Snow Surface

- Sensitive register of the forces that mold it:
  - Thermal and mechanical energy
  - Gravity
- Visual, feel, and auditory clues help to assess:
  - Snow behavior
  - Stability

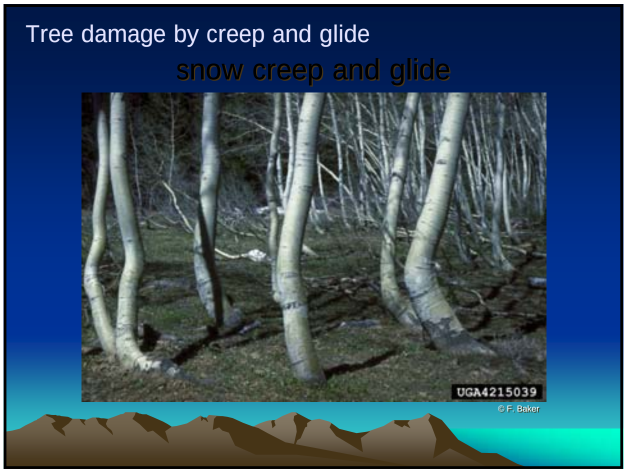
Snow slumps

Salt Lake City, Utah, 17 Mar 2002

Whiteman photo

Plastic nature of snow

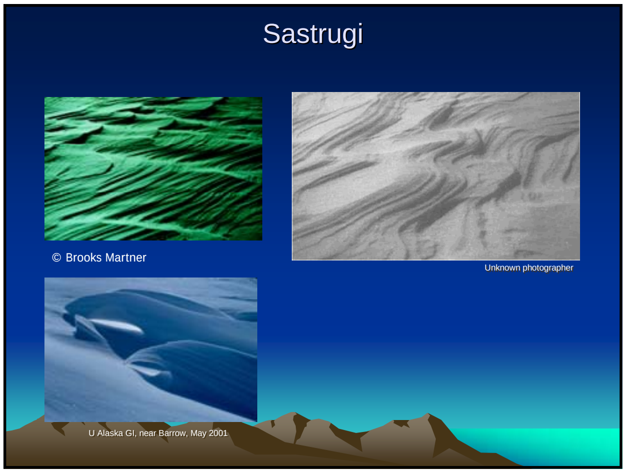
© Ladona and Barry Haslam



Tree damage by creep and glide

snow creep and glide

© F. Baker

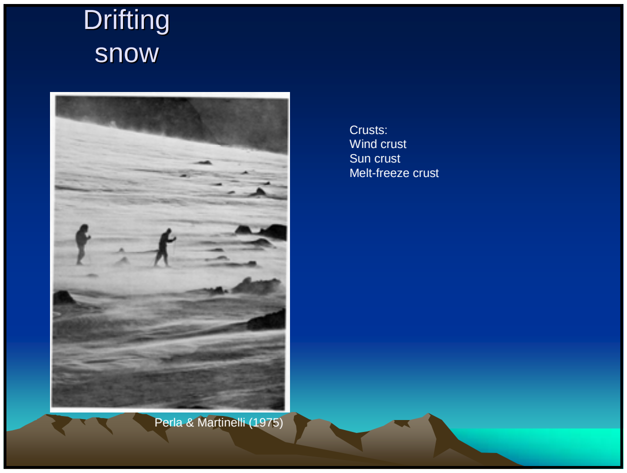


Sastrugi

© Brooks Martner

Unknown photographer

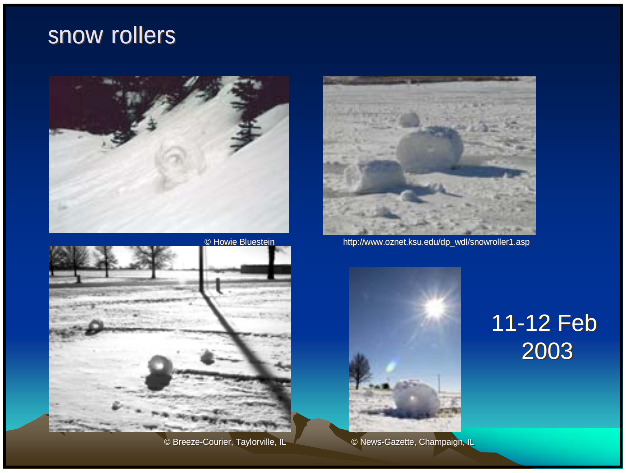
U Alaska GI, near Barrow, May 2001



Drifting snow

Crusts:
Wind crust
Sun crust
Melt-freeze crust

Perla & Martinelli (1975)



snow rollers

© Howie Bluestein

http://www.oznet.ksu.edu/dp_wdl/snowroller1.asp

11-12 Feb 2003

© Breeze-Courier, Taylorville, IL

© News-Gazette, Champaign, IL

Snow cornice

Perla & Martinelli (1975)

Riming on snowpack

Mt. Washington

© Adam R. Jones

Dachstein

© B. Pospichal

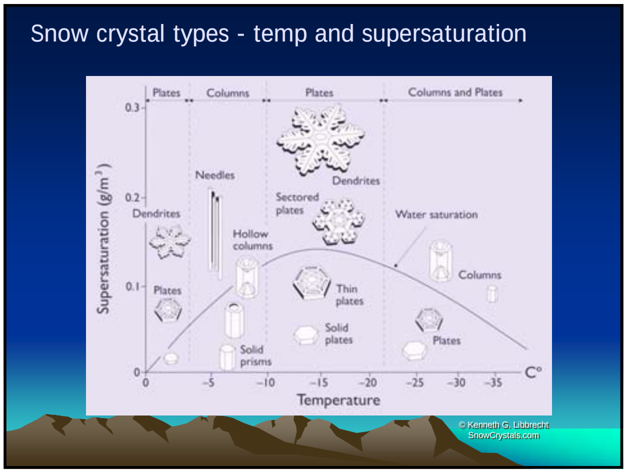
Nieve Penitente

A spike or pillar of compacted snow or glacier ice, caused by differential melting and evaporation. The pillars form most frequently on low-latitude mountains where air temperatures are near freezing, dew points are much below freezing and insolation is strong.

© Graeme Major

New snow

- Characteristics of snow that are most important:
  - Crystal form
  - Amount of riming
  - Breakage of crystal branches
- Changes of crystal types and riming during storms can create conditions where one layer does not bond well to the next; affecting snow stability. Ex: layers of graupel do not bond well to neighbors.
- Breaking of crystal branches during transport at surface is generally considered even more important than riming



Snow crystal types - temp and supersaturation

© Kenneth G. Libbrecht
SnowCrystals.com

Ice crystal forms

stellar dendrites
plates
sectored plates
needles
spatial dendrites
rimed crystals
hollow columns
capped columns
oddballs

© Kenneth G. Libbrecht

Classification of newly fallen snow

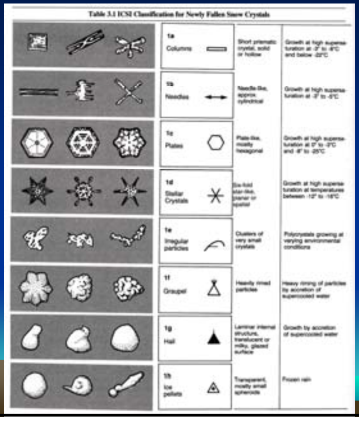


Table 3.1 ICSI Classification for Newly Fallen Snow Crystals

Snowpack physical characteristics

- Snowpack density:
  - The mass of snow per unit volume which is equal to the water content of the snow divided by its depth
  - pure ice 0.917, water 1.0
  - Normal snow 0.06 - 0.11, very dense snow 0.40
  - Rule of thumb: 10 cm snow gives 1 cm water equivalent
- Snow-to-liquid equivalent ratio (SLR)
  - 10 implies 10 cm snow melted down yields 1 cm water
- Albedo
  - Fresh snow >0.9, wet snow 0.6
- Snowpack temperature:
  - In temperate zones, ground surface is maintained throughout the winter very close to the melting point of 0°C.
  - The snow temperature *gradient* is determined by the thickness of the snowpack and snow surface temperature

SLR

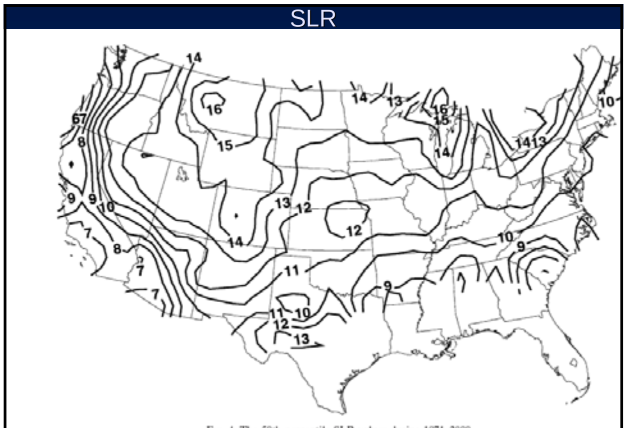
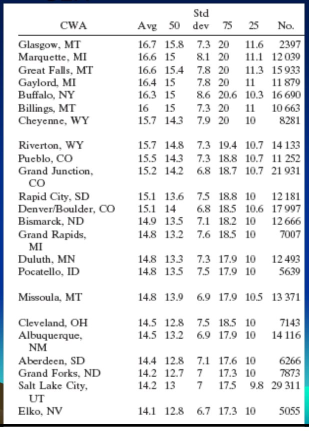


Fig. 4. The 50th percentile SLR values during 1971–2000.

Baxter et al. 2005

SLR



CWA	Avg	50	Std dev	75	25	No.
Glasgow, MT	16.7	15.8	7.3	20	11.6	2397
Marquette, MI	16.6	15	8.1	20	11.1	12 039
Great Falls, MT	16.6	15.4	7.8	20	11.3	15 933
Gaylord, MI	16.4	15	7.8	20	11	11 879
Buffalo, NY	16.3	15	8.6	20.6	10.3	16 690
Billings, MT	16	15	7.3	20	11	10 663
Cheyenne, WY	15.7	14.3	7.9	20	10	8281
Riverton, WY	15.7	14.8	7.3	19.4	10.7	14 133
Pueblo, CO	15.5	14.3	7.3	18.8	10.7	11 252
Grand Junction, CO	15.2	14.2	6.8	18.7	10.7	21 931
Rapid City, SD	15.1	13.6	7.5	18.8	10	12 181
Denver/Boulder, CO	15.1	14	6.8	18.5	10.6	17 997
Bismarck, ND	14.9	13.5	7.1	18.2	10	12 666
Grand Rapids, MI	14.8	13.2	7.6	18.5	10	7007
Duluth, MN	14.8	13.3	7.3	17.9	10	12 493
Pocatello, ID	14.8	13.5	7.5	17.9	10	5639
Missoula, MT	14.8	13.9	6.9	17.9	10.5	13 371
Cleveland, OH	14.5	12.8	7.5	18.5	10	7143
Albuquerque, NM	14.5	13.2	6.9	17.9	10	14 116
Aberdeen, SD	14.4	12.8	7.1	17.6	10	6266
Grand Forks, ND	14.2	12.7	7	17.3	10	7873
Salt Lake City, UT	14.2	13	7	17.5	9.8	29 311
Elko, NV	14.1	12.8	6.7	17.3	10	5055

Baxter et al. 2005

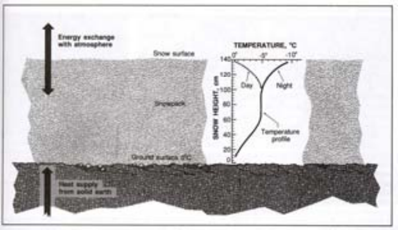
Consolidation of snow crystals in the snowpack

- Character of snow initially defines character of snowpack
- The snowpack can be transformed by wind action even after snowfall has stopped
- Location of wind deposited snow depends on terrain
- Transformation or *metamorphism* of snowpack begins as the snow crystals are consolidated into the snowpack
- Stratigraphy is a record of meteorology/climate
- Sequence of soft/hard layers and binding between layers - wind strength and direction, number and intensity of storms, rain, solar and longwave radiation, temperature, melting, humidity, pressure, snow crystal types, free water in snowpack

Temperature gradients

- The ground surface, when buried under a snowpack in temperate climate zones, usually maintains a temperature of 0°C because of the release of the heat stored in the ground earlier in the year.
- Vertical temperature gradients in the snowpack thus depend on the depth of snow and the air temperature above the snow.
- Maritime climate: usually, temperatures are mild and snowpacks are deep so that there are weak temperature gradients and warm temperatures in the snowpack.
- Continental climate: thinner snowpacks and colder air temperatures produce large temperature gradients. This leads, more often, to faceted snow crystals in the snowpack and buried layers of instability.

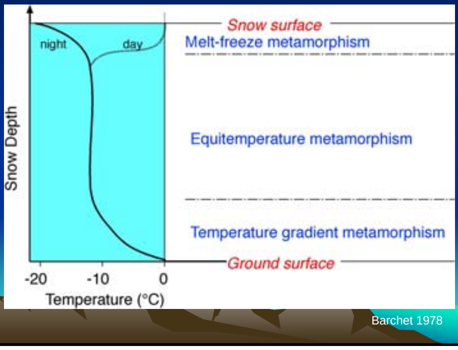
Snowpack temperature profile



Types of metamorphism

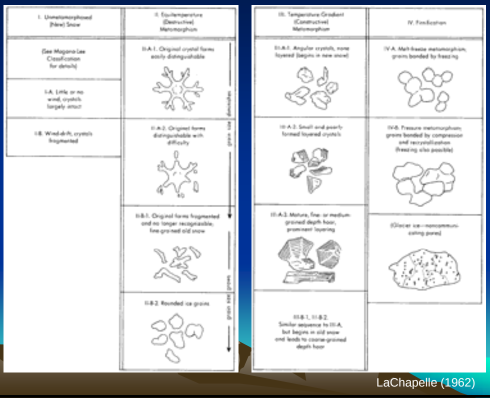
- Metamorphism: snow texture changes due to T and P
  - Equitemperature – rounded grains, formation of necks between grains
  - Temperature-gradient – grains enlarge while necks remain constant
  - Melt-freeze – rain water or melt water, percolation, ice lenses. Pack is weak in melt cycle and strong in freeze cycle. Melt can lubricate sliding surface in Spring.

Snow temperature profile and snow metamorphism



Barchet 1978

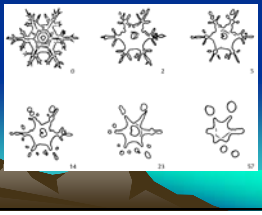
Metamorphic forms



LaChapelle (1962)

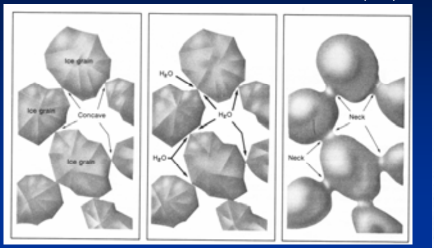
Settling and equitemperature metamorphism

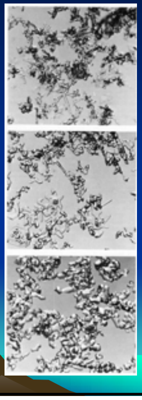
Crystal metamorphism (at constant temperature) by curvature effects.
The time in days in given in the lower right.



Equitemperature Metamorphism - Sintering

Perla & Martinelli (1975)



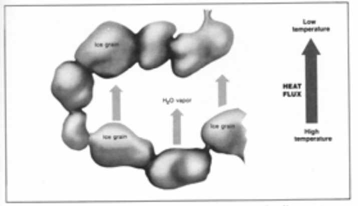


Sintering - formation of bonds between snow crystals

There is a tendency for water vapor to evaporate from convex surfaces and condense at concave surfaces where grains touch to form necks.

Rounded forms that grow at small rates are small and tend to pack closer together. This produces more bonds per unit volume and greater strength.

Snowpack vapor diffusion



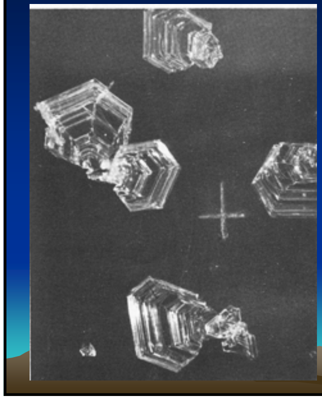
Perla & Martinelli (1975)

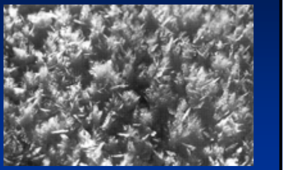
Vapor moves up through the pore space by leaving the top of one crystal and condensing on a crystal somewhere above.

Surface hoar

- Faceted crystals that form by deposition onto the snowpack surface when water vapor pressure in the air exceeds the equilibrium vapor pressure over ice at the surface.
- The crystals usually form when 1) a sufficient supply of water vapor is present in the air, and 2) a high temperature gradient (inversion) is present above the snow surface. Thus surface hoar usually forms on cold, clear nights with calm or nearly calm conditions (continental climate conditions).
- Surface hoar may be inhibited in concave areas of the snow surface
- Surface hoar is extremely fragile and easily destroyed by sublimation, wind, melt-freeze cycles, and freezing rain.
- When buried in the snowpack, a surface hoar layer is extremely efficient in propagating shear instabilities (fractures).
- Surface hoar may gain strength by bond formation with adjacent layers, but thick layers may persist for months within the snowpack.

Surface hoar - sublimation/deposition





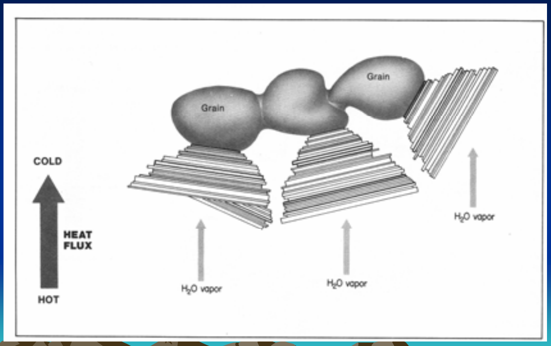
LaChapelle (2001)

USFS (1968)

Growth of crystals within the snowpack

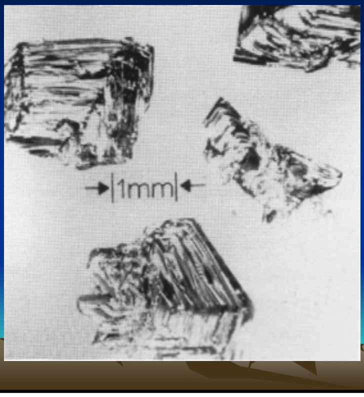
- Close correlation between overall growth rate and crystal forms.
- Growth rate and crystal forms depend on 1) temperature gradient, 2) temperature, and 3) pore space size. TG is most important in determining crystal form. The highest crystal growth rates occur for the largest TG, highest temperatures and largest pore spaces. Angular or faceted grains with steps or striations on their surfaces are produced under these conditions; cup crystals; depth hoar; sugar snow
- Low crystal growth rates (low TG, tightly packed crystals, and low temperatures) tend to produce crystals with rounded forms
- The critical TG to produce faceted forms in alpine snowpacks is 10°C/m. Rounded forms occur with lower TGs
- Crystals produced under high growth rates (surface hoar, depth hoar, faceted snow, radiation recrystallization) form weak, unstable snow that is often responsible for serious avalanche conditions.

Temperature gradient metamorphism



Perla & Martinelli (1975)

Depth hoar

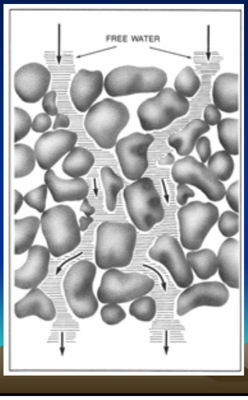


Doesken & Judson, 1996
Richard L. Armstrong photo

Melt-freeze metamorphism

- Warm snowpacks have variable amounts of liquid water
  - Water-saturated snow (slush; water content exceeds 15% by bulk volume)
  - very wet snow (8-15% by volume)
  - wet snow (3-8%, water cannot be pressed out by gentle hand squeezing, but a meniscus of water occurs between grains)
  - moist (<3%; snow sticks together to make a snowball)
- Strength of wet snow decreases with increasing water content
- Small particles have a lower melting temperature than larger ones, so they melt first. The heat of melting comes from larger particles, which undergo surface re-freezing (release of heat) and an increase in size; corn snow

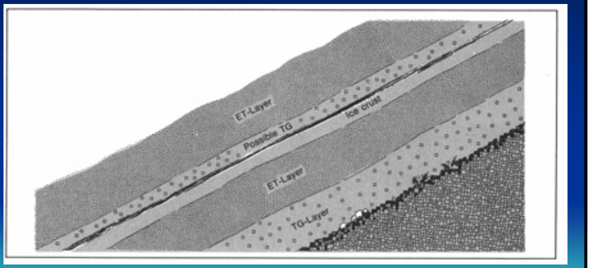
Melt-freeze metamorphism



At low water contents, clusters of grains form near the snowpack surface where melting and freezing cycles can occur, particularly in late winter and spring. After night cooling this combination produces very strong crusts composed of frozen grain clusters that lose almost all their strength after midday heating. During melt, the average grain size increases and the small grains and bonds disappear. After several day-night cycles, clusters of large grains are produced. This process is called melt-freeze metamorphism.

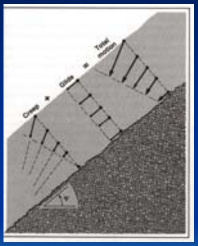
Perla &Martinelli (1975)

Snowpack layering



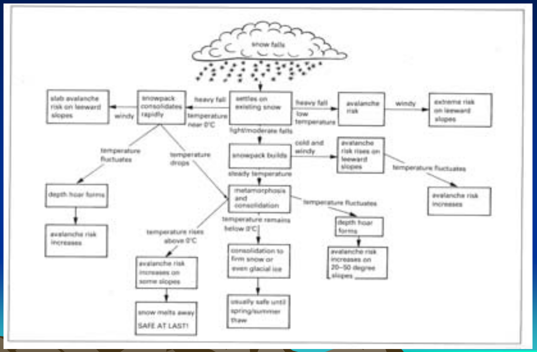
Perla &Martinelli (1975)

Creep and glide

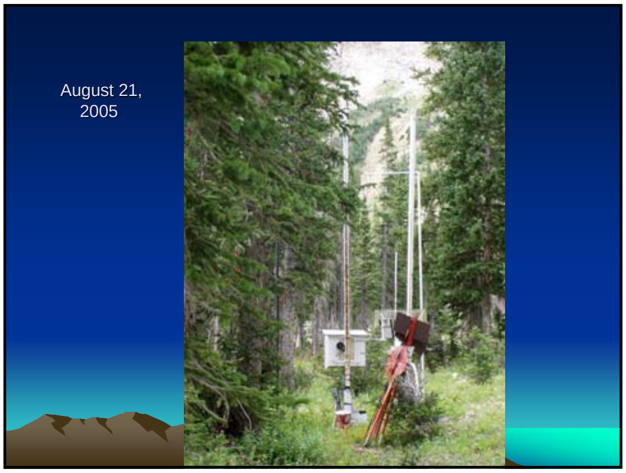


McClung and Schaerer (1993)

What happens in the snowpack?



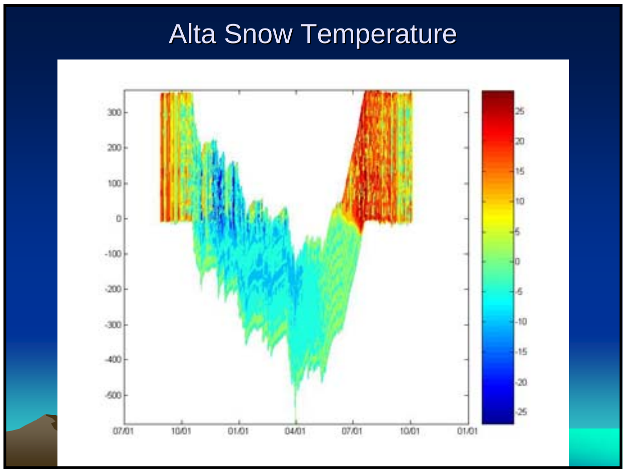
Perla & Martinelli (1975)



August 21,
2005

April 12
(173 inches)

Alta Snow Temperature



Alta Snow Temperature