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Measurements of bottom temperature of the winter snow cover (BTS) in relation to rock glacier activity, Corviglia, Swiss Alps: a preliminary report

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Introduction

Bottom temperature of the winter snow cover (BTS) has been used as an indicator of the occurrence of permafrost (*e.g.* Haeberli, 1973; Hoelzle, 1992). Under a heat-insulating dry snow cover (>80 cm deep), ground temperature depends mainly on the geothermal condition. Thus the BTS value approaches 0 °C where permafrost is absent, while it generally falls below −3 °C if permafrost is present (Hoelzle *et al.,* 1993, 1999). BTS can be evaluated by two methods: the manual installation of a temperature probe and the automated recording with a data logger (Hoelzle *et al.,* 1999). The former permits the understanding of spatial variation in BTS at a particular time in winter, while the latter provides temporal variation at a particular site.

In an attempt to evaluate rock glacier activity which reflects the permafrost condition, BTS measurements were undertaken in the Corviglia region, Upper Engadin, southeastern Switzerland. The study area lies between 2400 and 2900 m ASL (Fig. 1) and has commonly 1-2 m deep snow cover in late winter. This area consists of sedimentary and plutonic rocks, dominated by limestone, shale, conglomerate and granite. A number of rock glaciers develop in each lithology.

Rock glaciers are classified into active, inactive, and fossil types in terms of the activity status and the presence of permafrost (*e.g.* Barsch, 1996). In this paper, the activity was tentatively evaluated by vegetation, on the basis of the empirical relations that the active type has no vegetation cover (Fig. 2), the inactive type partial vegetation (Fig. 3) and the fossil type extensive vegetation (Fig. 4). The lower limit of the snout of the active rock glaciers lies at 2760 m ASL in the southern exposures, while it lies at 2540 m ASL in the northern exposures, in response to the amount of insolation.

Manual measurements in late winter

A thermistor probe, consisting of a 2-3 m rod, was pushed through the snow cover to the ground surface, thereby BTS was measured (Hoelzle *et al.,* 1999). Figure 1 shows the result of the manual measurements carried out in early March, 1999. The BTS values roughly corresponded to the landforms. The active and inactive rock glaciers showed lower temperatures (usually below −3 °C), in contrast to fossil rock glaciers and inter-rock-glacier sites showing temperatures near 0 °C. This region belongs to the discontinuous permafrost area and thus the permafrost distribution is considerably affected by the ground surface conditions. Openwork blocky layers on the active and inactive rock glaciers permit the storage of cold air, protecting permafrost from direct solar radiation. As a result, the downslope movement of rock glaciers allows the permafrost distribution at low altitudes.

In contrast, rock glaciers covered with small clasts seem to be unfavorable for the permafrost protection. For example, although the rock glacier northwest of Las Trais Fluors (S1 site in Fig. 1a) is situated in a favorable condition for permafrost in terms of altitude and aspect, the BTS values on the rock glacier are marginal (−2 °C to −3 °C). This rock glacier consists mainly of shale clasts (about 10 cm in diameter) lacking a blocky layer through which air can circulate.

Year-round automated measurements

Ten miniature data loggers (Thermo Recorder TR-51, manufactured by T & D corporation, Japan) were placed on nine rock glaciers and a lateral moraine of presumably Late Glacial period (Fig. 1, Table 1). They recorded temperatures under a surface clast (ca. 2 cm thick) at 1-hr intervals with resolution of 0.1 °C. Figure 5 displays year-round data from an active rock glacier (L1) and a fossil rock glacier (L5). Both sites were first covered by snow in early October, but at L1 site the snow cover is likely to have been thin such that the ground surface temperature was affected by air temperature until middle December. After the influence of air temperature was shut off by thick snow cover, BTS was maintained at a nearly constant value until late spring when the snow became wet. The BTS value was about −5 °C on the active rock glacier, compared with about −1 °C on the fossil one.

Data during the whole snow-covered period are shown for all sites in Fig. 6. BTS is quite low (ca. −5 °C) on some active rock glaciers (G1, L1) and below −3 °C on some inactive rock glaciers (G2, L2, L3). L4

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and S1 sites seem to lie in the marginal condition for permafrost (BTS = −2 to −3 °C). Both rock glaciers lack vegetation cover despite having partially collapsed features possibly resulting from permafrost melting. The BTS values at the fossil rock glacier sites (L5, C1) indicate the absence of permafrost (BTS > −2 °C). The moraine site (M1) also showed BTS close to −2 °C. BTS does not necessarily correlate with ground surface temperatures in early winter. In fact, the ground surface at C1 site was cooled below −5 °C in early winter, but in late winter it was warmed above −1 °C under thick snow cover.

In the case of openwork blocky surfaces, air circulation through the voids would complicate the relationship between BTS and permafrost. Even if the data logger site is covered with thick snow, there may be some snow free sites on talus slopes from which cold air penetrates to the logger site. For example, unstable BTS values under the snow cover at G1, G2 and L2 sites (see Fig. 6), all of which are made of large boulders, may not only result from thin snow cover but also from air circulation. On such rock glaciers, air circulation seems to intensify both production and protection of permafrost, lowering BTS below −5 °C regardless of the activity of rock glacier.

Figure 7 shows the relationship between BTS in early

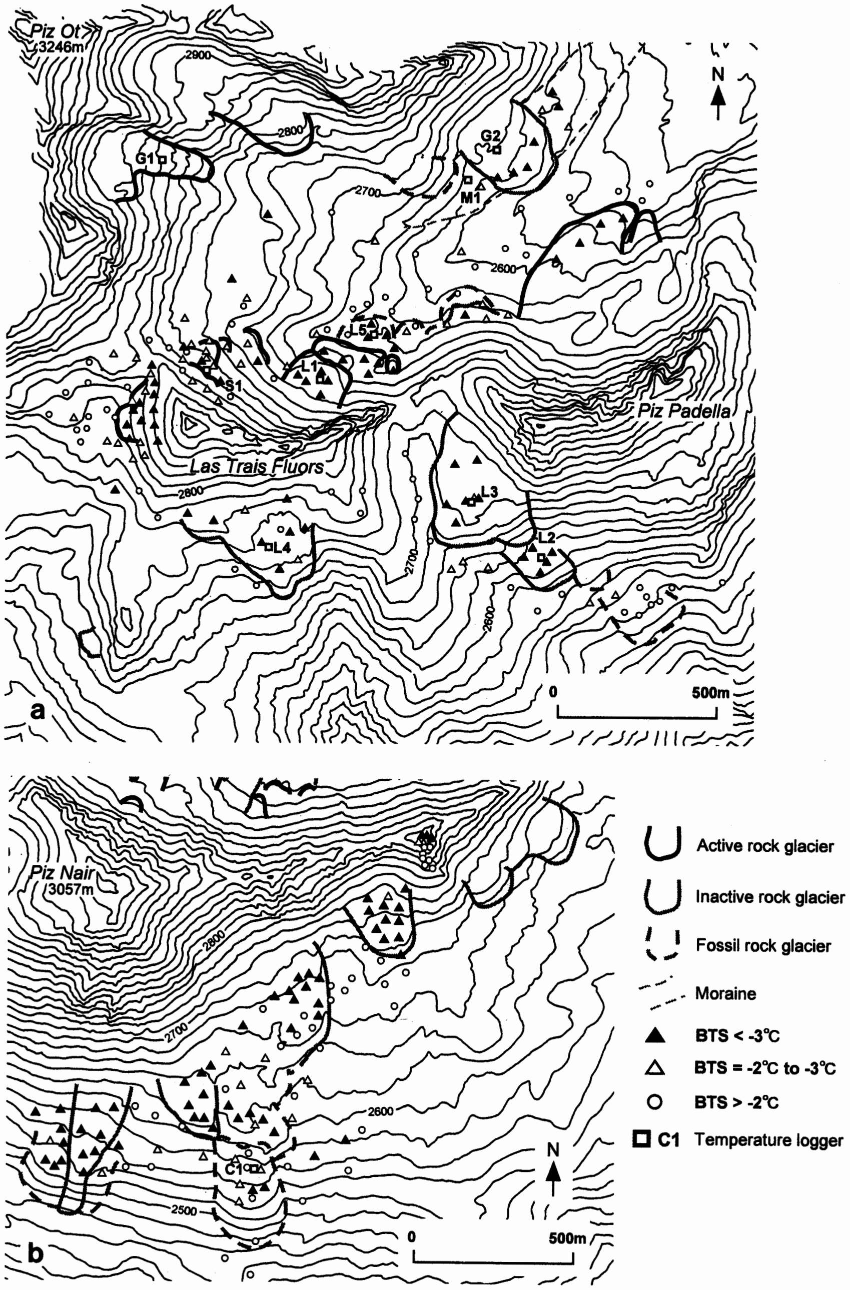

Fig. 1. Distribution of rock glaciers in (a) northern and (b) southern Corviglia regions, shown with the manual values of bottom temperature of the winter snow cover (BTS) measured on 2–9 March 1999.

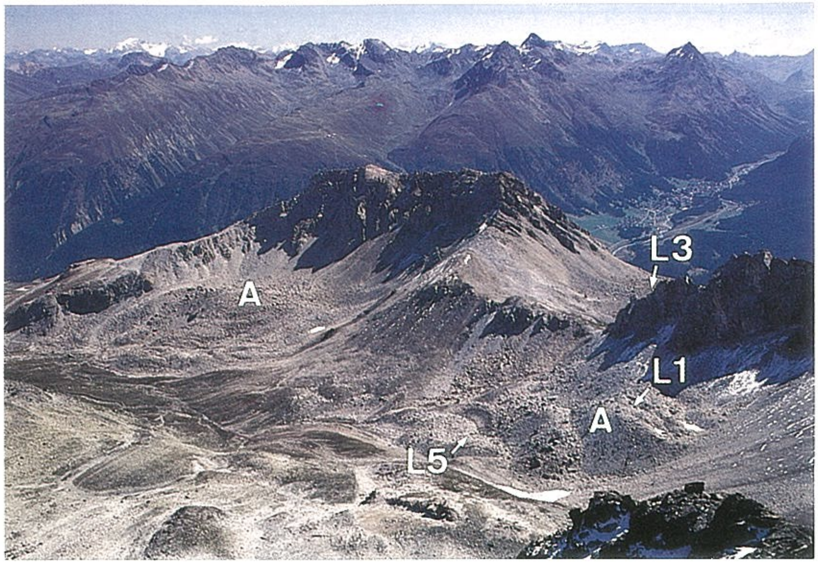

Fig. 2.
Active rock glaciers (A) on the northern slopes of Las Trais Fluors/ Piz Padella. Data logger sites (L1, L3, L5) are indicated.

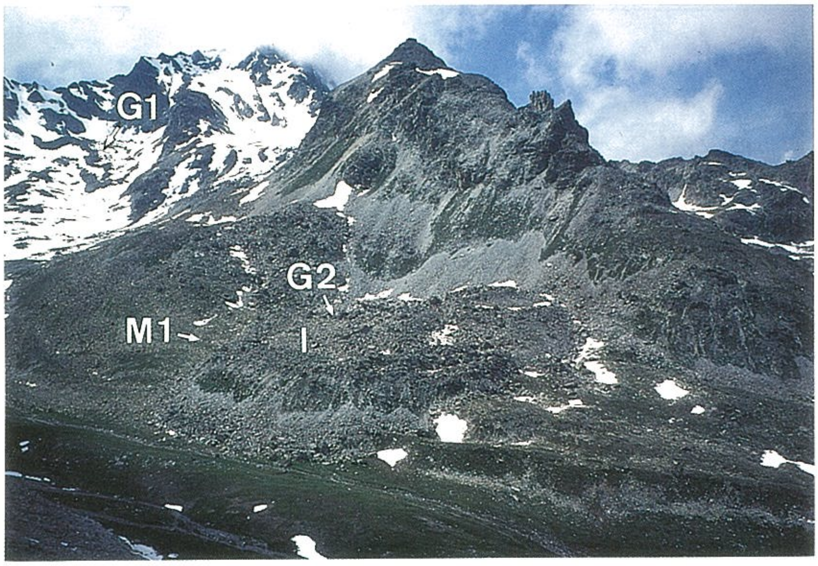

Fig. 3.
An inactive rock glacier (I) developed over Late Glacial moraines on the southeastern slope of Piz Ot. Data logger sites (G1, G2, M1) are indicated.

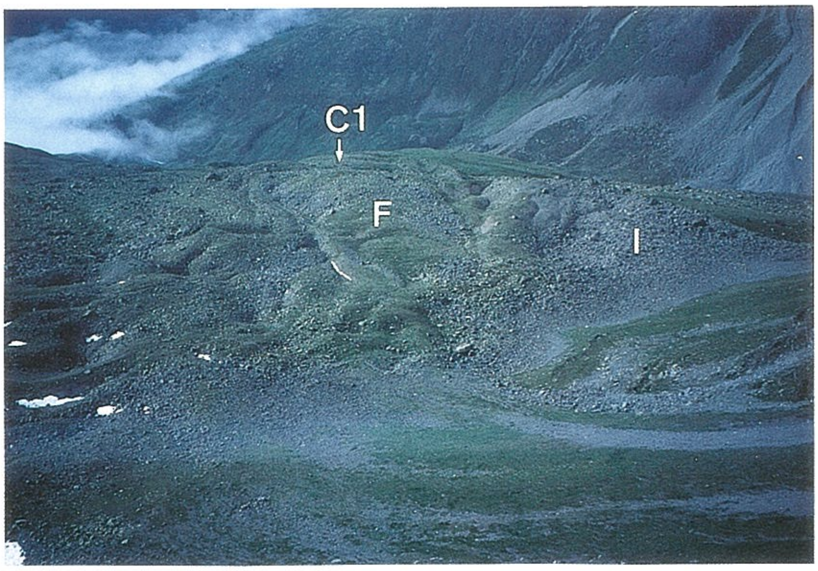

Fig. 4.
An inactive (I) and a fossil rock glacier (F) on the southern slope of Piz Nair. A data logger site (C1) is indicated.

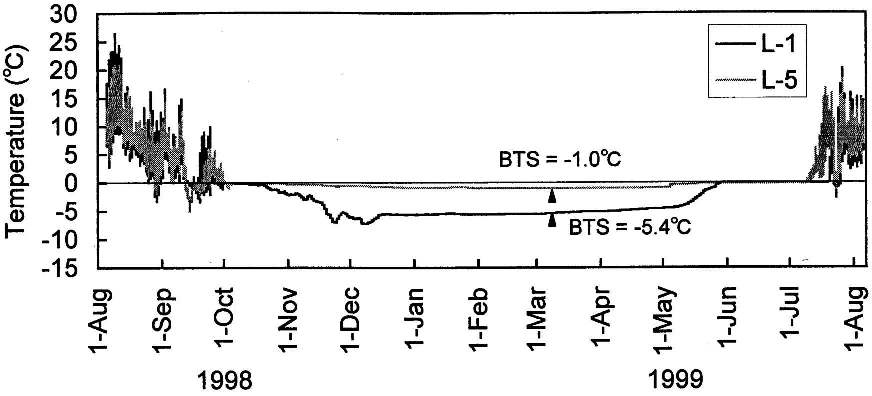

Fig. 5. Annual variation in ground surface temperature on an active rock glacier (L1) and a fossil rock glacier (L5).

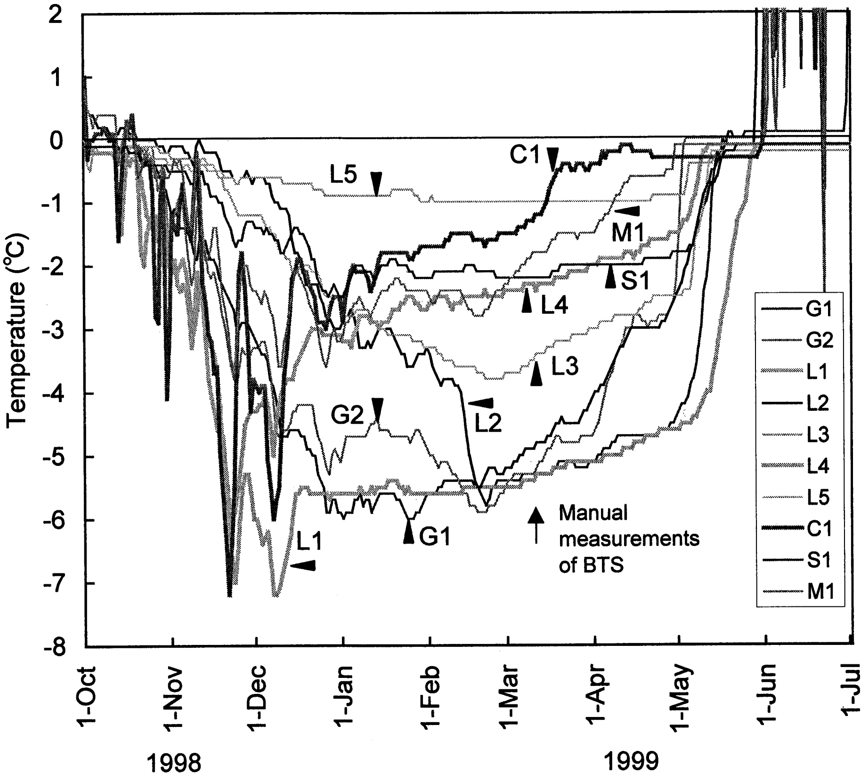

Fig. 6. Variation in bottom temperature of the winter snow cover (BTS) at all data logging sites.

Table 1. Site characteristics and summary of automated measurements.

Site	Geology	Geomorpology	MAST (℃)	BTS (℃)
G1	Granite	Active rock glacier	-0.8	-5.4
G2	Granite	Inactive rock glacier	0.7	-5.3
L1	Limestone	Active rock glacier	-1.7	-5.5
L2	Limestone	Inactive rock glacier	0.9	-5.0
L3	Limestone	Inactive rock glacier	0.5	-3.7
L4	Limestone	Inactive (?) rock glacier	-0.1	-2.4
L5	Limestone	Fossil rock glacier	0.9	-1.0
C1	Conglomerate	Fossil rock glacier	1.7	-1.4
S1	Shale	Active (?) rock glacier	-0.1	-2.2
M1	Granite	Late Glacial moraine	1.6	-2.1

MAST = Mean annual surface temperature
BTS = Bottom temperature of the winter snow cover

March and the mean annual surface temperature (MAST), which were calculated from the logger data. The BTS values in this figure are averages for 2–8 March 1999, during which the manual measurements were undertaken. The MAST values are averages for 365 days starting from 5 August 1998. The relationship between the two values corresponds to the rock glacier morphology. On active rock glaciers (G1, L1), MAST is below 0 °C and BTS is also relatively low. Inactive rock glaciers (G2, L2, L3) have relatively low BTS values, despite having MAST slightly above 0 °C (0 to 1 °C). On rock glaciers situated in the marginal condition for permafrost (L4, S1), MAST is close to 0 °C although BTS is marginal (−3 to −2 °C). Positive

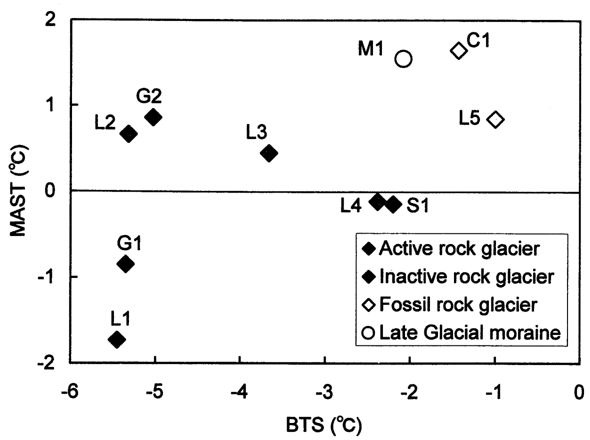

Fig. 7. Relationship between bottom temperature of the winter snow cover (BTS) and mean annual surface temperature (MAST), recorded with data loggers.

MAST and relatively high BTS (> −2 °C) values were observed on fossil rock glaciers and a moraine. Consequently, under positive MASTs below 1 °C, permafrost may still be maintained though rock glaciers seem to be inactivated.

Finally, the validity of the manual measurement is examined in comparison with the automated measurement (Fig. 8). The BTS probe data in Fig. 8 represent the average of two or three data acquired near a data logger, except for M1 site where only one measurement was done. The probe values nearly equal the logger ones for most sites. At three sites, however, the probe values are considerably lower than the logger values. The distance between the logger and probing sites may result in different surface conditions and thus explain the disparity at G2 site. The disparity at L3 and L5 sites may be attributed to the length of the probe. These two sites had snow cover of 2 m or deeper in early March, while the BTS probing was possible only where snow was shallower than 3 m. Such a site with thin snow cover is largely located on the top of a huge boulder which is probably affected by cold snow temperatures. As a result, the probe values are likely to underestimate the average BTS values on a rock glacier. This indicates that the spatial intervals of the manual BTS measurement should be as short as possible enough to cancel the disparities arising from the irregular topography on the surface of rock glaciers.

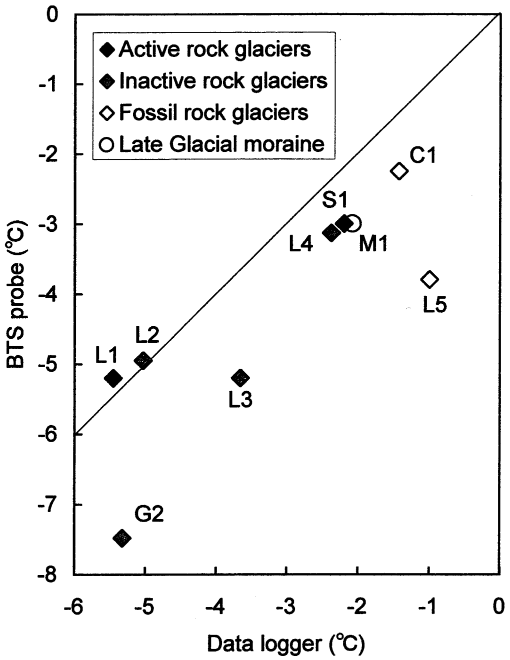

Fig. 8. Bottom temperature of the winter snow cover (BTS) in early March: comparison between the manual (BTS probe) and automated (data logger) measurement.

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