Mapping Features of Fedchenko Glacier, the Pamirs, Central Asia from Space

宇宙から見た中央アジア，パミールのフェドチェンコ氷河の特徴

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キーワード：氷河流域形態，複合流域谷氷河，末端変動，サージ，流域争奪

要旨

さまざまなインターネット情報，とくにGoogle Earthの立体画像やGoogle Mapの等高線地図によってフェドチェンコ氷河の地形特徴を明らかにできるようになった。これらの情報と1970年代のソビエト陸軍の地図（1:100,000）を用いると，ロシア語圏以外の人々にはあまり知られていないフェドチェンコ氷河の氷河地形学的側面が理解できる。フェドチェンコ氷河はパミールの北西部の山岳地にある長さ77 ㎞の巨大な谷氷河で，偏西風によって大西洋からの湿気によっておもに冬に涵養される。フェドチェンコ氷河は革命峰（6,940 m）の西側斜面の海抜5,400 mから始まり北に流れ高度 2,900 mの末端で終わる。氷河下流区間（末端から30 ㎞まで）は表面岩屑に覆われた細長い氷舌で，中流区間（30 ㎞地点，高度4,050 mから45 ㎞地点，高度4,500 mまで）は南東から北西に流下し多くの支氷河を合わせる。中間地点の最上部の右岸には，氷河本流が東側にあふれ出し小規模な氷舌（タヌィマス末端）を形成している。上流区間（45 ㎞から流域上端まで）は，非対称形である。右岸側には革命峰を含む6,000 m級の山塊になっているが左岸側には顕著な高まりがなく，氷河に覆われた緩やかな分水界を経て，南西側の谷氷河へと通じている。氷河の上流区間を含む流域は小規模な氷原，または横断型氷河系を形成しているが全体としてみると，フェドチェンコ氷河は谷氷河である。氷河下流区間で本流に接しているビバーク氷河（パミール最高峰イスモイル=ソモニ，7,495 mがある）では，繰り返し氷河サージが起こっている。人工衛星画像の比較によれば，1990年代以後のフェドチェンコ氷河の末端の縮小はおこっていない。氷河変動の状況はカラコラム山脈の大型氷河とよく似ている。フドチェンコ氷河がこのような大きな氷河にまで発達したのは氷河侵食による流域の争奪が起こったからと考えられる。

Ⅰ．Introduction

The Pamirs in eastern Tajikistan are called the roof of the world. Those rooftops are capped with numerous glaciers. Fedchenko Glacier is the greatest of them in the Pamir, and is called by various superlative expressions such as “the world’s largest”（Table 1）. Although Fedchenko Glacier is extremely well known, its actual features are not known except in Russia because most literature related to the glacier is written in Russian.

Recent great advantages for conducting geomorphological and geographical works are attributable to the development and accessibility of satellite information such as Google Earth and Google Maps. Google Earth 3D images are mosaic of satellite images which shows vertical and bird’s-eye views in various scales and Google Map Terrain is a global map with 20-40 m interval contours. They are useful tools for preliminary surveys of unknown terrain and glaciers such as the Pamirs and Fedchenko Glacier. The satellite images used in Google Earth and Google Map were taken in recent

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Table 1. Expressions of the superlative degree on Fedchenko Glacier.

The largest glacier in Eurasia	Kotlyakov et al., 2008
The largest mountain glacier in the world	Froebrich et al., 2008
The largest alpine dendrite glacier in the world	Aizen et al., 2009
The longest and deepest alpine glacier in the world	Aizen et al., 2009
The largest valley glacier in the world	Yahoo! Encyclopedia (in Japanese)
The longest glacier in the world outside of the polar regions	Wikipedia 09/04/26

2–3 years so that they provide recent details of glaciers. Moreover, Japan Aerospace Exploration Agency (JAXA) has presented images and explanations of Fedchenko Glacier on its website (JAXA, 2006a, b). The author believes that the Pamirs are a convenient area for elaboration of satellite mapping because of the large glaciers and favorable weather conditions because of the many cloud-free days in summer, as emphasized by Kotlyakov et al. (2008). This special issue a fitting occasion to present data from preliminary mapping and investigations of Fedchenko Glacier obtained using satellite information to describe some notable and interesting features of Fedchenko Glacier's geomorphology.

Ⅱ. The Pamirs and Fedchenko Glacier

1. Mountain ranges and glaciers

The Pamirs are a rough mosaic terrain comprising high-mountain ranges and high basins, forming a node of complex mountain chains in the central Asian highlands (Iwata, 2008). The western half of the Pamirs is a system of mountain ranges with predominantly east-west extension cut by deep, narrow valleys. High mountains are covered with snow and ice; in the mid-1970s, 6,730 glaciers (7,493 km^2 total area) were identified in the Pamirs (Kotlyakov et al., 2008). The major glacier-covered areas are concentrated in the middle section of the Zaalaysky range (Trans Alai range) and the Akademiya Nauk range (Academy of Science range). Fedchenko Glacier, more than 70–77 km long and with 650–990 km^2 area (Table 2), is the largest glacier not only in the Pamirs, but also in the Asian High Mountains. Several glaciers over 50 km long, rivaling the Fedchenko Glacier, exist in the Karakoram Mountains. All of these glaciers–Siachen, Baltro, Biafo, Hispar, and Batura–are situated in longitudinal valleys parallel to the mountain axes. Fedchenko Glacier, however, lies at right angles to the extension of mountain ranges, and mountain ranges on both sides of the Fedchenko Glacier are discontinuous (Fig. 1). The Akademiya Nauk range, which contains the highest summit in the Pamirs, Ismoil Somoni 7,495 m, is the only remarkable range running parallel to the glacier. Numerous glaciers located around Fedchenko Glacier are all small. In the Karakorum Mountains, several long

Table 2. Numerical features of Fedchenko Glacier.

Length (km)	Total area (km^2)	Elevation (m a.s.l.)	Equilibrium-line altitude (m)	Sauces
77	649	2900–6300	4700	Aizen et al., 2009 (after Dolgushin and Osipova, 1989)
77	650			Kotlyakov et al., 2008
77	700	2909–6200		Wikipedia, 26 Apr. 2009
70	900			Encyclopaedia Britannica Online, 25 Apr. 2009
77	992	2900–6200		JAXA, HP, 16 June 2006

valley glaciers form transection glacier systems, whereas Fedchenko Glacier is the only large glacier in the mountains. The questions persist: Why is Fedchenko Glacier the only large glacier in the Pamirs? How could the Fedchenko Glacier develop to such a large size?

Glacial melt-water from Fedchenko Glacier flows into the Belandkiik River, which joins the Muksu River, the uppermost tributary of the large Amu-Dar'ya River, and eventually empties into the Aral Sea.

The Fedchenko Glacier, discovered in 1878, was named after the Russian explorer Alexei Pavlovich Fedchenko (1844-1873), but the upper and entire glacier basins were explored in 1928 by a German-Soviet joint expedition.

2. Climate

The Pamirs are situated in the arid zone of central Eurasia, but sufficient precipitation occurs in the high mountain region to nourish the large glacier area. In summer 2005, two bored snow/firn cores were obtained from Fedchenko Glacier's upper basin at over 5,200 m a.s.l. (Aizen et al., 2009). The well-defined seasonal layers that are detectable by stable-isotope and trace element distribution indicate that most precipitation over the glacier originated in the Atlantic. In summer, water vapor was re-evaporated from semi-arid regions in central Eurasia. Consequently, the main moisture to the region comes with the westerlies, so that precipitation in the glacier basin is greatest during the winter and spring. Summer and autumn are dry seasons with many days of sunny weather. The Fedchenko Glacier Observatory (Fedchenko Station), located at the middle bank (38.83°N, 72.22°E, 4,156 m a.s.l.) of the Fedchenko Glacier, provides important climatic data (Fig. 2). Annual precipitation in the Pamirs shows a clear contrast with the Himalayas, Tibet, and the eastern Tien

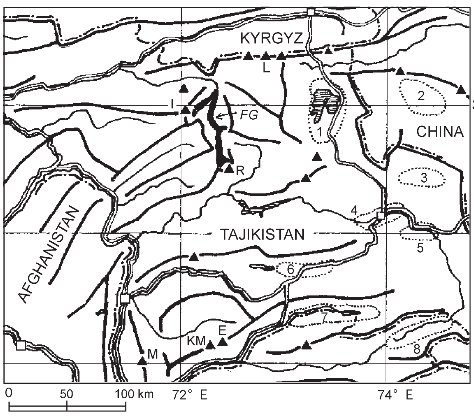


Fig. 1. Location of Fedchenko Glacier (*FG*) and landforms of the Pamirs, central Asia. Mountain ranges are oriented nearly east-west, but Fedchenko Glacier flows at a right angle to the ranges. Peaks: I, Ismoil Somoni (7495 m), KM; Karl Marx (6723 m); M, Mayakovskiy (6095 m); L, Lenin (7134 m); R, Revolution (6940 m). Pamirs (basins): 1, Kara Kul (Khargush), 2, unnamed; 3, Rang Kul; 4, Sarez; 5, unnamed; 6, Alichur; 7, Great; 8, Little.

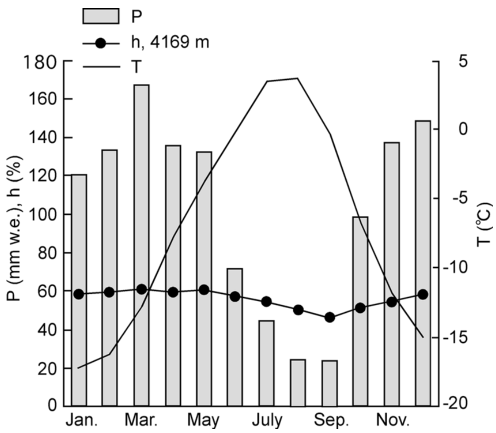


Fig. 2. Monthly distribution of air temperature T, precipitation P, and relative humidity h at Fedchenko station in the middle segment at 4,169 m a.s.l. (Aizen et al., 2009).

Shan, where precipitation is greatest in summer.

3. General configuration of Fedchenko Glacier

(1) Plan form of the glacial basin

Fedchenko Glacier originates from the western slope at 5,400 m a.s.l. of the Revolutsiya Peak (Revolution Peak, 6,940 m), flows north, joins tributary glaciers on its way, and ends at 2,900 m a.s.l. The southern end of the glacier basin is located at 38°30'16"N, 72°17'00"E; the northern end is 39°05' 10"N, 72°18'52"E. Viewed from above, the glacier shows a dendritic form, as depicted in Fig. 3-1. It is classified as a compound basins glacier under the IHD classification scheme (UNESCO/IASH, 1970).

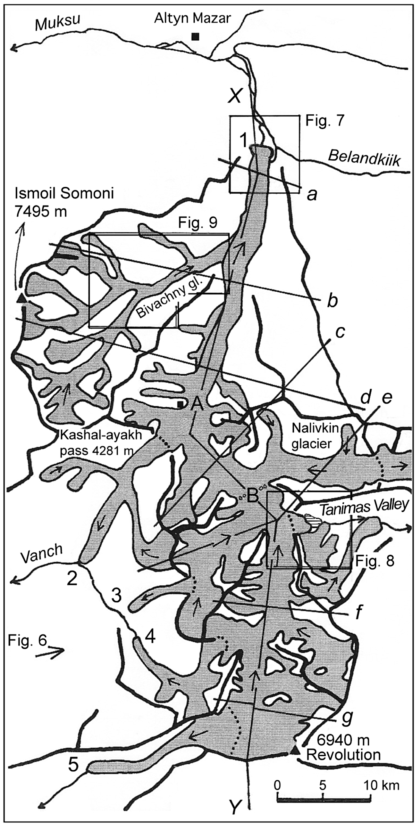


Fig.3-1. Fedchenko Glacier and the basin. Thick lines are profiles in Figs. 4 and 5. 1, Fedchenko Glacier front; 2, Royal Geographical Society (R.G.S.) Glacier; 3, Bears Glacier; 4. Abdulkhagor Glacier, 5; Yazgulem Glacier.

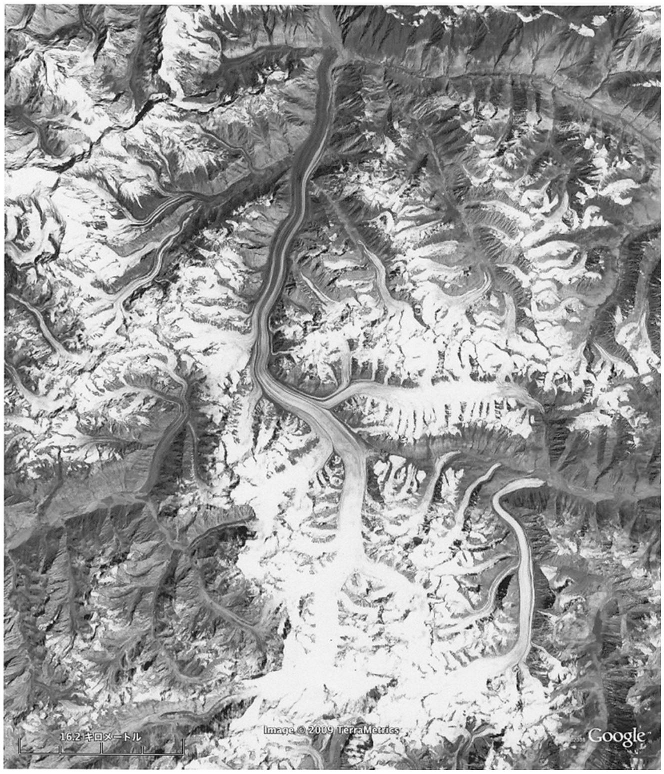


Fig.3-2. Google Earth image showing Fedchenko Glacier and glaciers located in the surrounding areas.

For convenience of the description for the discussion presented herein, the main trunk of the glacier is conceptualized as divided into three segments: lower, middle, and upper. The lower segment is from the glacial front to 30 km upstream at 4,050 m a.s.l., the middle one is from 30 km to 45 km upstream at 4,500 m, and the upper is from 45 km to the upper end. The glacier flows straight north-

northeast with 2 ㎞ width in the lower segment. There is no joining tributary glacier except two small ones from the left bank. The Fedchenko Glacier Observatory is located at 30 ㎞ from the front on the corner of the confluence of the left bank.

In the middle segment, the glacier turns to a northwest-southeast direction and widens to 2.5-3.0 ㎞. Several large tributary glaciers, such as the Nalivkina and Akademiya Nauk (Academy of Science) glaciers join this segment. At 45 ㎞ from the front, which is the boundary between the middle and upper segments, some ice spills out from the main glacier to the east and into Tanimas (Танымас) Valley forming a small glacier tongue. Here, an ice divide, called Tanimas Pass, separates the main glacier from "Tanimas glacier branch". This low pass played an important role in approaching the upper basin of the glacier for the 1928 expedition (Krilenko, 1978: 37-47). Such glacial diffluence is not rare in outlet glaciers from ice fields and ice sheets, but it is unusual in the high mountains of central Asia.

At that point, the glacier reverts to a north-south direction and enters the upper segment of 2.5-3.0 km width. Several glaciers with gentle and wide basins join from both sides. Consequently, the entire upper basin at 4,500-5,400 m altitude appears as a wide snow basin. The upper basin, higher than 4,900 m altitude, shows a distinct asymmetrical plan form by which all tributary glaciers are located on the eastern side. No tributary glacier exists on the western side. Instead of tributary glaciers, two wide ice divides separate from Adbulkhagor and Yazgulem glaciers, which belong to a different river system and flow to the west (Fig. 3-1).

(2) Vertical forms of the glacial basin

a. Longitudinal profile

Figure 4 presents a longitudinal profile compiled from 1:100,000 Russian maps. The surface gradient along the axis of the main trunk of the glacier (Fig. 3-1) is smooth or nearly rectilinear without steep sections. The estimated ice thickness, as ascertained from seismic and gravitational surveys during the International Geophysical Year (1957/58), is also indicated at three points: the glacier ice thickness of 250 m at the glacier tongue, 800 m at 4,000 m a.s.l., and 1,000 m at 5,000 m a.s.l. (Aizen et al., 2009). Profiles of the east and west divides (interfluves) are also depicted in Fig. 4. The interfluves on the western side in the lower segment are high and include the Ismoil Somoni peak (7,495 m), whereas those in the middle and higher segments are low and distinctive low saddles exist such as that at Kashal-ayakh Pass (4,281 m) and Tanimas Pass (4,540 m). Both divides in the upper segment show an asymmetrical height-difference that the high eastern and low western sides exhibit.

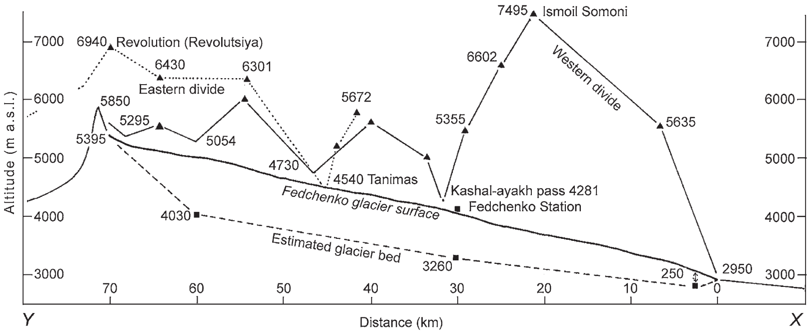


Fig. 4. Longitudinal profile of Fedchenko Glacier. The profile was plotted from Russian Maps 1: 100,000 compiled in 1975-79. Profile line (X-Y) is shown in Fig. 3-1.

b. Transverse profiles

Figure 5 presents transverse profiles at 10 km interval from the glacier front to the upper 70 km point produced in the same manner as that shown in Fig. 4. Profile lines are depicted in Fig. 3-1. Except for the two lower sections, profiles show a wide basin with many tributaries and interfluves that are not very high. Profiles at 35 km and 55 km points show asymmetrical landforms of the basin. As presented in the 65 km profile, the entire form of the basin's west side is a plateau of which the western rims are bordered by steep cliffs and rock slopes in the Bears and Abdulkhagor glacier basins (Fig. 6).

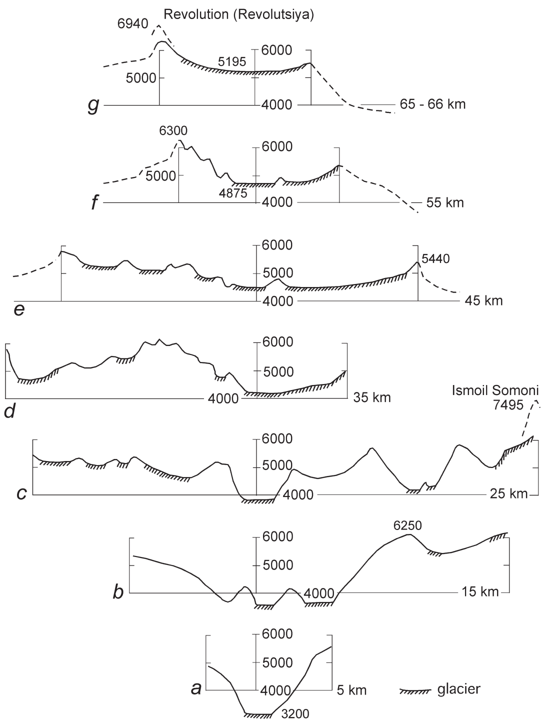


Fig. 5. Transverse profiles of Fedchenko Glacier. Profiles were plotted from Russian Maps 1: 100,000 compiled in 1975-79. Profile lines are shown in Fig. 3-1.

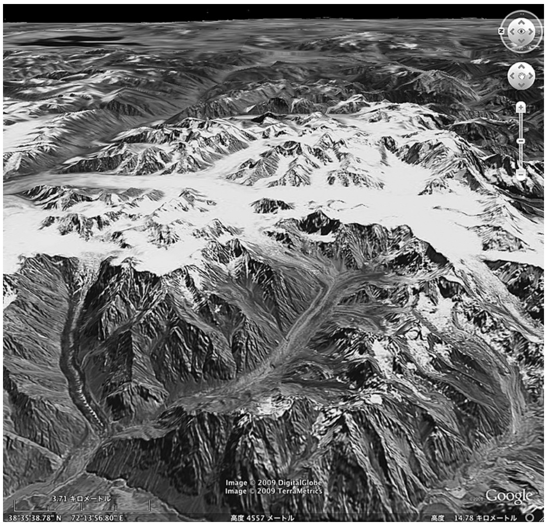
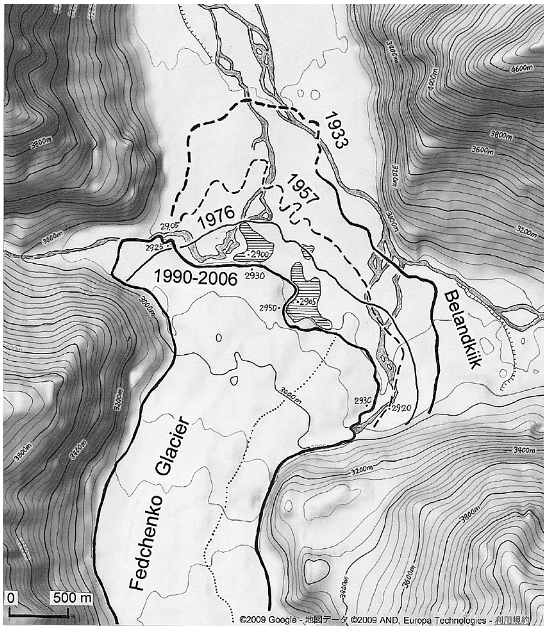


Fig. 6. Uppermost accumulation basin of Fedchenko main glacier viewed from the west arranged from Google Earth 3D image. The viewing direction is shown in Fig. 3-1. The Fedchenko Glacier main trunk flows from the right to the left. Many high peaks including Revolution Peak (6940 m) are located backside of the glacier basin (right bank), while the glacier basin is bounded by steep cliffs without an apparent high divide at the western side (left bank). For that reason, the ice overspills as the Yazgulem and Abdulkhagor glaciers.

Ⅲ. Details of Fedchenko Glacier

1. Glacier front of Fedchenko Glacier

At present, the Fedchenko Glacier front is located at a cross-shaped confluence of three rivers so that the glacier terminus extends to east and west sides (Fig. 7). Two shallow ponds (river lakes) occur between the glacier front and small fragments of terrace-like depositional forms. No frontal moraine is identified in the proglacial area. Measurements on Google Earth 3D images indicate that the height difference between the ground surface in front of the glacier and the glacier surface at the frontal margin is about 30-45 m at the center and 10-20 m at both sides (Fig. 7). Large parts



of the glacier surface are covered with dark supraglacial debris, but the right one-third of its surface is covered with light debris. Figure 7 portrays positions of glacier fronts in 1933, 1957, and 1990/2006 shown by this author from available information (Tajikistan, 2002; JAXA, 2006b; Tajik Agency on Hydrometeorology, 2007). The glacier front shrank by about 1,400 m between 1933 and 1990, but the two images of JAXA show that the frontal positions and two lakes have not changed much during the last 13 years of 1993-2006.

Fig. 7. Fedchenko Glacier front showing a retreat between 1933 and the 1990s/2006. Compiled by the author. Prepared by the information of UNEP/GRID (2003).

2. Tanimas Pass and glacial lake

At the Tanimas Pass (Fig. 8) a small ice contact lake occurs at the glacial front and drains into the Tanimas Valley to the east. Three other small ponds are found in the trough between the main glacier and the valley slopes. Although JAXA (2006b) reported by comparing the two satellite images that the lake and ponds appearing between 1993 and 2006 were attributable to glacier melting, these lakes are likely to have been produced before 1993 because they appeared on the 1970s Russian map (Fig. 8).

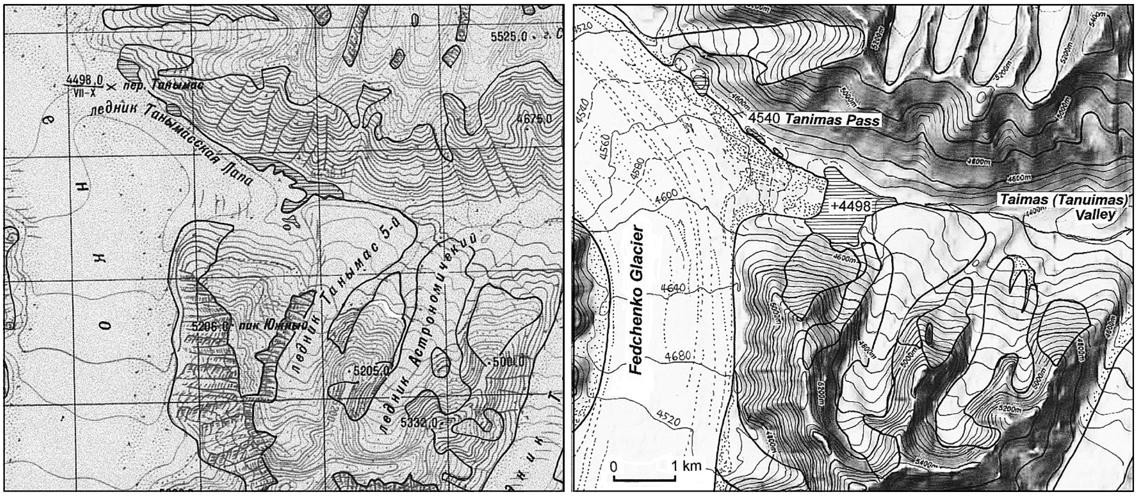


Fig. 8. Maps of Tanimas Pass and surrounding areas in the 1970s (left): Russian Map 1:100,000; and 2006 (right): compiled by the author using Google Earth images in 2006 and Google Map terrain.

3. Surface features

(1) Supraglacial debris

Fedchenko Glacier, which extends north and south in the center of the satellite image (Fig. 3-2), appears white on the upper basin (southern part) and dark-gray on the lower trunk (downstream side) because the upstream glacier is covered with snow and ice, whereas the surface of the downstream glacier is covered with supraglacial debris. In the middle part, clear white and dark lines are visible parallel to the glacier flow. The dark lines are median moraines formed by joining of two lateral moraines where glaciers have merged. They increase their width as the glacier flows downstream.

The surface of the main trunk from the front up to the 6.5 km point at 3,280 m a.s.l. is covered completely with supraglacial debris, where the surface relief is moderate compared with the debris-mantled glaciers in the eastern Himalayas, such as Khumbu Glacier south of Mt. Everest. Many thaw ponds were drawn on the Russian map, but they are not visible on Google images. These features suggest that the debris thickness of this segment is small, probably of less than 0.5 m in average depth. Upstream, at the 6.5 km point, a debris-free narrow band appears on the right-bank side and increases its width gradually. Meanwhile, the same debris-free band appears at 16 km from the front (3,560 m a.s.l.) on the left-bank side. The debris-free area becomes about 50% at 25 km from the front. The debris thickness in the middle segment is apparently less than 10 cm. In this lower segment of the main trunk, relatively thick supraglacial lateral moraines or ice-cored lateral moraines extend along both valley slopes.

At the middle segment, ice needles (small scale penitentes) commonly occur on the glacier-ice surface, as shaped by the strong solar radiation in summer (Krilenko, 1978: 48; Aizen et al., 2009), which indicates that the glacier surface has been affected strongly and lowered largely by solar radiation.

(2) Firn limit altitude

Glaciology emphasized that an equilibrium line is the most important attribute of a glacier. The equilibrium line altitude (ELA) of Fedchenko Glacier was reported by Aizen et al. (2009) (Table 2), but the original literature is not available. Estimation of ELA values is not easy because only continuous mass-balance measurements can determine the value, but some proxies exist to yield approximate values such as i) the altitude of the firn limit (firn/ice boundary altitude at the end of ablation season), ii) the highest altitudes of supraglacial debris and median moraines, iii) the highest altitude of lateral moraines, and iv) an altitude at which contour lines on the glacier surface change from convex to concave. These proxies are expected to be obtained from Google Earth 3D images.

A boundary between new snow and firn was unidentifiable clearly on Google Earth images, but the upper margin of the gray surface reveals bare ice at 4,640-4,680 m altitude. Therefore, the firn line existed at 4,640-4,680 m when the satellite image was taken (date unknown). New snow areas are presented at the Russian Maps (1:100,000); their lower limit is 5,200 m on the main trunk of the Fedchenko Glacier. Therefore, the firn limit is located at least lower than this altitude. Supraglacial debris on the glacial surface is visible on the right bank side at 5,020 m, and a lateral moraine ridge is identifiable at 5,000 m on the Google Earth image. Contour-line plan shapes change at two altitudes on the Russian Maps at 4,720 m and at between 5,200 and 5,240 m a.s.l. These facts imply that the assumed firn limit is at around 5,000 m a.s.l.

4. A tributary glacier: surging Bivachny Glacier

Bivachny Glacier is the longest tributary glacier (27 km long), joining at 10 km upstream from the glacier front. Its lower reaches have changed to a completely stagnant state at present. Therefore, the ice has not entered into the main trunk (Kotlyakov et al., 2008). Satellite images reveal tortuous patterns in the upper reaches of the Bivachny Glacier and its tributaries (Fig. 3-2). Surging glaciers are well known to leave distinctive structural imprints on glaciers, such as looped median moraines. The most impressive ones are striking tear-drop-shaped loops of debris patterns on the glacier surface. Traces of looped moraines and clean 'drop' features indicate that this glacier system is a surging glacier (Fig. 9).

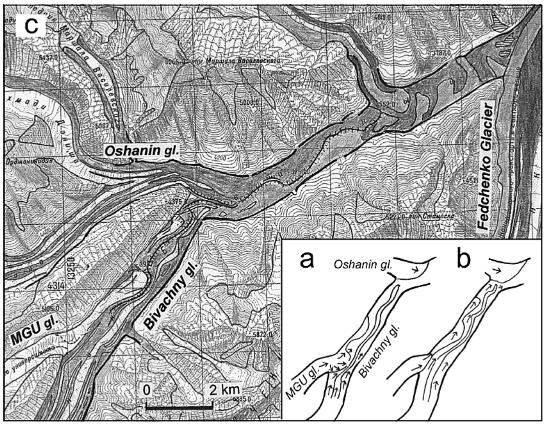


Fig. 9. Features of glacier surge of Bivachny Glacier drawn by the author using Google Earth image in 2006 (c). Scheme of the flow lines of ice at the Bivachny-MGU glacier confluence before the surge (a) and at the culmination (b): (a) and (b) are from Kotlyakov et al. (2008).

Remote-sensing surveys conducted by the Institute of Geography, Russian Academy of Sciences since the early 1970s discovered more than 60 surging glaciers in the Pamirs (Kotlyakov et al., 2008); Bivachny Glacier is the only known surging glacier of the Fedchenko Glacier system. Kotlyakov et al. (2008) analyzed surge phenomena of Bivachny Glacier during 1972-1991 using satellite monitoring and reconstructed the history and interpretation of Bivachny Glacier surges as described below. After the restoration stage in 1972-75, Bivachny Glacier's main body started to show rapid movement in 1975-76 and entered the culmination stage in 1976-78; the flow speed became maximal (>1,200 ma^{-1}). For the subsequent 4 years, the velocity dropped close to zero, indicating a complete surge termination. Meanwhile the quiescent stage of Bivachny Glacier, MGU glacier, a tributary glacier, started to advance into the main valley with velocity of 50-120 ma^{-1}. The advanced MGU glacier tongue dammed more than half of Bivachny Glacier. In the area upstream from this dam, compression strain in the main body of Bivachny Glacier increased. When stress in the upstream section overcame the resistance of this dam, the surge of the main trunk of Bivachny Glacier began (Fig. 9a). Because of the surge movement, the MGU glacier dam moved down along the valley together with the main body almost 3 km (Fig. 9b). After the Bivachny Glacier tongue became inactive, MGU Glacier again started advancing into the main valley, producing preparation for the next surge.

Two to three visible traces of tear-drop-shaped loops in the debris-covered downstream area of Bivachny Glacier indicate periodicity of the phenomenon described above (Fig. 9c). During the latter half of the 20th century, three surges of this glacier were recognized (Kotlyakov et al., 2008). For this surge phenomenon, MGU Glacier plays a significant role in the Bivachny Glacier evolution. Consequently, the repeated surge of the Bivachny Glacier system occurred because of the interaction of the two glaciers.

Ⅳ. Discussion

Some remarks and inferences based on the information described above.

(1) Glacier type: A unique mountain glacier

Fedchenko Glacier is a compound-basins valley glacier showing typical features of a valley glacier, especially in the lower and middle segments. In the upper segment, however, several parts of interfluves/divides are covered with glaciers forming ice divides. Therefore, the glacier basin connects with other glacier basins, so that the upper segment is classifiable as a transection-type valley glacier. However, the lower and middle segments in which the features show those of a typical valley glacier are distinctively longer than the upper segment, which shows transection features. Accordingly, the entirety of Fedchenko Glacier is classifiable as a valley glacier. General features of Fedchenko Glacier share similar characteristics with large glaciers in the Karakoram Mountains, but should be distinguished from transaction-type glaciers there.

Fedchenko Glacier is a debris-mantled glacier: the terminus is covered completely with supraglacial debris. However, its areal proportion to the entire area is not large. In addition, the debris layer is thinner than those of typical debris-mantled glaciers in the eastern Himalayas. Consequently, Fedchenko Glacier is a unique glacier of the world.

(2) Glacier variations: influences of global warming

Although many mountain glaciers in the world have been retreating in the last decade, Fedchenko Glacier has been stable since the 1990s. The glacier fronts, including the small Tanimas front, have retained their positions, as described above. Change of the glacier surface elevation has not been recognized, but glacial surges—rapid glacial advances—have occurred many times in tributary glaciers. On the other hand, a comparison study between the 1970s Russian maps and Google Earth images shows that small glaciers around Fedchenko Glacier have been retreating these past 25 years. These glacier behaviors closely resemble those of large glaciers in the Karakoram Mountains (Hewitt, 2005, 2007; Nagaoka, 2007), where large glaciers with high accumulation basins are advancing during the recent decade and where surges have been reported from many glaciers. These glacier behaviors in the Karakoram and Pamirs differ from tendencies of glaciers worldwide, but the reason is not clear. Continuous monitoring of glacier fluctuations is necessary in the Pamirs.

(3) The only large glacier in the mountains: causes of the long glacier basin

As presented in Fig. 1, Fedchenko Glacier has a peculiar and unusual configuration and a spatial setting by which the glacier extends in a north-south orientation opposing the general directions of mountain ranges of the Pamirs. A complex dendritic form of the glacier basins and profile forms interfluves with deep gaps, suggesting that the Fedchenko Glacial basin in the past was not a simple north-south oriented basin, but occupied using a few different basins having outlets to different directions. Assumed past outlets are the Tanimas Valley flowing to the east and R.G.S. Glacier on the southwest of Kashal-ayakh Pass to the southwest. At that time, Fedchenko Glacier was separated into at least three independent basins with different outlets by divides at A and B, as indicated in Fig. 3-1. A mountain ice field or an extensive transection valley glacier system covered the area during glacial periods. The glaciers cut deep low divides: eventually a few basins were joined together. Two glacier basins with latitudinal extension were likely to be captured by the southern expansion of a north-flowing glacier located in the north. The large meridional expansion of Fedchenko Glacier is the result of basin piracies (basin capture) during glacial periods.

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