NEAR-SURFACE FACETED CRYSTALS ON A SLOPE COVERED WITH STONE PINE TREES

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ABSTRACT: This paper presents snow surface temperature measurements as well as snow temperature investigations in the uppermost layer of the snowpack on a slope covered with stone pine trees. The experimental site was in the Kühtai (appr. 1950 m MSL) which is about 35 km from Innsbruck, Austria. Measurements were done on three characteristic sites (great clearing, small clearing, forest) which were situated on a north-facing slope (inclination appr. 30°). The investigations were carried out in January 1999, December 2000 and January 2001.The temperature of the snow surface and the uppermost layer of the snowpack can differ strongly during clear nights. This high temperature gradient in the uppermost centimeters of the snowpack leads to the formation of near-surface faceted crystals. The highest temperature gradient was measured in the great clearing with a maximum of 130 °C m^{-1} (31 December 2000). While in January 1999 near-surface faceted crystals were documented only in the great clearing, in January 2001 faceted crystals could be identified in the small clearing too. This seems to be a result of the different temperature gradients which were higher in January 2001 than in January 1999. However, no faceted crystals were found in the forest (neither in 1999 nor in 2001).

Keywords: snow metamorphism, forest, avalanches

1. INTRODUCTION

Investigations on snow crystal growth and the formation of faceted snow were done among others by Akitaya (1974), Colbeck (1982, 1989), Marbouty (1980), Sturm and Benson (1997).

The formation of near-surface faceted crystals was investigated by Birkeland (1996, 1998). Main factor for near-surface faceted crystal growth is a great difference in temperature between snow surface and the underlying snow. Fukuzawa and Akitaya (1993) found gradients of 159 °C m^{-1} between the surface and 2 cm depth.

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Birkeland et al. (1998) documented gradients of more than 200 °C m^{-1}; they found the vapor pressure gradient in the uppermost layer of the snowpack to exceed -25 hPa m^{-1} during the night. These extreme vapor pressure gradients led to the formation of near-surface faceted crystals.

These crystals often form weak layers, which are the fracture line of slab avalanches (Hardy et al., 2001). Birkeland et al. (1996) found that 30 of 51 avalanches in Montana (period 1990/91 to 1995/96) could be associated with near-surface faceted crystals. However, observations showed that the formation of near-surface faceted crystals is limited not only to open sites, under certain conditions they may be formed also in forested areas near the timberline.

To get more information on near-surface faceted crystals in forested areas measurements were performed on three characteristic sites (great clearing, small clearing, forest). The objective of this paper is to find out under which conditions near-surface faceted crystals may form in forested areas.

2. EXPERIMENTAL SITE AND METHODS OF MEASUREMENTS

The experimental site was located in a stone pine stand in approximately 1950 m MSL (latitude: 47° 12‘ N; longitude: 11° 05‘ E) in the western part of the Tyrol, Austria (about 35 km from Innsbruck) near to the Kühtai (Fig.1).

Fig.1: Overview on the experimental site

Three different measuring zones (great clearing (1), clearing (2) and forest (3)) were selected. Site 1 was in a great clearing (diameter:15 m x 15 m) on a N-facing slope (inclination 30°); site 2 was a smaller clearing (same aspect and slope angle as 1) with a diameter of approximately 10 m x 15 m (about 30 % of the sky was covered by the forest canopy); site 3 was in the forest (aspect: N; slope angle: 25°) with touching crowns (about 75 % of the sky was covered by the forest canopy). Investigations were performed in January 1999, December 2000 and January 2001.The following measurements were done: Site 1 (great clearing): air temperature in 2 m, temperature at 0.1 m above snow surface ($T_{+0.1}$), snow surface temperature (T_s), temperature in 0.1 m below the surface ($T_{-0.1}$) and temperature of the snow/ground interface ($T_{g/s}$). Sites 2 (small clearing) and 3 (forest): snow surface temperature (T_s).

The measuring periods were selected in January because this is the only time where clear and cold weather can be expected and consequently the formation of near-surface faceted crystals.

All temperature measurements were done with calibrated thermistors; the following design was used. Sensors were mounted on small poles before the winter season for measuring temperature in 0.1 m above the surface. Sensors to measure T_s were placed directly on the snow surface which was possible because the site was not influenced by direct solar radiation in January. Sensors were put into the snowpack (0.1m below the snow surface) to measure snow temperature. To avoid that air temperature sensors (0.1m above snow) and snow surface temperature sensors are covered by new snow they were readjusted if required. All data were stored by data loggers with an interval of 30 min; in the forest and in the small clearing the interval was 60 min.

3. RESULTS

During the relevant measuring periods (15 January 1999 to 20 January 1999 and 14 January 2001 to 18 January 2001) the weather was characterized by clear skies but different temperature regimes. In 1999 air temperature was higher than in 2001. During the measuring period 1999 average air temperature was -1°C, while it was -9 °C during the measuring period 2001. Snow depth was between 0.6 and 0.7 m in the period 1999 while it reached up to 0.8 m in the period 2001. The density of snow was about 200 kg m^{-3}.

Taking into account two continuous time series from 31 December 2000 to 3 January 2001 and from 14 January 2001 to 18 January 2001 it was found for site 1 that air temperature and snow surface temperature show a clear diurnal variation, while the temperature in 0.1 m below the snow surface has already a reduced variation. The snow/ground interface temperature was nearly constant. Air temperature in 0.1 m was always lower (1.5 to 2°C) than in 2 m; this finding agrees with a previous study (Höller, 2001) and these values correspond to a gradient of about 1°C m^{-1}. However the difference in temperature between snow surface and 0.1 m above snow surface as well as between snow surface and the uppermost layer of the snowpack (0.1 m below the surface) can be very large. For example on 01 January 2001 a temperature gradient of more than 70 °C m^{-1} was measured between the snow surface and 0.1 m above the surface.

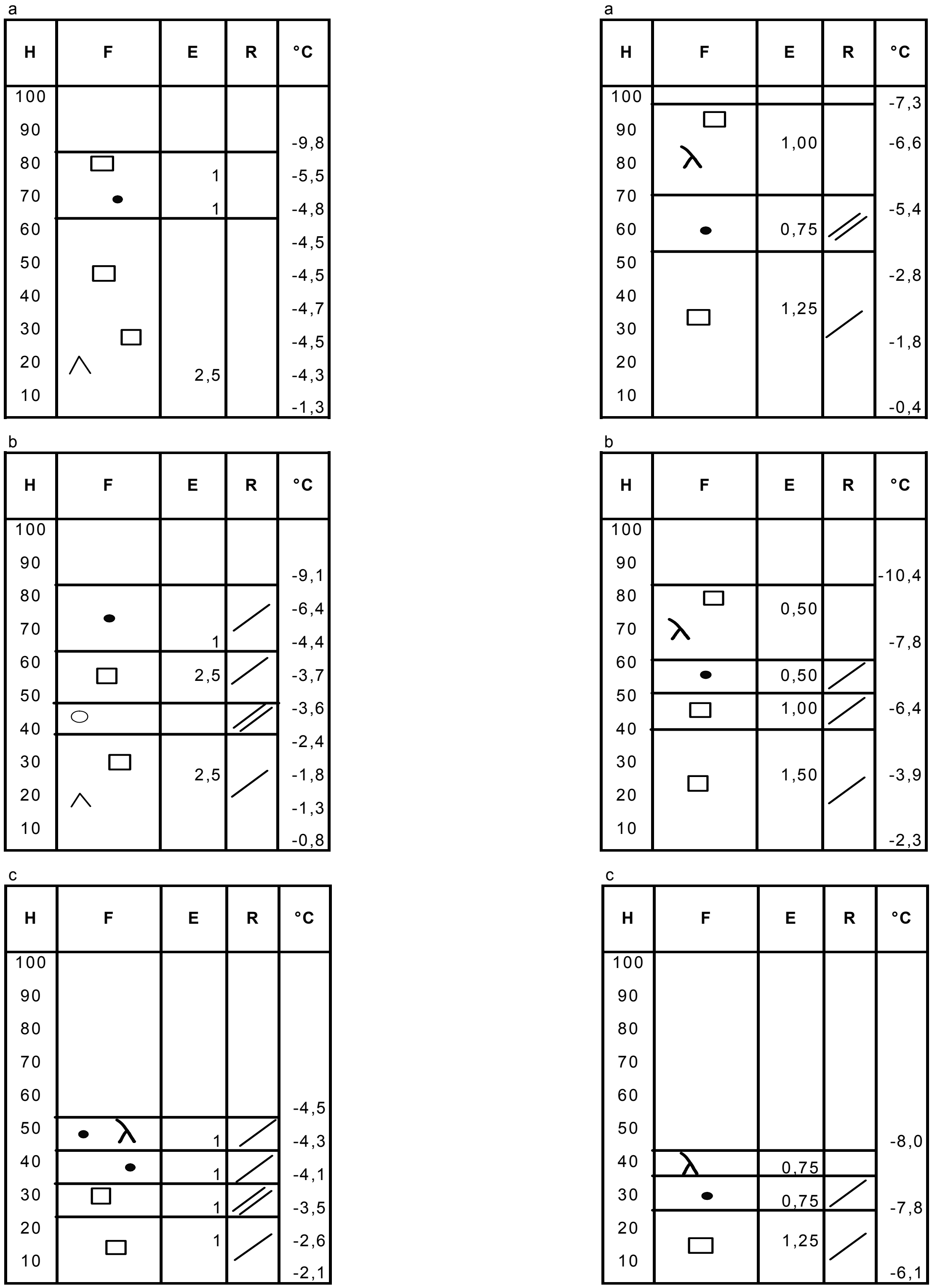

Fig. 2 Snow profiles from 20 Jan 1999 (left column) and 18 Jan 2001 (right column)
a…great clearing, b…small clearing, c…forest [H..snow depth (cm), F…grain shape (λ …fragmented particles ●…rounded grains, ○…wet grains, □…faceted grains, ∧…depth hoar), E…grain size (mm), R…hardness (/…low, //…high)]

The strongest temperature gradient between the snow surface and the uppermost layer of the snowpack (0.1 m below the surface) was found on 31 December, 2000 with about 130 °C m^{-1}, where the temperature gradient was defined positive when the snow surface was colder than the underlying snow (in 0.1 m) and vice versa. To determine temperature gradients on site 2 and 3 calculated snow temperatures ($T_{-0.1}$) were used.

A simple way to calculate snow temperature is to use characteristic temperature profiles; the typical temperature profile during nighttime shows a strong concave-downward curvature, while during daytime there is an increase of snow temperature in the uppermost 30 to 40 cm of the snowpack (McClung and Schaerer, 1993). These calculations do not have a physical significance but it seems that such a method is sufficient to determine the snow temperatures below the surface ($T_{-0.1}$).

The temperature gradients (during nighttime) in the designated periods (15 January 1999 to 20 January 1999 and 14 January 2001 to 18 January 2001) were higher in the clearings (site 1 and 2) than in the forest which is evident due to a higher snow surface temperature in the forest. At measuring zone 1 and 2 (great and small clearing) the gradients were lower in January 1999 than in January 2001. The averaged gradient in the small clearing was 30°C m^{-1} in 1999 and 55°C m^{-1} in 2001, while in the great clearing the corresponding values were 40°C m^{-1} and 42°C m^{-1} in 1999 and 2001, respectively. In the forest the temperature gradients did not exceed 25°C m^{-1} (January 1999).

These data were compared with on-site observations (snow profiles), which were carried out at the end of the respective period. Fig. 2 shows the corresponding snow profiles of 20 January 1999 and 18 January 2001. While in January 1999 near-surface faceted crystals are documented only in the great clearing (no crystals could be identified in the small clearing), in January 2001 faceted crystals were also found on site 2 (small clearing). However, no faceted crystals were found in the forest (neither in 1999 nor in 2001).

4. DISCUSSION AND CONCLUSIONS

Near-surface faceted crystals were found in the clearings but none could be identified in the forest. The reason that faceted crystals did not occur in the forest seems to be the low temperature gradient, which was less than 25 °C m^{-1}. In several experiments Marbouty (1980) has found the existence of a threshold around 25 °C m^{-1} above which TG-metamorphism becomes truly considerable. Sturm and Benson (1997) give the critical gradient necessary for kinetic growth with about 25 °C m^{-1}. However, in January 1999 in the small clearing the gradient was around 30 °C m^{-1} on average, nevertheless no faceted crystals were found.

To give an explanation the weather conditions before 15 January 1999 were analyzed. These days were characterized by a cloud covered sky, that prevented a strong cooling of the snow surface and led to relative high values of T_s. Thus it can be assumed that the time with prevailing cold and clear weather (to produce high temperature gradients) was too short to form near-surface faceted crystals. However, a gradient of 40°C m^{-1} was enough for near-surface faceted crystal growth as otherwise no faceted crystals would have formed on site 1 (large clearing). In January 2001, the temperature gradients were high both on site 1 and 2 (great and small clearing) and these high gradients on average more than 40 °C m^{-1} led to the formation of near-surface faceted crystals (Fig. 2).

It can be concluded that near-surface faceted crystals can build in clearings of forested areas. It was found that several days (4 to 5 days) with temperature gradients of 40 °C m^{-1} and more may lead to the formation of faceted crystals. No faceted crystals could be identified when the temperature gradient was about 30 °C m^{-1}. However, near-surface faceted crystals will not form in the forest as these sites are characterized by a lower temperature gradient because of the reduced cooling of the snow surface due to the forest canopy.

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