TEMPERATURE GRADIENT WEAKENING OF SNOWPACKS NEAR RAIN CRUSTS OR MELT-FREEZE LAYERS[1]

M.B. Moore[2]

Abstract

Given certain meteorological conditions, temperature gradient weakening of upper layers in the snowpack may be an important, although infrequent contributing factor to slab avalanche releases in maritime mountains, and to a lesser degree, in continental mountains experiencing relatively deep consolidated snowpacks. Observations indicate that such temperature gradient weakening, when it occurs, is concentrated around or within rain crusts or melt-freeze regions in the upper layers of these snowpacks. Although well developed temperature gradient crystals (i.e., hollow cups, large, loose stepped crystals) are rarely found within maritime snowpacks, observations indicate that they are not required for significant mechanical weakening of the snowpack in the vicinity of crusts, and large climax slides have been observed to release on these weakened layers.

INTRODUCTION

Temperature gradient (TG)—or kinetic (Colbeck, 1984)—weakening of snow layers has long been a nemesis to avalanche forecasters, researchers, and recreationalists alike. Even though definitive conclusions regarding specific formation mechanisms remain elusive, combining data from weather and snowpit observations with known thermal properties of ice and snow can provide some insight into probable snowpack locations for such TG weakening.

FIELD SNOW AND WEATHER DATA

Recent weather and snowpit analyses in the Cascade Mountains of Washington State (Moore, 1975, 1981; Ferguson, 1983) have documented gradual mechanical weakening of crust regions by a strong temperature gradient. These crust regions-- refrozen rain or melt-water soaked layers of snow within the upper portion of the snowpack--had typical densities ranging from 0.20- 0.40 gm/cm3 (200-400 kg/m3), were most probably formed as a result of variable liquid water retention within surface layers of snow, and observations indicated that densities generally decreased toward the snow surface. Additional field snowpack observations from the British Columbia Coast Range (C. Stethem, K. Fenwick, personal communication) and the Chugach Range of Alaska (D. Hamre, personal communication) have also exhibited cases of TG weakening within upper layers of primarily maritime snowpacks. To a somewhat lesser degree, similar snow structure weakening has been observed in the upper levels of continental snowpacks (B. Armstrong, personal communication), given an appropriately deep snowdepth and the correct sequence of antecedent weather conditions. In many instances, subsequent slab slides were observed to involve the TG weakened snow layers.

[1]Presented at the International Snow Science Workshop, Montana State University, Bozeman, Montana, October, 1982.

[2]Meteorologist—Northwest Avalanche Center, C-15700, 7600 Sandpoint Way NE, Seattle, Washington, 98115.

From all data examined in which a relatively dense, deep snowpack minimized the occurrence of the more common well developed TG crystals near the ground-snow interface, the general meteorological trends and associated snowpack changes producing the observed upper level TG weakening consisted of: (1) a period of relatively warm, wet weather--the "warming" phase--which warmed (snowpack temperatures approached isothermal in the layers in question), saturated and densified (densities increased from ~.05-.15 gm/cm3 (50-150 kg/m3) to ~.20-.40 gm/cm3 (200-400 kg/m3)) the upper snowpack, followed by (2) a period of cold, relatively dry weather--the "cooling" phase--which refroze, cooled and gradually weakened the upper crust region thru resultant strong temperature gradients in the upper layers of the snowpack.

A case example which profiles snow structure changes thru time and illustrates observed TG weakening and resultant slab slide releases for a maritime site (Stevens Pass, Washington) is presented in Figures 1-8. A summary of snow profile symbols used is given in Figure 9, while related weather trends and avalanche occurrences recorded in the ski area during the period of interest are shown in Figure 10. During the cold, dry weather regime (Figures 3-6) the observed temperature gradient is shown across various snow layers as well as the average temperature gradient both within and above the indicated crust region. The snowpit data shows several unifying physical characteristics: (a) significantly warmer temperatures in the crusts (~-1 to -5 deg C) than above the crusts (~-5 to -12 deg C); (b) significantly greater temperature gradients above crusts than within crusts (especially average gradients); (c) the upper layers of the crust region had lower densities than lower layers of the crust region; and (d) local temperature gradient maximums commonly occurred just above crusts or in relatively lower density layers near the top of the crust. These conditions produced general mechanical weakening in the upper layers of the crust region with time (from the indicated rramsonde measurements and related hand strength tests).

In all of the Washington Cascade cases studied, the observed temperature gradients appeared to produce snowpack weakening thru the gradual separation of previously bonded snow grains into loose snow grains, with texture changes from coarse-grained multi-granular clusters to relatively loose coarse-grained angular grains (see Figure 11). When the above snowpack evolution was followed by cool, wet weather producing progressive snow loading (increasing overburden) of the weakened snow structure, direct action and climax snow slab failure was observed to involve the TG weakened snow within or near the upper crust region.

THEORY AND APPLICATION

To determine if this data can aid in defining optimal location(s) of probable TG weakening at other than the snow-ground interface, some primary physical factors affecting local temperature gradients and their effectiveness in vapor transport in a dry snowpack (refrozen if previously wet) must be considered. In general the vertical temperature distribution in a snowpack is most strongly controlled by time and density. If approximate steady state conditions are assumed,

~~the controlling factor is snow density. Known thermal properties of~~ snow (after Mellor, 1964 and List, 1966--see Figure 12) show that conductivity increases with increasing density. The ratio of thermal conductivities of "lower" density snow (100-200 kg/m3) to that of "higher" density snow (300-400 kg/m3) ranges from about 25% to 67%. Further, the rate of change of conductivity increase versus density increase is a maximum in snow densities ranging from approximately 250 to 450 kg/m3. Due to these conductivity differences in differing density snow, local temperature gradients (and local gradients of the gradient) should be introduced into the snow and be maximum near snow layer interfaces where significant density changes occur. These gradients may also produce a net vapor convergence just above the layer interface within decreasing density snow layers due to expected local decreases in the associated vapor pressure gradient. above

Given a steady state temperature distribution in the snowpack determined by the various layer densities (and associated conductivities), the magnitude of the associated vapor transport is also strongly dependent on the absolute temperature of the involved snow layers. This vapor transport is a maximum at relatively warm temperatures (close to 0 deg C) due to several factors: (a) for a given temperature change the vapor pressure gradient versus temperature is a maximum at warm temperatures close to 0 deg C (from the triple point diagram of water/ice/vapor); and (b) the ratio of vapor flow to heat flow is a maximum close to freezing (Colbeck, 1982). These "warmer" regions of the snowpack can be maintained at levels well above the warm ground in a given snowpack by crusts and higher density snow, owing to their relatively more efficient conduction of geothermal heat.

Applying this information above to a specific snowpack, and given a critical temperature gradient (approximately 10 deg C/m, depending on temperature and density) across a given part of the snowpack, the optimal location of TG weakened layers appears to be near relatively warm snow layer interfaces having significant density differences.....specifically, at or near interfaces of lower density snow over higher density snow. Note that conductivity and heat flux considerations would not produce local temperature gradient maximums at interfaces of higher over lower density snow. Observed TG crystals under ice lenses are possibly due to locally increased supersaturation occuring under the lens due to its lack of porosity. below

SUMMARY

The obvious base application of this optimal TG weakening location is at the ground-snow interface, where indeed most significant TG crystal growth is observed in continental climates. In more maritime climates or abnormally deep continental snowpacks, the actual effect of higher density snows or crusts in relationship to TG weakening is to raise the effective 0 deg C horizons to some intermediate level in the snowpack so that any TG weakening that does occur does so at increasingly greater heights above the ground. Generally this weakening is most pronounced near rain or melt-freeze crusts where temperature gradients and changes of the temperature gradient are often a maximum.

BIBLIOGRAPHY

Colbeck, S.C. 1982. "An Overview of Seasonal Snow Metamorphism." Reviews of Geophysics and Space Physics, Vol. 20, #1, pp. 45-61.

Colbeck, S.C. 1984. "A New Classification System for the Seasonal Snow Cover." Proceedings of International Snow Science Workshop, Aspen, Colorado.

Ferguson, S.A. 1983. Field Observations in the Washington Cascades and Olympics; Chugack, Talkeetna, Kenai and Alaska Mountains in Alaska; and New Zealand's South Alps: 1979-1983." Unpublished.

List, R.J. 1966. "Smithsonian Meteorological Tables." Sixth edition, Smithsonian Institute, Washington D.C., p. 104.

Mellor, M. 1964. "Properties of Snow." Cold Regions Science and Engineering, Part III, Engineering; Section A, Snow Engineering. Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire.

Moore, M. B. 1975. "Weather and Snowpack Developments Associated with Avalanching in the Washington Cascades." Master's thesis, University of Washington, Seattle, Washington.

Moore, M. B. 1982. "Temperature Gradient Weakening near Crusts in a Maritime Snowpack." International Snow Science Workshop Abstracts, October 21-23, Montana State University, Bozeman, Montana.

Figure 1. Fracture-line profile of slab avalanche at Stevens Pass, 1/15/75. (See Figure 9 for explanation of snow profile data.) Snowpack pictured is just before major warming and rain episode.

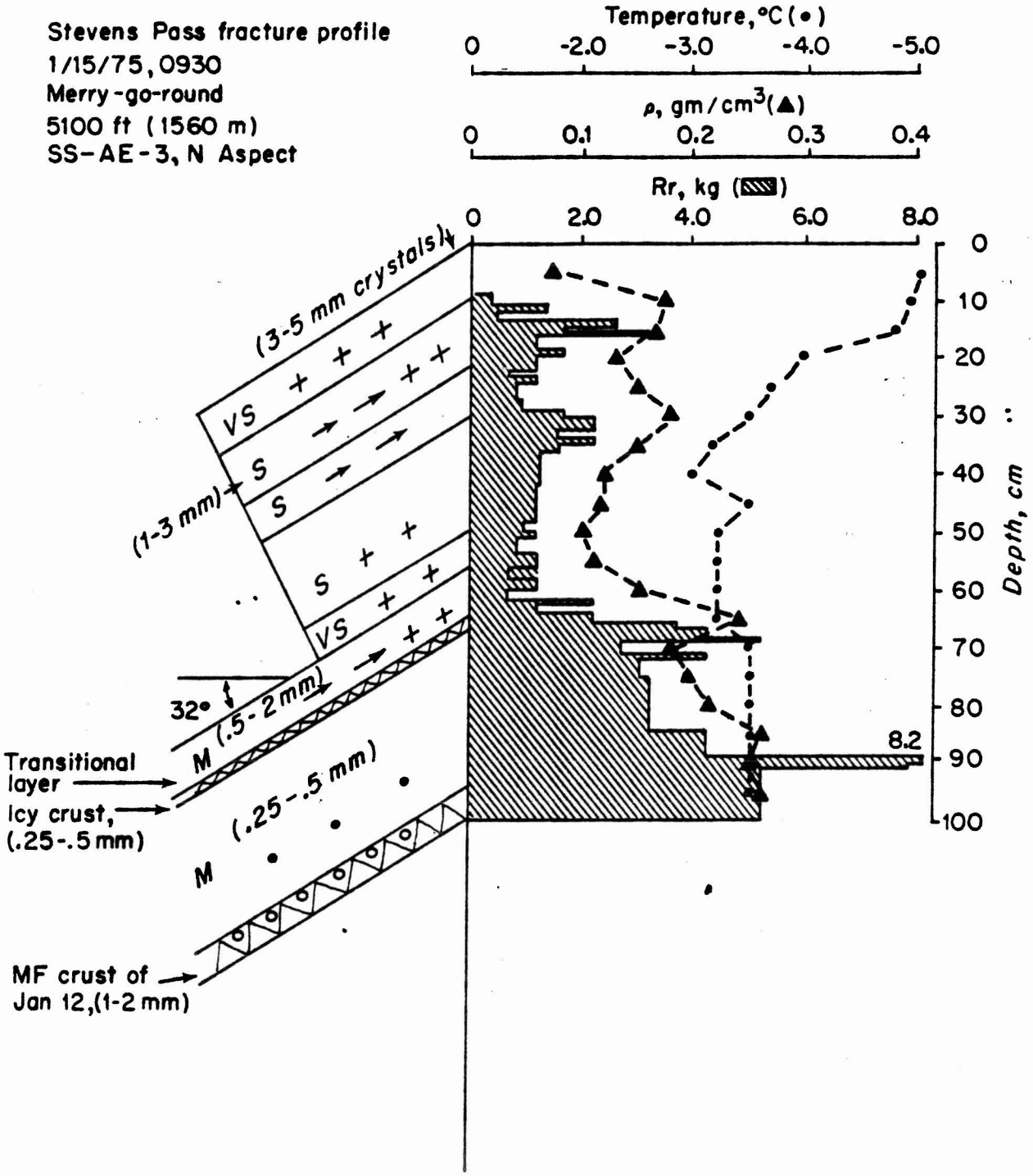


Figure 2. Snowpit study at Stevens Pass, 1/18/75. Warm weather with significant rain has arrived and is soaking upper snowpack layers.

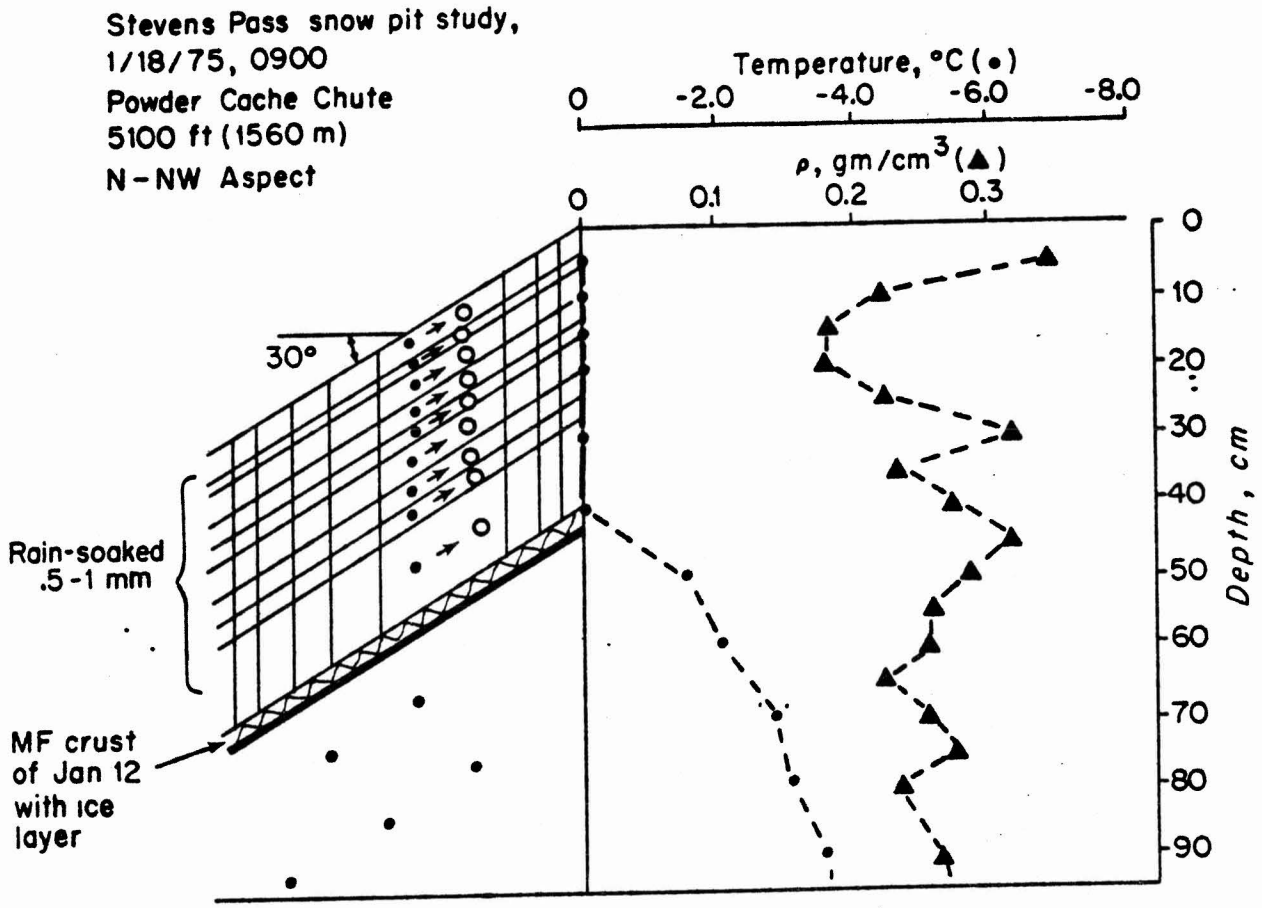
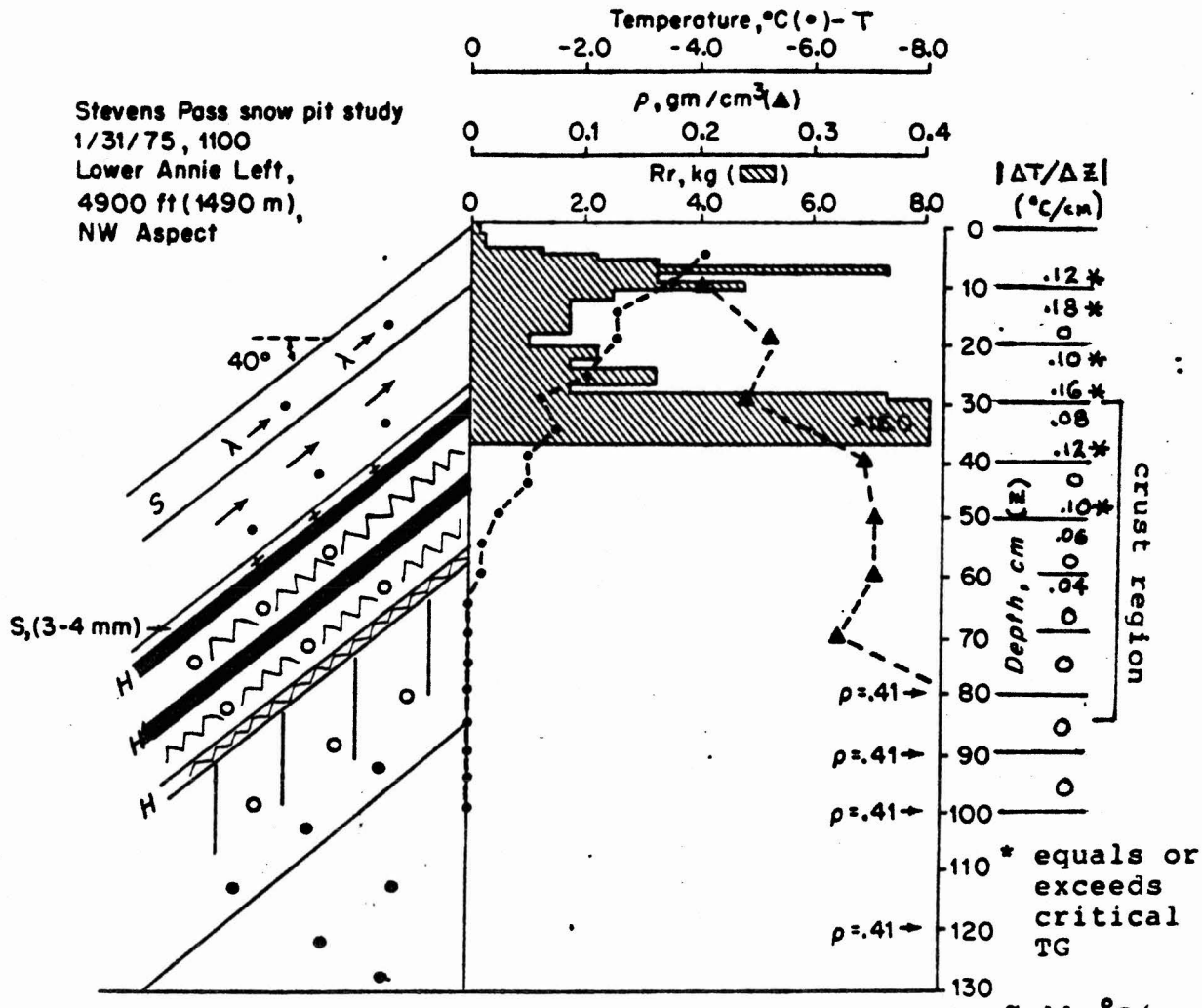
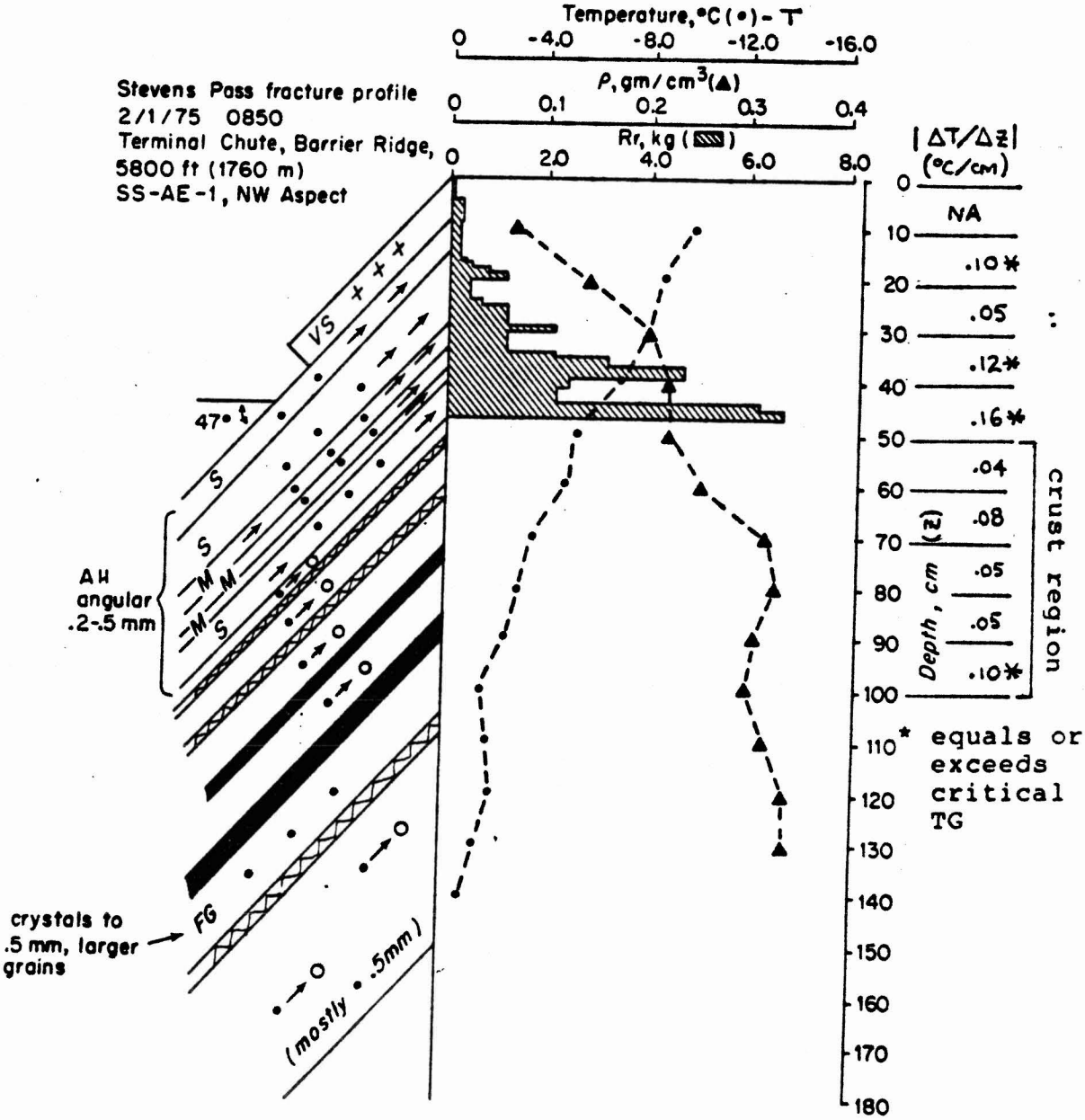


Figure 3. Snowpit study at Stevens Pass, 1/31/75. Precipitation has ended, being replaced by cold, relatively dry weather.



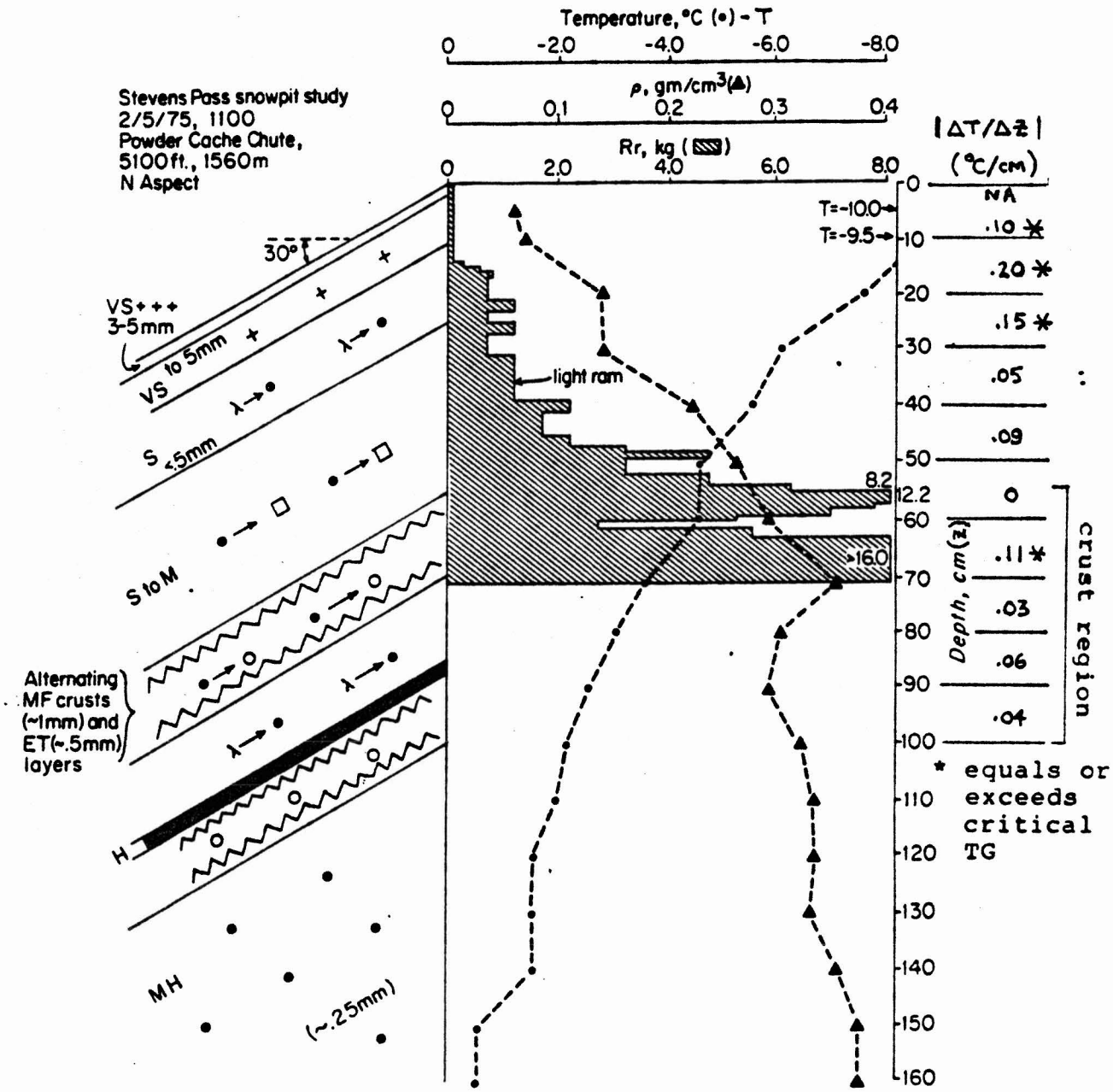
Average temperature gradients--above crust ~.11 °C/cm
--within crust ~.04 °C/cm

Figure 4. Fracture-line profile of slab avalanche at Stevens Pass, 2/1/75. Cold, relatively dry weather is continuing.



Average temperature gradients--above crust ~.11 °C/cm
--within crust ~.07 °C/cm

Figure 5. Snowpit study at Stevens Pass, 2/5/75. Cold, relatively dry weather continues; temperature gradient weakening within upper snowpack layers is becoming evident.



Average temperature gradients--above crust ~.12 °C/cm
--within crust ~.05 °C/cm

Figure 6. Fracture-line profile of slab avalanche at Stevens Pass, 2/7/75. Weather remains cold and dry; further temperature gradient weakening of upper snowpack layers is evidenced.

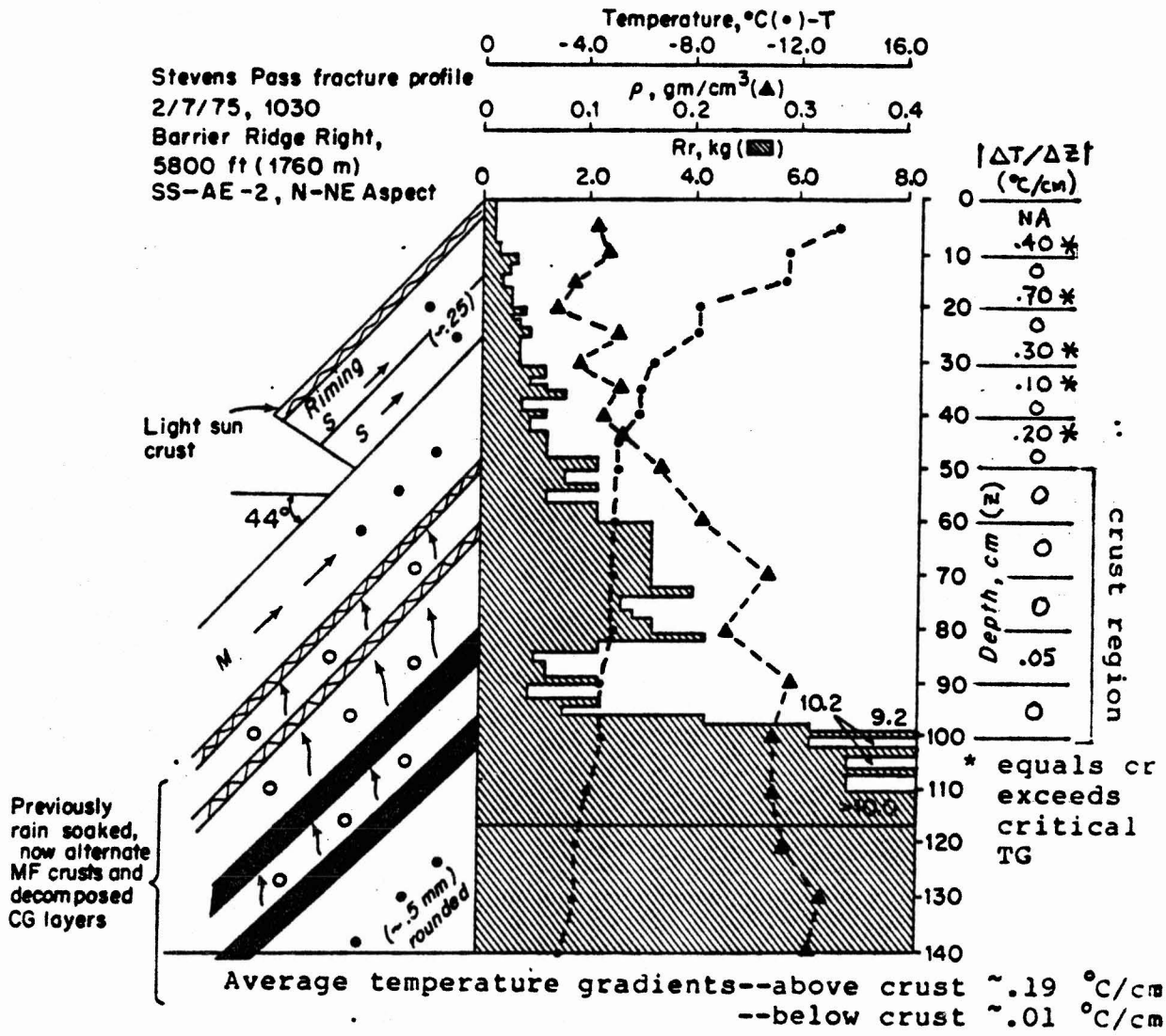


Figure 7. Fracture-line profile of slab avalanche at Stevens Pass, 2/14/75. Cool, wet weather has returned, with resultant climax slide release on temperature gradient weakened layer.

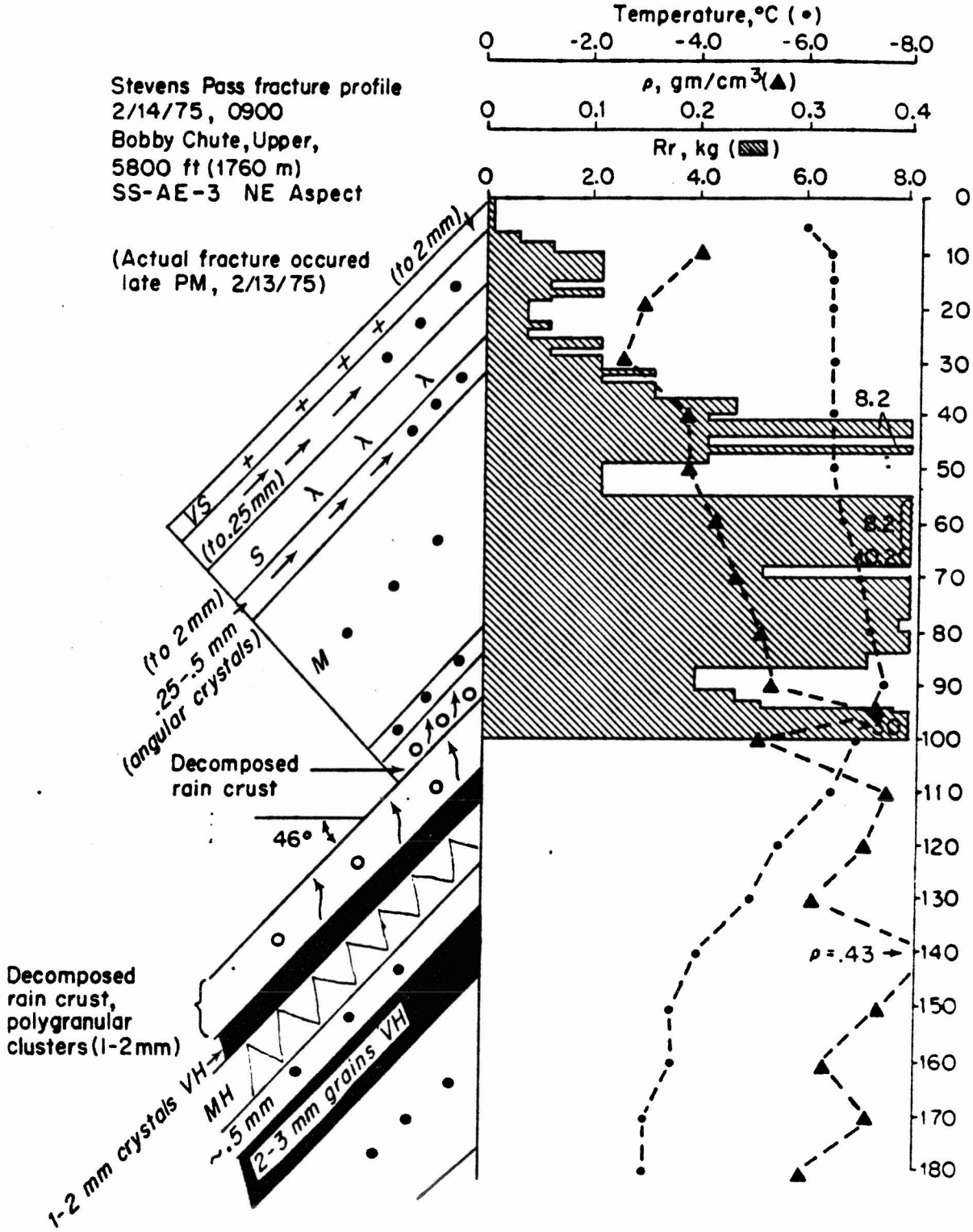


Figure 8. Fracture-line profile of slab avalanche at Stevens Pass, 2/15/75. Cool, wet weather is continuing; another climax slide has involved temperature gradient weakened layer.

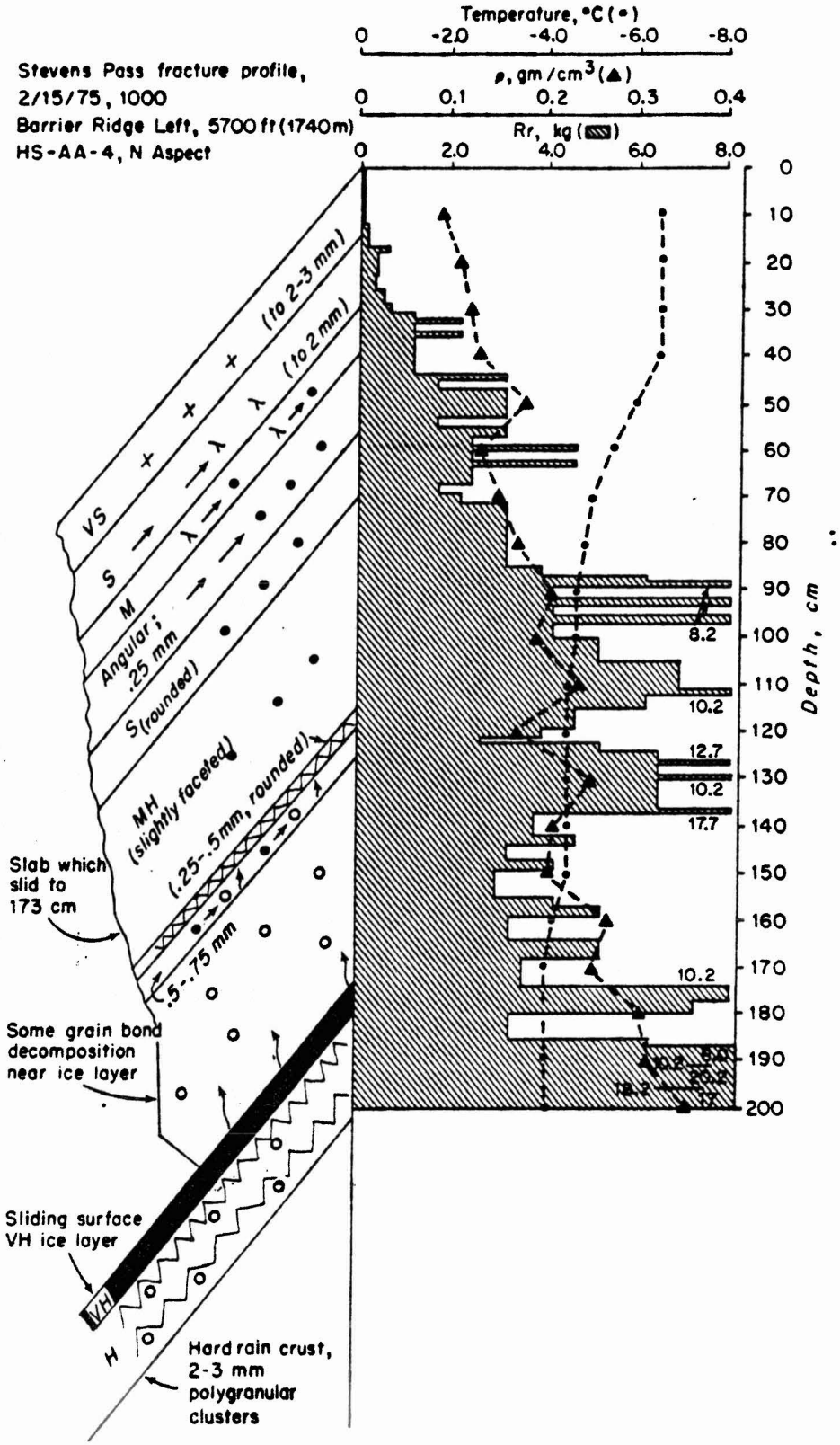


Figure 9. Summary of snow profile symbols.

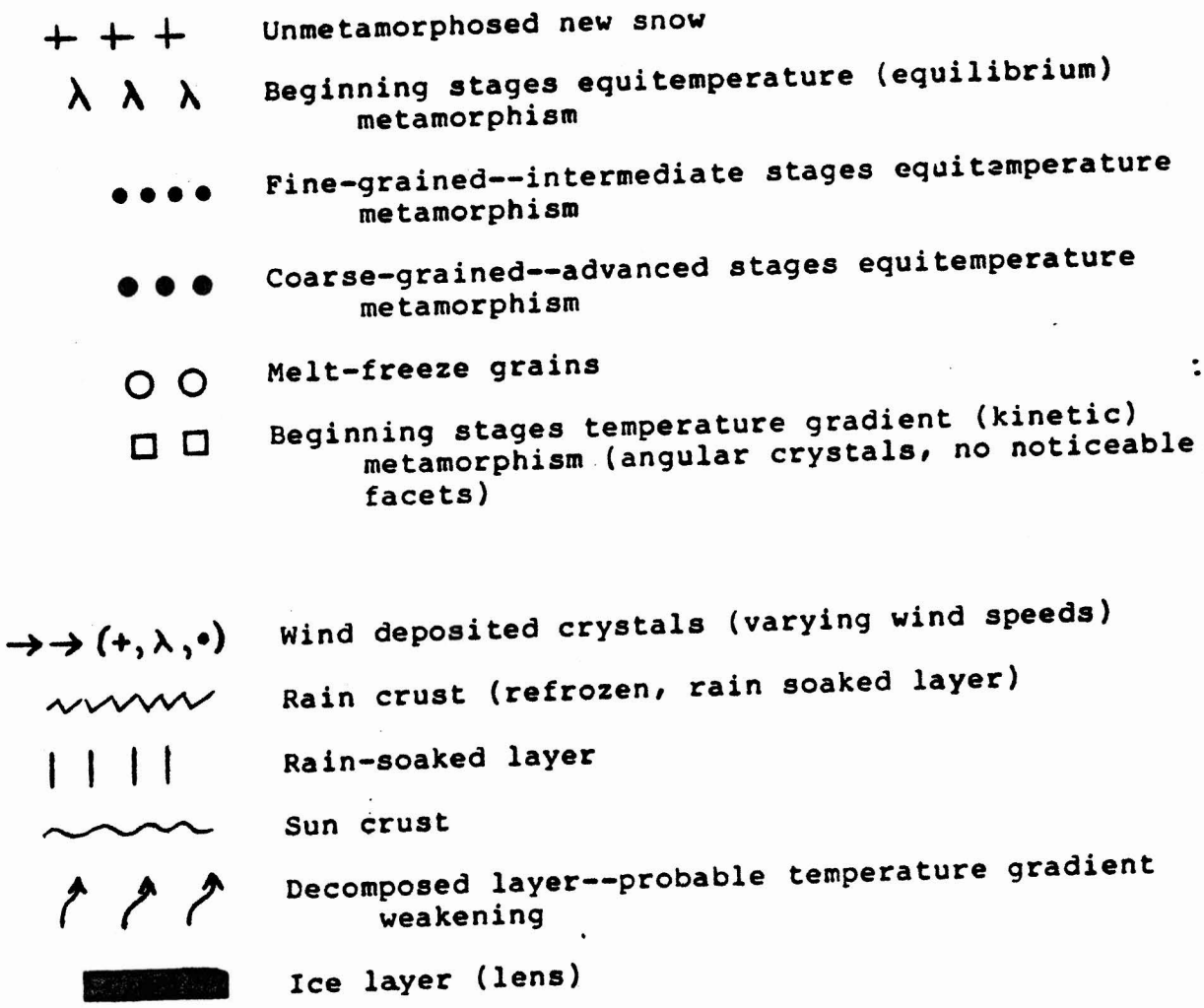


Figure 10. Twenty-four hour maximum and minimum temperatures, new snow depth, water from rain, and avalanche occurrences for Stevens Pass, Washington, January-March 1975.

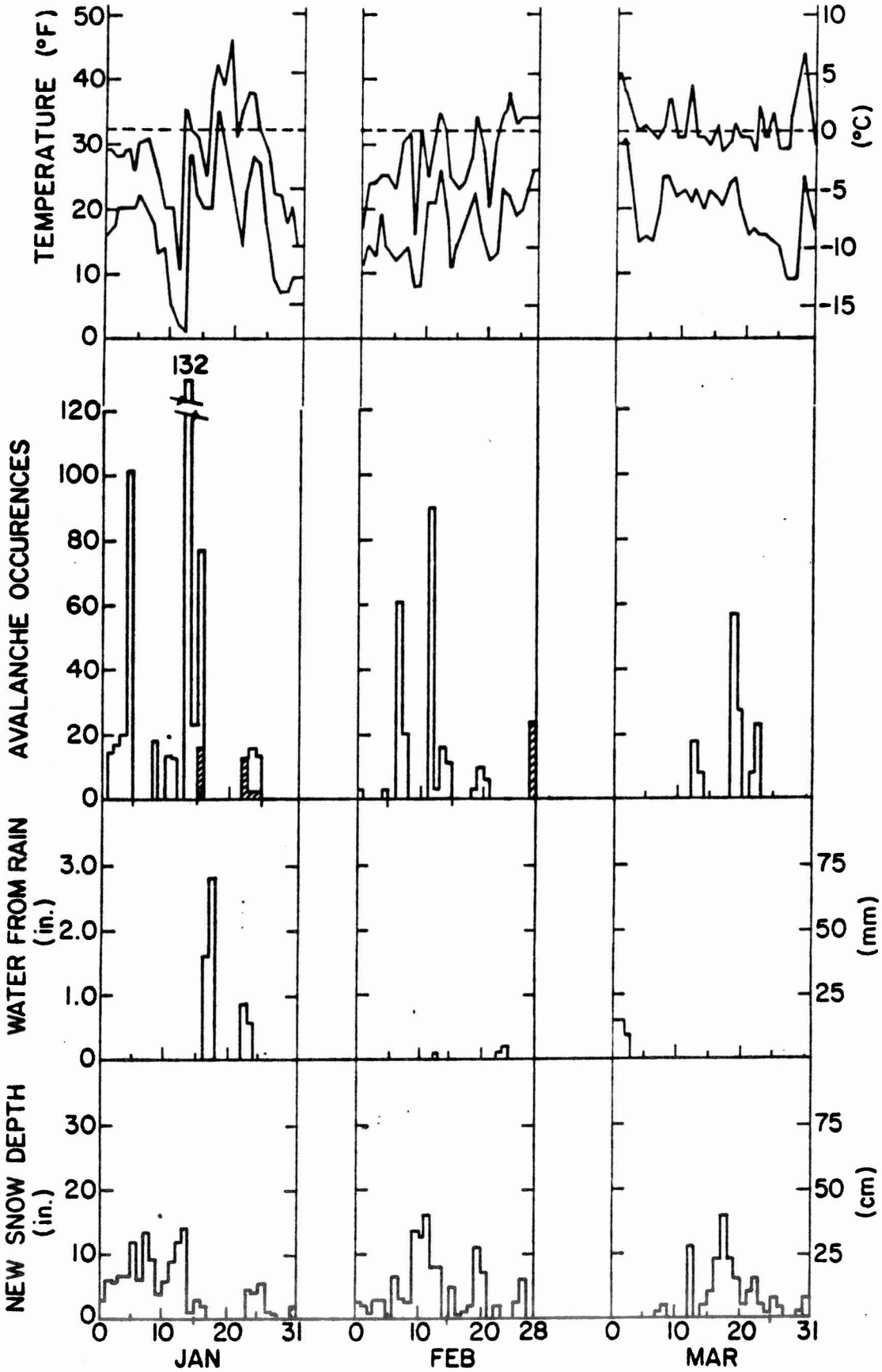
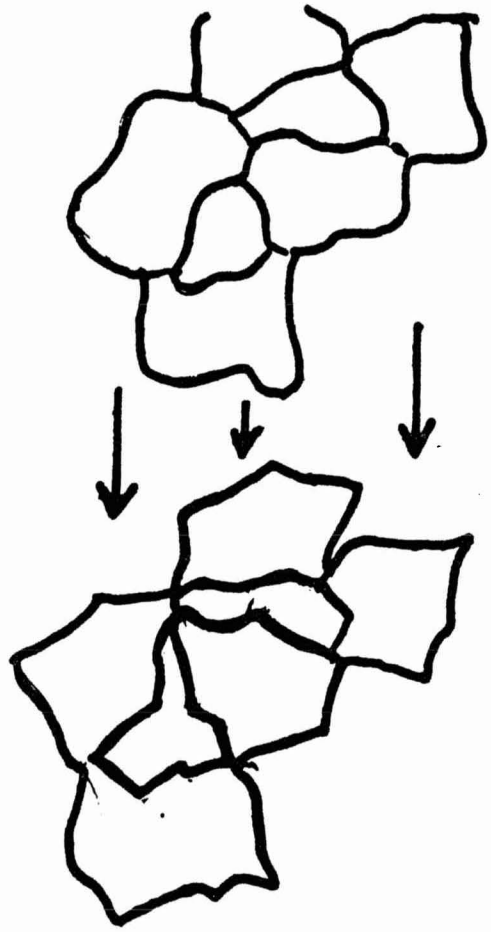


Figure 11. Pictorial representation of observed grain shape changes in Stevens Pass snowpack sequence, from approximately 1/31/75-2/15/75.

Associated texture changes--grains are metamorphosing from coarse-grained multi-granular clusters

TO

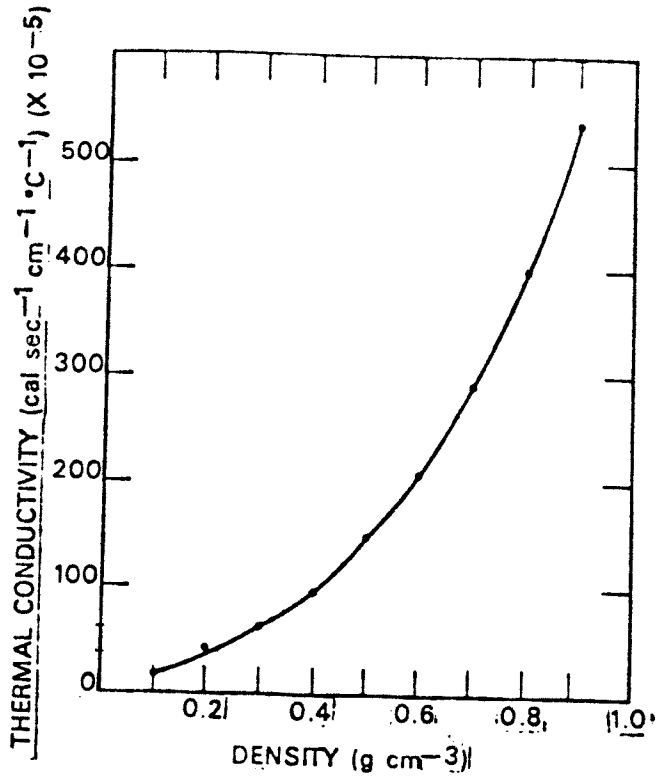
relatively loose coarse-grained angular grains.



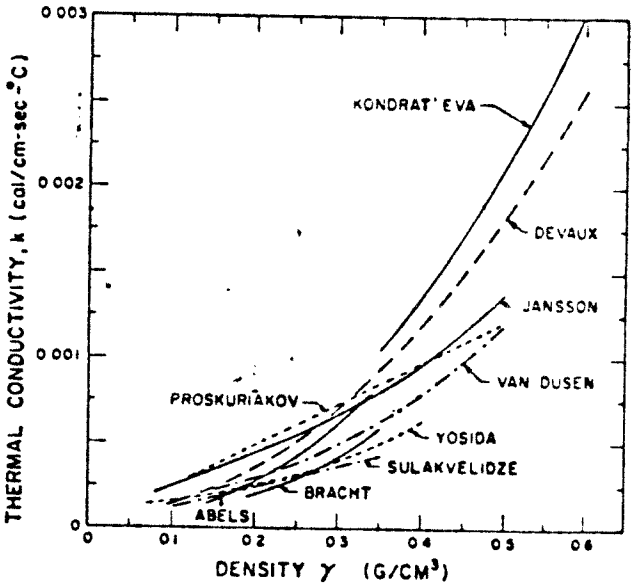
Apparent texture changes most probably due to temperature gradient related loss of mass from both melt-freeze grains and necks, with subsequent deposition producing observed angularities (no faceted faces obvious). Although preferential mass transfer occurs from convex grain surface, temperature gradients also result in mass transfer from neck area, which weakens the snow structure significantly.

Figure 12. Relationship between snow density and thermal conductivity. Data from List, 1966 (a) and from Mellor, 1964 (b).

(a)



(b)



Mark Moore 1982?

****

TEMPERATURE GRADIENT WEAKENING OF SNOW AROUND OR WITHIN CRUST REGIONS IN A MARITIME SNOWPACK

****

DEFINITIONS.....

CRUST REGIONS.....REFROZEN RAIN-SOAKED (OR MELT-WATER SOAKED) LAYERS OF SNOW WITH AVERAGE DENSITIES RANGING FROM ABOUT 0.20-0.40 GM/CM3. MAY CONTAIN SEVERAL INTERSPERSED ICE LENSES AND MELT FREEZE CRUSTS AND ARE USUALLY QUITE HARD. THESE CRUST REGIONS ARE FORMED AS A RESULT OF VARIABLE LIQUID (E.G., RAIN) WATER RETENTION WITHIN SUB-LAYERS OF THE SNOW....AND OBSERVATIONS INDICATE THAT THE LOWEST DENSITIES ARE USUALLY FOUND IN THE UPPER PARTS OF SUCH REGIONS.

MARITIME....REFERS TO THE WASHINGTON CASCADE MTN RANGE IN NORTHWESTERN US, WHICH EXPERIENCES BOTH WARM, MOIST AND COLD, DRY WINTER WEATHER.

TEMPERATURE GRADIENT WEAKENING (DECOMPOSITION)....THE MECHANICAL WEAKENING OF SNOW LAYERS (E.G., MELT-FREEZE CRUSTS) BY THE ACTION OF A STRONG TEMPERATURE GRADIENT, WHERE THE GRADUAL SEPARATION OF PREVIOUSLY BONDED SNOW GRAINS INTO INDIVIDUAL LOOSE SNOW GRAINS, OR THE RECRYSTALLIZAION OF NEW SNOW GRAINS, OFTEN OCCURS.

****

WEATHER AND SNOWPACK COMPARISON

	ROCKIES	CASCADES
WEATHER	CONTINENTAL CLIMATE (COLD, RELATIVELY DRY)	MARITIME CLIMATE (RELATIVELY WARM, WET)
SNOWPACK	RELATIVELY SHALLOW, WEAK	RELATIVELY DEEP, GENERALLY STABLE
SLIDES	COMBINATION OF CLIMAX AND DIRECT ACTION, MANY TG RELATED	PRIMARILY DIRECT ACTION (STORM RELATED), INFREQUENT CLIMAX WHERE TG A FACTOR

GOALS.....

- WANT TO SHOW HOW THIS TG WEAKENING OCCURS (THRU METEOROLOGY AND SNOW-PACK OBSERVATIONS), ESPECIALLY IN REGARD TO WEAKENING OF CRUST REGIONS

- WHERE THIS WEAKENING MOST LIKELY TO OCCUR IN RELATIONSHIP TO THE CRUST REGIONS

- SOME PRELIMINARY THEORETICAL CONSIDERATIONS RELATING TO LOCATION OF TG WEAKENING

OBSERVATIONS

- WASHINGTON CASCADE CREST AT STEVENS PASS, WASH, AT ELEVATIONS FROM APPROX 1370-1770 METERS (4500-5800 FT)

****

SPECIFIC WEATHER AND SNOWPACK EVOLUTION PRODUCING CRUST RELATED CLIMAX SLIDES

SPECIFIC WEATHER--STEVENS PASS, WA

JANUARY 12-25, 1975----WARM AND WET, MAX TEMPS APPROX 0 TO +7 DEG C; HEAVY OROGRAPHIC RAIN JAN 16-18, GRADUAL COOLING JAN 21-25

JANUARY 26-FEBRUARY 8, 1975----COLD AND RELATIVELY DRY, MAX TEMPS APPROX -5 TO -10 DEG C

FEBRUARY 9-15, 1975----COOL AND WET, HEAVY SNOW, MAX TEMPS APPROX 0 TO -5 DEG C

****

ASSOCIATED SNOWPACK CHANGES

JAN 12-25, 1975----UPPER SNOWPACK LAYERS GRADUALLY WARMING TO ISOTHERMAL (0 DEG C) AND BECOMING SATURATED; INCREASING SNOW DENSIFICATION (FROM APPROX .05-.15 GM/CM3 TO ABOUT .15-.30 GM/CM3)

JAN 26-FEB 8, 1975----REFREEZING OF SNOWPACK FOLLOWED BY PROGRESSIVE SNOWPACK COOLING AND GRADUAL WEAKENING OF UPPER CRUST REGION, ESPECIALLY FEB 1-8; NOTE DENSITY DECREASES IN UPPER CRUST REGIONS (1/31, 2/1, 2/5, 2/7); ALSO NOTE TG WITHIN CRUST REGION AND ABOVE CRUST REGION

FEB 9-15, 1975----PROGRESSIVE LOADING OF WEAKENED SNOW STRUCTURE; FAILURE OCCURS ON TG WEAKENED SNOW OF UPPER CRUST REGION HAVING GENERALLY LOWER DENSITY

****

GENERAL PHYSICAL CHARACTERISTICS

OF SNOWPITS SHOWING CRUST WEAKENING AND TEMPERATURE GRADIENTS NEEDED

TO SUSTAIN WEAKENING

---

1. SIGNIFICANTLY WARMER TEMPERATURES IN THE CRUSTS (~-1 TO -5 DEG C) THAN ABOVE CRUSTS (~-5 TO -12 DEG C)

2. SIGNIFICANTLY GREATER TEMPERATURE GRADIENTS ABOVE CRUSTS THAN WITHIN CRUSTS (AVERAGE TEMP. GRADIENTS)

3. UPPER LAYERS OF THE CRUST REGION OBSERVED TO HAVE GENERALLY LOWER DENSITIES THAN LOWER LAYERS OF THE CRUST REGION

4. LOCAL TEMPERATURE GRADIENT MAXIMUMS GENERALLY OBSERVED TO OCCUR JUST ABOVE CRUSTS OR IN RELATIVELY LOWER DENSITY LAYERS NEAR THE TOP OF THE CRUST

5. GENERAL MECHANICAL WEAKENING OBSERVED IN UPPER LAYERS OF CRUST REGION WITH TIME (FROM HAND STRENGTH AND RAMSONDE TESTS)

****

SOME PROBABLE FORMATION MECHANISMS PRODUCING TG WEAKENED LAYERS IN A (MARITIME) SNOWPACK....AND PROBABLE OPTIMAL LOCATIONS OF SUCH WEAKENING

FIRST CONSIDER

I. SOME PRIMARY FACTORS--THERMAL PROPERTIES OF ICE/SNOW--AFFECTING LOCAL TEMPERATURE GRADIENTS AND THEIR EFFECTIVENESS IN VAPOR TRANSPORT IN A DRY SNOWPACK (REFROZEN IF PREVIOUSLY WET, AS LIQUID WATER INTRODUCES OTHER COMPLICATIONS)

A. SNOW/ICE CONDUCTIVITY VERSUS DENSITY

1. HIGHER DENSITY SNOW HAS GREATER CONDUCTIVITY (I.E., CONDUCTIVITY INCREASES WITH INCREASING DENSITY)

2. RATE OF CONDUCTIVITY INCREASE VERSUS DENSITY INCREASE A MAXIMUM IN DENSITY RANGE APPROX. 0.25-0.45 GM/CM3

3. RATIO OF THERMAL CONDUCTIVITY OF "LOWER" DENSITY SNOW (APPROX 0.1.-0.20 GM/CM3) TO THAT OF "HIGHER" DENSITY SNOW (APPROX 0.30-0.40 GM/CM3) RANGES FROM ABOUT 1.5-4.0

B. DEPENDENCE OF TG PROCESS ON ABSOLUTE TEMPERATURE

1. TEMPERATURE GRADIENT RELATED VAPOR TRANSPORT A MAXIMUM AT RELATIVELY WARM TEMPERATURES (CLOSE TO 0 DEG C) DUE TO SEVERAL FACTORS:

a. FOR A GIVEN TEMPERATURE CHANGE THE VAPOR PRESSURE GRADIENT VERSUS TEMPERATURE IS A MAXIMUM AT WARM TEMPERATURES CLOSE TO 0 DEG C (FROM THE TRIPLE POINT DIAGRAM OF WATER/ICE/VAPOR)

b. RATIO OF VAPOR FLOW TO HEAT FLOW IS A MAXIMUM CLOSE TO FREEZING (0 DEG C) (COLBECK, 1982)

****

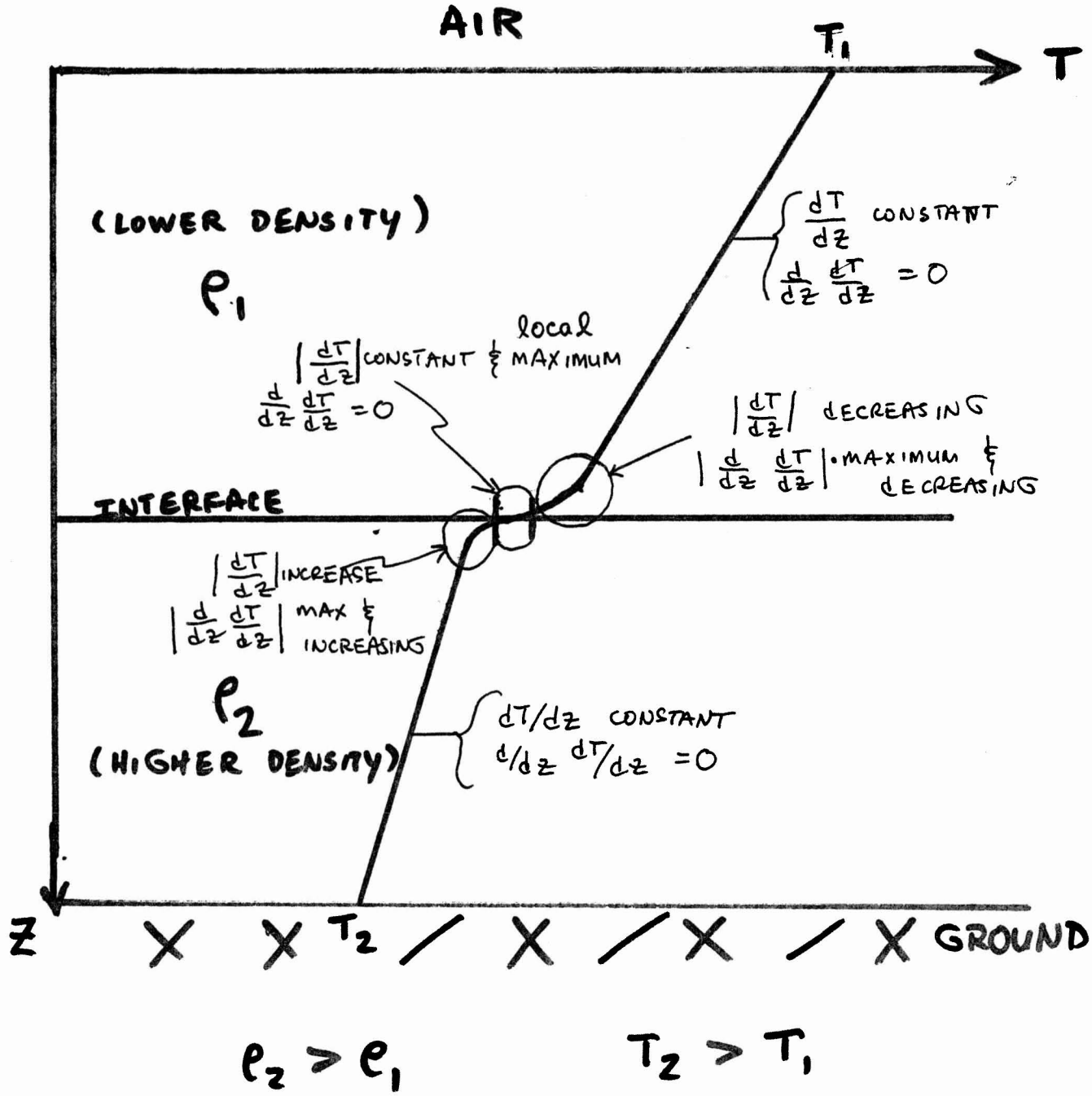
PRELIMINARY CONCLUSIONS REGARDS PROBABLE FORMATION MECHANISMS

---

1. DUE TO CONDUCTIVITY DIFFERENCES IN DIFFERING DENSITY SNOW, LOCAL TEMPERATURE GRADIENTS, AND LOCAL GRADIENTS OF THE TEMPERATURE GRADIENT, ARE A MAXIMUM NEAR SNOW LAYER INTERFACES WHERE SIGNIFICANT DENSITY CHANGES OCCUR. (THESE GRADIENTS MAY ALSO PRODUCE A NET VAPOR CONVERGENCE JUST ABOVE THE LAYER INTERFACE WITHIN DECREASING DENSITY SNOW LAYERS...DUE TO EXPECTED LOCAL DECREASES IN THE VAPOR PRESSURE GRADIENT).

2. FOR GIVEN TEMPERATURE GRADIENTS AND GRADIENTS OF THE TEMPERATURE GRADIENT, ASSOCIATED VAPOR PRESSURE GRADIENTS AND VAPOR FLOW ARE MAXIMIZED IN WARMER REGIONS (CLOSE TO 0 DEG C) OF THE SNOWPACK. (THESE WARM REGIONS ARE MORE LIKELY TO BE MAINTAINED AT HIGHER LEVELS IN A GIVEN SNOWPACK BY CRUSTS AND HIGHER DENSITY SNOWS).

FIGURE IDEALIZED PLOT OF TEMPERATURE GRADIENT AND CHANGE OF TEMPERATURE GRADIENT VERSUS DEPTH IN TWO LAYER SNOWPACK



$\rho_2 > \rho_1$ $T_2 > T_1$

[IF $\rho_2 < \rho_1$, NO TEMP GRAD MAX AT INTERFACE]

****

APPLICATIONS OF PROBABLE FORMATION MECHANISMS TO DETERMINING OPTIMAL LOCATIONS OF TEMPERATURE GRADIENT WEAKENED LAYERS IN A (MARITIME) SNOWPACK

I. GENERAL APPLICATION.....

GIVEN: A CRITICAL TEMPERATURE GRADIENT ACROSS A GIVEN SNOWPACK,

AND A NORMAL POSITIVE HEAT FLUX FROM BOTTOM TO TOP (I.E., WARM GROUND, COLD AIR),

THE TEMPERATURE GRADIENT (KINETIC GROWTH) WEAKENING PROCESS SHOULD BE MOST ACTIVE-----

NEAR RELATIVELY WARM (CLOSE TO 0 DEG C) SNOW LAYER INTERFACES HAVING SIGNIFICANT DENSITY DIFFERENCES....SPECIFICALLY.... AT OR NEAR INTERFACES OF LOWER DENSITY OVER HIGHER DENSITY SNOW.

(CONDUCTIVITY AND HEAT FLUX CONSIDERATIONS WOULD NOT PRODUCE LOCAL TG OR GRADIENT OF TG MAXIMUMS AT INTERFACES OF HIGHER OVER LOWER DENSITY SNOW)

****

SOME SPECIFIC APPLICATIONS / EXAMPLES (SUPPORTED BY OBSERVATIONS)

A. GIVEN: SNOWPACK WITH RELATIVELY WARM DENSE CRUSTS (~0.25-0.40 GM/CM UNDERLYING LOWER DENSITY (~0.10-0.20 GM/CM3) "NEWER" SNOW....

TEMPERATURE GRADIENT WEAKENING OF SNOW MOST LIKELY IN THE SNOW JUST ABOVE THE CRUST OR NEAR THE INTERFACE OF CRUST AND LOWER DENSITY SNOW

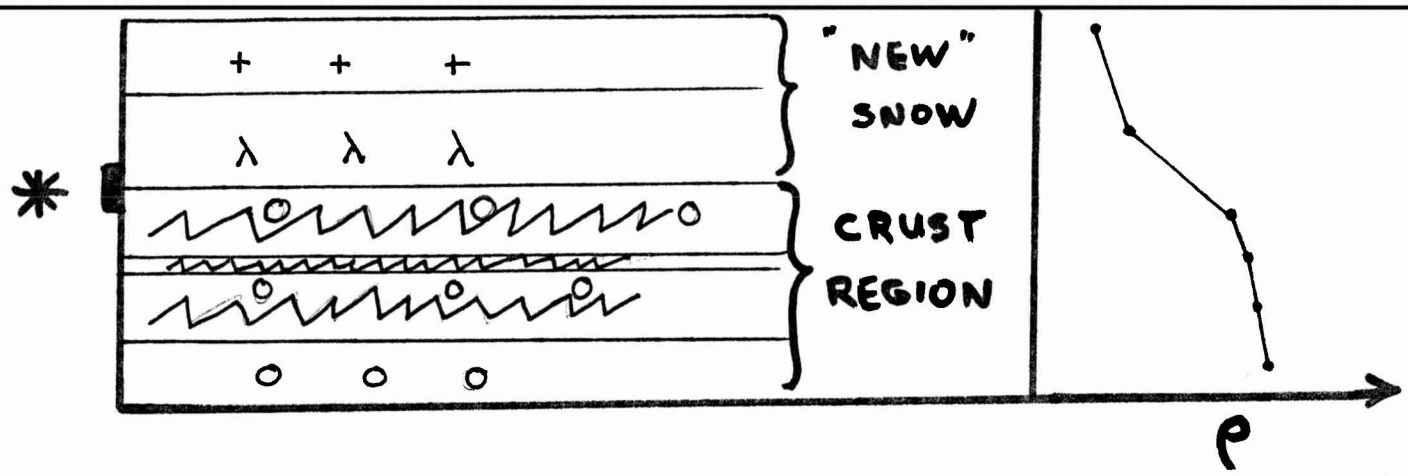
B. GIVEN: SNOWPACK WITH RELATIVELY WARM DENSE CRUST REGION (~~0.20-0.4 GM/CM3) OF DECREASING LAYER DENSITY WITH HEIGHT ABOVE GROUND,

TEMPERATURE GRADIENT WEAKENING MOST LIKELY IN UPPER SNOW LAYERS (~0.20-0.25 GM/CM3) WITHIN THE CRUST REGION.... ESPECIALLY NEAR OR JUST ABOVE THE HIGHER TO LOWER CRUST DENSITY INTERFACES

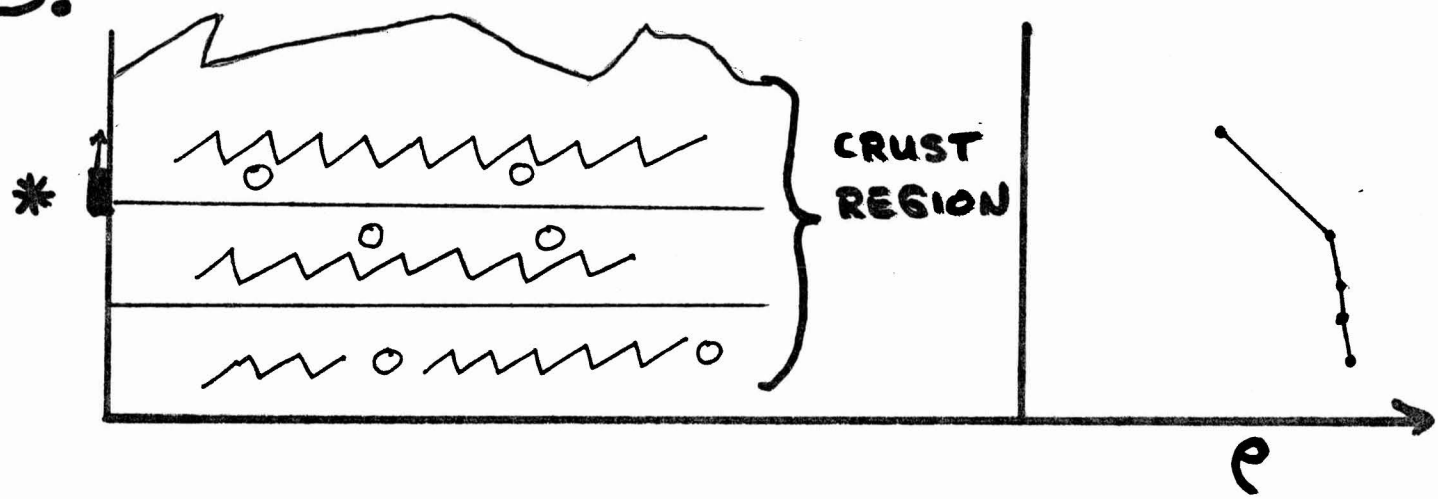
C. GIVEN: SNOWPACK WITH ICE LENS (GENERALLY >0.40 GM/CM3) OVER LOW DENSITY SNOW (~0.05-0.15 GM/CM3) OVER SNOW LAYERS OF SIGNIFICANTLY INCREASING DENSITY SNOW.....

TEMPERATURE GRADIENT WEAKENING MOST LIKELY IN LOW DENSITY SNOW LAYER OR NEAR INTERFACE OF LOW DENSITY SNO LAYER AND UNDERLYING HIGHER DENSITY SNOW. (THIS WEAKENING MAY ALSO BE A FUNCTION OF LOCALLY INCREASED SUPERSATURATION OCCURRING UNDER LENS DUE TO ITS LACK OF POROSITY).

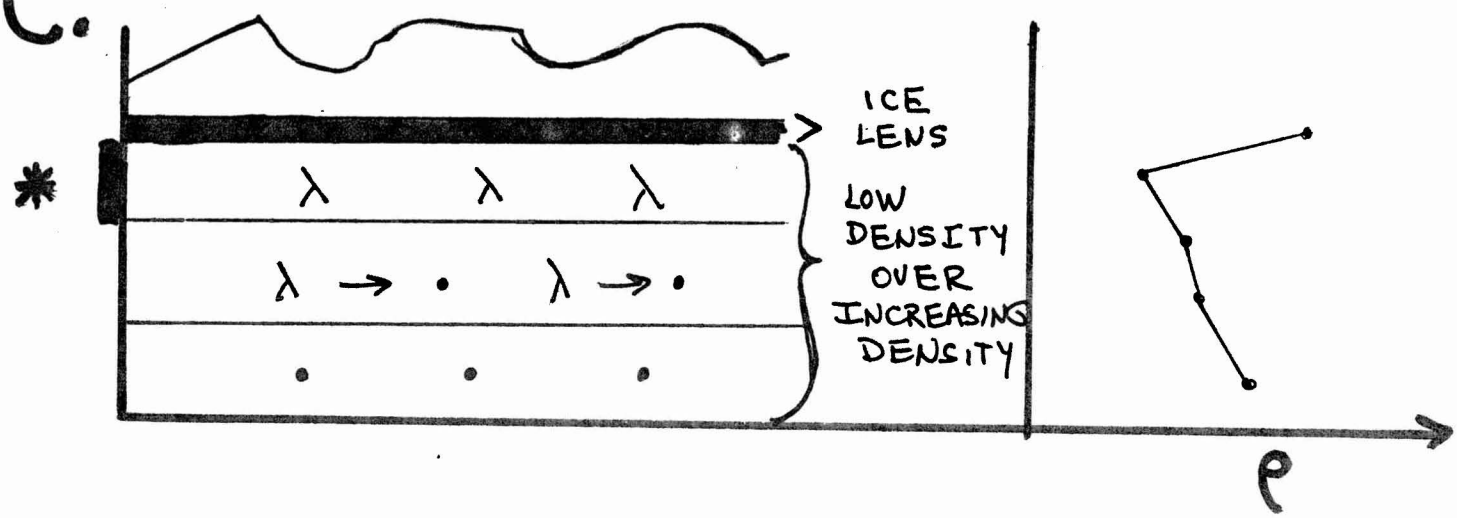
A.



B.



C.



* MOST LIKELY AREA FOR TG WEAKENING

****

SUMMARY AND CONCLUSIONS REGARDING TG WEAKENING OF MARITIME SNOWPACKS

I. GIVEN CERTAIN ANTECEDENT WEATHER CONDITIONS, TG WEAKENING OF MARITIME SNOWPACKS MAY BE AN IMPORTANT, ALTHOUGH INFREQUENT, CONTRIBUTING FACTOR TO SLAB AVALANCHE RELEASES IN THE WASHINGTON CASCADES.

II. WELL DEVELOPED TEMPERATURE GRADIENT CRYSTALS ARE RARELY OBSERVED IN TRUE MARITIME SNOWPACKS AND DO NOT APPEAR TO BE REQUIRED FOR MECHANICAL WEAKENING OF THE INVOLVED CRUST AREAS TO OCCUR.

III. THIS TEMPERATURE GRADIENT WEAKENING IS GENERALLY CONCENTRATED AROUND CRUSTS (WHERE RELATIVELY WARM TEMPERATURES AND DECREASING DENSITY IN THE UPPER CRUST LAYERS ARE OFTEN OBSERVED).

IV. MORE SPECIFIC RESEARCH NEEDS TO BE DONE REGARDS THIS CRUST-RELATED TEMPERATURE GRADIENT WEAKENING.

****

SOME CONSIDERATIONS ON POSSIBLE / PROBABLE TG WEAKENING JUST ABOVE RELATIVELY WARM (CLOSE TO 0 DEG C), DENSE (ABOUT 20-40 %) CRUST INTERFACE WITH OVERLYING LOWER DENSITY (APPROX 15-25 %) SNOW

---

1. JUST BELOW THE INTERFACE, TG (dT/dZ) AND CHANGE OF TG (d/dZ(dT/dZ)) ARE BOTH NEGATIVE (BUT INCREASING MAGNITUDE) WITH TG APPROACHING A LOCAL MAXIMUM. AT THE INTERFACE TG AND CHANGE OF TG SHOULD BE CONSTANT (MAXIMUM) AND ZERO, RESPECTIVELY. ABOVE THE INTERFACE, TG AND CHANGE OF TG SHOULD BE NEGATIVE (AND DECREASING IN MAGNITUDE) AND POSITIVE (DECREASING IN MAGNITUDE), RESPECTIVELY, AS THEY APPROACH THE LINEAR GRADIENT WITHIN THE MEDIUM FOLLOWING CHARACTERISTIC EXPONENTIAL DECAY.

2. RESULTING FROM THE ABOVE TEMPERATURE GRADIENT CONSIDERATIONS, THERE SHOULD BE ASSOCIATED VAPOR FLUX GRADIENTS WHICH WOULD RESULT IN VAPOR CONVERGENCE JUST ABOVE THE INTERFACE. SINCE THE ASSOCIATED SUPERSATURATION ABOVE THE SNOW GRAINS THERE COULD NOT INCREASE, THERE MUST BE A CORRESPONDING LOCALLY INCREASED VAPOR DEPOSITION RATE ABOVE THE INTERFACE OR LOCALLY ENHANCED TG METAMORPHISM (LOCAL FAST CRYSTAL GROWTH).

3. SINCE THIS SITUATION IS DYNAMIC, THE LOCALLY ENHANCED TG PROCESS NEAR THE INTERFACE SHOULD GRADUALLY INVOLVE DEEPER SNOW MASSES WITHIN EACH ADJACENT SNOW LAYER, RESULTING IN GRADUAL DECOMPOSITION OF BOTH LAYERS, ALTHOUGH NOT NECESSARILY AT THE SAME RATE.

4. ACTING AGAINST THE VAPOR CONVERGENCE DISCUSSED ABOVE IS THE INCREASING POROSITY OF THE LOWER DENSITY LAYER ABOVE THE INTERFACE WHICH WOULD TEND TO MAXIMIZE VAPOR FLOW RATES AND POSSIBLY CARRY EXCESS VAPOR TO HIGHER LEVELS WITHIN THE LAYER.

****

RELATIVE THERMAL CONDUCTIVITIES OF VARIOUS SUBSTANCES

SUBSTANCE	CONDUCTIVITY (X 10E-3 CAL/(CM-S-DEG C)
AIR	0.057
SNOW	~0.10-1.0 (DENSITY RANGES ~0.10-0.40 GM/CM3)
WATER	~1.75
ICE	~5-6
GRANITE	~6-7
FROZEN SATURATED SAND	~7.5-9.5
QUARTZ	~26

NOTE----
----

1. THERMAL CONDUCTIVITY OF FROZEN SOILS APPRECIABLY GREATER THAN THAT OF UNFROZEN SOILS

2. IN GENERAL, CONDUCTIVITY OF SUBSTANCES INCREASES WITH INCREASING DRY DENSITY

3. AN INCREASE IN THE DRY DENSITY OF SNOW (ROCK, SOIL) WITH ITS ASSOCIATED DECREASE IN POROSITY, LEADS TO AN INCREASE IN THERMAL CONDUCTIVITY MAINLY DUE TO: (AFTER MELLOR, "THERMAL PROPERTIES OF SOILS")

   a. MORE SOLID MATTER PER UNIT VOLUME

   b. LESS PORE AIR SPACE PER UNIT VOLUME

   c. BETTER HEAT TRANSFER ACROSS THE GRAIN CONTACTS SINCE MORE CONTACTS (I.E., IN THE CASE OF SNOW...MORE SINTERING)..