Snow Pit Measurements at Stake 18 on Storglaciären, Northern Sweden – March 2003

Picture 1: Fay Campbell and Martin Mergili measuring snow temperature at pit1 – stake 18 Storglaciären (29.03.2003)

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Preview

A glaciological field course at the Tarfala Research Station was Part 5 of an EU EuroLab (GlacioEuroLab5). The course lasted from March 27th to April 3rd 2003.

The main goal of the course was to introduce young professional researchers and (P.H:D.) students to glaciological field measurements like ground penetrating radar measurements, drilling with PICO-corer, snow stratification, temperature, and density measurements, thin sections of glacier and lake ice, introduction to safety at glaciers and avalanche basics.

The Tarfala Research Station is located at 67°55'N, 18°35'S in the Tarfala valley in Lapland, northern Sweden, which is a typical high alpine area between 800 and 2141m a.s.l.. The station has a unique place in the history of glaciology and has been the focus of continuous glaciological work since 1946. Storglaciären - on the eastern side of the Kebnekaise massif - (Picture 2) is situated in the immediate vicinity of the Tarfala Station and has the longest continuous series of mass balance measurements in the world (HOLMLUND and JANSSON 2002).

Picture 2: Students skiing up on Storglaciären (31.03.2003)

.1 Introduction

The main aim of this paper is to give an overview of snow stratification, temperature and density on Storglaciären. Therefore two snow pits were dug at about 1320 m a.s.l. at stake 18 on that glacier. Beside the measurements we checked the snow layers with a simple hand test in order to check the snowpack's hardness.

Because the Kebnekaise massif is a high alpine area some facts about avalanches will be discussed and will be brought in relationship with results of the measurements.

After a brief explanation of the methods, results will be presented and discussed.

.2 Methods

In order to investigate properties of snow and firn, like snow stratification, temperature, density and hardness a snow pit has to be dug.

First of all a location for the snow pit has to be chosen. Therefore it is recommended to check the proximate snow depth with a probe. During our investigations we decided to dig two pits beside stake 18 on Storglaciären which is around 1320 m a.s.l., just below the equilibrium line. At stake 18 data loggers (Picture 3) are installed to collect data from ice temperatures along a borehole, snow temperatures at different levels and snow heights all over the year. Generally spoken it is important not to disturb the snow surface where the profile should later be taken. For that reason there is a confined area for taking snow profiles where nobody should step on or throw the removed material. Moreover it is important to keep the probe side of the profile protected from solar radiation because radiation can change the snow properties along a profile. This is especially important for snow temperature measurements and stratification. Before starting with the measurements a smooth wall has to be prepared and a meter has to be fixed along the wall.

Snow temperature was measured with a 30 cm long digital thermometer every 10 cm (Picture 1), snow density was obtained by using a 25 x 8 cm metal cylinder, probing from top to bottom and weighing the content with a spring balance. Snow stratification was done along the whole profile which is a product of crystal type (Table 1), size, hardness (Table 2) and water content of the snow. The hardness is measured by using the hand test (scale: fist, 4 fingers, 1 finger, pencil, knife, ice), for the water content you use the scale from dry to moist, wet, very wet, and slush. This system of classification for snow stratification and hardness is based on *ICSI*, an international system for classifying seasonal snow. It is recommended for avalanche workers in snow profile work (McCLUNG and SCHAERER 1993).

Term	Symbol
New snow	+
Decomposed and fragmented snow	/
Faceted crystals	□
Cup shaped crystals; depth hoar	Λ
Wet grains	O
Feathery crystals; surface hoar	V
Ice Masses	–

Table 1: Basic ICSI system for classifying snow crystals (McCLUNG AND SCHAERER 1993)

Hardness usually increases with depth in a uniform layer of a snow pack. Especially for avalanche work hardness of snow is normally measured by a hand test or the swiss ram profile. A hand test involves pressing "objects" of various sizes into the snow to break it in compression (Table 2) and to penetrate into the snow. For avalanche workers it is quite common to check layer hardness with the hand test in order to get a brief overview.

Term	Hand test (by penetrating into snow)	Order of magnitude strength [N/m²]
very low	fist	0-20
low	4 fingers	10^3-10^4
medium	1 finger	10^4-10^5
high	pencil	10^5-10^6
very high	knife blade	>10^6
ice		

Table 2: Hardness classification for snow (McCLUNG AND SCHAERER 1993)

Picture 3: Stake 18/ Storglaciären – Regine Hock downloading data (29.03.2003)

.3 Results and Discussion

.3.1 Snow Stratification and Hardness

The stratification of the two snow pits showed different properties. The measurements were carried out by different participants which could explain the differences between the profiles.

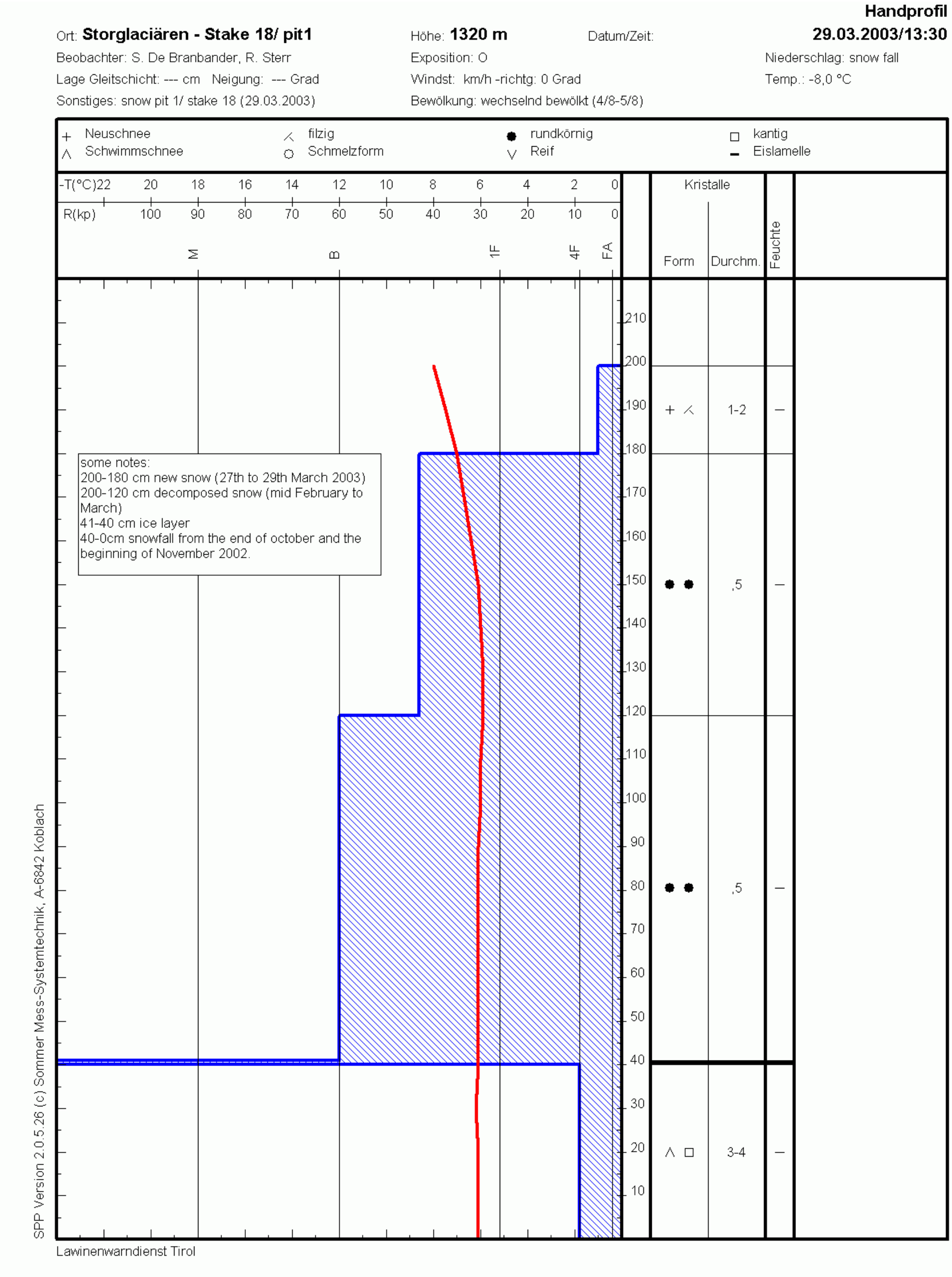

Figure 1: Snow stratification, snow temperature, and snow hardness (hand test) – pit1

Pit1 showed a total height of 200 cm above the ice. During digging the snow profile the snow surface was influenced by snow which was thrown on the snow surface. Therefore the uppermost layer of the profile was drawn by checking the snow surface beside that spot (Figure 1).

The uppermost 20 cm of pit1 shows the amount of new and decomposed snow which was fallen during the period from the March 27^{th} to the 29^{th} 2003. The grain size is between 1 to 2 mm and the hardness of this layer is fist to 4 fingers. Decomposed snow is snow which was either influenced by wind, by temperature or by global radiation just after or during a snowfall. You can not see anymore the whole crystal in its full hexagonal shape - the branches of the crystal got already broken.. The layer below from 180 to 120 cm shows rounded grains with a size of 0.5 mm and a hardness of 1 finger to pencil. Rounded grains are the result of decomposing processes in a snow pack. The amount of snow from 200 to 120 cm can be regarded as the snow which was fallen since mid of February until the end of March 2003. Hardness is further increasing to pencil down to 41 cm just above the ice surface. The grain size is similar to the upper layer. Between 41 and 40 cm an ice layer can be determined with the hardness classification of a knife. This layer might have been exposed to strong and cold winds until mid of January 2003 when it started to snow again. The lowest layer between the ice surface and the icy layer contains depth hoar and faceted crystals with a grain size 3 to 4 mm and a hardness of 4 fingers. The lowest layer was formed after a snowfall end of October and the beginning of November 2003.

In general, crystals that are produced under high growth rates - large temperature gradients with high temperatures on the ground and low temperatures on the snow surface and with large spaces between the crystals - form weak, unstable snow. The reasons for depth hoar and faceted crystal processes are therefore cold and long weather periods by high temperature gradients and a relatively thin snow cover. Those kind of crystals which are formed under high growth rates are often the reason for avalanches and large numbers of fatalities. Especially back country skiers must pay big attention when such snow crystals appear in the snow cover.

Similar to depth hoar is the so-called surface hoar which usually forms during cold, clear nights with calm conditions in the lowest meter of air. Surface hoar forms when the water vapour pressure in the air exceeds the equilibrium vapour pressure of snow grains at the surface (Picture 4). Especially buried surface hoar is a matter of avalanches because it can be a perfect gliding surface for slab avalanches like a depth hoar layer (McCLUNG and SCHAERER 1993).

Picture 4: Surface hoar formed on cold, clear nights

Pit2 shows a total height of 215 cm. Down to 162 cm it consists of new snow with a grain size of approximately 1 mm and a hardness of 4 fingers (Figure 2). The significant difference of the uppermost layer of those two pits could be explained by different wind influence. When comparing both profiles it is assumed that different participants have different methods and experience looking at a snow profile. Between 162 to 25 cm there is a snow layer with a hardness of pencil. Then you find a thin layer with hardness 4 finger and downwards again a layer with a hardness of pencil. The grain size of the latter layer is around 0.5 mm, the crystal type is decomposed snow. There was no ice layer observed like in pit1. The lowest layer contains sugar snow (depth hoar and faceted crystals) like in pit1 with a grain size 2 to 4 mm and a hardness of fist.

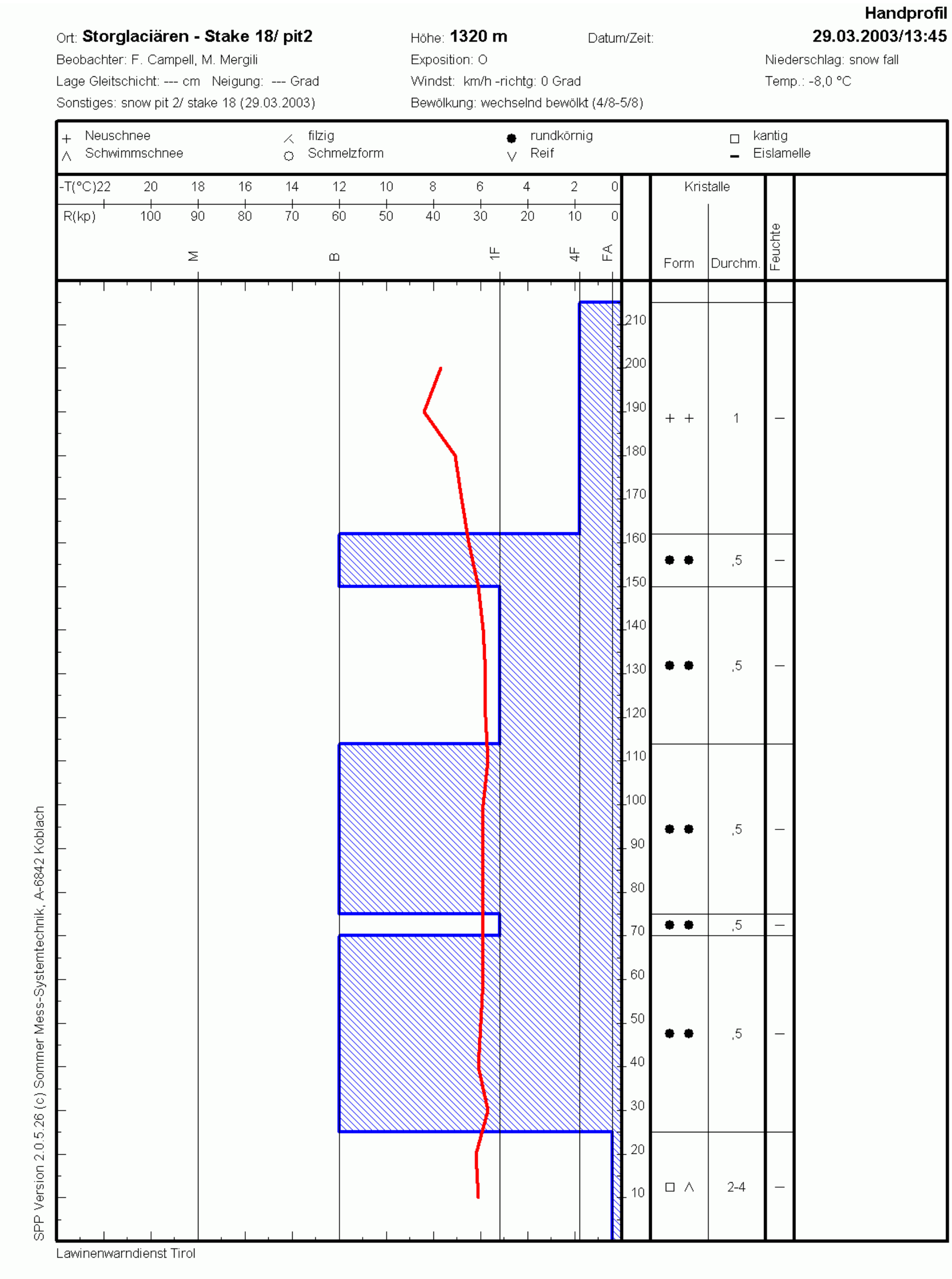

Figure 2: Snow stratification, snow temperature, and snow hardness (hand test) – pit2

.3.2 Snow Temperature

Snow temperature measurements shows nicely the short term influence of penetrating cold air into a snow pack especially in the lower layers (Figure 3). Between 40 and 140 cm snow temperature is colder in the profile which was done 35 minutes later than the first measurements at pit1. Up to approximately 90 cm above the ice surface the temperature is nearly constant for each measurement and fluctuated between -5.9 and -6.3 °C from pit1 to pit2. In the upper 40 cm there is a steady decrease of snow temperature and all three measurements come close to air temperature. In general the differences in the measured temperatures were within 0.2 °C which can be neglected. The temperature down to the bottom shows nicely the isolation effect of snow and the damping effect of a snow cover.

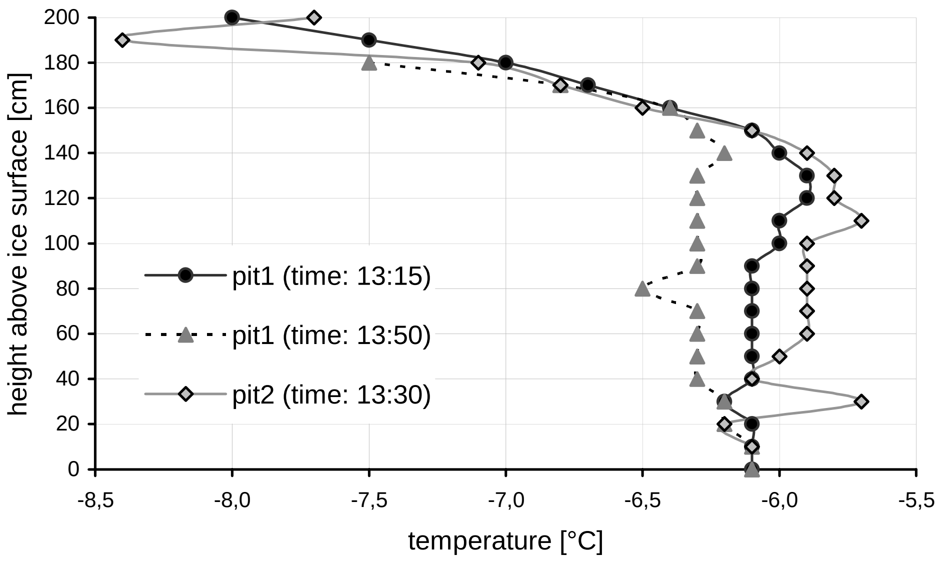

Figure 3: Snow temperature measurements pit1/ pit2 at stake 18 (29.03.2003)

.3.3 Snow density

Snow density (Figure 4 and Table 3) was increasing down to approximately 51 cm in measurement 1 and down to 40 cm in measurement 2 which corresponds with the hand test (Figure 1 and 2).

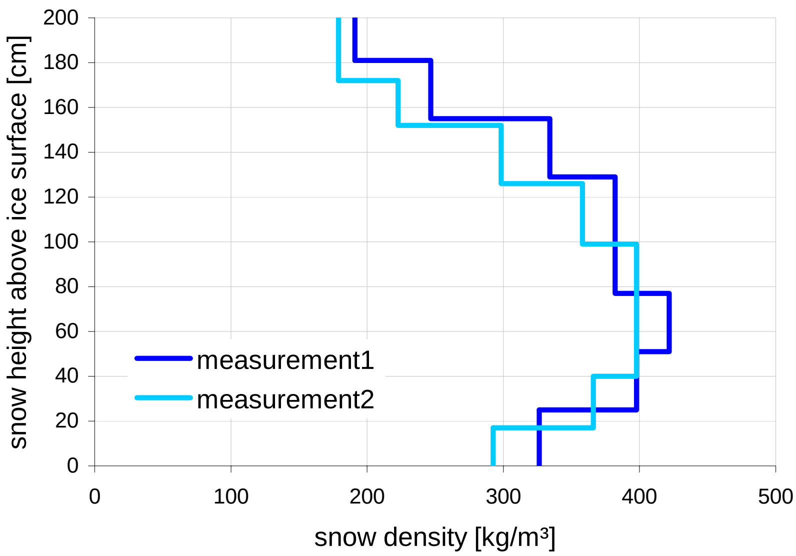

Figure 4: Snow density profile at pit2 stake 18 Storglaciären/ measurement 1 and 2 (30.03.2003)

Measurement 1					Measurement 2				
Height above ice surface [cm]		Weight [g]	Snow density [kg/m³]	Water equivalent [mm]	Height above ice surface [cm]		Weight [g]	Snow density [kg/m³]	Water equivalent [mm]
207	- 181	240	191	50	207	- 172	225	179	45
181	- 155	310	247	64	172	- 152	280	223	67
155	- 129	420	334	87	152	- 126	375	298	78
129	- 103	480	382	99	126	- 99	450	358	97
103	- 77	480	382	99	99	- 69	500	398	119
77	- 51	530	422	110	69	- 40	500	398	115
51	- 25	500	398	103	40	- 17	460	366	84
25	- 0	410	326	82	17	- 0	250	293	50
sum				694	sum				655

Table 3: Snow densities and water equivalent pit2/ measurement 1 and measurement 2 (30.03.2003)

The density profiles are also in agreement with typical densities given in literature (Table 4). Upper layers present new snow and damp new snow, layers which are closer to the bottom show settled or wind packed snow, the lowest layer presents depth hoar. The differences in the measurements are probably due to the different participants who took the profiles and also due to a lack of experience. But the snow density measurements show more or less expected values. Someone can nicely see the steady increase of density because of the load of the snow pack and the influence of wind which formed snow pack with high density.

Different material	Density [kg/m³]
new snow (immediately after falling in calm)	50-70
damp new snow	100-200
settled snow	200-300
depth hoar	100-300
wind packed snow	350-400
firn	400-830
very wet snow and firn	700-830
glacier ice	830-917

Table 4: Typical densities of different materials (PATERSON 1994)

.4 Conclusion

Snow profiles are of big interest for calculations of glacier runoffs. By measuring snow density and calculating the water equivalent on several points on the glacier one can make spatial and temporal calculations by modelling runoffs of the glaciers. An annual snow cover is especially important for glaciers because it protects the ice form from radiation and in consequence minimizes melting. The snow cover on glaciers also influences the runoff positively.

The avalanche risk in a high alpine area like the Kebnekaise massif should not be underestimated, although there are not so many accidents happening respectively reported like in the Alps. There is a big potential of avalanche terrain. The Kebnekaise area is influenced by strong winds and cold and long weather periods. As we know there are four main factors for the development of slab avalanches. Beside a certain slope angle you need a gliding surface, bonded snow on it and a loose connection between the bonded snow and the gliding surface. Wind is the "master of building avalanches" because snow which is transported by wind is always bonded snow. So also in this remote place in northern Sweden someone has to be aware of avalanches. Backcountry travellers should know how to analyse snow profiles (internal structure). Keep always your eyes open and do not hesitate to dig into the snow. It is much better to check it by your own. In case you are not sure how to interpret certain things just make the step to the safe side.

Acknowledgements

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References

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Pictures and Profiles

All pictures were taken by the author except Picture 1 which belongs to the Avalanche Warning Centre of the Tyrol. For drawing the profiles the snow profile program from the Avalanche Warning Centre of the Tyrol was used.