that massive ice blocks' breaking off from glaciers and their rapid descent down the valley is not unique for that region. The damage caused to human economic activity as a result of the investigated glacier surges is described. Periods of pulsation of some glaciers are determined.

Key words: *glacier surge, pulsating glacier, Didal Glacier, Surkhob, Vayzirek, Peter the First Ridge, satellite image.*

INTRODUCTION

Surging glaciers, also known as pulsating or surge-type glaciers, are a fairly formidable natural phenomenon and occupy a special place in glaciology, but remain largely understudied. Among mid-latitude mountain regions, surging glaciers are most common in the Pamirs, where they were investigated by the IG RAS researchers (Institute of Geography of the Russian Academy of Sciences). Results of their study were successfully applied as *Directions for compilation of Inventory of surging glaciers of the USSR* [*1982*]; the map of surging glaciers of the Pamirs (1983) which was made part of the *Atlas of Snow and Ice Resources on the Earth* [*1997*]; *Inventory of surging glaciers of the Pamir* [*1998*]. In recent years, this topic has received much interest from foreign scientists as well [*Mölg et al., 2018; Goerlich et al., 2020*].

One of the first and most intriguing glacier surges studied in the Pamirs by the Russian glaciologists occurred in 1974. The implications of the actively advancing Didal glacier during the summer of 1974 were that a ~600 m long fragment broke off from its tongue which travelled a distance of 3 km down the valley. The surging was accompanied by a discharge of large amounts of water which destroyed the bridge in the lower part of the valleys [*Rototaev, 1974; Suslov, 1974*].

Such natural phenomena involving detachment of huge portions of mountain glaciers and their fast moving downhill occur fairly regularly in different parts of the globe, which can be exemplified by the events documented for Kolka (1902 and 2002) [*Kotlyakov et al., 2014*], Allalin (1965) [*Dolgushin, Osipova, 1982*], Ravak (1967) [*Dolguschin, Osipova, 1982*], and Aru (2016) glaciers [*Gilbert et al., 2018*]. Published literature also contains a few mentions of the evidence of ice masses likewise shearing away in the past in Pamir valleys [*Rototaev, 1978*]. The question as to whether they are inherent in the Pamir surging glaciers and how frequently they occur is therefore of great interest. This requires observations on the patterns of after-surge motion for the glaciers with confirmed surges, as well as on the dynamics of glaciers that were so far not marked by surges.

Despite the established fact that glaciers surge with some periodicity, this phenomenon is interpreted as long-term, with its cycle commonly spanning several decades. Although surging glaciers have been monitored in Russia since the 1960s, sufficient data have not yet been accumulated. However, several intriguing natural events reported from the Pamir Mountains in recent years, have largely contributed to the existing knowledge of surge-type glaciers for deeper study of the issues posed.

With this paper, we begin a series of publications to provide an overview of glacier surges in the Pamir Mountains since 2001.

BRIEF CHARACTERIZATION OF STUDY REGION

The investigated glaciers are located on the northern slope of the Peter the First Ridge in the western Pamirs, a generally east-west trending mountain range. Although the highest peak rises to 6785 m (Moskva Peak) in its eastern part, the heights of this mountain range are generally lower and measure from 3800 to 5400 m (Fig. 1) within the study area.

Peter the First Ridge branches into two subordinate ranges in the area occupied by the eponymous glacier. All glaciers investigated by the author are located on the northern slope, while they belong to the basins of two different rivers: Surkhob (glaciers numbered 504, 505, 506, Didal) and Obikhingou (glaciers 85 and 88). These rivers subsequently merge, to

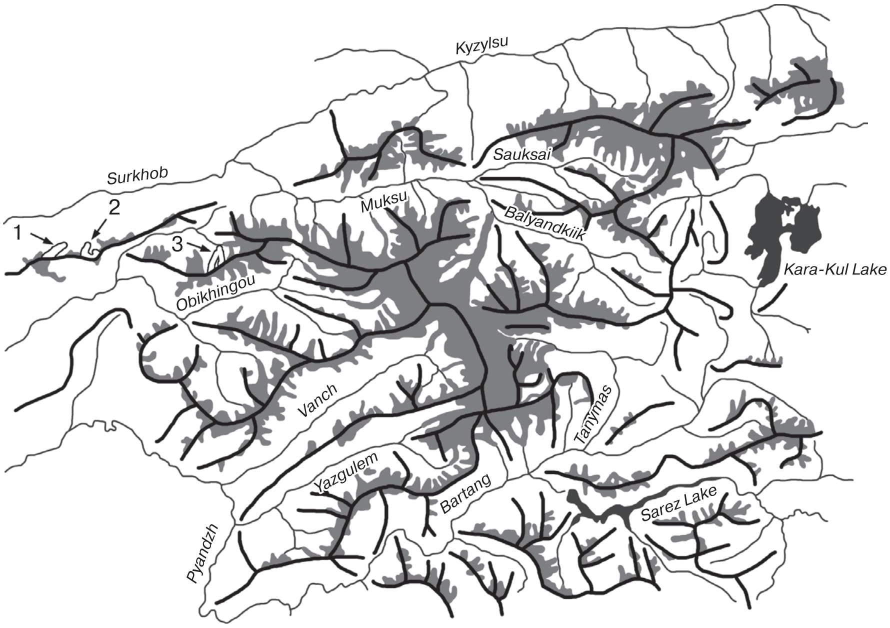

Fig. 1. Schematic view of Pamir glaciation and locations of the studied glaciers.
1 – Didal Glacier; 2 – group of glaciers 504–507; 3 – glaciers 85, 88.

form the Vakhsh River (one of the elements of the Amu-Darya River).

The slopes of the mountain range dipping towards the Surkkhob River that runs parallel to it from the north, are very steep (ca. 3 km) at a distance of 12–15 km. The outflowing streams' valleys commonly form narrow gorges (V-shaped valleys), while those extending from the southern chain of the mountain range towards the Obikhingou River are generally with broader and flatter floor (U-shaped valleys); the elevation difference and relief dissection are also remarkable there.

There are no weather stations in the area embracing the investigated glaciers. The two stations in the Surkhob and Obikhingou valleys are located at a considerable distance from the glacier entities under study and at lower hypsometric levels, so that one can count them out.

DATA PROCESSING METHODS

Since 2001, the Institute of Geography RAS, have been partnering with the Rocket and Space Public Corporation (RSC) Energia in carrying out the Uragan space experiment consisting in observations and photographing the Earth's surface from the Russian Orbital Segment (ROS) of the International Space Station (ISS). The experiment results largely underlie this work. We also used images obtained from several remote sensing satellites, topographic maps of scales 1:100 000 and 1:50 000, and data from the *Inventories of the USSR glaciers* [*1971, 1978*] and of *Inventory of surging glaciers of Pamir* [*1998*].

The ISS-produced images taken in the visible part of the spectrum have a spatial resolution of up to 5 m and encompass a time period of the past 20 years. This makes them appropriate for dynamics analysis of natural objects (glacier entities). The Global Mapper software enabled geographically aligned image rectification, as well as delineation of glaciers contours and allowed measuring distances between key points on the surface. The measurement error is not more than 10 m.

Images from a number of international Earth remote sensing satellites have recently become available free in the public domain. This paper uses a time series analysis of Landsat, Sentinel-2, and RapidEye imagery with a spatial resolution of 15, 10, and 7 m, respectively. Given that declassified high-resolution data contain images only after 2016, they were used as a minor resource (i.e. do not provide a sufficient variable image coverage). These images were processed with the ArcGIS, a GIS software suite.

Not all of the images available for the analysis, had the required brightness and contrast characteristics. For more distinct delineation of the glacier fronts and surface morphology, many images were processed using IrfanView software capable of viewing and editing most graphics formats.

Satellite images remarkably document changes in glacier extent, however with some discreteness. It is therefore not always possible to determine the exact date and timing of simultaneous events. In such cases, one needs to specify a time period at the beginning of which the event has not yet taken place, whereas at the end, it is interpreted as post-event with its impacts already manifested.

We have also analyzed open-source meteorological and earthquake data for the area. The former show no significant time-specific variations as compared to the mean annual values, while the weather stations available in the study area are located at a considerable distance from the investigated glaciers, at completely different hypsometric levels. Since the latter (earthquake data) suggest the absence of remarkable events within a radius of several hundred kilometers during the investigation period, they were therefore rejected from this analysis.

Didal Glacier surges in 2015–2016

Didal Glacier is located on the northern slope of the Peter the First Ridge, and is related to the group of glaciers on the left side of the Surkhob River valley. This is a complex valley glacier exposed to the northeast, and is numbered 513 in *Inventory of USSR Glaciers* [*1971*]. The glacier meltwater forms the headstream of the Dara River.

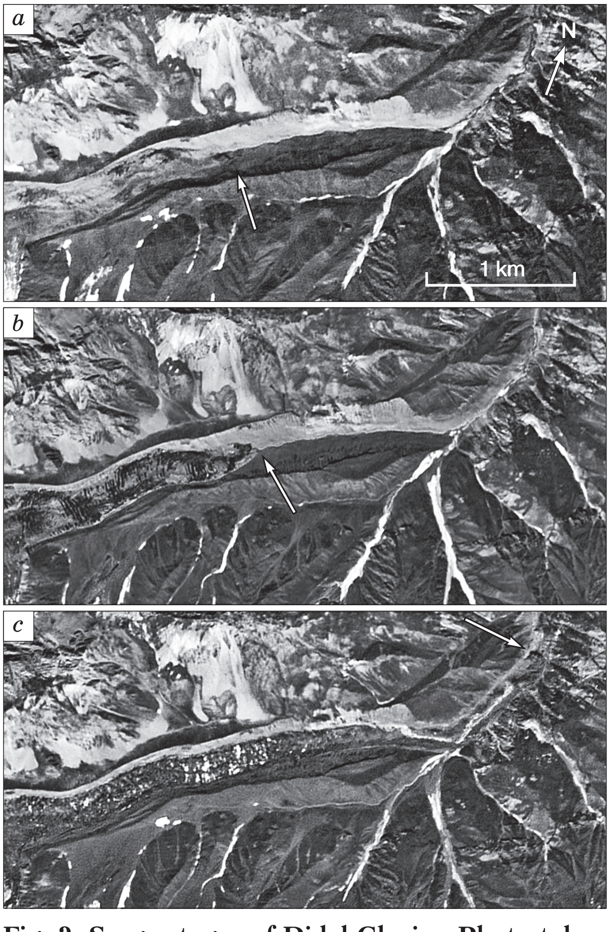

Fig. 2. Surge stages of Didal Glacier. Photo taken onboard the ISS.

a – August 2014; *b* – August 2015; *c* – July 2016. The arrows show the position of the lower end of the tongue.

V.I. Lipsky [*1902*] in his observations of the glacier during the 1897 expedition, marked visible signs of a recent surge (e.g., highly crevassed glacier surface and "terrible snowslide"), which can be interpreted as analog of the 1974 surges. Different sources suggest that yet another glacier surge occurred in 1929 or 1939 [*Inventory..., 1998*]. The 1974 glacier surge accompanied by detachment of a portion of the glacier terminus and its moving rapidly down the valley was discussed in [*Rototaev, 1974; Suslov, 1974*]. The surge left the glacier terminus largely shrunk (in 2014, the glacier had a length of 3350 m, its terminus elevation was 3060 m asl). Considering the surge pattern and the hazard that may ensue (in the case of repeated events) for the infrastructure located in the valley downstream, the author conducted systematic satellite imagery-based monitoring of the glacier changes.

While the glacier gradually recovered from the surge of 1974, there were no remarkable signs of its changes until 2015. The surface of the moraine material covered the glacier tongue was generally levelled with lateral moraines; its ice had locally developed sinks.

Changes became explicitly discernible early in the summer of 2015. The volume of ice dramatically increased in the middle portion of the tongue, with a salient boundary suddenly appeared between the activating region (surge wave) of the glacier and the region remaining quiescent, i.e. dead (material from a previous surge) stagnant basal part with a length of about 500 m. While rare large transverse crevasses became visible in the activating region, most of the surface was still relatively smooth and continued to be buried under a layer of dark surface moraine.

By August, the front of the glacier activating part had been distinctly outlined, while its surface became chopped into blocks and was lighter in color. By September, the front of the activating region had reached the lower line of the tongue position; the glacier had thus began advancing forward. It moved intensely during the autumn and winter, while in February–March 2016 some slowdown was observed. In April the movement accelerated again, and by June the surge front had reached its ultimate position. Didal Glacier advanced down the valley to a distance totaling 1950 m, at an average rate 7.2 m/day (Fig. 2). The glacier terminus came to a standstill at an elevation of 2550 m asl.

As such, the glacier advancement is referred to as classical. There was nothing which would remind of the glacier's front portion detachment reported in 1974.

The data on the surges of 1897, 1929 (or 1939), 1974 and 2016 allow determining the intervals between them, as follows: 32 (42), 45 (35) and 42 years.

One can only wonder how often Didal Glacier surges follow the 2015–2016 classical scenario or the 1974 scenario. According to the global statistics of the study of surging glaciers, the phenomenon of a head part separation and its rapid descent down happen extremely rarely. However, the events which occurred almost synchronously with the above discussed Didal Glacier surges, have shown a great similarity with those reported from the Dara River valley in 1974 in its immediate vicinity.

Surges of glaciers No. 504, 505 and 506 during 2016–2019

The Vostochny Shurak (aka Shuraki Kapali) River valley located 8–10 km to the east of the Dara River valley and Didal Glacier is also attributed to the Surkhob River basin and is seated on the left slope. The three small-sized unnamed glaciers in the upper part of the valley are numbered 504, 505 and 506 in the glacier inventory. These are exposed to northwest, north and northeast and have areas of 0.3, 0.3 and 0.2 km^2, respectively [*Inventory..., 1971*]. Slightly further down the valley, glacier 507, the largest among them, comes out of the valley on the left. The literature sources contain a mention of its internal surge in 1949 [*Inventory..., 1998*]. However, no surging activity of glaciers 504, 505 and 506 has hitherto been mentioned in published literature.

Above glacier 507, the valley structure is described as trough-like. At the point of the glacier debouch into the valley, the latter slightly expands, and almost immediately passes into a narrow canyon. As the valley approaches its mouth, it widens again. The confluence of the Vostochny Shurak and the Surkhob rivers occurs in the western part of the Tajikobod district center.

Glaciers 504 and 506 are valley glaciers, while glacier 505 is corrie-hanging glacier. The dimensions specified in [*Inventory..., 1971*] (from aerial photography 1956) for the glaciers (No.) are: 1.0 km (504), 0.6 km (505) and 0.8 km (506). Analysis of satellite images showed that the glaciers length gained by the by 2015 was 450 m and 120 m for No. 504, 505, respectively, while the length of glacier No. 506 remained unchanged.

At the beginning of June 2016, one could observe the left part of the tongue of glacier 505 (250 m long) breaking off and slowly sliding down the slope. In a month and a half, its front part advanced by 160 m and lost 50 m in height. A time period spanning the latter half of July, specifically, between the 15th and 24th (it was impossible to determine the more precise timing), is referred to as the onset of rapid advance of the detached mass of ice down the valley. After running out 2.5 km, the masses approached the valley widening, opposite the glacier 507 outlet on the left, where a major portion of the discharged mass spread out taking the shape of a "snout". However, a small portion sheared away from the masses and slid down the river canyon as a narrow body (1220 m long and 80–90 m wide). The distance between the upper boundary of this body and the descended, already motionless, masses is about 450 m.

The lower edge of the bulk masses ("snout") has advanced by 3650 m from the former lower elevation point of the glacier. Thus, the cumulative advance down the valley totaled 5320 m (Fig. 3).

Ice that came downhill was highly fractured and heavily laden with rock debris. During the first month after the surge, the surface-exposed ice soon became compacted, and the surface smoothed out and totally moraine-covered.

A year later, in early July 2017, glacier 504 likewise started moving. However, given that it was larger than glacier 505, the magnitude of surges was greater. Almost the entire 1280 m long tongue broke away and slid downhill. At the end of May, the tongue surface elevation remarkably rose which was followed by enhanced crevassing. The upper boundary of the

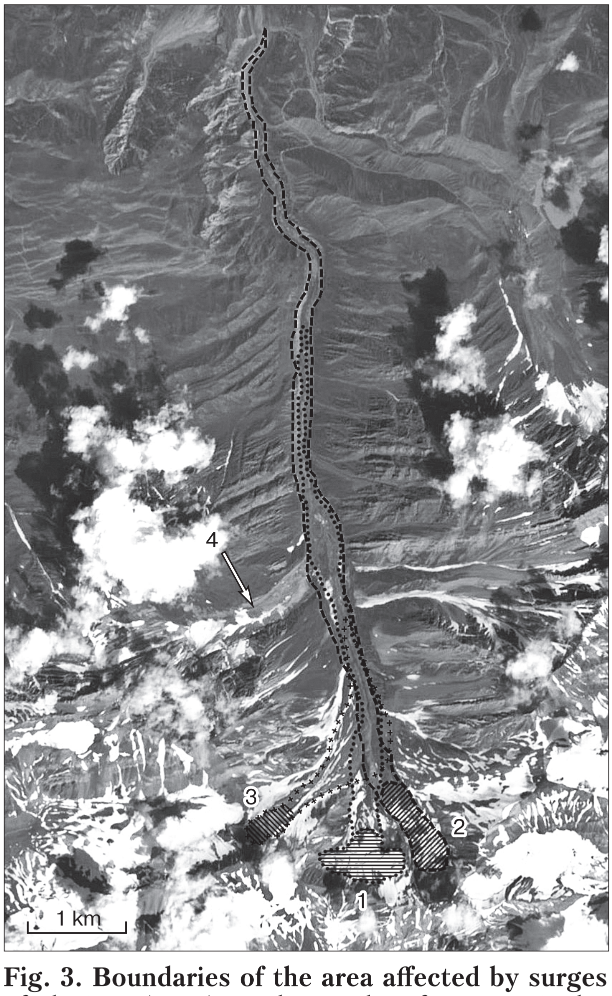

Fig. 3. Boundaries of the area affected by surges of glaciers 504–506. Photo taken from Sentinel-2 satellite, 2017.

1 – glacier 505 in 2016; 2 – glacier 504 in 2017; 3 – glacier 506 in 2019; 4 – glaciers 507. The striated areas were occupied by glaciers before the described events.

Fig. 4. Near-mouth zone of the Vostochy Shurak River. Sentinel-2 imagery.

a – June 2017; *b* – August 2017.

surge zone transpired as rare large crevasses developing from one side to the other, across the entire glacier's width. Over a month time, significant mass transfer occurred from the back of the tongue to its front, and the front of the glacier has moved forward to a distance of 180 m along its length, losing 40 m in height. On July 11, the active surge was succeeded by another phase: the ice came down in dramatic fashion. The traces of the previous descent of glacier 505 described above were therefore blocked, and formed an identical snout at the same place of the valley widening. A significant portion of the ice which, similarly to the previous year, passed through the narrowing down the valley, however, this time, it has advanced further without detaching from the snout residing on higher elevation and extending as a single tongue.

The Vostochny Shurak River canyon was filled with ice almost to the brim. The ice moved downstream to a distance totaling 7840 m. A small ice-dammed lake (~11,000 m^2) formed in the contact zone between the descended ice and the tongue of glacier 507. A month later, the water found its way and discharged through a natural conduit leaving the lake completely drained and, ultimately, nonexistent.

During first post-surge days, the material making up the snout abounded with rock debris was already dark in color. However, the surface of the tongue that descended beneath it was very light in color at first, which suggests that it was largely composed of loose ice. In a month's time, it darkened, the surface subsided considerably because of the ice rapidly melting, and soon became rock debris-covered.

While the previous year's surge-related hazards practically did not affect the infrastructure located in the lower part of the Vostochny Shurak River valley, the 2017 events' impact was measurable. In last 2 km upstream of the Vostochny Shurak River confluence with the Surkhob River, it flows in the cultivated margin between the fields of Tajikobod district. The ice-rockslide-avalanche event in the upper reaches of the valley released considerable amount of water, which strongly affected the river banks. Comparison of images taken in June and August 2017, i.e. before and after the event, has shown that the width of the Vostochny Shurak River bed has more than doubled in its mouth area. As many as 20.5 hectares of fertile land (Fig. 4) and several buildings have been destroyed or partially washed away.

The third stage of the aforementioned events occurred late in June 2019. This time round, the process affected glacier 506, at a much more moderate scale, though. In the period from June 24 to 26, its ice descended down the valley only by 1300 m, thus failing to approach glacier 507. A mudslide flowed down a lower slope, without severe impacts. Unfortunately, cloud screening of the satellite image precluded a detailed reconstruction of this event.

At the end of the summer of 2020, masses of glacier 504 which came down three years earlier, became compacted. The tongue that descended through the river canyon to rest below glacier 507, in a severely degraded state, its lower edge has receded 1300 m from the July 2017 outlines. Waters of the Vostochny Shurak River carved their way through the ice. Its channel's arches locally collapsed, forcing the river to come onto the surface. In 2 or 3 years' time, one should expect a breakup of what is presently interpreted as a single body into separate parts and their rapid disappearance.

The question as to whether the above mentioned events represent a random and unique combination of natural controls for this valley or whether they occur with some periodicity remains open. Given that the systematic monitoring of glaciers in the Pamirs covers mainly the central and eastern (more expressly glaciated) areas, published literature provides no mention (descriptions) of earlier comparable surges. Besides, obtaining regular images with high level of definition was problematic until recent times, therefore the researcher would simply miss out on the signs of such processes.

At this, a number of indirect indications confirm this event to be not one-off. These include: the satellite image taken in 2008 clearly showing traces of mudflow mass transfer from the upper reaches of the valley towards glacier 507 and passing it by on the right side. However, the absence of evidence of any significant mass transport may suggest that a mass wave that came down either was small in size and short-lived (i.e. ice could have already melted), or that initially it was rock-debris laden mudflow, rather than ice.

Also worth nothing is that the image taken in July 1976 from a helicopter (Fig. 5) shows the upper reaches of the valley from glacier 507 (debouching from the gorge to the right of the observer) and above; large dark mass exactly at the place where the snout formed in 2016 and 2017. The extents of glaciers 504 and 505 are found to be lesser, as compared to what they were in 2015, before the initiation of the latest surges. Glacier 506 is poorly visible due to the slope bend. The volume of material that mantle the valley bottom can be interpreted as slope or mudflow deposits, however we find the inference about this to be ice that had previously descended more appropriate. Given that several glacier reservoirs overlap these deposits, the material removal occurred earlier than 1976.

In the upper reaches of the valley, geomorphological traces of the past hypothetical events, if they existed, were destroyed in 2016–2017. Although the Vostochny Shurak River mouth zone, specifically, on its left bank, exhibits discernible traces of ancient watercourses (Fig. 4), one can hardly claim these to be remnants of a mudslide similar to the one occurred in 2017. In equal measure, they can be associated either with floods caused by heavy rains, or with a gradual displacement of the main stream bed to the right.

Surges of glaciers 85 and 88 in 2013–2017

The space between the two branches (northern and southern) of the Peter the First Ridge is occupied by the Vaizirek River valley, a tributary of the Shaklysu River. These rivers belong to the Obihingou River basin, with the Aizirek River feeding from Peter the First Glacier. Almost immediately (1 km down the headstream), a leftward side valley merges with it perpendicularly and is divided into two branches 2 km upstream. They accommodate two unnamed glaciers referred to in [*Inventory…, 1978*] as glacier 85 (eastern) and glacier 88 (western). Until relatively recently (late in the 19th century), they were an integrate part of Peter the First Glacier, however later separated from it contemporaneously with retreat of the majority of Pamir glaciers.

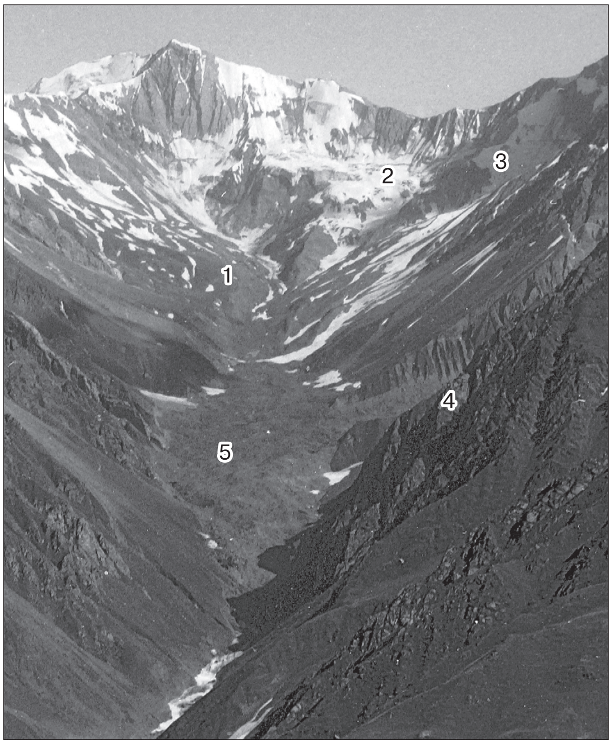

Fig. 5. Upper reaches the Vostochy Shurak River valley in 1976.

1 – glacier 504; 2 – glacier 505; 3 – glacier 506; 4 – debouch of glacier 507 into the valley; 5 – ice avalanche descended from higher elevations. Photo by V. Rudakov.

These are valley glaciers generally exposed to the north. Their lengths are 8.1 km (glacier 85) and 6.6 km (glacier 88), and their areas are 4.6 and 3.7 km^2, respectively [*Inventory…, 1978*].

Both of the glaciers are interpreted as surging. Glacier 88 advanced in 1975–1978, leaving a 480 m space to the Vaizirek River [*Desinov, 1984*]. Surging activity of glacier No. 85 was reported for 1990–1992 [*Inventory…, 1998*], catching up with the Vaizirek River and the opposite side of its valley, thus blocking the river with an ice-dam. At this, however, no ice-dammed lake was formed, most likely because the glacier approached the river at the waning stage of the surge (i.e. the energy of motion has largely declined and its speed lowered), thus allowing the waters of the blocked river to escape.

From that time on and until 2013, the glaciers had been degrading. The Vaizirek River was freed from the “glacial ice roof” only in 1999. By 2013, the lowest glacier points had been distanced from the Vaizirek River by 2050 m (glacier 85) and 2820 m (glacier 88).

In 2012, a surge wave was reported from glacier 88. At that time, it was documented 4360 m from the Vaizirek River and 1540 m from the lowest glacier point. In 2013, it approached the glacier terminus, and the glacier began to advance in December, preceded with its steep and remarkably expressed front.

Glacier 88 was advancing forward in the year of 2014. By August, it had reached the zone of confluence of with the glacier 85 valley and began to encroach onto its highly down-wasted thin tongue which still remained in this place after the previous surge. In October, glacier 88 reached the opposite (right-hand) coastal moraine. By that time, the advance amounted to 1310 m at an average rate of 12 m/day. However, after October, the movement decelerated to a few first meters per day, and the glacier

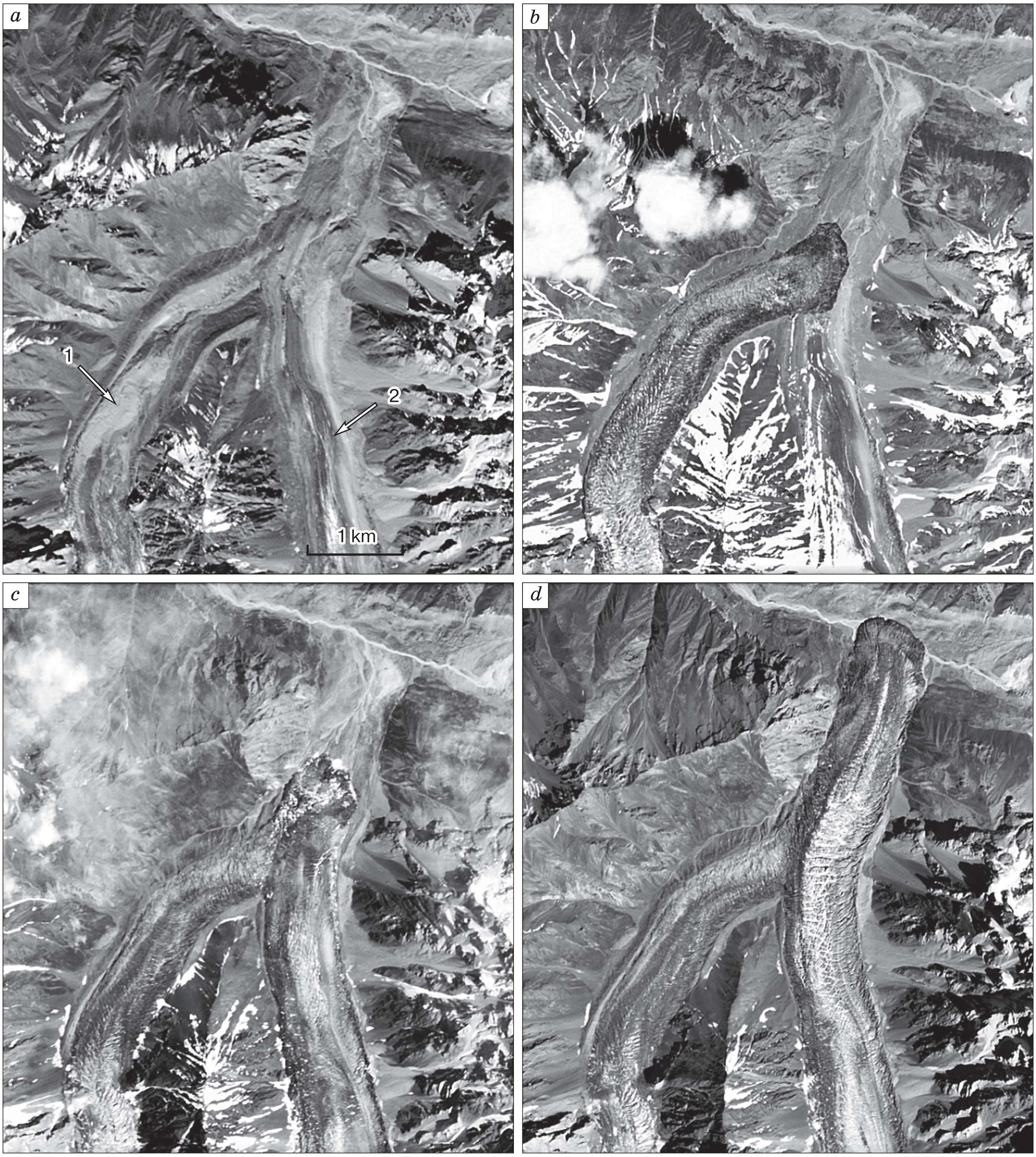

Fig. 6. Surge stages of glaciers 85, 88.

a – September 2013; *b* – July 2015; *c* – August 2016; *d* – August 2017. *a*, *d* – RapidEye imagery; *b*, *c* – images from the ISS. 1 – glacier 88; 2 – glacier 85.

flowed down the valley for another 370 m, with its front spreading out as a snout. By April 2015, the glacier advance had been arrested.

Thus, independent advance of glacier 88 was 1680 m, the surge front stopped at 1140 m from the Vaizirek Rv.

Shortly before that, signs of activation of glacier 85 became noticeable. In late autumn 2014, the activation front was remarkably identifiable and at that time located 850 m above the contact between the degrading tongue of glacier 85 and the advancing glacier 88. By September 2015, the activating part had reached the contact zone, while ice, having encountered a dam made up by glacier 88 that arrived six months earlier, began aggrading in its front to form a swell extending across the valley. In December, glacier 85 broke the dam's resistance by finally succeeding in setting it in motion and began to descend down the valley, pushing the ice of glacier 88 in its front.

Importantly, during the surge of glacier 88, its tongue had a classical appearance for this phase (i.e. ubiquitously crevassed, chopped into blocks), while at the post-surge phase (the spring of 2015) its tongue surface gradually became smooth out and covered with moraine material, thereby suggesting the glacier to have passed into the recovery stage. Therefore, further lowering of the glacier's basal part (its former snout) was driven by the energy gained from the surge of glacier 85, rather than by its own energy. This means that glacier 85 being in its active phase, moved the lower terminus of the neighbor already in its quiescent phase (Fig. 6).

During 2016 and the first half of 2017, glacier 85 continued its advancement. Like a bulldozer, it moved the ice of glacier 88 in its front, gradually shifting it leftwards. By January 2017, the masses reached the Vaizirek River, and the opposite side of the valley at the end of February. The Vaizirek River became again blocked, however without formation of ice-dammed lake, similarly to the previous surge. While the glacier terminus has practically stopped there, however, until August 2017, ice masses continued to aggrade and bulge in the frontal part, thereby gradually increasing its elevation. The glacier position of 1992 were restored, with the previous surge coming to an end. Although it should be noted that this time the valley was filled not only by its ice: a strip about 100 m wide on the left side of their common valley and an arc up to 150 m wide in the frontal part were composed of the material transferred by glacier 88.

Counting its ice alone, glacier 85 has advanced by 1900 m, and by 2050 m with adding up the ice of glacier 88. The maximum speed of movement documented in the autumn of 2016 amounted to 9 m/day.

The onset of glaciers degradation is evidenced primarily by first sinks appeared in the "ice roof" over the Vaizirek River in the summer of 2019, although its integrity remained generally preserved during the summer of 2020. It is obvious that the river will be completely freed only in a few years' time, and the glaciers will be gradually retreating until they become separated at their valleys confluence.

Thus, glaciers 85 and 88 have been jointly surging for more than 5 years. Individually, the surge periods lasted 25 and 37 years for glacier 85 and 88, respectively.

CONCLUSION

The satellite monitoring data have shown that glacier surge-driven detachment of a glacier portion and its rapid descent down the valley is not unique for the northern slope of the Peter the First Ridge. Based on numerous literature mentions of the indications of similar phenomenon in other regions of the Pamirs, one can make a preliminary inference about such scenario being widespread in this mountain system. Given the paucity of observations, a final conclusion can hardly be expected about the combination of surge-driving factors. Note that all the glaciers described in this paper surged during the summer when the content of free water in the ice column is explicably enhanced. However, the question whether this is the only appropriate factor is debatable. The slope steepness of the Peter the First Ridge and geology of the underlying surface may also make difference.

Evidences of surging activity were noted for three glaciers (numbered 504, 505 and 506) of the Surkhob River basin. Repeated surges were documented for glacier 513 (Didal), which also belongs to the Surkhob River basin; the latest surge allows estimating the surge period as 35–42 years. For the two glaciers (85 and 88) of the Obikhingou River basin, surges were reported repeatedly, thereby enabling estimation of their surge periods, as follows: 25 years for glacier 85 and 37 years for glacier 88.

Since the studied surges of ice masses can lead to catastrophic consequences and significant damage to economic activity, additional research is needed to identify a complex of factors that can cause such developments. Besides, this requires regular monitoring of the upper reaches of mountain valleys for the sake of early warning of the population. This issue appears the more so salient despite the fact that no connection with the weather factors has thus far been revealed, since it is highly likely to exist and to be recognized with longer series of observations. In the context of global climate warming, the latter may affect the area of a glaciated region to the extent that saturation of the glacier body with water during the summer will enhance, thus making probability of a surge higher.

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