Plate 3.9 Permafrost

Introduction

Permanently frozen ground, i.e. permafrost, is usually associated with Siberia and Alaska. In the Alps this temperature phenomenon has been more intensively researched since the 1970s. The formation of permafrost can be graphically explained as follows: if the cold which accumulates in the soil during the winter is not fully compensated in the summer, temperatures remain below 0 °C the whole year, forming permafrost below the so-called permafrost table. It is only in the uppermost layer, which thaws, that the temperature rises above freezing point during the summer. Beneath this level, and therefore not visible, is the permafrost layer. Although through the natural heat flow in the Earth's crust the ground temperature rises with increasing depth, positive values are only achieved at the level of the permafrost base.

Permafrost is essentially defined by temperature; the ice which forms in the permafrost layer is merely a consequence. Accordingly, there also exists dry permafrost, which contains almost no ice.

Distribution of permafrost in the Alps

As a general rule, permafrost can be expected above the tree-line. The distribution of permafrost is mainly influenced by solar radiation, as well as mean annual air temperature. For this reason permafrost is observed at lower altitudes on north-facing than on south-facing slopes. Further decisive factors include snow, surface characteristics and water supply.

In the mid-1970s basic rules were drawn up for estimating the distribution of permafrost. Twenty years later these rules were incorporated into Geographical Information Systems (GIS) and adapted to various regions. There now exist different statistical models [2] for estimating permafrost distribution on the basis of a digital elevation model with various degrees of spatial resolution. Each cell is analysed in relation to altitude, aspect and special characteristics (e.g. foot of a slope). In another model, altitude is replaced by mean annual temperature and aspect by direct radiation [4]. In [2] these models were applied to the same test area and the results were compared. The probable distribution of permafrost as shown on the map was calculated using three regionally differing models. Permafrost occurs in around 4 to 6 % of the total surface of Switzerland, corresponding to approximately twice the area covered by glaciers.

Rock glaciers

Permafrost is particularly evident when it occurs in loose surface material, which is pressed apart by ice that forms in the pores. This process often enlarges them and the result is referred to as ice-supersaturated material. The ice plays an important role in determining the characteristics of such a mixture of debris and ice. On a slope the permafrost gradually starts creeping and forms typical patterns which resemble lava-flow. These are called rock glaciers, even if neither their formation nor their behaviour has anything to do with glaciers.

Rock glaciers are normally some hundred meters long, their surface being covered with debris. They creep some tens of centimeters downhill each year (cf. fig.1). Since the speed of movement is normally lower at the edges, a typical flow pattern emerges. The front and the sides are often quite steep (up to 40°) and are covered with large rough blocks which occasionally roll down and are deposited to form a so-called apron. In between, a zone of fine material forms where vegetation can develop if the rock glacier is no longer active. In the case of active rock glaciers any plant-life is destroyed by their movement and by falling rocks. Fossil rock glaciers normally contain no ice, have therefore collapsed and have an established vegetation cover. The table shows a number of easily identifiable and accessible rock glaciers of all three types (active, inactive, fossil).

Snow melt processes and hydrological significance of permafrost

In frozen loose material hydrological conditions are considerably influenced by the practically impervious permafrost layer. Furthermore, there is interaction between the permafrost and snow melt: in permafrost areas snow melt is delayed by around 15 to 20 days, for example [6].

These aspects were more closely studied in two areas: the Furggentälti and the Vallon de Réchy. In the Furggentälti a 350 m long rock glacier at the northern foot of the Plattenhörner was investigated (cf. photo, [7]). At present it is very active; its front advances 40 cm on average every year. Between 1960 and 1992 the total mass loss was 48 000 m^3 (ice), the annual melt-rate between 1985 and 1992 being four times that of the previous 25 years. Field investigations have shown that permafrost is chiefly restricted to those areas that receive relatively little direct radiation (fig. 4).

Snow melt in the area of the rock glacier was recorded by an automatic camera (fig. 6). This process starts at different times of the spring and continues at varying rates (fig. 7). The ablation pattern over the years, however, shows strong similarities (fig. 5), and is determined mainly by surface curvature, wind transport, radiation and ground temperatures (permafrost!). On the other hand, the distribution of permafrost can be inferred from analysis of ablation in combination with radiation.

In the Vallon de Réchy runoff has been observed since 1988 in two sub-catchments (fig. 8, [1]). Around 90 % of catchment 2 (approx. 20.5 hectares) lies within the permafrost area. It also includes the south-western part of the Becs de Bosson rock glacier. The larger part of the latter is within catchment 1, however, which has an area of 76 hectares and is 50 % permafrost. As can be seen in figure 8, the proportion of vegetation cover is far smaller in catchment 2 than in catchment 1.

The hydrological conditions are influenced by low temperatures (1993–1997: annual mean -1 °C), sparse vegetation and permafrost. Annual evaporation is around 300 mm (cf. map 4.1). The marked seasonal pattern of the hydrological processes is typical. The runoff pattern is strongly influenced by snow, with low runoff in winter and higher values between May and August, due to snow melt. The comparison of discharge patterns given in figure 9 clearly shows the differences between the two catchments, specific discharge being far greater in catchment 2, where permafrost is predominant. Melt-water flows through the thawing surface layer, above the permafrost table (cf. fig. 10) and feeds the springs that lie along the edge of the rock glacier. In catchment 1, storage capacity is considerably greater thanks to the relatively larger area free of permafrost, which results in much lower discharge values. In addition, it is possible that parts of catchment 1, in particular the area of the rock glacier, drain underground into catchment 2. The comparatively high base flow from catchment 2 probably comes from a reservoir underneath the rock glacier.

The Murtèl-Corvatsch rock glacier (Engadine)

As part of a research project, the Murtèl-Corvatsch rock glacier was drilled to a depth of 60 m in 1987 [3]. Drill cores were obtained, geophysical measurements were made in the borehole and instruments were installed for further, long-term observations (fig. 2). This drilling provided a novel insight into the internal structure of creeping permafrost [8].

The surface of the rock glacier consists of rocks of different sizes (from some centimeters to some meters in diameter). As can be seen from the density profile in figure 2, almost pure ice is found under this roughly 3 m thick layer to a depth of around 30 m. Between 30 m and 57 m, blocks of rock dominate, the spaces between them being filled with ice; at 57 m bedrock was found.

At the bore-site the permafrost layer creeps 6 cm downhill every year at the surface. Measurements of borehole distortion show that the major part of this movement (4 cm per year) can be accounted for by the shearing zone at a depth of between 28 m and 30 m (fig. 2).

Special, high-resolution, analytical aerial photogrammetry was used to detect changes at the surface (fig. 1). Results concerning the surface movement at the bore-site correlated closely with the borehole measurements. On average, the surface of the rock glacier sank at an annual rate of 4 cm between 1987 and 1996. The maximum rate of horizontal creep was around 15 cm per year. According to the flow-field the rock glacier is probably around 10 000 years old [5].

At depths of between 3.5 m and around 50 m temperatures remain below 0 °C all year round. Seasonal variations can be observed down to a depth of 20 m (fig. 3). A surprising observation was that between 52 m and 56 m seasonal temperature variations also occur, while at greater depths temperatures are stable and below zero. This implies active summer ground-water flow within the permafrost layer. The temperature of the uppermost 30 m rose considerably between 1987 and 1994. The Engadine saw relatively little snow in winter 1994/95 and winter 1995/96, which meant that the thin snow cover did not provide much insulation and the low temperatures could easily penetrate the ground. Consequently, in 1996, temperatures at a depth of 11.6 m were similar to those in 1987 and have since risen (fig. 3).

References

[1] **Gardaz, J.-M. (1999):** Permafrost prospecting, periglacial and rockglacier hydrology in mountain areas: Cases studies in the Valais Alps, Switzerland. University of Fribourg, Fribourg.

[2] **Haeberli, W. et al. (1996):** Simulation der Permafrostverbreitung in den Alpen mit Geographischen Informationssystemen. Arbeitsbericht NFP 31, Zürich.

[3] **Haeberli, W. et al. (1998):** Ten years after drilling through the permafrost of the active rock glacier Murtèl, Eastern Swiss Alps: answered questions and new perspectives. In: Seventh International Conference on Permafrost, Yellowknife, Canada. Proceedings:403–410, Collection Nordicana, N^{o} 57, Laval.

[4] **Hölzle, M. (1994):** Permafrost und Gletscher im Oberengadin. Grundlagen und Anwendungsbeispiele für automatisierte Schätzverfahren. Mitteilung der VAW, Nr. 132, Zürich.

[5] **Kääb, A. (1998):** Oberflächenkinematik ausgewählter Blockgletscher des Oberengadins. In: Beiträge aus der Gebirgs-Geomorphologie. Jahrestagung 1997 der Schweizerischen Geomorphologischen Gesellschaft. Mitteilung der VAW, Nr. 158:121–140, Zürich.

[6] **Keller, F. (1994):** Interaktion zwischen Schnee und Permafrost. Eine Grundlagenstudie im Oberengadin. Mitteilung der VAW, Nr. 127, Zürich.

[7] **Krummenacher, B. et al. (1998):** Periglaziale Prozesse und Formen im Furggentälti, Gemmipass. Mitteilung Nr. 56, Eidgenössisches Institut für Schnee- und Lawinenforschung, Davos.

[8] **Vonder Mühll, D. (1993):** Geophysikalische Untersuchungen im Permafrost des Oberengadins. Mitteilung der VAW, Nr. 122, Zürich.