Plant quiz

We will display 12 examples of plants for the teaching collection for you to identify with the following information:

Latin name (Genus, species) **Family name**

On the final I will deduct for incorrect spellings, capitalization and italization of names.

- Latin are underlined (or italicized).
- Capitalize the genus name, no caps on the species name.
- Items like ssp., var. cf. are not italicized.
- Family names are <u>not</u> italicized.

<u>Options for today:</u>

1. Display the correct answers after the quiz so you can correct your own.
2. Turn in the quiz in for a grade, e.g. 25 points. If you go for the second option, I would give you 1/2 point for the genus name, 1/2 point for the species name, and 1/2 point for the family name, and 1/2 point if everything is spelled, captitalized and underlined properly. You get one point for putting your name on the quiz.

Field trip

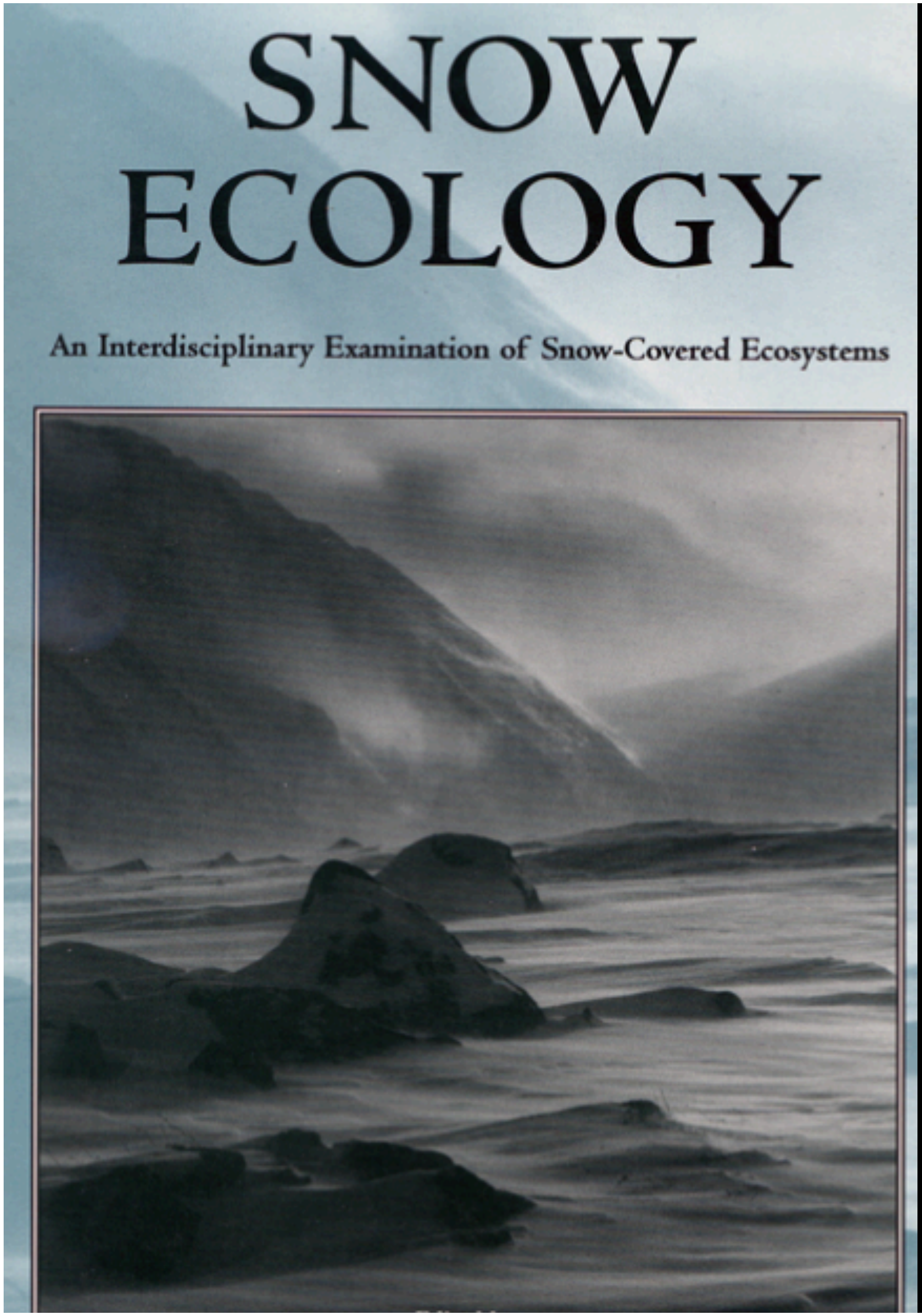
1. **Logistics too complicated for such a large group, so local trip on Saturday Mar 9 instead.**

2. **North Campus Lands, Smith Lake and Ester Dome or Murphy Dome.**

3. **Will still need snow shoes or skis for the day. Walking may be possible because we will be near the walking trails on the NCL, and snow will likely be hard packed in the alpine.**

4. **Bring a sack lunch.**

5. **Clothing and equipment list will follow.**



Lesson 7
Snow Ecology

D.A. (Skip) Walker
Biol 488, Arctic Vegetation Ecology
University of Alaska Fairbanks

Overview of lecture 7

Focus on the ecology of snow

- **Lecture 7: An interdisciplinary examination of snow covered ecosystems**
  - Physical properties of snow (Pomeroy and Brun 2003)
  - Characterization of snow (UNESCO-IHP 2009)
  - Snow metamorphosis (Sommerfeld and Chapelle 1970)
  - Global snow cover classification (Sturm, Holmgren, Liston 1995)
  - Snow chemistry (Tranter & Jones 2001)
  - Snow ecosystems (Hoham 2001, Aitchison 2001)

- **Lecture 8: Snow vegetation interactions (Walker et al. 2001)**

Biological relevance of physical and chemical properties of snow

Photo: Sastrugi at the South Pole. Photo by Bill McAfee, National Science Foundation.

Important physical properties of snow for ecology

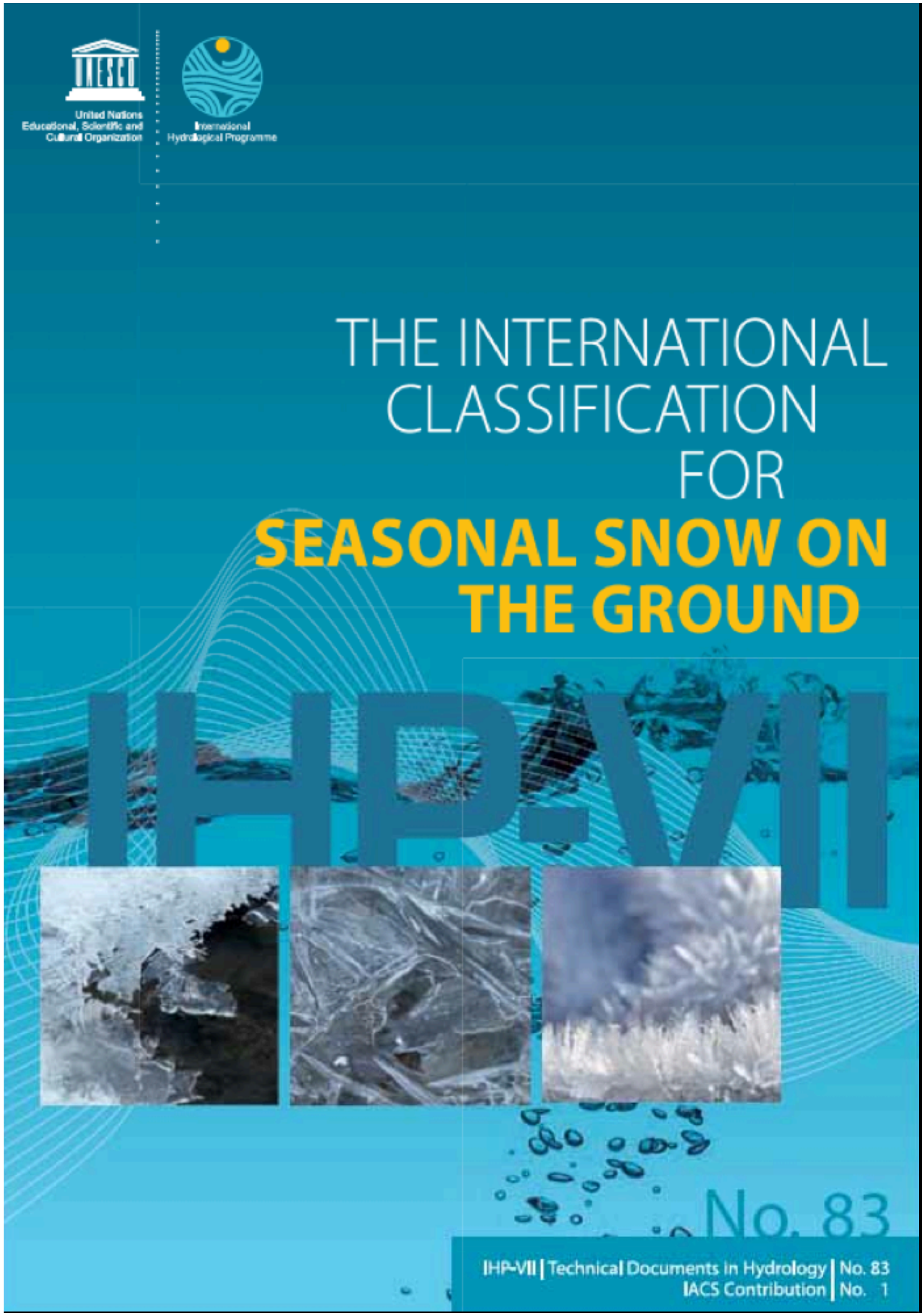
1. May exist as a solid, liquid or vapor at 0 ˚C. All these may exist in a snow pack, and have important implications for snow metamorphosis and life in, on and beneath the snow pack.
2. Extremely large latent heat of vaporization (2.83 MJ kg^{-1}) and latent heat of fusion (333 kJ kg^{-1}). Energy required to sublimate 1 kg of snow at 0 ˚C is equivalent to energy required to raise 10 kg of water 67 ˚C! Energy required to melt 1 kg of snow at 0 ˚C is equivalent to energy required to raise 1 kg of water 79 ˚C. Many important effects for permafrost and plant energy relationships.
3. Thermal conductivity of snow is low (compared to soil), but varies with snow density. Thermal conductivity of dry snow at density of 100 kg m^{-3} is 0.045 W m^{-1} K^{-1} (6 times that of soil). Generally a very good insulator.
4. Albedo of shortwave (solar) radiation is very high (0.8 to 0.9 for fresh snow), but is strongly affected by impurities and aging of the snow pack. At the same time, snow is a blackbody for long-wave (thermal infrared) radiation. Hence it readily absorbs heat and reradiates it.
5. Snow cover is generally smooth. This creates higher wind speed (less ground friction and turbulent transfer of sensible and latent heat is less than for a vegetated surface. Provides for ready transport of erosive snow and mineral particles and plant propagules.

Pomeroy, J. W. and E. Brun. 2001. Physical properties of snow. Pages 45-126 in H. G. Jones, J. W. Pomeroy, D. A. Walker, and R. W. Hoham, editors. Snow Ecology: An Interdisciplinary Examination of Snow-covered Ecosystems. Cambridge University Press, Cambridge.

Important physical properties of snow for ecology

- **For example, large physical effect influencing evolution of plant architecture in northern latitudes.**

Photos: UAF North Campus Lands, January 2012, D.A. Walker

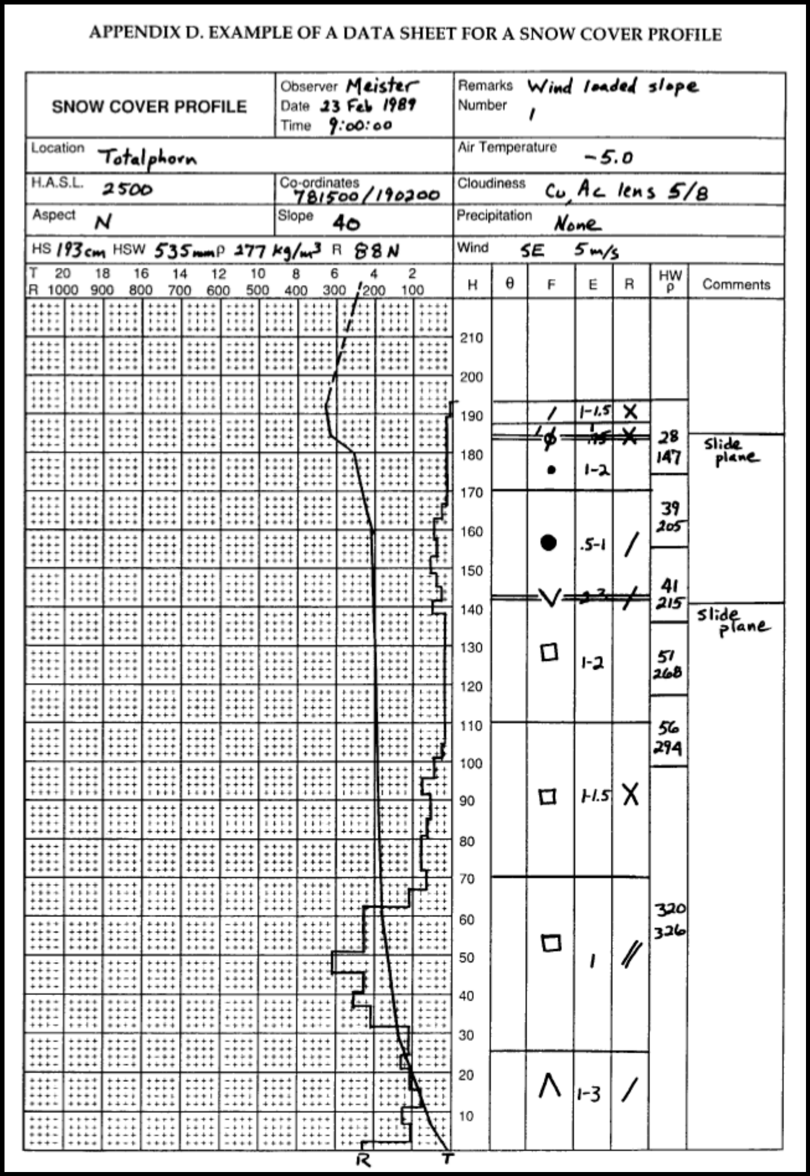


Characterization of snow

- ❖ Features of deposited snow
  - Grain shape and size
  - Snow density and hardness
  - Liquid water content
  - Layer thickness and total depth
  - Surface features
- ❖ Grain shape classification
- ❖ Observation guidelines

Fierz, C., R. L. Armstrong, Y. Durand, P. Etchevers, E. Green, D. M. McClung, K. Nishimura, P. K. Satyawali, and S. A. Sokratov. 2009. The International Classification for Seasonal Snow on the Ground. UNESCO-IHP, IHP-VII Technical Documents in Hydrology No. 83, IACS Contribution No. 1, Paris.

Snow pit descriptions



APPENDIX D. EXAMPLE OF A DATA SHEET FOR A SNOW COVER PROFILE

SNOW COVER PROFILE	Observer Meister Date 23 Feb 1989 Time 9:00:00	Remarks Wind loaded slope Number 1
Location Totalphorn		Air Temperature −5.0
H.A.S.L. 2500	Co-ordinates 781500/190200	Cloudiness Cu, Ac lens 5/8
Aspect N	Slope 40	Precipitation None
HS 193cm HSW 535mm ρ 177 kg/m³ R 88 N		Wind SE 5 m/s

T 20 18 16 14 12 10 8 6 4 2
R 1000 900 800 700 600 500 400 300 200 100

H	θ	F	E	R	HW ρ	Comments
190		/	1-1.5	X		
		ϕ	~~.5~~	X	28 147	Slide plane
180		•	1-2			
160		●	.5-1	/	39 205	
140		V	~~2-3~~	/	41 215	Slide plane
130		□	1-2		51 268	
110					56 294	
90		□	1-1.5	X		
50		□	1	//	320 326	
20		Λ	1-3	/		

Mary Albert (CRREL) sampling snow in Antarctica. http://snow.usace.army.mil/heat_mass_transfer/

Characteristics typically described in snow pits

- Grain shape (form) (F)
- Grain size (E)
- Snow density (ρ_s)
- Snow hardness (R)
- Liquid water content (LWC, θ_w)
- Temperature (T_s)
- Impurities (J)
- Layer thickness (L)

Snow grain shape and size classification

Shape

Class	*Symbol*	*Code*
Precipitation Particles	+	PP
Machine Made snow	◎	MM
Decomposing and Fragmented precipitation particles	/	DF
Rounded Grains	●	RG
Faceted Crystals	□	FC
Depth Hoar	Λ	DH
Surface Hoar	V	SH
Melt Forms	○	MF
	⊚⊚	MFcr
Ice Formations	▬	IF

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

Fierz, C., R. L. Armstrong, Y. Durand, P. Etchevers, E. Green, D. M. McClung, K. Nishimura, P. K. Satyawali, and S. A. Sokratov. 2009. The International Classification for Seasonal Snow on the Ground. UNESCO-IHP, IHP-VII Technical Documents in Hydrology No. 83, IACS Contribution No. 1, Paris.

Grain shape classification

1. **Precipitation (PP)** (columns, needles, plates, stellar dendrites, irregular crystals, graupel, hail, ice pellets)
2. **Decomposing and fragmented precipitation particles (DF)** partially decomposed, highly broken particles)
3. **Rounded grains (RG)** (small, large, mixed)
4. **Faceted crystals (FC)** (solid faceted, small faceted, mixed)
5. **Cup-shaped crystals and depth hoar (DH)** (cup crystals, columns of depth hoar, columnar crystals)
6. **Wet grains (WG)** (clustered rounded grains, rounded poly-crystals, slush)
7. **Feathery crystals (SH)** (surface hoar, cavity hoar)
8. **Ice forms (IF)** (Ice layer, ice column, basal ice, sun crust, rain crust)

Fierz, C., R. L. Armstrong, Y. Durand, P. Etchevers, E. Green, D. M. McClung, K. Nishimura, P. K. Satyawali, and S. A. Sokratov. 2009. The International Classification for Seasonal Snow on the Ground. UNESCO-IHP, IHP-VII Technical Documents in Hydrology No. 83, IACS Contribution No. 1, Paris.

APPENDIX A: GRAIN SHAPE CLASSIFICATION

A.1 Main and subclasses of grain shapes

Morphological classification				*Additional information on phy*	
Basic classification	*Subclass*	*Shape*	*Code*	*Place of formation*	*Physical process*
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 Size: $\leq$5 mm
	Hail	Laminar internal structure, translucent or milky glazed surface	PPhl	Cloud	Growth by accretion of supercooled water Size: >5 mm
	Ice pellets	Transparent, mostly small spheroids	PPip	Cloud	Freezing of raindrops or refreezing of largely melted snow crystals or snowflakes (sleet) Graupel or snow pellets encased in thin ice layer (small hail) Size: both $\leq$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. Thin breakable crust forms on snow surface if process continues long enough

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

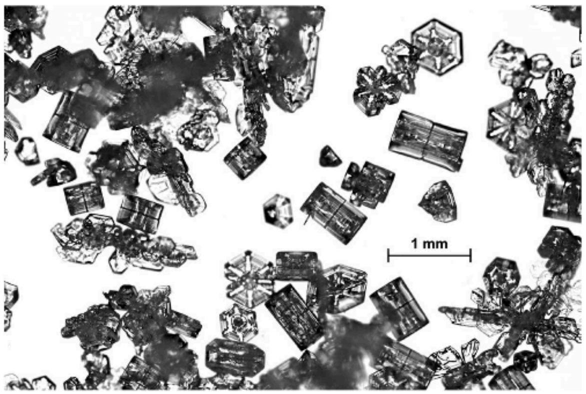
References: Magono & Lee, 1966; Bailey & Hallett, 2004; Dovgaluk & Pershina. 2005; Libbrecht, 2005

Precipitation particles (Class PP)

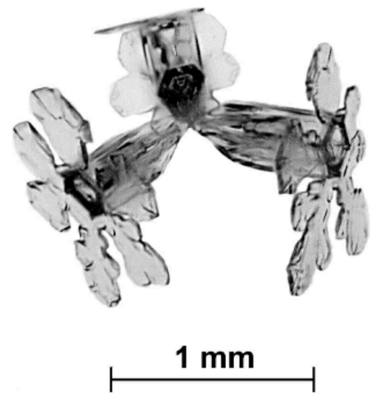
- Columns
- Needles
- Plates
- Stellar, dendrites
- Irregular crystals
- Graupel
- Hail
- Ice pellets
- Rime

Fierz, C., R. L. Armstrong, Y. Durand, P. Etchevers, E. Green, D. M. McClung, K. Nishimura, P. K. Satyawali, and S. A. Sokratov. 2009. The International Classification for Seasonal Snow on the Ground. UNESCO-IHP, IHP-VII Technical Documents in Hydrology No. 83, IACS Contribution No. 1, Paris.

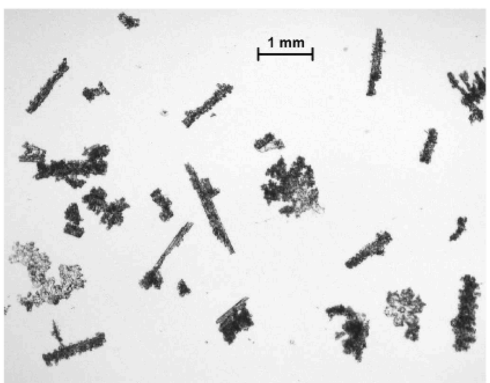
Precipitation particles (class PP cont)



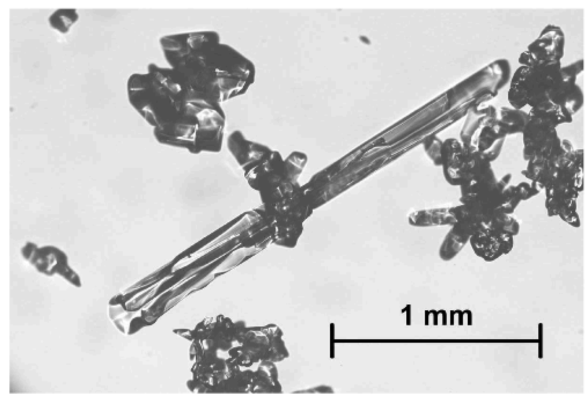
Columns PPco, ▭ (Elder) #01



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



Rimed needles PPnd, ↔ (Fierz) #03

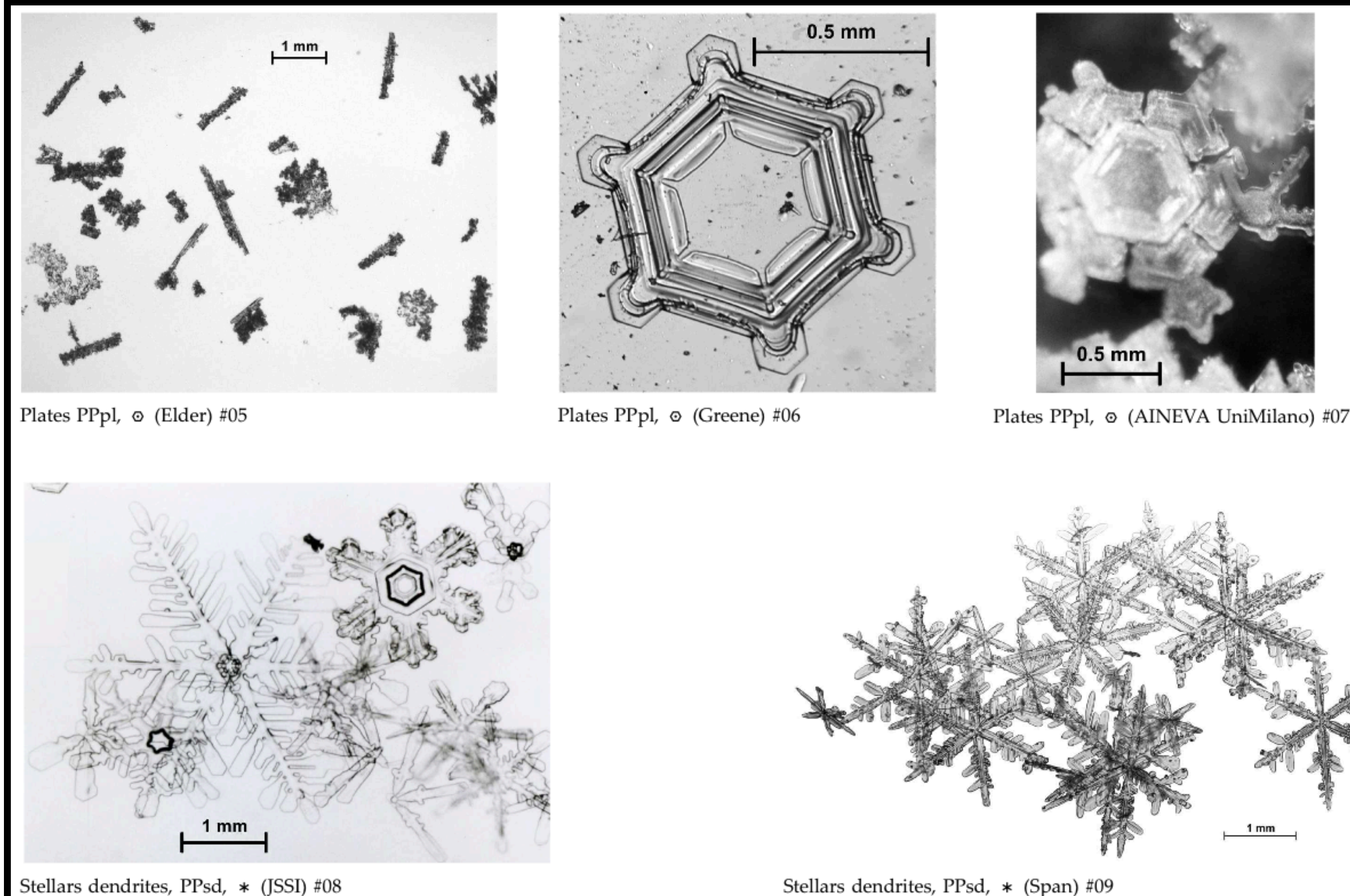


Needles PPnd, ↔ (Elder) #04

- **Columns (PPco):** Growth from water vapour at –8°C and below–30°C
- **Needles (PPnd):** Growth from water vapour at super-saturation at –3 to –5°C and below –60°C
- **Plates (PPpl):** Growth from water vapour at 0 to –3°C and –8 to –70°C

Fierz, C., R. L. Armstrong, Y. Durand, P. Etchevers, E. Green, D. M. McClung, K. Nishimura, P. K. Satyawali, and S. A. Sokratov. 2009. The International Classification for Seasonal Snow on the Ground. UNESCO-IHP, IHP-VII Technical Documents in Hydrology No. 83, IACS Contribution No. 1, Paris.

Precipitation particles (class PP cont')



Plates PPpl, ⊙ (Elder) #05

Plates PPpl, ⊙ (Greene) #06

Plates PPpl, ⊙ (AINEVA UniMilano) #07

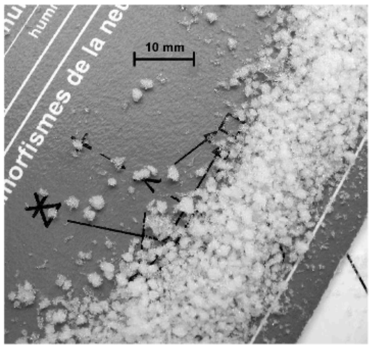
Stellars dendrites, PPsd, ∗ (JSSI) #08

Stellars dendrites, PPsd, ∗ (Span) #09

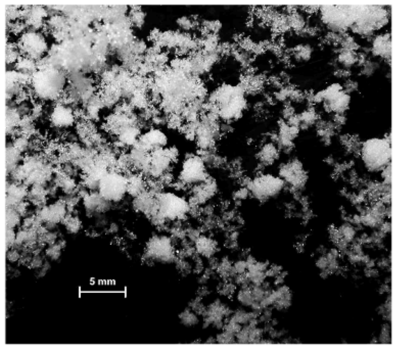
- **Plates (PPpl)**
- **Stellars, dendrites(PPsd):** Growth from water vapour at supersaturation at 0 to –3°C and at –12 to –16°C

Fierz, C., R. L. Armstrong, Y. Durand, P. Etchevers, E. Green, D. M. McClung, K. Nishimura, P. K. Satyawali, and S. A. Sokratov. 2009. The International Classification for Seasonal Snow on the Ground. UNESCO-IHP, IHP-VII Technical Documents in Hydrology No. 83, IACS Contribution No. 1, Paris.

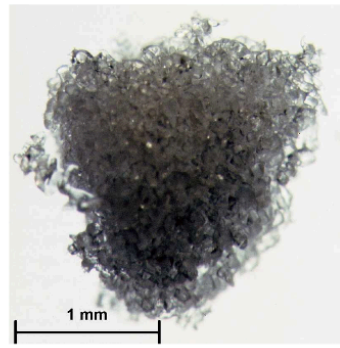
Precipitation particles (class PP cont')



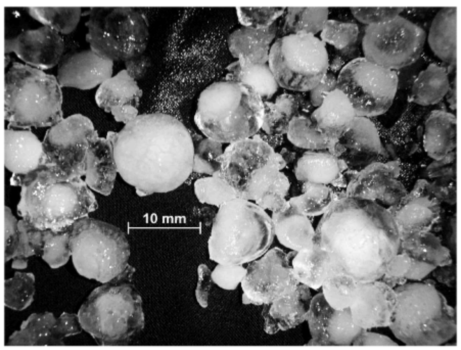
Graupel PPgp, Ѫ (Garcia Selles) #10



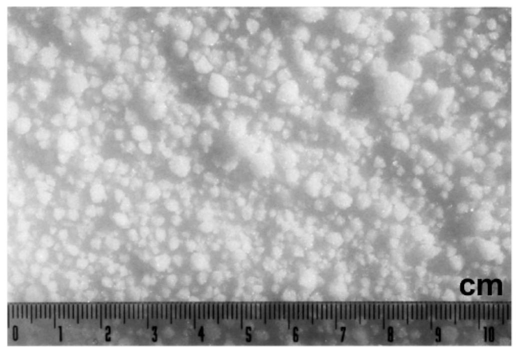
Graupel PPgp, Ѫ (Elder) #11



Graupel PPgp, Ѫ (AINEVA UniMilano) #12



Hail PPhl, ▲ (Elder) #13



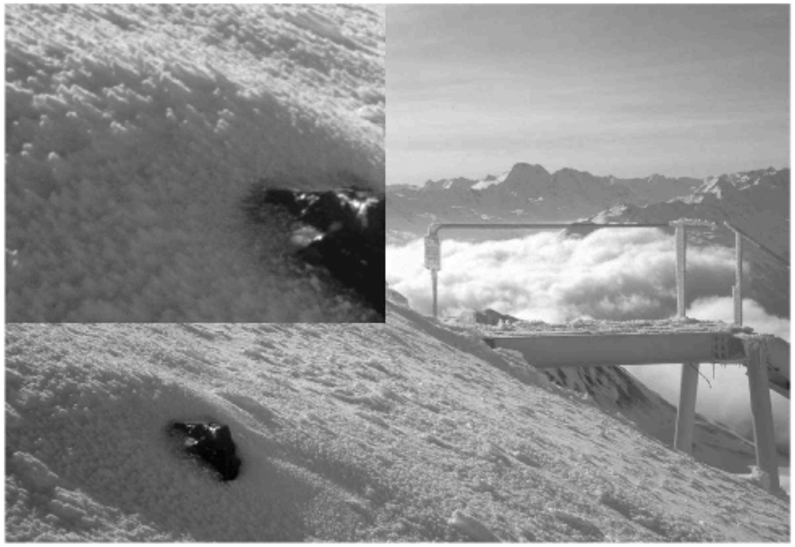
Ice pellets PPip, △ (JSSI) #14

- ❖ **Graupel (PPgp):** Growth by accretion of supercooled water Size: >5 mm
- ❖ **Ice pellets (PPip):** Freezing of raindrops or refreezing of largely melted snow crystals or snowflakes (sleet)
- ❖ **Hail (PPhl):** Growth by accretion of supercooled water Size: >5 mm

Fierz, C., R. L. Armstrong, Y. Durand, P. Etchevers, E. Green, D. M. McClung, K. Nishimura, P. K. Satyawali, and S. A. Sokratov. 2009. The International Classification for Seasonal Snow on the Ground. UNESCO-IHP, IHP-VII Technical Documents in Hydrology No. 83, IACS Contribution No. 1, Paris.

Precipitation particles (class PP cont')

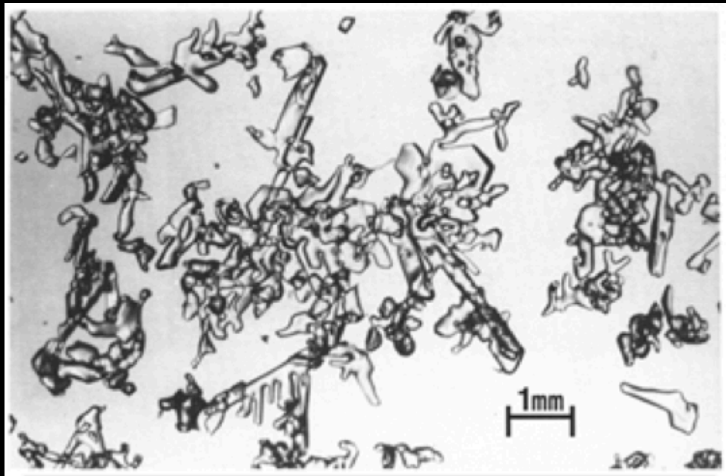
Rime PPrm, ∀ (Schweizer) #15



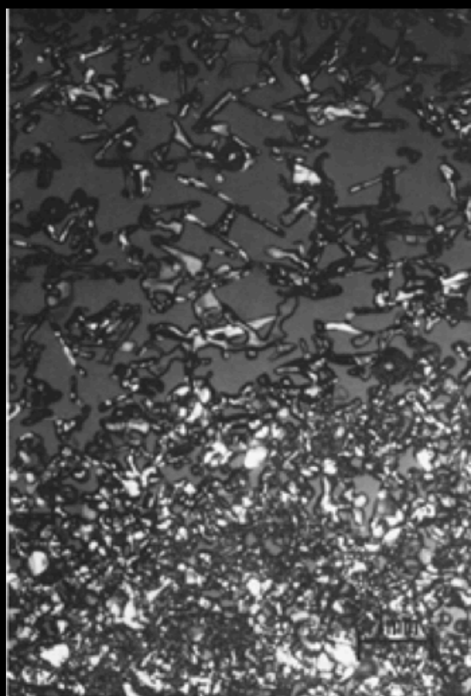
Rime on snow-cover surface PPrm, ∀ (Schweizer) #16

- **Rime (PPm):** Accretion of small, supercooled fog droplets frozen in place. Thin breakable crust forms on snow surface if process continues long enough

Fierz, C., R. L. Armstrong, Y. Durand, P. Etchevers, E. Green, D. M. McClung, K. Nishimura, P. K. Satyawali, and S. A. Sokratov. 2009. The International Classification for Seasonal Snow on the Ground. UNESCO-IHP, IHP-VII Technical Documents in Hydrology No. 83, IACS Contribution No. 1, Paris.



Class 2dc, partly decomposed precipitation particles. Photo by E. Akitaya.



Class 2bk and 9wc, highly broken particles (on top) and wind crust (on bottom). Photo by E. Akitaya.

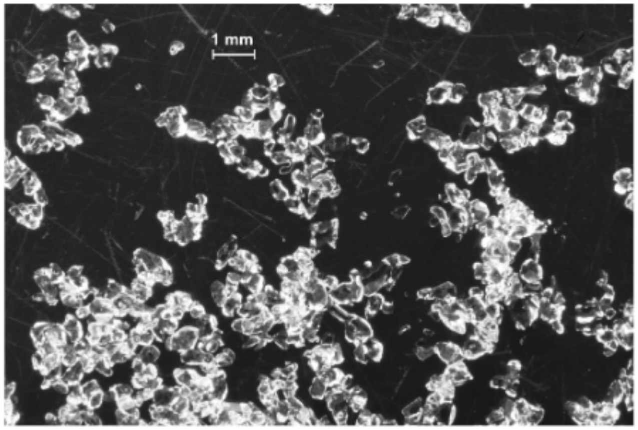
Decomposed precipitation snow particles (class DF)

Decomposition due to either increasing temperatures, decreasing thermal gradient (DFdc)

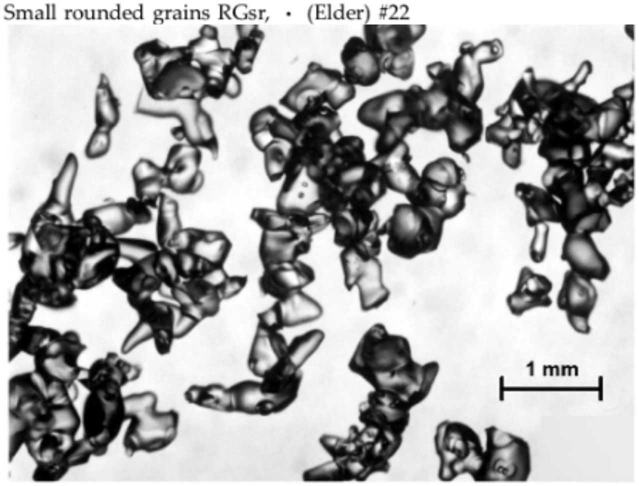
Or to fragmentation and packing by wind and sintering (DFbk)

Fierz, C., R. L. Armstrong, Y. Durand, P. Etchevers, E. Green, D. M. McClung, K. Nishimura, P. K. Satyawali, and S. A. Sokratov. 2009. The International Classification for Seasonal Snow on the Ground. UNESCO-IHP, IHP-VII Technical Documents in Hydrology No. 83, IACS Contribution No. 1, Paris.

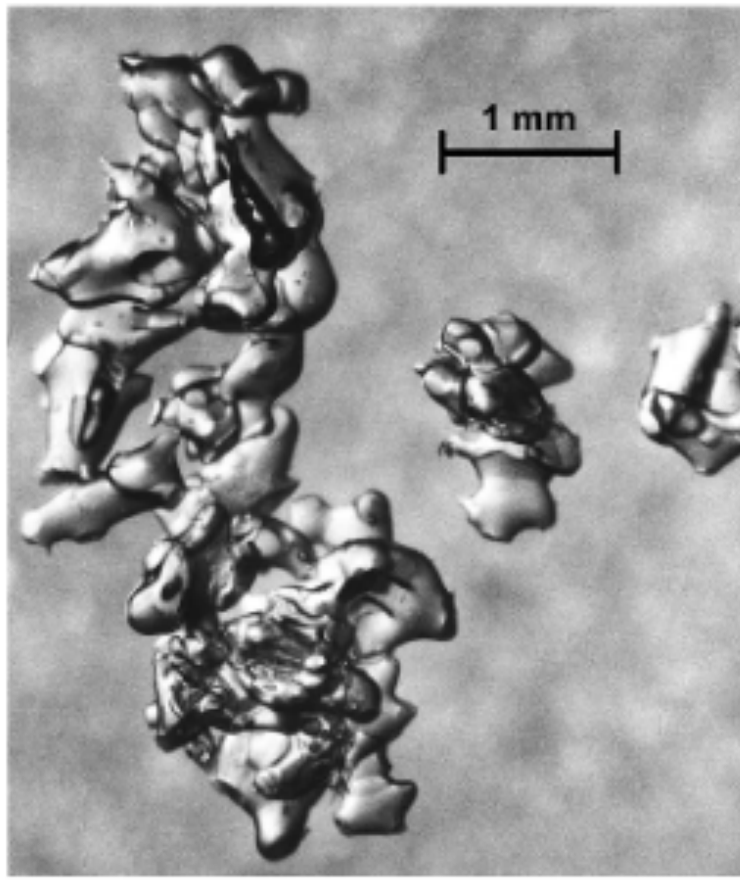
Rounded grains
(class RG)



Small rounded grains RGsr, • (Elder) #22



Large rounded grains RGlr, ● (JSSI) #23



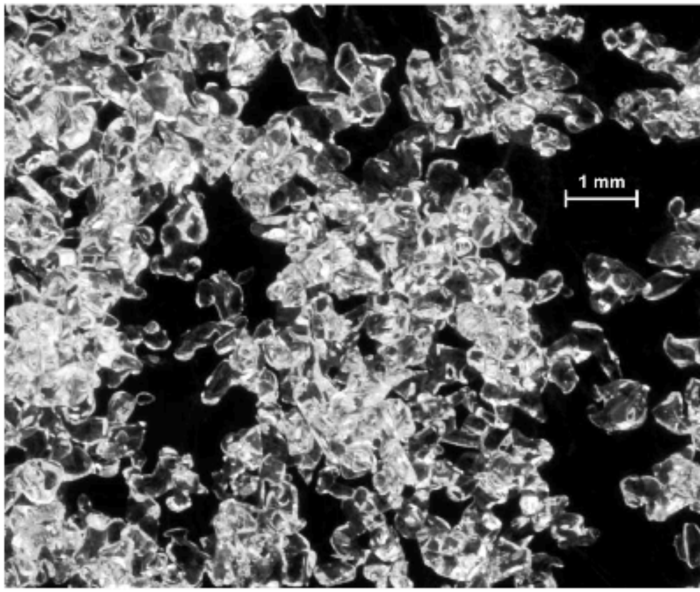
Wind packed RGwp, ● (Sturm) #24

Small (RGsr): Result of low temperature metamorphosis, decrease in surface area, slow sintering.

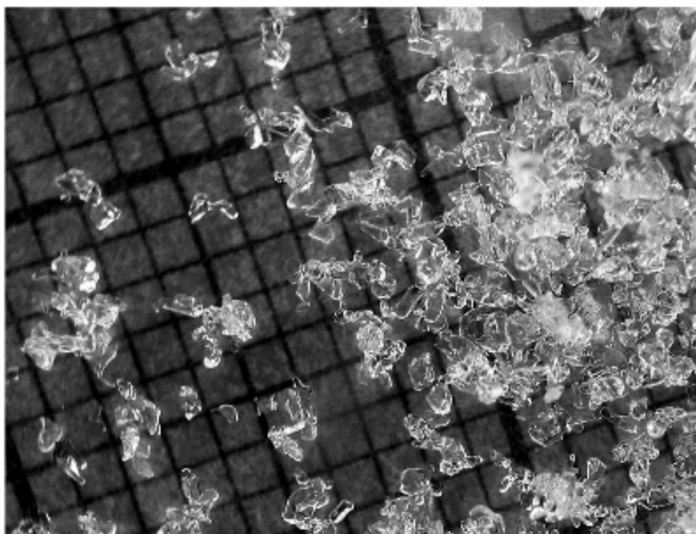
Large (RGlr): Effect of grain to grain vapor diffusion and sintering.

Wind packed (RGwp): Packing and fragmentation with sintering.

Fierz, C., R. L. Armstrong, Y. Durand, P. Etchevers, E. Green, D. M. McClung, K. Nishimura, P. K. Satyawali, and S. A. Sokratov. 2009. The International Classification for Seasonal Snow on the Ground. UNESCO-IHP, IHP-VII Technical Documents in Hydrology No. 83, IACS Contribution No. 1, Paris.



Faceted rounded particles RGxf, (Elder) #25



Faceted particles (class FC)

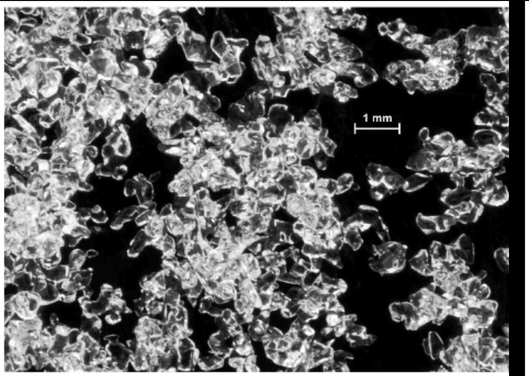
Grain to grain vapor diffusion driven by high temperature gradient.

Faceted rounded particles (FCxr): Transitional form to faceted.

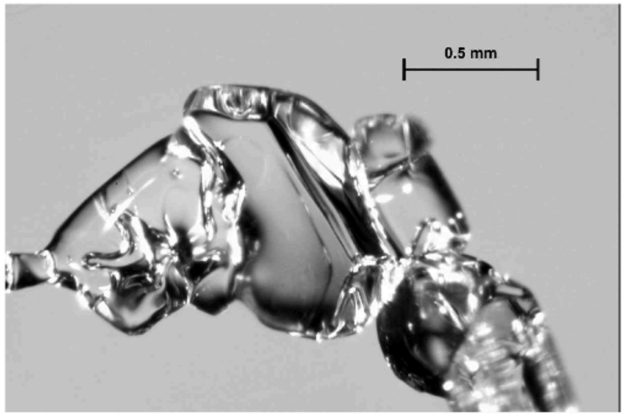
Solid faceted particles (FCso): Solid kenetic growth form with sharp edges, glassy smooth faces.

Fierz, C., R. L. Armstrong, Y. Durand, P. Etchevers, E. Green, D. M. McClung, K. Nishimura, P. K. Satyawali, and S. A. Sokratov. 2009. The International Classification for Seasonal Snow on the Ground. UNESCO-IHP, IHP-VII Technical Documents in Hydrology No. 83, IACS Contribution No. 1, Paris.

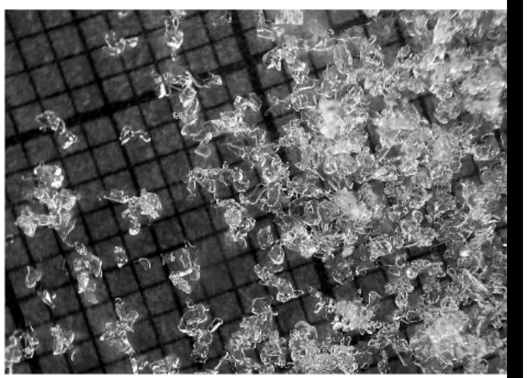
Faceted particles (class FC)



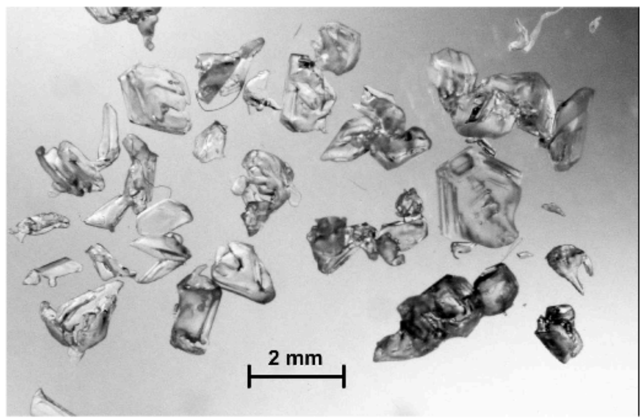
Faceted rounded particles RGxf, (Elder) #25



Faceted rounded particles RGxf, (CEN) #26



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



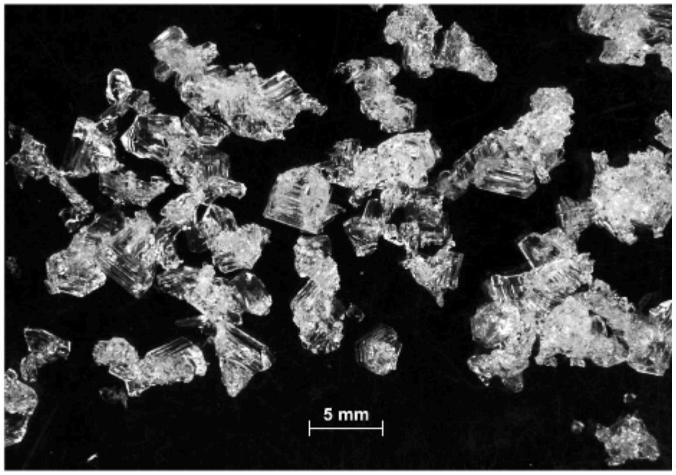
Solid faceted particles FCso, □ (AINEVA UniMilano) #28

Grain to grain vapor diffusion driven by moderate temperature gradient.

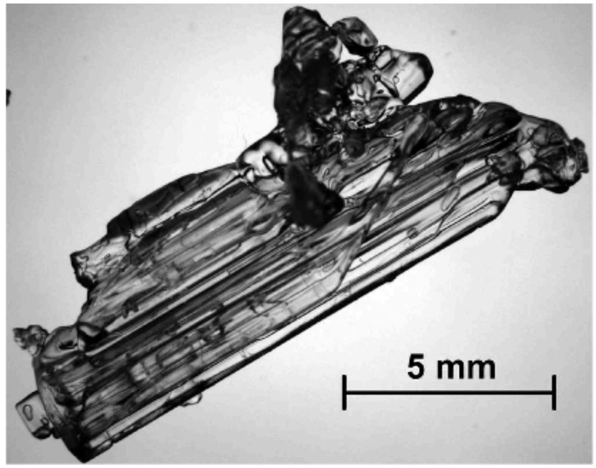
Faceted rounded particles (FCxr): **Transitional form to faceted.**

Solid faceted particles (FCso): **Solid kenetic growth form with sharp edges, glassy smooth faces.**

Fierz, C., R. L. Armstrong, Y. Durand, P. Etchevers, E. Green, D. M. McClung, K. Nishimura, P. K. Satyawali, and S. A. Sokratov. 2009. The International Classification for Seasonal Snow on the Ground. UNESCO-IHP, IHP-VII Technical Documents in Hydrology No. 83, IACS Contribution No. 1, Paris.

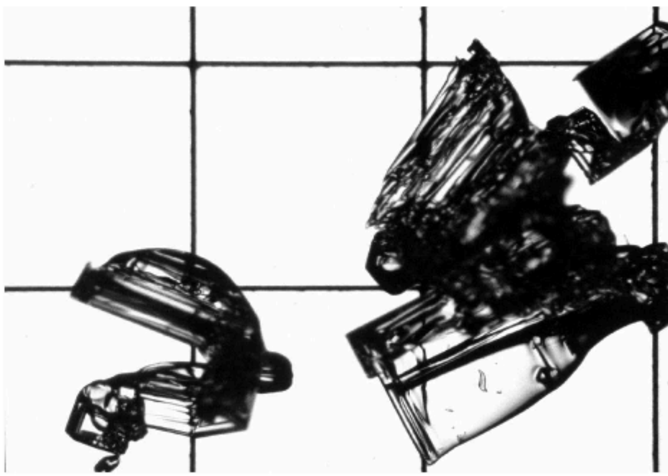


Hollow cups DHcp, ∧ (Greene) #33



Large striated crystals DHla, ∧ (Fierz) #40

Depth Hoar (class DH)

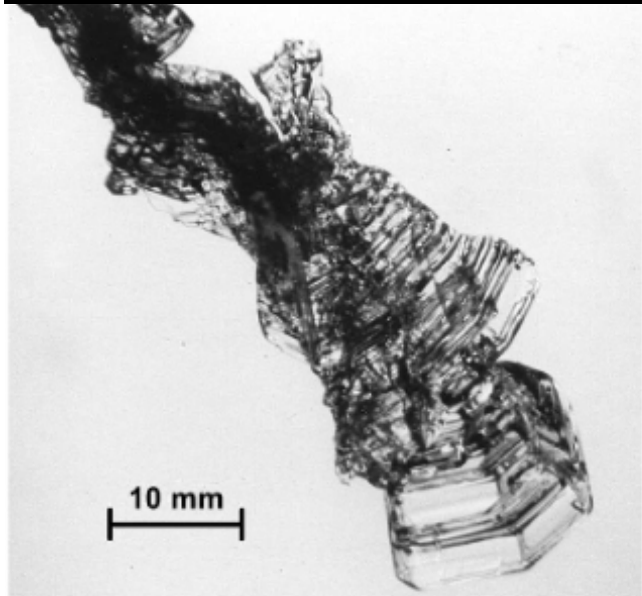


Hollow cups DHcp (DHpr), ∧(⊓), 2 mm grid (Fierz) #35

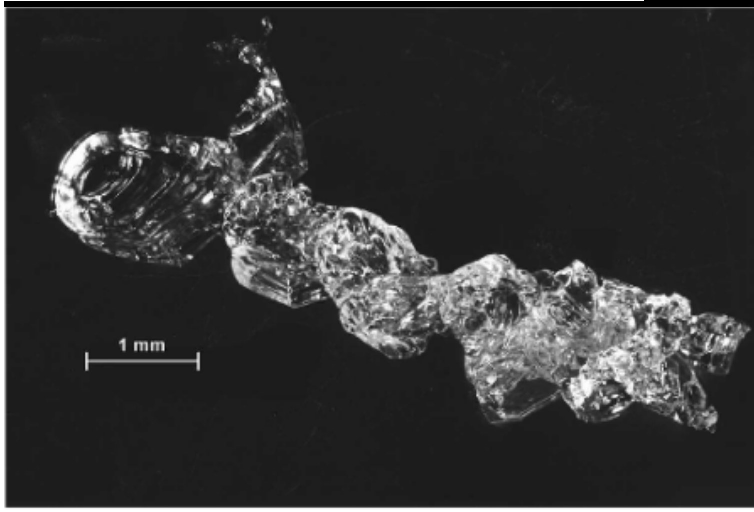
Grain to grain vapor diffusion driven by large temperature gradient.

Hollow cups (DHcp): Large temperature gradient
Large striated crystals (Dhla): Long time with large temperature gradient required.

Fierz, C., R. L. Armstrong, Y. Durand, P. Etchevers, E. Green, D. M. McClung, K. Nishimura, P. K. Satyawali, and S. A. Sokratov. 2009. The International Classification for Seasonal Snow on the Ground. UNESCO-IHP, IHP-VII Technical Documents in Hydrology No. 83, IACS Contribution No. 1, Paris.



Chains of depth hoar DHch, ⋏ (Sturm) #38



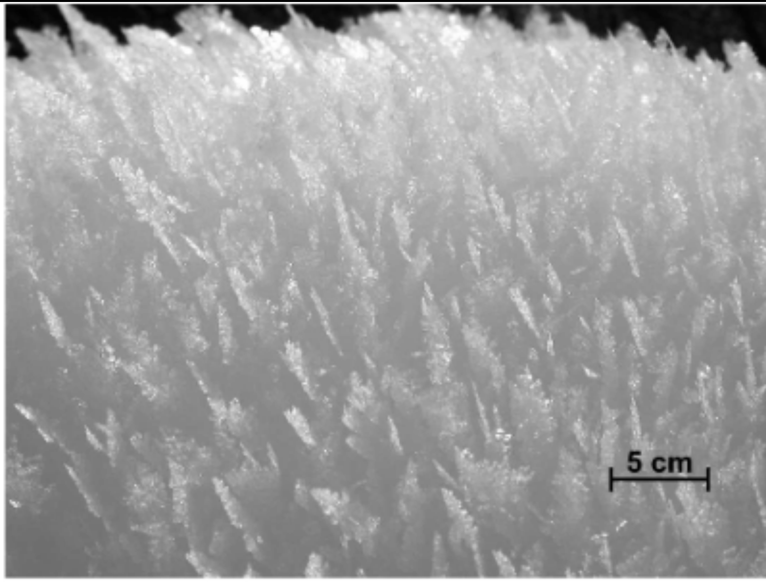
Chains of depth hoar DHch, ⋏ (Domine) #37

Depth Hoar (class DH) (cont')

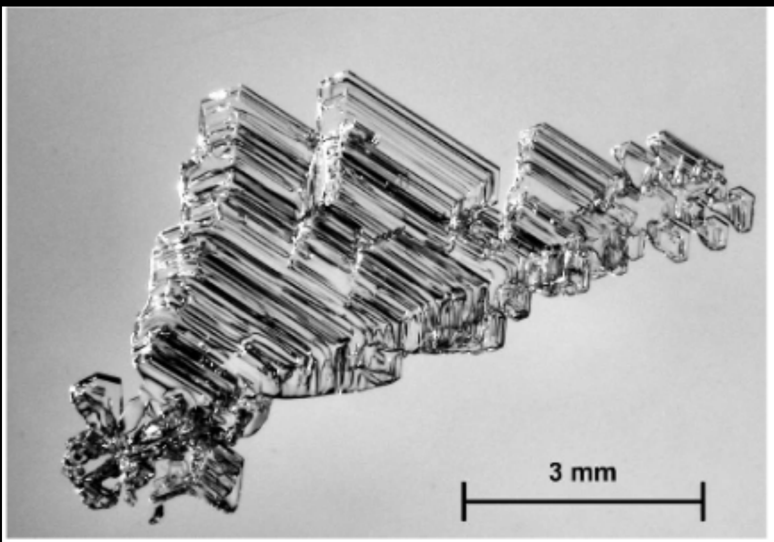
Grain to grain vapor diffusion driven by very large temperature gradient.

Chains of depth hoar (DHch): High recrystallation rate for long time. Snow has completely recrystallized.

Fierz, C., R. L. Armstrong, Y. Durand, P. Etchevers, E. Green, D. M. McClung, K. Nishimura, P. K. Satyawali, and S. A. Sokratov. 2009. The International Classification for Seasonal Snow on the Ground. UNESCO-IHP, IHP-VII Technical Documents in Hydrology No. 83, IACS Contribution No. 1, Paris.



Surface hoar crystals SHsu, ∨ (Elder) #42



Surface hoar crystals SHsu, ∨ (CEN) #44

Surface Hoar (class SH)

Rapid kenetic growth of crystals on snow surface from water vapor in air combined with cold snow surface.

Surface hoar (SHsu): Conditions of combined cooling of snow surface with increasing relative humidity. Common on lakes and near creeks.

Fierz, C., R. L. Armstrong, Y. Durand, P. Etchevers, E. Green, D. M. McClung, K. Nishimura, P. K. Satyawali, and S. A. Sokratov. 2009. The International Classification for Seasonal Snow on the Ground. UNESCO-IHP, IHP-VII Technical Documents in Hydrology No. 83, IACS Contribution No. 1, Paris.

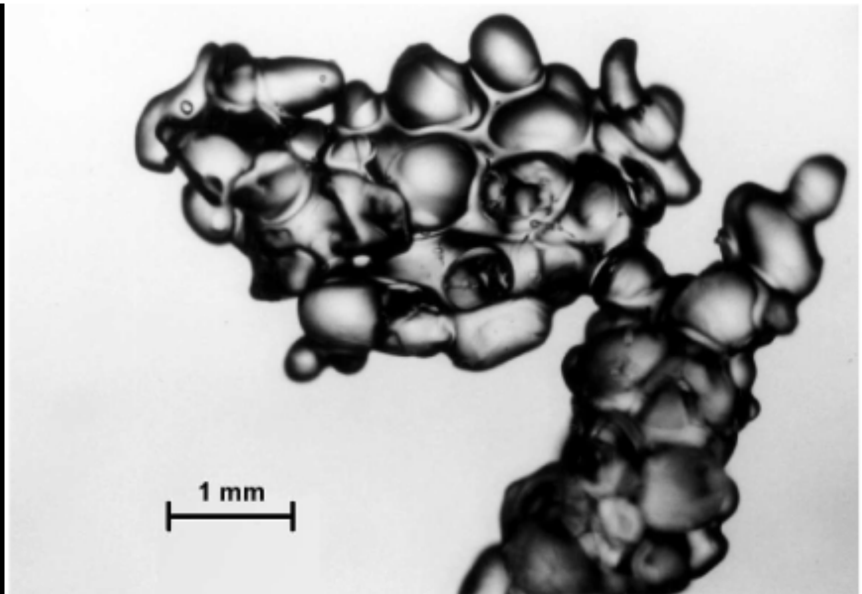
Surface Hoar on Smith Lake (Oct 2008)

Photos: D.A. Walker

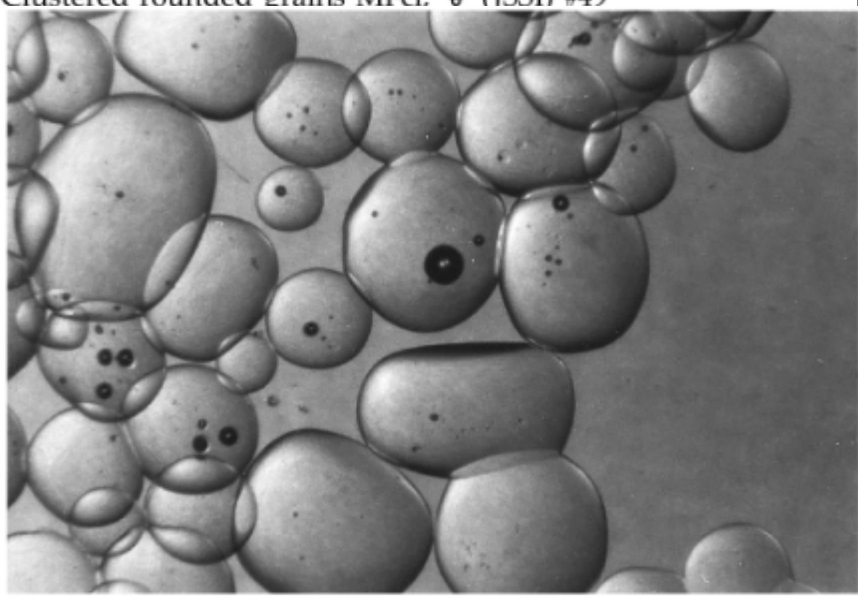
Surface Hoar on Smith Lake (Oct 2009)




Photos: D.A. Walker



Clustered rounded grains MFcl, (ISSI) #49


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

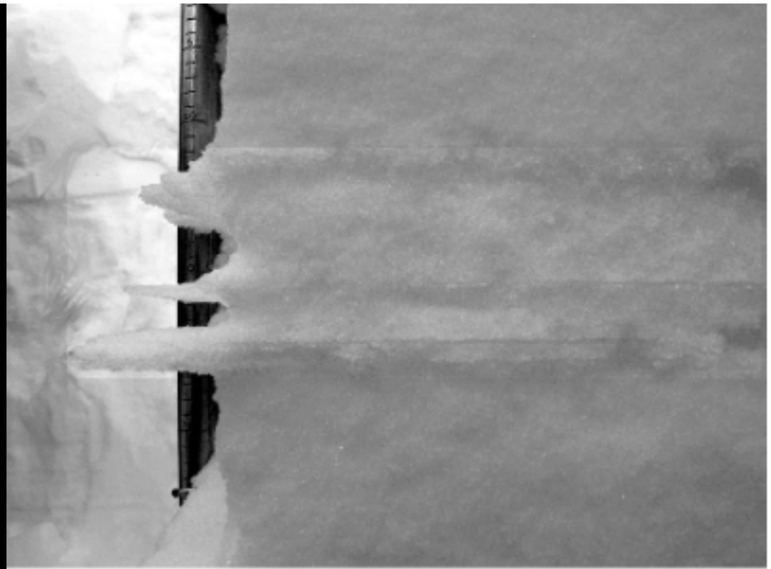
Melt forms (class MF)

Wet snow with liquid water content.

Clustered rounded grains (MFcl): Wet snow with low liquid water content. Meltwater can drain, usually near the surface.

Slush (MFsl):Wet snow with high liquid water content. Meltwater is blocked, sometimes with very high solar radiation, temperature or rain.

Fierz, C., R. L. Armstrong, Y. Durand, P. Etchevers, E. Green, D. M. McClung, K. Nishimura, P. K. Satyawali, and S. A. Sokratov. 2009. The International Classification for Seasonal Snow on the Ground. UNESCO-IHP, IHP-VII Technical Documents in Hydrology No. 83, IACS Contribution No. 1, Paris.



Ice layer IFil, ▪ (Stucki) #57

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

Ice forms (class IF)

Ice layer (IFil): Rain or meltwater percolates into snow and refreezes along layer of cold snow.

Ice column (IFic): Draining water freezes in flow fingers surrounded by subfreezing snow.

Basal ice (Ifbi): Forms at top of frozen soil, common in permafrost areas.

Rain crust (IFrc): Freezing rain on snow.

Sun crust (sunspiegel) (IFsc): Thin tranparent and shiny glaze on surface often with space beneath.

Fierz, C., R. L. Armstrong, Y. Durand, P. Etchevers, E. Green, D. M. McClung, K. Nishimura, P. K. Satyawali, and S. A. Sokratov. 2009. The International Classification for Seasonal Snow on the Ground. UNESCO-IHP, IHP-VII Technical Documents in Hydrology No. 83, IACS Contribution No. 1, Paris.

Snow density (ρ_s)

- **Mass per unit volume (kg m^{-3}).**
- **Determined by weighing snow of a known volume.**
- **Can be done for the whole profile in a long tube.**
- **And/or in small samples from each layer in the snow profile using a small can or snow sampling container of known volume.**

http://www.skiingthebackcountry.com/skiing-resources/snow_density

Fierz, C., R. L. Armstrong, Y. Durand, P. Etchevers, E. Green, D. M. McClung, K. Nishimura, P. K. Satyawali, and S. A. Sokratov. 2009. The International Classification for Seasonal Snow on the Ground. UNESCO-IHP, IHP-VII Technical Documents in Hydrology No. 83, IACS Contribution No. 1, Paris.

Snow hardness (R)

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	X
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.

Fierz, C., R. L. Armstrong, Y. Durand, P. Etchevers, E. Green, D. M. McClung, K. Nishimura, P. K. Satyawali, and S. A. Sokratov. 2009. The International Classification for Seasonal Snow on the Ground. UNESCO-IHP, IHP-VII Technical Documents in Hydrology No. 83, IACS Contribution No. 1, Paris.

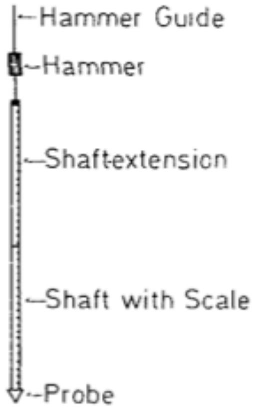


FIGURE 1. The Rammsonde.

Pene-tration Speed [m/s]	Mean Hard-ness [N]	Highest measured Hardness [N]	Lowest measured Hardness [N]	Timedependence of the Hardness R	Total Penetra-tion [10^{-3}m]
$.068 \cdot 10^{-3}$	900	900	-		17
$.26 \cdot 10^{-3}$	600	800	400		15
$1.9 \cdot 10^{-3}$	400	-	-		20
.65	120	140	100		186
normal Ramtest starting speed .7 m/s	100	Variation 15 N			10 mm

FIGURE 2. Hardness and deformation mechanism as a function of penetration speed.

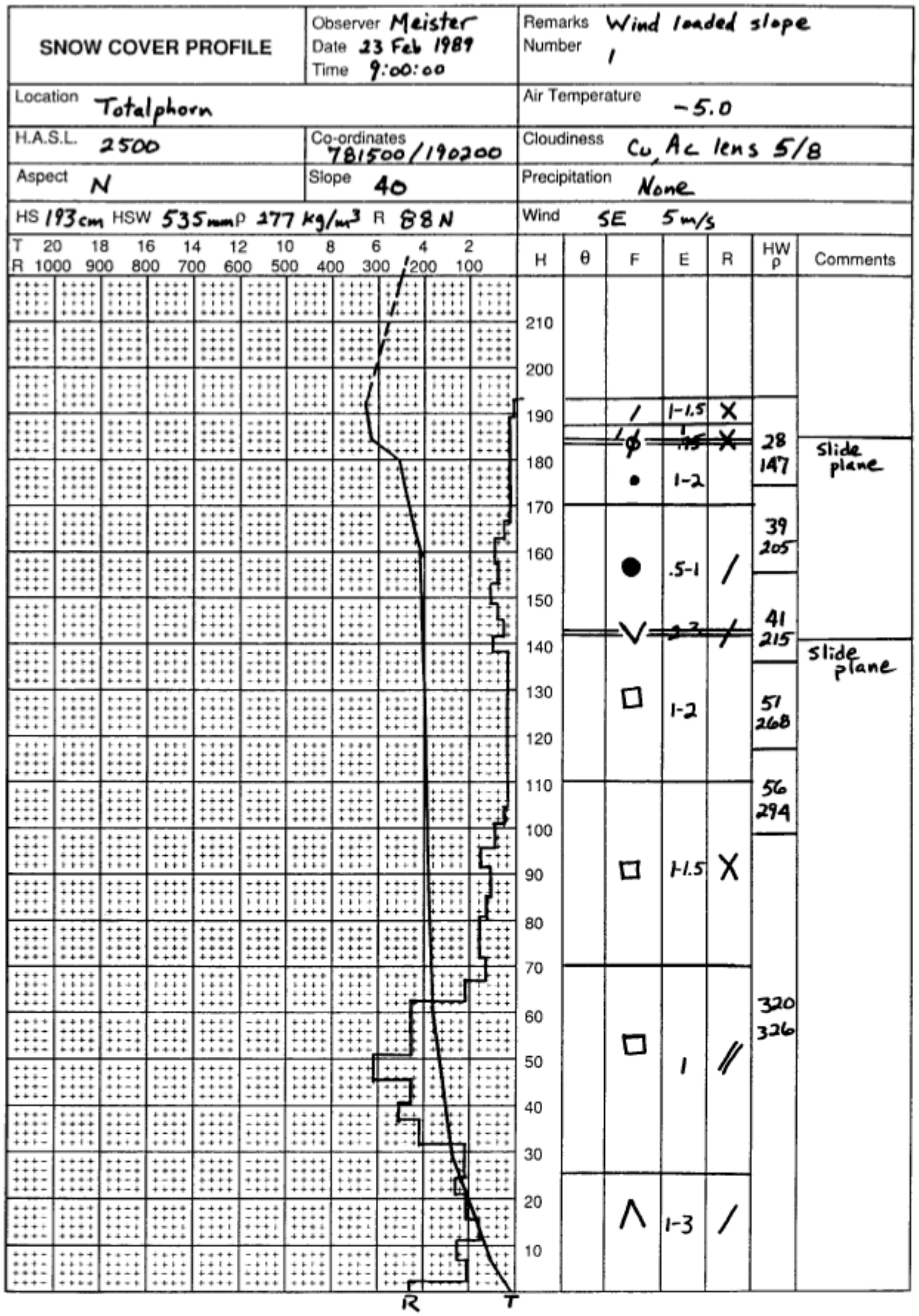
Snow hardness: Swiss Rammsonde

Penetration depth is translated into force in Newtons (N).

Has its own problems.

See: Haefeli, R. (1936) Beitrâge zur Géologie der Schweiz Geotechn. *Serie-Hydrol. Lieferung 3.* Waterhouse, R. (1966) Re-evaluation of the Rammsonde hardness equation. *CRREL Special Report 100.*

APPENDIX D. EXAMPLE OF A DATA SHEET FOR A SNOW COVER PROFILE



Snow description form

Also take photo of pit wall with tape for scale and markers showing layer boundaries.

Mary Albert (CRREL) sampling snow in Antarctica. http://snow.usace.army.mil/heat_mass_transfer/

Snow metamorphosis

Journal of Glaciology, Vol. 9, No. 55, 1970

THE CLASSIFICATION OF SNOW METAMORPHISM

By R. A. Sommerfeld

(U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station,* Fort Collins, Colorado 80521, U.S.A.)

and E. LaChapelle

(Department of Atmospheric Sciences, University of Washington, Seattle, Washington 98105, U.S.A.)

Abstract. A new classification of snow on the ground is based on the major physical processes involved in the metamorphism of a snow cover. The major divisions are based on (I) the mechanical damage to snow crystals during precipitation, (II) the transport of water vapor at constant temperature because of surface-energy differences, (III) the transport of water vapor along a thermal gradient, and (IV) firnification because of melting and refreezing, and pressure consolidation.

Résumé. *La classification*
basée sur les principaux processus physiques du métamorphisme d'une couverture de neige. Les divisions principales sont basées sur (I) les dommages mécaniques causés par les cristaux de neige pendant la précipitation, (II) le transport de la vapeur d'eau à température constante dû aux différences d'énergie superficielle, (III) le transport de vapeur d'eau le long d'un gradient thermique et (IV) la formation de névé dûe à la fonte au regel de même qu'au tassement.

Zusammenfassung. *Die Klassifikation*
Schnee geht von den wichtigsten physikalischen Vorgängen bei der Metamorphose einer Schneedecke aus. Die Hauptgliederung beruht auf (I) der mechanischen Beschädigung der Schneekristalle beim Niederschlag, (II) dem Transport von Wasserdampf bei konstanter Temperatur infolge von Unterschieden in der Oberflächenenergie, (III) dem Transport von Wasserdampf längs eines Temperaturgradienten, und (IV) der Verfirnung infolge von Schmelzen und Wiedergefrieren sowie der Druckverfestigung.

Sommerfeld, R. A. and E. LaChapelle. 1970. The classification of snow metamorphism. Journal of Glaciology 9:3-17.

Snow metamorphosis

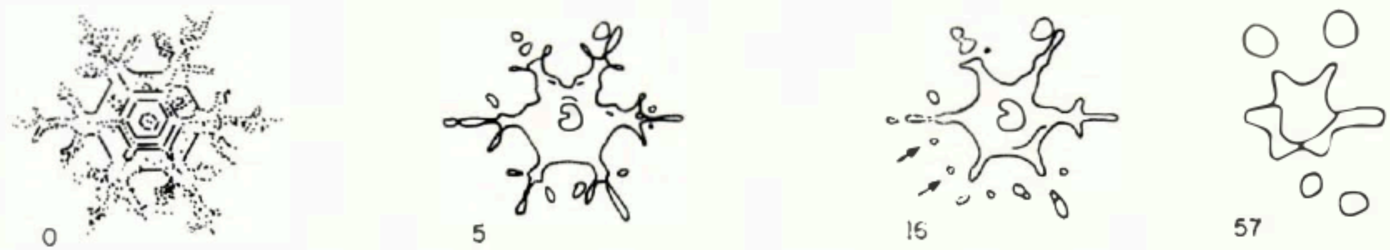


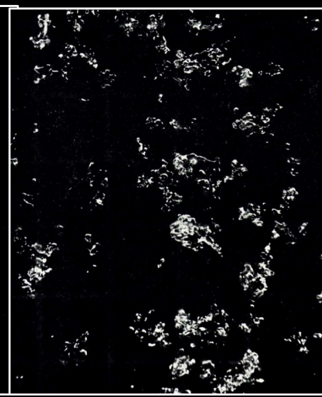
Fig. 2. The progress of equi-temperature metamorphism (the numbers are days). The temperature varied between −2.5°C and −11.5°C. Drawn from photographs in Bader and others (1939).

Sommerfeld, R. A. and E. LaChapelle. 1970. The classification of snow metamorphism. Journal of Glaciology 9:3-17.

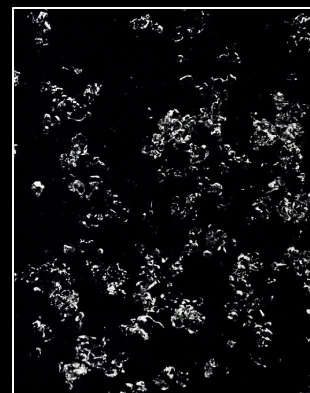
Equi-temperature vs. temperature-gradient snow metamorphosis

Beginning equi-temperature, decreasing grain size metamorphism

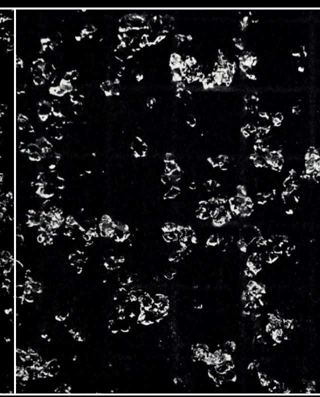
Late equi-temperature, decreasing grain size metamorphism



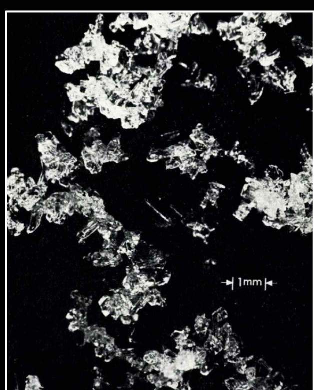
Beginning equi-temperature, increasing grain size metamorphism



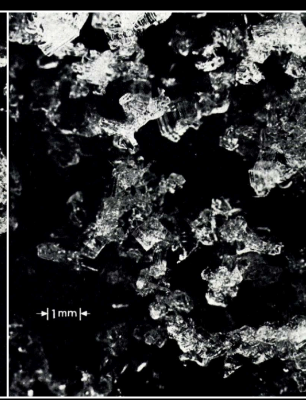
Advanced equi-temperature, increasing grain size metamorphism



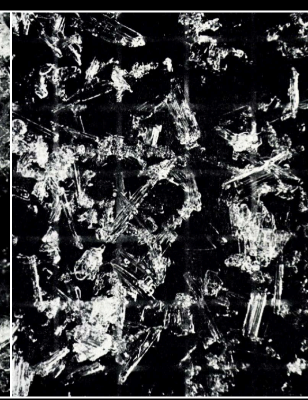
Beginning, early, temperature-gradient metamorphism



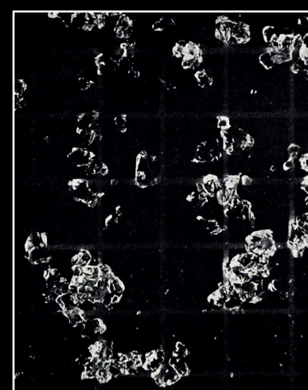
Partial, early, temperature-gradient metamorphism



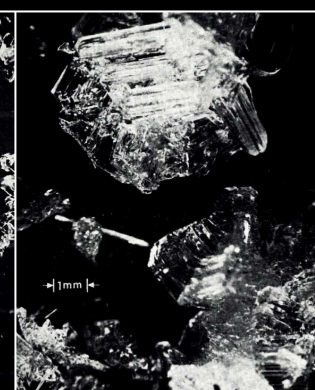
Advanced, early, temperature-gradient metamorphism



Beginning, late, temperature-gradient metamorphism



Advanced, late, temperature-gradient metamorphism



Sommerfeld, R. A. and E. LaChapelle. 1970. The classification of snow metamorphism. Journal of Glaciology 9:3-17.

Low-temperature-gradient vs. High-temperature-gradient snow metamorphosis

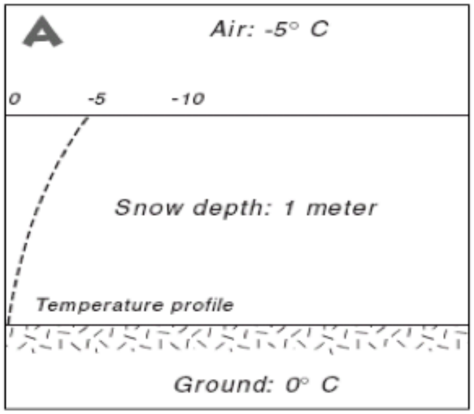
Low-temperature-gradient metamorphosis: Temperature gradient < 5˚C m^{-1}, produces small rounded grains (class 3), efficient settling rate, good cohesion due to growth of ice bonds between grains (**sintering**). Typical of in regions with heavy snowfalls or strong redistribution by wind.

Medium-temperature-gradient metamorphosis: Temperature gradient 5-15 ˚C m^{-1}, produces faceted crystals (class 4). Crystal growth is slow because gradient effects are partially balanced by curvature effects.

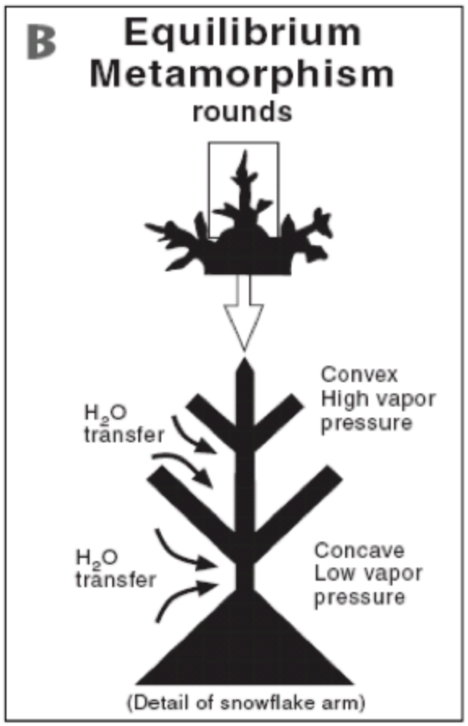
High-temperature-gradient metamorphosis: Temperature gradient > 15˚C m^{-1}, produces depth hoar crystals (class 5). Large plate-like crystals grow quickly. Characterized by very slow settling rate, weak cohesion. Typical in cold and dry climate regions.

Pomeroy, J. W. and E. Brun. 2001. Physical properties of snow. Pages 45-126 in H. G. Jones, J. W. Pomeroy, D. A. Walker, and R. W. Hoham, editors. Snow Ecology: An Interdisciplinary Examination of Snow-covered Ecosystems. Cambridge University Press, Cambridge.

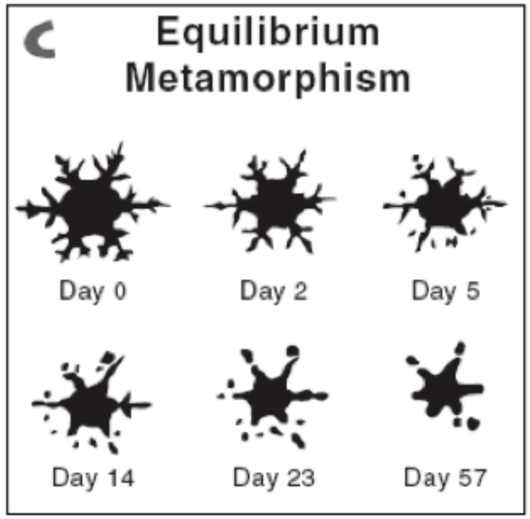
Equilibrium (= low-temperature-gradient) snow metamorphosis



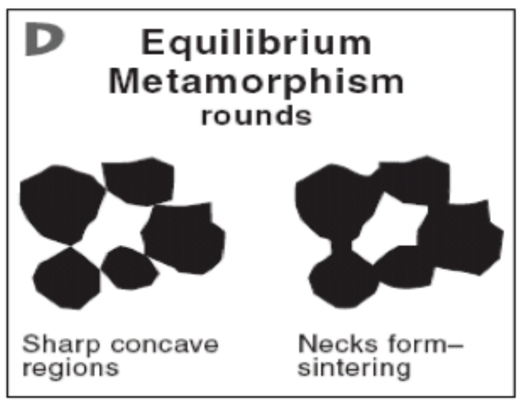
A small temperature gradient pro-motes equilibrium metamorphism



Original crystals lose their sharp points



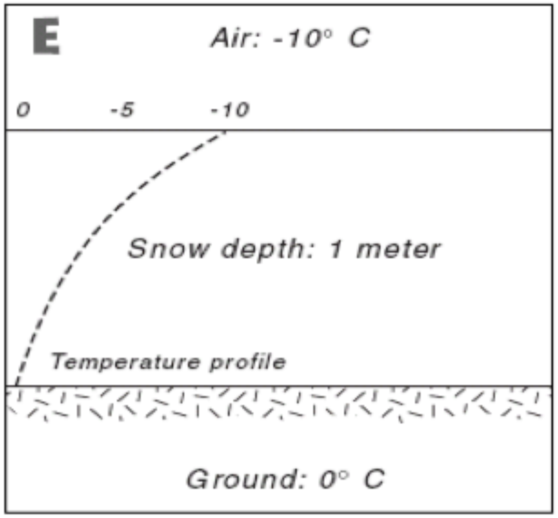
Rounds develop from equilibrium metamorphism



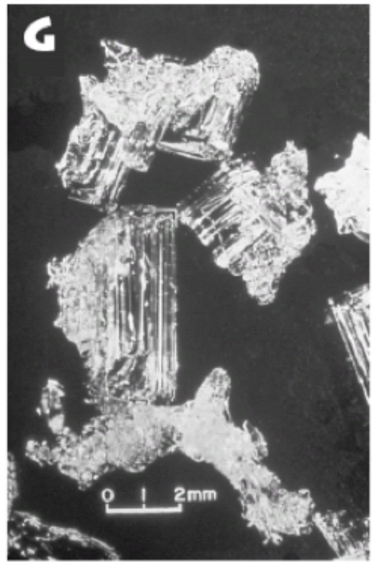
Strong bonds form between grains

http://www.geotech.org/survey/geotech/Snow%20Metamorphosis.pdf

Kenetic (= high-temperature-gradient) snow metamorphosis

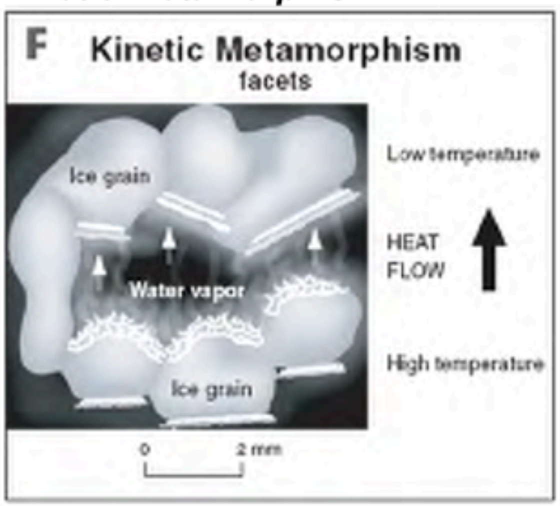


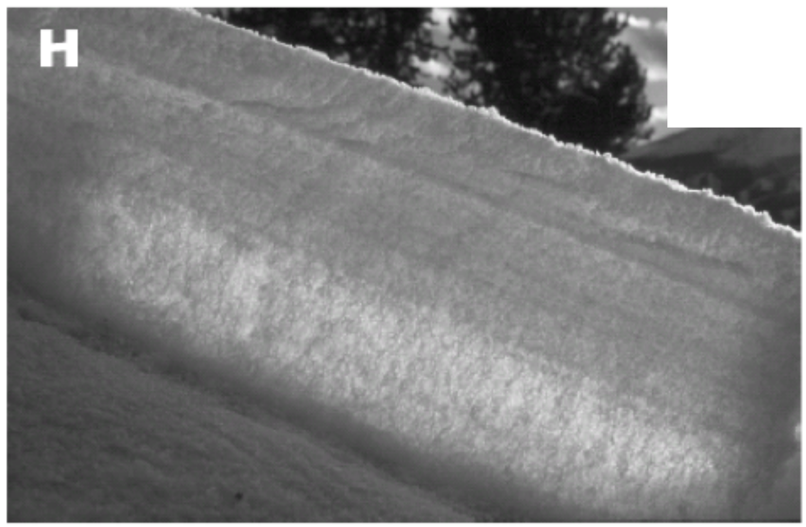
A large temperature gradient promotes kinetic metamorphism



Depth hoar grains with weak bonds

Squares developing from kinetic metamorphism





A snow profile that is back lit. The lighter layer near the bottom is a weak layer of faceted grains (depth hoar).

http://www.geotech.org/survey/geotech/Snow%20Metamorphosis.pdf

Snow metamorphosis animation

http://www.slf.ch/ueber/organisation/schnee_permafrost/projekte/schneemetamorphose/index_EN

WSL, Institute for Snow and Avalanche Research, Davos, Switzerland, SLF

Sommerfeld, R. A. and E. LaChapelle. 1970. The classification of snow metamorphism. Journal of Glaciology 9:3-17.

Snow Cover Classification

A Seasonal Snow Cover Classification System for Local to Global Applications

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(Manuscript received 1 September 1994, in final form 7 December 1994)

ABSTRACT

A new classification system for seasonal snow covers is proposed. It has six classes (*tundra*, *taiga*, *alpine*, *maritime*, *prairie*, and *ephemeral*), each class defined by a unique ensemble of textural and stratigraphic characteristics including the sequence of snow layers, their thickness, density, and the crystal morphology and grain characteristics within each layer. The classes can also be derived using a binary system of three climate variables: wind, precipitation, and air temperature. Using this classification system, the Northern Hemisphere distribution of the snow cover classes is mapped on a 0.5° lat × 0.5° long grid. These maps are compared to maps prepared from snow cover data collected in the former Soviet Union and Alaska. For these areas where both climatologically based and texturally based snow cover maps are available, there is 62% and 90% agreement, respectively. Five of the six snow classes are found in Alaska. From 1989 through 1992, hourly measurements, consisting of 40 thermal and physical parameters, including snow depth, the temperature distribution in the snow, and basal heat flow, were made on four of these classes. In addition, snow stratigraphy and texture were measured every six weeks. Factor analysis indicates that the snow classes can be readily discriminated using four or more winter average thermal or physical parameters. Further, analysis of hourly time series indicates that 84% of the time, spot measurements of the parameters are sufficient to correctly differentiate the snow cover class. Using the new snow classification system, 1) classes can readily be distinguished using observations of simple thermal parameters, 2) physical and thermal attributes of the snow can be inferred, and 3) classes can be mapped from climate data for use in regional and global climate modeling.

Sturm, M., J. Holmgren, and G. E. Liston. 1995. A seasonal snow cover classification system for local to global applications. Journal of Climate 8:1261-1283.

Snow Cover Classification

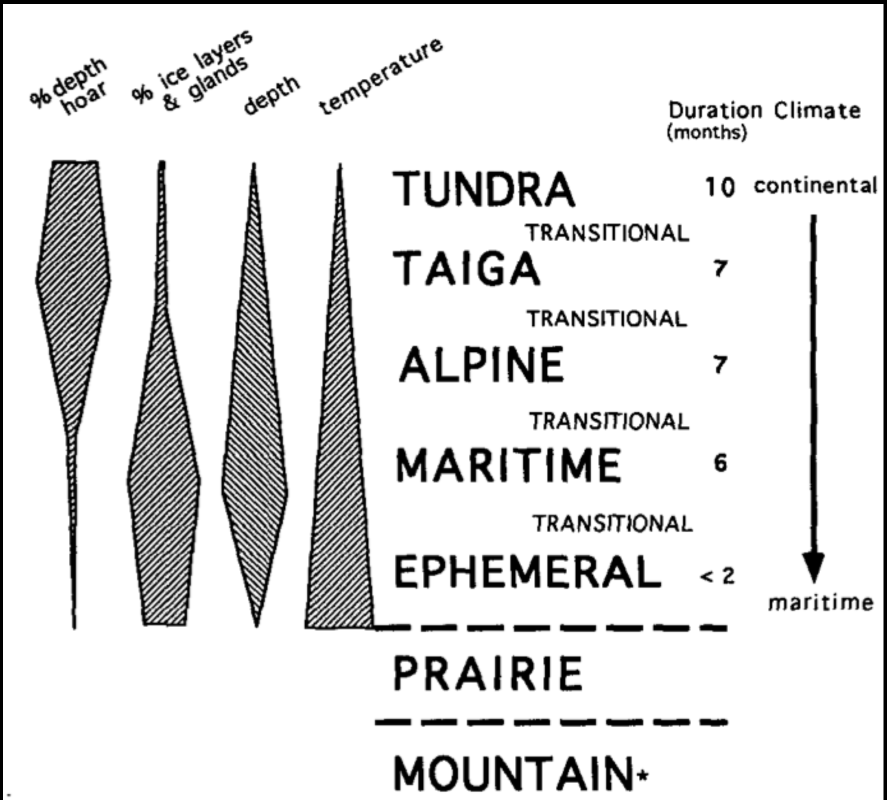


FIG. 1. Seasonal snow cover classes in the new system. Note that mountain (*) snow is a special designation for regions where the snow cover is highly variable.

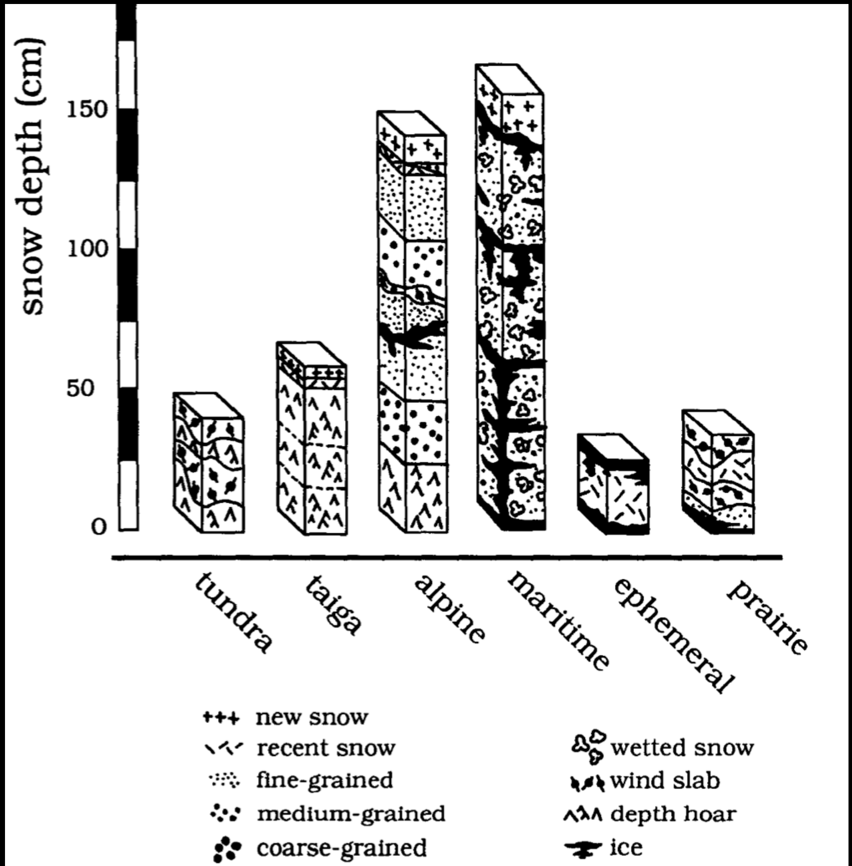


FIG. 2. The basic stratigraphic and textural attributes of each class of snow cover as they would appear in middle to late winter. Symbols follow Colbeck et al. 1992.

Sturm, M., J. Holmgren, and G. E. Liston. 1995. A seasonal snow cover classification system for local to global applications. Journal of Climate 8:1261-1283.

Snow Cover Classification

TABLE 2. Snow class descriptions.

Snow cover class	Description	Depth range (cm)	Bulk density (g cm^{-3})	Number of layers
tundra	A thin, cold, wind-blown snow. Max. depth approx. 75 cm. Usually found above or north of tree line. Consists of a basal layer of depth hoar overlain by multiple wind slabs. Surface sastrugi common. Melt features rare.	10–75	0.38	0–6
taiga	A thin to moderately deep low-density cold snow cover. Max. depth: 120 cm. Found in cold climates in forests where wind, initial snow density, and average winter air temperatures are all low. By late winter consists of 50% to 80% depth hoar covered by low-density new snow.	30–120	0.26	>15
Alpine	An intermediate to cold deep snow cover. Max. depth approx. 250 cm. Often alternate thick and thin layers, some wind affected. Basal depth hoar common, as well as occasional wind crusts. Most new snowfalls are low density. Melt features occur but are generally insignificant.	75–250	no data	>15
maritime	A warm deep snow cover. Max depth can be in excess of 300 cm. Melt features (ice layers, percolation columns) very common. Coarse-grained snow due to wetting ubiquitous. Basal melting common.	75–500	0.35	>15
ephemeral	A thin, extremely warm snow cover. Ranges from 0 to 50 cm. Shortly after it is deposited, it begins melting, with basal melting common. Melt features common. Often consists of a single snowfall, which melts away, then a new snow cover reforms at the next snowfall.	0–50	no data	1–3
prairie	A thin (except in drifts) moderately cold snow cover with substantial wind drifting. Max. depth approx. 1 m. Wind slabs and drifts common.	0–50	no data	<5
[a]mountain	A highly variable snow cover, depending on solar radiation effects and local wind patterns. Usually deeper than associated type of snow cover from the adjacent low-lands.		no data	variable

[a] Special class.

Sturm, M., J. Holmgren, and G. E. Liston. 1995. A seasonal snow cover classification system for local to global applications. Journal of Climate 8:1261-1283.

Snow Cover Classification

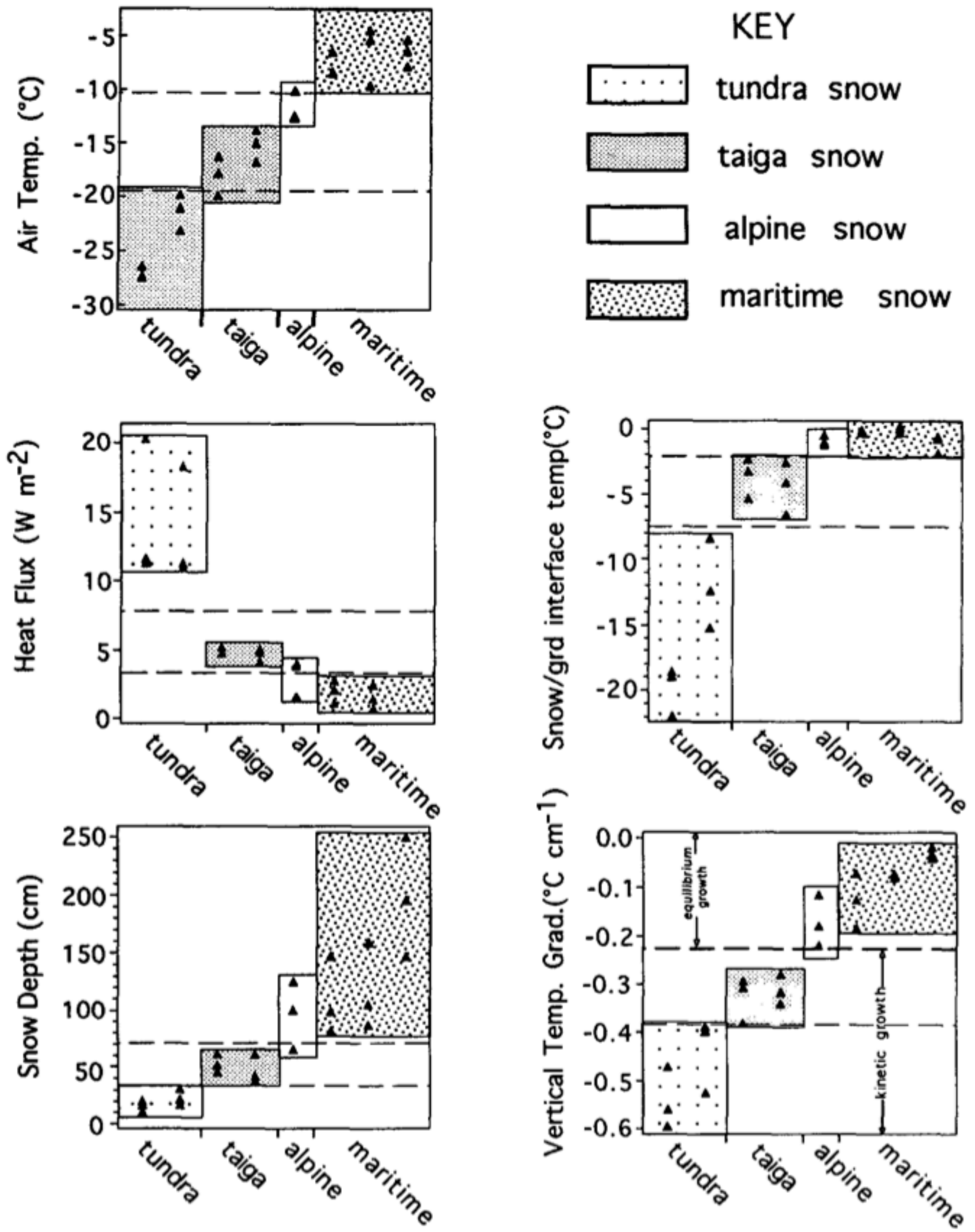


FIG. 5. Five representative single-value discrimination plots. The snow class is indicated along the abscissa, and the value of the parameter along the ordinate. The boundaries are set equidistant between the data points. Note that one boundary for vertical temperature gradients corresponds to the critical gradient necessary for depth hoar growth according to Akitaya (1974), Marbouty (1980), and Colbeck (1983).

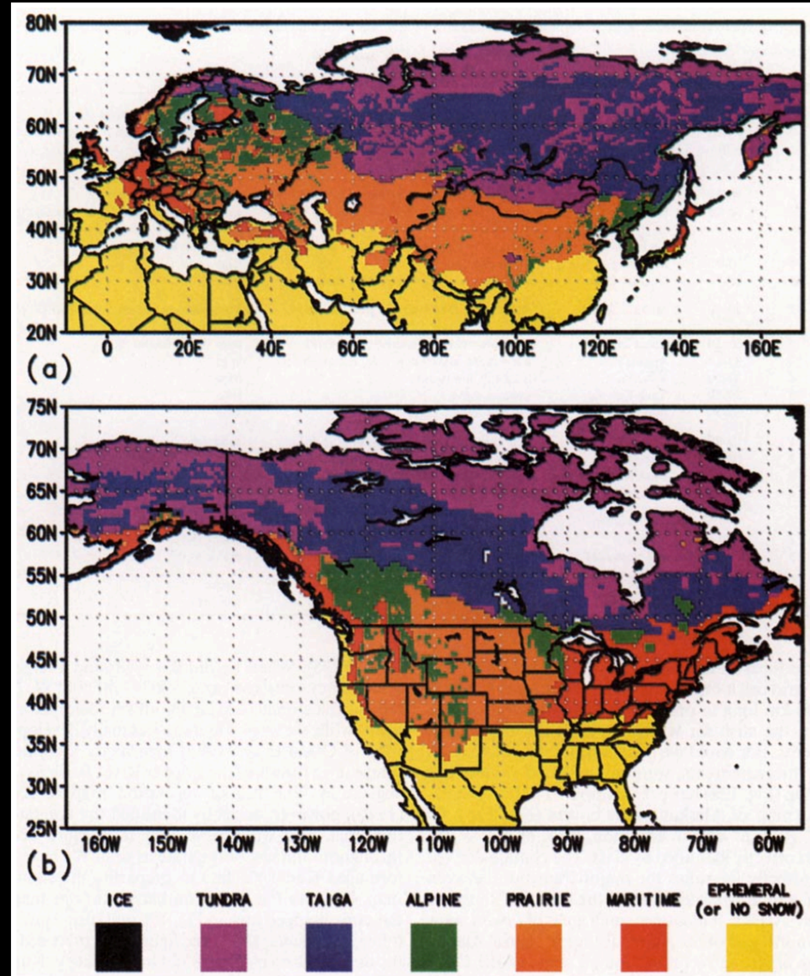
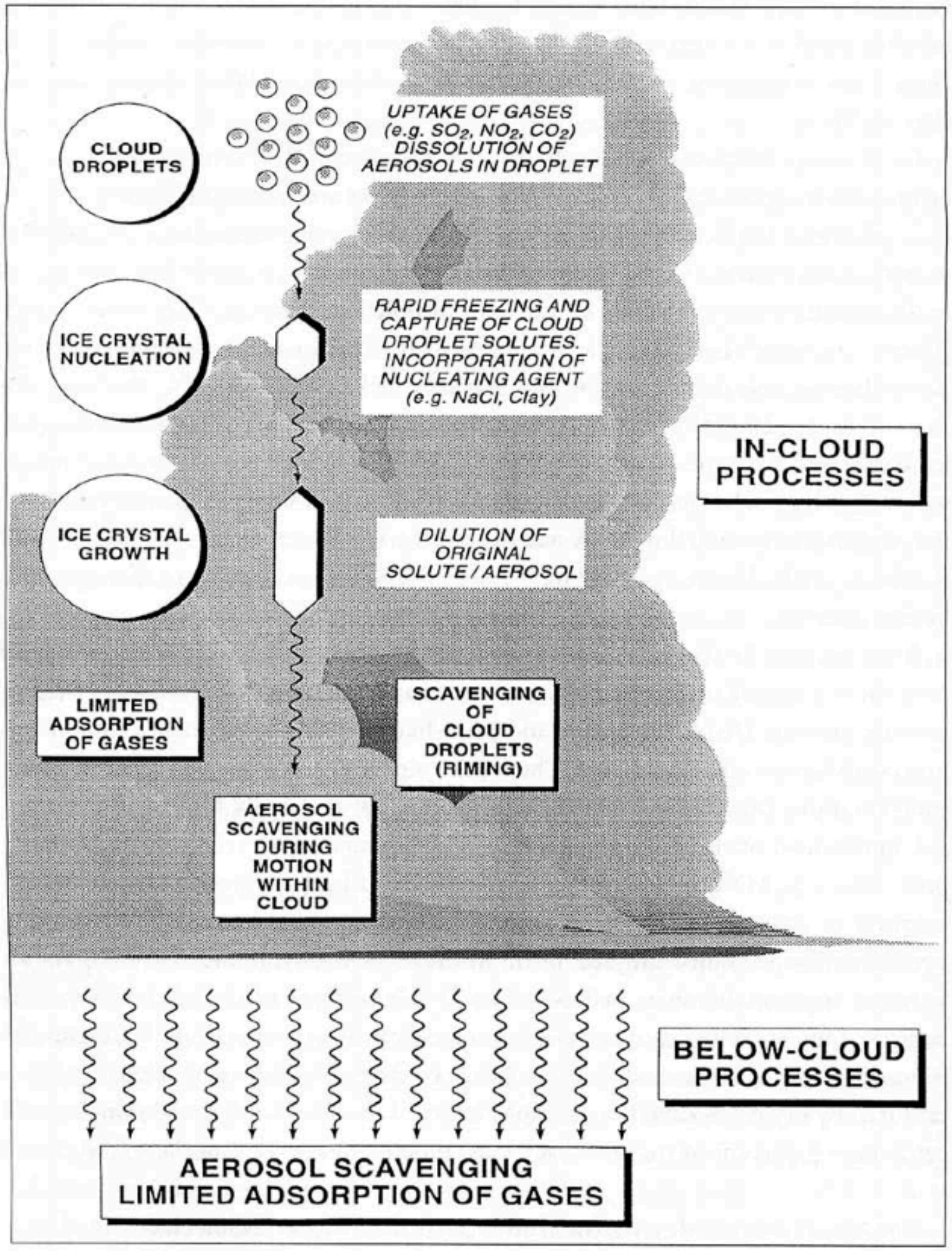


FIG. 10. Snow class distribution based on climate variables in (a) Eurasia and (b) North America.

Sturm, M., J. Holmgren, and G. E. Liston. 1995. A seasonal snow cover classification system for local to global applications. Journal of Climate 8:1261-1283.



Snow chemistry

Processes affecting snow chemistry during growth and fall:

- **In-cloud processes**
  - Cloud droplet formation (uptake of gases)
  - Ice crystal nucleation (incorporation of nucleating agents)
  - Ice-crystal growth (dilution)
  - Scavenging of cloud droplet during motion within cloud.
- **Below cloud processes**
  - Aerosol scavenging of gases

Tranter, M. and G. Jones. 2001. The Chemistry of Snow: Processes and Nutrient Cycling. Pages 127-167 in H. G. Jones, J. Pomeroy, D. A. Walker, and R. Hoham, editors. Snow Ecology. Cambridge University Press, Cambridge.

Snow chemistry

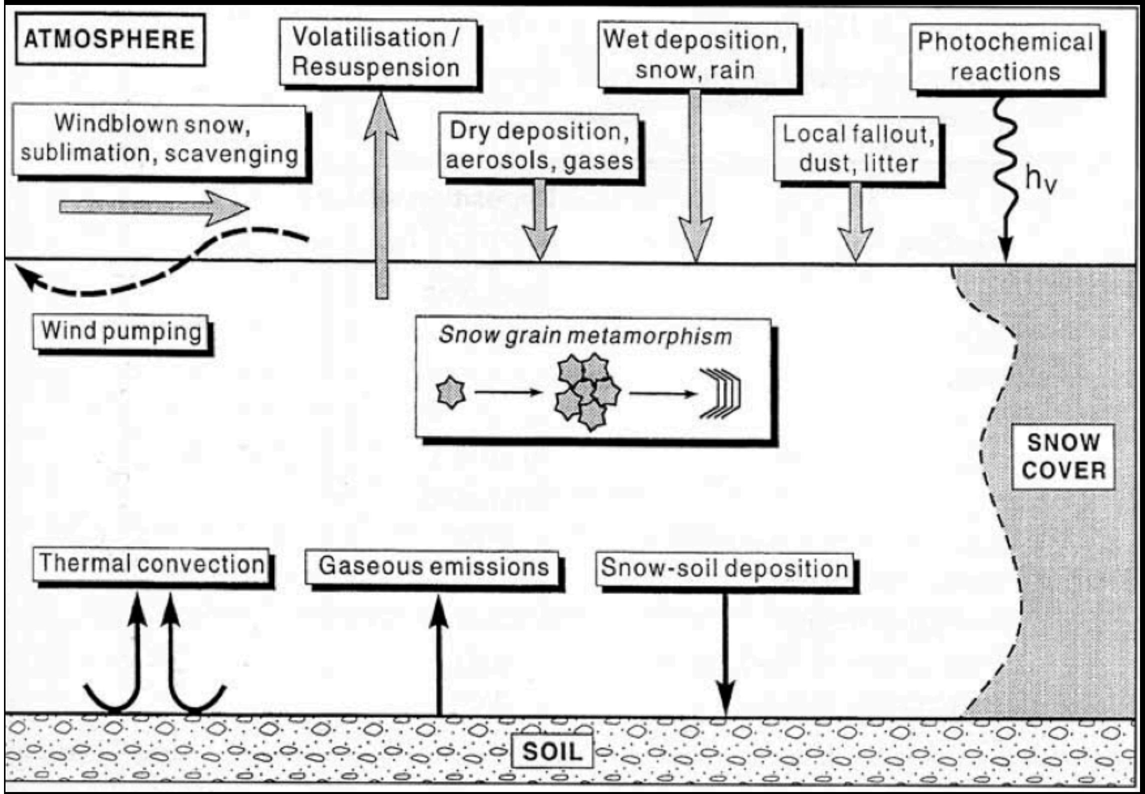
Chemical composition of snowfall at selected sites:

Location	pH	Ca^{2+}	Mg^{2+}	Na^+	K^+	NH_4^+	NO_3^-	SO_4^{2-}	Cl^-	Source
European Alps	4.4–5.3	18–49	3–15	3–27	1–6	17–60	12–46	28–68	8–32	Puxbaum, Kovar, and Kalina (1991)
Central Asian Mountains	*	19–70	*	1–44	*	*	2.9–60	2.2–51	1–32	Lyons, Wake, and Mayewski (1991)
Turkey Lakes Watershed, SE Canada	4.57	34	0.9	10	0.2	7.5	19	17	3.7	Semkin and Jeffries (1988)
Mid-Wales	3.9–4.5	4–14	4–11	13–30	1–5	*	11–64	16–78	21–69	Reynolds (1983)
Sapporo, Japan	4.4–6.4	13–63	18–67	59–190	2.3–6.4	*	*	70–99	63–310	Suzuki (1987)
Cairngorms, Scotland	4.4	2.5	11	52	2.1	9.8	20	26	91	Davies et al. (1992)
Svalbard	5.4–6.7	0–46	0–200	4–2000	0–96	*	0–7	0–240	0–2400	Hodgkins, Tranter, and Dowdeswell (1997)
South Pole	5.4	*	0.16	0.63	0.03	0.16	1.4	1.5	1.3	Legrand and Delmas (1984)

*Missing values. Single values refer to volume-weighted mean concentrations. All units (except pH) are μEq/L.

Tranter, M. and G. Jones. 2001. The Chemistry of Snow: Processes and Nutrient Cycling. Pages 127-167 in H. G. Jones, J. Pomeroy, D. A. Walker, and R. Hoham, editors. Snow Ecology. Cambridge University Press, Cambridge.

Snow chemistry



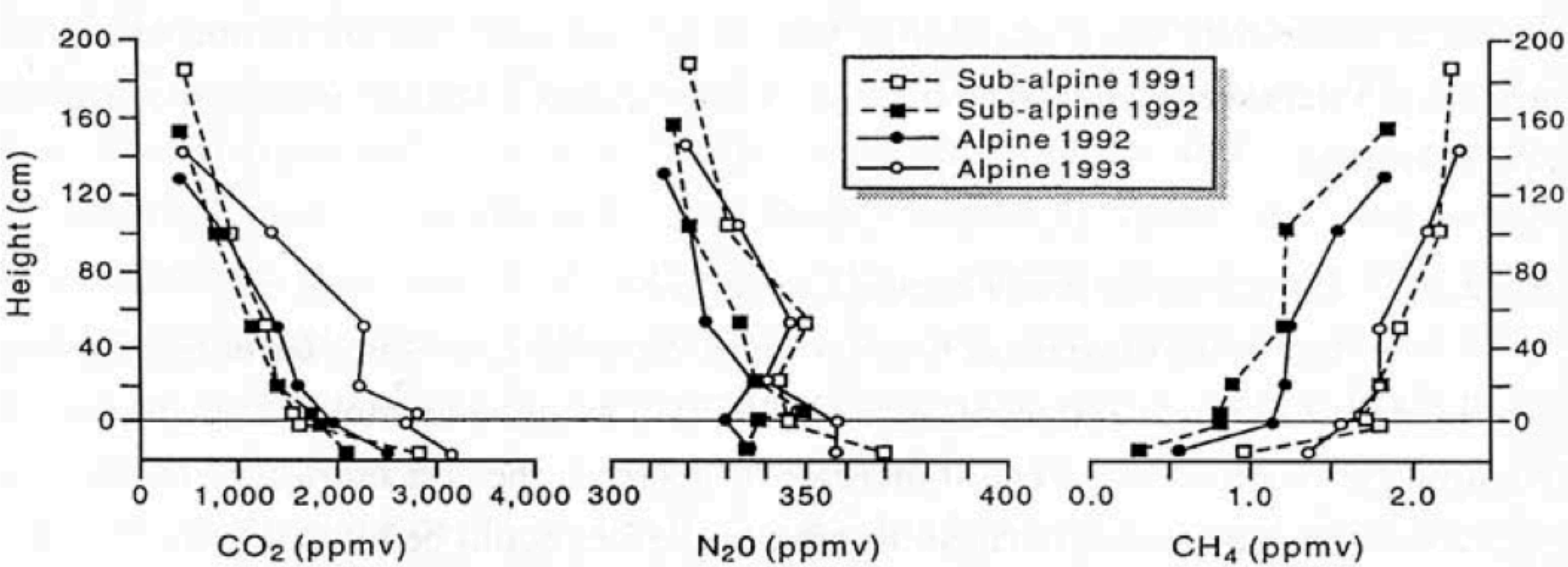
Processes affecting dry snow chemistry during **accumulation season**:

- **Above-snow processes:**
  - **Windblown snow scavenging**
  - **Dry deposition.**
  - **Wet deposition**
  - **Local litter, dust**
  - **Photochemical reactions**
- **Within snow processes:**
  - **Dry snow metamorphism**
- **Below-snow processes:**
  - **Gaseous emissions**
  - **Snow- soil deposition**
  - **Microbial activity (if soil is warm enough)**

Tranter, M. and G. Jones. 2001. The Chemistry of Snow: Processes and Nutrient Cycling. Pages 127-167 in H. G. Jones, J. Pomeroy, D. A. Walker, and R. Hoham, editors. Snow Ecology. Cambridge University Press, Cambridge.

Snow chemistry: Exchange with soil surface

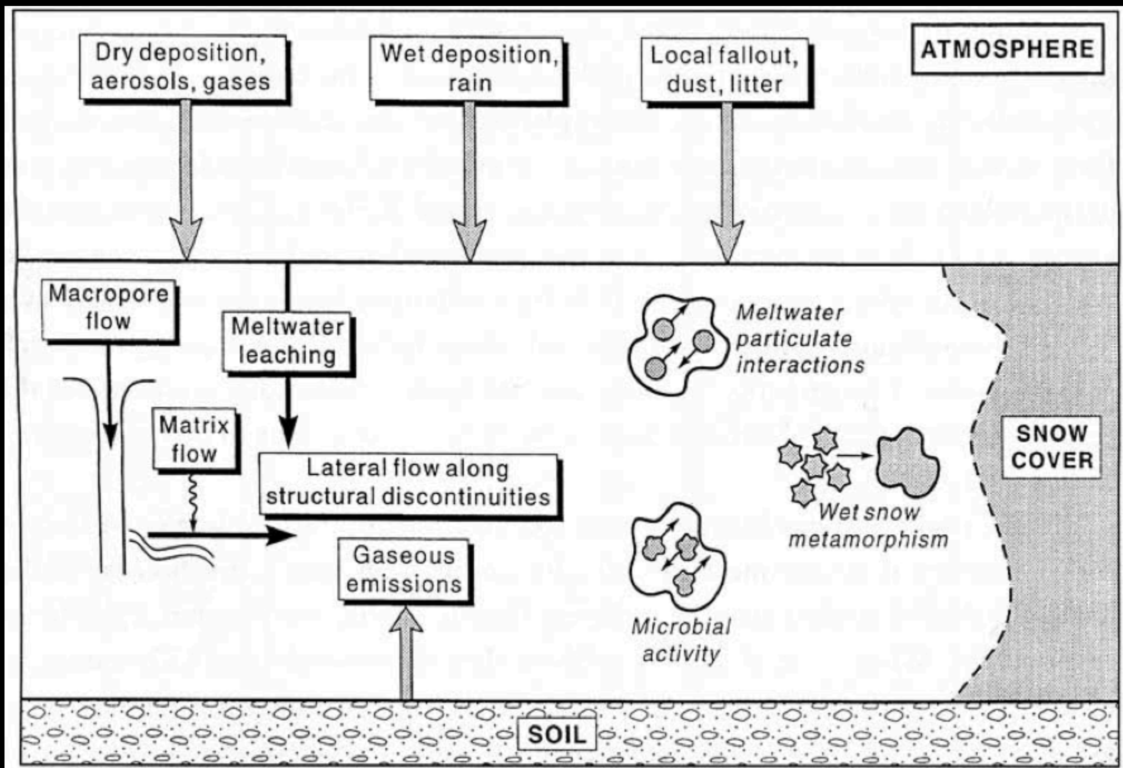
Gas concentrations within snow pack:



- Mainly a result of microbial decomposition beneath the snowpack.
- Ceases at about -8˚C.

Tranter, M. and G. Jones. 2001. The Chemistry of Snow: Processes and Nutrient Cycling. Pages 127-167 in H. G. Jones, J. Pomeroy, D. A. Walker, and R. Hoham, editors. Snow Ecology. Cambridge University Press, Cambridge.

Snow chemistry



Processes affecting snow chemistry during **thaw**:

- **Above-snow processes:**
  - **Windblown snow scavenging**
  - **Dry deposition.**
  - **Wet deposition**
  - **Local litter, dust**
- **Within snow processes:**
  - **Wet snow metamorphism**
  - **Micro-pore flow**
  - **Melt-water leaching**
  - **Melt-particulate interactions**
  - **Microbial activity**
- **Below-snow processes:**
  - **Gaseous emissions**
  - **Microbial activity**

Tranter, M. and G. Jones. 2001. The Chemistry of Snow: Processes and Nutrient Cycling. Pages 127-167 in H. G. Jones, J. Pomeroy, D. A. Walker, and R. Hoham, editors. Snow Ecology. Cambridge University Press, Cambridge.

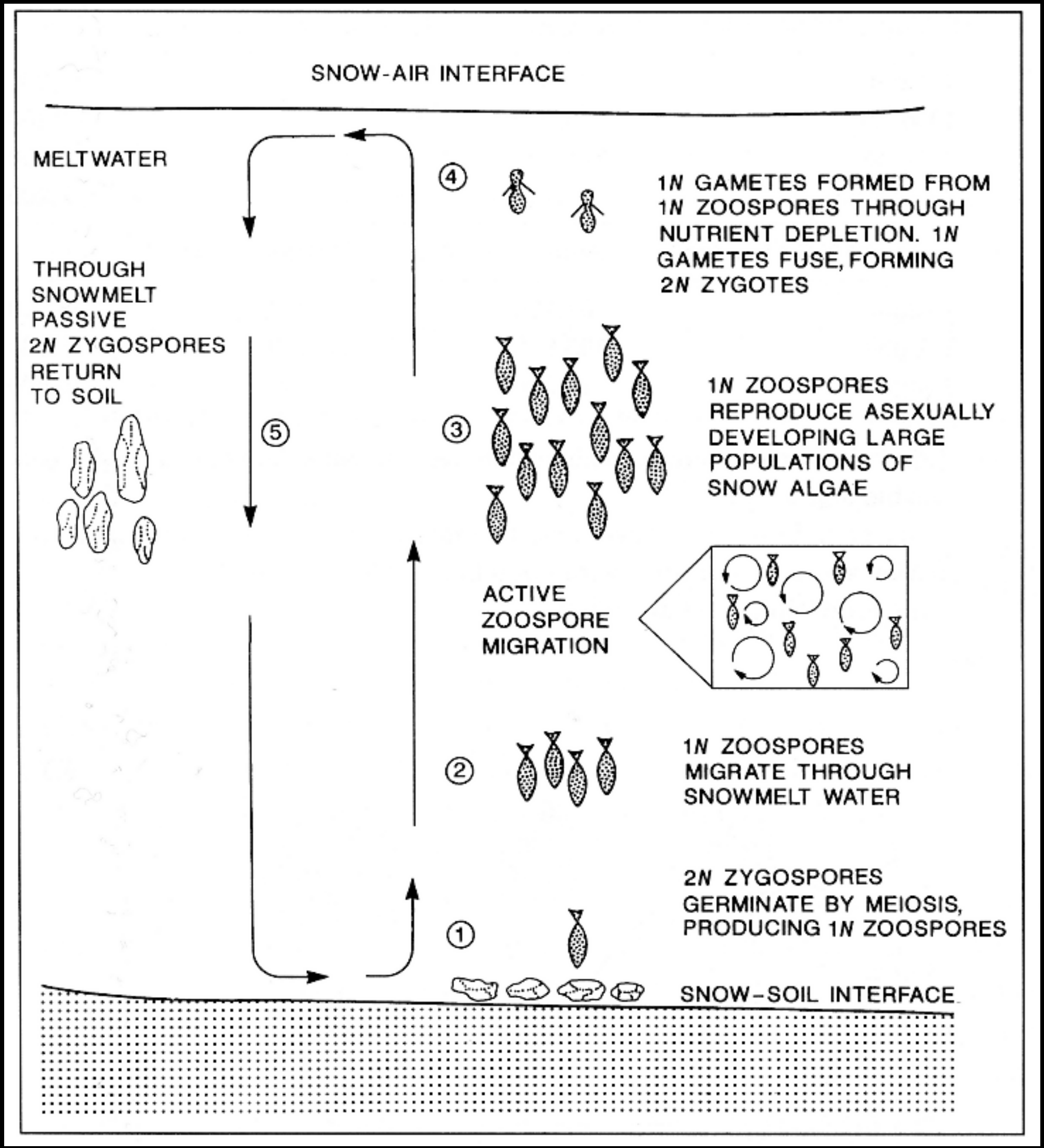
Snow as a habitat:
Microbial ecology of snow

Watermelon snow

Green alga: *Chlamydomonas nivalis.*
Source: http://emu.arsusda.gov/typesof/pages/green%20algal.html

Photo: Watermelon snow in Sierra mountains, Green snow alga: *Chlamydomonas nivalis*
Will Beback, http://en.wikipedia.org/wiki/File:Watermelon_snow_streaks_3.jpg

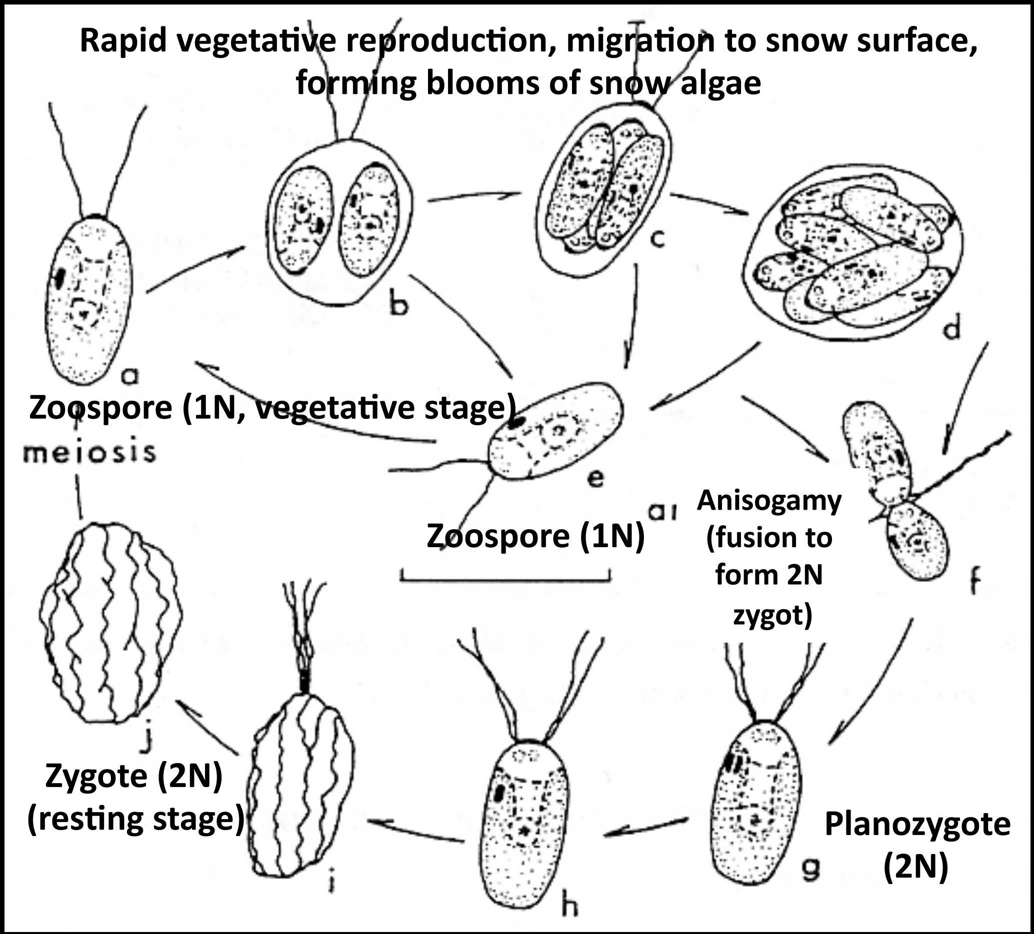
Life cycle of algal flagellate, *Chloromonas*



1. 2N Zygospores germinate by meiosis on soil surface producing bi-flagellated 1N zoospores.
2. 1N Zoospores "swim" upward to snow surface within liquid water surrounding snow crystals of isothermal snow.
3. Zoospores reproduce asexually developing large populations of snow algae.
4. Zoospores create visible blooms of snow algae on the snow surface. With nutrient depletion, 1N gametes from 1N zoospores fuse to form 2N resting zygotes.
5. Zygotes return to soil passively through meltwater percolation and settling of the snow.

Hoham, R. W. and B. Duval. 2001. Microbial ecology of snow and freshwater ice with emphasis on snow algae. Pages 168-228 in H. G. Jones, J. W. Pomerory, D. A. Walker, and R. W. Hoham, editors. Snow Ecology. Cambridge University Press, Cambridge.

Life cycle of algal flagellate, *Chloromonas polyptera*



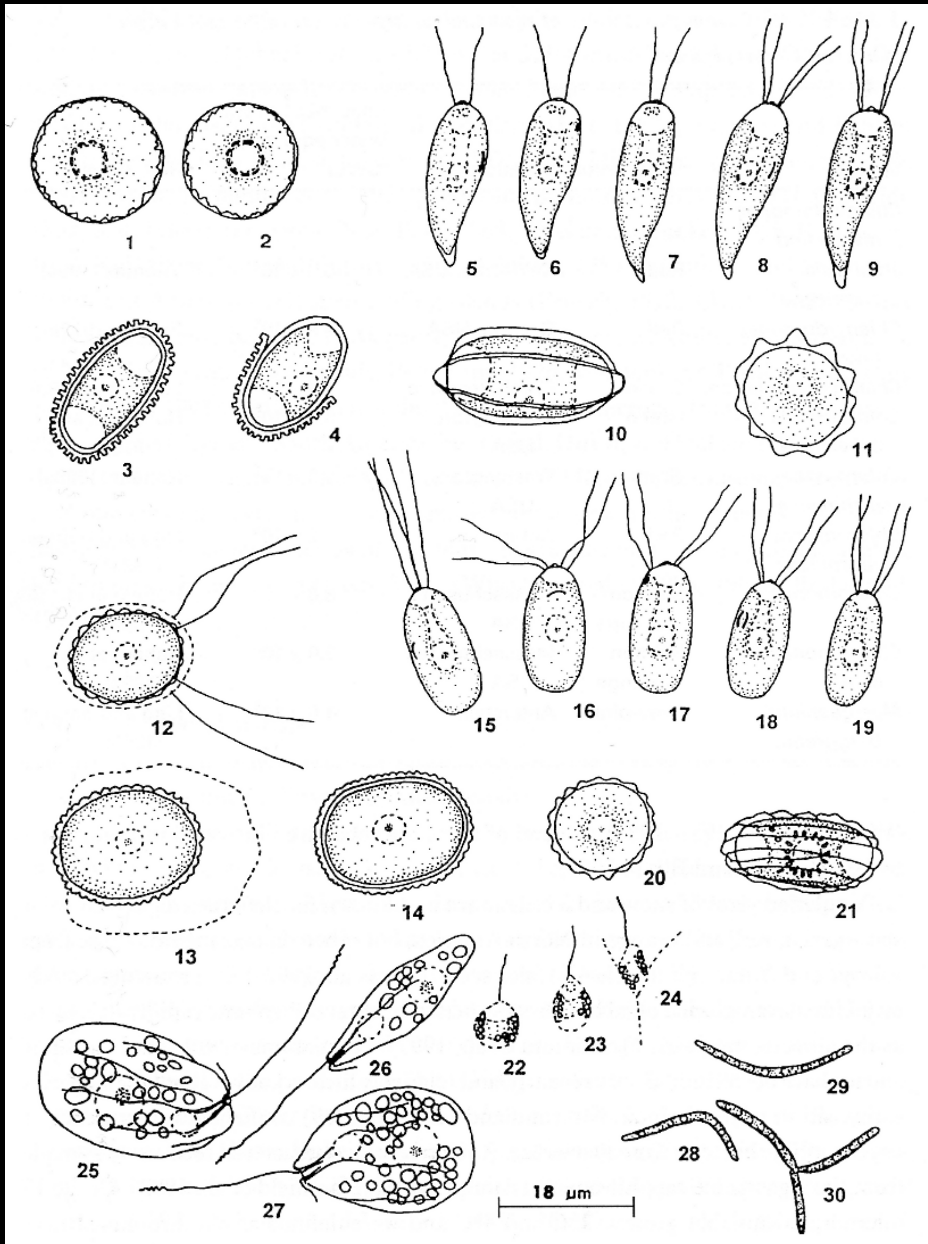
a. bi-flagellated 1N zoospores.

b-e. 1N Zoospores "swim" upward to snow surface within liquid water surrounding snow crystals of isothermal snow. Zoospores reproduce asexually developing large populations of snow algae. Zoospores create visible blooms of snow algae on the snow surface.

f. With nutrient depletion, 1N gametes from 1N zoospores fuse (anisogamy) to form 2N resting zygotes.

g-j. Zygotes return to soil passively through meltwater percolation melting and settling of the snow.

Hoham, R. W. and B. Duval. 2001. Microbial ecology of snow and freshwater ice with emphasis on snow algae. Pages 168-228 in H. G. Jones, J. W. Pomerory, D. A. Walker, and R. W. Hoham, editors. Snow Ecology. Cambridge University Press, Cambridge.



Other cryophilic organisms found in snow

1-2 Green alga (*Chlamdomonas nivalis*) resting spores

3-4 Green alga (*Chloromonas brevispina*) zygospores.

5-9 Green alga (*Chlamdomonas nivalis*) vegetative cells.

10-11 Green alga (*Chlamdomonas nivalis*) zygospores.

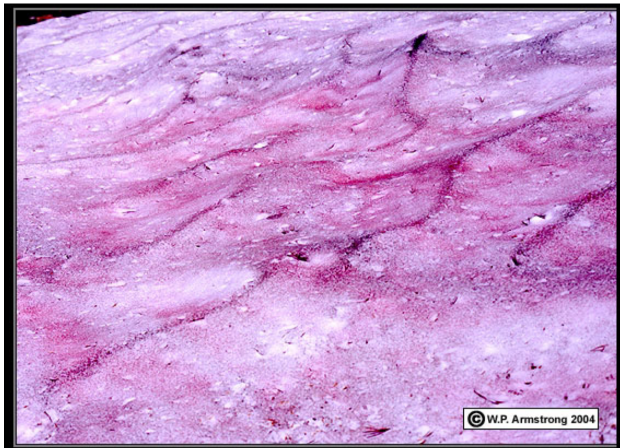
12-21 Other green algae forms.

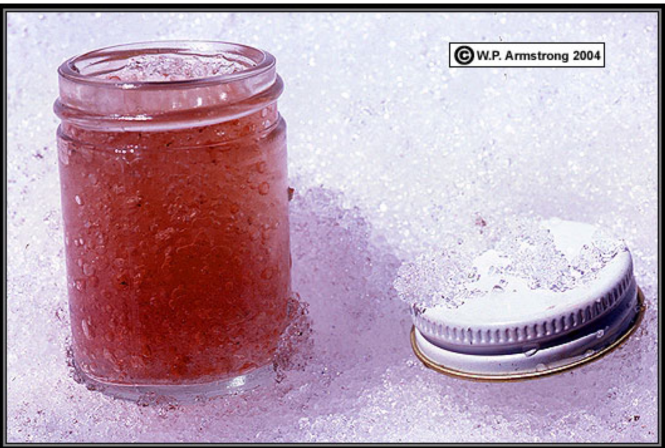
22-24 Golden alga (*Chromolina chionophilia*)

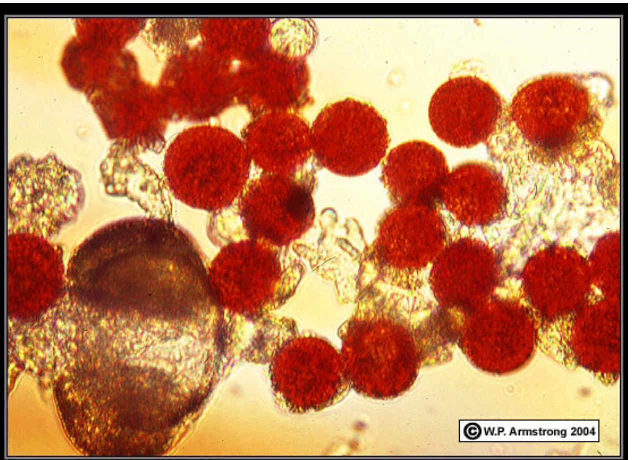
25-27 Euglena (*Notosolenus* sp.)

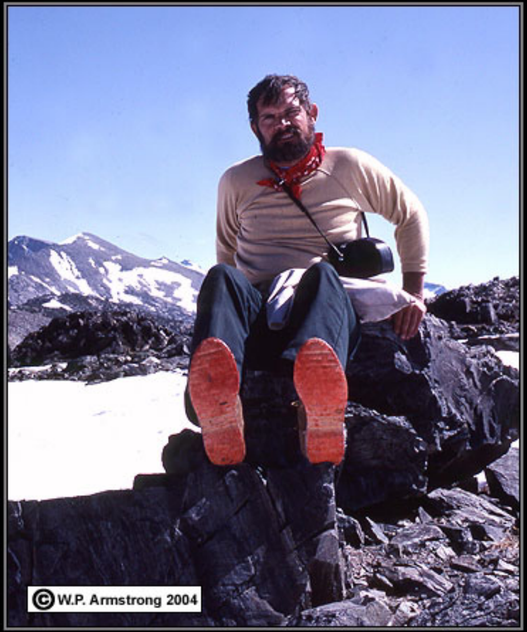
28-30 Fungus (*Selenotila nivalis*)

Hoham, R. W. and B. Duval. 2001. Microbial ecology of snow and freshwater ice with emphasis on snow algae. Pages 168-228 in H. G. Jones, J. W. Pomerory, D. A. Walker, and R. W. Hoham, editors. Snow Ecology. Cambridge University Press, Cambridge.









http://waynesword.palomar.edu/index.htm

Red snow in the Sierras

Upper right Microscopic view (400 X) of the bright red resting cells (aplanospores) of *Chlamydomonas nivalis*. The larger winged structure (lower left) is a pollen grain from the timberline whitebark pine (*Pinus albicaulis*). The smaller, transparent-green cells (center) with a lipid droplet at each end are *Chloromonas*, another species of snow alga. The red coloration is due to carotinoid pigments that protect the cells from intense solar radiation. (From Wayne's World, Noteworthy plant for 1998. http://waynesword.palomar.edu/plaug98.htm).

Yellow snow (where the doggies didn't go!)

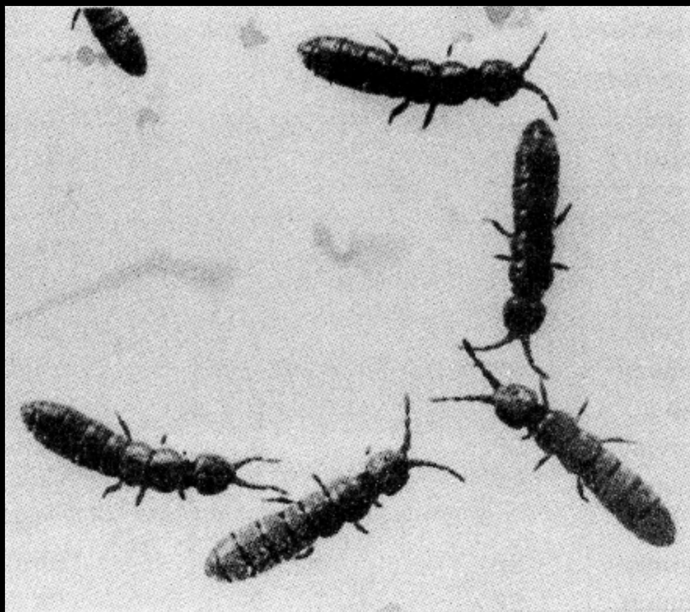
Photo: Brian Duval

- Non red forms thrive in shaded areas, e.g. spruce and fir forests.

Some consequences of snow algae:

1. Bacterial colonies develop around the algae.
2. These are fed on by rotifers and other higher-level predators.
3. More complex animals, such as *Mesenchytraeus* ice worms, and Collembola, snow fleas, also graze on algae.
4. Tardigrades, or water bears, prey on a variety of organisms.
5. Fungi decompose the organic material.

Snow fleas (Collembola)



Collembola (*Isotoma* sp.)

Aitchison, C. A. 2001. The effect of snow cover on small animals. Pages 229-265 in H. G. Jones, R. W. Hoham, J. W. Pomeroy, and D. A. Walker, editors. Snow Ecology. Cambridge University Press, Cambridge.

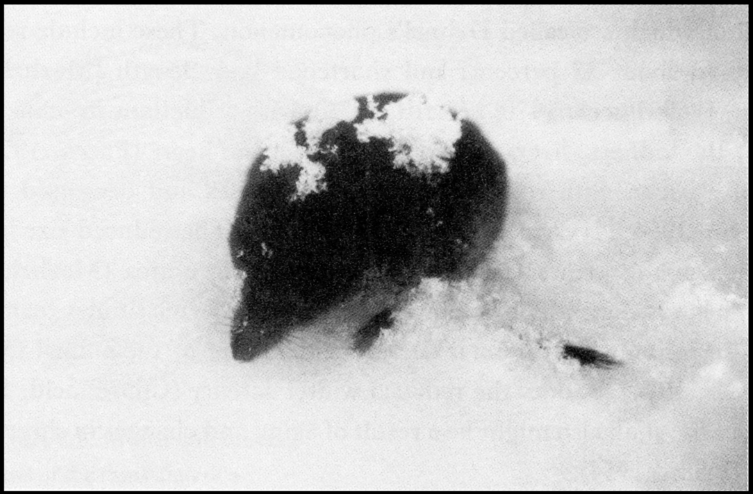
Table 5.3. *Collembolans associated with snow cover in different countries, location in the snow cover, and temperature range of activity.*

Species	Country	Location*	Temperature (°C)	Reference
Dicyrtomina rufescens	Japan	SP	eats at –1	Uchida and Fujita (1968)
Hypogastrura socialis	USA	SP	eats at 0	MacNamara (1924)
Hypogastrura socialis	Finland	SP	0	BK & BK (1980)†
Hypogastrura socialis	Norway	SP	migrates at 0	Hågvar (1995)
Hypogastrura spp.	Nepal	SP	0	Mani (1962)
Hypogastrura spp.	Norway	SP	0	Østbye (1966)
Hypogastrura spp.	Finland	SP	0	Levander (1913), Koponen (1983)
Hypogastrura spp.	Germany	SP	0	Strübing (1958)
Entomobrya nivalis	Finland	SP	0	BK & BK (1980)†
Entomobrya spp.	USA	SB	0	Holmquist (1926)
Tomocerus flavescens	USA	SB	0	Holmquist (1926)
Tomocerus flavescens	Finland	SP	0	BK & BK (1980)†
Tomocerus flavescens	Canada	SB	eats at –2	Aitchison (1983)
Tomocerus spp.	USA	SP	eats at 0	Knight (1976)
Lepidocyrtus cyaneus	Canada	SB	eats at –2	Aitchison (1983)
Lepidocyrtus lignorum	Finland	SP	0	BK & BK (1980)†
Orchesella bifasciata	Finland	SP	0	BK & BK (1980)
Orchesella ainslei	Canada	SB	eats at –2	Aitchison (1983)
Isotoma alpa	USA	SB	>–4	Schmidt and Lockwood (1992)
Isotoma gelida	USA	SB	>–4	Schmidt and Lockwood (1992)
Isotoma hiemalis	Finland	SP	0	BK & BK (1980)†
Isotoma hiemalis	Switzerland	SP	>–3	Zettel (1984)
Isotoma olivacea	Poland	SP	+5 to –5	Wolska (1957)
Isotoma saltans	Poland	SP	0 to –4	Wolska (1957), Wojtusiak (1951)
Isotoma saltans	Germany	SP	+5 to –5	Strübing (1958)
Isotoma viridis	Sweden	SP	>–8	Agrell (1941)
Isotoma viridis	Canada	SB	eats at –2	Aitchison (1983)
Isotoma viridis	USA	SB	>–4	Schmidt and Lockwood (1992)

*SB – subnivean; SP – supranivean.

†BK & BK, Brummer-Korvenkontio and Brummer-Korvenkontio.

Winter food of shrew (*Sorex minutus*)

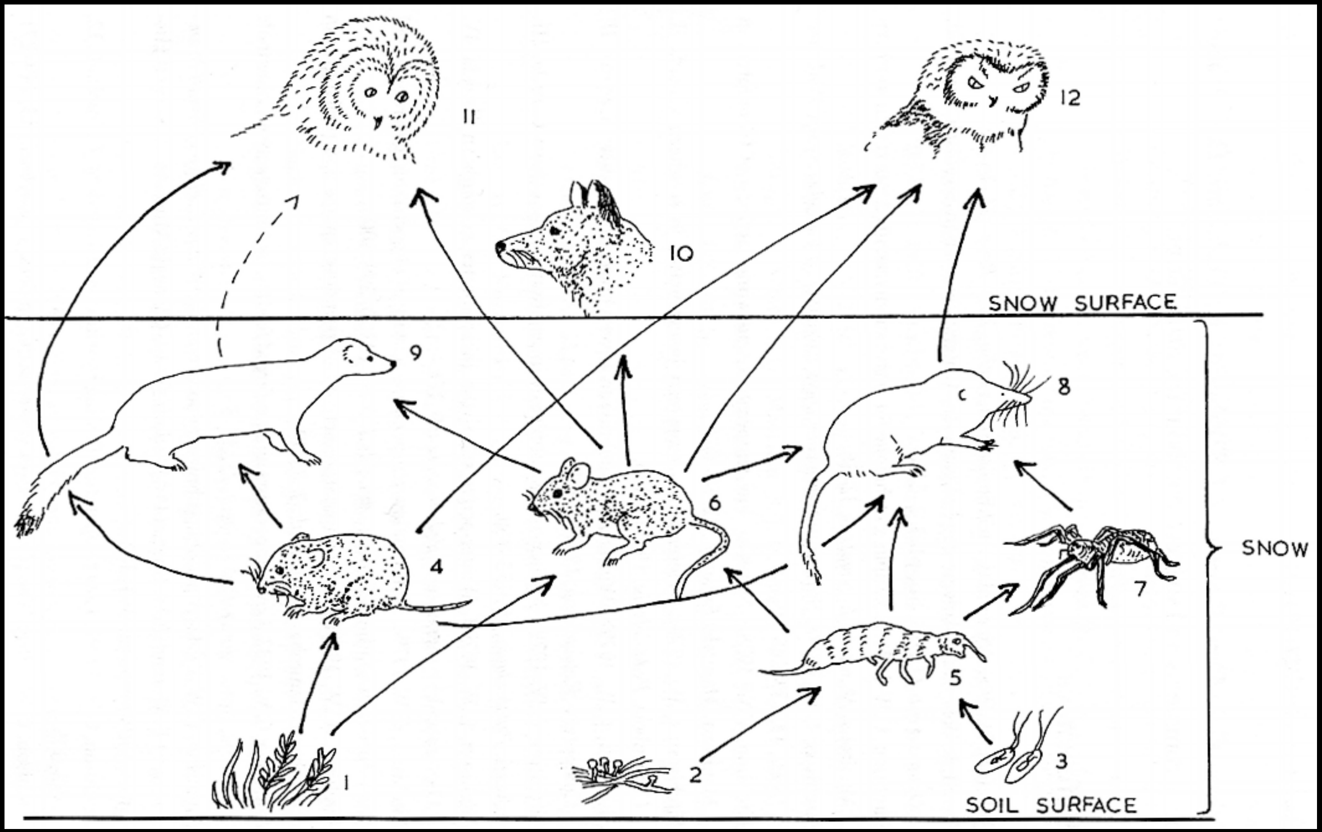


Aitchison, C. A. 2001. The effect of snow cover on small animals. Pages 229-265 in H. G. Jones, R. W. Hoham, J. W. Pomeroy, and D. A. Walker, editors. Snow Ecology. Cambridge University Press, Cambridge.

Table 5.5. *Percentage frequency of occurrence of winter food items in the guts of S. minutus (after Grainger and Fairley, 1978; Yudin, 1962).*

Food item	Ireland ($n = 87$)	Siberia ($n = 35$)
Lumbricids	0	5.6
Molluscs	0	19.6
Isopods	69	0
Araneae	21	47.6
Acari	42	5.6
Opilionids	30	0
Collembola	0	11.2
Hemiptera	37	17.0
Carabidae	0	42.0
Staphylinidae	0	19.6
Chrysomelidae	0	14.0
Coleopteran adults	90	58.8
Coleopteran larvae	37	0
Hymenoptera	0	16.8
Diptera	49	16.8
Vegetation	53	0

Snow as a habitat: Snow ecosystems



1. **Subnivian plants.**
2. **Fungi**
3. **Snow algae**
4. **Red backed vole (*Clethrionomys gapperi*)**
5. **Collembola (*Isotoma* sp.)**
6. **Deer mouse ()**
7. **Wolf spider (*Pardosa* sp.)**
8. **Masked shrew (*Sorex cinereus*)**
9. **Shorttail weasel (*Mustela erminea*)**
10. **Red fox (*Vulpes fulva*)**
11. **Great gray owl (*Strix nebulosa*)**
12. **Boreal owl (*Aegolium funereus*)**

Aitchison, C. A. 2001. The effect of snow cover on small animals. Pages 229-265 in H. G. Jones, R. W. Hoham, J. W. Pomeroy, and D. A. Walker, editors. Snow Ecology. Cambridge University Press, Cambridge.

Take home points

1. Go over methods of describing snow pits in the UNESCO manual (slides 8-32). We will describe three snow pits during the field trip.

2. Understand the processes of low-temperature-gradient (equilibrium) and high-temperature-gradient (kenetic) snow metamorphosis (slides 33-39).

3. Be able to recognize the physical properties of tundra, tiaga, prairie, alpine, and maritime snow (slides 40-43).

4. Be able to describe the major processes contributing to changes in snow chemistry in the atmosphere, in dry snow on the ground, and during the snow melt period (slides 44-48).

5. Highly recommend reading Hoham & Duval's and Aitchison's chapters (p.168-265) in *Snow Ecology* book (briefly discussed in slides 49-57).

Next papers: Week after spring break

Discussion Group 1,

1. Walker, D. A., J. C. Halfpenny, M. D. Walker, and C. Wessman. 1993. Long-term studies of snow-vegetation interactions. Bioscience 43:287–301.

2. Aitchison, C. W. 2001. The effect of snow cover on small mammals. P. 229-265 in Jones H.G. et al. Snow Ecology. Cambridge: Cambridge University Press.

Discussion Group 2,

1. Ehrich, D., J.-A. Henden, R. A. Ims, L. O. Doronina, S. T. Killengren, N. Lecomte, I. G. Pokrovsky, G. Skogstad, A. A. Sokolov, V. A. Sokolov, and N. G. Yoccoz. 2011. The importance of willow thickets for ptarmigan and hares in shrub tundra: the more the better? Oecologia 168:141–151.

2. Tape, K. D., R. Lord, H.-P. Marshall, and R. W. Ruess. 2010. Snow-Mediated Ptarmigan Browsing and Shrub Expansion in Arctic Alaska. dx.doi.org 17:186–193.