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SOME OBSERVATIONS ON SNOWPACK FEATURES IN NORTHERN VICTORIA LAND, ANTARCTICA

ABSTRACT: A. CAGNATI, *Some observations on snowpack features in Northern Victoria Land, Antarctica.* (IT ISSN 0391-9838, 1997).

The first results of snowpack observations carried out in Antarctica during the Italian scientific expedition in 1994/95 winter are presented here. In a mountainous area of about 50,000 km² in the Northern Victoria Land, where the Terra Nova Station is located, several conventional snow profiles were performed at variable depths, from some centimetres to a maximum of one metre according to situation. Observations have been carried out utilizing the traditional field instruments. In particular, for every snow profile the following characteristics were analysed: grain shape and grain size, hardness index, density, liquid water content and snow temperature. During the helicopter flights, observations on avalanche activity were also made. Analysis of snow profiles has high lighted some characteristics that distinguish antarctic from alpine snowpack. In general, a low structural diversification was found with an alternance of layers of small rounded particles and layers of faceted crystals. Hardness index profiles present on average patterms of «quasi-hydrostatic» type that confer a relative stability on the snowpacks. Snow characteristics integrated with climatological analysis of the period made possible to formulate some hypotheses on the low avalanche activity observed in the region.

KEY WORDS: Snowpack, Snow profiles, Avalanche activity, Antarctica.

RIASSUNTO: A. CAGNATI, *Alcune osservazioni sulle caratteristiche del manto nevoso nella Terra Vittoria Settentrionale, Antartide.* (IT ISSN 0391-9838, 1997).

Sono qui presentati i primi risultati delle osservazioni effettuate sul manto nevoso in Antartide durante la spedizione scientifica italiana dell'inverno 1994/95. In una regione montagnosa di circa 50.000 km² nella Terra Vittoria settentrionale, dove è ubicata la stazione di Terra Nova, sono stati eseguiti diversi profili del manto nevoso di tipo convenzionale fino a profondità diverse, da un minimo di qualche centimetro a un massimo di un metro a seconda delle situazioni. Le osservazioni sono state effettuate utilizzando la classica strumentazione da campagna. In particolare, per ciascun profilo, sono state analizzate le seguenti caratteristiche: forma e dimensione dei grani, indice di durezza, densità, contenuto in acqua liquida e tempertaura della neve. Inoltre, durante gli spostamenti effettuati con l'elicottero, sono state eseguite osservazioni sull'attività valanghiva. Le analisi dei profili hanno evidenziato alcune caratteristiche che differenziano il manto nevoso antartico dalle tipologie alpine. In generale, è stata riscontrata una bassa diversificazione strutturale con una alternanza di strati di grani arrotondati di piccole dimensioni e strati di cristalli sfaccettati. I profili degli indici di durezza presentano mediamente degli andamenti di tipo «quasi-idrostatico» che conferiscono una relativa stabilità al manto nevoso. Le caratteristiche del manto nevoso integrate con l'analisi climatologica del periodo, hanno consentito infine di formulare delle ipotesi sulla scarsa attività valanghiva osservata nella regione.

TERMINI CHIAVE: Manto nevoso, Profili del manto nevoso, Attività valanghiva, Antartide.

INTRODUCTION

Among one of the research activity of the Italian Antarctic Research Programme (Pnra), the 1994-95, field season was the carrying out of a radiometric measurements of the different kinds of snow and ice covers. The radiometric response of the surfaces, in terms of reflectance, facilitates identification of their nature on satellite pictures. During the tenth expedition, which took place during the winter 1994-95, beside the radiometric measurements, a series of observations on the snowpack were carried out in order to define the physical and structural features of the surface layers. The decreasing in radiation through the snowpack is in fact very rapid with the increase of depth, and it can be calculated that, in the case of new snow, from a depth of 30 to 50 cm, most of the radiation is discharged. However, also for the glaciological interest that the data gathered may have, in several cases observations were made to a maximum depth of 100 cm. Studies on the Antarctic snowpack, and in particular concerning the space-time variability of snow accumulation, have been carried out by several researchers (Palais & *alii*, 1982; Young & *alii*, 1982; Reinwarth & *alii*, 1982). During the same research programme, Italian researchers (Meneghel & *alii*, 1990) have recently carried out snowpack analyses for the purpose of

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glaciological study in the Browning Pass area. In addition to the possible implications of the studies on mass balance and on the dynamics of glaciers, the analyses carried out on Antarctic snowpacks are interesting precisely because they make possible the identification of several features which distinguish them from to Alpine types.

LOCATION OF STUDY AREA

The research was carried out in an area of about 50,000 km^2 in the Northern Victoria Land, where a permanent Italian base has been operative since 1985. The zone, at the western margin of the Ross Sea, lies betwen 73°-76° latitude South and 160°-166° longitude East (fig. 1) and is characterized by several coastal mountain chains which are, from south to north, the Prince Albert Mountains, the Deep Freeze Range, the Southern Cross Range and the Mountaineer Range. The highest peak in the zone is Mount Murchison (3,501 m), but many other peaks are over 3,000 m. Near the base, the main peaks are Mount Melbourne (2,732 m) whose volcanic cone is quite visible thanks to its isolated position, and Mount Nansen (2,737 m), which dominates the ice shelf bearing the same name. Ice cover, except for a few limited areas near the coast, takes up almost the whole territory and and is characterized, to the north, by several névés (vast snow plains acting as accumulation zones) and peripheric ice tongues (Aviator, Campbell), and to the south by outlet glaciers (David, Reeves and Priestley) which drain part of the eastern cap (Dome Circe and Talos Dome). The coastal zone is characterized by floating shelfs (either tabular flat glaciers extended toward the sea on which they float) or floating ice tongues. In particular, the outlets of Reeves and Priestley Glaciers join to form the Nansen Ice Shelf; while the David Glacier actually outflows to the sea for around 90 km (Drygalski Ice Tongue). The coastal margin is extensively occupied by pack and matrine ice also during the summer months.

As for the climatic features, there is a considerable variability in parameters in relation to altitude. However, the zone can be compared to the coastal mountain range category (according to Campbell and Claridge) with temperatures ranging between +5°C and –30°C (referring to sea-level) and snowfalls between 150 and 250 mm water equivalent. An average yearly accumulation of 300 mm water equivalent has been estimated on the ice tongue of the Campbell glacier (Zanon, 1989). The zone is also characterized by strong catabathic winds which blow from the cap along the valleys of the David, Reeves and Priestley glaciers, mainly during the winter, and cause an intense snow drift.

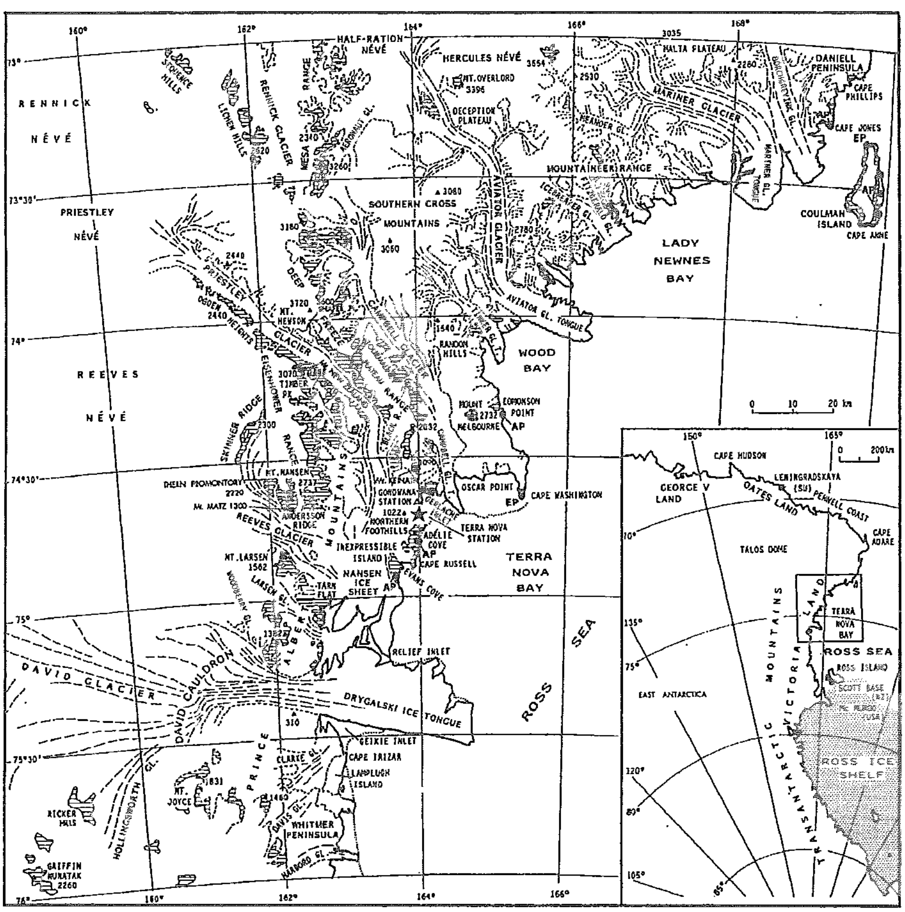

FIG. 1 - The Terra Nova Bay region in Northern Victoria Land, Antarctica (star indicates the position of the Italian Base Station) (Orombelli, 1989).

Starting from the base at Terra Nova Bay, measurements were made in 9 sites chosen according to their particular snow and ice features (fig. 1 and tab. 1). To reach the sites, distances between 25 km (Hells Gate Moraine) and 185 km (Hercules Névé) were covered in helicopter, exept for the measurements carried out near the base. The Hercules Névé site (2960 m) was also the highest reached.

TABLE 1 - Sites where snowpack measurements were made. The last column gives the types of measurements (Sa = snowpack analysis, Rp = ram profiles) the date of the same and, in brackets, the depth in cm at which they were carried out

MEASUREMENTS SITES				
LOCALITY	ELEVATION	COORDINATES	ENVIRONMENT	MEASUREMENTS
Terra Nova Bay (base) Sa 19.12.94 (6)	0 m	74°42'00" 164°08'00"	pack	Sa 08.12.94 (4)
Hells Gate Moraine	20 m	74°52'00" 163°48'00"	floating iceshelf	Sa 15 12 94 (30)
Nansen Ice Shelf	40 m	74°52'48" 163°00'00"	floating ice shelf	Sa 07.12 94 (18)
Drygalski Ice Tongue	50 m	75°31.028' 165°21.891'	floating ice tongue	Sa+Rp 10.12.94 (50) Sa+Rp 08.01.95 (100)
Reeves Névé	1220 m	74°39.720' 161°35.320'	névé	Sa 06.12.94 (50) Sa 13.12.94 50) Sa+Rp 30.12.94 (100)
Mc Carthy Ridge	650 m	74°34.485' 163°03.957'	névé	Sa+Rp 21.12.94 (97) Sa+Rp 28.12.94 (83)
Styx Glacier	1660 m	73°51.490' 163°41.275'	névé	Sa+Rp 21.12.94 (100) Sa+Rp 09.01.95 (90)
Hercules Névé	2960 m	73°06'23" 165°27'47"	névé	Sa+Rp 24.12.94 (79)
Priestley Névé	1983 m	73°38'18" 160°38'32"	névé	Sa+Rp 11.01.95 (55)

OBSERVATION METHODS

Conventional type ram profiles and snowpack analyses were carried out in all sites during the period 01.12.1994-13.01.1995. Some sites were visited several times during the period, for the purpose of analysing any variations due to weather factors. The parameters measured were the following: layer thickness, grain shape, grain size, liquid water content, snow hardness, density and snow temperature.

The hardness measurements were carried out using a Swiss rammsonde (cone tip angle: 60°, base diameter: 40 mm, tube weight: 10 N/m, ram weight: 10 N) and also using the hand test. To examine the grain shape and size, a 10X lens equipped with reticle at 1/10 mm was used. Snow density was measured by horizontal sampling carried out every 10 cm, with 0.5 l sampler and 500 g dynamometer, whereas the snow temperature was measured on the surface and along the section every 10 cm by a digital electronic thermometer. The liquid water content was estimated in the very few cases where this was present in the snowpack.

In all, 9 ram profiles and 15 snowpack analyses were carried out. The measurements were made to various depths, from a minimum of a just a few cm to a maximum of 1 m, depending on the situation. In several cases (Hells Gate Moraine, Nansen Ice Shelf, Terra Nova Bay) the limit was determined by the presence of underlying ice, and in other cases (Reeves, Hercules Névé) the deep layers of past years, constituted by firn were so hard that measuring with traditional snow-instruments was impossible. And lastly, the measurements in other cases were interrupted because of the limited time available, or by the extreme environmental conditions (very strong wind with snow drift). As regards the radiometric measurements, all measurements were made on flat ground free of obstacles or nearby slopes.

As regards the standard used in the descriptions, the International Snow and Ice Commission's «International classification for seasonal snow on the ground», recently published and used in Italy by avalanche services, was referred to.

SNOWPACK FEATURES

In general, the Antarctic snowpack has a poor structural diversity (compared with the Alpine snowpack) and mainly consists of a sequence of rounded grains (monocrystals) and layers of faceted crystals where the all important part played by the wind often is evident (fig. 2). In the hottest and sunniest sites these layers are often broken up by thin layers of ice or sun crust which correspond to brief periods of surface melting, and sometimes enable identification of the yearly accumulation of snow on the ground. In areas exposed to the wind, they are often made up of wind crust recovered by subsequent accumulations. Naturally, after the precipitations, superficial layers of recent snow can be found, but in general, they are rapidly compacted by the wind and some hours after the end of the falls, the crystals of fresh snow are already transformed into monocrystals.

Grain shape and size

Regarding the morphological aspect of the grains, a clear prevalence of layers made up of rounded grains (monocrystals) was found. Since the snow has a high density and therefore low porosity (due to the strong action of the wind) the growth rate of the grains is rather low and hence small particles prevail (3a), having dimensions between 0.3 and 0.5 mm. In several cases, particles smaller than 0.3 mm were found. Mixed forms (3c o 4c) were also very frequent, especially in those situations characterized by significant temperature gradients. In such cases, the most frequent sizes of individual particles were from 0.6 to 0.9 mm. (tab. 2). The solid faceted particles (4a) with dimensions of 1 and 2 mm, even if present, are not very frequent, and this can be attributed to the low kinetic growth rate of the crystals. Depth hoar was never found in any of the measurements made, whereas in several locations that were particularly protected from the wind (Mc Carthy Ridge and Styx Glacier) the snowpack had a layer of surface hoar crystals (7a); this was formed both by long flat crystals of dimensions up to 3 mm, and by striated flat crystals of dimensions of 1 mm. And again in the sites which are protected from the wind, there are small faceted particles (4b) in the surface layer; these particles were probably directly formed by precipitation particles due to the high surface temperature gradients. In several rather hard, dense layers

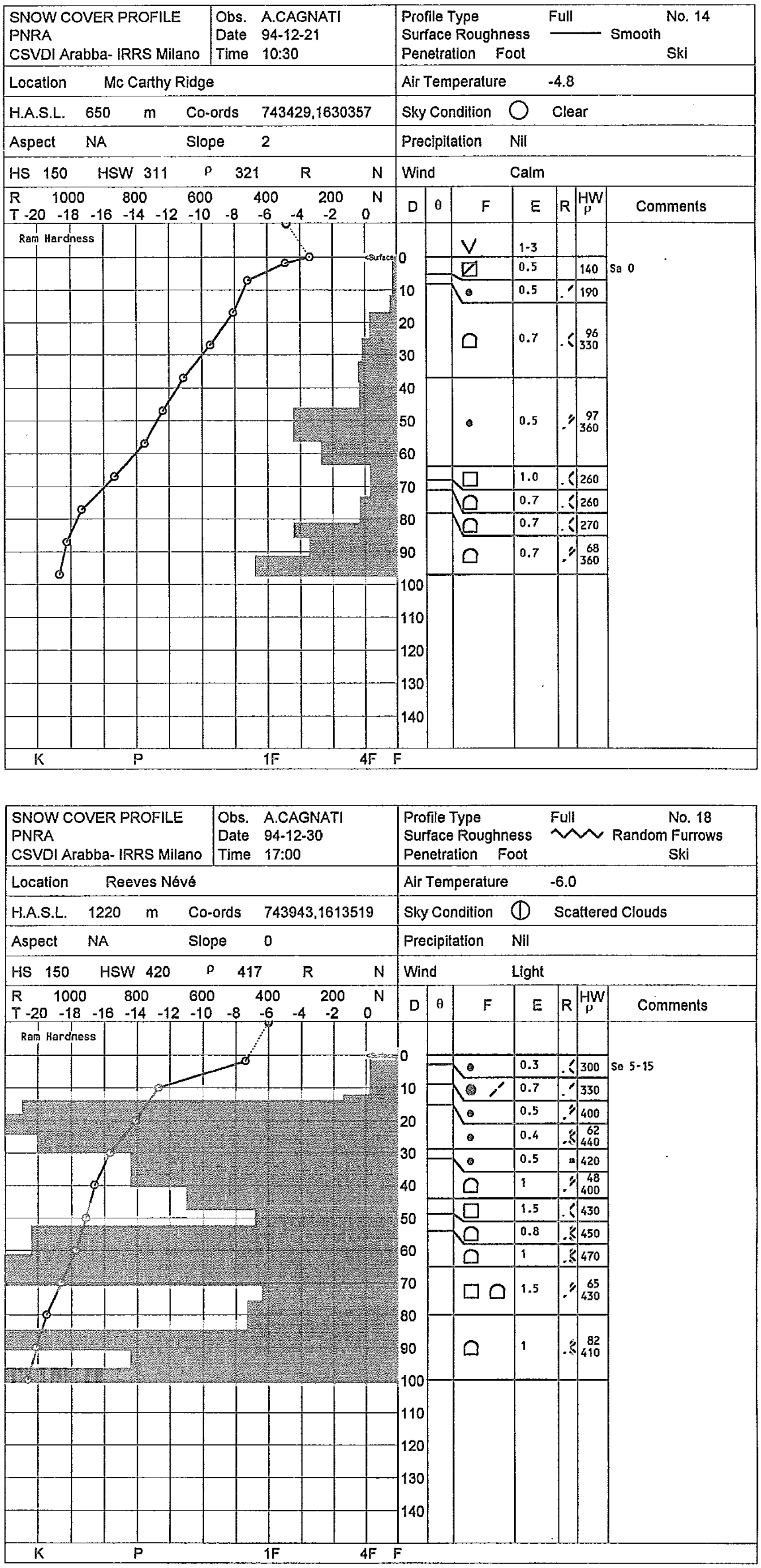

FIG. 2 - Snow profiles carried out in a site protected from the wind (Mc Carthy Ridge, 94.12.21) and in a very windy site (Reeves Névé, 94.12.30). In the former case (less common) the snowpack evolution is very similar to Alpine snowpack, whereas in the latter case (more common) the all-important action of the wind can be clearly seen. (Note in both cases, the reverse temperature trend with respect to Alpine snowpack).

TABLE 2 - Percentage distribution of the morphological classes in 5 different size classes

Grain shape	< 0.3 mm	0.3-0.5 mm	0.6-0.9 mm	1-2 mm	> 2 mm
Precipitation particles					
Fragmented particles					
Surface hoar (classes 1,2 and 7a)		12%	25%	63%	
Small faceted particles (class 4b)		75%	25%		
Rounded particles (classes 3a and 3b)	8%	67%	23%	2%	
Solid faceted particles (class 4a)				100%	
Mixed forms (classes 3c and 4c)		11%	62%	23%	
Rounded polycrytals (classe 6b)					100%

(around 0.4) a polycrystal structure with smallish (0.2-0.5 mm) grains is found, but this is presumably due to the strong action of compaction by the wind, even if, especially in less windy places like Styx Glacier, an additional contribution by the refreezing of melting water cannot be excluded.

Snow hardness

Considering those measurements where it was possible to carry out a ram profiles test up to a depth of at least 50 cm (9 cases), for thickness intervals of 5 cm, the average hardness values generally increase with depth (fig. 3). This gives rise, at least for the more superficial layers, to profiles of the quasi-hydrostatic type which contribute to stabilizing the snowpack. However, though confirming this general trend which has also been found by other researchers (Meneghel & *alii*, in the Browning Pass zone), especially in the depth range of 50 to 100 cm, frequent trend reversals corresponding to the presence of layers made up of small rounded particles, are evident.

Density

The snow-density values measured ranging between 0.12 and 0.49, with no clear trend being noted in an increase of density with depth, at least with respect to the first metre. This is due to the presence, in certain cases, of layers formed of faceted or mixed form particles where the stage of more or less fast kinetic growth brought about an increase in porosity. As shown in tab. 3, the trend is confir-

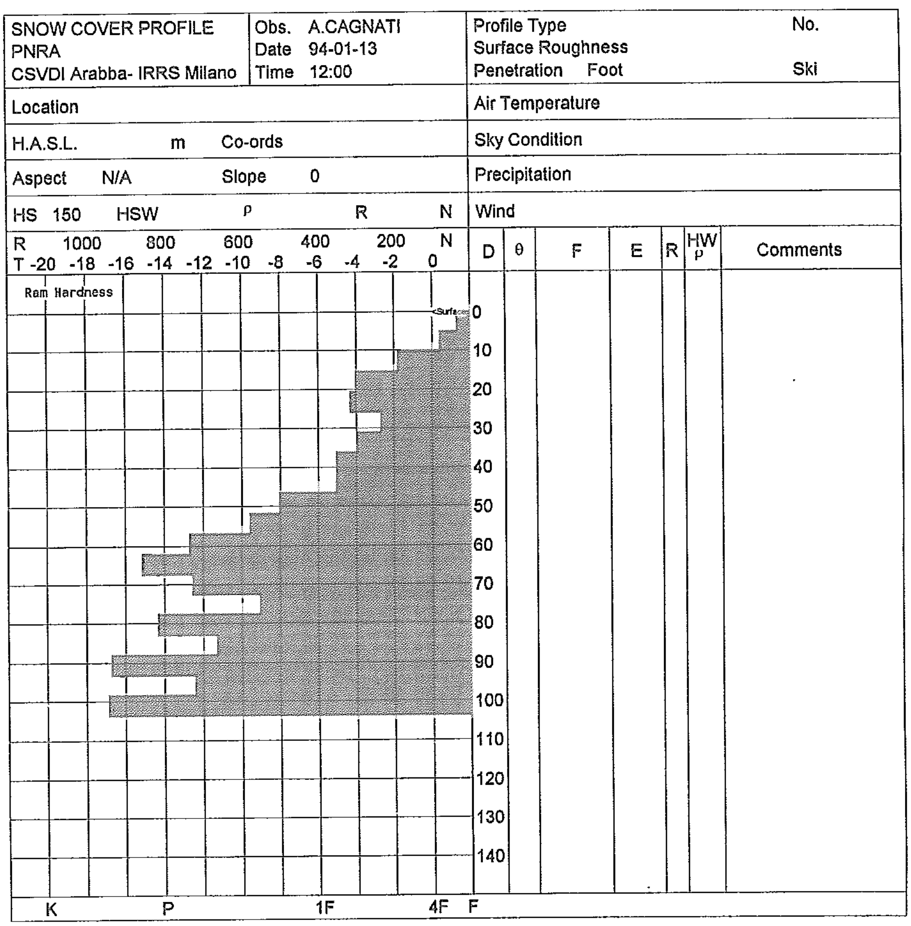

FIG. 3 - The average trend of the snow hardness (averages of data relative to 9 snow profiles carried out in the period 94.12.01-95.01.13).

TABLE 3 - Snow density for 3 different depth classes (the groupings relative to the morphological classes were pre-defined according to the assumed homogeneity with respect to the density parameter)

Grain shape	Depth class 0-15 cm	16-45 cm	46-100 cm	average
Precipitation particles and fragmented particles (classes 1 and 2) sometimes with surface hoar or small faceted particles (classes 7a and 4b)	0.15			0.15
Rounded particles (classes 3a and 3b)	0.35	0.39	0.40	0.38
Solid faceted particles and mixed forms (classes 4a, 3c and 4c)	0.31	0.36	0.36	0.34

med for the same class of grains. The slight differences in density between depth class 15-45 cm and depth class 45-100 cm, more than a stabilization in values, are due to the fact that in the 45-100 cm class there are less data available because several snowpack analyses, especially in the case of very hard snowpacks, and hence with high density values, were carried out only to a depth of 50 cm. The lowest values, with averages of around 0.15, obviously refer to recent snow (precipitation particles or decomposing and fragmented particles). It must be remembered that for reasons connected to radiometric measurement needs, no measurements were taken during precipitations. The absolute lowest density value of 0.12 refers to a layer of recent snow measured at the Terra Nova Bay site after a precipitation lasting two days. The layer was formed of graupel snow and fragmented particles which were originally needles. The highest density values were measured in windy sites where the wind compacting action is more marked. At the Reeves Névé site, which is particularly subject to catabathic winds, densities of 0.49 were measured at a depth of about one metre and of 0.41 at a depth of 30 cm. The small rounded particles (class 3a) have densities of between 0.35 and 0.39 whereas the faceted crystals included in this category are both solid faceted particles (class 4a) and the mixed form (class 3c or 4c) have values between 0.31 and 0.36. Generally it can be said that for the same grain class the density values of Antarctic snow are 0.05 higher than the values of corresponding classes of Alpine snow.

Liquid water content

The presence of water in the liquid state inside the snowpack is rather a random factor and is tied to particular microclimatic conditions. In one single measuring carried out at Hells Gate Moraine, a locality near the coast, a surface layer of wet snow (water content < 3% of the volume) was measured. In this case the air temperature was 2.2°C and surface temperature of the snow was 0°C.

Temperatures

Unlike what happens in the Alpine-type snowpacks, the temperatures decrease with depth. The vertical temperature gradient is therefore the opposite, and while it is rather variable in the first 10 cm, and is considerably affected by the air temperature (hence an average value has little meaning), below this it tends to stabilize and the average value gap diminishes. For depths from 10 to 50 cm, values between 0.03 and 0.24 °C/cm were measured, with an average of 0.12 °C/cm, whereas from 50 to 100 cm the values vary from 0.07 to 0.13 °C/cm with an average of 0.10 °C/cm (tab. 4). Even if only three depth classes were analysed, it appears clear that the vertical temperature gradient decreases with depth. The individual temperature values of the snow measured naturally depend on the weather conditions of the station (nearness to the coast and altitude). The lowest values to a depth of 50 cm were measured in the two continental-like stations of Hercules Névé (2960 m) and Priestley Névé (1983 m), with respectively -26.9 °C and –22.3 °C (air temperatures of –14.2 °C and –22.1 °C). In one single case, at Hells Gate Moraine, a surface snow temperature of 0°C was measured.

TABLE 4 - Average vertical temperature gradient of the snowpack and standard deviation for 3 depth classes

	Depth class 0 - 10 cm	10 - 50 cm	50 - 100 cm
Vertical temperature gradient (°C/cm)	0.42	0.12	0.10
Standard deviation	0.34	0.06	0.03

AVALANCHE ACTIVITY

The natural avalanche activity measured in the zone concerned was modest or almost absent, except for fresh snow slides caused by the falling of seracs. At first sight this fact may appear surprising, because the territory visited is mainly characterized by an Alpine morphology with typical avalanche terrain. Furthermore, in the 44 days' stay at the Terra Nova Bay base, there were 11 days with snowfall, with an overall accumulation of about 30 cm of fresh snow (on the coast) and the snowfalls were often accompanied or followed by strong winds. Even though the causes determining the low avalanche activity were not investigated, several assumptions can be made:

– the scarcity of fresh snow for individual snowfalls (rarely over 10-15 cm) from time to time produces a modest additional load on the pre-existing snowpack;

– the constant wind action which, in addition to producing deposits of drifted snow, causes the fresh snow crystals to break up into very small particles, and hence a very strong compaction of the deposits (lack of soft wind-slabs and a rapid destructive metamorphism, with subsequent stabilizing of the layer);
– the lack of depth hoar in the more superficial layers, because of kinetic growth difficulty of the grains due to the low porosity of the snowpack (the eventual presence of depth hoar in the deep layers becomes irrelevant to stability because the snowpack is consolidated by the high-density layers above, which form a bridge);
– the lack in the snowpack of water in the liquid state, which has a lubricating action in the surfaces separating the various layers;
– the «quasi-hydrostatic» trend in hardness of the layers with increasing depth (this is an indicator of the snowpack stability).

Certainly this aspect merits a more thorough investigation, with extensive field controls.

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