United Nations
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# THE INTERNATIONAL CLASSIFICATION FOR SEASONAL SNOW ON THE GROUND

IHP-VII

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United Nations Educational, Scientific and Cultural Organization

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IACS

International Association of Cryospheric Sciences

# The International Classification for Seasonal Snow on the Ground

*Prepared by the ICSI-UCCS-IACS Working Group on Snow Classification*

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## FOREWORD

Undoubtedly, within the scientific community consensus is a crucial requirement for identifying phenomena, their description and the definition of terms; in other words the creation and maintenance of a common language. While there is broad agreement on the requirement, finding volunteers to do the job is not always easy. We all like performing science, but no one really likes to do the hard work of providing a classification, e.g., of snow on the ground. *Charles Fierz* has dedicated much of his time over the past years to provide this extraordinary service to the snow and avalanche community. As Head of the Division on Seasonal Snow Cover and Avalanches of the International Commission on Snow and Ice, ICSI, he, together with colleagues, identified the need for a revision of the existing classification, took the lead in organising a working group, inspired the participation and contribution of a broad variety of colleagues, persisted over the years, and now gives us the revised *International Classification for Seasonal Snow on the Ground*. Charles also negotiated the publication of the classification, finally finding support from UNESCO-IHP, to which the International Association of Cryospheric Sciences, IACS, expresses its gratitude.

This revised snow classification is the first product delivered under the auspices of IACS. IACS was approved by the council of the International Union of Geodesy and Geophysics, IUGG, in July 2007 as its eighth association. Previously, ICSI had developed its activities and international awareness to a level at which the commission status within the International Association of Hydrological Sciences, IAHS, was recognised as inappropriate. With this first product IACS also proves its direct legacy to ICSI, which had already provided sponsorship of The International Classification for Snow – with special reference to snow on the ground in 1954 and the 1990 International Classification for Seasonal Snow on the Ground.

On behalf of the International Association of Cryospheric Sciences, I gratefully acknowledge the debt which we all owe to all authors of this work.

*Innsbruck*
*January 2009*

**Georg Kaser**
*President*
*International Association of Cryospheric Sciences*

## ACKNOWLEDGEMENTS

As in the past, it is probably impossible to provide a classification that will truly satisfy all levels of users in all countries. However, this present document offers a reasonable solution because from the beginning we have involved a broad community of snow scientists and snow practitioners in the updating process. In this revised classification, we expanded and clarified where necessary but did not include those most recent developments that are not fully agreed upon by the whole community.

Informal discussions with *J. Bruce Jamieson* and *Jürg Schweizer* initiated the idea for the present revision of the International Classification for Seasonal Snow on the Ground. Under the auspices of *Paul Föhn*, Head of the Division on Seasonal Snow Cover and Avalanches, the Working Group was installed in 2003 by the Bureau of the former International Commission on Snow and Ice, ICSI. Its successors, UCCS and finally IACS, the International Association of Cryospheric Sciences, always strongly supported the work. The chair of the 1990 Working Group, *Sam Colbeck*, was also very much in favour of this revision. His encouragement and feedback were always highly appreciated.

Needless to say, such a work could not have been completed without the support, the help, and the suggestions for improvements from many people. In particular, I would like to acknowledge the work of a large panel of snow practitioners and scientists who helped to improve substantially the present document by giving either their personal or consolidated feedback on the final draft of the revised International Classification for Seasonal Snow on the Ground: *Edward E. Adams, Roger G. Barry, Peter Bebi, Karl W. Birkeland, Anselmo Cagnati, Cam Campbell, J. Graham Cogley, Stephan G. Custer, Florent Dominé, Peter Gauer, Martin Heggli and colleagues, Erik Hestnes and colleagues, J. Bruce Jamieson, Michael Kuhn, Spencer Logan, Adrain McCallum, Ron Perla, Atsushi Sato, Martin Schneebeli, Jürg Schweizer, Thomas Stucki, Matthew Sturm,* and *Simon Walker and colleagues*. Finally, the text of the classification would not read as smoothly without the careful editing work of *Betsy Armstrong*.

Several people and organizations took responsibility for checking and providing suitable translations for the multilingual list of terms: the Centre d'Etudes de la Neige, members of the Canadian committee for a standardized Avalanche Bulletin Vocabulary, as well as *Florent Dominé* (French), *Andres Rivera* and *Javier Corripio* (Spanish), *Sergey A. Sokratov* (Russian), and the Swiss Avalanche Service (German).

UNESCO (www.unesco.org) through its International Hydrological Programme, IHP, agreed to publish the revised International Classification for Seasonal Snow on the Ground in the series *IHP Technical Documents in Hydrology*. We are thankful to *Siegfried Demuth*, head of the section on Hydrological Processes and Climate at IHP, who pursued the long standing collaboration between UNESCO/IHP on one side and IACS and its predecessors on the other. The publishing of a hard copy version of the International Classification for Seasonal Snow on the Ground will undoubtedly help meet the goal of making the classification available to as many groups of interested users as possible. By providing authoritative translations of the classification, as well as additional versions of the multilingual list of terms on its website (www.cryosphericsciences.org), IACS will further contribute to the dissemination of the classification.

The International Glaciological Society, IGS, graciously and professionally typeset the document, thereby underlining the good relationship among cryospheric organizations.

*Stefan Huber*, student at the 'Zürcher Hochschule der Künste ZHdK' under the supervision of *Rudolf Barmettler*, Design Department, designed the symbol font used in this document. This would not have been feasible without the financial support from the WSL Institute for Snow and Avalanche Research SLF in Davos. The symbol font will be made available for free on the IACS website.

Finally, I would like to personally thank all members of the Working Group who provided support and guidance throughout the five-year duration of this work. Among them, *Ethan Greene* should be recognized for having collected and summarized the different views on snow microstructure from *Edward E. Adams*, *Jean-Bruno Brzoska*, *Frédéric Flin*, *Martin Schneebeli*, and *Sergey A. Sokratov*. I particularly thank *Ethan Greene* for his continuing support through all phases of this revision.

Finally I would also like to warmly acknowledge my home institution, the WSL Institute for Snow and Avalanche Research SLF in Davos, and in particular the head of the research unit Snow and Permafrost, *Michael Lehning*, for giving me the opportunity and the time necessary to complete this task.

*Davos*
*January 2009*

**Charles Fierz**
*Chair*
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## INTRODUCTION

Snow research is an interdisciplinary field, as reflected in variety of books dedicated to snow and its various aspects, such as *Handbook of Snow: Principles, Processes, Management and Use* (Gray & Male, 1981), *The Avalanche Handbook* (McClung & Schaerer, 2006), *Snow Ecology: An Interdisciplinary Examination of Snow-Covered Ecosystems* (Jones *et al.*, 2001) and *Snow and Climate: Physical Processes, Surface Energy Exchange and Modeling* (Armstrong & Brun, 2008) to cite only a few. Such a wide range of interest and knowledge in snow makes common descriptions of snow as well as common measurement practices very desirable.

The International Commission of Snow and Glaciers of the International Association of Scientific Hydrology, IASH, recognized this need in 1948 by appointing a committee to report as soon as possible on the possibilities of standardizing an international snow classification system. This resulted in the 1954 publication, *The International Classification for Snow – with special reference to snow on the ground* (Schaefer *et al.*, 1954), issued by the then named International Commission on Snow and Ice, ICSI, of IASH. Over time, knowledge about snow processes increased and observation practices differed increasingly from country to country. That is why in 1985 ICSI, now of IAHS, the International Association of Hydrological Sciences, established a new committee on snow classification. Five years later, a fully revised and updated *International Snow Classification of Seasonal Snow on the Ground* was issued (Colbeck *et al.*, 1990).

This work has been widely used as a standard for describing the most important features of seasonal snow on the ground and is often cited in publications where a common description is needed. The 1990 classification is also well accepted by practitioners world wide, providing the basic framework aimed at in 1954, namely:

*To set up a classification as the basic framework which may be expanded or contracted to suit the needs of any particular group ranging from scientists to skiers. It has also to be arranged so that many of the observations may be made either with the aid of simple instruments or, alternatively, by visual methods. Since the two methods are basically parallel, measurements and visual observations may be combined in various ways to obtain the degree of precision required in any particular class of work.*

Since 1990 our collective knowledge of snow and the techniques we use to observe its characteristics have evolved. Thus, in 2003, the current classification (Colbeck *et al.*, 1990) needed an update, but the users of the 1990 classification felt that corrections and additions should be kept to a minimum. Following the spirit of the previous editions, the Working Group on Snow Classification took care to again provide a concise document usable by user groups of quite different specialties: snow scientists, practitioners, scientists from other fields, as well as interested lay persons. However, classification schemes typically become more technical as knowledge, measurement techniques, and observation methods evolve.

The classification deals primarily with seasonal snow, even though many concepts in the present snow classification can also be applied to firn, which is the first stage in the formation of glacier ice. Definitions and tools are provided mainly to describe point observations of the snowpack, e.g., from snow pit work. However, the classification does not attempt to classify snow covers from a climatic point of view, a topic that is dealt with in other publications (Sturm *et al.*, 1995).

Precipitation particles are included in much the same way as was proposed in 1948. This neither renders the full variety of solid hydrometeors, such as the specialised classification of Magono & Lee (1966), nor does it fully correspond to the way solid hydrometeors are coded according to WMO standards (WMO, 1992). However, it provides a useful framework for classifying the first, usually short lived, stage of seasonal snow on the ground.

The grain shape classification is augmented by one new main class (Machine Made Snow, MM), a few additional sub-classes, and a redistribution of the old surface deposit sub-classes among other main classes. The abbreviation code is no longer alphanumeric, helping to do away with the idea of a tree-like classification that cannot represent the subtleties of snow metamorphism. The new code helps avoid misunderstandings and adds flexibility to the classification scheme. Users of this classification should keep in mind that a snow layer cannot be classified with a single parameter such as grain shape. Finally, the 1990 process-oriented classification has been merged with the description of the process itself. This avoids repetition and allows for a more focussed description of the processes at work.

Promising research tools and methods such as the Snow Micro Penetrometer, Near Infrared Photography, or 3D-tomography are neither included nor mentioned in this document. Although they offer quantitative methods of characterizing snow layers, their use has not yet reached the point where they can be considered a standard method for both research and operations. Appendix B provides a discussion of the most promising snow microstructure parameters currently in use. This was included to give snow scientists a common language to describe the microstructure of snow, even though full consensus among experts in the field has not yet been reached.

We considered including special sections or appendices on forest snowpacks and surface formations (mainly in polar regions). However, there was no clear consensus among experts working in the field to produce a standard for these observations. In future, the International Association of Cryospheric Sciences, IACS, will establish a permanent agenda item entitled 'Standards and Classifications´, to be discussed at each Bureau Meeting. In this manner, the IACS Bureau expects to be able to react more promptly and flexibly to future developments related to standards and classifications in any field of the cryospheric sciences. Input from the cryospheric community to this agenda item will always be welcome. In addition, companion documents, the symbol font and an XML-based international exchange format for snow profiles will be made available on the IACS website.

Part 1 of the classification describes the fundamental characteristics of snow on the ground as well as a link to snow microstructure that is examined in Appendix B. Part 2 introduces additional features of snow as well as important measurements of the snow cover. Appendix A presents the grain shape classification, including photographic material. Basic guidelines for snow and snowpack observations are provided in Appendix C. The final three Appendices list the symbols used (D), define principal terms used in the text (E), and present a multilingual list of terms (F). A comprehensive but non-exhaustive bibliography completes the document.

The units used in this document conform to the Système International d'Unités, the International System of Units or SI system. Note that we use the complete set of SI units that includes the coherent set and the multiples and submultiples of the latter formed by combining them with the SI prefixes; e.g., both the millimetre and the centimetre belong to this complete set (see BIPM 2006, p. 106).

# 1 FEATURES OF DEPOSITED SNOW

From the time of its deposition until melting or turning from firn to ice, snow on the ground is a fascinating and unique material. Snow is a highly porous, sintered material made up of a continuous ice structure and a continuously connected pore space, forming together the snow microstructure. As the temperature of snow is almost always near its melting temperature, snow on the ground is in a continuous state of transformation, known as metamorphism. At the melting point, liquid water may partially fill the pore space. In general, therefore, all three phases of water can coexist in snow on the ground.

Due to the intermittent nature of precipitation, the action of wind and the continuously ongoing metamorphism of snow, distinct layers of snow build up the snowpack. Each such stratigraphic layer differs from the adjacent layers above and below by at least one of the following characteristics: microstructure or density, which together define the snow type, additionally snow hardness, liquid water content, snow temperature, or impurities that all describe the state of this type of snow (see also Table 1.1). Thus, at any one time, the type and state of the snow forming a layer have to be defined because its physical and mechanical properties depend on them.

For practical reasons, the sintered ice structure of snow is usually disaggregated into single particles for recording both grain shape and grain size instead of characterizing microstructure itself, thereby loosing most information on grain bonds (interconnections). In this context, ‘particle’ and ‘grain’ are used interchangeably. While the former may consist of several single crystals, the latter, strictly speaking, would stand for one single crystal of ice only.

**Table 1.1** Primary physical characteristics of deposited snow

| *Characteristic* | *Units* | *Symbol* |
|---|---|---|
| Microstructure | see Appendix B | |
| Grain shape | | $F$ |
| Grain size | mm | $E$ |
| Snow density | kg m$^{-3}$ | $\rho_s$ |
| Snow hardness | depends on instrument | $R$ |
| Liquid water content | either volume or mass fraction | $\theta_w$, $LWC$ |
| Snow temperature | °C | $T_s$ |
| Impurities | mass fraction | $J$ |
| Layer thickness | cm | $L$ |

Lateral heterogeneities inherently occur on spatial scales larger than that of a point observation of the snowpack. Heterogeneities on the point scale, e.g., within a snow pit, can occur within snow layers for various reasons such as wind, water percolation, or snow unloading from trees. Inhomogeneous water percolation into a subfreezing snowpack leads to the formation of flow fingers and ponding or flow along capillary barriers. Subsequent refreezing of this percolating water often results in horizontal and vertical solid ice formations that can be found anywhere within the snowpack.

These features can be taken into account by adding a description of the extent and shape of the disturbance and, if necessary, by classifying the snow within the disturbed areas separately. The latter is certainly the case for forest snowpacks and Pielmeier & Schneebeli (2003) report on one such specialised classification scheme.

The standard features of snow enumerated above and in Table 1.1 are defined further below, while more detailed guidelines for snow and snowpack observations are included in Appendix C.

## 1.1 Grain shape (form)

*Symbol: F*

Table 1.2 displays the main morphological classes of grain shapes. This basic classification is augmented by subclasses in Appendix A.1, where a process-oriented characterisation of all sub-classes supplements the morphological classification. This side-by-side representation of morphological classification and physical processes should help various user groups arrive at a more reliable classification and an easier physical interpretation of their observations.

Main grain shape classes are classified by using either a symbol or a unique two-letter upper case abbreviation code. Subclasses are classified either by using the proper symbol or a four-letter abbreviation code, where two lower case letters are appended to the main class code. This abbreviation code will be useful for electronic data exchange formats while colours may be used for continuous representations in either space or time, e.g., in outputs of snowpack models. A convention on colours to use for the main classes is given in Appendix A.2.

**Table 1.2** Main morphological grain shape classes

| *Class* | *Symbol* | *Code* |
|---|---|---|
| **P**recipitation **P**articles | + | PP |
| **M**achine **M**ade snow | ⊚ | MM |
| **D**ecomposing and **F**ragmented precipitation particles | ⁄ | DF |
| **R**ounded **G**rains | ● | RG |
| **F**aceted **C**rystals | □ | FC |
| **D**epth **H**oar | ∧ | DH |
| **S**urface **H**oar | ∨ | SH |
| **M**elt **F**orms | ○ | MF |
| **I**ce **F**ormations | ▬ | IF |

The arrangement in main and subclasses does not represent a temporal evolution of snow in the snowpack as some specialised classifications do (Sturm & Benson, 1997; Kolomyts, 1984). On the other hand, shape alone cannot fully characterise a snow type and its state.

If obviously different classes of grain shapes are present in a layer, they may be characterised individually, putting either symbol or abbreviation code of the minority class in round brackets. However, symbols and abbreviations should not be used together. Additional attributes such as riming, grain interconnections, etc., can be used to refine the description of the grain shape by adding it as a comment to the layer (see Appendix C).

Grain shape is most easily determined in the field by using a crystal card and a magnifying glass (8× magnification at least), while a stereo-microscope may be required for specialised work. Preserving methods allow classification of field collected grains afterwards in a cold laboratory (Lesaffre *et al.*, 1998).

## 1.2 Grain size

*Symbol: E*

The classical grain size $E$ of a snow layer is the average size of its grains. The size of a grain or particle is its greatest extension measured in millimetres. Alternatively, $E$ can be expressed by using the terms in Table 1.3. Some users will want to also specify the average maximum size $E_{max}$ (See Appendix C) or even a distribution of sizes. Note that grain size must be regarded as a property of the snow layer and not of the grain shape or shapes.

A simple method suitable for field measurements is to place a sample of the grains on a plate that has a millimetre grid (crystal card). Both average size and average maximum size are then estimated by comparing the size of the grains with the spacing of the grid lines on the plate. Both these estimates correspond well to values retrieved by image processing but may differ from those obtained by either sieving or stereology (Fierz & Baunach, 2000).

**Table 1.3** Grain size

| *Term* | *Size* (mm) |
|---|---|
| very fine | < 0.2 |
| fine | 0.2–0.5 |
| medium | 0.5–1.0 |
| coarse | 1.0–2.0 |
| very coarse | 2.0–5.0 |
| extreme | > 5.0 |

However, classical grain size $E$ may not always be the physically relevant size to describe, e.g., the grain size determined from standard field techniques may not adequately represent the electromagnetic properties of snow. For this purpose, a so called optical-equivalent grain size, *OGS*, can be defined (see, e.g., Grenfell & Warren, 1999). Optical-equivalent grain size is related to the specific surface area and therefore to the microstructure of snow (see Appendix B). Although *OGS* depends on the wavelength of the electromagnetic waves of interest, the concept is equally applicable from the visible throughout to the microwave range. It is therefore particularly useful for remote sensing applications. To a first approximation, *OGS* can be estimated from the branch width of dendrites, the thickness of either thin plates or dendrites, the diameter of needles, or the shell thickness of hollow crystals (Mätzler, 2002; Aoki *et al.*, 2003).

## 1.3 Snow density

*Symbol:* $\rho_s$

Density, i.e., mass per unit volume (kg m$^{-3}$), is normally determined by weighing snow of a known volume. Sometimes total and dry snow densities are measured separately. Total snow density encompasses all constituents of snow (ice, liquid water, and air) while dry snow density refers to the ice matrix and air only.

Although snow density is a bulk property, an accurate value is necessary for microstructure based studies (see Appendix B). Note that an alternative method to measure density in the field is by taking advantage of the dielectric properties of snow (Denoth, 1989; Mätzler, 1996).

## 1.4 Snow hardness

*Symbol:* $R$

Hardness is the resistance to penetration of an object into snow. Hardness measurements produce a relative index value that depends on both the operator and the instrument; therefore, the device has to be specified. A widely accepted instrument is the Swiss rammsonde. Using this instrument, 'ram resistance' is a quasi-objective measure of snow hardness in newtons. Profiles of snow hardness can be obtained from the wall of a snow pit using so called push-pull gauges (see, e.g., Takeuchi *et al.*, 1998).

De Quervain (1950) introduced a hand test with five steps that he assigned rather intuitively to ram resistance ranges. The test uses objects of decreasing areas. For any single layer of the snowpack, hand hardness index corresponds to the first object that can be gently pushed into the snow, thereby not exceeding a penetration force of 10–15 N. The hand test is a relative, subjective measurement. It is thus suggested that operators 'calibrate' themselves against colleagues or against another snow hardness measuring instrument such as the ramsonde. Therefore Table 1.4 also shows de Quervain's ranges adapted to today's use.

Note that recent studies including the hand test almost exclusively use the hand hardness index as a reference value.

**Table 1.4** Hardness of deposited snow

| Term | *Hand test* | | | *Ram resistance* (Swiss rammsonde) (N) | | *Graphic symbol* |
|---|---|---|---|---|---|---|
| | *Hand hardness index* | *Object* | *Code* | *Range* | *Mean* | |
| very soft | 1 | fist | F | 0–50 | 20 | |
| soft | 2 | 4 fingers | 4F | 50–175 | 100 | / |
| medium | 3 | 1 finger | 1F | 175–390 | 250 | × |
| hard | 4 | pencil[1] | P | 390–715 | 500 | // |
| very hard | 5 | knife blade | K | 715–1200 | 1000 | ⋇ |
| ice | 6 | ice | I | > 1200 | > 1200 | ■ |

[1]Here 'pencil' means the tip of a sharpened pencil.

## 1.5 Liquid water content

*Symbol:* $\theta_{\mathrm{w}}$*, LWC*

Liquid water content is defined as the amount of water within the snow that is in the liquid phase. This parameter is synonymous with the free-water content of a snow sample. Liquid water in snow originates from either melt, rain, or a combination of the two. Measurements of liquid water content or wetness are expressed as either a volume ($\theta_{\mathrm{w,V}}$ or $LWC_{\mathrm{V}}$) or mass ($\theta_{\mathrm{w,m}}$ or $LWC_{\mathrm{m}}$) fraction. Both can be reported as a percent (%), which usually requires a separate measurement of density. A general classification of liquid water content $\theta_{\mathrm{w,V}}$ in terms of volume fraction is given in Table 1.5.

Liquid water is only mobile if the residual or irreducible water content is exceeded. The latter is the water that can be held by surface forces against the pull of gravity (capillary action). Residual water content in snow corresponds to a volume fraction of about 3–6 %, depending on the snow type.

There are several methods to determine liquid water content of snow in the field. These include cold (freezing) calorimetry, alcohol calorimetry, and the dilution method (Boyne & Fisk, 1990) as well as dielectric measurements (Denoth *et al.*, 1984). Hot (melting) calorimetry requires both a properly designed device and a meticulous observer to obtain accurate measurements (Kawashima *et al.*, 1998).

## 1.6 Snow temperature

*Symbol:* $T_s$

The temperature of snow should be given in degrees Celsius (°C). Sometimes it is desirable to record other temperatures of interest; the suggested symbols for the more common ones are:

$T_{\mathrm{s}}(H)$: Snow temperature at height $H$ in centimetres above the ground

$T_{\mathrm{s}}(-H)$: Snow temperature at depth $-H$ in centimetres below the surface

$T_{\mathrm{ss}}$: Snow surface temperature

$T_{\mathrm{a}}$: Air temperature 1.5 m above snow surface

$T_{\mathrm{g}}$: Ground surface temperature (the same as Bottom Temperature of Snow, BTS, in the field of permafrost).

## 1.7 Impurities

*Symbol:* $J$

This subsection has been included in the classification to cover those cases in where the kind and amount of an impurity have an influence on the physical characteristics of the snow. In these cases the type of impurity should be fully described and its amount given as mass fraction (%, ppm). Common impurities are dust, sand, soot, acids, organic and soluble materials. Low amounts of impurities do not strongly influence the physical properties of snow but are of hydrological and environmental interest. Type and amount of impurities can be obtained by collecting snow samples in-situ and analysing them in a laboratory.

## 1.8 Layer thickness

*Symbol:* $L$

The snow layer thickness (measured in centimetres or fractions thereof) is an essential parameter when characterising the current state of a snowpack. Layer thickness is usually measured vertically. If the measurement is taken perpendicular, i.e., slope normal, layer thickness should be denoted by $L_p$.

**Table 1.5** Liquid water content

| *Term* | *Wetness index* | *Code* | *Description* | *Approximate range of $\theta_{\mathrm{w,V}}$ (volume fraction in %)*[1] | | *Graphic symbol* |
|---|---|---|---|---|---|---|
| | | | | *range* | *mean* | |
| dry | 1 | D | Usually $T_{\mathrm{s}}$ is below 0°C, but dry snow can occur at any temperature up to 0°C. Disaggregated snow grains have little tendency to adhere to each other when pressed together, as in making a snowball. | 0 | 0 | |
| moist | 2 | M | $T_{\mathrm{s}}$ = 0°C. The water is not visible even at 10× magnification. When lightly crushed, the snow has a distinct tendency to stick together. | 0–3 | 1.5 | \| |
| wet | 3 | W | $T_{\mathrm{s}}$ = 0°C. The water can be recognised at 10× magnification by its meniscus between adjacent snow grains, but water cannot be pressed out by moderately squeezing the snow in the hands (pendular regime). | 3–8 | 5.5 | \|\| |
| very wet | 4 | V | $T_{\mathrm{s}}$ = 0°C. The water can be pressed out by moderately squeezing the snow in the hands, but an appreciable amount of air is confined within the pores (funicular regime). | 8–15 | 11.5 | \|\|\| |
| soaked | 5 | S | $T_{\mathrm{s}}$ = 0°C. The snow is soaked with water and contains a volume fraction of air from 20 to 40% (funicular regime). | >15 | >15 | \|\|\|\| |

[1]For a conversion from volume to mass fraction, see Appendix C.2.

# 2 ADDITIONAL MEASUREMENTS OF DEPOSITED SNOW

A snow profile is a vertical section of the snowpack. It characterizes the stratification or layering of the snowpack. This involves classifying each layer within the snow as outlined in Part I and Appendix C, including the surface of the snow cover. Some of the important measurements in addition to those described in Section I are listed in Table 2.1.

Procedures on how to best perform these measurements can be found in Brown & Armstrong (2008), Doesken & Judson (1997), UNESCO (1970), or in observational guidelines such as CAA (2007) and AAA (2009).

**Table 2.1** Snow cover measurements

| *Term* | *Units* | *Symbol* |
|---|---|---|
| Height (vertical coordinate) | cm | *H* |
| Thickness (slope – perpendicular coordinate) | cm | *D* |
| Height of snowpack | cm | *HS* |
| Height of new snow | cm | *HN* |
| Snow water equivalent | mm w.e. *, kg $m^{-2}$ | *SWE* |
| Water equivalent of snowfall | mm w.e. *, kg $m^{-2}$ | *HNW* |
| Snow strength (compressive, tensile, shear) | Pa | $\Sigma$ |
| Penetrability of snow surface | cm | *P* |
| Surface features | (cm) | *SF* |
| Snow covered area | 1, % | *SCA* |
| Slope angle | ° | $\psi$ |
| Aspect of slope | ° | *AS* |
| Time | s, min, h, d, week, month, year | *t* |

*Note that mm w.e. – or mm – is not a SI unit even though it is the most used in hydrological sciences.

## 2.1 Height (vertical coordinate)

Symbol: *H*

Height is the coordinate measured vertically (line of plumb) from the base. Ground surface is usually taken as the base, but on firn fields and glaciers, it refers to the level of either the firn surface or glacier ice. Usually expressed in centimetres, height is used to denote the locations of layer boundaries but also of measurements such as snow temperatures relative to the base. Where only the upper part of the snowpack is of interest, the snow surface may be taken as the reference. This should be indicated by using negative coordinate values (depth). The symbol *H* should be used for all vertical measurements, regardless of whether they are taken at a place where the snow surface is horizontal or inclined.

## 2.2 Thickness (slope-perpendicular coordinate)

Symbol: *D*

Thickness is the slope normal coordinate to be used when measurements are taken perpendicular, i.e., at right angle to the slope on inclined snow covers. It is measured in centimetres from the base and the same comments apply as for height.

When observers use thickness, they should also report the slope angle with respect to either the snow surface or a layer within the snowpack, e.g., the bed surface of an avalanche.

## 2.3 Height of snowpack, snow depth

Symbol: *HS*

Snow depth denotes the total height of the snowpack, i.e., the vertical distance in centimetres from base to snow surface. Unless otherwise specified snow depth is related to a single location at a given time. Thus, manual snow depth measurements are often made with one or more fixed snow stakes. On the other hand, portable snow depth probes allow for measurements along snow courses and transects. The slope-perpendicular equivalent of snow depth is the total thickness of the snowpack denoted by *DS*.

Automated measurements of either snow depth or snow thickness are possible with ultrasonic and other fixed and portable snow depth sensors.

## 2.4 Height of new snow, depth of snowfall

Symbol: *HN*

Height of new snow is the depth in centimetres of freshly fallen snow that accumulated on a snow board during a standard observing period of 24 hours. Additional observation intervals can be used, but should be specified. For example, the notation *HN*(8h) or *HN*(2d) denotes an observation interval of 8 hours or 2 days, respectively. Height of new snow is traditionally measured with a ruler. After the measurement, the snow is cleared from the board and the board is placed flush with the snow surface to provide an accurate measurement at the end of the next interval. The corresponding slope-perpendicular measurement is denoted by *DN*.

## 2.5 Snow water equivalent

Symbol: *SWE*

Snow water equivalent is the depth of water that would result if the mass of snow melted completely. It can represent the snow cover over a given region or a confined snow sample over the corresponding area. The snow water equivalent is the product of the snow height in metres and the vertically-integrated density in kilograms per cubic metre (Goodison *et al.*, 1981, p. 224). It is typically expressed in millimetres of water equivalent, which is equivalent to kilograms per square metre or litres per square metre, thus referring to the unit surface area of the considered snow sample. Table 2.2 summarizes the various symbols used for snow water equivalent measurements.

**Table 2.2** Symbols for snow water equivalent measurements

| *Description* | *Symbol* |
|---|---|
| Snow water equivalent of snow cover | SWE, *HSW* |
| Water equivalent from the base up to the height *H* | *HW* |
| Water equivalent of a single layer of thickness *L* | *LW* |
| Water equivalent of snowfall | HNW |

Snow water equivalent is most simply measured by weighing samples of known cross sections (see WMO, 1994; Goodison *et al.*, 1981; UNESCO, 1970). Note that measurements are always expressed with respect to the vertical, regardless of whether they are taken vertically or slope normal.

## 2.6 Water equivalent of snowfall

Symbol: *HNW*

Snow water equivalent of snowfall is typically measured for a standard observing period of 24 hours. Other periods can be specified, e.g., *HNW*(8h) or *HNW*(2d) for periods of 8 hours or 2 days, respectively.

*HNW*(24h) can be very roughly estimated from the height of new snow *HN*(24h) assuming a mean new snow density of 100 kg $m^{-3}$.

## 2.7 Snow strength

Symbol: $\Sigma$

Snow strength can be regarded as the maximum or failure stress on a stress–strain curve. It is the maximum stress snow can withstand without failing or fracturing. Snow strength depends on the stress state ($\sigma$: compressive or tensile; $\tau$: shear) in pascals and the strain, $\varepsilon$, which is dimensionless, as well as on their rates in pascals per second and per second, respectively. Snow strength depends also on microstructure and on the homogeneity of the sample. To make measurements meaningful, all of these parameters must be considered. Moreover, failure types such as ductile or brittle fracture or maximum stress at low strain rates must be given.

Shear strength of snow can be measured relatively simply in the field by using a shear frame (Jamieson & Johnston, 2001). Shear strength is important in evaluating the stability of the snowpack. Mechanical properties of snow were comprehensively reviewed by Shapiro *et al.* (1997).

## 2.8 Penetrability of snow surface

Symbol: *P*

Penetrability is the depth that an object penetrates into the snow from the surface. It can be used as a rough measure of the amount of snow available for transport by aeolian processes or the ability of a snowpack to support a certain load. The depth of penetration of some suitable object, such as a ramsonde element, a foot, or a ski, is measured in centimetres.

The following symbols are suggested:

*PR*: Penetration depth of the first element of a Swiss rammsonde by its own weight (1 m, 10 N)

*PF*: Penetration depth of a person standing on one foot (foot penetration)

*PS*: Penetration depth of a skier supported on one ski (ski penetration)

## 2.9 Surface features

Symbol: *SF*

This subsection refers to the general appearance of the snow surface. These surface features are due to the following main processes: deposition, redistribution and erosion by wind, melting and refreezing, sublimation and evaporation, and rain. A classification that allows the characterisation of vast areas as found in polar and sub-polar regions as well as alpine snow surfaces has not yet been developed.

**Table 2.3** Surface roughness

| *Term* | *Process* | *Graphic symbol* | *Code* | *Roughness elements* |
|---|---|---|---|---|
| smooth | Deposition without wind | | rsm | |
| wavy | Wind deposited snow | | rwa | *ripples* |
| concave furrows | Melt and sublimation | | rcv | *ablation hollows, sun cups, penitents* |
| convex furrows | Rain or melt | | rcx | *rain or melt groves* |
| random furrows | Erosion | | rrd | *zastrugi, erosion features* |

However, the snow surface can be described more generally in terms of roughness elements that are not related to snow microstructure. The surface roughness types are given in Table 2.3.

The average vertical extent of any of these roughness elements, measured in centimetres, can be combined with the relevant symbol or code, e.g., *SF*rcv 10. The wavelength and compass direction may also be of interest.

Note that surface features are not a substitute for the characterisation of the topmost snowpack layer according to Part I and Appendix C.

## 2.10 Snow covered area

Symbol: *SCA*

Snow covered area is defined as the areal extent of snow-covered ground, usually expressed as a fraction (%) of the total area investigated. The latter must be defined, e.g., observation site, catchment, district, country, continent. Unless otherwise specified, only seasonal snow cover is considered. Hence, on glaciers and névés, ground refers either to glacier ice or to an old firn surface.

## 2.11 Slope angle

Symbol: $\psi$

Slope angle is the acute angle measured from the horizontal to the plane of a slope. Slope angle is measured with a clinometer.

## 2.12 Aspect of slope

Symbol: *AS*

Aspect is the compass direction towards which a slope faces. The direction is taken downslope and normal to the contours of elevation, i.e., along the fall line.

Aspect should be given either in degrees, clockwise from true North N = 0° = 360°, or as cardinal and inter-cardinal points, i.e., N, NE, E, SE, S, SW, W, NW.

## 2.13 Time

Symbol: $t$

Time is usually given in seconds. To indicate either time periods over which a measurement takes place or the age of snow deposits and layers, the following units may be used: minutes (min), hours (h), days (d) as well as week, month and year.

# APPENDIX A: GRAIN SHAPE CLASSIFICATION

## A.1 Main and subclasses of grain shapes

| *Morphological classification* | | | | *Additional information on physical processes and strength* | | | |
|---|---|---|---|---|---|---|---|
| *Basic classification* | *Subclass* | *Shape* | *Code* | *Place of formation* | *Physical process* | *Dependence on most important parameters* | *Common effect on strength* |
| ***Precipitation Particles*** | | | **PP** | | | | |
| | Columns | Prismatic crystal, solid or hollow | PPco | Cloud; temperature inversion layer (clear sky) | Growth from water vapour at –3 to –8°C and below–30°C | | |
| | Needles | Needle-like, approximately cylindrical | PPnd | Cloud | Growth from water vapour at high super-saturation at –3 to –5°C and below –60°C | | |
| | Plates | Plate-like, mostly hexagonal | PPpl | Cloud; temperature inversion layer (clear sky) | Growth from water vapour at 0 to –3°C and –8 to –70°C | | |
| | Stellars, Dendrites | Six-fold star-like, planar or spatial | PPsd | Cloud; temperature inversion layer (clear sky) | Growth from water vapour at high supersaturation at 0 to –3°C and at –12 to –16°C | | |
| | Irregular crystals | Clusters of very small crystals | PPir | Cloud | Polycrystals growing in varying environmental conditions | | |
| | Graupel | Heavily rimed particles, spherical, conical, hexagonal or irregular in shape | PPgp | Cloud | Heavy riming of particles by accretion of supercooled water droplets<br>Size: ≤5 mm | | |
| | Hail | Laminar internal structure, translucent or milky glazed surface | PPhl | Cloud | Growth by accretion of supercooled water<br>Size: >5 mm | | |
| | Ice pellets | Transparent, mostly small spheroids | PPip | Cloud | Freezing of raindrops or refreezing of largely melted snow crystals or snowflakes (sleet)<br>Graupel or snow pellets encased in thin ice layer (small hail)<br>Size: both ≤5 mm | | |
| | Rime | Irregular deposits or longer cones and needles pointing into the wind | PPrm | Onto surface as well as on freely exposed objects | Accretion of small, supercooled fog droplets frozen in place.<br>Thin breakable crust forms on snow surface if process continues long enough | Increase with fog density and exposure to wind | |

*Notes:* Diamond dust is a further type of precipitation often observed in polar regions (see Appendix E).
Hard rime is more compact and amorphous than soft rime and may build out as glazed cones or ice feathers (AMS, 2000).
The above subclasses do not cover all types of particles and crystals one may observe in the atmosphere. See the references below for a more comprehensive coverage.
*References*: Magono & Lee, 1966; Bailey & Hallett, 2004; Dovgaluk & Pershina. 2005; Libbrecht, 2005

| *Morphological classification* | | | *Additional information xon physical processes and strength* | | | | |
|---|---|---|---|---|---|---|---|
| *Basic classification* | *Subclass* | *Shape* | *Code* | *Place of formation* | *Physical process* | *Dependence on most important parameters* | *Common effect on strength* |
| ***Machine Made snow*** | | | **MM** | | | | |
| | Round polycrystalline particles | Small spherical particles, often showing protrusions, a result of the freezing process; may be partially hollow | MMrp | Atmosphere, near surface | Machined snow, i.e., freezing of very small water droplets from the surface inward | Liquid water content depends mainly on air temperature and humidity but also on snow density and grain size | In dry conditions, quick sintering results in rapid strength increase |
| | Crushed ice particles | Ice plates, shard-like | MMci | Ice generators | Machined ice, i.e., production of flake ice, subsequent crushing, and pneumatic distribution | All weather safe | |

*References*: Fauve *et al.*, 2002

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| ***Decomposing and Fragmented precipitation particles*** | | | **DF** | | | | |
| | Partly decomposed precipitation particles | Characteristic shapes of precipitation particles still recognizable; often partly rounded. | DFdc | Within the snowpack; recently deposited snow near the surface, usually dry | Decrease of surface area to reduce surface free energy; also fragmentation due to light winds lead to initial break up | Speed of decomposition decreases with decreasing snow temperatures and decreasing temperature gradients | Regains cohesion by sintering after initial strength decreased due to decomposition process |
| | Wind-broken precipitation particles | Shards or fragments of precipitation particles | DFbk | Surface layer, mostly recently deposited snow | Saltation particles are fragmented and packed by wind, often closely; fragmentation often followed by rounding | Fragmentation and packing increase with wind speed | Quick sintering results in rapid strength increase |

| *Morphological classification* | | | *Additional information xon physical processes and strength* | | | | |
|---|---|---|---|---|---|---|---|
| *Basic classification* | *Subclass* | *Shape* | *Code* | *Place of formation* | *Physical process* | *Dependence on most important parameters* | *Common effect on strength* |
| ***Rounded Grains*** ● | | | **RG** | | | | |
| | Small rounded particles • | Rounded, usually elongated particles of size < 0.25 mm; highly sintered | RGsr | Within the snowpack; dry snow | Decrease of specific surface area by slow decrease of number of grains and increase of mean grain diameter. Small equilibrium growth form | Growth rate increases with increasing temperature; growth slower in high density snow with smaller pores | Strength due to sintering of the snow grains [1]. Strength increases with time, settlement and decreasing grain size |
| | Large rounded particles ● | Rounded, usually elongated particles of size $\geq$ 0.25 mm; well sintered | RGlr | Within the snowpack; dry snow | Grain-to-grain vapour diffusion due to low temperature gradients, i.e., mean excess vapour density remains below critical value for kinetic growth. Large equilibrium growth form | Same as above | Same as above |
| | Wind packed | Small, broken or abraded, closely-packed particles; well sintered | RGwp | Surface layer; dry snow | Packing and fragmentation of wind transported snow particles that round off by interaction with each other in the saltation layer. Evolves into either a hard but usually breakable wind crust or a thicker wind slab. (see notes) | Hardness increases with wind speed, decreasing particle size and moderate temperature | High number of contact points and small size causes rapid strength increase through sintering |
| | Faceted rounded particles | Rounded, usually elongated particles with developing facets | RGxf | Within the snowpack; dry snow | Growth regime changes if mean excess vapour density is larger than critical value for kinetic growth. Accordingly, this transitional form develops facets as temperature gradient increases | Grains are changing in response to an increasing temperature gradient | Reduction in number of bonds may decrease strength |

*Notes:* Both wind crusts and wind slabs are layers of small, broken or abraded, closely packed and well-sintered particles. The former are thin irregular layers whereas the latter are thicker, often dense layers, usually found on lee slopes. Both types of layers can be represented either as sub-class RGwp or as RGsr along with proper grain size, hardness and/or density.

If the grains are smaller than about 1 mm, an observer will need to consider the process at work to differentiate RGxf from FCxr.

*References*: [1] Colbeck, 1997

| Morphological classification | | | | Additional information xon physical processes and strength | | | |
|---|---|---|---|---|---|---|---|
| Basic classification | Subclass | Shape | Code | Place of formation | Physical process | Dependence on most important parameters | Common effect on strength |
| ***Faceted Crystals*** | | | **FC** | | Grain-to-grain vapour diffusion driven by large enough temperature gradient, i.e., excess vapour density is above critical value for kinetic growth | | |
| | Solid faceted particles | Solid faceted crystals; usually hexagonal prisms | FCso | Within the snowpack; dry snow | Solid kinetic growth form, i.e., a solid crystal with sharp edges and corners as well as glassy, smooth faces | Growth rate increases with temperature, increasing temperature gradient, and decreasing density; may not grow to larger grains in high density snow because of small pores | Strength decreases with increasing growth rate and grain size |
| | Near surface faceted particles | Faceted crystals in surface layer | FCsf | Within the snowpack but right beneath the surface; dry snow | May develop directly from Precipitation Particles (PP) or Decomposing and Fragmented particles (DFdc) due to large, near-surface temperature gradients [1] Solid kinetic growth form (see FCso above) at early stage of development | Temperature gradient may periodically change sign but remains at a high absolute value | Low strength snow |
| | Rounding faceted particles | Faceted crystals with rounding facets and corners | FCxr | Within the snowpack; dry snow | Trend to a transitional form reducing its specific surface area; corners and edges of the crystals are rounding off | Grains are rounding off in response to a decreasing temperature gradient | |

*Notes:* Once buried, FCsf are hard to distinguish from FCso unless the observer is familiar with the evolution of the snowpack

FCxr can usually be clearly identified for crystals larger than about 1 mm. In case of smaller grains, however, an observer will need to consider the process at work to differentiate FCxr from RGxf.

*References*: [1] Birkeland, 1998

| *Morphological classification* | | | | *Additional information xon physical processes and strength* | | | |
|---|---|---|---|---|---|---|---|
| *Basic classification* | *Subclass* | *Shape* | *Code* | *Place of formation* | *Physical process* | *Dependence on most important parameters* | *Common effect on strength* |
| ***Depth Hoar*** | | | **DH** | | Grain-to-grain vapour diffusion driven by large temperature gradient, i.e., excess vapour density is well above critical value for kinetic growth. | | |
| | Hollow cups | Striated, hollow skeleton type crystals; usually cup-shaped | DHcp | Within the snowpack; dry snow | Formation of hollow or partly solid cup-shaped kinetic growth crystals [1] | See FCso. | Usually fragile but strength increases with density |
| | Hollow prisms | Prismatic, hollow skeleton type crystals with glassy faces but few striations | DHpr | Within the snowpack; dry snow | Snow has completely recrystallized; high temperature gradient in low density snow, most often prolonged [2] | High recrystallization rate for long period and low density snow facilitates formation | May be very poorly bonded |
| | Chains of depth hoar | Hollow skeleton type crystals arranged in chains | DHch | Within the snowpack; dry snow | Snow has completely recrystallized; intergranular arrangement in chains; most of the lateral bonds between columns have disappeared during crystal growth | High recrystallization rate for long period and low density snow facilitates formation | Very fragile snow |
| | Large striated crystals | Large, heavily striated crystals; either solid or skeleton type | DHla | Within the snowpack; dry snow | Evolves from earlier stages described above; some bonding occurs as new crystals are initiated [2] | Longer time required than for any other snow crystal; long periods of large temperature gradient in low density snow are needed | Regains strength |
| | Rounding depth hoar | Hollow skeleton type crystals with rounding of sharp edges, corners, and striations | DHxr | Within the snowpack; dry snow | Trend to a form reducing its specific surface area; corners and edges of the crystals are rounding off; faces may lose their relief, i.e., striations and steps disappear slowly. This process affects all subclasses of depth hoar | Grains are rounding off in response to a decreasing temperature gradient | May regain strength |

*Notes:* DH and FC crystals may also grow in snow with density larger than about 300 kg $m^{-3}$ such as found in polar snowpacks or wind slabs. These may then be termed 'hard' or 'indurated' depth hoar [3].
*References*: [1] Akitaya, 1974; Marbouty, 1980; Fukuzawa & Akitaya, 1993; Baunach *et al.*, 2001; Sokratov, 2001; [2] Sturm & Benson, 1997; [3] Akitaya, 1974; Benson & Sturm, 1993

| *Morphological classification* | | | | *Additional information xon physical processes and strength* | | | |
|---|---|---|---|---|---|---|---|
| *Basic classification* | *Subclass* | *Shape* | *Code* | *Place of formation* | *Physical process* | *Dependence on most important parameters* | *Common effect on strength* |
| ***Surface Hoar*** | | | **SH** | | | | |
| | Surface hoar crystals | Striated, usually flat crystals; sometimes needle-like | SHsu | Usually on cold snow surface relative to air temperature; sometimes on freely exposed objects above the surface (see notes) | Rapid kinetic growth of crystals at the snow surface by rapid transfer of water vapour from the atmosphere toward the snow surface; snow surface cooled to below ambient temperature by radiative cooling | Both increased cooling of the snow surface below air temperature as well as increasing relative humidity of the air cause growth rate to increase.In high water vapour gradient fields, e.g., near creeks, large feathery crystals may develop | Fragile, extremely low shear strength; strength may remain low for extended periods when buried in cold dry snow |
| | Cavity or crevasse hoar | Striated, planar or hollow skeleton type crystals grown in cavities; orientation often random | SHcv | Cavity hoar is found in large voids in the snow, e.g., in the vicinity of tree trunks, buried bushes [1] Crevasse hoar is found in any large cooled space such as crevasses, cold storage rooms, boreholes, etc. | kinetic growth of crystals forming anywhere where a cavity, i.e., a large cooled space, is formed or present in which water vapour can be deposited under calm, still conditions [2] | | |
| | Rounding surface hoar | Surface hoar crystal with rounding of sharp edges, corners and striations | SHxr | Within the snowpack; dry snow | Trend to a form reducing its specific surface area; corners and edges of the crystals are rounding off; faces may lose their relief, i.e., striations and steps disappear slowly | Grains are rounding off in response to a decreasing temperature gradient | May regain strength |

*Notes:* It may be of interest to note more precisely the shape of hoar crystals, namely plates, cups, scrolls, needles and columns, dendrites, or composite forms [3]. Multi-day growth may also be specified.

Surface hoar may form by advection of nearly saturated air on both freely exposed objects and the snow surface at subfreezing temperatures. This type of hoarfrost deposit makes up a substantial part of accumulation in the inland of Antarctica. It has been termed 'air hoar' (see [2] and [4]).

Crevasse hoar crystals are very similar to depth hoar.

*References*: [1] Akitaya, 1974; [2] Seligman, 1936; [3] Jamieson & Schweizer, 2000; [4] AMS, 2000

| Basic classification | Subclass | Shape | Code | Place of formation | Physical process | Dependence on most important parameters | Common effect on strength |
|---|---|---|---|---|---|---|---|
| *Morphological classification* | | | | *Additional information xon physical processes and strength* | | | |
| ***Melt Forms*** | | | **MF** | | | | |
| | Clustered rounded grains | Clustered rounded crystals held by large ice-to-ice bonds; water in internal veins among three crystals or two grain boundaries | MFcl | At the surface or within the snowpack; wet snow | Wet snow at low water content (pendular regime), i.e., holding free liquid water; clusters form to minimize surface free energy | Meltwater can drain; too much water leads to MFsl; first freezing leads to MFpc | Ice-to-ice bonds give strength |
| | Rounded polycrystals | Individual crystals are frozen into a solid polycrystalline particle, either wet or refrozen | MFpc | At the surface or within the snowpack | Melt-freeze cycles form polycrystals when water in veins freezes; either wet at low water content (pendular regime) or refrozen | Particle size increases with number of melt-freeze cycles; radiation penetration may restore MFcl; excess water leads to MFsl | High strength in the frozen state; lower strength in the wet state; strength increases with number of melt-freeze cycles |
| | Slush | Separated rounded particles completely immersed in water | MFsl | Water-saturated, soaked snow; found within the snowpack, on land or ice surfaces, but also as a viscous floating mass in water after heavy snowfall. | Wet snow at high liquid water content (funicular regime); poorly bonded, fully rounded single crystals – and polycrystals – form as ice and water are in thermodynamic equilibrium | Water drainage blocked by capillary barrier, impermeable layer or ground; high energy input to the snow-pack by solar radiation, high air temperature or water input (rain) | Little strength due to decaying bonds |
| | Melt-freeze crust | Crust of recognizable melt-freeze polycrystals | MFcr | At the surface | Crust of melt-freeze polycrystals from a surface layer of wet snow that refroze after having been wetted by melt or rainfall; found either wet or refrozen | Particle size and density increases with number of melt-freeze cycles | Strength increases with number of melt-freeze cycles |

*Notes:* Melt-freeze crusts MFcr form at the surface as layers at most a few centimetres thick, usually on top of a subfreezing snowpack. Rounded polycrystals MFpc will rather form within the snowpack. MFcr usually contain more refrozen water than MFpc and will not return to MFcl.

Both MFcr and MFpc may contain a recognizable minority of other shapes, particularly large kinetic growth form FC and DH. See the guidelines (Appendix C) for examples on the use of the MFcr symbol.

| Morphological classification | | | | Additional information xon physical processes and strength | | | |
|---|---|---|---|---|---|---|---|
| *Basic classification* | *Subclass* | *Shape* | *Code* | *Place of formation* | *Physical process* | *Dependence on most important parameters* | *Common effect on strength* |
| ***Ice Formations*** | | | **IF** | | | | |
| | Ice layer | Horizontal ice layer | IFil | Within the snowpack | Rain or meltwater from the surface percolates into cold snow where it refreezes along layer-parallel capillary barriers by heat conduction into surrounding subfreezing snow, i.e., snow at T<0°C; ice layers usually retain some degree of permeability | Depends on timing of percolating water and cycles of melting and refreezing; more likely to occur if a stratification of fine over coarse-grained layers exists | Ice layers are strong but strength decays once snow is completely wetted |
| | Ice column | Vertical ice body | IFic | Within snowpack layers | Draining water within flow fingers freezes by heat conduction into surrounding subfreezing snow, i.e., snow at T<0°C | Flow fingers more likely to occur if snow is highly stratified; freezing enhanced if snow is very cold | |
| | Basal ice | Basal ice layer | IFbi | Base of snowpack | Melt water ponds above substrate and freezes by heat conduction into cold substrate | Formation enhanced if substrate is impermeable and very cold, e.g., permafrost | Weak slush layer may form on top |
| | Rain crust | Thin, transparent glaze or clear film of ice on the surface | IFrc | At the surface | Results from freezing rain on snow; forms a thin surface glaze | Droplets have to be supercooled but coalesce before freezing | Thin breakable crust |
| | Sun crust, Firnspiegel | Thin, transparent and shiny glaze or clear film of ice on the surface | IFsc | At the surface | Melt water from a surface snow layer refreezes at the surface due to radiative cooling; decreasing shortwave absorption in the forming glaze enhances greenhouse effect in the underlying snow; additional water vapour may condense below the glaze [1] | Builds during clear weather, air temperatures below freezing and strong solar radiation; not to be confused with melt-freeze crust MFcr | Thin breakable crust |

*Notes:* In ice formations, pores usually do not connect and no individual grains or particles are recognizable, contrary to highly porous snow. Nevertheless, some permeability remains, in particular when wetted, but to much a lesser degree than for porous melt forms.

Most often, rain and solar radiation cause the formation of melt-freeze crusts MFcr.

Discontinuous ice bodies such as ice lenses or refrozen flow fingers can be identified by appropriate remarks (see Appendix C.2).

*References*: [1] Ozeki & Akitaya, 1998

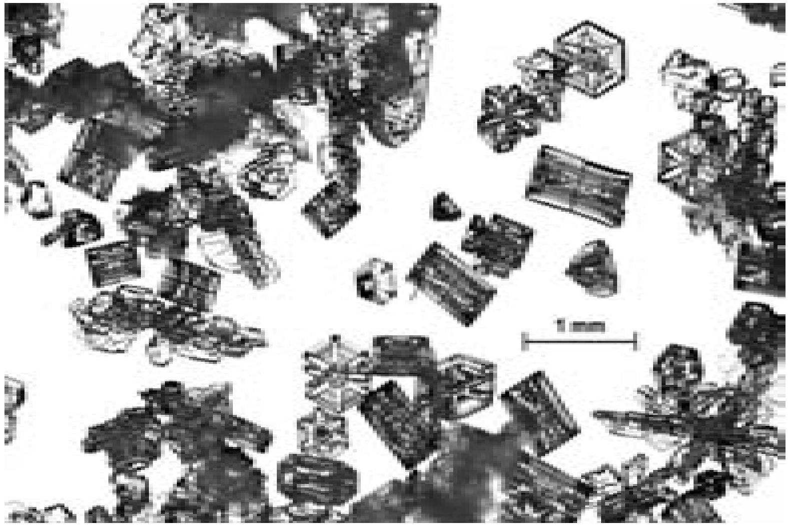
## A.2 Colour convention for main morphological grain shape classes

| *Class* | *Symbol* | *Code* | *Colour*[1] | Web colour name | *RGB*[2] (0–255) | (HEX) | *CMYK*[3] (%) | Pantone® solid coated | *Greyscale*[4] (%) | (HEX) |
|---|---|---|---|---|---|---|---|---|---|---|
| **P**recipitation **P**articles | + | PP | | Lime | 0 / 255 / 0 | #00FF00 | 100 / 0 / 100 / 0 | 802C | 41 | #969696 |
| **M**achine **M**ade snow | ◎ | MM | | Gold | 255 / 215 / 0 | #FFD700 | 0 / 16 / 100 / 0 | 116C | 20 | #CBCBCB |
| **D**ecomposing and **F**ragmented precipitation particles | / | DF | | ForestGreen | 34 / 139 / 34 | #228B22 | 76 / 0 / 76 / 45 | 363C | 76 | #3C3C3C |
| **R**ounded **G**rains | ● | RG | | LightPink | 255 / 182 / 193 | #FFB6C1 | 0 / 29 / 24 / 0 | 707C | 20 | #CDCDCD |
| **F**aceted **C**rystals | □ | FC | | LightBlue | 173 / 216 / 230 | #ADD8E6 | 25 / 6 / 0 / 10 | 629C | 21 | #CACACA |
| **D**epth **H**oar | ∧ | DH | | Blue | 0 / 0 / 255 | #0000FF | 100 / 100 / 0 / 0 | Blue 072C | 89 | #1C1C1C |
| **S**urface **H**oar | ∨ | SH | | Fuchsia | 255 / 0 / 255 | #FF00FF | 0 / 100 / 0 / 0 | 232C | 59 | #696969 |
| **M**elt **F**orms | ○ | MF | | Red | 255 / 0 / 0 | #FF0000 | 0 / 100 / 100 / 0 | Red 032C | 70 | #4D4D4D |
| | ◎◎ | MFcr | | | | | | | | |
| **I**ce **F**ormations | ▬ | IF | | Cyan/Aqua | 0 / 255 / 255 | #00FFFF | 100 / 0 / 0 / 0 | 318C | 30 | #B3B3B3 |

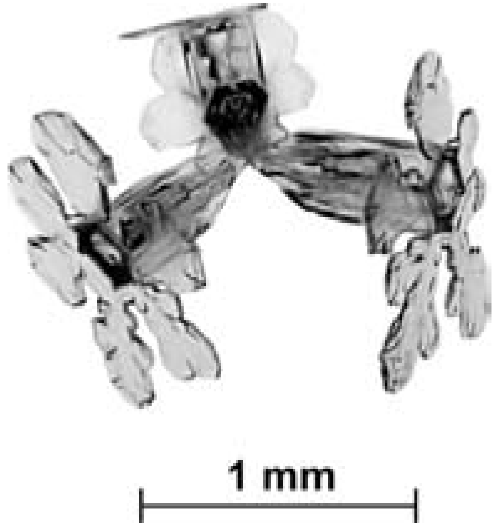
[1]The colour convention is not optimized for people affected by colour vision deficiencies.
[2]RGB codes for web colours: http://en.wikipedia.org/wiki/Web_colors; http://www.w3.org/TR/css3-color/#svg-color.
[3]RGB conversion to CMYK as well as to grey scale (both not unique!): http://www.usq.edu.au/users/grantd/WORK/216color/ConvertRGB-CMYK-Grey.htm
[4]Use of Greyscale is not recommended. However, values are provided for consistency: % grey = 0.3×R + 0.59×G + 0.11×B, see http://www.dfanning.com/ip_tips/color2gray.html

## A.3: Photographs of various grain shapes

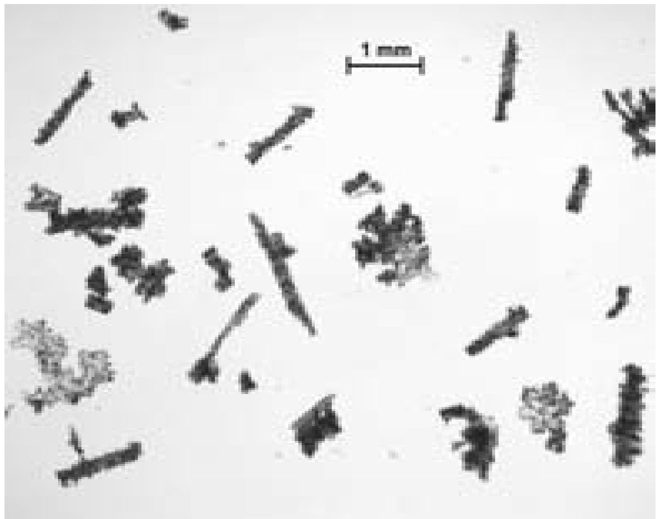
The classification contains 60 pictures collected by practitioners and scientists around the world, from the high Arctic to Antarctica, from North America to Far-East Russia and Japan.



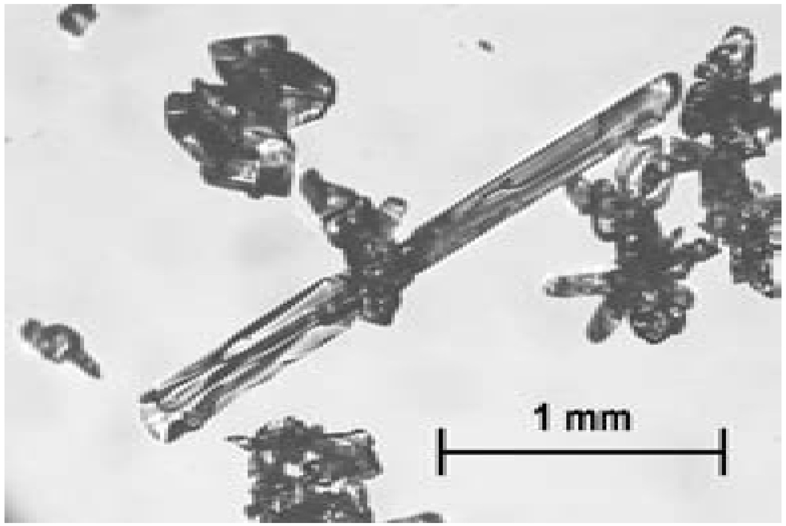

Columns PPco, ▭ (Elder) #01



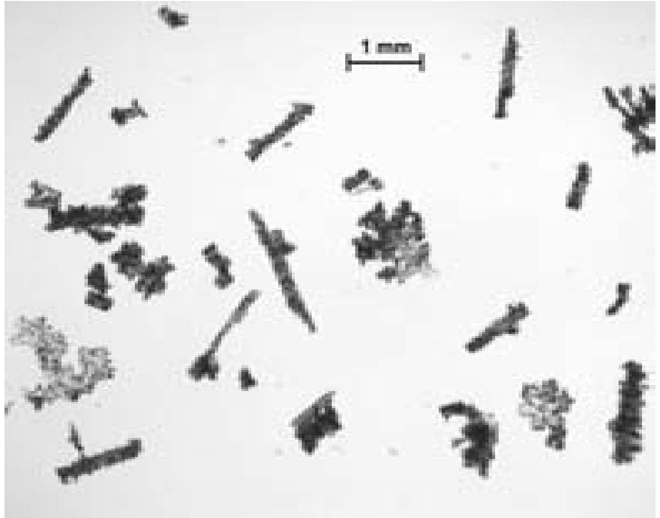

Columns and plates PPco (PPpl), ▭ (⊙) (Span) #02



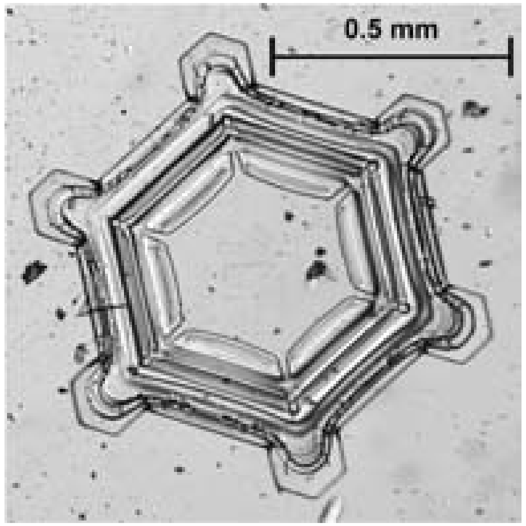

Rimed needles PPnd, ↔ (Fierz) #03



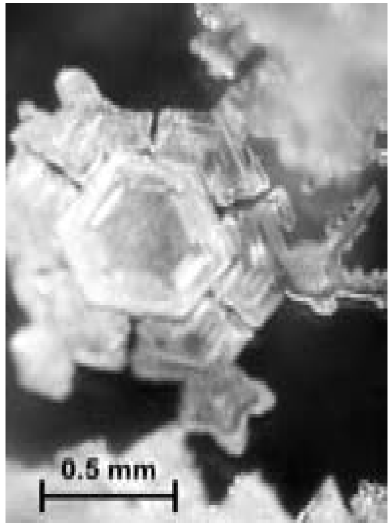

Needles PPnd, ↔ (Elder) #04




Plates PPpl, ⊙ (Elder) #05

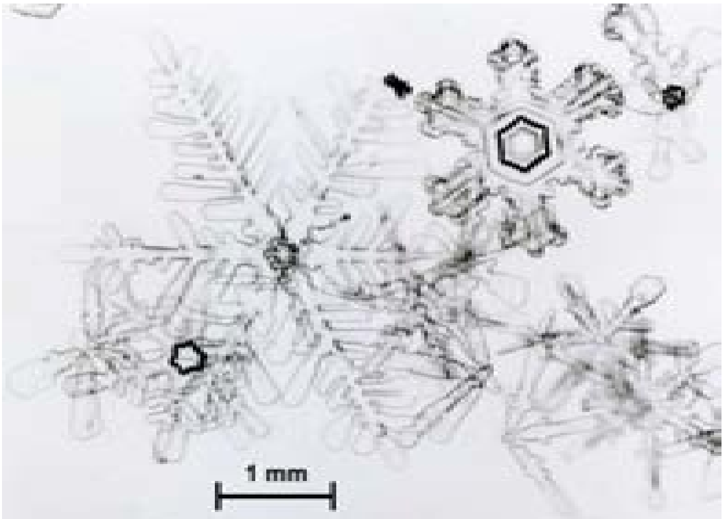



Plates PPpl, ⊙ (Greene) #06

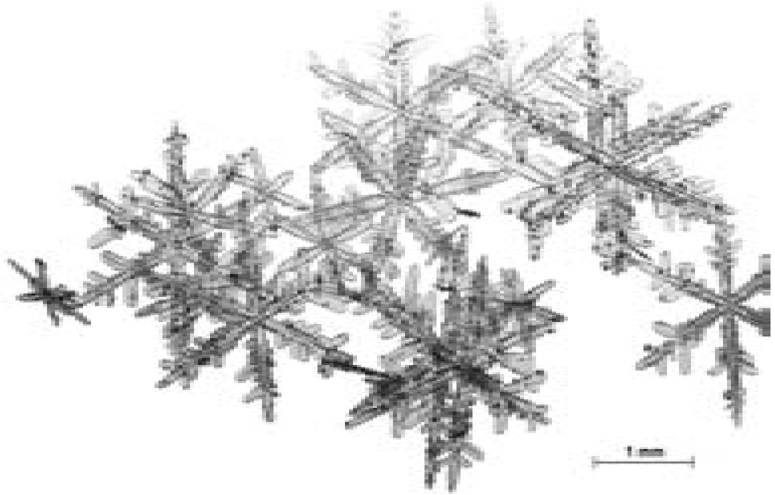



Plates PPpl, ⊙ (AINEVA UniMilano) #07

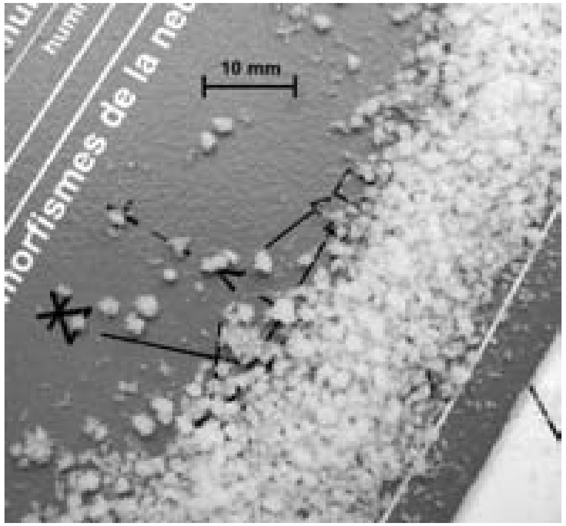




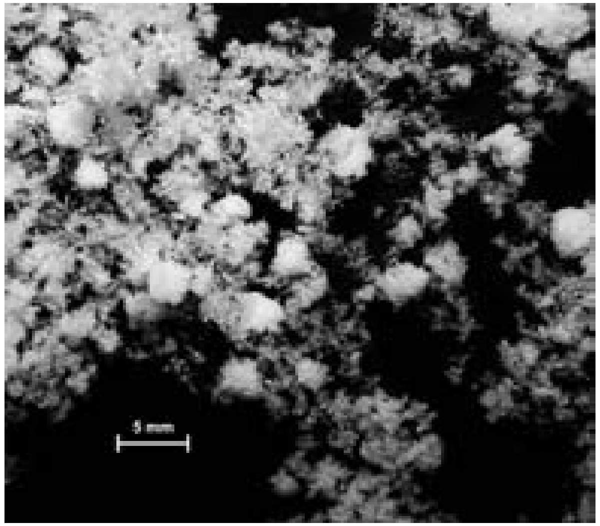

Stellars dendrites, PPsd, ∗ (JSSI) #08




Stellars dendrites, PPsd, ∗ (Span) #09

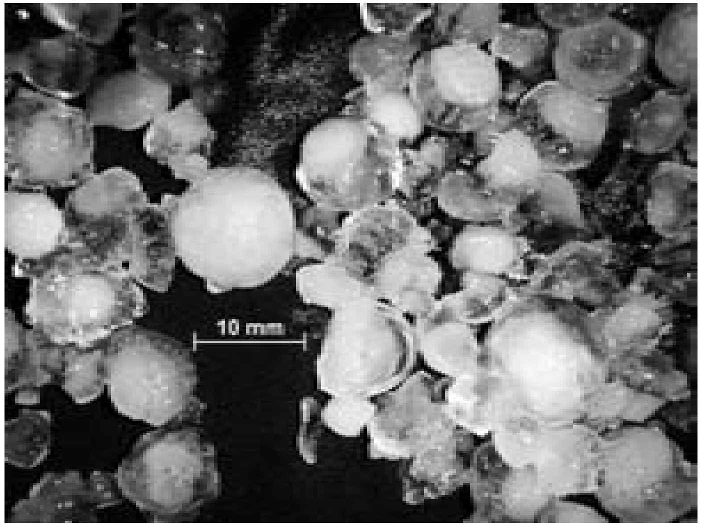



Graupel PPgp, △ (Garcia Selles) #10

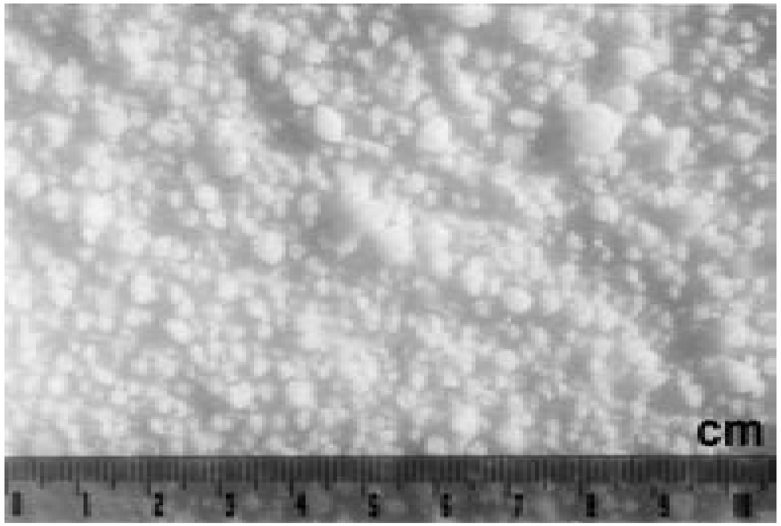



Graupel PPgp, △ (Elder) #11


Graupel PPgp, △ (AINEVA UniMilano) #12

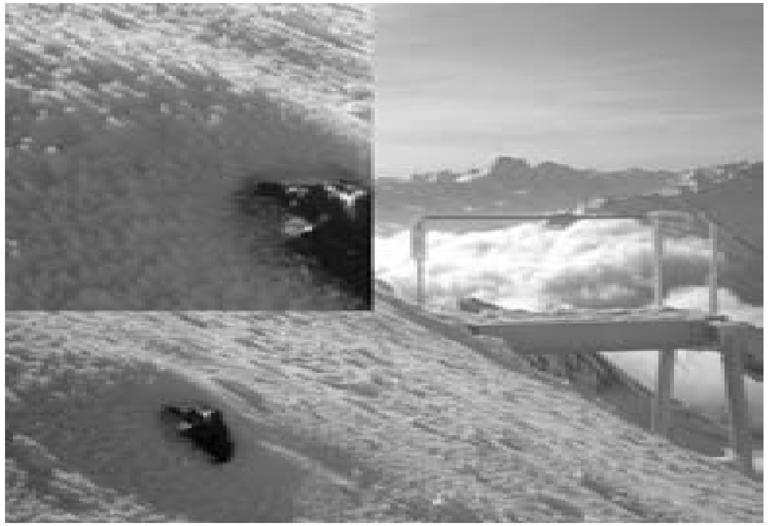



Hail PPhl, ▲ (Elder) #13

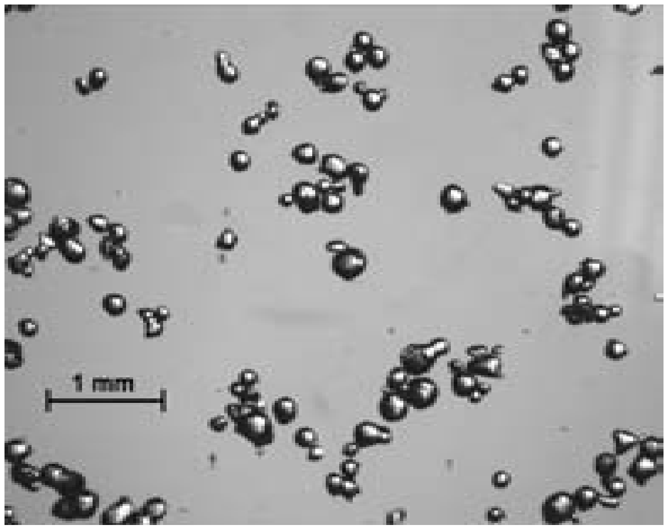



Ice pellets PPip, ◬ (JSSI) #14

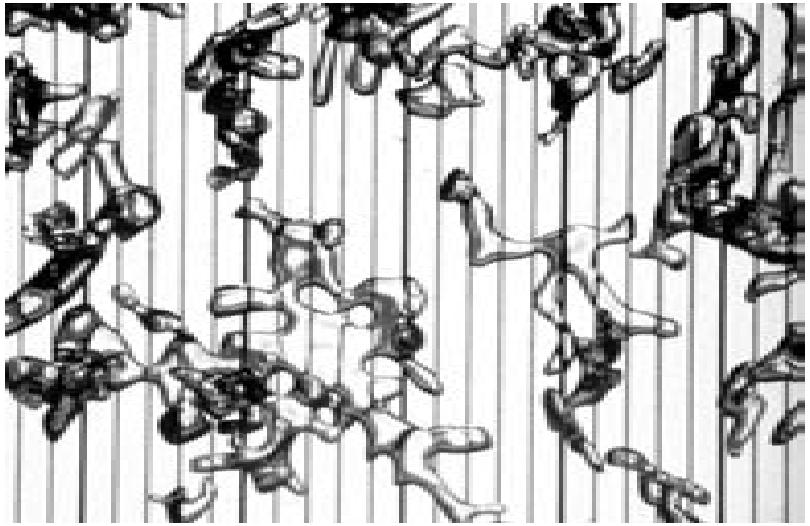
Rime PPrm, ∀ (Schweizer) #15



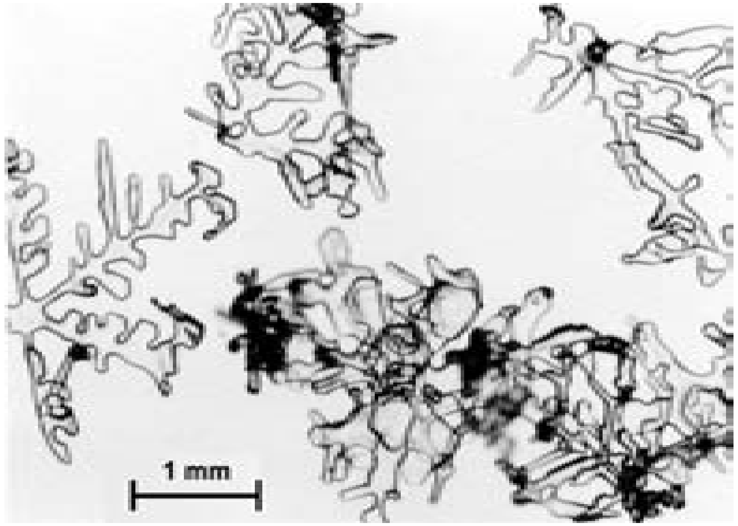
Rime on snow-cover surface PPrm, ∀ (Schweizer) #16




Round polycrystalline particles MMrp, ⊚ (Fauve) #17

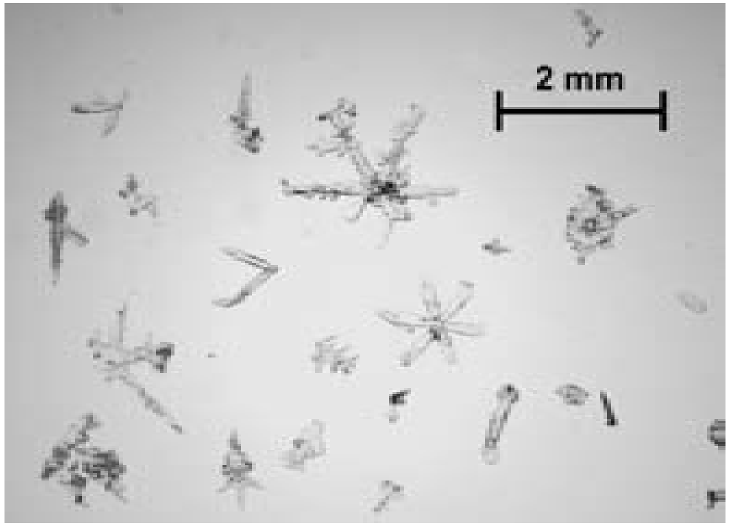


Partly decomposed precipitation particles DFdc, ⟋, 0.2 mm grid (CEN) #18

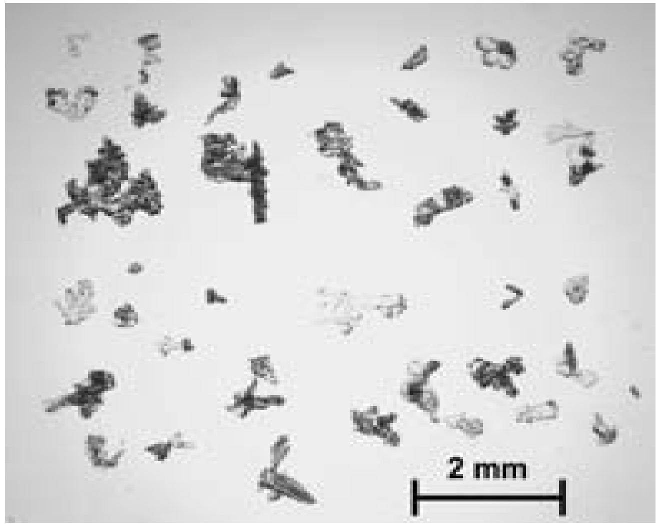



Partly decomposed precipitation particles DFdc, ⟋ (JSSI) #19

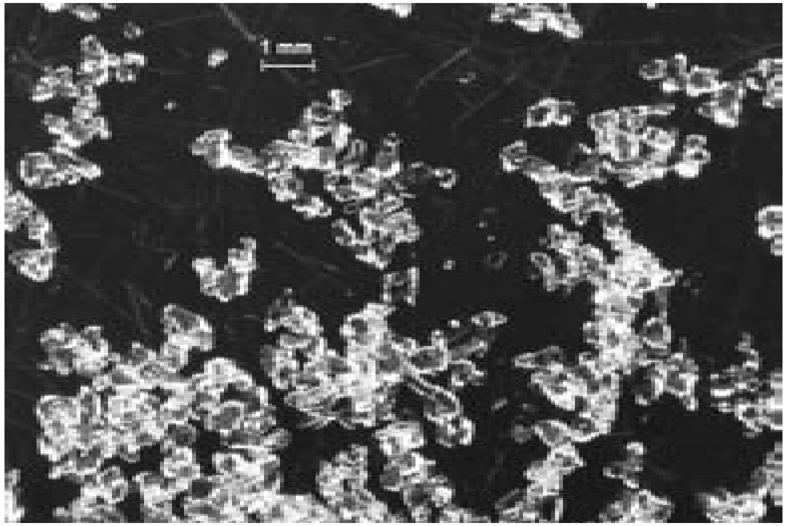




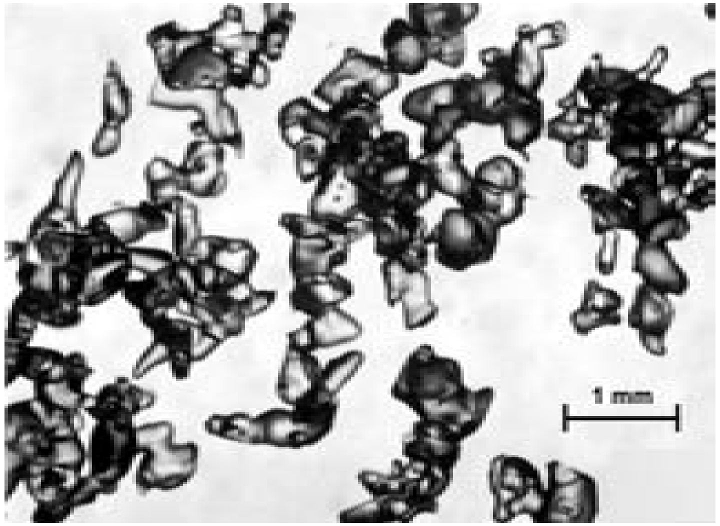

Wind broken precipitation particles DFbk, ⟋ (Fierz) #20



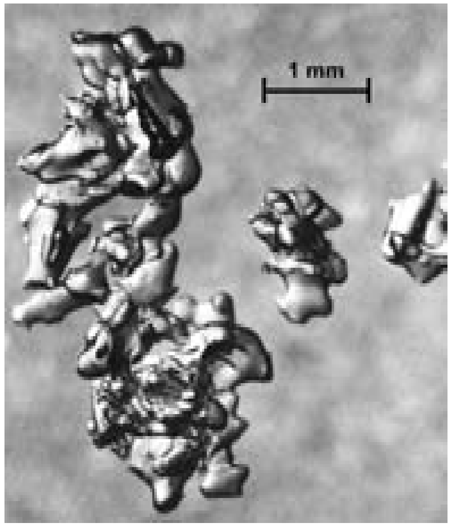

Wind broken precipitation particles DFbk, ⟋ (Fierz) #21



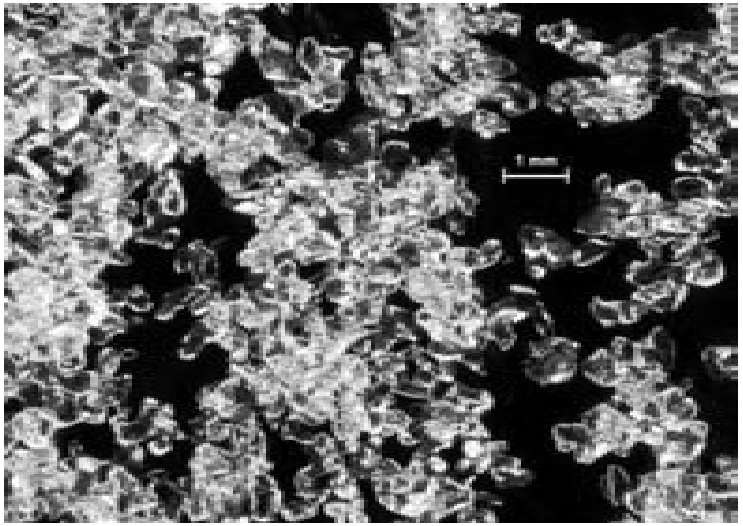

Small rounded grains RGsr, · (Elder) #22



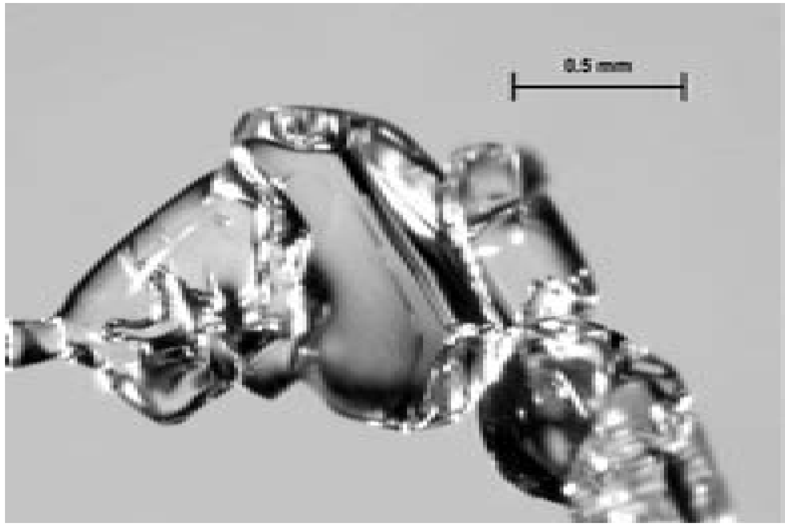

Large rounded grains RGlr, ● (JSSI) #23



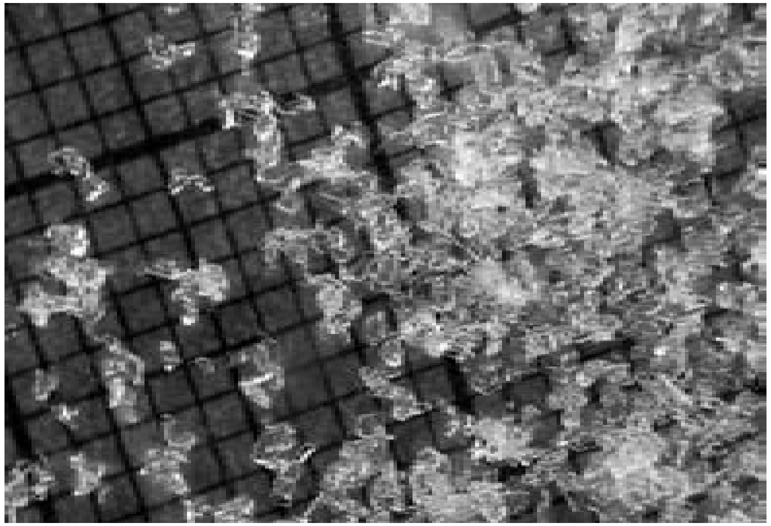

Wind packed RGwp, ⊘ (Sturm) #24



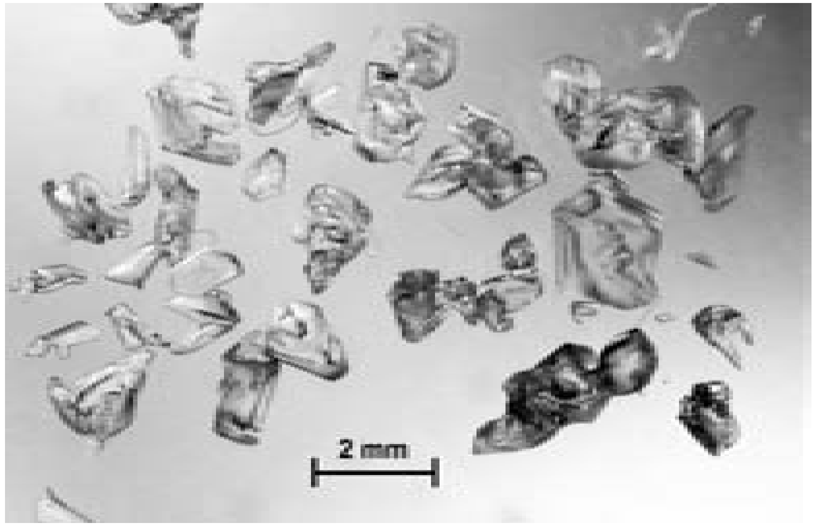

Faceted rounded particles RGxf, ◘ (Elder) #25



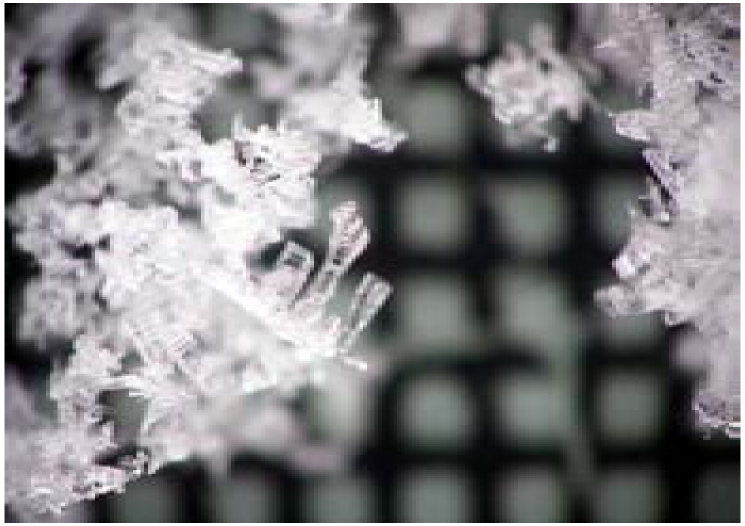

Faceted rounded particles RGxf, ◘ (CEN) #26



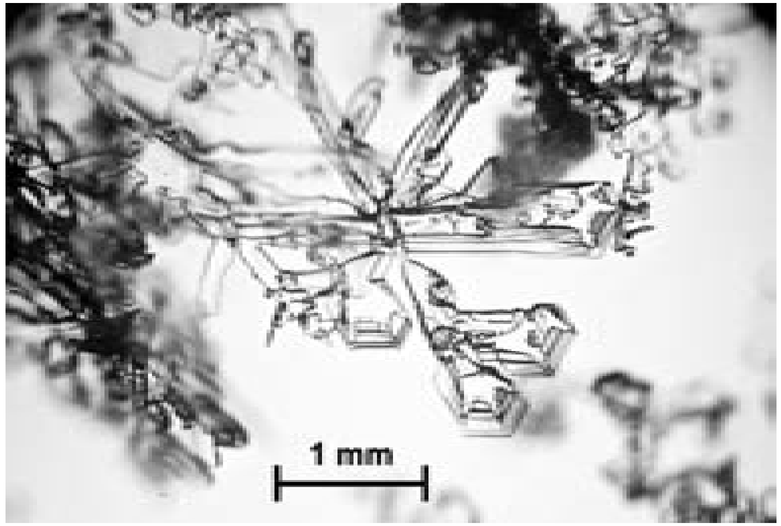
Solid faceted particles FCso, □, 1 mm grid (Kazakov) #27



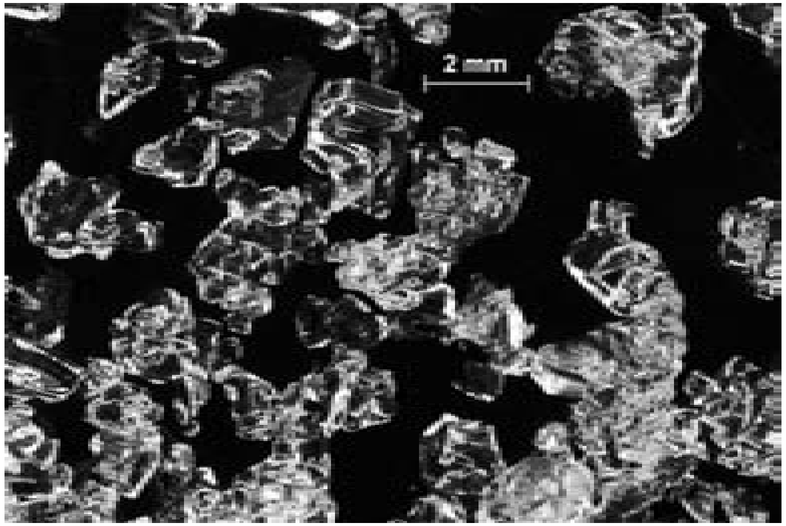

Solid faceted particles FCso, □ (AINEVA UniMilano) #28



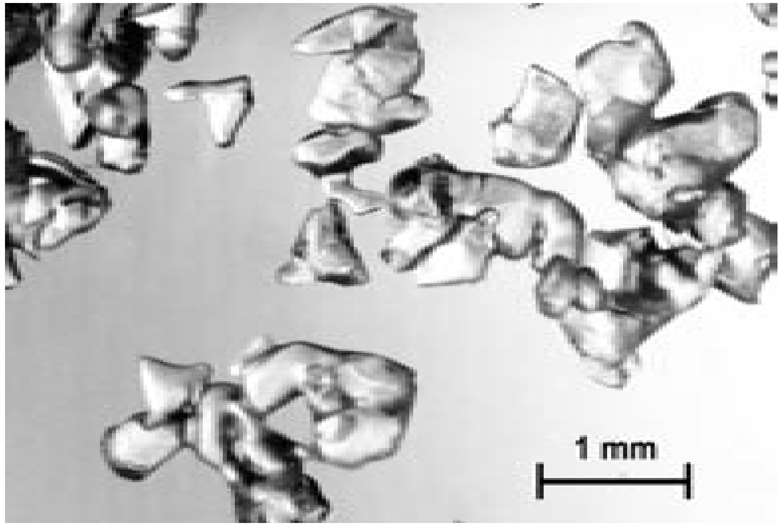
Near surface faceted particles FCsf, ⊠ (Munter) #29



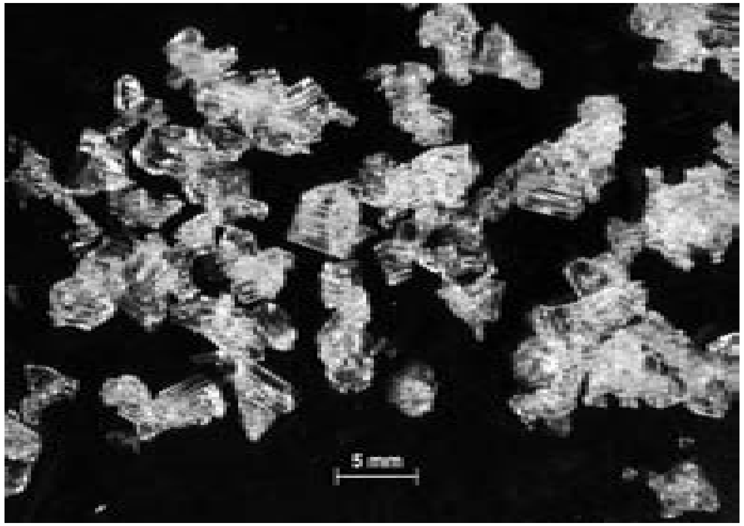

Near surface faceted particles FCsf, ⊠ (Stock) #30



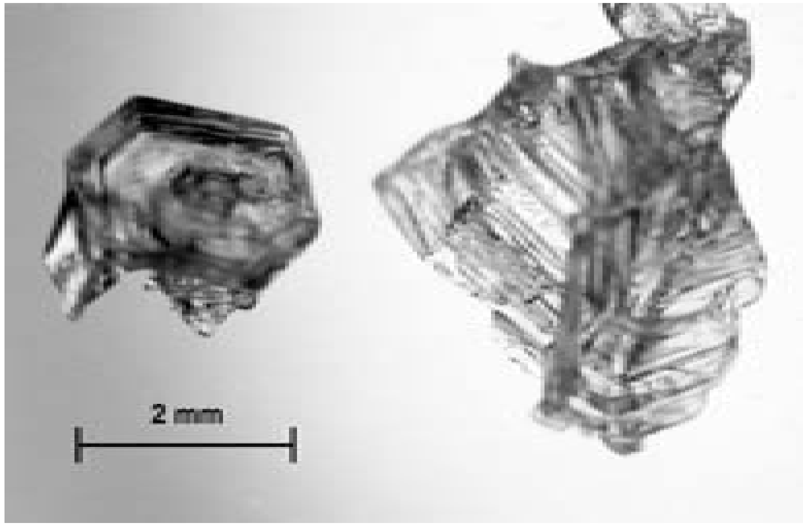

Rounding faceted particles FCxr, ⊟ (Elder) #31



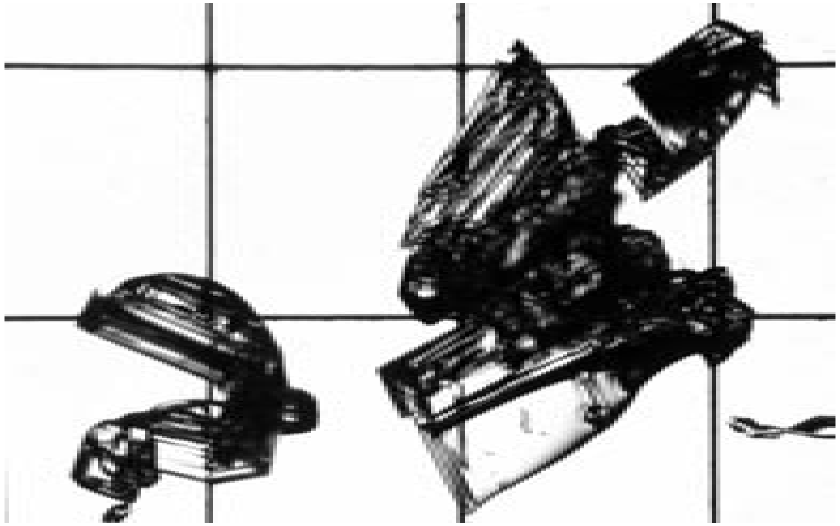

Rounding faceted particles FCxr, ⊟ (AINEVA UniMilano) #32



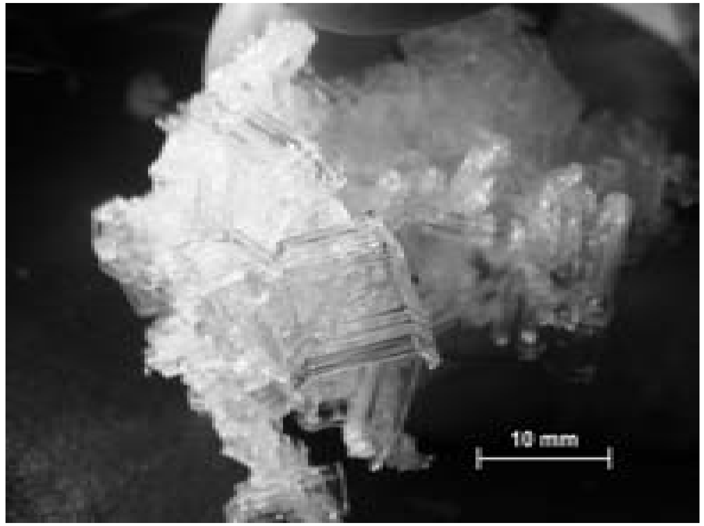

Hollow cups DHcp, ∧ (Greene) #33



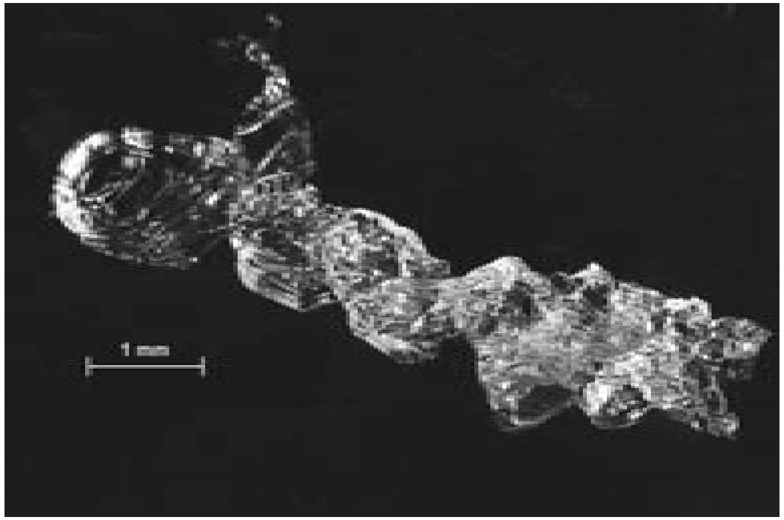

Hollow cups DHcp, ∧ (AINEVA UniMilano) #34



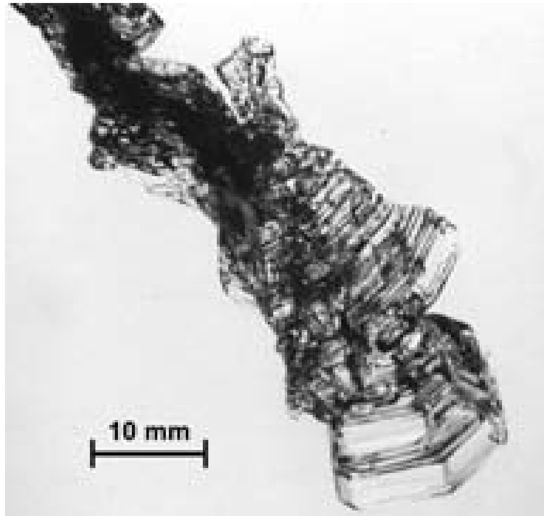
Hollow cups DHcp (DHpr), ∧(⊓), 2 mm grid (Fierz) #35




Hollow prisms DHpr, ⊓ (Sturm) #36

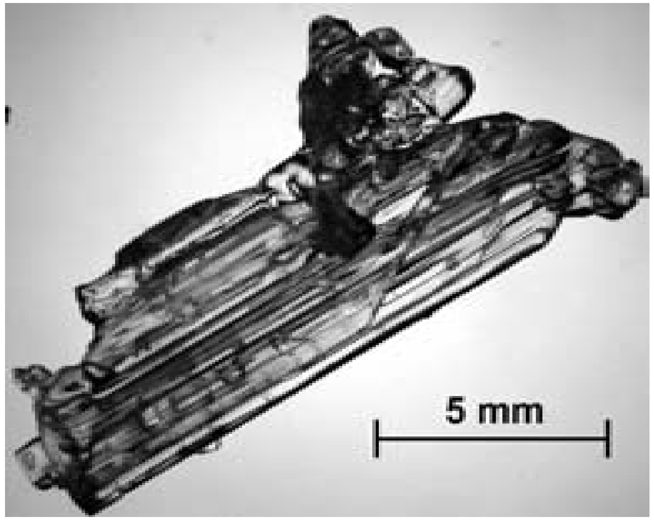



Chains of depth hoar DHch, $\wedge$ (Domine) #37

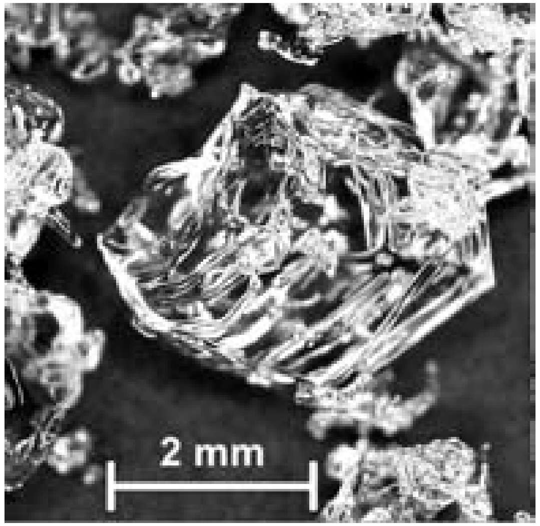



Chains of depth hoar DHch, $\wedge$ (Sturm) #38

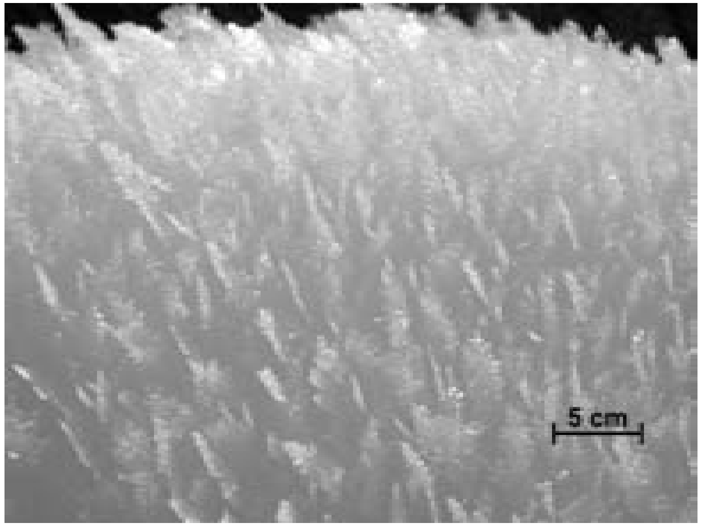

Large striated crystals DHla, $\wedge$ (AINEVA UniMilano) #39



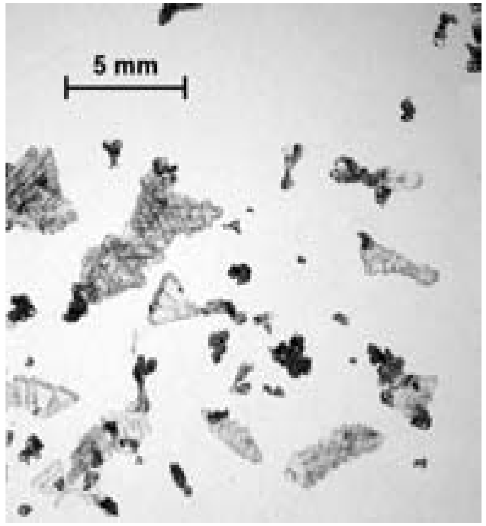

Large striated crystals DHla, $\wedge$ (Fierz) #40



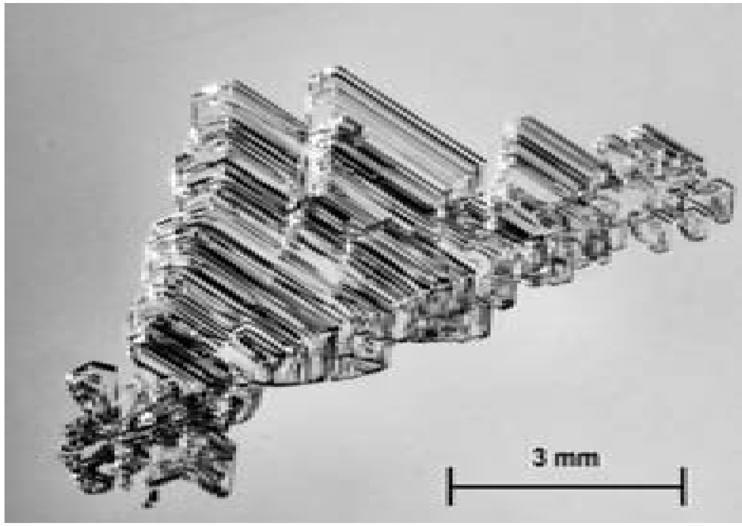

Rounding depth hoar DHxr, ∧ (Lipenkov) #41



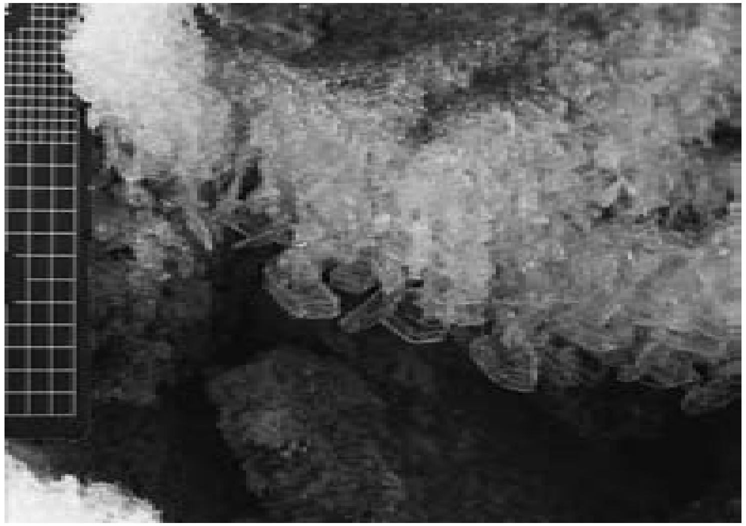
Surface hoar crystals SHsu, ∨ (Elder) #42



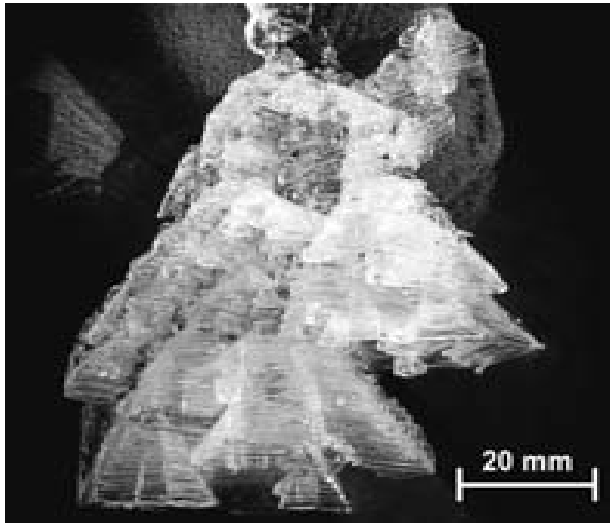
Surface hoar crystals SHsu, ∨ (Fierz) #43



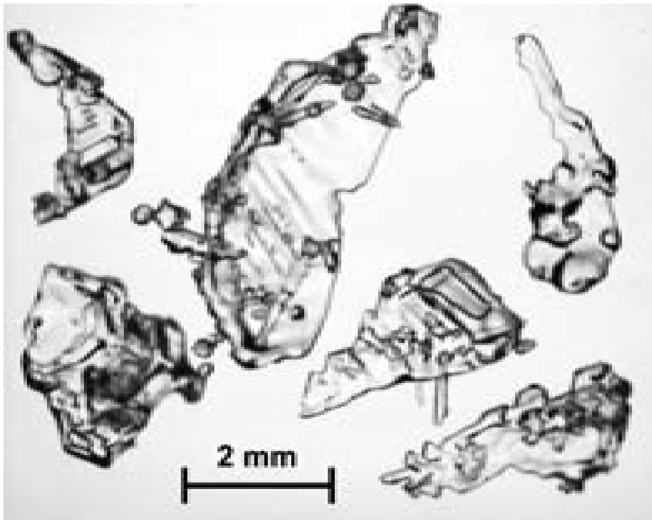
Surface hoar crystals SHsu, ∨ (CEN) #44



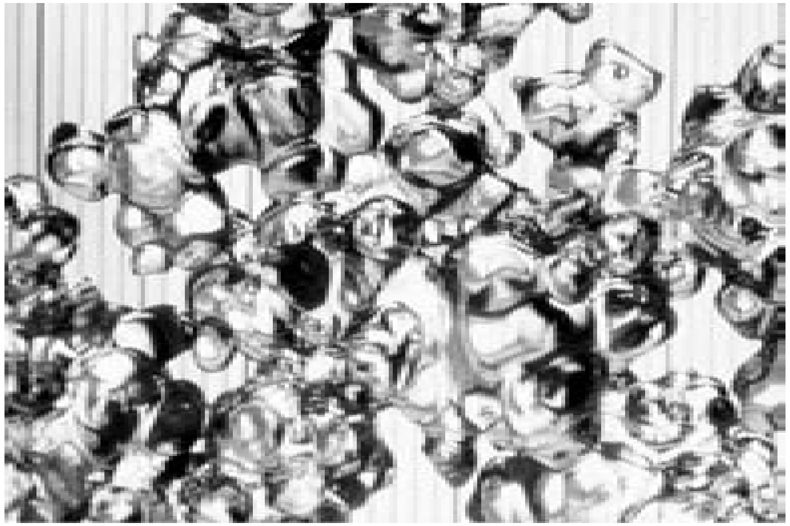
Cavity or crevasse hoar SHcv, $\triangledown$, 2 & 4 mm grid (Stucki) #45



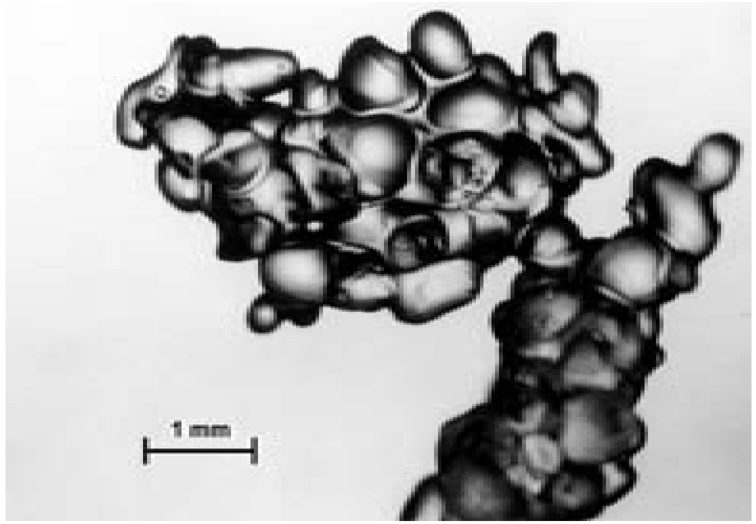

Cavity or crevasse hoar SHcv, $\triangledown$ (Elder) #46




Rounding surface hoar SHxr, $\vee$ (Fierz) #47

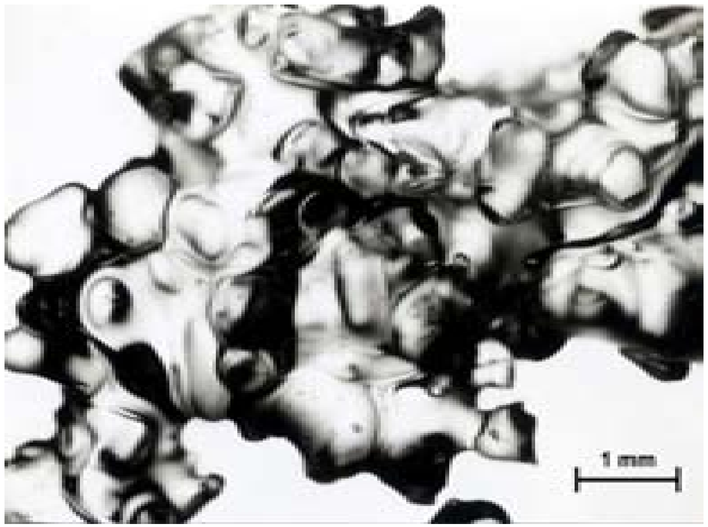


Clustered rounded grains MFcl, , 0.2 mm grid (CEN) #48

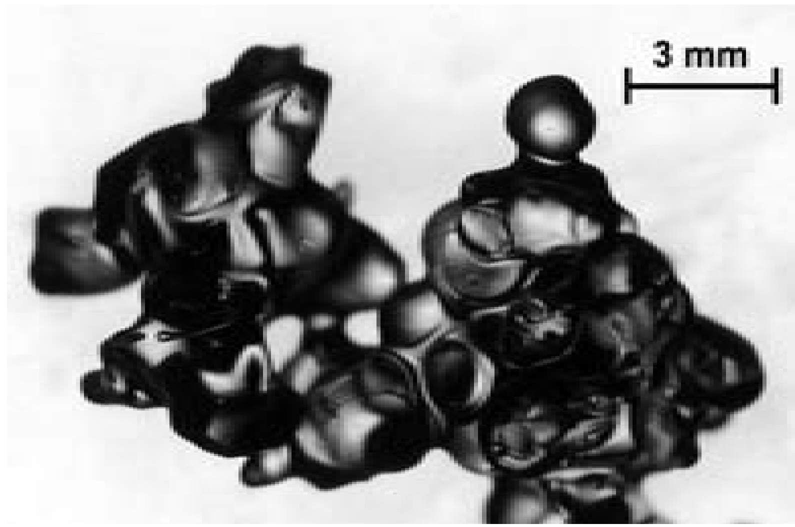



Clustered rounded grains MFcl,  (JSSI) #49

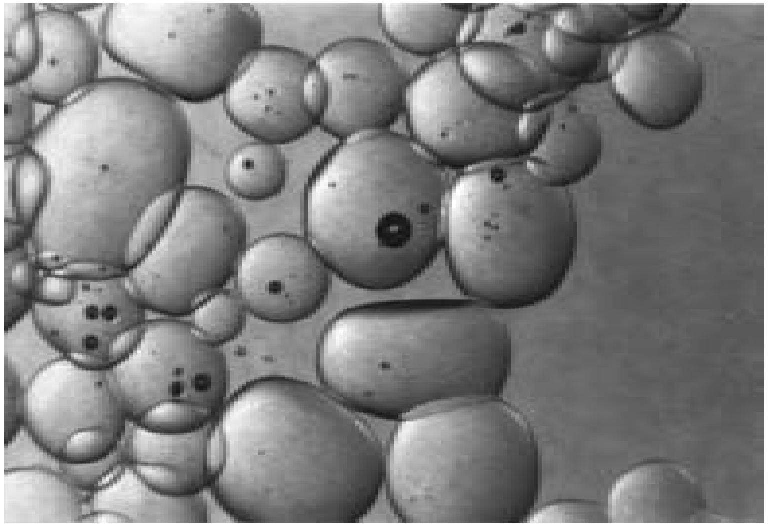




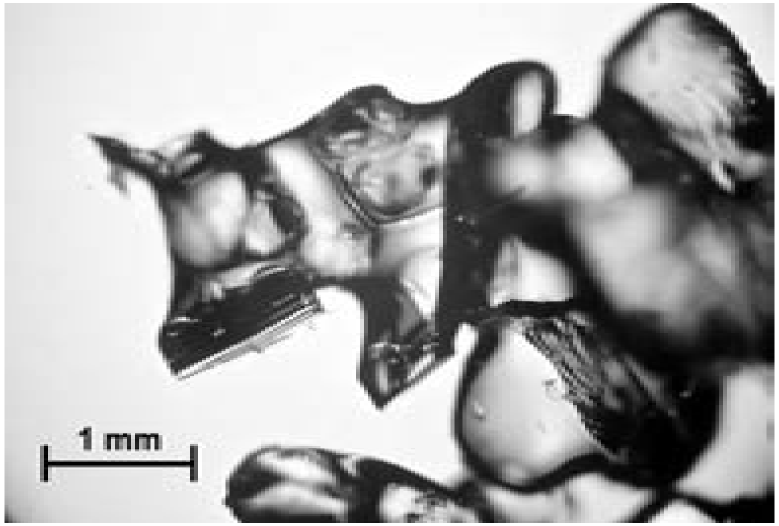

Rounded polycrystals MFpc,  (JSSI) #50



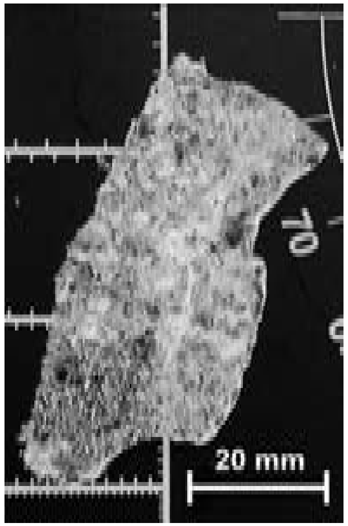

Rounded polycrystals MFpc,  (Sturm) #51



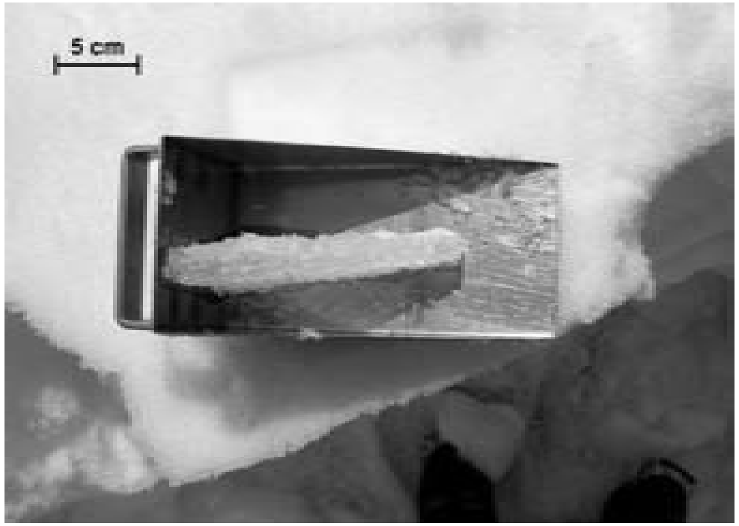
Slush MFsl, , grain size E 0.5-1 mm (Colbeck) #52



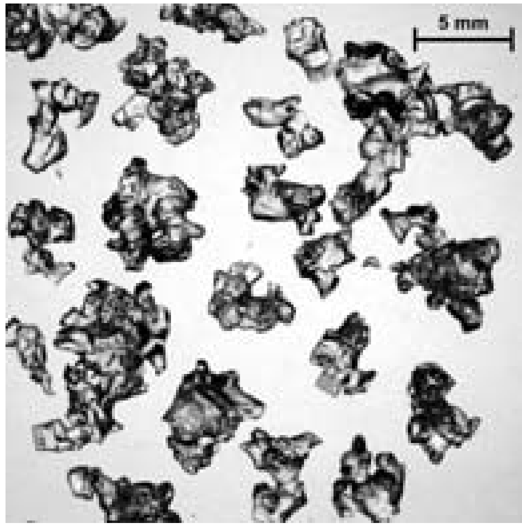

Melt-freeze crust MFcr (FCso),  (Stock) #53



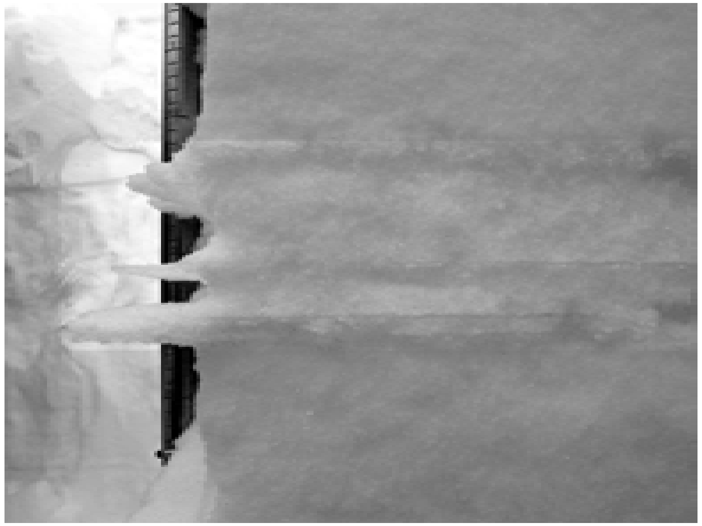

Melt-freeze crust MFcr,  (ARPAV) #54



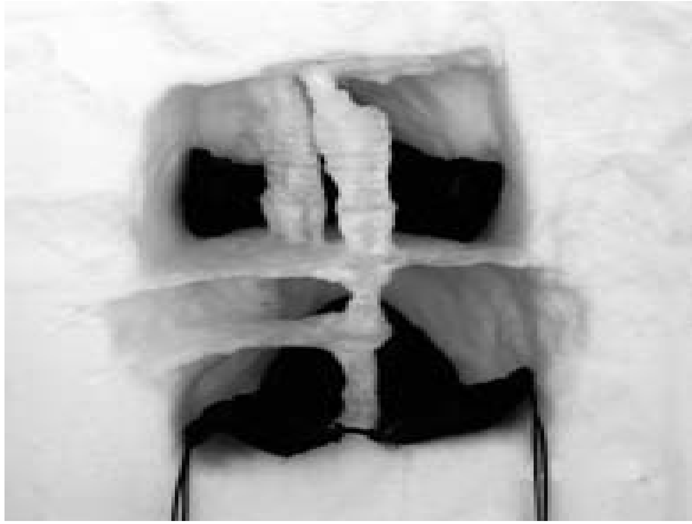

Melt-freeze crust MFcr,  (Elder) #55




Melt-freeze crust MFcr,  (Fierz) #56



Ice layer IFil, ▬ (Stucki) #57



Ice columns and layers IFic (IFil), ▮ (▬) (Stucki) #58



Sun crust (Firnspiegel) IFsc, – (van Herwijnen) #59

Sun crust (Firnspiegel) IFsc, – (JSSI) #60

## A.4: Photographic credits

| | |
|---|---|
| AINEVA & Università di Milano Bicocca<br>Vicolo dell'Adige 18<br>38100 Trento, Italy | PPpl, ; PPgp, ; FCso, ; FCxr, ;<br>DHcp, ; DHla, |
| ARPAV –- Centro Valanghe Arabba<br>Via Pradat, Arabba 5<br>32020 Livinallongo (BL), Italy | MFcr, |
| CEN – Centre d'Etudes de la Neige<br>Météo-France<br>38406 St Martin d'Hères Cedex, France | DFdc, ; RGxf, ; SHsu, ;<br>MFcl, |
| Colbeck, Sam C.<br>311 Goose Pond Road<br>Lyme, NH 03768, USA | MFsl, |
| Domine, Florent<br>CNRS – Laboratoire de Glaciologie et Geophysique de l'Environnement<br>Saint Martin d'Hères, France | DHch, |
| Elder, Kelly<br>USDA Forest Service, Rocky Mountain Research Station<br>Fort Collins, CO 80526, USA | PPco, ; PPnd, ; PPpl, ;<br>PPgp, ; PPhl, ; RGsr, ;<br>RGxf, ; FCxr, ; SHsu, ;<br>SHcv, ; MFcr, |
| Fauve, Mathieu<br>WSL Institute for Snow and Avalanche Research SLF<br>7260 Davos Dorf, Switzerland | MMrp, |
| Fierz, Charles<br>WSL Institute for Snow and Avalanche Research SLF<br>7260 Davos Dorf, Switzerland | PPnd (rimed), ; DFbk, ;<br>DHcp (DHpr), ( ); DHla, ;<br>SHsu, ; SHxr, ; MFcr, |
| Garcia Selles, Carles<br>Predicció d'Allaus - Unitat de Riscos Geològics<br>Institut Geològic de Catalunya<br>Balmes, 209-211, 08006 Barcelona, Spain | PPgp, |
| Greene, Ethan<br>Colorado Avalanche Information Center CAIC<br>325 Broadway WS1<br>Boulder, CO 80305, USA | PPpl, ; DHcp, |

| | |
|---|---|
| JSSI – The Japanese Society of Snow & Ice<br>Kagaku-Kaikan 3F (Chemistry Hall)<br>1-5 Kanda-Surugadai, Chiyoda<br>Tokyo 101-0062, Japan | PPsd, ∗; PPip, ◬; DFdc, ⁄; RGlr, ●; MFcl, ∞; MFpc, ∞; IFsc, – |
| Kazakov, Nikolai A.<br>Sakhalin Office of the Far-East Institute of Geology, Far-East Branch of the Russian Academy of Sciences<br>Gorky Str. 25<br>Yuzhno-Sakhalinsk 693023, Russia | FCso, □ |
| Lipenkov, Vladimir Ya.<br>Arctic and Antarctic Research Institute<br>Bering Str. 38<br>St Petersburg 199397, Russia | DHxr, ∧ |
| Munter, Henry<br>Yellowstone Club Ski Patrol<br>PO Box<br>Big Sky, MT 59716, USA | FCsf, ⊠ |
| Schweizer, Jürg<br>WSL Institute for Snow and Avalanche Research SLF<br>7260 Davos Dorf, Switzerland | PPrm, ∀; PPrm, ∀ (on snow-cover surface) |
| Span, Norbert<br>Team Eiswelten<br>Trinserstrasse 80a<br>6150 Steinach in Tirol, Austria | PPco (PPpl), ▭ (⊙); PPsd, ∗ |
| Stock, Joe<br>Freelance writer and alpine guide<br>www.stockalpine.com<br>Anchorage, AK 99508, USA | FCsf, ⊠; MFcr (FCso), ⊚⊡ |
| Stucki, Thomas<br>WSL Institute for Snow and Avalanche Research SLF<br>7260 Davos Dorf, Switzerland | SHcv, ▿; IFil, ▬; IFic (IFil), ▮ (▬) |
| Sturm, Matthew<br>USA-CRREL-Alaska<br>P.O. Box 35170<br>Ft Wainwright, AK 99703-0170, USA | RGwp, ●; DHpr, ⊓; DHch, ∧; MFpc, ∞ |
| van Herwijnen, Alec<br>WSL Institute for Snow and Avalanche Research SLF<br>7260 Davos Dorf, Switzerland | IFsc, – |

# APPENDIX B: SNOW MICROSTRUCTURE

The thermal, mechanical, and electromagnetic – including optical – properties of snow depend heavily on the configuration of the ice and air spaces. The microstructure of snow is complex, since the size, shape, and number of structural elements vary widely in natural snowpacks. Although snow is commonly disaggregated into ice particles for recording grain shape and size, this process destroys the microstructure and changes the properties we are attempting to measure. As a result, snow characterization solely by shape and size is incomplete.

Currently no standard method or parameter exists for characterizing snow microstructure. Many of the quantities discussed below are volumetric averages and therefore cannot represent the unique geometric configuration of the air and ice matrix. Some success has been achieved in parameterizing the physical properties of snow by combining snow crystal morphology and one or more of the quantities listed below. However, researchers must choose parameters carefully to make sure correlations between geometric and other parameters are physically meaningful.

Recent collaboration between material and mathematical scientists shows that concepts from mathematical geometry are useful for describing porous materials (see Ohser & Mücklich, 2000). Theoretically, porous materials such as snow can be described by their porosity, specific surface area, and curvature. The thermal, mechanical, and electromagnetic properties of some porous materials are well correlated to these microstructural parameters. However, we are just beginning to investigate if a similar approach will work with snow.

## B.1 Density

Symbol: $\rho_s$ Units: $\mathrm{kg\,m^{-3}}$

is a fundamental parameter of any material. In porous media, density generally refers to the bulk density, which is the total mass per volume (solid material and pore space; see also 1.3). Snow exists in nature over a large range of densities. Metamorphism, which produces all the shapes described in this document, typically results in a constant or increasing density. Density is easily measured in the field with light-weight and inexpensive equipment. Combining density and the grain classification is the most common method for characterizing snow layers, and we strongly recommend including density measurements in every observation scheme. However, density is a bulk property of snow and provides only a coarse measure of the microstructure.

## B.2 Porosity

Symbol: $\phi$ Units: 1

is a fundamental parameter of any porous medium. It is defined as the volume of the pore space divided by the total volume. Porosity can be calculated from the snow density. Direct measurements are possible with specialized equipment, but are difficult in the field.

## B.3 Specific surface area

Symbol: *SSA* Units: $\mathrm{m^2\,kg^{-1}}$ or $\mathrm{m^2\,m^{-3}}$

is an important parameter for characterizing porous materials that is increasingly being used in snow research. Specific surface area is important for applications involving chemical or electromagnetic interactions and is defined as the total surface area of the air/ice interface either per unit mass of a snow sample, $SSA_m$, or per ice volume, $SSA_V$, given in $m^2 kg^{-1}$ or $m^2 m^{-3}$, respectively. The density of ice, $\rho_i$, simply relates $SSA_m$ to $SSA_V = \rho_i \, SSA_m$. Snow metamorphism generally reduces the specific surface area even when other parameters, such as density, remain constant. Most measurement methods require specialized laboratory equipment, but emerging techniques may make field measurements of specific surface area possible. Like density, the specific surface area by itself does not adequately represent all features of the microstructure.

### B.4 Curvature

Symbols: $\kappa$ (mean); $G$ (Gaussian) Units: $m^{-1}$

Mean curvature and Gaussian curvature are defined locally by the mean and product of the principal curvatures, respectively. Both values are useful in describing the microstructure of snow. The mean curvature plays a significant role in interfacial thermodynamics, while Gaussian curvature can be used to characterize the mechanical properties. Both quantities are measured locally and averaged over a volume. Local curvature measurements are easy to interpret for certain shapes such as crystal facets (zero curvature) and sharp corners (very high positive curvature). Obtaining precise curvature values currently requires three-dimensional images of snow microstructure.

### B.5 Tortuosity

Symbol: $\tau$

is defined as the ratio of two distances: the path between two points through the ice or pore space and the straight line between them. The tortuosity of the ice matrix may be the primary factor determining the thermal conductivity of snow. It also affects the elastic modulus and heat and mass fluxes through the pore space. Currently, tortuosity measurements require three-dimensional reconstructions of the ice/air matrix combined with numerical simulations.

### B.6 Coordination number

Symbol: $CN$ Units: 1

is the number of connections between a particle and its neighbours. It can be represented with indices, averaged over a volume or determined for an individual structure. These geometric parameters are common in numerical models of snow. No algorithm exists to measure the coordination number in different snow types, as the traditional methods only work for convex bodies.

The present classification provides a framework for making observations of seasonal snowpacks and is designed to address the needs of a broad group, from scientists to skiers. The scheme includes both morphological and process distinctions. Combined with the other parameters outlined in the classification, it provides a relevant scheme for nearly all snow applications. Although these simple methods are useful, they also have limitations. Many applications will require a more comprehensive description of the snow microstructure. Observers must carefully select the parameters to measure or estimate to ensure they are collecting the necessary information for their application.

# APPENDIX C: OBSERVATION GUIDELINES

## C.1 Snow observations

Penetrability of snow surface *P*

> *PR* (ram penetration):
> It is recommended to not just let the ramsonde drop but to slightly guide it with the hand.
>
> *PF* (foot penetration) and *PS* (ski penetration):
> Take the average of two points or, if on a slope, take the average of up- and down-slope sides.

## C.2 Snowpack observations

Performing snowpack observations requires digging a large enough snow pit to allow for multiple observations. The pit face on which the snow is to be observed should be in the shade, vertical and smooth. On inclined terrain the shaded observation face should be parallel to the fall line, i.e., the natural downhill course of a slope.

Characterizing a distinct layer of snow requires more than simply classifying the observed grain shapes. Additional properties defined in Part I of this document also need to be recorded to give an as accurate as possible description of the snow type and its state. Below are some guidelines for how this is best achieved, with examples shown either in graphical or tabular form (see Figures C.1 to C.5 and Table C.4 for examples). Avoid using narrative text for describing snow profiles except for a single layer. In that case, make full sentences with the terms defined in the classification and do not use abbreviations, which can result in compressed, hard to read codes.

*H* Usually *H* designates the top boundary of a layer measured from either the base (positive) or the snow surface (negative). See 2.1, height, for a definition of 'base'.

L In tables, layer thickness *L* is best given explicitly, but ranges of *H* may also be used (see Table C.4).

$\theta_w$ , *LWC*

> Half index steps can also be used, best indicated as range, e.g., moist to wet or 2–3.
>
> Liquid water content may be recorded as a continuous profile, independent of layer boundaries.
>
> Conversions between volume and mass fractions:
> from volume to mass fraction: $LWC_{\mathrm{m}} = (\rho_{\mathrm{w}} / \rho_{\mathrm{s}}) \times LWC_{\mathrm{V}}$,
> from mass to volume fraction: $LWC_{\mathrm{V}} = (\rho_{\mathrm{s}} / \rho_{\mathrm{w}}) \times LWC_{\mathrm{m}}$,
> where $\rho_s$ is the snow density and $\rho_w$ is the density of liquid water (1000 kg m$^{-3}$).
>
> Wetness index can be converted to $LWC_{\mathrm{V}}$ using the following equation: $LWC_{\mathrm{V}} = 1.13\,\mathrm{s}^2 - 1.9\,\mathrm{s} + 0.8\%$ where s is the wetness index.

### Grain shape *F*

If two shapes are present in a layer, the shape in the minority is put in round brackets. Indicating more than two shapes per layer is not recommended.

In the case of a melt-freeze crust MFcr, the minority shape can be included as a second form in the surrounding sign, e.g., in the presence of faceted crystals (FC): .

Record discontinuous ice formations (ice lenses, etc.) in the comments. Size, diameter, and spacing of columnar features or the slope parallel dimension of ice lenses are essential for their complete description.

Some subclasses that formed at or near the surface may not always be classified with confidence once buried within the snowpack. When in doubt use the corresponding main class.

### Grain size E

Very often the average maximum grain size $E_{max}$ of a snow layer is also estimated. This is the average size of the largest grains found in this layer.

If both $E$ and $E_{max}$ are measured, they are best recorded as, e.g., 0.5–1 mm,

i.e., $E$–$E_{max}$.

As long as single crystals or grains are recognizable, grain size refers to the single crystals in clusters and polycrystals.

*R* Half index steps can also be used, best indicated as range, e.g., medium to hard or 3–4. They correspond to the upper limit of the corresponding range, e.g., 1.5 = 50 N. Alternatively, + and – qualifiers can be used, where a value of 4F+ (2+) is less hard than 1F– (3–).

In graphical form (see Figures C.1 to C.5), both ram resistance and the hand test are best represented as step profiles.

Hand hardness index can be converted to mean ram resistance $R$ in newtons using the following equation:
$R = 19.3\ r^{2.4}$ N where $r$ is the hand hardness index.

$\rho_s$ While it is not recommended, one may record the snow water equivalent *LW* of a single layer instead of its density. In this case *LW* very often spans several distinct stratigraphic layers. Use the following equation to convert density to snow water equivalent: $LW = \rho_s \times L\ /\ 100$ where $\rho_s$ is given in kg m$^{-3}$ and $L$ is the layer thickness in cm.

$T_s$ Snow temperature is usually recorded as a continuous profile, independent of layer boundaries, e.g., every 10 or 20 cm. Measurements should be more closely spaced near the surface.

In tabular form, measured temperatures should best be interpolated to the layer's top boundary.

*Comments*
Comments referring to a layer help to improve its description (see Figures C.1 to C.5 and Table C.4).

Examples of useful comments are:

- indicating whether Precipitation Particles (PP) are rimed (do not use with graupel (PPgp), hail (PPhl), or ice pellets (PPip))
- grain interconnections (bond size, number of bonds per grain, clustered, arranged in columns, etc.)
- the presence of isolated grains of yet another shape (see grain shape above)
- distinct features of a layer (weak layer, glazed surface, etc.)
- results of stability tests
- impurities (see 1.7)
- etc.

## C.3 Representations of snowpack observations

Snowpack observations recorded as snow profiles, that is, over many layers of the snowpack, are best represented graphically. The graphical form should include a header that conveys general information about the displayed snow profile. Tables C.1 and C.2 list recommended header entries while Table C.3 enumerates recommended components for the graphical parts. All components are drawn either as curve or in tabular form versus the height $H$ in centimetres. Figures C.1 to C.5 below provide examples of snow profiles observed on different locations of the earth under various climatic conditions.

If one single layer or only few layers of the snowpack are to be described, tabular forms as presented in Table C.4 may be a better choice. Keep the same recording style throughout the table.

## Table C.1 Recommended header entries for graphical forms

| *Entry* | *Symbol* | *Recommended format* |
|---|---|---|
| Air temperature | $T_a$ | See 1.6 |
| Aspect of slopes | *AS* | See 2.12 |
| Coordinates | | Latitude and longitude or UTM[1] coordinates |
| Date | | ISO 8061[2]: YYYY-MM-DD |
| Elevation | | metres above sea level |
| Height of snowpack | *HS* | See 2.3 |
| Location | | Geographical name |
| Observer | | Family name in full |
| Organization | | |
| Precipitation | | |
| Remarks | | |
| Sky condition | | METAR[3] cloud cover terms; see Table C.3 |
| Slope angle | $\psi$ | See 2.11 |
| Snow water equivalent | *SWE* or *HSW* | See 2.5 |
| Time | | ISO 8061[2]: hh:mm |
| Wind (direction and speed) | | Speed in kilometres per hour |
| Optional: | | |
| Mean ram resistance | $R_m$ | Average over height of snowpack HS; see also 1.4 |
| Penetrability of snow surface | *P* | See 2.8 |

[1]Universal Transverse Mercator (UTM) coordinate system is a grid-based method of specifying locations on the surface of the Earth
[2]ISO 8601 is an international standard for date and time representations issued by the International Organization for Standardization (ISO)
[3]METAR stands for METeorological Aviation Routine weather report

## Table C.2 METAR cloud cover terms

| *Term* | *Code* | *Cloudiness* |
|---|---|---|
| Clear | CLR | 0/8 |
| Few | FEW | 1/8–2/8 |
| Scattered | SCT | 3/8–4/8 |
| Broken | BKN | 5/8–7/8 |
| Overcast | OVC | 8/8 |
| Obscured (fog or observation not possible) | X | |

## Table C.3 Recommended graph components

| *Component* | *Symbol* | *Units* | *Remarks* |
|---|---|---|---|
| Snow temperature | $T_s$ | °C | See 1.6 |
| Snow hardness | $R$ | N | Ram resistance and/or hand hardness index; the latter should follow the resistance scale given in Table 1.4 |
| Liquid water content | $\theta_w$ | | See 1.5 |
| Grain shape | $F$ | | See 1.1 |
| Grain size | $E$ | mm | See 1.2 |
| Hand hardness index | $R$ | | Index, code, or graphic symbol; see Table 1.4 |
| Snow density | $\rho_s$ | kg m$^{-3}$ | See 1.3; may be combined with *LW*, see Table 2.2 |
| Comments | | | See Appendix C.2 |

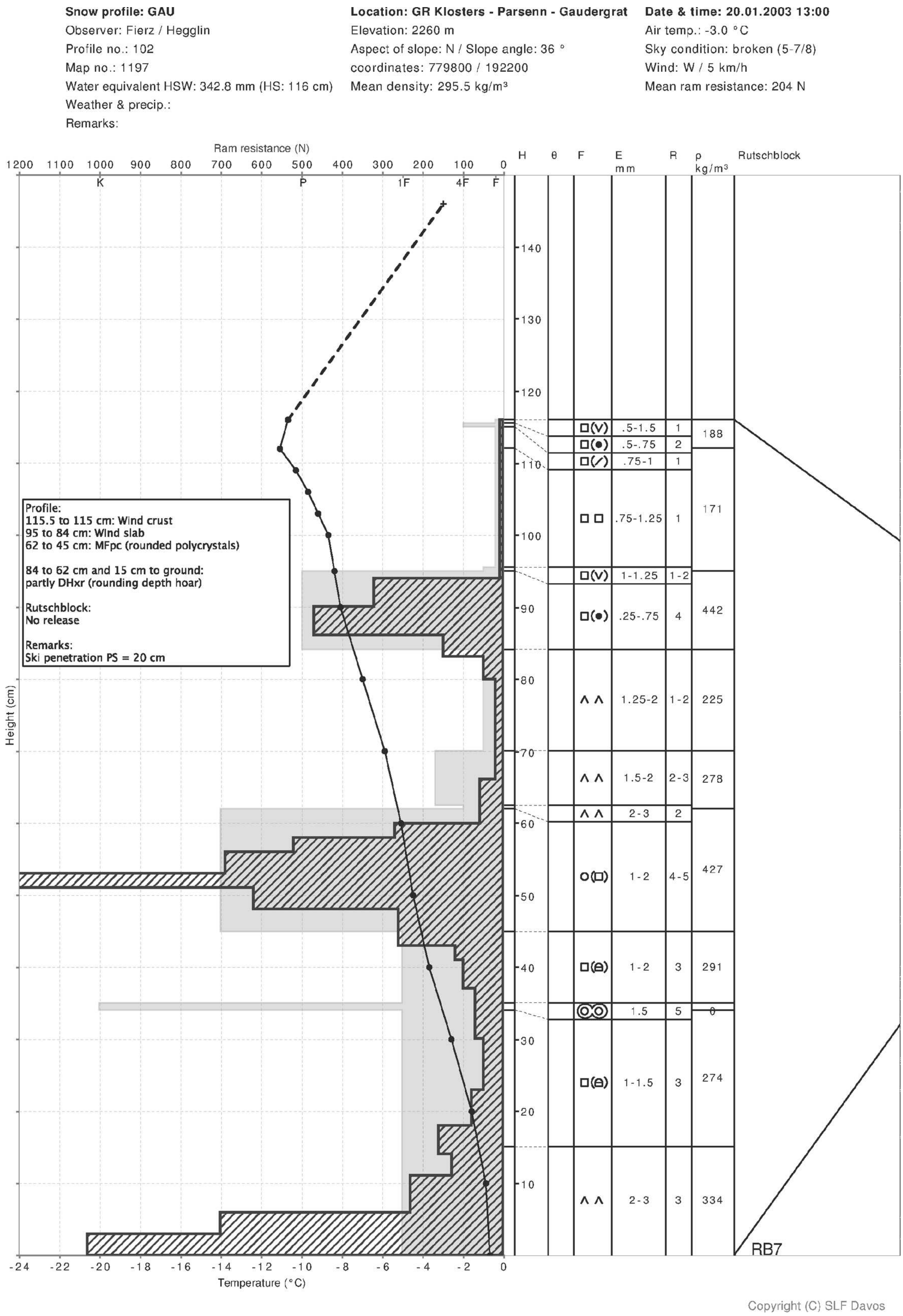



**Figure C.1** Snow profile observed in Graubünden Switzerland (slope)

| | | | |
|---|---|---|---|
| Organization: | Snow and Ice Research Center<br>National Research Institute for Earth Science and Disaster Prevention NIED | | |
| Observer: | S. Yamaguchi | Date: | 2006-02-05 09:40 |
| Location: | Nagaoka | Elevation: | 97 m |
| Aspect of slope: | – | Slope angle: | 0° |
| Snow depth: | 162 cm | SWE: | 519 mm w.e. |
| Air temperature: | –4.1°C | Wind (direction/speed): | N / 3.6 km $h^{-1}$ |
| Precipitations: | none | Sky condition: | overcast |
| Remarks: | – Liquid water content $\theta_w$ is given as mass fraction<br>– Snow hardness measured in kilopascal with a push-pull gauge (see 1.4); the circular indentation surface has a diameter of 15 millimetres, i.e., one kilopascal corresponds to 0.1766 newtons | | |

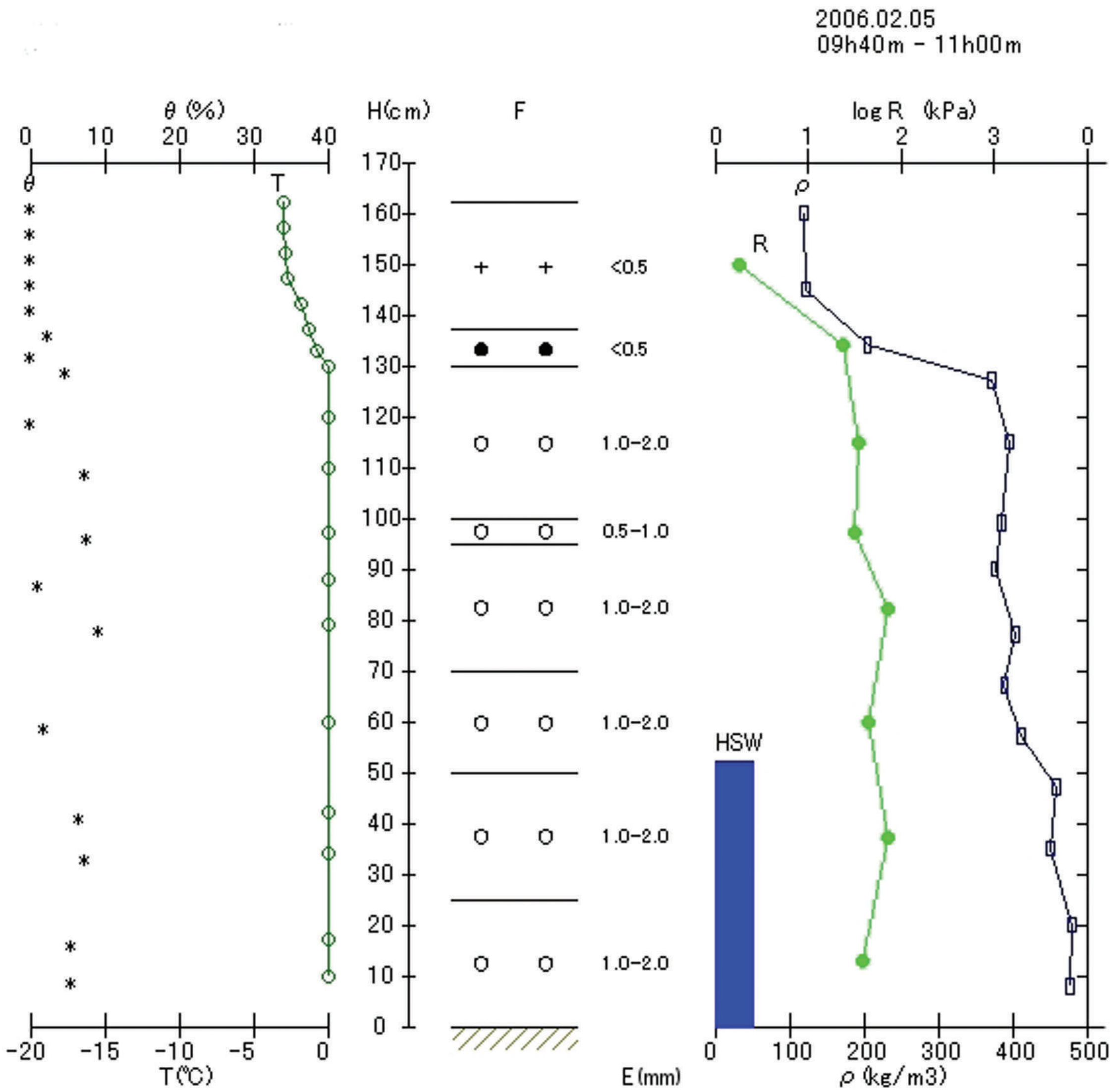



**Figure C.2** Snow profile observed in Nagaoka Japan (flat field) (Yamaguchi, 2007)

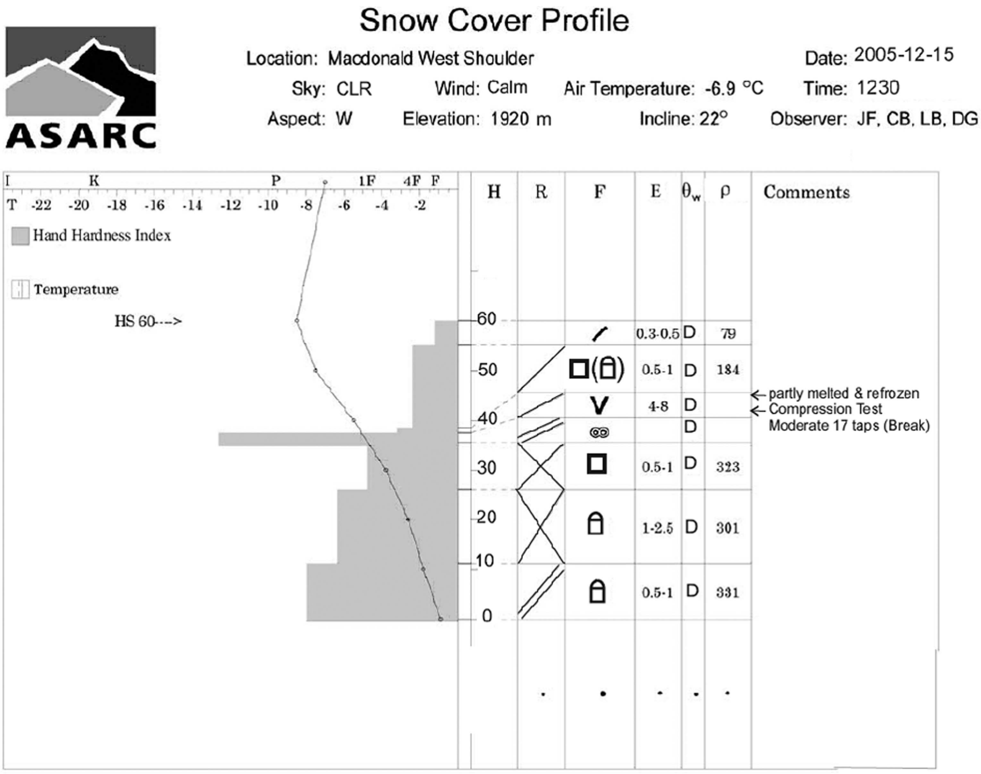



**Figure C.3** Snow profile observed in British Columbia Canada (slope)

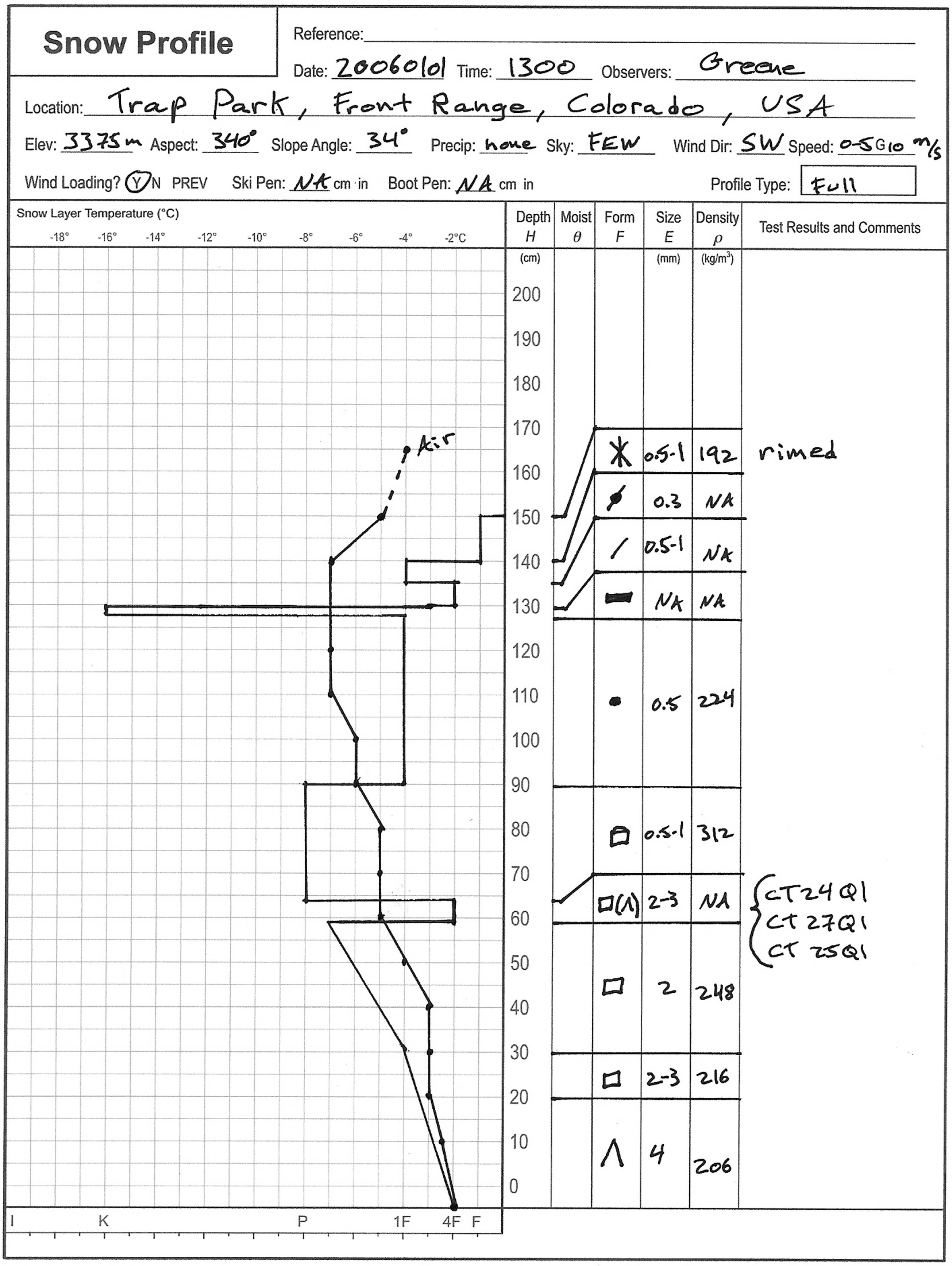



**Figure C.4** Hand-drawn snow profile observed in Colorado USA (slope)
CT24Q1: Compression Test, Hard, 24 taps; shear quality Q1
CT27Q1: Compression Test, Hard, 27 taps; shear quality Q1
CT25Q1: Compression Test, Hard, 25 taps; shear quality Q1
(see also AAA, 2009 and CAA, 2007)

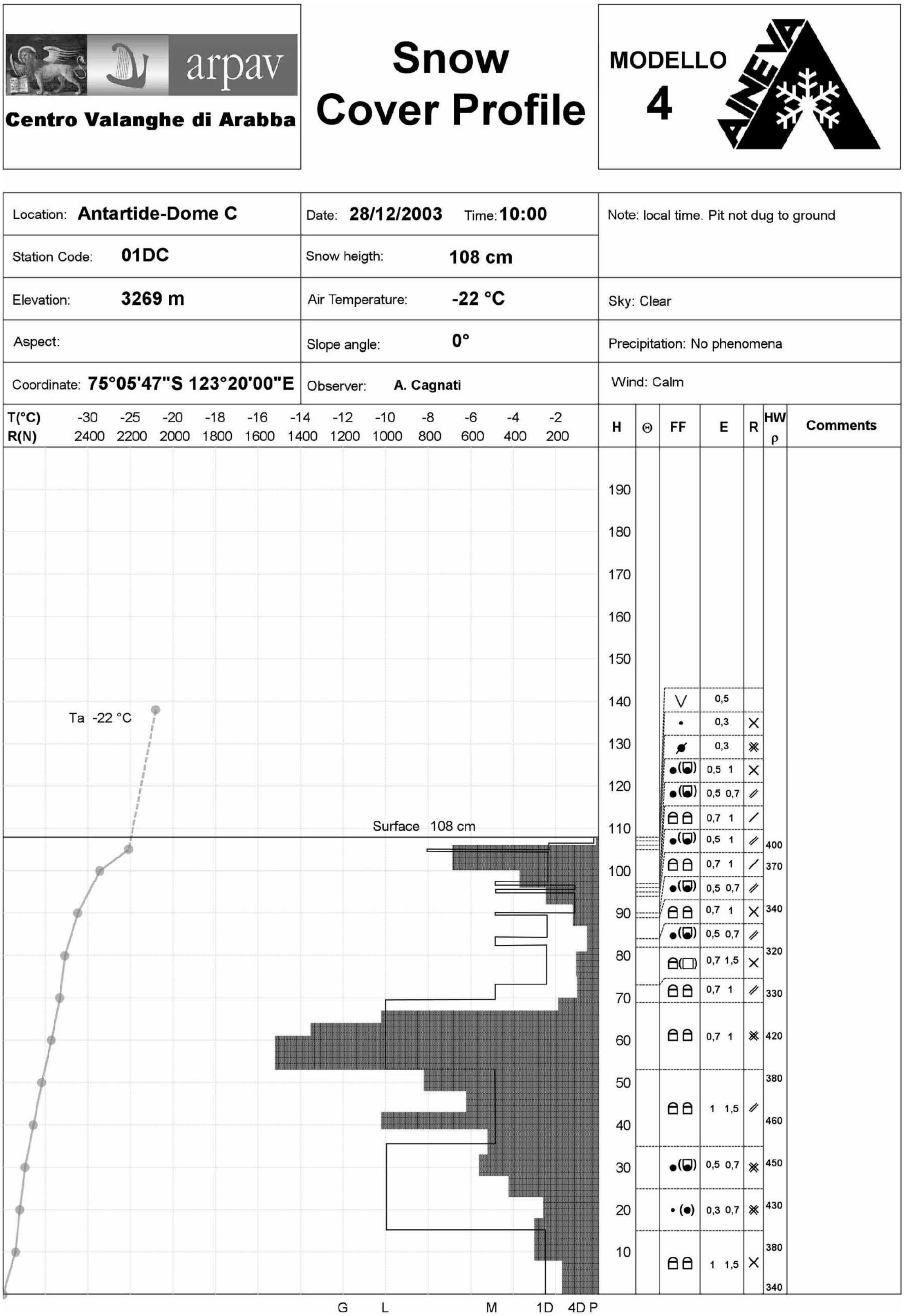



**Figure C.5** Snow profile observed at Dome C East Antarctica (flat field)

## Table C.4 Snowpack observations in tabular form

Height relative to ground:

| $H$ (cm) | $L$ (cm) | $\theta_w$, $LWC$ | $F$ [1,2] | $E$ (mm) | $R$ | $\rho$ (kg m$^{-3}$) | $T_s$ (°C) | Comments |
|---|---|---|---|---|---|---|---|---|
| 23 | 5 | wet | ○ ( + ) | 1.0–2.0 | fist | 250 | 0.0 | $HN$(24h) observed before snow got wet: 9 cm |
| 18 | 0.2 | | ▬ | | ice | | | |
| 17.8 | 1.8 | dry to moist | ◎◎ | 0.5–1.0 | very hard | 600 | 0.0 | |
| 16 | 6 | dry | ♡ | 1.0 | medium to hard | 400 | –0.1 | Discontinuous ice lenses, 30 cm in length, 2 mm thick |
| 10 | 7 | dry | ♡ ( □ ) | 1.5–2.0 | medium | 310 | –2.0 | Only few faceted crystals (FC) |
| 3 | 3 | dry | ◎□ | 1.0–1.5 | hard | 450 | –0.5 | $T_g$ = 0.0°C |

Height ranges relative to ground:

| $H$ (cm) | $L$ (cm) | $\theta_w$, $LWC$ | $F$ [1,2] | $E$ (mm) | $R$ | $\rho$ (kg m$^{-3}$) | $T_s$ (°C) | Comments |
|---|---|---|---|---|---|---|---|---|
| 15–14 | 1 | 1 | • | 0.2 | 4 | 340 | –2.8 | Wind crust |
| 14–10 | 4 | 1 | ● ( ⁄ ) | 0.3–0.5 | 2–3 | 250 | –2.5 | DF broken by wind |
| 10–3 | 7 | 1 | ∧ ( ∧ ) | 2.0–2.5 | 1–2 | 210 | –1.1 | Weakly bonded |
| 3–0 | 3 | 1 | ∧ ( ○ ) | 2.0–3.0 | 3 | 290 | –0.4 | $T_g$ = -0.2°C |

Depth relative to snow surface (Antarctic snow):

| $H$ (cm) | $L$ (cm) | $\theta_w$, $LWC$ | $F$[1,2] | $E$ (mm) | $R$ | $\rho$ (kg m$^{-3}$) | $T_s$ (°C) | Comments |
|---|---|---|---|---|---|---|---|---|
| 0 | 1 | D | RGwp | | I | | –19.7 | glazed surface, thin (0.1 mm) film of regelation ice on top |
| –1 | 2 | D | RG | 0.10 | K | 450 | –20.3 | Wind packed |
| –3 | 1 | D | RGwp | | I | | –21.5 | Old glazed surface |
| –4 | 4 | D | FCso (RGxf) | 1.0–2.0 | 1F | 360 | –22.1 | |

[1] Ideally symbols should be used for shapes while terms are preferred to steps and codes elsewhere. The same style should be kept throughout a table.

[2] Both MFcr and MFpc may contain recognizable remnants of other shapes, particularly large kinetic growth forms (FC or DH). Accordingly, the minority shape is included in the MFcr symbol ◎□, while the majority-minority coding convention is used with MFpc ♡ ( □ ).

## APPENDIX D: LIST OF SYMBOLS

| *Symbol* | *Description* | *Units* |
|---|---|---|
| *AS* | Aspect of slope | ° |
| *CN* | Coordination number | 1 |
| *D* | Thickness, i.e., slope-perpendicular coordinate, measured from either the base* (positive) or the snow surface (negative) | cm |
| *DN* | Thickness of new snow (slope-perpendicular) | cm |
| *DS* | Total thickness of snowpack (slope-perpendicular) | cm |
| *E* | Average size of the grains of a snow layer | mm |
| $E_{\mathrm{max}}$ | Average maximum size of the grains of a snow layer | mm |
| *F* | Grain shape | |
| *G* | Gaussian curvature | $m^{-1}$ |
| *H* | Height, i.e., vertical coordinate, measured from either the base* (positive) or the snow surface (negative) | cm |
| *HN* | Height of new snow, depth of snowfall (measured vertically) | cm |
| *HNW* | Water equivalent of daily snowfall | mm w.e., $kg\,m^{-2}$ |
| *HS* | Height of snowpack, snow depth (measured vertically) | cm |
| *HSW* | Water equivalent of snow cover (see also SWE) | mm w.e., $kg\,m^{-2}$ |
| *HW* | Water equivalent from the base* up to the height *H* | mm w.e., $kg\,m^{-2}$ |
| *J* | Impurities | mass fraction (%, ppm) |
| *L* | Layer thickness (measured vertically) | cm |
| $L_{\mathrm{p}}$ | Layer thickness (slope-perpendicular) | cm |
| *LW* | Water equivalent of a single layer of thickness *L* | mm w.e., $kg\,m^{-2}$ |
| *OGS* | Optical-equivalent grain size | mm |
| *P* | Penetrability of snow surface | cm |
| $P_{\mathrm{F}}$ | Foot penetration | cm |
| $P_R$ | Ram penetration | cm |
| $P_S$ | Ski penetration | cm |
| *R* | Snow hardness | –, N |
| *SF* | Surface features | cm |
| *SCA* | Snow covered area | 1 |
| *SSA* | Specific surface area (either per mass or volume) | $m^2\,kg^{-1}$, $m^2\,m^{-3}$ |
| *SWE* | Snow water equivalent (see also *HSW*) | mm w.e., $kg\,m^{-2}$ |
| $T_a$ | Air temperature | °C |
| $T_g$ | Ground surface temperature | °C |
| $T_s$ | Snow temperature | °C |
| $T_{ss}$ | Snow surface temperature | °C |
| *t* | Time | s, (min, h, d) |
| $\varepsilon$ | Strain | 1 |
| $\theta_{\mathrm{w}}$, *LWC* | Liquid water content | either volume or mass fraction (%) |
| $\kappa$ | Mean curvature | $m^{-1}$ |
| $\rho_{\mathrm{s}}$ | Density | $kg\,m^{-3}$ |
| $\sigma$ | Tensile or compressive stress | Pa |
| $\tau$ | Shear stress | Pa |
| $\tau$ | Tortuosity | 1 |
| $\phi$ | Porosity | 1 |
| $\psi$ | Slope angle | ° |
| $\Sigma$ | Snow strength | Pa |

* See 2.1 Height for a definition of ‘base'

## APPENDIX E: GLOSSARY

This glossary is intended to define the most important terms used in the present classification. All entries of Part 1, Part 2 and of Appendix B are included in this glossary without definitions but with appropriate cross references.

Note that there are several more comprehensive glossaries related to snow, avalanches, the cryosphere, or the atmosphere that also can be consulted.

*On line:*

- *NSIDC*'s Cryopheric Glossary
  The National Snow and Ice Data Center, Boulder, CO, USA.
  (NSIDC, 2008)
  http://nsidc.org/cgi-bin/words/glossary.pl
- *Glossary of Meteorology*
  2nd edition, 12000 terms. American Meteorological Society, Boston, USA.
  (AMS, 2000)
  http://amsglossary.allenpress.com
- *The Avalanche Glossary*
  Canadian Avalanche Centre, Revelstoke, BC, Canada
  http://www.avalanche.ca/CAC_Knowledge_Glossary
- *Glossary snow and avalanches*
  European Avalanche Warning Services EAWS
  http://www.lawinen.org
- *International Glossary of Hydrology*
  http://www.cig.ensmp.fr/~hubert/glu/aglo.htm

*Downloadable:*

- *Snow, Weather, and Avalanches: Observational Guidelines for Avalanche Programs in the United States; Glossary*
  The American Avalanche Association, Pagosa Springs, CO, USA.
  http://www.americanavalancheassociation.org/research/index.html
- *IKAR-CISA-ICAR dictionary* (1995)
  http://www.ikar-cisa.org
- *Illustrated Glossary of Snow and Ice*
  (Armstrong *et al.*, 1973)
  http://www.comnap.aq/content/temp/glossary-snow-ice/view

*Print only:*

- *Elsevier*'s Dictionary of Glaciology (Kotlyakov & Smolyarova, 1990)
- *Glyatsiologicheskii slovar*' [Glaciological dictionary] (Kotlyakov, 1980)
- *Avalanche Atlas - Illustrated International Avalanche Classification* (UNESCO, 1981)

### Ablation

All processes that remove snow, ice, or water from a snowfield, glacier, etc., that is typically melt, *evaporation*, *sublimation* as well as wind *erosion*, *avalanches*, calving, etc.; in this sense, the opposite of *accumulation*.

In many publications before 1980, ablation did not include mechanical removal of either snow or ice, i.e., wind *erosion*, *avalanches*, calving, etc.

### Ablation hollows

Depressions in the snow surface caused by either a warm, gusty wind or the sun (NSIDC, 2008), see also *sun cups*.

### Accretion

1 – Growth of a cloud or precipitation particle by collision with *supercooled* liquid droplets that freeze wholly or partially on impact (AMS, 2000, NSIDC, 2008).
2 – The process by which a layer of ice or snow builds on solid objects such as overhead lines that are exposed to precipitation icing events.

### Accumulation

All processes that add mass to the *snow cover* or to a glacier, i.e., typically solid and liquid precipitation, ice *deposition* from atmospheric water vapour, wind-deposited snow, but also *avalanches*, etc. (opposite of *ablation*).

### Aspect of slope

See 2.12

### Coordination number

See Appendix B

### Capillarity

A phenomenon associated with the surface tension of a liquid in contact with a solid. It occurs in fine bore tubes or channels such as found in porous snow. Capillary barriers refer to the interface between an upper fine-grained and a lower coarse-grained snow *layer*. Under unsaturated conditions, water in the small pores of the fine-grained snow *layer* is held at high tension and will not flow into the large pores of the coarse-grained snow *layer* where the water tension is low.

### Condensation

The process of forming a liquid from its vapour (opposite of *evaporation*).

### Crust

A friable, firm *layer* of snow or ice of varying thickness formed at the surface of the *snowpack*. It is designated as ‘breakable’ or ‘unbreakable’ according to its ability to support a person on skis. Examples are wind crusts and slabs, melt-freeze crusts as well as sun and rain crusts (see Appendix A.1, DF or RG, MF, and IF, respectively). Melt-freeze-crusts can be up to several centimetres thick while sun and rain crusts usually form a thin, i.e., a few millimetres thick *glaze* of ice on the surface.

## Crystal

A solid body whose atoms or molecules have a regularly repeated arrangement called crystal lattice. The latter may be outwardly expressed by plane faces (see *crystal facet*). Single crystals grow from a single nucleus (see also *grain*).

Skeleton type or hopper crystals grow faster along their edges than in the centres of their faces, so that the faces appear to be recessed. This type of skeletal (*re-*) *crystallization* usually determines the morphology of depth hoar crystals.

## Crystal card

Usually dark metallic or plastic screen that simplifies snow *crystal* analysis by providing a grid to determine grain shape and size. Also known as crystal screen.

## Crystal facet

A crystal face, i.e., a small, plane or flat surface of a *crystal*. Facets appear on many growing crystals because some surfaces grow much more slowly than others.

## Curvature

See Appendix B

## Deposition

1 - A process by which gases are deposited as a solid without first forming as a liquid (inverse *sublimation*). Surface hoar (SH) growth at the surface of the *snowpack* as well as *recrystallization* of snow within the *snowpack* (FC, DH) result from deposition of water vapour on ice (see *kinetic growth*).
2 – The process by which snow is deposited on the ground either with or without wind action (see also 2.9, surface features). As a result, stationary snow deposits such as snow dunes, *snowdrifts*, or the *snow cover* itself may form.

## Depth of snowfall

See 2.4

## Diamond dust

Diamond dust forms under very low air temperatures in strong, surface-based temperature inversion layers. Either vertical mixing within or radiational longwave cooling of this layer causes the air to become supersaturated with respect to ice, so that small ice *crystal*s form. These mostly unbranched *crystals* are seemingly floating in the air, slowly falling from an often apparently cloudless sky (AMS, 2000).

Columns (PPco) and plates (PPpl) are the dominant shapes found in diamond dust (Walden *et al.*, 2003), but stellar dendrites (PPsd) may also be observed. Long-prism columns having a ratio of length to width >5 are defined as 'Shimizu crystals' (Shimizu, 1963).

## Dielectric device

Instrument that uses the dielectric properties of snow to determine its *liquid water content* through capacitance and density measurements; it may also be used to determine dry snow *density*.

## Equilibrium growth

Slow growth of grains and bonds within the *snowpack* resulting in a decrease of the *specific surface area* of *snow*. Causes particles to round off. Works at low temperature gradients, i.e., when excess *water vapour density* is below the critical value for *kinetic growth* to occur.

An extreme case of equilibrium growth is isothermal – or equi-temperature – growth in dry snow. This is the type of *metamorphism* that in nature occurs only in the centre of polar ice shields and may allow *grains* to develop facets. The latter is still a matter of research.

## Erosion

The process by which the surface of the *snow cover* is worn away, primarily by the action of wind (see also 2.9, surface features, and *zastrugi*). Wind erosion is a very important factor in the *redistribution* of surface snow.

## Evaporation

The conversion of a liquid into vapour, at temperatures below the boiling point (opposite of *condensation*).

## Firn

Well-bonded and compacted snow that has survived the summer season, but has not been transformed to glacier ice. Typical densities are 400-830 kg $m^{-3}$ (*perennial snow, névé*). Thus *firn* is the intermediate stage between snow and glacial ice where the pore space is at least partially interconnected. *Firn* usually results from both melt-freeze cycles and compaction by overload, or from compaction alone, as in inland Antarctic snow.

## Flow finger

Vertical flow channel formed by *percolating* water in a subfreezing *snowpack*.

## Freezing point

The temperature at which a substance begins to solidify (see *melting point*). The freezing point of water is 273.15 K at an ambient pressure of 1013.25 hPa.

## Funicular regime (of water)

The condition of high *liquid water content* where liquid exists in continuous paths covering the ice structure; grain-to-grain bonds are weak. The volume fraction of free water exceeds 8 %, i.e., the wetness index is >3 (see also *pendular regime*).

## Glaze

A coating of ice, generally clear and smooth, formed on exposed objects by the freezing of a film of *supercooled* water deposited by rain, drizzle, fog, or possibly condensed from *supercooled* water vapour (AMS, 2000).

## Glazed surface

A multi-layered structure found in polar regions and consisting of single snow-grain *layers* cemented by thin (0.1 mm) films of *regelation* ice. The *regelation* ice films form on the surface following the kinetic heating of *saltating* drift snow under constantly strong katabatic wind flow (Goodwin, 1990).

**Grain**

1 – With respect to both shape and size of snow grains, the same as *particle*, i.e., the smallest characteristic subunit of snow microstructure recognizable with a hand lens (8-10x magnification).
2 – One single *crystal* of ice making up the ice structure of *snow*. The crystal orientation is continuous across each individual grain. Several grains together form a polycrystal having grain boundaries where crystal orientation changes.

**Grain bond**

The interconnection between snow *particles*, most often neck-like and located around grain boundaries (see *grain*).

**Grain shape (form)**

See 1.1

**Grain size**

See 1.2

**Height**

See 2.1

**Height of snowpack**

See 2.3

**Height of new snow**

See 2.4

**Hoarfrost, hoar**

A deposit of ice crystals (hoar crystals) formed by direct *deposition* on objects, usually those of small diameter freely exposed to the air, such as tree branches, plant stems and leaf edges, wires, poles, etc. It forms when air with a dew point below freezing is brought to saturation by cooling, i.e., usually *radiative cooling*. Hoarfrost also forms on snow surfaces (SH), within the *snowpack* (FC, DH), as well as inside unheated buildings and vehicles, in caves, and in crevasses (SHcv).

**Ice**

1 – Ice is the solid form of water. It is a transparent crystalline material having a density of 917 kg $m^{-3}$ for pure, bubble-free ice at 0°C.
2 – Ice in the context of snow must be regarded as a polycrystalline material. Ice formations (IF) in and on the *snowpack* consist of ice *crystals* frozen together that are not recognizable as single particles with a hand lens. They usually contain isolated air pores. Thus their density is less than that for pure ice but is greater than about 700 kg $m^{-3}$. Note that the transition from *firn* to ice containing air bubbles occurs at a density of about 830 kg $m^{-3}$.

**Impurities**

See 1.7

### Kinetic growth

Grain growth at high temperature gradients, i.e., when excess *water vapour density* is above a critical value (see also *equilibrium growth*). Water vapour diffuses from *grains* showing higher to those having lower water vapour density, i.e., the so called hand-to-hand mechanism (Yosida *et al.*, 1955). This process results in the *sublimation* and *deposition* – or *recrystallization* – of ice as well as changes in crystal size and shape. These changes usually result in a decrease of the *specific surface area* of snow.

Examples of kinetic growth shapes are faceted crystals (FC) and depth hoar (DH) that form within the *snowpack*, or surface hoar (SH) that grows on the snow surface.

### Layer

A stratum of snow that is different in at least one respect from the strata above and below (see also introduction to Part 1).

### Layer thickness

See 1.8

### Liquid water content

See 1.5

### Melting point

The temperature at which a solid liquefies (see *freezing point*). The melting point of ice is 273.15 K at 1013.25 hPa.

### Microstructure

See Appendix B

### Moisture content

Synonymous with *liquid water content*.

### Morphological classification

A classification based on the shape of the individual *grains* or *particles*.

### Névé

1 – A more or less extensive and persistent surface of snow, generally at high altitude. Synonymous with snowfield.
2 – Synonymous with *firn*. Used less frequently in this sense now than formerly.

### New snow

Recently fallen snow in which the original form of the ice *crystals* can be recognized (AMS, 2000, NSIDC, 2008).

### Optical-equivalent grain size

See 1.2

### Particle

The smallest characteristic subunit of snow microstructure recognizable with a hand lens (8-10x magnification); a particle can consist of one or more *crystals* of *ice* (see also *grain*).

**Pendular regime** (of water)

The condition of low *liquid water content* where a continuous air space as well as discontinuous volumes of water coexist in a *snowpack*, i.e., air-ice, water-ice, and air-liquid interfaces are all found. Grain-to-grain bonds give strength. The volume fraction of free water does not exceed 8 %, i.e., the wetness index is $\leq 3$ (see also *funicular regime*).

**Penetrability of snow surface**

See 2.8

**Penitent**

A spike or pillar of compacted snow, *firn*, or glacier ice caused by differential melting and *evaporation*. It is the extreme relief of *sun cups* found most often at high altitudes in low latitude regions; the resulting spikes resemble repentant souls. (AMS, 2000, NSIDC, 2008)

**Percolation**

Flow of a liquid through an unsaturated porous medium such as snow under the action of gravity.

**Perennial**

Persisting for an indefinite time longer than one year, e.g., perennial snow (see also *seasonal snow*).

**Porosity**

See Appendix B

**Radiative cooling**

1 – Radiative cooling is the process by which the temperature of a body decreases due to an excess of emitted longwave radiation over absorbed energy. Radiative cooling occurs typically on calm, clear nights but may be effective at daytime to form firnspiegel (suncrusts, IFsc, Ozeki & Akitaya, 1998) as well as to preserve surface hoar (SH, Hachikubo & Akitaya, 1998).

2 – In meteorology, the result of radiative cooling is termed 'radiational cooling', i. e., the decrease of both the earth's surface and adjacent air temperatures (AMS, 2000).

**Ram penetrometer**

A cone-tipped metal rod designed to be driven downward into deposited snow. The measured amount of force required to drive the rod a given distance is an indication of the ram resistance of the snow (see 1.4, snow hardness).

(Swiss rammsonde: cone tip angle: 60°; base diameter: 40 mm; weight: 10 N $m^{-1}$; ram weight: 10 N).

**Recrystallize**

To crystallize again, i.e., to form into new *crystals*.

**Redistribution**

Redistribution of previously *deposited* snow that was *eroded* and transported by the wind. Redistribution features such as *snowdrifts* are usually formed from densely packed and friable snow (see also 2.9, surface features).

**Regelation**

Process by which ice melts when subjected to pressure and refreezes when pressure is removed.

**Relative density**

While density (see 1.3) is mass per unit volume given in kilograms per cubic metre, relative density or specific gravity is the ratio of the mass of a given volume of a substance to the mass of an equal volume of water at a temperature of 4°C.

**Saltation**

Saltation is the mechanism by which snow *particles* are *eroded* from or *deposited* onto the snow surface and transported by the wind near to the surface. The process involves *particles* bouncing downstream and shattering new *particles* from the snow surface (King *et al.*, 2008).

**Sastrugi** (from Russian '**zastrugi**', plural form of '**zastruga**')

See *zastrugi*.

**Seasonal snow**

Snow that accumulates during one season and does not last for more than one year (NSIDC, 2008). See also *perennial*.

**Settlement**

The settlement of snow is the result of creep under the action of overburden pressure as well as of *metamorphic* processes going on within the *snowpack*.

**Sintering**

The process by which intergranular bonds form in a powder or porous material such as snow – dry or wet, decreasing thereby the surface energy of the material. In dry snow, direct *deposition* of water vapour diffusing through the pore space is usually the dominant bond growth mechanism, but several other mechanisms may contribute depending on the prevailing conditions: surface, volume, and grain boundary diffusion as well as plastic flow. Externally applied pressures, e.g., overburden by snow or ice, assist the sintering process by so-called pressure sintering (Maeno & Ebinuma, 1983; Colbeck, 1997; Blackford, 2007).

**Slope angle**

See 2.11

**Slushflow**

A mudflow-like outburst of water-saturated, i.e., soaked snow (see slush, MFsl), often along a stream course. Commonly occurring after rainfall and/or intense thawing have produced more water than can drain through the snow. A flowing mixture of snow and water.

**Snezhnik (Russian term)**
A perennial *snow patch* (Kotlyakov, 1980).

**Snow**
Precipitation in the form of small ice *crystals* which may fall singly or in *flakes*. *Deposited* snow is a highly porous material that builds up the *snow cover* on the ground.

**Snow avalanche**
Mass of snow which becomes detached and slides swiftly down a slope. Large snow avalanches may contain rocks, soil, vegetation, or ice. Avalanche formation was comprehensively reviewed by Schweizer *et al.* (2003).

**Snow cover**
In general, the *accumulation* of snow on the ground surface, and in particular, the areal extent of *snow-covered* ground (NSIDC, 2008); term to be preferably used in conjunction with the climatologic relevance of snow on the ground. See also *snowpack*.

**Snow covered area**
See 2.10

**Snow density**
See 1.3 and Appendix B; see also relative density

**Snow depth**
See 2.3

**Snow hardness**
See 1.4

**Snow layer**
See Part 1

**Snow level**
The lowest atmospheric level or altitude where hydrometeors remain in the solid (ice) phase. This often occurs within two to three hundred meters below the freezing level (the lowest elevation in the free atmosphere where the air temperature is 0°C). Snow level should not be confused with *snowline*.

**Snow metamorphism**
The transformation that the snow undergoes in the period from *deposition* to either melting or passage to glacial ice. Meteorological conditions as well as mechanical or gravitational *stresses* are the primary external factors that affect snow metamorphism. Dry snow metamorphism is governed by both *equilibrium* and *kinetic growth*. In presence of liquid water snow transformation is driven by wet snow metamorphism.

In English, snow metamorphism is sometimes and incorrectly called snow metamorphosis.

**Snow patch**

1 – The snow remaining on the ground close to the end of snowmelt (Jones *et al.*, 2003). Such a patchy, discontinuous *snow cover* is usually the result of slowly melting snow due to shading or areas of high *accumulation*.
2 – An isolated mass of snow, especially one which persists through most or all of the *ablation* season (see also *snezhnik*).

**Snow pit**

A pit dug vertically into the *snowpack* where snowpack *stratigraphy* and characteristics of the individual *layers* are observed; see also *snow profile*.

**Snow profile**

A *stratigraphic* record of the *snowpack* including characteristics of individual *layers*. Usually performed in *snow pits*.

**Snow strength**

See 2.7

**Snow temperature**

See 1.6

**Snow type**

Snow characterized by its microstructure and density (see 1.3). Note that grain shape and grain size are only an incomplete record of snow microstructure (Appendix B).

**Snow water equivalent**

See 2.5

**Snowdrift**

A mound or bank of snow deposited as sloping surfaces and peaks, often behind obstacles, irregularities, and on lee slopes. Due to eddies in the wind field (AMS, 2000, see also *deposition*).

**Snowfall**

The quantity of snow falling within a given area in a given time.

**Snowflake**

An interlocked bunch or aggregate of ice *crystals* that falls from a cloud. Air temperatures near the *melting point* favour the formation of snowflakes.

**Snowline**

In general the outer boundary of a snow covered area (see 2.10). This may be the ever-changing latitudinal limit of *snow cover*, particularly in the Northern Hemisphere winter, or the lower limit in altitude of the permanent *snow cover* in mountainous terrain. The latter strongly depends on the aspect of slope (see 2.12). Snowline should not be confused with *snow level*.

**Snowpack**
The accumulation of snow at a given site and time; term to be preferably used in conjunction with the physical and mechanical properties of the snow on the ground. See also *snow cover*.

**Specific surface area**
See Appendix B

**State of snow**
Snow characterization by properties such as hardness, *liquid water content*, temperature, and impurities.

**Strain**
The ratio of change in dimension to the original dimension. A material is said to be strained when a *stress* acting on it distorts it (see also 2.7, snow strength).

**Stratigraphy**
In the context of snow, the definition and description of the stratified, i.e., *layered* snowpack (see also *snow profile*).

**Stratification**
The vertical structure or *layering* of the snowpack, usually observed in *snow pits*.

**Stress**
The force per unit area acting on a material and tending to change its dimensions, i. e., to cause a *strain*. The two main types of stress are direct or normal (i.e., tensile or compressive) stress and shear stress (see also 2.7, snow strength).

**Striation**
Easily recognizable convex growth feature across *facets* or *crystal* surfaces.

**Sublimation**
The process in which a solid turns to a gas without first forming a liquid (opposite of *deposition*).

**Sun cups**
*Ablation hollows* that develop during intense sunshine (NSIDC, 2008). On low-latitude snow, *firn*, and ice fields these may grow into spectacular features called snow or ice *penitents*.

**Supercooled**
For liquids, cooled below normal *freezing point* without a change of phase. Water droplets in the atmosphere can continue to exist in the liquid state down to temperatures as low as –40°C.

**Surface features**
See 2.9

### Surface roughness
Refers to the roughness of a snow surface caused by precipitation or the wind as well as by uneven *evaporation*, *sublimation*, or melt. It does not refer to roughness due to snow microstructure (see also 2.9, surface features).

### Thickness
See 2.2

### Time
See 2.13

### Tortuosity
See Appendix B.

### Water equivalent of snowfall
See 2.6

### Water vapour
Water vapour is the gaseous form of water. It is colourless and odourless.

### Water vapour density
In a system of moist air, the ratio of the mass of *water vapour* present to the volume occupied by the mixture, i.e., the density of the water vapour component (AMS, 2000). Also called absolute humidity.

A critical excess water vapour density, i.e., supersaturation, of about 5-6 $\times 10^{-4}$ kg m$^{-3}$ separates *equilibrium* from *kinetic growth* (Colbeck, 1983).

### Water vapour concentration
Synonymous with *water vapour density*.

### Wetness
Synonymous with *liquid water content*.

### **Zastrugi** (from Russian, plural form of '**zastruga**'; variant spelling: **sastrugi**)
Ridges of hard snow alternating with wind-blown furrows running parallel with the direction of the wind. This surface formation results from the *erosion* of transverse waves previously formed (see also 2.9, surface features). Zastrugi may be up to several meters long and up to several tens of centimetres high.

# APPENDIX F: MULTILINGUAL LIST OF TERMS

## F.1 Terms used in tables

Country specific translations are preceded by the appropriate country code (CA: Canada, CH: Switzerland).
Terms in parentheses refer to the body of the text.

| *English* | *Français* | *Español* | *Russian* | *Deutsch* |
|---|---|---|---|---|
| **Table 1.1** | | | | |
| **Primary physical characteristics of deposited snow** | **Caractéristiques physiques élémentaires de la neige au sol** | **Características primarias de la nieve depositada** | **Основные физические характеристики отложенного снега** | **Physikalische Haupteigenschaften von abgelagertem Schnee** |
| microstructure (App. B) | microstructure | microestructura | микроструктура | Mikrostruktur |
| grain shape (1.1) | forme des grains | forma de los granos | форма зёрен | Kornform |
| grain size (1.2) | taille des grains | tamaño de granos | размер зёрен | Korngrösse |
| snow density (1.3) | masse volumique de la neige | densidad de nieve | плотность снега | Schneedichte |
| – dry | – sèche | – seca | – скелета | – Trocken- |
| – total | – totale | – total | – общая | – Gesamt- |
| snow hardness (1.4) | dureté de la neige | dureza de la nieve | твёрдость снега | Schneehärte |
| liquid water content (1.5) | teneur en eau liquide | contenido de agua líquida | содержание жидкой фазы | Wassergehalt |
| snow temperature (1.6) | température de la neige | temperatura de la nieve | температура снега | Schneetemperatur |
| impurities (1.7) | impureté | impurezas | загрязнённость | Verunreinigung |
| layer thickness (1.8) | épaisseur d'une couche | espesor de la capa | толщина слоя | Schichtdicke |
| **Table 1.2** | | | | |
| **Main morphological grain shape classes** | **Classification morphologique élémentaire** | **Clases morfológicas principales de formas de granos** | **Основные морфологические классы формы зёрен** | **Hauptkornformen** |
| precipitation particles (PP) | cristaux de neige fraîche CA: nouvelle, récente | cristales de nieve fresca | свежевыпавший снег | Neuschneekristalle |
| machine made snow (MM) | neige de culture | nieve artificial | искусственный снег | technischer Schnee |
| decomposing and fragmented precipitation particles (DF) | particules reconnaissables, CH: neige feutrée | cristales de nieve fresca descompuestos y fragmentados | разрушающиеся и разломанные снежинки | filziger Schnee |
| rounded grains (RG) | grains fins | granos redondeados | округлые зёрна | feinkörniger Schnee, kleine runde Körner |
| faceted crystals (FC) | grains à faces planes, CA: faces planes, facettes | cristales con caras planas | гранные зёрна | kantigkörniger Schnee, kantige Körner |
| depth hoar (DH) | givre de profondeur, gobelets | escarcha de profundidad | глубинная изморозь | Tiefenreif, Becherkristalle, Schwimmschnee |
| surface hoar (SH) | givre de surface | escarcha de superficie | поверхностный иней, изморозь | Oberflächenreif |
| melt forms (MF) | grains ronds, CH: grains de fonte | granos derritiéndose | талые формы | Schmelzformen |
| ice formations (IF) | formations de glace | formaciones de hielo | ледяные включения | Eisgebilde |

| *English* | *Français* | *Español* | *Russian* | *Deutsch* |
|---|---|---|---|---|
| **Table 1.3** | | | | |
| **Grain size** | **Taille des grains** | **Tamaño de grano** | **Размер зёрен** | **Korngrösse** |
| very fine | très fin | muy fino | очень мелкий | sehr fein |
| fine | fin | fino | мелкий | fein |
| medium | moyen | medio | средний | mittel |
| coarse | grossier | grueso | крупный | groß |
| very coarse | très grossier | muy grueso | очень крупный | sehr groß |
| extreme | extrêmement grossier | extremadamente grueso | экстремально крупный | extrem groß |
| **Table 1.4** | | | | |
| **Snow hardness** | **Dureté de la neige** | **Dureza de nieve** | **Твёрдость снега** | **Schneehärte** |
| very soft | très tendre | muy blanda | очень мягкий | sehr weich |
| soft | tendre | blanda | мягкий | weich |
| medium | mi-dur | media | средний | mittelhart |
| hard | dur | dura | твёрдый | hart |
| very hard | très dur | muy dura | очень твёрдый | sehr hart |
| ice | glace | hielo | лёд | Eis |
| **Table 1.4** | | | | |
| **Hand hardness test** | **Test manuel de la dureté** | **Prueba de dureza manual** | **Испытание ручным способом** | **Handhärtetest** |
| fist | poing | puño | кулак | Faust |
| 4 fingers | 4 doigts | 4 dedos | 4 пальца | 4 Finger |
| 1 finger | 1 doigt | 1 dedo | 1 палец | 1 Finger |
| pencil | crayon | lápiz | карандаш | Bleistift |
| knife | couteau | cuchillo | нож | Messer |
| ice | glace | hielo | лёд | Eis |
| **Table 1.5** | | | | |
| **Liquid water content** | **Teneur en eau liquide** | **Prueba de humedad manual** | **Содержание жидкой фазы** | **Wassergehalt** |
| dry | sèche | seca | сухой | trocken |
| moist | légèrement humide | ligeramente húmeda | слабо влажный | schwach feucht |
| wet | humide | húmeda | влажный | feucht |
| very wet | mouillée | muy húmeda | очень влажный | nass |
| soaked | très mouillée | empapada | водонасыщенный | sehr nass |

| *English* | *Français* | *Español* | *Russian* | *Deutsch* |
|---|---|---|---|---|
| **Table 2.1** | | | | |
| **Snow cover measurements** | **Mesure du couvert neigeux** | **Mediciones de cobertura de nieve** | **Измерения снежного покрова** | **Schneedecken-messungen** |
| height (vertical) (2.1) | hauteur | altura (vertical) | толщина, высота (по вертикали) | Höhe |
| thickness (slope-perpendicular) (2.2) | épaisseur | espesor (perpendicular a la pendiente) | мощность (по перпендикуляру к подстилающей поверхности | Mächtigkeit, Dicke |
| height of snowpack, snow depth (2.3) | hauteur (totale) de neige | altura del manto de nieve, profundidad de la nieve | толщина (высота) снежного покрова | (Gesamt-)Schneehöhe |
| height of new snow, depth of snowfall (2.4) | hauteur de neige fraîche CA: récente, nouvelle | altura de nieve fresca, profundidad de nieve caída | толщина свежевыпавшего снега | Neuschneehöhe, Neuschneemenge |
| snow water equivalent (2.5) | équivalent en eau de la neige | equivalente en agua de la nieve | водный эквивалент снежного покрова | Wasserwert des Schnees |
| water equivalent of snowfall (2.6) | équivalent en eau de la neige fraîche (récente, nouvelle) | equivalente en agua de precipitación sólida | водный эквивалент свежевыпавшего снега | Wasserwert des Neuschnees |
| snow strength (2.7) | résistance mécanique | resistencia mecánica | прочность снега | Festigkeit |
| penetrability of snow surface (2.8) | pénétrabilité de la surface | penetrabilidad de la superficie de la nieve | проницаемость поверхности снега | Einsinktiefe |
| surface features (2.9) | éléments de surface | características de la superficie | особенности поверхности | Eigenschaften der Oberfläche |
| snow covered area (2.10) | étendue du couvert neigeux | area cubierta de nieve | заснеженность | Schneebedecktes Gebiet |
| slope angle (2.11) | inclinaison, déclivité de la pente | inclinación de la pendiente | крутизна склона | Hangneigung |
| aspect of slope (2.12) | orientation, exposition de la pente | exposición de la pendiente | экспозиция склона | Hangexposition |
| time (2.13) | temps | tiempo | время | Zeit |
| **Table 2.3** | | | | |
| **Surface features** | **Eléments de surface** | **Elementos de la nieve** | **Особенности поверхности** | **Eigenschaften der Oberfläche** |
| smooth | lisse | lisa | гладкая | glatt |
| wavy | ondulé | ondulada | волнистая | gewellt |
| concave furrows | dépression concaves | surcos cóncavos | вогнутая (борозды) | konkave Furchen |
| convex furrows | sillons convexes | surcos convexos | выпуклая (валы) | konvexe Furchen |
| random furrows | érosion irrégulière | surcos irregulares | нерегулярно-эрродированная | unregelmässig erodiert |

## F.2 Terms used in appendices A.1 and B

Underlined entries are defined in the glossary (Appendix E), terms in parentheses refer to the body of the text.

| *English* | *Français* | *Español* | *Russian* | *Deutsch* |
|---|---|---|---|---|
| **Appendix A.1**<br>**Some grain shape subclasses** | **Quelques classes morphologiques secondaires** | **Algunas subclases de formas de granos** | **Отдельные подклассы по форме зёрен** | **Einige Nebenkornformen** |
| graupel (PP) | neige roulée, grésil | granizo fino | снежная крупа | Graupel |
| hail (PP) | grêle | granizo | град | Hagel |
| ice layer (IF) | couche de glace | capa de hielo | ледяная прослойка | Eisschicht |
| ice pellet (PP) | granule de glace | gránulo de hielo | ледяная крупа | Frostgraupel |
| needle (PP, SH) | aiguille | aguja | иглы | Nadel |
| plate (PP, MM, SH) | plaquette | placa | пластинки | Plättchen |
| rime (PP) | givre | cencellada | иней, изморозь | Rauhreif |
| – soft | – mou | – blanca | – изморозь, иней | – Rauhreif |
| – hard | – dur | – transparente | – твёрдый налёт, ледяной налёт | – Rauheis |
| stellar (PP) | en étoile | en estrella | звёздчатые (дендритные) формы | sternförmig |
| sun crust, firnspiegel (IF) | croûte de rayonnement<br>CA: de radiation, de soleil | Costra de radiación | радиационная корка | Firnspiegel |
| **Appendix A.1**<br>**Grain shape related terms** | **Terminologie relative à la forme des grains** | **Términos relacionados con formas de granos** | **Терминология связанная с формой зёрен** | **Kornform bezogene Terminologie** |
| abraded (RG) | abrasé | escoriado | отшлифованный | abgeschliffen |
| accretion (PP) | accrétion | acreción | наращенный | Zuwachs |
| broken (DF, RG) | brisé | quebrada | поломанный | zerbrochen |
| clustered (MF) | en agrégat | agregada | гроздевидный | verklumpt |
| column (PP, RG, IF) | colonne | columna | столбик, колонна | Säule |
| cup (DH, SH) | gobelet | copa | бокал | Becher |
| crushed | écrasé, concassé | picado | колотый | zermahlen, zerkleinert |
| crust (PP, DH, SH, IF) | croûte | costra | корка | Kruste, Harsch |
| decompose (DF) | décomposer | descompuesta | разрушать | abbauen, zerfallen |
| drain (MF, IF) | s'écouler | drenar | стекать | abfliessen |

| English | Français | Español | Russian | Deutsch |
|---|---|---|---|---|
| **Appendix A.1 (continued)** | | | | |
| feathery (SH) | frêle, en forme de feuille | pluma | перьевидный | zart, fedrig |
| flake ice | glace écaille | hielo en escamas | чешуйчатый лёд | Scherbeneis |
| fragmented (DF) | fragmenté | fragmentada | разломанный | zerbrochen |
| freezing rain (IF) | pluie verglaçante | lluvia helada | замёрзший дождь | vereisender Regen |
| hexagonal (PP, FC) | hexagonale | hexagonal | гексагональный (шестиугольный) | hexagonal |
| hollow (PP, DH, SH) | creux | hueco | полый | hohl |
| ice lens (IF) | lentille de glace | lente de hielo | ледяная линза | Eislinse |
| planar (PP, SH) | plan | plana | плоский | eben |
| prismatic (PP, DH) | prismatique | prismática | призматический | prismatisch |
| rimed (PP) | givré | escarchado | намёрзший | verreift |
| scrolls (SH) | volute | voluta | спирали | Spiralform |
| shard (MM, DF) | tesson | fragmento | осколок | Scherbe |
| sintered (MM, DF, RG) | fritté | sinterizado | спёкшийся | gesintert |
| slush (MF) | neige détrempée, soupe | nieve sopa | талый снег | Schneematsch |
| solid (PP, FC, DH, MF) | plein | sólida | сплошной | voll |
| spatial (PP) | spatiale (structure) | espacial | пространственный | räumliche (Struktur) |
| striated (DH, SH) | strié | estriada | бороздчатый | gerippt, geriffelt |
| striation (DH, SH) | strie | estría | бороздка | Rippe, Riffel |
| **Appendix B** | | | | |
| **Snow microstructure** | **Microstructure de la neige** | **Microestructura de nieve** | **Микроструктура снега** | **Schneemikrostuktur** |
| density (B.1) | masse volumique | Densidad | плотность | Dichte |
| porosity (B.2) | porosité | porosidad | пористость | Porosität |
| specific surface area (B.3) | surface spécifique | área específica | удельная поверхность | spezifische Oberfläche |
| curvature (B.4) | courbure | curvatura | кривизна | Krümmung |
| tortuosity (B.5) | tortuosité | tortuosidad | извилистость | Tortuosität |
| coordination number (B.6) | nombre de coordination | número de coordinación | координационное число | Koordinationszahl |

## F.3 Further terms used in the text

Underlined entries are defined in the glossary (Appendix E).

| *English* | *Français* | *Español* | *Russian* | *Deutsch* |
|---|---|---|---|---|
| **A** | | | | |
| ablation | ablation | ablación | абляция | Ablation |
| – hollows | – creux d’ | – huecos de | абляционные полости | Wabenschnee |
| accumulation | accumulation | acumulación | накопление, аккумуляция | Akkumulation, Ablagerung |
| air | air | aire | воздух | Luft |
| – temperature | – température de l’ | – temperatura del | температура воздуха | –temperatur |
| airborne | aéroporté | aerotransportando | (наблюдения) с воздуха | luftgetragen |
| atmosphere | atmosphère | atmósfera | атмосфера | Atmosphäre |
| atom | atome | átomo | атом | Atom |
| avalanche | avalanche | avalancha | лавина | Lawine |
| – formation | – formation des | – formación de | лавинообразование | –nbildung |
| **B** | | | | |
| barchan | barkhane | barján | бархан | Barkhandüne |
| bed surface (of an avalanche) | plan de glissement (d’une avalanche) | superficie de deslizamiento (de una avalancha) | подстилающая поверхность, поверхность скольжения (лавины) | Gleitfläche (einer Lawine) |
| bond size | taille des ponts | tamaño del puente | размер контакта (шейки, связи) | Bindungdurchmesser |
| bonded | soudé | adherido | связанные | gebunden |
| brittle | fragile | quebradizo | хрупкий | spröd |
| **C** | | | | |
| calorimetry | calorimétrie | calorimetría | калориметрия | Kalorimetrie |
| capillarity | capilarité | capilaridad | капиллярность | Kapillarität |
| cardinal point | point cardinal | punto cardinal | страна света | Haupthimmelsrichtung |
| classification | classification | clasificación | классификация | Klassifizierung |
| – morphological | – morphologique | – morfológica | морфологическая - | – morphologische |
| code | code | código | код | Kürzel |
| condensation | condensation, liquéfaction | condensación | конденсация | Kondensation, Verflüssigung |
| compaction | compactage | compactación | уплотнение | Verdichtung |

| *English* | *Français* | *Español* | *Russian* | *Deutsch* |
|---|---|---|---|---|
| coordinate | coordonnée | coordenada | координата | Koordinate |
| cornice | corniche | cornisa | карниз | Wächte |
| crystal | cristal | cristal | кристалл | Kristall |
| – card or screen | – grille | – tarjeta para medir cristales | кристаллическая решётка | –raster |
| – facet | – facette d'un | – faceta | грань кристалла | –facette |
| **D** | | | | |
| degree | degré | grado | градус | Grad |
| deposition | dépôt | depositación | отложение | Ablagerung |
| diamond dust | poudrin de glace | polvo diamante | алмазная пыль | Diamantenstaub |
| dielectric device | instrument pour mesurer la constante diélectrique | instrumento para mediciones de la constante dieléctrica | прибор для измерения диэлектрической постоянной | Instrument zur Messung der Dielektrizitätskonstante |
| dilution method | méthode par dilution | método de dilución | метод растворения | Verdünnungsmethode |
| droplet | gouttelette | gotícula | капля | Tröpfchen |
| ductile | ductile | dúctil | пластичный | duktil |
| dune | dune | duna | дюна | Düne |
| **E** | | | | |
| erosion | érosion | erosión | эрозия | Erosion |
| evaporation | évaporation | evaporación | испарение | Verdampfen, Verdunstung |
| **F** | | | | |
| firn | névé | neviza | фирн | Firn |
| flow finger | cheminée de percolation | | язык просачивания | Fliessfinger |
| fracture | fracture | fractura | разрушение | Bruch |
| freeze | geler | congelar | замерзание | gefrieren |
| freezing point | point de congélation | punto de congelación | точка замерзания | Gefrierpunkt |
| **G** | | | | |
| glacier | glacier | glaciar | ледник | Gletscher |
| glaze | verglas | recubierto de hielo | обледенение, гололёдица | Glatteis |
| glazed surface | surface verglacée | superficie con hielo | обледеневшая поверхность | vereiste Oberfläche |
| grain | grain | grano | зерно | Korn |
| – bond | – pont ou liaison entre les | – enlace/puente | шейка, контакт зерна | –bindung |
| graphic, graphical | graphique | gráfico | графический | grafisch |
| ground | sol | suelo | грунт | Boden |

| *English* | *Français* | *Español* | *Russian* | *Deutsch* |
|---|---|---|---|---|
| growth | croissance | crecimiento | рост | Wachstum |
| – equilibrium | – par gradients de température faibles | – equilibrado | равновесный– | – bei abbauender Umwandlung (Metamorphose) |
| – kinetic | – par gradients de température moyens à forts | – cinético | неравновесный– | – bei aufbauender Umwandlung (Metamorphose) |
| – step | – palier de | | ступень (шаг) показателя | –sstufe |
| **H** | | | | |
| hoarfrost | gelée blanche | escarcha | изморозь, иней | Reif |
| homogeneous | homogène | homogéneo | однородный | homogen, einheitlich |
| horizontal | horizontal | horizontal | горизонтальный | waagrecht |
| **I** | | | | |
| ice | glace | hielo | лёд | Eis |
| – layer | – couche de | – capa | прослой льда (ледяная корка) | –schicht |
| inclined | incliné | inclinado | наклонный | geneigt |
| index | indice | índice | показатель | Index |
| – step | – niveau de l' | – paso | ступень (шаг) показателя | –stufe |
| instrument | instrument | instrumento | инструмент | Instrument |
| intergranular | intergranulaire | intergranular | межзёренный | intergranular |
| irregular | irrégulier | irregular | неправильный, неравномерный | unregelmässig |
| isothermal | isotherme | isotérmico | изотермический | isotherm |
| isotropic | isotrope | isotrópico | изотропный | isotrop |
| **L** | | | | |
| laminar | laminaire | laminar | ламинарный | laminar |
| layer | couche, strate | capa | слой | Schicht |
| layering, see stratification | | | слоистость, стратификация | |
| low | faible, bas | bajo | слабый, малый | gering, tief |
| **M** | | | | |
| magnifying glass | loupe | lupa | лупа | Lupe |
| mean | moyenne | media | средний | Mittelwert |
| melt | fondre | derretir/fundir | талый | schmelzen |
| melting point | point de fusion | punto de fusión | точка таяния | Schmelzpunkt |
| mixture | mélange | mezcla | смесь | Mischung |

| *English* | *Français* | *Español* | *Russian* | *Deutsch* |
|---|---|---|---|---|
| **N** | | | | |
| névé | névé | neviza | фирн | Firnfeld, Firn |
| new snow | neige fraîche<br>CA: nouvelle, récente | nieve nueva | свежевыпавший снег | Neuschnee |
| **O** | | | | |
| optical-equivalent grain size | taille optique des grains | tamaño óptico de granos | оптически подобранный размер зерна | optische Korngrösse |
| **P** | | | | |
| particle | particule | partícula | частица | Partikel |
| penetration | pénétration | penetración | проникновение | Eindringen |
| penitent snow | pénitents de neige | nieve penitente | кающиеся снега | Büsserschnee |
| percolation | percolation | percolación | просачивание | Durchsickerung |
| permeability | perméabilité | permeabilidad | проницаемость | Durchlässigkeit |
| perpendicular | perpendiculaire | perpendicular | перпендикулярный | rechtwinklig, senkrecht |
| pneumatic | pneumatique | neumático | пневматический | pneumatisch |
| precipitation | précipitation | precipitación | осадки | Niederschlag |
| – liquid | – liquide | – líquida | жидкие– | – flüssiger |
| – solid | – solide | – sólida | твёрдые– | – fester |
| process | processus | proceso | механизм, процесс | Prozess |
| **R** | | | | |
| radiative cooling | refroidissement par rayonnement thermique ou infra-rouge | enfriamiento radiativo | радиационное выхолаживание | Abkühlung durch langwellige Ab- oder Ausstrahlung |
| rain | pluie | lluvia | дождь | Regen |
| ram penetrometer | sonde de battage | sonda de nieve de percusión | ударный пенетрометр | Rammsonde |
| – Swiss rammsonde | – suisse | – suiza | Швейцарский– (зонд Хефели) | – schweizerische |
| range | intervalle, plage | rango | диапазон | Bereich |
| recrystallize | recristalliser | redistribución | перекристаллизовываться | umkristallisieren |
| redistribution | redistribution | recristalización | перераспределение | Verfrachtung |
| regelation | regel | regelación | режеляция, смерзание | Regelation |
| relative density | densité | densidad relativa | относительная плотность | relative Dichte |

| *English* | *Français* | *Español* | *Russian* | *Deutsch* |
|---|---|---|---|---|
| residual liquid water content | teneur résiduelle en eau liquide | contenido de agua líquida residual | остаточная влагоёмкость | irreduzibler Wassergehalt |
| ripple | ondulation | ondulación | нанос | kleine Welle |
| roughness | rugosité | rugosidad | шероховатость | Rauheit, Rauigkeit |
| **S** | | | | |
| saltation | saltation | saltación | сальтация | Saltation |
| sastrugi, see zastrugi | | | заструги | |
| settlement | tassement | asentamiento | оседание | Setzung, Verdichtung |
| sintering | frittage | sinterización | спекание | Sinterung |
| slope | pente | pendiente | склон | Hang |
| – perpendicular | – perpendiculaire à la pente | – perpendicular | нормаль (перпендикуляр) к склону | -senkrecht |
| slushflow | écoulement de neige détrempée | flujo de agua-nieve | водоснежный поток | Sulzstrom |
| snow | neige | nieve | снег | Schnee |
| – cover | – couvert neigeux, CA: couverture neigeuse | – cobertura | снежный покров | -decke |
| – deposit | – dépôt de | – depósito | отложение снега | -ablagerung |
| – hydrology | – hydrologie nivale | – hidrología | гидрология снега | -hydrologie |
| – layer | – couche ou strate de | – capa | слой снега | -schicht |
| – level | – limite des chutes de neige | – nivel | уровень снегопада | -fallgrenze |
| – mechanics | – mécanique de la | – mecánica | механика снега | -mechanik |
| – metamorphism | – métamorphose de la, transformation de la | – metamorfismo | метаморфизм снега | -metamorphose, -umwandlung |
| – patch | – plaque de neige | – nevero | снежник | -fleck |
| – perennial | – neige éternelle | – perenne | вечные (многолетние) снега | – mehrjähriger |
| – pit | – tranchée de sondage | – pozo | снежный шурф | -schacht |
| – profile | – profil de neige | – perfil | снежный профиль | -profil |
| – physics | – physique de la | – física | физика снега | -physik |
| – seasonal | – neige saisonnière | – estacional | сезонный снежный покров | – jahreszeitlicher, saisonaler |
| – state of | – état de la | – estado de | установление снежного покрова | -zustand |
| – type | – type de | – tipo | тип снега | -art |
| snowdrift | congère | banco de nieve | сугроб, снежный занос | Triebschneeansammlung |

| *English* | *Français* | *Español* | *Russian* | *Deutsch* |
|---|---|---|---|---|
| snowfall | chute de neige | nevada | снегопад | Schneefall |
| snowflake | flocon de neige | copo de nieve | снежинка | Schneeflocke |
| snowline | limite des neiges éternelles | línea de nieve | снеговая линия | Schneegrenze |
| snowpack | manteau neigeux | manto de nieve | снежная толща | Schneedecke |
| solid | solide | sólida | твёрдый | fest |
| strain | déformation | deformación | деформация | Verformung |
| – rate | – vitesse de | – tasa | скорость деформации | -sgeschwindigkeit |
| stratigraphy | stratigraphie | estratigrafía | стратиграфия | Stratigrafie |
| stratification | stratification | estratificación | слоистость | Schichtung |
| stratum | couche, strate | estrato | пласт | Schicht |
| stress | contrainte | tensión | напряжение | Spannung |
| – compressive | – à la compression | – compresivo | – давления | – Druck- |
| – shear | – au cisaillement | – de cizalla | – сдвига | – Scher- |
| – tensile | – à la tension | – tensional | – растяжения | – Zug- |
| stress rate | vitesse de contrainte | tasa de tensión | скорость изменения напряжения | Spannungsrate |
| subfreezing | en dessous du point de fusion | bajo el punto de congelación | ниже точки замерзания | unterhalb des Schmelzpunktes |
| sublimation | sublimation | sublimación | сублимация (возгонка) | Sublimation |
| – inverse (see deposition) | – condensation solide | – inversa | десублимация | Resublimation |
| subunit | sous unité | sub unidad | элемент | Untereinheit |
| sun | soleil | sol | солнце | Sonne |
| sun cups | mini-pénitents de neige | | ледниковые стаканы, ледяные соты (в т.ч. аналоги на поверхности снега) | (kleiner) Büsserschnee |
| supercooled | surfondu | subfusión | переохлаждённый | unterkühlt |
| surface | surface | superficie | поверхность | Oberfläche |
| – roughness | – rugosité de la | – rugosidad de la | шероховатость поверхности | -nrauigkeit |
| – temperature | – température de | – temperatura de la | температура поверхности | -ntemperatur |
| symbol | symbole | símbolo | символ | Symbol |
| **T** | | | | |
| temperature | température | temperatura | температура | Temperatur |
| term | terme | término | термин | Begriff |
| thermal | thermique | termal | термический, тепло- | thermisch |
| transformation | transformation | transformación | преобразование | Umwandlung |

| English | Français | Español | Russian | Deutsch |
|---|---|---|---|---|
| **V** | | | | |
| vertical | vertical | vertical | вертикальный | lotrecht |
| **W** | | | | |
| water | eau | agua | вода | Wasser |
| – funicular | – funiculaire | –funicular | легкоподвижная капиллярная– | – offenes Kapillar-, Strang- |
| – pendular | – pendulaire | –pendular | малоподвижная капиллярная– | – Pendel- |
| – vapour | – vapeur d’ | – vapor de | водяной пар | -dampf |
| – vapour density | – masse volumique de la vapeur d’ | – densidad de vapor | концентрация, плотность водяного пара, абсолютная влажность воздуха | -dampfdichte |
| wetness see liquid water content | humidité | humedad | влажность | Feuchtigkeit |
| wind | vent | viento | ветер | Wind |
| – katabatic | – catabatique | – catabático | катабатический– | - Fall-, katabatischer |
| **Z** | | | | |
| zastrugi | zastrugi, sastrugi | sastrugi | заструги | Zastrugi |

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