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MONITORING OF GROUND SURFACE TEMPERATURE ON BLOCKY LANDFORMS AROUND MT. SUISYO, CENTRAL PART OF THE NORTHERN JAPANESE ALPS

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Abstract Four rock glaciers and several blocky landforms are distributed around Mt. Suisyo, central part of the northern Japanese Alps. Surface features of these rock glaciers (subdued and subsidence topography, gentle frontal slope with dense vegetation) suggest that these rock glaciers are inactive or relict. On the blocky landform (protalus lobe) located in the Suisyo C cirque, the bottom temperature of the winter snow cover (BTS) was lower than −3°C, and mean annual ground surface temperature (MAST) was lower than 0°C. These BTS and MAST values indicate the presence of permafrost in this blocky landform.

Key words: mountain permafrost, rock glacier, ground surface temperature, Mt. Suisyo

1. Introduction

Mountain permafrost is reacts sensitively to changing climatic conditions, and atmospheric warming during the twentieth century has caused the degradation of mountain permafrost (e.g., Haeberli *et al.* 1993). Active and inactive rock glaciers can be used as indicators of present mountain permafrost, and relict rock glaciers can be used as indicators of past mountain permafrost in their present location (e.g., Barsch 1996). Therefore, the study of mountain permafrost and rock glaciers is important and promoted to detect climatic changes.

In Japan, mountain permafrost was detected in the Daisetsu Mountains (Fukuda and Kinoshita 1974), Mt. Fuji (Fujii and Higuchi 1972) and the Tateyama Mountains, the northern part of the northern Japanese Alps (Fukui and Iwata 2000). By monitoring the ground temperature, possible permafrost occurrence was determined at some specific locations in the Japanese Alps (Matsuoka and Ikeda 1998; Aoyama 2003, 2005; Ishikawa *et al.* 2003). Although several blocky landforms have been identified as rock glaciers in the central part of the northern Japanese Alps (Aoyama 2002; Ishikawa *et al.* 2003), insufficient information is available regarding geomorphologic characteristics and thermal regime of rock glaciers. This paper presents geomorphologic features of rock glaciers and the results of monitoring of ground surface temperature on rock glaciers and blocky landforms located around Mt. Suisyo, central part of the northern Japanese Alps.

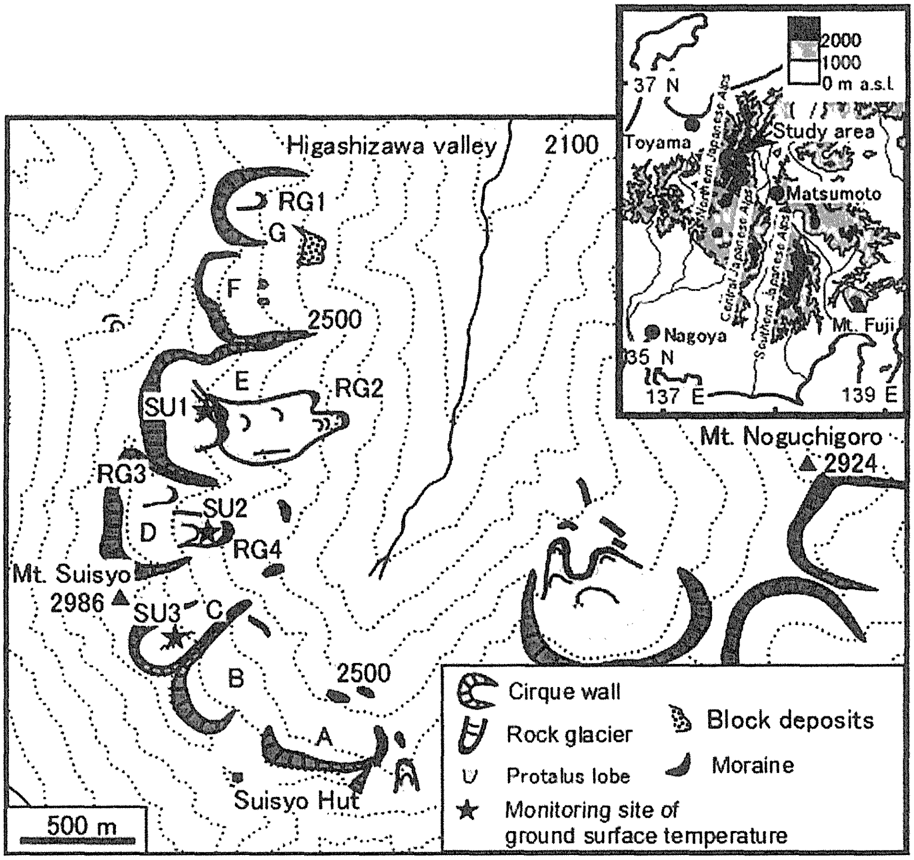

Fig. 1 Location map of the study area. Location of the measurement site of ground surface temperature and the distribution of cirque walls, rock glaciers, moraines and block deposits are shown. A-G represents the cirque name around Mt. Suisyo.

2. Study area

The study area is located in the central part of the northern Japanese Alps (Fig. 1). The highest peak in the study area, Mt. Suisyo, reaches 2986 m a.s.l., and a number of peaks exceed 2900 m a.s.l. The main ridge of the study area runs in a roughly north-south direction. Well-developed glacial landforms, such as cirques, moraines and glacial troughs are distributed (Shiki 1956; Iozawa 1979), and the occurrences of two glacial advances during the Last Glacial were identified (Iozawa 1979). Some cirques have blocky landforms, which were interpreted as moraines (Iozawa 1979; Aoki 2003) and rock glaciers (Aoyama 2002). Aoki (2003) used cosmogenic Beryllium-10 (^{10}Be) dating to show that some of these blocky landforms date to around 10 ka. The bedrock geology consists mainly of the Okukurobe Granite, the Funatsu Granitic Rocks and the Early Cretaceous sandstone (Harayama *et al.* 1991).

3. Methods

The distribution of rock glaciers and blocky landforms, which are considered to originate from permafrost creep, was investigated by aerial photograph interpretation and extensive field observations. Detailed topographical maps of rock glaciers were constructed by using a Leica Photogrammetric Workstation SD 3000 (digital stereo plotter), and extensive field observations were carried out in order to clarify the geomorphological features of rock glaciers.

The ground surface temperature was monitored from September 2004 to September 2005, by using miniature data loggers (Thermo Recorder TR-52, manufactured by T & D Corporation, Japan). They recorded temperatures at 1-h intervals with a resolution of 0.1°C. The locations of the monitoring sites are shown in Fig. 1. Three loggers were placed on rock glaciers and blocky landform (protalus lobe). They were installed beneath large boulders at the surfaces of the rock glaciers and blocky landform in order to avoid the effect of direct solar radiation.

The bottom temperature of the winter snow cover (BTS) can be used as an indicator of the occurrence or absence of permafrost in areas with a sufficiently thick winter snow cover (e.g., Haeberli, 1973; Hoelzle *et al.*, 1999). Since snow has a low heat transfer capacity, if the winter snow cover is sufficiently thick (>80 cm), it insulates the ground surface from short-term variations in atmospheric conditions, and the BTS is mainly controlled by the geothermal heat flow. Based on the permafrost occurrence, the BTS values were grouped into three categories (Haeberli, 1973): (a) probable permafrost (<−3°C), (b) possible permafrost (−2°C to −3°C), and (c) improbable permafrost (>−2°C). In addition to the BTS, the mean annual ground surface temperature (MAST) was obtained by monitoring the ground surface temperature throughout the year. Assuming thermal equilibrium, the presence of permafrost requires a subzero value of MAST, because the geothermal flow tends to increase the mean annual ground temperature with depth. In reality, global warming after the Little Ice Age seems to have slightly raised MAST toward the ground surface (e.g. Haeberli *et al.* 1993); hence, permafrost possibly exists even where MAST is slightly above 0°C (Matsuoka and Ikeda 1998).

4. Geomorphologic characteristics of rock glaciers

Several cirques have been identified on the eastern slope of Mt. Suisyo (Shiki 1956; Kobayashi 1958; Iozawa 1979), and these cirques are named the A-G cirque (Shiki 1956). In this study, four rock glaciers (RG1-RG4) were identified in these cirques. In addition, several protalus lobes, which are considered to originate from permafrost creep but are much smaller than typical rock glaciers (e.g. Whalley and Martin 1992), are developed on the western slope of the main ridge around Mt. Suisyo and below the north-facing talus slope in the C cirque. These lobes have dimensions 20-30 m long, 10-20 m wide and 3-5 m high, and they are thicker than typical solifluction lobe (0.2-2 m in thickness; e.g. Matsuoka 2001). The surface of these protalus lobes are predominantly characterized by angular or subangular open-work boulders that are 30-100 cm in diameter. RG1 is located in the G cirque and RG2 is located in the E cirque. RG3 and RG4 are located in the D cirque. In this study, detailed topographical maps of RG2 and RG4, which the ground surface temperature is monitored, were constructed (Figs. 2 and 3), and described in detail.

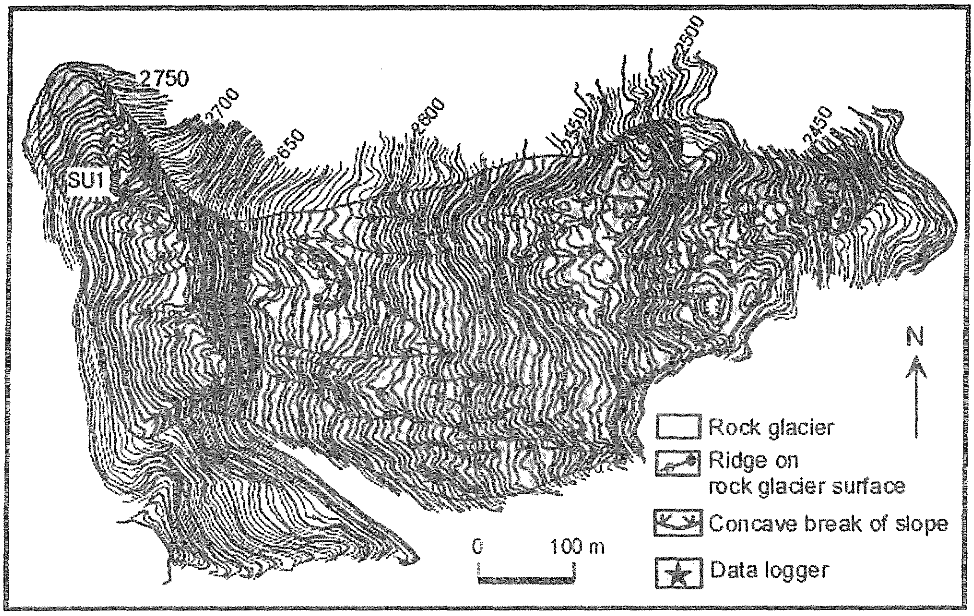

Fig. 2 Detailed topographical map of RG2 on the Suisyo E cirque. Contour interval is 2 m.

RG2 is located at the cirque floor of the E cirque. The aspect of the rock glacier is east. RG2 is a tongue-shaped form with a length of 970 m and a width of 280 m. Detailed topographical map of RG2 is shown in Fig. 2. The upper zone of the rock glacier (2650 m a.s.l.-2750 m a.s.l.) consists of M-shaped ridge. This M-shaped ridge is completely vegetated with alpine pines (*Pinus pumila*). Several discontinuous ridges are distributed inside (upslope) of the M-shaped ridge. Several previous studies (Shiki 1956; Kobayashi 1958; Tozawa 1979) have interpreted the M-shaped ridge as a moraine formed during the younger stade of the Last Glacial. However, the distance between the ridge and talus foot upslope is too short to feed a glacier. Terminal moraines of alpine glaciers have regularly been breached by an outwash stream (cf. Hambrey 1994), however, this breached feature is not found on the ridge. On the other hand, the melting a talus-derived rock glacier with high ice content produces an arcuate ridge fringing talus slope (Ikeda and Matsuoka 2002). Thus, M-shaped ridge is interpreted as outer ridge of inactive or relict rock glacier produced by the melting of ice-rich permafrost and the subsequent subsidence of the rock glacier. The middle and lower zone of the rock glacier consists of subdued transverse ridges and small enclosed hollows with dense vegetation. Kobayashi (1958) considered this blocky landform as an ablation moraine or outwash deposits. However, these transverse ridges are similar to the flow structure of rock glaciers associated with the deformation of permafrost, and small enclosed hollows may have produced by the melting of ice-rich permafrost. The head and front altitudes of RG2 are 2750 m a.s.l. and 2420 m a.s.l., respectively. The height of the frontal slope of RG2 is 25 m with an angle of 26° with dense vegetation. Active rock glaciers have a steep vegetation-free frontal slope

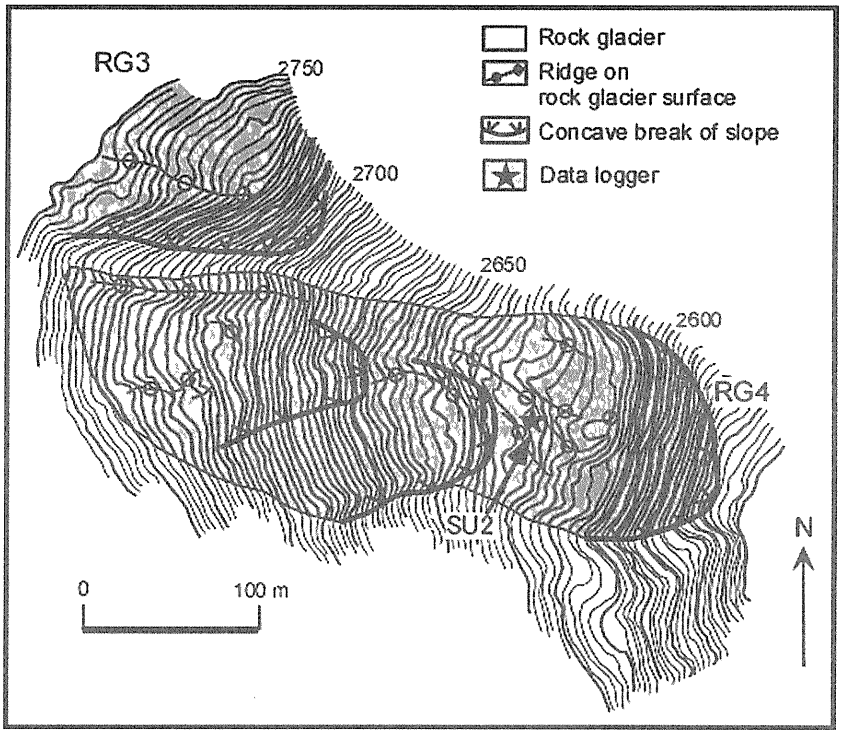

Fig. 3 Detailed topographical map of RG4 on the Suisyo D cirque. Contour interval is 2 m.

(approximately 40°), while many inactive and relict rock glaciers have more gentle frontal slopes, with partial or full vegetation covers (Ikeda and Matsuoka 2002). These surface features of the rock glacier suggest that RG2 is an inactive or a relict rock glacier.

RG4 is located at the cirque floor of the D cirque. The aspect of the rock glacier is east. RG4 shows a tongue-shaped form with a length of 410 m and a width of 150 m. Detailed topographical map of RG4 is shown in Fig. 3. RG4 consists of multiple lobes and transverse ridges. Each of these lobes consists of an upper lobe overriding a lower lobe. Several previous studies (Shiki 1956; Kobayashi 1958; Iozawa 1979) have interpreted this blocky landform as a moraine, and Iozawa (1979) presumed that the landform has been formed during the younger stade of the Last Glacial. However, these morphological features are similar to the surface morphological features of rock glaciers associated with the deformation of permafrost (e.g. Haeberli 1985; Kirkbridge and Brazier 1995; Barsch 1996). In addition, the breached feature formed by an outwash stream is not found on this blocky landform. Thus, this blocky landform is interpreted as a rock glacier rather than as a moraine. A continuous rounded ridge developed at the margin of RG4. This ridge is interpreted as an outer ridge of an inactive or a relict rock glacier produced by the melting of ice-rich permafrost and the subsequent subsidence of the rock glacier. The head and front altitudes of RG4 are 2740 m a.s.l. and 2570 m a.s.l., respectively. The frontal slope is entirely covered with alpine pine (*Pinus pumila*), suggesting that RG4 is inactive or relict. The height of the frontal slope of RG4 is 51 m

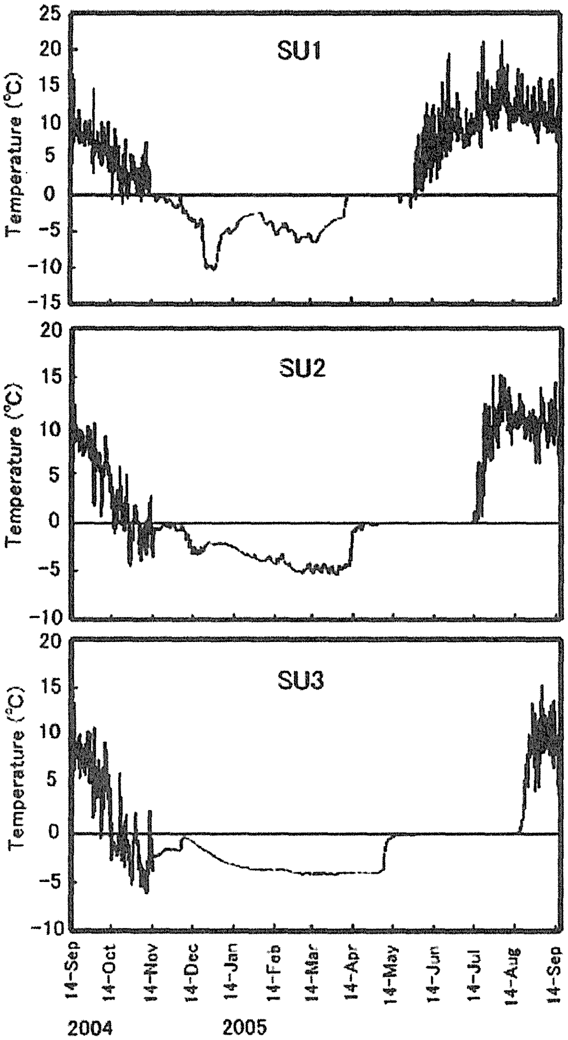

Fig. 4 Annual variations in ground surface temperature at the three monitoring sites. See Figs. 1, 2 and 3 for locations of the monitoring sites.

with an angle of 36°. These surface features of the rock glacier suggest that RG4 is also inactive or relict.

5. Ground surface temperature

The ground surface temperature was monitored at three sites around Mt. Suisyo (Fig. 1). Site

SU1 is located at the upper part of RG2. Site SU2 is located on RG4 and site SU3 is located on the protalus lobe in the C cirque. Measured ground surface temperatures at three sites are presented in Fig. 4. At these sites, the temperatures showed a gradual decrease with daily fluctuations in autumn, and these fluctuations decreased in mid-November. These temporal variations suggest that these sites were covered by snow in mid-November. However, at sites SU1 and SU2, short-term temperature fluctuations within negative temperature occurred throughout the winter. These fluctuations were probably due to the thin snow cover (<1 m), and atmospheric temperatures affect ground surface temperature. Thus, the BTS values at SU1 and SU2 cannot be used as an indicator of the presence of permafrost. At site SU1, the temperature fell rapidly to −10°C during December but soon rose to −2.5°C during January. Thereafter, the temperature fell gradually to −6.3°C with short-term temperature fluctuations toward mid-March. At site SU2, the temperature fell gradually to −5°C with short-term temperature fluctuations during December and March. On the other hand, at site SU3, temperature evolution did not show short-term fluctuation throughout the winter. Subfreezing temperatures occurred before the site SU3 was covered by snow in mid-November. Thereafter, the temperature rose to 0°C, and the subsequent temperature decreased gradually to −4°C from early December to early March. During the following two months, before snowmelt starts, the temperature remains nearly constant. This ground surface temperature evolution suggests that cold air is funneled through the surrounding open space of large blocky surface material though the thick snow cover (>1 m) insulates the ground surface from short-term variation in atmospheric temperature throughout the winter. Thus, the BTS values at SU3 can be used as an indicator of the presence of permafrost. The temperature increased rapidly to 0°C at sites SU1 and SU2 during April, and at site SU3 during May. This result indicates that the rapid melt water percolation to the base of the snow cover occurred during these periods, and the timing of the arrival of the wet-snow front to the ground at sites SU1 and SU2 is approximately one month earlier than at site SU3. Then the temperature remained constant values at 0°C (zero curtain) at site SU1 until the end of May, at the site SU2 until mid-July and at site SU3 until mid-August, indicating that seasonal snow remained at these sites until these periods.

The stable BTS in late winter is indicative of the presence of permafrost. At site SU3, the BTS values in late winter were lower than −3°C. In addition, MAST value was negative (−0.5°C) at this site. These values show the probable presence of permafrost at site SU3. MAST was 2.1°C at site 1, and 0.8°C at site SU2. Positive MAST close to 1°C was observed on inactive rock glaciers, possibly reflecting progressive melting of permafrost (Ikeda and Matsuoka 2002; Ikeda 2006). Therefore, MAST at site SU2 does not exclude the possibility of the presence of permafrost.

6. Conclusions

Four rock glaciers and several blocky landforms (protalus lobes) are distributed around Mt. Suisyo, central part of the northern Japanese Alps. Subsidence features, subdued topography and dense vegetation cover were observed on these rock glaciers. These surface features may result from the melting of permafrost, and suggest that these rock glaciers are inactive or relict. Low BTS (< −3°C) and negative MAST on protalus lobe in the Suisyo C cirque indicate the presence of permafrost.

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