Avalanche School Rogers Pass

2 - 6 December 1974

Date Time	Location	Topic	Instructor
2 December			
0900	Meeting room	Objective of course; program; Introduction to avalanche safety and control	Schaerer
1000	Meeting room	Physics of the snow cover	Perla
1200	Hotel	Lunch	
1300	Meeting room	Snow profile observations	Schaerer
1345	Observation site	Observation of snow profile	Schaerer Anhorn
1530	Meeting room	Recording of snow profile	Schaerer
1615	Meeting room	Weather observations	
1700		Break	

Date Time	Location	Topic	Instructor
3 December			
0830	Observation site	Weather observations	
	Meeting room	Recording of observations Observation site	Schleiss
1000	Meeting room	Avalanche Safety program of Department of Highways	Godfrey
1030	Meeting room	Characteristics of avalanches, classification and recording	Schaerer
1200	Hotel	Lunch	
1300	Meeting room	Film: Avalanche	
1400	Meeting room	Search and Rescue	Pfisterer
1700		Break	

Date Time	Location	Topic	Instructor
4 December			
0830	Meeting room	Avalanche control Rogers Pass Work in 2 groups a) Rescue practice b) Visit of avalanche sites, and analysis office recording avalanches.	Schleiss Pfisterer Schleiss
1230	Hotel	Lunch	
1330	Field	as in morning, groups with changed activity.	
1600		Break	
5 December			
0900	Flat Creek	Departure for Fidelity Mtn.	
1000	Fidelity Mtn.	Snow profile, slope testing Visit observatory	
1500	Meeting room	Plotting profile Stability analysis	Schaerer
1700		Break	
6 December			
0830	Observation site	Weather observations	
0900	Meeting room	Evaluation avalanche hazard, Avalanche control, case histories.	Schaerer

NATIONAL RESEARCH COUNCIL OF CANADA

British Columbia Institute of Technology

Avalanche Courses

1974-75

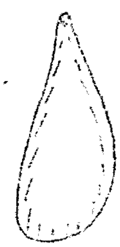
Snow Stability Analysis

P. Schaerer

1. Manners of start of Avalanches

Loose snow avalanches

Start at a point.



Loose snow avalanches contain cohesionless snow:

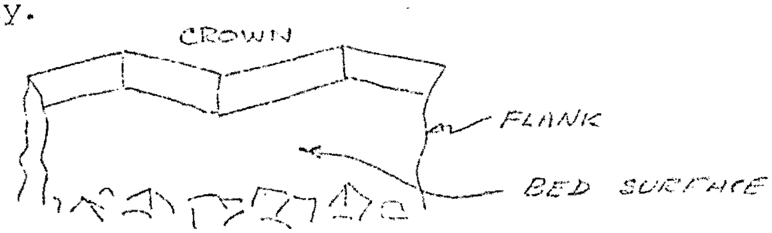
a) Dry new snow, usually a day after a snowfall when the crystals are rounded but before they have sintered; surface sluff, usually small.

b) Wet new snow.

c) Wet old now, during snow melt periods; these avalanches can be large.

Slab avalanches

Start from a line; the whole width of a slope moves simultaneously.

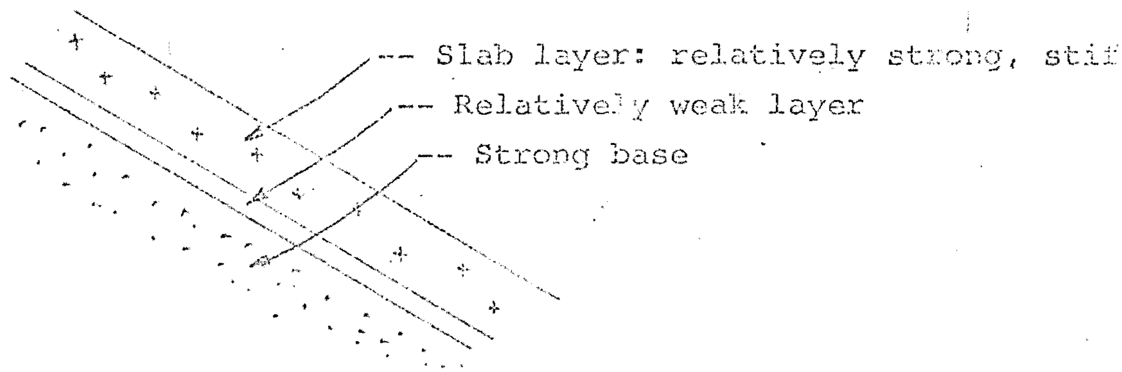


Slab avalanches form in snow that has a strength.

Avalanches may start as loose snow avalanches, and the moving snow can release a slab lower down the slope.

2. Start of slab avalanches

Slab avalanches are caused by an instability of the snow cover due to the layering.



A relatively strong, stiff layer (slab layer) overrides a relatively weaker, instable layer.

The weight of the slab layer results in shear stresses in the weak layer. A fracture occurs when the stresses exceed the strength of the weak layer. An instability and fracture is produced either through an increase of the stresses due to overloading from a snowfall, snow drifting, the weight of a skier, explosions, vibrations, or through a loss of strength due to high temperatures, melt water, temperature-gradient metamorphism.

There are several different modes of failure of the snow.

After the slab has fractured it must overcome the friction on the bed surface. A minimum incline of the slope is necessary. Sometimes a slab that has fractured remains at its place.

3) Stability analysis

The stability analysis is an estimate that avalanches will start within a given time. The analysis is based on human judgement using rules of thumb and personal experience.

Observations (input) used in snow stability analysis:

Snow depth
Snow profile (Layering of the snow, snow pack structure)
Weather: snowfall, temperature, wind.
Avalanche occurrences: current and past.
Slope tests: cutting of slab, skiing, explosions.

The weather forecast for predictions of the development of the snow stability.

Certain groups of observations are stressed and others omitted, depending on local conditions, such as accessibility of the avalanche starting zones, climate, control methods. Following are recommended methods for stability analysis.

4) Influence of snow depth

A minimum snow depth is necessary to cover the roughness of the ground before avalanches occur. The threshold depth can be established from observations of several years. It is usually:

On a smooth ground, e.g. rock slabs, grass, permanent snowfields — 30 cm (12 inch)

On average mountainslopes, covered with boulders, shrubs, rough bedrock — 60 cm (24 inch)

On very rough ground, with big boulders, big stumps, fallen trees — 90 cm to 120 cm (3 feet to 4 feet)

5) Uncontrolled, accessible slopes

Most frequent application: skitouring, construction sites.

Order of importance of observations: Snow profile
Slope tests
Weather
Avalanche occurrences

a) Observe a snow profile at a representative location near the starting zone and look for weak layers; determine their strength (hand test), the depth and strength of the slab layer.

The following can be critical weak layers:
- surface hoar
- depth hoar
- crusts
- old snow surfaces that have gone through a strong metamorphism
- at significant changes of hardness
- very wet snow

Evaluate the strength of the layers vs. the weight on top of them; develop your experience.

Some rules of thumb:
- The depth of snow above a weak layer must be 30 cm (12 inch) to produce instability.
- Snow with a hardness of 4 fingers can support a layer up to 100 cm deep (about 3 feet).
- Snow with a temperature between 0° C and -1° C may become unstable rapidly when the air temperature increases or with strong radiation.
- During the snow melt period, deep avalanches will not release before isothermal condition is attained (0°C).

b) Test a short, steep slope of critical exposure.

c) Consider how the wind and sun could influence the conditions on slopes with different aspects.

d) Observe avalanche occurrences, note the exposure of the starting zones.

6) <u>Uncontrolled, inaccessible slopes</u>

Most frequent application: roads
planning of skitouring.

Order of importance of observations:

Weather

Avalanche occurrences

Snow profile

Slope tests

a) Estimate from weather observations how the snowfall, wind, temperatures influence the stability of the snow in the avalanche starting zones.

Significant weather observations:

- Amount of snowfall
- Intensity of snowfall
- Settlement of new snow
- Windspeed and direction
- Temperature
- Solar radiation

<u>Some rules of thumb:</u>

When the old now cover is stable, instability begins when <u>snowfall</u> exceeds about 2.5 cm water equivalent, or about 30 cm new snow.

High avalanche hazard when <u>snowfall intensity</u> greater than 2.5 cm. per hour; greater than 1.5 cm per hour in association with strong wind.

<u>Snowfall of rimed crystals,</u> graupels, needles are more likely to form avalanches than stellar crystals (e.g. after 20 cm new snow).

Rain adds weight to existing snow cover and decreases stability; high temperatures associated with rain produce additional weakening of the snow.

Rapid settlement of snow means rapid increase of strength. The new snow becomes usually stable when the settlement is greater than about 15 percent per day.

Wind can move loose snow and produce avalanches even after a snowfall. Avalanches form on a leeside of ridges. Observe for drifting, snow plumes, cornices, drifts around buildings and trees.

Critical windspeed about 20 m.p.h.

Wind breaks up the snow crystals and the small fragmented crystals pack densely to form a slab. Slab can be dangerous when supported by a weaker base.

High relative humidity in association with wind produces slabs more readily.

Low temperature: slow metamorphism, little change of strength, unstable conditions may persist.

High temperatures, but not higher than 30° F (-1° C): rapid gain of strength, leads to stable snow.

Temperatures higher than 30°F: loss of strength, leads to instability.

Drop of temperature from 31°F and higher: weak snow becomes stable.

Strong radiation from the sun increases the temperature on exposed slopes. The radiation usually not significant in December and January, but it is an important cause of avalanches in spring. The effect of solar radiation is intensified when the sky is hazy.

The combination of adverse weather factors is important.

b) Observe avalanche occurrences. There are usually indicator slopes on which avalanches run first.

Avalanches remove the snow in the starting zones and the tracks, and this snow is not available in subsequent storm periods.

c) The stability analysis by using weather observations is satisfactory for avalanches that form during snow storm, but it becomes difficult when the avalanches build up over more than one storm period. The starting zones should be visited about once per month (by ski, helicopter) for observation of snow profiles.

7) Controlled Slopes

Most frequent application: Skiareas
Roads with artillery control

Order of importance of observations: Weather
Slope tests
Avalanche occurrences
Snow profile

The objective of the application of explosives, ski stabilization is to remove the unstable snow by producing harmless avalanches. The stability analysis determines the time when control measures must be applied.
The method used for stability analysis is essentially the same as for uncontrolled inaccessible slopes, but it must also consider how well a slab has formed in the starting zone. The formation of a slab is important for the successful application of explosives.

The terrain and experience will determine the amount of snow that may be permitted to accumulate before avalanches must be released.

Slabs form readily with wind, moist air, and high temperatures. Snowfalls with wind and in cold weather do usually not produce slabs.

8) Avalanche hazard evaluation

The avalanche hazard is the probability of avalanches inflicting a given degree of damage to skies, vehicles, property. The damage is a function of the size and type of the avalanches as well as the terrain.

The snow stability analysis is the first step of the avalanche hazard evaluation. The size of the avalanches and the outrim distances must be considered in a second step.

a) Rules of estimating the size of avalanches:
The deeper the slab layer, the larger the avalanche.
An avalanche in motion may break deeper weak layers.
The harder the slab the more likely a fracture could propagate and a wide slop may start to slide at once.
The surface penetration measure by the foot or the ramsonde is an indicater of the amount of unstable snow in the track.
A penetration less than 30 cm produces small avalanches, more than 60 cm large avalanches.

b) Rules fo estimating the outrim distance:
Large avalanches have a higher speed and a larger outrim distance than avalanches on an open slope.
A smooth track of old snow produces longer outrim distances.
Be safe and assume that avalanches might go further than estimated.

AVALANCHE COURSES

AVALANCHE RESCUE

by: W. Pfisterer - Regional Alpine Specialist

Department of Indian and Northern Affairs

Parks Canada

Avalanche Rescue:

- History.
- Classic cases.
- Research.

Vanni Eigenmann Foundation:

- Background.
- Function.
- Results.

Statistics:

- 85 victims.
- 28 found alive
- 57 found dead.
- 67% death rate.

Time limit:

- 28 victims found alive.
- 11 within first hour.
- 12 within second hour.
- 2 within third hour.
- 2 within fourth hour.
- 1 after six hours.

Causes of death:

- External - internal injuries - 4%
- Suffocation by compression - 16%
- Suffocation - snow in lung - 4%
- Suffocation - settling snow - 66%
- Exposure.................. - 8%
- Shock - 2%
- Unconsciousness, combined with any of the above named causes.

Conclusion:

- Death caused by suffocation - 86%

- Suffocation by settling snow - 66%
- Time elapsed............... 2 hours.

A rescue team has a fair chance to recover an avalanche victim alive, providing they are:

- Well organized.
- Well trained.
- Well equipped.

Equipment:

- Standard equipment.
- Special equipment.
- Improvised equipment.

Standard equipment:

- Probe.
- Shovel.
- Spacer.
- Marker.

Special equipment:

- Dog.
- [illegible].
- Magnetometer.

Improvised equipment:

- Rods.
- Poles.
- Shovels.

Rescue organization:

- Co-ordinator.
- Leaders.
- Team members.

Rescue procedure:

- Accident report form.
- First party.
- Follow up party.
- Communication.

Search methods:

- Safety of rescue team.
- Last seen point.
- Hasty search.
- Probe line.
- First aid.

Search for vehicle:

- Safety of rescue team.
- Last seen point.
- Upper road limit.
- Use of snow removal equipment.

"A rescue leader's foremost consideration is the safety of his team."

Survival in an avalanche:

- Unprotected victim (skier, etc.).
- Protected victim (motorist, etc.).

Accident Witness:

- Reporting.
- Assisting.
- Personal safety.

IN ANY CASE - KEEP CALM, - BUT HURRY!!!

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BRITISH COLUMBIA INSTITUTE OF TECHNOLOGY

AVALANCHE COURSE 1974-75

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......./2

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All publications of the Alta Avalanche Study Center and U.S.D.A. Forest Service must be requested from:-

Rocky Mountain Forest and Range Experiment Station
240 West Prospect Street
Fort Collins, Colorado
U.S.A. 80521

SNOW PHYSICS

by R.I. Perla

Glaciology Division Environment Canada

1. Density of new snow

Reference is water, density 1000 kg m^{-3} (spec. grav. = 1.0). Layers of newly fallen snow have densities in the range from about 30 kg m^{-3} to 300 kg m^{-3} (S.G. from 0.03 to 0.30). The higher densities are due to wind fragmantation, or special crystal forms such as needles.

2. Densification

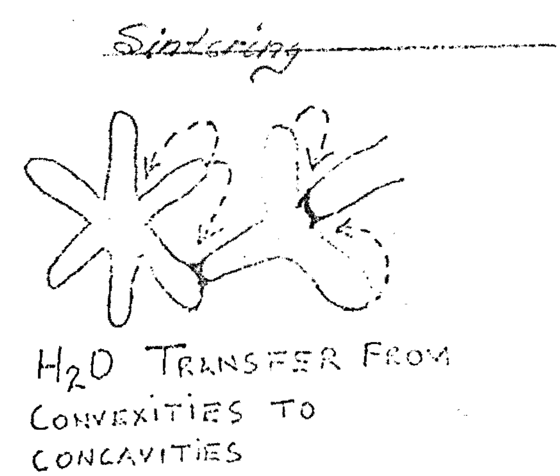
As weight is added to the pack, snow layers may compress and double or triple in density (for example, in a few days a new snow layer may densify from 100 kg m^{-3} to 200 kg m^{-3}). Densification is observed as settlement. Season snow may densify up to about 500 kg m^{-3}. Crusts and firn may reach higher densities.

3. Snow strength

The main factors are density, grain size, and wetness. High density snow (400 kgm $^{-3}$) may be 1000 times as strong as newly fallen snow (100 kgm $^{-3}$); glacial ice (900 kgm $^{-3}$) is a million times as strong as newly fallen snow.
At a given density, snow layers which consist of small, fine grains may be over ten times as strong as layers which consist of large, coarse grains. In general, the larger the snow grains, the weaker the snow. Temperature does not play a major role in determining the strength of dry snow; however, snow drastically loses strength when warmed to the meltpoint.

4. Sintering

Sintering, or the formation of necks between grains, occurs along with densification. This process involves the transfer of H_2O molecules from sharp grain convexities to grain concavities. Sintering is always



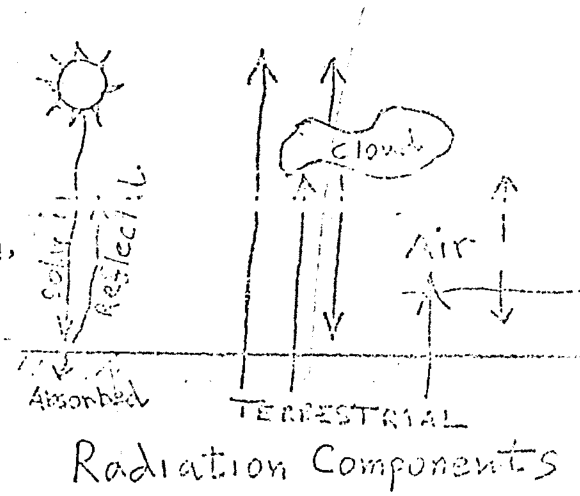
the dominant type of metamorphism in dry snow layers of newly fallen snow which steadily settle, densify, and gain strength. During the initial stages of sintering, grains tend to become smaller and rounded (destructive metamosphism, or equi-temperature metamorphism).

5. Recrystallization T/G.

The natural evolution of snow grains to small, rounded shapes with large adjoining necks is sometimes offset by recrystallization. This may occur at any stratigraphic level, including the snow surface. Recrystallization within a layer depends on the temperature difference across the layer (the temperature gradient). In general, strong temperature gradients are caused by low temperature at the snow surface.

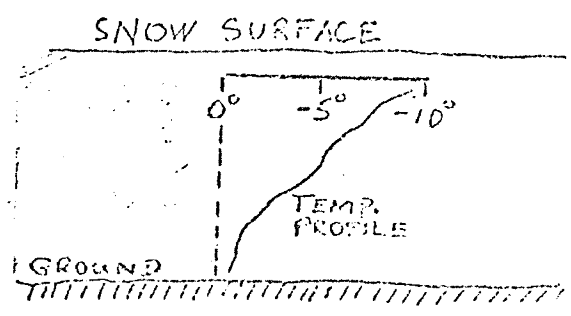
6. Energy balance at the snow surface

The temperature of the snow surface is a function of solar radiation, the terrestrial radiation balance, and several molecular processes, which include: heat conducted to or from the atmosphere, sublimation, evaporation, heat added by rain, and heat added or lost with the addition of new snow. Wind plays an important role in adding or removing heat.



7. Temperature gradient

Ground temperature is usually 0°C (or possibly lower in high alpine areas or at high latitudes). Snow surface temperature may fall well below 0°C. A temperature difference of about 10°C per meter is considered a significant temperature gradient.



8. Recrystallization deep in the pack

When the temperature gradient is significant, vapor is transported across layers from warm levels to cold levels. The vapor is deposited on crystal faces rather than on the necks between grains. Thus, the grains enlarge without corresponding increase in the size of adjoining necks. This type of metamorphism (which results in weak layers of large, coarse grains) is called temperature-gradient metamorphism. The enlarged grains are called TG-grains. Very large, coarse grains (3 to 8 mm) are known as depth hoar.

9. Recrystallization at the surface

Vapor may also flow from a relatively warm, humid atmosphere to a cold snow surface. The result is a thin weak layer of TG-grains called surface hoar. It is also possible that certain radiation conditions can cause strong temperature gradients at the surface, producing radiation recrystallized grains.

10. Recrystallization as a function of density

Recrystallization deep in the pack depends also on density. The denser the snow, the slower the temperature gradient metamorphism. Hence, ski and boot compaction is an important defense against the formation of depth hoar.

11. The wet snowpack

When the snowpack temperature is 0°C from surface to ground, the snowpack is said to be isothermal. At this time, significant melt water can form within the pack, and wet avalanches may become a problem. Melt or rain water percolates down thru the pack until reaching a hard crust where the water may reduce bonds between the hard surface and the over-riding wet slab.

12. Viscoelastic model of snow

Under stress, a snow sample will show both a viscous and elastic response. The viscous behavior is quite evident in nature (settlement, creep). Elastic behavior, that is, the ability to store spring-like energy, is revealed in more subtle ways--for example, the propagation of rapid brittle fractures.

13. Fracture of snow

If snow is loaded at a relatively slow rate, the snow will dissipate energy through viscous flow (densification, creep). However, at high load rates (intense snowfall, explosive blast, ski pass), the viscous dissipation cannot keep up with the energy input. Elastic energy will build up in the slab (elastic stretching), until the slab fractures catastropically. Fractures tend to propagate between stress concentrations (trees, rocks, ski tracks).

14. Shear stress and fracture

Shear weakening or fracture may initiate along a stratigraphic discontinuity stressed beyond its capacity. Shear stress is a function of slope angle, density, and slab thickness

$$\text{shear stress} \approx \bar{\rho}\, h\, g \sin\theta$$

An index of shear strength can be measured with the shear frame.

It is not clear how shear fractures propagate over the enormous areas of slab avalanches, but it is thought that the opening of tensile fractures jars the weakened shear surface into final fracture. On the other hand, tensile fractures cannot advance over long distances without accompanying shear fracture. The conclusion is that the tension and shear fractures reinforce one another.

15. <u>Origin of tensile stress</u>

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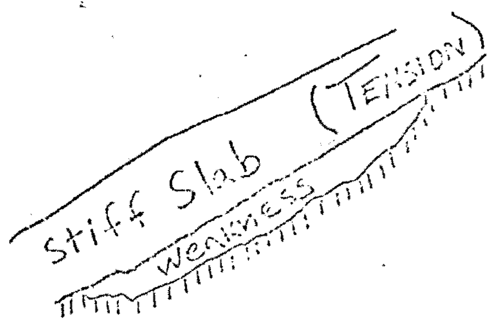
over
weakness</td><td>
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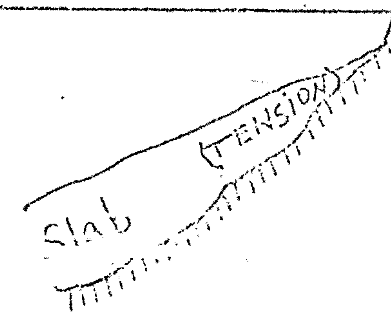
effects</td><td>
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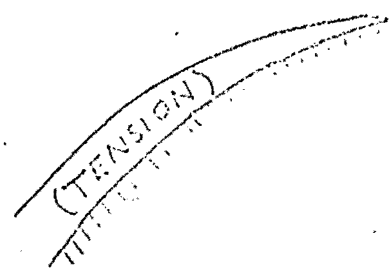
curvature</td><td>
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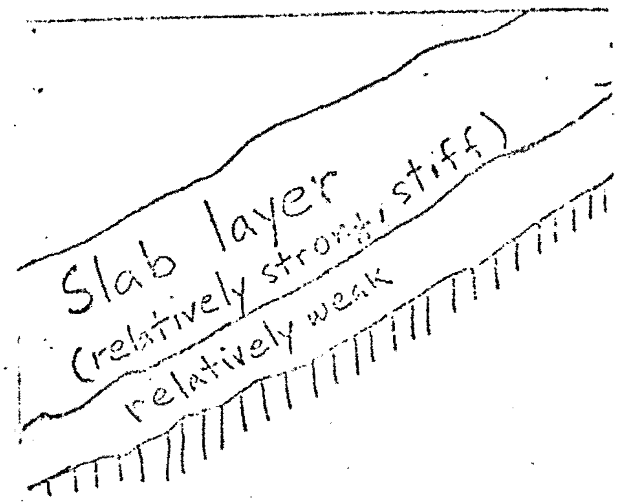
FORMATION OF AVALANCHES

by R.I. Perla

Glaciology Division Environment Canada

1. Slab instability

Basically due to layering effects whereby a relatively strong, stiff layer (the slab layer) overrides a relatively weaker layer which contains the main shear surface. There are several categories of slabs.



2. Wet slab instability

Hard surfaces which block water percolation are possible shear planes. Normally, wet slabs can always be expected during heavy rains, thaws, and habitually in the afternoon during the Spring. However, it is difficult to predict the timing of deep wet slabs, for example, those which slide near the ground or on deeply buried ice crusts. Sometimes, glide cracks which open late in the season give ample warning. Wet instability should always be expected during the first thaw following a late season snow. Evaluation is based on temperature profiles, and visual warning signs (increasing activity).

3. Dry new snow instability

Occurs during or following storms. Besides heavy precipitation, the following storm sequences may contribute to producing a relatively stiff over relatively weak layering:

- Rising temperature during storm (cold front followed by warm front).
- Increasing winds (wind slab over lightly blown snow).
- Increasing riming (heavy snow over light snow).
- Increasing humidity (heavy snow over light snow).

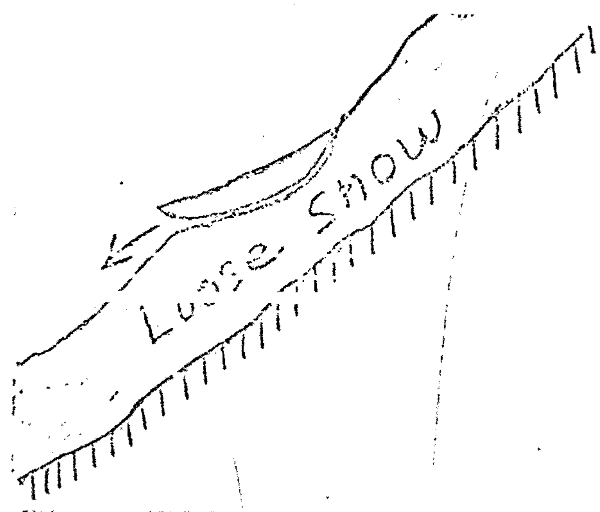
Methods of evaluating instability in the new snow include: storm record, test skiing, small explosive charges (about 1/2 kg. TNT), tilt board test, shear frame test, and visual warning signs.

4. Dry deep slab instability

Mostly during or following storms, but often deep instability persists for long periods after storms. In general, dry deep instability is most intense early season, and diminishes as snowpack goes isothermal toward spring. The most common weaknesses are TG-layers (depth hoar, surface hoar). Sometimes, if new snow instability is not removed, the weakness gets buried under a deep slab and becomes a future problem. Since deep slabs are unpredictable and tricky, the situation should be avoided by compaction and continual stabilization of new snow instability from early season onward. Methods of evaluation include: snowpits, meteorological records, and explosive tests (1 or 2 kg charges).

5. Loose snow avalanches

Initiation starts as failure in a relatively cohesionless surface layer of dry or wet snow, and hence does not depend on the stiff over weak layering. However, once initiated, the loose failure may propagate to a weak discontinuity and release large quantities of dry or wet snow. Evaluated on the basis of visual warning signs.



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BRITISH COLUMBIA INSTITUTE OF TECHNOLOGY

AVALANCHE COURSE

November 1974

SNOWPROFILE OBSERVATION

Objective

The Snow profile, is a record of the stratigraphy of the snow cover and the characteristics of the individual snow layers. The objective of observing the snow profile is to determine:

a) weak layers that are potential failure planes,

b) the snow temperatures,

c) the thickness of a potential slab avalanche,

d) the state of metamorphism of the snow,

Other than for snow stability analysis the information can be used for climatological studies, forecasts of the snow-melt runoff, studies of the effect of snow on vegetation, wildlife, structures.

The amount of information that must be collected depends on the time available and the application. It may be more advantageous to concentrate on a few essential observations at several locations with variable exposure, than making complete observations at one spot.

Equipment

Snow shovel

Snow thermometer (preferably two thermometers)

Ruler

Magnifying glass

Crystal screen

Snow density sampler with weigh scale

Cutter

Metal plate

Note book with water resistant paper

Gloves

For Special Observations

Ramsonde

Shear frame with spring balance

Hardness gage

Climometer

Collapsible probe

Location

a) Study plot

Regular snow profiles may be observed on a standard, level, drained area, and if possible sheltered from wind. The study plot must be selected before the winter and be marked with at least two poles. The ground between the poles must be cleared from bush and large rocks. The snow pits are excavated on a line between the poles, each new pit at a distance about equal to the snow depth from the last one. The location of the last pit must be marked with a pole.

b) Slope

The best information with respect to snow stability is obtained from profiles on slopes that have the same exposure as the avalanche slopes. The observation slope should be at an elevation close to that of the avalanche starting zones.

c) Fracture Line

Snow profiles taken at the fracture lines shortly after avalanches have occurred are important aids in checking the stability analysis.

Procedure

1) Prepare the notebook before going into the field.
2) Select the location of the pit. The wall on which the snow is observed should be in the shade. On a slope it is advantageous to make the observations on a side wall.
3) Dig pit; consider the depth and make the hole wide enough to allow shovelling near the bottom. In deep pits the complete observation must be carried out in steps of about 1.5 m depth. The observation wall must be vertical and smooth.

   The second observer begins the following work while the first observer prepares the pit.

4) Record date, time, location, aspect, incline of terrain, weather.
5) Observe air temperature (Ta). Must be observed with a dry thermometer in the shade. Read after about 5 minutes, wait another minute and read again.

6) Observe surface temperature. Place the thermometer on the snow surface and parallel to it; shade it. Wait at least one minute, read the temperature, wait another minute and read again. Record temperature if it has not changed between two readings.

7) Observe surface condition, e.g. surface hoar, crust, wind packed; penetration by foot or by skis.

8) Observe snow temperatures (Ts). Two or more thermometers may be used simultaneously, but compare them first. The temperatures are measured at intervals of height of 10cm and 20cm in greater depths. Allow about one minute for each measurement. On sunny days the thermometers must be shaded to a depth of 50cm in order to eliminate influences of radiation.

9) Determine the location of each major layer boundary. Record their height from the bottom of the pit.

10) Determine the unstable layers or interfaces of layers where a failure may occur and which are potential bed surfaces for slabs.

11) Observe the hardness (R) of the snow by classifying each layer according to its resistance in horizontal direction with the hand test.

	Symbol
a. gloved fist	
b. four fingers	////
c. one finger	XX
d. pencil	// //
e. knife	✻ ✻

12) Determine the shape and size of the crystals of each layer, as well as that at the snow surface. The shape, or form (F) is recorded with a graphic symbol:

+	new snow
/ \	partially settled, branches rounded
●	rounded
□	with facets
Λ	depth hoar, partically or fully developed cups, lines on crystal faces
V	surface hoar

if necessary add to the symbol

r	rimed
C	clusters, conglomerates

Do not mistake conglomerates for basic forms. Watch for melting on the crystal screen.

The crystal size (D) is measured in millimeters with the aid of the screen. Record the range of average sizes.

13) Determine the Free Water Content (W) of each layer. Only snow with a temperature 0° C can contain free water. Squeeze gently a sample of snow and observe the reaction.

		Symbol
a.	dry; no balls form	
b.	moist; a snowball forms	I
c.	wet; shiny surface, water can be recognized adjacent to snow grains, no drops	II
d.	very wet water can be squeezed out	III
e.	slush; snow flooded, water runs off	IIII

14) Measure the Specific Gravity of layers that are at least 6 cm thick. The sampling tube is inserted in a horizontal direction about in the centre of the layer. Take a sample in vertical direction when the thickness of the layer exceeds the length of the tube. Trim the ends with the cutter or a thin plate and weigh the sample.

$$\text{Specific gravity} = \frac{\text{Weight of snow}}{\text{Weight of an equivalent volume of water}} \times 100\%$$

$$= \frac{\text{Weight of snow, gram}}{500 \text{ ; gram}} \times 100\%$$

Practical method of calculation when using the 500 cm^3 samples:

Weight of snow divided by 5 gives the specific gravity in percent

OR

WT. SNOW X 2 ÷ 1000 = %

NOTE:

Wear gloves when handling the instruments.
Keep all the equipment in the shade.

ORGANIZATION NATIONAL RESEARCH COUNCIL

SNOW PROFILE

DATE 22 FEB 1973 OBSERVER PAS

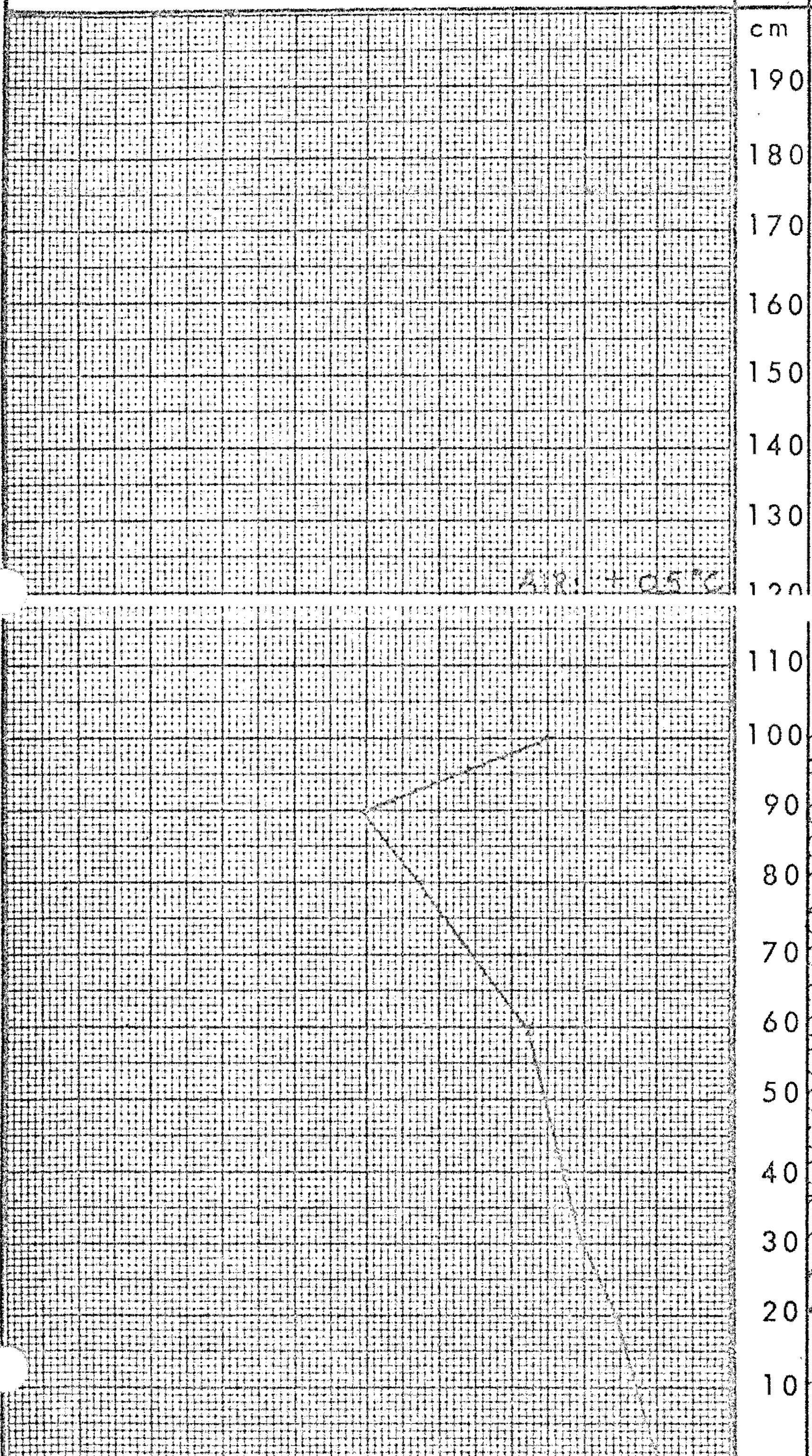
LOCATION LAKE LOUISE ; LARCH CHALLENGE

ASPECT NORTH, SHELTERED SLOPE INCLINE 15 DEG.

WEATHER CLEAR

SURFACE PENETRATION 70 cm (FOOT)

T -16° -14° -12° -10° -8° -6° -4° -2°



R 80 70 60 50 40 30 20 10 kg

H (cm)	F	D (mm)	W	G
100	□ ∧	½-1		
	∧ ∧	¼-½		–
90	● □	¼-½		.22
80	● ● □	½-1		.26
70	□ □	1		.26
60	□ V	1½		← SLIDE LAYER
50–40	□ ∧ ↓ ●	½-1½		.235
30	∧ ∧	2-3		.26
10	∧ ∧	3-4		.22

BR 5111

Appendix 2

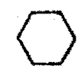
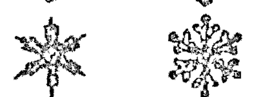
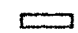
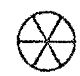
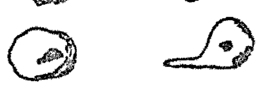
Abstract of the International Classification for Snow

This classification was prepared by a committee formed by the International Commission of Snow and Ice in 1948 (Oslo). It was principally adopted in 1951 (Brussels) and subsequently published (ICSI/IASH, 1954; Schaefer, Klein and de Quervain, 1951).

Some minor adjustments are included in this abstract—marked with an asterisk (*)

Solid precipitation

Type of particles

Particles		Code	Graphic symbol	D[1]
	Snow			
Plates		F1		0.-12
Stellar crystals		F2		1-8
Columns (+ pyramids)		F3		1-4
Needles		F4		2-8
Spatial dendrites		F5		2-8
Capped columns		F6		1-4
Irregular crystals		F7		1-8
Snow particles without any specification		F1 to F7		
(Deposited new snow)		Fa		
	Other solid precipitation			
Graupel		F8		1-5
Ice pellets (includes frozen rain)		F9		0.5-5
Hail		F0		5-100

1. | D | gives the common size range (mm).

Size of particles (D)
Largest dimension measured in millimetres.

Modifying features	Symbol
Broken crystals	p
Rime-coated crystals	r
Clusters (flakes)	f
Wet crystals	w

Example. Wet clusters (flakes) of stellar crystals, average size of the crystals 2.5 mm, F2, D2.5, fw.

Deposited snow

The material snow in its physical behaviour is usually well enough defined by the following features:

Density (or porosity); Free-water content; Impurities	Representing the constituents
Grain shape (see below); Grain size (see below); Strength or hardness(see below); Temperature	Representing the structure

Grain shape and size
A snow grain is the unit which can easily be loosened from the structure. It may be composed of more than one single crystal (distinguishable only in polarized light or on specially treated sections). Grain size as visually determined is the average greatest extension of the predominant grain fraction. Often grains belonging to different shape groups are found in a snow layer. This is indicated in combining symbols or code figures.

Strength or hardness
Strength is a defined and measurable physical property such as tensile strength, [illegible]
Hardness, however, is a complex property related to a particular instrument and method. As hardness is easier to measure than strength, hardness figures may be used as a substitute, but the particulars of the instrument should always be given. Strength and hardness are correlated mutually and, to a certain extent, with density.

Subclassification of deposited snow (see facing page)

Snow-cover measurements

	Vertical	Perpendicular to slope
Coordinate (cm) (from ground up)	H	M
Total depth (cm)	HS	MS
Total water equivalent (mm)	HSW	—
Daily new snow (cm)	HN.	MN
Water equivalent of daily new snow (mm)	HNW	—
Snow-covered area / total area (tenth)	Q	
Age of deposit (hrs, days, etc.)	A	
Inclination of snow surface (degrees)	N, ψ	

Snow-surface conditions

Surface deposit	Code symbol	Graphic symbol
Surface hoar	V1	⊔ or V
Soft rime	V2	V
Hard rime	V3	V̸
Glazed frost	V4	∾

These symbols are also used if such surface deposits are identified inside the snow cover.

Surface roughness

	Smooth	Wavy	Concave furrows	Convex furrows	Random furrows
Code symbol	Sa	Sb	Sc	Sd	Se
Graphic symbol	—	∿∿	⌣⌣⌣	⌢⌢⌢	⋀⋀⋀

Surface penetrability
PP Footprint depth (Man standing on one foot)
PS Ski track depth (Man supported on one ski)

	a	b	c	d	e
Depth of penetration (cm)	< 0.5	0.5-2	2-10	10-30	> 30

A similar value to PS is obtained by letting the first element of a 4 cm-ramsonde (1 kg) steadily penetrate under its own weight.*

Figure 6 shows the representation of a snow profile by curves, symbols and figures (see also Fig. 2).

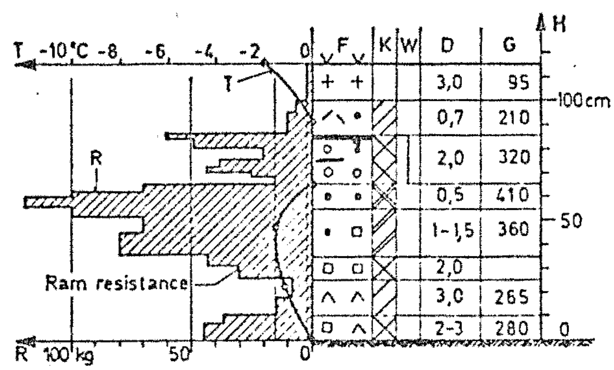


FIG. 6
Representation of a snow profile by curves, symbols and figures.

Subclassification of deposited snow

Feature	Units	Symbol	Subclassification a	b	c	d	e
Density	g cm⁻³ kg m⁻³	G					
Free water	%	W	Dry	Moist	Wet	Very wet	Slush
Grain shape	—	F	+ + + New snow. Close to F1-F7[1]	Often felt-like. Partly settled[2]	Granular. Rounded without/with melting[3]	Granular. With facets, full crystals[4]	Depth hoar. Cup-shaped[5]
Grain size	mm	D	0.5 Very fine	0.5-1 Fine	1-2 Medium	2-4 Coarse	4 Very coarse
Strength hardness[6]	9 cm⁻², kp cm⁻² kp	K R	Very soft	Soft	Medium	Hard	Very hard
Snow temperature	°C	T	Impurities		Ice (layer, lens, [illegible]) or		

1. Unchanged new snow crystals according to F1 to F7 of table 'Type of particles' above or slightly transformed crystals. Original shape well recognizable.
2. Crystals in advanced transformation (destructive and/or constructive metamorphism), but elements of original new snow crystals still recognizable. Symbol for b may be mixed with type a, c or d to characterize intermediate states. Snow of type b often has a felt-like structure.
3. Rounded, often elongated grains formed in prevailing destructive metamorphism without melting are marked with full dots. They are usually in the size range below medium. Melting and refreezing produces characteristic rounded grains with strong bonds*. They are symbolized with open circles. Grain size usually ranges from medium upward.
4. Usually only parts of the surface of a crystal of this type are developed as even glittering facets. Often rounded grains or cup-shaped elements are intermixed. Combined symbols of a with b, c and e are possible.
5. Depth hoar does not necessarily imply fully developed cup-shaded crystals. Usually only fragments of cups characterized by re-entrant angles and peculiar ledges are found (for combination of symbols see note 4).
6. The subdivision of strength and hardness is based on the Ram hardness (4 cm diameter cone-penetrometer with 60° apex) and the following rough correlation:

	Ramsonde 4 cm diam. R (kp)	Hand test	Shear strength (cohesion) K_s (g cm⁻²)
a Very soft	0-2	Fist	0-10
b Soft	2-15	4 fingers	10-75
c Medium	15-50	1 finger	75-250
d Hard	50-100	Pencil	250-500*
e Very hard	> 100	Knife	> 500*

The hand test indicates the object which can be pushed in the snow with a pressure of about 5 kp up to the upper limit of the given hardness class. (Unit kp stands for kg weight.)

NATIONAL RESEARCH COUNCIL OF CANADA

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AVALANCHE COURSES 1974-75

WEATHER OBSERVATIONS

The times of observation may depend on the operation and the needs. Standard observations should be made twice daily, once in the morning and once in the evening and always at the same time, e.g. 7:00 a.m. and 5:00 p.m. A reading once per day is a minimum. Additional observations must be made when the weather changes significantly and affects the avalanche hazard, e.g. during snow storms.

The following information must be recorded.

Date

Time - Use the 24 hour scale, e.g. 1700 and not 5:00 p.m.

Clouds

Estimate how much of the sky is covered with clouds and record with a symbol or report in words.

	Symbol	Report
No clouds		clear
¼ clouds		
½ clouds		cloudy
3/4 clouds		
fully covered		overcast
fog		fog

Type of Precipitation

	Symbol
Light snowfall	L ✳
Heavy snowfall	H ✳
Rain	R

If necessary, other types of precipitation may be recorded, e.g. graupel , hail, drizzle.

Air temperatures

Measured with a maximum and a minimum thermometer or a thermograph, housed in a Stevenson screen. The door of the screen must face away from the sun.

Minimum temperature: to be read at the end of the needle closer to the alcohol vapor column.

Present temperature: to be read at the alcohol column of the minimum thermometer.

Be careful not to warm up the thermometer with hands or breath.

After recording the temperatures, shake the maximum thermometer down. The minimum thermometer is reset by elevating the bulb end and permitting the needle to slide against the alcohol vapor column; do not shake.

Snow fall

The depth of new snow is measured with a ruler on platform stakes, preferably in centimeters.

Daily stake (HN): Depth of new snow deposited since the last twice daily observation. The board is cleared after sampling the snow for specific gravity observation and replaced on the snow surface.

Storm stake (STORM): Depth of snow deposited since the beginning of the storm. The board is cleared and replaced on the snow surface when the storm period is over.

Additional platform stakes, e.g. 24 hours, 3 hours, 6 hours, artillery control periods, may be used.

Total snowdepth (HS):

Total depth of the snow on the ground, observed on a preset and calibrated pole. The snow around the pole must not be disturbed. Level the snow that clings around the pole.

Penetration

It is observed by stepping with one foot into an area of undisturbed snow and measuring the depth of penetration. A more accurate and less subjective method is observing the penetration of the ramsonde.

Weight New snow

Snow is collected from the daily stake with a sampling tube of known cross section area and weighed. The tube is inserted vertically; more than one sample is collected when the snow depth exceeds the height of the sampling tube.

The standard 500 cm^3 sampler has a cross section area of 28 cm^2.

Record the weight of snow in grams.

Water equivalent (HNW)

The water equivalent of the new snow is calculated by dividing its weight, measured in grams, by the cross section area of the sampling tube, measured in cm^2.

$$* \text{HNW} = \frac{\text{Weight, gram}}{28 \text{ cm}^2}$$

Specific gravity (G)

The specific gravity of the new snow is determined by dividing its water equivalent by the depth of new snow.

$$G = \frac{\text{HNW}}{\text{HN}}$$

* It may be recorded in millimeters.

NOTE:

1 cm^3 water has a weight of 1 gram

1 cm = 10 mm

1 inch = 2.54 cm = 25.4 mm

Precipitation gauge

These are available different types of gauge that collect all the precipitation, snow or rain, and indicate its water equivalent. Basically any container with an open top will serve. The collector should contain an alcohol-glycol-water mixture to melt the solid precipitation.

Wind Direction

Direction where the wind blows from, recorded to 8 points of the compass (N,NE,E...)

Wind speed

If an anemometer is available, record in miles per hour .

If no anemometer is available record either as calm, low, moderate, high, or very high.

SAMPLE PAGE FOR FIELD BOOK

Date		2 Dec	2 Dec	3 Dec
Time		0700	1600	0700
Clouds				
Precipitation		Nil	L	Nil
Max Temp	°F	20	25	23
Min Temp	°F	12	20	8
Present	°F	20	23	12
Snowfall (HN)	cm	Nil	10	15
Storm	cm		10	22 cl
Total snow (HS)	cm	120	130	141
Penetration	cm	45	52	60
Weight	gr		22.5	36.6
Water equiv. [illegible]	[illegible]		[illegible]	[illegible]
Gravity			0.08	0.09
Wind direction		s	sw	
Wind speed		low	moderate	calm

AVALANCHE COURSES

OBSERVATION SITES

by V.G. Schleiss

Study areas and wind stations must be established in order to obtain snow and weather observations which represent the conditions in an avalanche area. The location of these representative or standard sites is selected by using experience and a thorough knowledge of the local area. A number of factors must be considered.

1. Study Areas

a) Location: Located in such a manner that the general prevailing weather and snow conditions for the area can be obtained. For avalanche hazard evaluation the sites should be close to the starting zones of the avalanches.

b) Elevation: At a key elevation to permit interpretation of conditions in the significant areas, such as artillery targets, accumulation areas of snow. An elevation equal to that of the avalanche starting zone is preferred.

c) Protection from wind: Snow drifting must be at a minimum. This is difficult to achieve for locations above the tree line.

d) Clearance: Obstructions (trees, buildings) must be at a distance at least their own height from the snow stakes and instrument screens.

e) Ground Cover: Covered with greenery (grass, moss).

f) Terrain: Fairly smooth, level and good drainage.

g) Other Protection: Fenced to prevent interference from outsiders (humans and game), sign.

2) Wind Stati ns:

When determining the location of wind stations it must be realized that wind effect in regard to avalanche hazard is the main requirement. For this reason it is in many instances advantageous to position a wind station on a ridge in preference to a peak, since large mountain slopes govern the local wind activity which in turn governs the avalanche hazard (slab formation).

Analysis of past records, if available, and shape of terrain should be used to determine representative locations. Observe locations of snow drifting at the mountain ridges.

October, 1972

AVALANCHE TERRAIN

by: Peter A. Schaerer

1) Definitions

Avalanche path or site: Entire area where snow moves.

The avalanche path contains 3 parts:

a) Starting zone (zone of origin): area where the snow breaks loose and starts to slide.

b) Track (zone of transition): slope or channel where the snow moves at more or less uniform speed; additional snow may or may not be set in motion.

c) Runout zone (zone of deposit): area where the snow decelerates and comes to rest.

The runout zone may be divided into a zone where the bulk of snow is deposited, and a wind blast zone. Only airborne snow dust would be deposited in the wind blast zone.

2) Recognition of Avalanche Paths from Vegetation

Scars in the forest: vertical strips having either no trees, or small trees, or young trees of uniform age.

Trees with broken tops, broken limbs, no limbs on the uphill side of the trunk. Broken trees, limbs, on the ground in an outrun zone. Damaged trees on the opposite valley side.

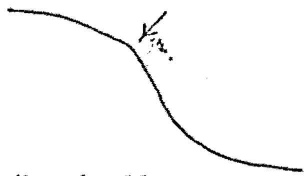
More sophistic methods for determining location and time of avalanches: studies of type and height of trees, growth patterns, tree rings.

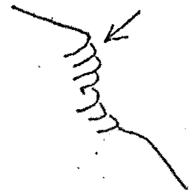
NOTE: A forest must be dense to prevent avalanches. Avalanches may start in areas covered with scattered large trees. The forest offers only limited protection against avalanches that start on open slopes above timber-lines. Large avalanches may break through heavy timber.

3) <u>Recognition from Characteristics of Terrain</u>

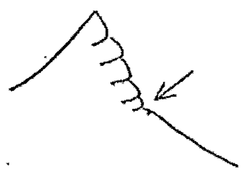
a) <u>Look for starting zones</u>. Avalanches usually fracture on steep terrain at characteristic spots:

- convex slope or cliff

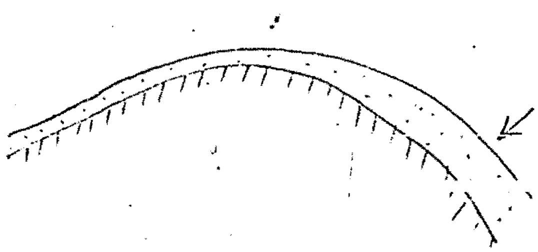


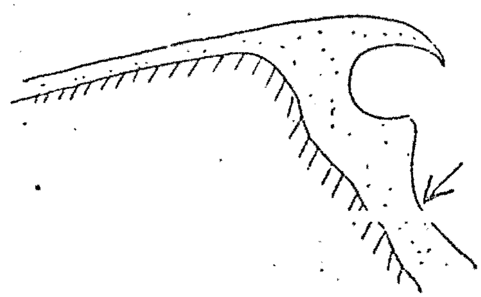


- headwall



- leeward side of ridge, often below a cornice.





Snow patches in summer often indicate the location of cornices and drifts. There are usually no avalanches on very steep terrain with incline more than 60 degrees.

b) <u>Look for Tracks</u>.

After fracturing the snow will continue to move only when there is a steep slope below the line or point of fracture. Inclines more than 30 degrees are usually necessary, but avalanches may slide on slopes with less incline under particularly unfavourable snow and weather conditions.

<u>Avalanches are more likely to run in channels than on open slopes</u>. <u>Rock gullies are always avalanche tracks</u>.

c) <u>Look for Outrun Zones</u>

Flat terrain or adverse slope below the track. The distance travelled by avalanches depends on their type (wet, dry, airborne) and size. Large, dry snow avalanches can move considerable distances, climb the opposite valley side and then fall back.

Avalanches may stop on wide terraces. Tree and rock debris indicate location of avalanche deposits.

4) Recognition from Observations of Snow

Avalanche sites may be identified from avalanches that have occurred. Look for:

- fracture lines
- deposits of avalanche snow with surface roughness, and colour different from surrounding snow
- flow channels in avalanche tracks
- snowfilled creeks and gullies in summer.

Avalanche deposits may often be recognized best in Spring when about half of the snow cover has melted.

5) Roughness of Surface

Irregularities of the surface, rocks, stumps, small trees must be covered before avalanches start to slide.

In rugged terrain, about 5 feet of snow is necessary, on smooth surfaces about 1 foot. Slopes that do not have at least this critical snow depth produce no avalanches.

6) Frequency of Avalanches

General rule:

The steeper the slope the more frequent the avalanches. The frequency depends also on other factors, such as snowfalls, exposure to wind, temperatures. Steep terrain produces usually frequent small avalanches, but sometime, for some reason large avalanches may occur.

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AVALANCHE COURSES

November 1974

Avalanche Classification and Recording

P. Schaerer

Avalanches that have occurred must be observed and recorded because the information is necessary,

a) for the day to day analysis of the snow stability and hazard evaluation,

b) for the planning of control measures and the design of defence structures.

An international avalanche classification which permits full description of the avalanches has been developed. For most purposes, however, it will be sufficient to record only the following information of each individual avalanche:

- Site (path): name, number, mileage, description
- Date, if possible time of occurrence.
- Location of starting zone: description, elevation, map code.
- Location of the tip of the deposit: distance from road, river, how far on the talus slope.
- Type of snow: dry, wet, damp, snow dust
- Size; either: small, medium, large, or major, relative to the size that is usual for this site, or: length, average width, average depth, maximum depth of the deposited snow, length of road buried.

- Damage to forest, structures, accidents, length of interruption of traffic.

The following additional information should be recorded when the starting zone is clearly visible or accessible (e.g. at a ski area):

- Type of fracture: slab avalanche, loose snow avalanche.
- Position of the sliding surface: new snow fracture, old snow fracture, on the ground.
- Depth of the slab, width of the slab.

International Classification

A proposal of an avalanche classification was published in-

Hydrological Sciences - Bulletin, XVIII, 4, 1973, pages 391-402. International Association of Hydrological Sciences, Gentbrugge, Belgium. Chart 1 is a summary of the morphological classification.

AVALANCHE CLASSIFICATION

Proposal of the Working Group on Avalanche Classification of the International Commission on Snow and Ice:

M. de Quervain, Chairman	(*Switzerland*)
L. de Crécy	(*France*)
E. R. LaChapelle	(*USA*)
K. Losev	(*USSR*)
M. Shoda	(*Japan*)

1. PRINCIPLES OF CLASSIFICATION

1.1. Purpose of Classification

Scientific Purpose

Grouping of various avalanche phenomena (morphological and others) in such a manner that statistical or functional relations can be established between any factors associated with avalanches and observed avalanche activity (terrain, weather, climate, forces etc.).

Practical Purpose

Recording and exchange of condensed information on avalanches that have occurred or are expected to occur in view of precautions, rescue operations or engineering measures.

1.2. Users of the Classification

According to the wide range of the purposes, users may possess very different levels of scientific and practical knowledge and experience. It is therefore intended to create a classification which is suited for general use but it should imply the basic elements of a systematic scientific classification which may be extended and refined without changing the fundamental structure.

1.3. Morphological and Genetic Classification

It is deemed adequate to split the problem of avalanche classification into two basic subclassifications, one dealing with *observed* (or observable) *facts* about the *immediate phenomenon* of an avalanche. We call this the *morphological classification* using the term 'morphological' in its widest sense. The other classification is focussed on *processes which induce avalanche situations*. We call this the *classification of avalanche conditions* or, shorter but less appropriately, '*genetic classification*'.

The morphological classification is concentrated on the avalanching snow, its properties and its appearance. It also includes the morphology of movement, which does not require an eye witness in most cases. The morphological classification as such does not imply knowledge or theories about avalanche formation and avalanche mechanics.

The *genetic classification* (classification of avalanche conditions), relating avalanche events or avalanche situations to prior influences, is based on certain more or less established connections. It envisages either a genetic analysis of an observed avalanche or the evaluation of developing avalanche danger. With the progress of science new knowledge and new concepts may introduce changes in this classification.

A complete description of an avalanche involves qualitative and quantitative observations. Whereas qualitative features like 'shape' or 'type' of a phenomenon call for a proper classification, quantitative properties like 'length', 'volume' etc. should be expressed in measured or estimated figures. Such precise properties, however important, are not part of the classifications.

As a further step it is planned to publish an *Avalanche Atlas* with photographs illustrating all typical features of avalanches.

2. MORPHOLOGICAL AVALANCHE CLASSIFICATION

Avalanches are classified according to a number of more or less independent *criteria* to be encountered in the zone of origin, transition or deposit. For each criterion two *alternative characteristics* are established, some being subdivided into two subgroups. In many avalanches both alternative characteristics of certain criteria are represented either simultaneously or in different phases or areas of an avalanche. In such cases *mixed types* are listed.

2.1. Morphological Avalanche Classification

See Chart 1.

2.2. Comments on Morphological Classification

Definition of Zones

Zone of origin

Zone in which the appearance and movement of an avalanche is characterized by the manner of starting. For a slab avalanche it comprises a distance down to the pressure fracture; for a loose snow avalanche there is no sharp lower limit. A distance of 100 m will include the zone of origin in most cases.

Zone of transition

Flow independent of manner of starting. The velocity may be increasing, steady or decreasing. No particular avalanche deposit is visible after movement has stopped, except for snow retained by roughness of terrain or narrow gullies.

Zone of deposit

A natural deposit is produced by loss of energy due to friction and compaction. It may exhibit a wide range of slope angles including even a reverse of slope. For powder avalanches the zone of deposit is the sediment zone of the snow cloud.

Criteria

Manner of starting

Loose snow avalanche — Starting point may be initiated by a falling object (stone, ice chunk etc.) or by a skier. In the latter case the point fracture mechanism is obscured.

Slab avalanche — 'Starting from a line' does not exclude the origin of the movement being propagated as an invisible fracture from a distant point of initiation.

CHART I

Morphological avalanche classification

Zone	Criterion	Alternative characteristics and denominations	
Zone of origine	A. Manner of starting	*A1* starting from a point (loose snow avalanche)	*A2* starting from a line (slab avalanche) *A3* soft *A4* hard
	B. Position of sliding surface	*B1* within snow cover (surface layer avalanche) *B2* (new snow fracture) | *B3* (old snow fracture)	*B4* on the ground (full-depth avalanche)
	C. Liquid water in snow	*C1* absent (dry snow avalanche)	*C2* present (wet snow avalanche)
Zone of transition (free and retarded flow)	D. Form of path	*D1* path on open slope (unconfined avalanche)	*D2* path in gulley or channel (channelled avalanche)
	E. Form of movement	*E1* snow dust cloud (powder avalanche)	*E2* flowing along the ground (flow avalanche)
Zone of deposit	F. Surface roughness of deposit	*F1* coarse (coarse deposit) *F2* angular blocks | *F3* rounded clods	*F4* fine (fine deposit)
	G. Liquid water in snow debris at time of deposition	*G1* absent (dry avalanche deposit)	*G2* present (wet avalanche deposit)
	H. Contamination of deposit	*H1* no apparent contamination (clean avalanche)	*H2* contamination present (contaminated avalanche) *H3* rock debris, soil | *H4* branches, trees

— The term 'slab' is often used synonymously with 'slab avalanche'. This should be avoided unless there is no doubt about the correct meaning.

— Distinction between soft and hard slab may be based on testing the snow at the fracture site, considering any changes that might have occurred, or, with less reliability, on the appearence of the avalanche.

soft slab: Broken snow layer is very soft, or soft and of low density (see snow classification). Slab disintegrates into loose material immediately after the start.

hard slab: Broken snow layer is medium hard, hard or very hard and of high density. A hard slab preserves chunks or blocks over longer avalanche paths depending on their roughness.

— Slab fracture may be observed without subsequent avalanche (often related to the gliding movement of wet snow on the ground).

Position of the sliding surface

Within snow cover — 'New snow' in 'new snow fracture' is defined by a uniform layer of snow more or less continuously deposited within the last 1–5 days previous to the avalanche date and not implying granular snow types. A fracture separating 'new snow' from underlying 'old snow' is a 'new snow fracture' even if the surface condition of the old snow (e.g. surface hoar, sun crust, loose surface) favoured the fracture.

— An 'old snow fracture' lies *within* the old snow, thus contributing old snow to the avalanche at the fracture line. Whether the majority of avalanching snow consists of new snow and the new snow load actually caused the avalanche does not matter.

On the ground. If some snow patches are left on the ground due to roughness of the ground surface, 'full depth avalanche' should be noted nevertheless.

Liquid water

A 'wet snow avalanche' requires liquid water to be present throughout the avalanching layer, otherwise the avalanche would be dry or mixed. Discrimination may be difficult without considering genetic elements (development of temperature, rain).

The classical term of 'ground avalanche', often being used as the opposite of powder avalanche, is reserved for heavy, wet spring avalanches dragging along rock or soil material.

Form of path

Many channelled avalanches start as unconfined avalanches and are concentrated in a channel only in the lower part of their course. If the dominant part of their path is channelled they are characterized as 'channelled', otherwise a mixed type is reported, describing the unconfined and channelled sections.

The *longitudinal profile* of an avalanche path is often very important (changes in slope angle, intermittent steps). A quantitative description of the profile is rated to be better than an elaborate classification of all possible terrain profiles.

Form of movement

Mixed types are very frequently observed. 'Mixed flowing-powder avalanche', 'powder avalanche with flowing component', 'flowing avalanche with powder component' are possible ways to characterize mixed types. A movement detached from the ground—either of powdery or flowing type—may be called a 'cascade'.

Liquid water in snow debris

Large avalanches which are dry in the zone of origin may pick up wet snow in lower parts of the track and change their character. Wet snow in debris causes hard and solid deposits, practically impermeable to air, an important fact for rescue work and avalanche clearing.

2.3. Code for Morphological Classification

Letter for each criterion
Figure for characteristics (alternatives or mixed type)
A full set of codings refers to one particular avalanche only

General use of figures

– unknown or not applicable	0
– specific characteristics	1-6
– mixed types	7,8
– reference to special remarks outside the code system	9

CHART 2

Code system

Manner of starting	*A*
Loose snow avalanche	1
Slab avalanche (general)	2
Slab avalanche soft	3
Slab avalanche hard	4
Mixed or intermediate type 1+2	7
Position of sliding surface	*B*
Surface layer avalanche general	1
Surface layer avalanche new snow fracture	2
Surface layer avalanche old snow fracture	3
Full depth avalanche	4
Mixed type 1 (2 and/or 3)+4	7
Mixed type 2+3	8
Liquid water in snow at fracture	*C*
Dry snow avalanche	1
Wet snow avalanche	2
Mixed type	7
Form of path	*D*
Unconfined avalanche	1
Channelled avalanche (dominant part)	2
Mixed type	7
Form of motion	*E*
Powder avalanche (dominant)	1
Flow avalanche (dominant)	2
Mixed type	7
Surface roughness of deposit	*F*
Coarse deposit (general)	1
Coarse deposit—angular blocks	2
Coarse deposit—rounded clods	3
Fine deposit	4
Mixed type	7
Liquid water in deposit	*G*
Dry deposition	1
Wet deposition	2
Mixed type (locally separated)	7
Contamination of deposit	*H*
Clean avalanche deposit	1
Contaminated deposit (general)	2
Contaminated deposit—rock, debris, soil	3
Contaminated deposit—branches, trees	4
Mixed type 1+2 (locally separated)	7
Mixed type 3+4	8
*Mode of release**	*J*
Natural release	1
Human release (general)	2
Human release—accidental triggering	3
Human release—artificial triggering	4

* This class is an element of the genetic classification.

Use of the code (example)

Either: *A*3 *B*9 *C*0 *D*7 *E*2 *F*2 *G*2 *H*4 *J*1

or (on a prepared form):

A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*J*
3	9	0	7	2	2	2	4	1

*B*9: 3 fracture levels

3. GENETIC AVALANCHE CLASSIFICATION

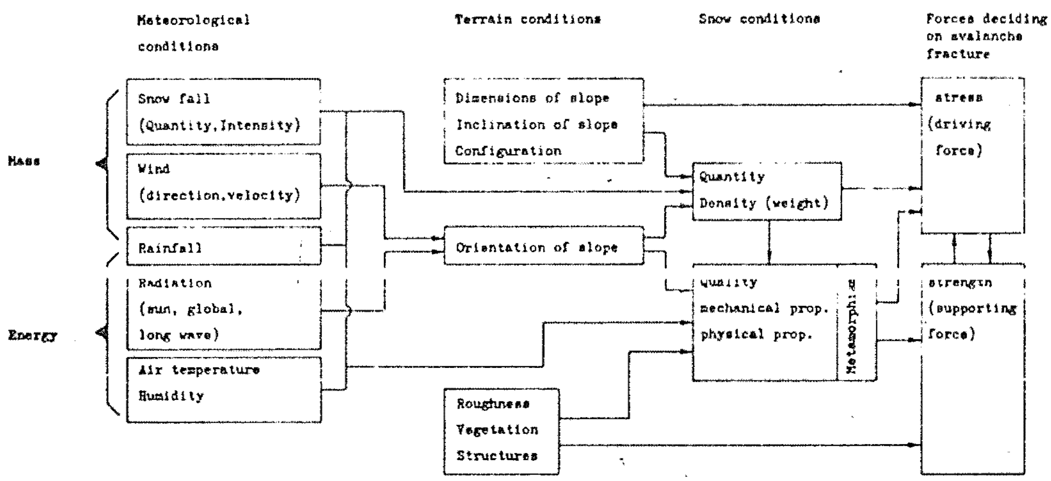
(Classification of avalanche conditions)

This section offers a tentative abstract of a very complex system of genetic relations between environmental conditions and avalanche activity. A more elaborate treatment as undertaken by the working group will be presented on a later occasion.

A general scheme (Chart 3, a slightly modified proposal of Mr. Shoda), shows the relations between genetic factors, snow conditions and the dominant mechanical parameters for avalanche formation (stress and strength).

CHART 3

Flow chart representing relations between genetic factors, terrain conditions and the development of stress (driving force) and strength (supporting force)



The chart refers to the interaction between variable factors (meteorological conditions) and stable parameters (terrain conditions). An attempt to establish for each individual genetic factor its specific influence on avalanche formation, or vice versa, to attribute to an avalanche event its specific genetic factors, will hardly reach quantitative results. One has to be satisfied with pointing out general tendencies. In Chart 4 dominant relations are plotted only, omitting exceptional features.

Given avalanche conditions—local, short term or long term—are entered in the left column. On the right-hand side reference to effects on the snow cover and possible avalanche development is found. The scheme needs to be completed by local experience which may vary from one climatic region to an other, the basic relations, of course, remaining the same.

No attempt has been made at the present time to cast the chart in the form of a code system, except for the triggering conditions (4) which have been added to the code of the morphological classification, since they offer no particular problems.

It may be mentioned, that statistical methods are being studied to correlate numerically an observed avalanche activity to a set of observed meteorological parameters. With the multi-dimensional system of correlations thus obtained, it should be possible to derive a forecast of avalanche activity for given or expected meteorological parameters. One day these investigations may serve to refine the genetic classification.

3.1. Scheme of Conditions and Effects (Abstract)

See Chart 4.

CHART 4

Scheme of conditions and effects (abstract)

[abbreviation: av. = avalanche(s)]

Condition	Effect on avalanche activity
A. Fixed framework	
(1) *Terrain Conditions*	
(1.1) *Relative altitude*	
General topographic situation:	Effect depending on latitude and level of surrounding mountains.
— zone of crests and high plateaux	Strong wind influence, cornices, local slab av.
— zone above timberline and below crests	Extended areas of slab av. formation.
— zone below timberline	Reduced wind influence. Reduced slab av. soft type prevailing.
(1.2) *Inclination* (ψ)	
$>35°$	Formation of loose snow av. possible.
$>25°$	Formation of slab av. possible.
$>15°$	Stationary or accelerated flow.
$<20°$	Retarded flow or deposition. (Slush av. at very low angles.)
(1.3) *Orientation of slope*	
— relative to sun	On shady slopes enhanced slab av. formation. On sunny slopes enhanced wet av. formation.
— relative to wind	On lee slopes increased drift accumulation; enhanced slab av. formation. On luff slopes vice versa.

CHART 4 (*continued*)

Condition	Effect on avalanche activity
(1.4) *Configuration of terrain*	
— open, even slopes	Unconfined av.
— channels, funnels, ridges	Confined, concentrated, channelled av.
— changes in gradient	Slab or loose snow fracture at convex gradients.
— steps	Powder av., cascade formation.
(1.5) *Roughness*	
— smooth ground	Snow glide (on wet ground); full depth av. favoured.
— protruding obstacles (rocks, cross ridges)	Surface layer av. above level of roughness.
— vegetation	Grass: promoting snow glide, and full depth av. shrubs: reduction of av. formation if not snow covered. forests: prevent av. formation if dense.
B. Genetic variables	
(2) *Recent Weather* (period ~ 5 days back)	
(2.1) *Snow fall*	Increasing load. Increasing mass of low stability. *Most important factor of av. formation.*
— type of new snow	Fluffy snow: loose snow av. Cohesive snow: slab av.
— depth of daily increments of new snow	Increasing instability with snow depth ($\psi > \sim 25°$). New or old snow fracture.
— intensity of snow fall	Progressive instability with higher intensity; promoting new snow fracture; expanding danger to low inclination.
(2.2) *Rain*	Promotion of wet loose snow av. or soft slab av. Mixed snow and land slides.
(2.3) *Wind*	Two effects: enhanced local snow deposit (see 1.3) and increased brittleness of snow.
— direction	Increased slab av. formation on leeward slopes. Formation of cornices.
— velocity and duration	Local slab av. formation increased with increasing velocity and duration.
(2.4) *Thermal conditions*	
Significant factors: Temperature and free water content of snow.	Ambivalent effect on strength and stress, i.e. on av. formation: Rise of snow temperature causes crisis, but ultimately stability. Rise of free water content promotes av. formation.
— air temperature	Similar effect to all exposures.
— sun radiation	Dominant effect on sun exposed slopes.
— temperature radiation	Cooling of snow surface at night and in shadow; important with cloudless sky. Promotion of surface and depth-hoar formation (see 3.2).

Condition	Effect on avalanche activity
(3) *Old Snow Conditions* Integrated past weather influences of the whole winter season	
(3.1) *Total snow depth*	Not dominant factor for av. danger. Influences mass of full depth av. Important to compaction and metamorphism of snow cover. Surface layer av. see (1.5).
(3.2) *Stratification* Sequence of strength	Stability governed by weakest layer with respect to state of stress.
— surface layer	Looseness (surface hoar), brittleness, roughness important to subsequent snow fall.
— interior of snow cover	Old snow fractures caused by *weak intermediate layers* (old surfaces) and *depth hoar.*
(4) *Triggering Conditions*	
(4.1) *Natural release*	Natural av.
— internal influences	Spontaneous av.
— external (non human) influences	Naturally triggered av.
(4.2) *Human release*	
— accidental triggering	— Accidental av. (triggering).
— intended release	— Artificial av. (triggering).

3.2. Comments on Genetic Conditions and Effects

(1.1) *Relative altitude*

The altitude effect is very complex. It involves variation with altitude of: temperature, radiation, wind, precipitation, duration of winter, vegetation, general topography. The effect is relative insofar as it is variable with respect to latitude and climatic region.

(1.2) *Inclination*

Due to variable strength and friction of snow there is a great variation in slope angle related to the starting and flowing conditions of avalanches. The given figures represent common values of inclination but not the extremes. There is an overlap for stationary or accelerated flow and retarded flow and deposition.

(1.5) *Roughness of ground*

Snow glide may provoke large fissures in the snow cover without resulting in avalanches. In avalanche protection techniques a particular classification of roughness is used characterized by a 'glide-factor' N.

(2) *Recent weather*

Only avalanches caused by recent weather conditions and running in new snow have been called 'direct action avalanches' (type *B*2). Avalanches involving a long-term development (metamorphism) in the old snow cover [see old snow conditions, stratification (3.2)] have been called 'climax avalanches' (type *B*3 or *B*4).

(2.1) *Depth of new snow*

Most catastrophic avalanches affecting settled zones and a high percentage of winter sports avalanches are related to *new snow deposition*. New snow depth is used as the most important factor in avalanche warning. A clear distinction should be made between the sum of daily snowfall measurements (daily new snow increments), the settled depth of a new snow layer built up within several days and the increase of total snow depth (three different figures).

(2.2) *Wind*

Brittleness of drift deposit causes local peak stresses and brittle fractures. As a rule cornices themselves are not the most dangerous spots for slab fracture. They indicate the prevailing wind conditions, but fracture usually occurs below cornices. From certain regions an upper limit of wind influence is reported. Higher areas may be deprived of snow by extremely high winds to such an extent that avalanche activity is reduced there.

4. QUANTITATIVE DESCRIPTION OF AVALANCHES

Research as well as investigation of avalanche accidents may necessitate a full quantitative description of all features of an avalanche and of the genetic conditions far beyond the schemes of both classifications. A list of possible observations is given below. The important characteristics are marked with *.

4.1. Notes on Inspection Trip

Name of observer(s). Date of inspection. Weather at time of inspection.

4.2. Maps, Sketches, Photographs*

On *maps* general location and outlines of avalanches are recorded.

Sketches are best suited for plotting dimensions and local characteristics of avalanches (scale 1 : 500 ÷ 1 : 5000).

Photographs (quality often depending on weather conditions) are of documentary value. Since, as a rule, the result is not immediately seen, photographs are taken in addition to sketches.

4.3. Notes on Characteristics of Avalanches

Location: District, town, mountainside, if necessary geographical coordinates.

Altitude: of fracture zone, of lowest deposit.*

Date and time: of avalanche descent.*

Characteristics of avalanche: according to morphological classification.*

UNITED NATIONS EDUCATIONAL,
SCIENTIFIC AND CULTURAL ORGANIZATION

Department of Environmental Sciences

Report on Destructive Avalanche

COUNTRY: Winter 19../19.. Serial No.:

Name and address of reporter: ....
....

LOCATION: (Name of district, nearest town or village, mountain area, avalanche path)

....

Latitude: .... Longitude: .... Altitude: ....

DATE: .... 19....; Time: ...., = ... (GMT)

DATA ON AVALANCHE:

Type (International classification): ....
.... Orientation: ....

*Dimensions**

Starting zone: Altitude: .... Width: .... Depth of fracture: ....

Avalanche path: Length: .... Width: .... Average slope: ....

Deposit: Maximum depth: .... Volume: ....

Causes

Snow structure: ....

Weather (snowfall, wind, temperature): ....
....

Triggering mechanism (if known): ....

CASUALTIES AND DAMAGE:

[illegible]

Damage to buildings (type, number, degree of destruction): ....
....

Other damage (forests, communications, etc.): ....
....

REMARKS (rescue work, former history of avalanches, etc.)

....
....
....
....

Attach photographs and/or sketches if possible. *Please use metric system

Note: This form should be completed as soon as possible after the event and, after checking by the national reporting centre, be sent, in duplicate, together with the corresponding annual avalanche report, to the following address:

The Director,
Department of Environmental Sciences,
Unesco,
Place de Fontenoy,
Paris 7e (France)

IMP/1520

Dimensions: Width and depth or thickness of fracture*, total snow depth in fracture area, length and width of avalanche *path**, dimensions and volume of avalanche *deposit*. Area of secondary action (blast effects). Former avalanche descents.

Dynamic characteristics: Velocity, pressure.

4.4. Description of Avalanche Conditions (Genetic Factors)

Terrain conditions: Inclination*, orientation*, apparent roughness, vegetation, geological aspects (in all sections of avalanche path).

Recent weather (about 5 days back): Snow fall*, rain, wind*, thermal conditions, humidity.

Old snow conditions: Description of stratification near fracture (if possible complete representation of snow profile).

Triggering conditions: natural release, human release.

4.5. Avalanche Effects

Number and names of persons affected: killed, injured, unharmed. (Circumstances of accident.)

Damages to buildings: Type, number, degree of destruction.

Blocking or destruction of traffic systems.

Damages to forests and pastures, lost cattle. Performance of anti-avalanche structures.

4.6. Rescue Operations

Persons and means involved. Chronology of operations. Location of victims etc. (depth, time since accident, physical conditions, success of reanimation etc.)

4.7. Form for Single Avalanche Accidents

A condensed *standard checklist* is available from UNESCO for plotting most important avalanche data (Chart 5, reproduced with permission of UNESCO).

AVALANCHE CONTROL

by Norman A. Wilson

INTRODUCTION

A. Man's efforts to prevent loss of life and property are broadly termed Avalanche Hazard Control.

1. These efforts take many forms

   a. Closure
   b. Artificial initiation of avalanche at selected times and locations (Test skiing, explosives, etc.)
   c. Physical interference with natural metamorphosis (protective skiing, boot packing, compaction)
   d. Structures
      1) To alter the course of avalanches
      2) To prevent avalanche movement

2. Method chosen should depend on specific need at specific location

   a. Need varies with use, terrain, climatic zone, and economic factors
   b. Examples
      1) Ski slope: structures, no
         Gully above ski slopes: structures, yes, if no other alternative
      2) Town, Alps, Rockies: structures, yes
      3) Town, Sierra, Cascades: structures, no
      4) Ski slope: closures, active control, yes
      5) Highway: closures, active control, no
      6) Town: closures, active control, no

B. Each method

1. Is valid where it applies

2. Has limitations, specific uses

C. No single method is applicable to all situations.

I Temporary Closure

A. Was once only form of control

B. Is least desirable form of control

C. Is simplest form of control

1. Quick and easy - smallest manpower, equipment requirements

2. Most effective if:

a. Physical (lift closure, road blockade)
b. At logical points - terrain separations
c. At routine points - not haphazardly posted
d. Understood by public - public information

D. Reliable only for short time periods

1. Only as long as public believes the need (storm)

2. Time period particularly short in clear weather

a. Physical clsoure will be resented
b. Signs will be disobeyed - resultant problems

E. Proper use = temporary supplement to other control measures

1. Test skiing

2. Explosives, artillery

F. On occasion, closure is utilized as final weapon in avalanche man's arsenal. During certain conditions of wind, rain, snowfall, or temperature, closure is the only method of avalanche hazard control that can be relied on. Even the most sophisticated control team cannot contain the hazard if it grows too rapidly and is too widespread. In these conditions the avalanche forecaster should exercise his most effective means of closure, then withdraw and wait for a change in the weather.

G. Permanent closure

1. To be effective, requires separation by natural terrain features

2. Within area, closures will be violated, thus hazard must be controlled by other means (clsoure can be maintained, but not for avalanche)

H. Summary

1. Closures necessary at times

2. Must be lifted as soon as possible or will be ineffective.

II. Stabilization by compaction

A. Protective skiing is the process of deliberate, day-to-day skiing of avalanche slopes, done in a manner calculated to encourage stabilization of the snow pack.

B. Age hardening is the process snow undergoes when it is skied on or stepped on (disturbed mechanically), and then allowed to set. This hardening process continues for a period of hours after the snow is disturbed until the snow reaches a maximum value of hardness, the degree of this hardness being influenced by the temperature and water content of the snow. Age hardening of snow slopes by artificial means such as skiing or foot packing can be an important factor in prevention of direct and delayed action avalanches.

C. Effect of breaking surface slabs

Another effect of protective skiing is the relief of [illegible] surface layer by the breaking up of homogeneous slabs. Slabs that have been broken in this manner without avalanche release tend to become bonded to the layer beneath. When protective skiing is performed while the snow is falling, slab formation can be completely prevented. Protective skiing will not affect hard slab.

D. Protective skiing differentiated from test skiing and the two combined.

1. Protective skiing is a continuing process designed to prevent, or at least minimize, the liklihood of deep (climax) avalanching at a later date.

2. Test skiing is an attempt to release avalanches on selected small slopes by skiing in a calculated manner along the normal fracture zones of those slopes. Test skiing is used primarily as a guide or indicator in determining the degree of direct action hazard buildup and the possible need for control measures: closures, blasting, protective skiing, or more test skiing. On selected small slopes and under low and sometimes moderate hazard conditions test skiing is frequently used as a means of control. The avalanche man, however, must beware of

heavy reliance of test skiing for control purposes. When avalanche control personnel are avalanched, it is usually because they were test skiing when they should have been using explosives. Similarly, the rare avalanches that occur within controlled areas after control measures have been completed and the slopes opened for skiing can usually be traced back to improper control measures; i.e., non-use or mis-use of explosives.

3. Test and protective skiing combined.

Test skiing should be followed immediately by protective skiing unless more extensive measure are indicated, thus, the test-protective skiing operations are often combined. Safety precautions for both are identical: one man on the slope at a time, all other crewmen watching him from anchor points, each crewman traversing the slope in turn, until the slope has been thoroughly cut up by a series of traverses, after which the slope may be skied normally.

E. Heavily skied slopes avalanche less often and less severely than lightly skied slopes. Lightly skied slopes probably yield more small avalanches and sluffs than slopes which are not skied at all but fewer large, deep avalanches. Thus, breaking up the snow with light skiing improves the stability of the pack in several ways. Compacting the snow with heavy skiing assures a solid, well anchored layer that will tend to hold itself and the layers beneath it in place.

1. The public should be encouraged to assist in the protective skiing process. Experienced avalanche men attempt to encourage the skiing public to ski onto avalanche slopes once they have been tested, so that the impact of numbers of skiers will thoroughly pack each layer of newfallen snow.

F. Immediate and long-range effects

1. The immediate effect of protective skiing is complete stabilization of the surface layer.

2. The long range effect is a snow pack that is much less prone to climax avalanching than a neighboring, unskied slope of the same angle and orientation if each new layer is completely stabilized in its turn. This long range effect applies to spring thaw conditions as well as to winter conditions.

G. Foot packing - TG-metamorphism (depth hoar)

1. Depth hoar does not compact as readily as new snow: age hardening is therefore more difficult to initiate.

2. Higher specific pressure of boot required to compact depth hoar.

3. Compaction will inhibit future growth of depth hoar but will not prevent its formation if other factors predominate (sharp temperature gradients).

4. Summary: surface layers of depth hoar can be compacted and stabilized by foot packing. Routine foot packing of each layer of new snow will only inhibit future growth or depth hoar within the pack. Where depth hoar is a serious problem (as in the Rockies), foot packing certain key slopes is economically justified but must be done to each layer before it is buried by later snowfalls. As a practical matter, only small slopes can be effectively treated with foot packing unless a great amount of manpower is available on a volunteer basis.

H. Thawing snow

1. Protective skiing in thawing snow assumes a different dimension from protective skiing in cold snow. It is actually a combination of test and protective skiing.

2. When thawing conditions create a hazardous, water-saturated layer on the surface of the snowpack, a simple traverse along the upper end of a steep slope may release a layer many inches deep across the entire width of the slope. Slopes in this condition, and their runout zones, should be closed to skiing until stabilized.

3. Such a condition should be anticipated as temperatures rise and the slope should be regularly and thoroughly sideslipped at the upper zone. This will:

a. Release shallower layers than mentioned, or large snowballs, that carry less destructive potential.

b. Reduce the hazards inherent to temporary closures in clear weather.

c. Tend to stabilize the layers that remain on the slope through release of the highly unstable overload, followed by age hardening processes.

4. Whether large or small, the resulting wet avalanches can attain the speed of running water on steep slopes and must be considered about the most dangerous of avalanches for the person on foot or skis.

5. The technique of protective skiing in thawing snow requires careful assessment of:

a. The extent of the previous night's freeze, or lack of same, the time of day, the cumulative effects of the sun, the current sun angle on the slope.

b. The position of the avalanche crewmen, and the technique he will use in the snow conditions encountered. For example: if the surface layer is highly unstable the simple swoop along the top described earlier may do the job. If the surface layer is only moderately unstable the crewman may have to sideslip vertically a few feet to initiate snow movement only as wide, at first, as his skis. He may have to do this many times, sidestepping back up to his starting elevation each time, across the width of the slope, before the slope can be considered stabilized. This is an arduous process, but the alternative is to close the slope and outrun areas and do nothing but hope for a deep freeze when the sun goes down. If the hoped-for freeze does not materialize, the water-soaked layer will be deeper and more hazardous the next day. In the sideslipping process, the crewman must continuously evaluate the snow he is dealing with and his loaction in it. He must stay above any snow movement he has initiated, or he may be part of the avalanche.

III. Hand Thrown Explosives

INTRODUCTION

The use of explosives in snow avalanche control is routine in North America. Explosives introduce a violent mechanical disturbance to the snow cover, thus provide a definite answer to the question, "Is this slope stable?", at locations and under conditions in which test skiing techniques would be excessively dangerous or ineffectual.

With explosives a positive test can be applied to a slope quickly, safely, and with a minimum of manpower. Explosives are the only means of testing snow effectively where there is hard slab.

Hand charges and their uses have become more sophisticated since the first Snow Ranger became dissatisfied with the effectiveness of his "Closed Area, Avalanche Danger" signs. On that day a quarter century ago, the Ranger had no history or any other data on which to base his thoughts regarding the amount of explosive he should use, or where to place it. His charge consisted to some twenty pounds of military explosive set at considerable personal risk "somewhere" on the avalanche slope.

The Ranger armed the charge with an electric blasting cap, wires were strung to a safe position, and the charge was detonated. The results were satisfying. The amount of overkill was discovered later, along with all the other refinements of explosives types, detonating velocities, trigger points, and occasional requirements for depth of placement in the snow.

A. Hand placed explosives

Hand placed explosives are here defined as any explosive charge thrown, dropped, lowered, or actually set into the blast position by member of an avalanche control team. Hand placed explosives are further referred to as "hand thrown charges" or simply as "hand charges."

B. The use of explosives, whether hand placed or delivered with projectiles, in avalanche control work serves several purposes:

1. To test the stability of new-fallen snow for avalanche hazard. The test yields one of three results:

a. An avalanche occurs. This proves that the snow is unstable and further control action is needed on other slopes.

b. The snow cracks and either slides only a short distance or stabilizes in place. This indicates a moderate degree of instability, and calls for further action.

c. Nothing happens except the formation of a crater in the snow. This suggests stability. If confirmed by several more tests at key avalanche slopes, it may be taken as evidence that all slopes of the same aspect and elevation are stable.

2. To hasten stabilization of new fallen snow (relief of creep tensions) as a means of preventing deep avalanching at a later date, and as a by-product: age hardening at limited locations.

3. To release hard slab formations, determined unstable by other tests such as stratigraphy studies, observation of artificial or natural avalanche occurrences at other avalanche sites, or analysis of snow, weather, and avalanche records.

4. To release cornice formations at selected times.

C. The basic principle in the use of explosives in avalanche control is to apply: the right charge--amount and type of explosive; at the right place--the trigger zone of the specific avalanche path being tested; at the right time--when a resulting avalanche would not endanger anyone, and when the snow has reached an unstable condition.

1. The right charge

A high detonation pressure is believed best for slope avalanche testing of newfallen snow. Detonation pressure varies approximately with the square of the detonation velocity and directly with the density of an explosive. Density is the mass to volume ratio of the explosive. Detonating velocity, or detonation rate is a measure of the speed with which an explosion propagates within a column of explosives. Detonating velocities are expressed in feet per second. An explosive with twice the detonating velocity of another of equal density will deliver, roughly, four times the detonating pressure of the other. Thus, the fastest, densest, explosives available should be used. T.N.T., with an unconfined detonation rate of 21,000 f.p.s., is used as the standard against which to compare other explosives for relative effectiveness as an avalanche charge. It has been determined through experimentation and field use that a two-pound charge detonating at a velocity equal to or in excess of that of T.N.T. will provide a satisfactory test for soft slab avalanche hazard. To achieve an equal effect with slower detonating explosives, a considerably greater amount of explosives-per-charge must be used. How much greater that amount must be has not been scientifically demonstrated. Controlled experiments involving as variable a component as snow are difficult; however, experimentation with explosives of different detonating velocities, combined with opinions formed during field use, permit this statement: in order to apply a test to a soft slab equal to that applied by two pounds of T.N.T. or a faster explosive, not less than four pounds of 60% gelatin dynamite (16,000 f.p.s. unconfined) or not less than eight pounds of 40% gelatin dynamite (8,000 f.p.s. unconfined) must be used.

Thus, for economic and practical reasons, two pounds of T.N.T.-or-a-faster explosive will be referred to here as the "standard slope charge" for soft slabs. Where avalanches are being controlled in broad cirques or bowls, or where terrain configurations or islands of timber provide numerous anchorages, it is often necessary to use more than one charge, perhaps many. On certain broad slopes the most effective procedure will be the use of double, triple, or even large size charges, or multiple charges strung out along the slope, detonated simultaneously with primacord. Avalanches that require this treatment will generally be hard slab or combination hard and soft slab avalanches.

Hard slabs form under known weather conditions: the avalanche forecaster must consider the possibility of their presence. Control of hard slabs frequently requires large charges. The size of the charge required for a particular avalanche path can best be determined through experience with that path. When in doubt, however, it is far better to use more than enough explosive than too little.

2. The right place: trigger zones

The right place for a hand charge on a given avalanche path will vary in some degree with the weather. Wind direction and velocity and the amount of new snow are key factors. The water content of the new snow is believed to be a factor here, but this has not been conclusively proven. Familiarity with his area will help the avalanche man choose the best shot placement at a given time. Lacking specific area familiarity, the avalanche worker may apply the following rules to both hard and soft slabs: the charge should be placed immediately below the steepest point in convex and concave slopes, preferably near the top of the slope, and not directly above anchorages such as rock outcrops or trees. If there is a wind roll present, the shot will be effective near the bottom of the roll; however, the blaster may wish to try shots higher in the roll in order to remove all of it, thus avoiding leaving a snow cliff in the slope. Good placements in gullies are in heavy depositions, or pockets of snow, created by the wind. These are nearly always on lee slopes, but occasionally will be found as hard slab formations on slopes adjacent to the true lee slope. Presence of such depositions can usually be observed by the avalanche crewman.

When abnormally high storm wind velocities are experienced, the avalanche crew should watch for a change in the relative elevations of the fracture zones. Fracture zones--trigger points--will frequently be abnormally low on the slope at these times, due to deposition and slab formations induced at the lower locations by the extra strong winds. Results yielded by hand charge placement at the first two or three targets should tell the avalanche forecaster if he is dealing with abnormal trigger zone locations. This information should be passed on to other avalanche personnel, if any.

If there is doubt about the very best placements for any avalanche path, the crewman should place his charge slightly low in the presumed trigger zone, rather than slightly high. The low placement is more likely to give a reliable indication of snow instability. In most cases the hand charge will

will simply be tossed into the trigger zone: the crewman will, therefore, have little control over how deeply the charge sinks into the snow before detonating. Where possible he should strive for a surface detonation or an above-surface detonation, by hanging the charge over a cornice by a cord, for example. These will give maximum air blast effect.

3. The right time

The right time to test an avalanche slope is selected on the basis of two factors: one is controllable, the other is not.

The controllable factor is safety. An avalanche slope must never be tested when a resulting avalanche could endanger someone below.

The uncontrollable factor is timing--when is the avalanche ready? Snow, weather, and avalanche observations determine this factor. The STRATEGY for dealing with this factor, once determined, follows:

The forecaster must: (1) Use all the hazard evaluation techniques at his disposal in his determination of the hazard build-up; (2) Allow an ample time interval to assure a margin of safety, then: (3) Make certain the danger zones are clear of people and apply the best test he can to the avalanche path. This will usually he will test the slopes a number of hours before he feels the slope would slide naturally. This should always mean testing the slope before it is triggered by passing skiers or other traffic. The forecaster must consider the liklihood of such artificial triggers in his calculations of the critical avalanche period.

A serendipitous benefit of the early test is this: by causing a small avalanche at an early point in the hazard period, large avalanching in what would have been the natural critical period is frequently avoided.

The preceding paragraphs refer to direct action avalanche hazard, for which standard slope charges or ski testing techniques are used. The strategy also applies to delayed action, deep hard slab, climax avalanche hazard. Calculation of appropriate timing for testing for this hazard is based on evaluation of stratigraphy studies and on a correlation of the snow, weather, and avalanche occurrence charts. Again, maintenance of a margin of safety is necessary. Hard slab testing techniques apply here.

D. Limitations: Hand placed explosives

The technique of hand placing explosives for avalanche control work is limited by factors of time and distance, and terrain, weather and snow conditions.

1. Where safe access to safe positions for throwing charges to avalanche trigger points is not possible during difficult weather conditions, hand placed charges are not a dependable means of control. In many cases an enjoyable, albeit strenuous climb up a ridge on a fine day will become an unreasonable if not impossible task on a day of high winds, cold temperatures, heavy snowfall, and zero visibility. In such situations, alternative means of avalanche controll must be available and should be a basic part of initial area planning, whether they be artillery or other projectile-throwing devices or simply closures.

2. Studies of the effects of explosives in rain-soaked snow are not conclusive. The obvious effects are a smaller crater than would be expected in dry snow, and extremely rapid attenuation of blast effect within the snow. The practical result of these effects is that explosives are not regarded as much use in stabilizing rain-soaked snow, neither by a settling effect nor by causing avalanching. Very large explosive charges have successfully caused avalanches in rainsoaked snow, but a negative result cannot be relied on as an indicator of stability.

E. Handcharge placement: Methods

1. When soft snow conditions prevail, hand charges may be thrown from ridgetops to avalanche slopes below, over cliffs, down into gullies, or dropped from overhead lifts if convenient and from helicopters if economics and weather permit.

2. When the snow surface is hard due to high winds and high snow density, thrown charges may bounce and roll or slide down the avalanche path, out of the trigger zone, to detonate uselessly below. In these conditions, charges should be attached to long cords and thrown or lowered to the trigger zones. The cord, most of it, is retrievable.

When charges will be dropped from a lift, no one should board the lift behind the blaster until he passes word that he is through dropping charges. The blaster should be moving uphill when dropping charges from a lift.

3. If oversize charges are used on hard slabs, the charge will be most effective if it is buried two or three feet

in the new snow, then detonated. This can sometimes be accomplished by ramming a hole in the snow with a ski pole and dropping the charge in the hole. When the snow is too hard for the ski pole, a shovel will be necessary. In either case maximum blast effect will be achieved if the hole is stemmed before detonation of the deep charge. Also in either case the man with the pole or shovel must be secured by a belay. The fuse length must be well calculated to allow ample time for the man to climb up from the charge: or the charge must be initiated from above with a long piece of detonating cord.

F. Standard control mission procedures

1. Routes must be carefully chosen for effective control and for crew safety. Safe points from which to throw charges into the trigger zones must be chosen and marked, so that there is no confusion during periods of zero visibility. These points are referred to as shot points.

2. Ridgetop routes and other routes which provide no landmarks or reference points should be marked with stakes at intervals, for the safety and convenience of the crews during whiteout conditions. The stakes can double as shot point markers. Routes and shot points must not be subject to secondary avalanches or to the occasional high avalanche fracture. The blaster must be certain that he and his partner are in a safe location before he lights his fuse.

3. Avalanche control work must never be done alone: the minimum party consists of two persons.

4. Avalanche control teams should maintain radio contact at all times. They should discuss results of testing of avalanche slopes as they become known, particularly results at slopes tested early in the operation and at indicator slopes. This communication provides knowledge that can increase the efficiency and safety of all control teams.

5. Placing slope avalanche charges:

a. Go to selected safe point above target, make certain you know where and how far to throw the charge.

b. Warn the blasting party, make certain all personnel are in safe locations.

c. Cut one inch off the end of the fuse.

d. This step is performed only after crewman is standing in the position from which he will throw his charge. Place pull wire igniter on fuse, making sure it is all the way on and seated. Note: make certain sparks or flame from igniter cannot make contact with the explosive material: broken packages must not be used unless sealed with tape or other protective covering. After igniter is on fuse, the charge must remain in the crewman's hand until it is thrown to the target. The charge must not be set down or handed to anyone.

e. Hold the charge AND the igniter firmly in one hand and pull (a fast pull) the igniter wire with the other hand.

f. Hold the charge long enough (normally 3 to 4 seconds) to be certain the fuse is burning, then throw it to the target.

1) Should the fuse fail to ignite, the igniter should be removed, the fuse freshly cut again, and another igniter attached.

2) When very high winds are experienced, the blaster may find it difficult to ignite his fuse, even with pull wire igniters. This will be the result of the wind actually blowing some of the powder out of the exposed freshly cut end of the fuse before the igniter is attached, leaving a gap between the igniter and the power train. When this occurs, the team make should stand by, ready to affix the igniter to the fuse the instant a fresh cut is made.

g. Step back one or two steps, if you are on a ridgetop, so that a terrain barrier is between you and the charge, and wait the 60 to 65 seconds for the explosion. Glance at your watch to establish the time of ignition in case of a dud. If establishment of a terrain barrier is not possible, seek a position not less than 100 feet from ignited charge.

IV. Cornice Work

A. Definition

A cornice is a projection, or an overhand, formed by wind deposition to the lee of a ridgeline or slope inflection. Cornices are formed at all elevations, on ridges, cliffs, large boulders, on the edges of creeks, and on the ends of roofs. They vary in size and bulk from brand new cornices only inches thick and a few feet wide to mature cornices many feet thick with overhangs of fifty feet or more and as wide as the parent ridge is long. Where cornices overhand slopes with a true (ground) angle of less than 50 degrees, the snow slope beneath the cornices universally assumes an angle of 50 to 52 degrees.

B. Problems cornices present

1. Unpredictable nature

Cornices can assume dangerous proportions overnight. They may fall as direct action collapses as soon as their weight and outward lean overcome their anchorages, or they may pass their period of instability and grow stronger with each snow storm. But they all fall sooner or later, either as drops of water, as chunks of the original mass, or en masse.

2. Strength question

At present there is no reliable method of determining the strength-weakness factor of cornices. It is known that cornices will often support thousands of pounds of applied weight at a given moment. It is known, too, that the same cornice--or one apparently the same--may collapse with little or no artificial provocation. Every experienced avalanche man has memories of cornices that sighed and fell as he approached them.

C. Methods of dealing with cornices

1. Removal after formation

a. Methods: stepping off, explosives, shaped charges. Removal can be accomplished as follows:

(1) At selected locations, small cornices, cornices in the process of being formed, and some moderately large cornices may be stepped, or stomped, off by a belayed crewman. This technique should be applied only where a smooth snow slope lies below the cornice and where the size of the cornice is not so great that the crewman will be injured should he drop beneath it before his belay rope stops him. If agressively performed during the cornice formation period, this method can reduce the incidence of large formations, thus reducing the amount of large rubble blocks that will lie in the ski slopes below.

(2) At all other cornices, the safest and most practical means of cornice removal is explosives.* The objective here is to blast away the cornice formation, and, with it, the hazard it presents to the slopes below. Slow detonating explosives, such as 40% gelatin, have been found the most effective for cornice work although the faster explosives, at a slightly higher cost, will do the job and obviate the need for purchasing and storing two types of explosives.

The explosives should be embedded in the center of the mass of the cornice, vertically above the slope-cornice overhand juncture. Standard procedure is: drill shot holes at six or eight ft. intervals along the expected shear plane, then load two to six pounds (depending on the size of the cornice) of 40% gelatin in each hole, link the charges together with primacord, stem each hole with snow, and detonate the whole thing as a simultaneous multiple shot. The shot holes can be made with a snow sampler or other conveniently sized tube, probe, or pipe. The relative hardness of cornices varies widely. At some locations shot hole making is easily accomplished by ramming a pipe down with the hands: at other places a sledge hammer is required.

An alternative procedure for removal of mature cornices is the use of shaped charges. These are commercially available charges used for boulder reduction without drilling holes. Shaped charges are so designed that virtually the entire force of the explosion moves in one direction.

The procedure: at the expected shear plane, dig an oblong hole 24" deep with the gloved hand, place the armed charge in the hole with the direction of force pointed along the horizontal length of the cornice, stem the hole with snow, and detonate. The result will be a crater where the charge was placed, a long vertical shearing along the direction of force applied by the charge, and a short vertical shearing behind it. The visual impression is much neater than that produced by the standard procedure, and the method leaves fewer odd chunks of snow precariously balanced on the rim. For long cornices, several shots, or a multiple shot may be required.

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*At certain locations cornices can be sawed through with rope or cable, but this requires elaborate measures and special circumstances to justify them. The simple technique of two men sawing through a cornice with a rope sounds nice and will work in some locations, but it likely to be less economical and certainly more dangerous than the use of explosives. (Loss of rope, time, and danger of entanglement.)

Tests indicate declining efficiency for added shape charge weights beyond five pounds, and that only poor results will be realized by directing the force straight downward. Avalanche crewmen must be well and snugly belayed whenever doing cornice work. A loose belay or an inattentive belayer should not be tolerated. A loose belay is nearly as dangerous as no belay. If avalanche control teams normally travel along ridge-top cornice-forming areas during storms, they may find it expedient to toss charges at intervals along the newly formed cornices to prevent them from growing to large size. Cornice falls initiated this way will usually stabilize the slope as well, although the avalanche man will not be certain of this if visibility below is poor.

b. Risk involved (to public)

A calculated risk to the slopes below is inherent when cornices are allowed to form and then are removed. The usual procedure is to allow the cornice to attain a certain size, or to wait for a rise in temperatures before removing the cornice. Here, the avalanche man is not really certain the cornice will not collapse by itself before he gets to it. Another method is to knock the cornice down systematically as it forms, no matter what the size. The latter technique, obviously, is a very time-consuming and continuing method, but it does provide maximum safety for the skiers below. The former method produces large--frequently very large--cornice blocks in the slopes below after cornice removal operations are completed. Where such rubble seriously affects skier use and enjoyment, prevention of cornice formation may be better than removal after formation.

2. Prevention of formation

Prevention of cornice formation can be accomplished by appropriately installed structures. There are two types in current use: snow deposition fences and snow blower structure (jet roofs).

a. Structures

(1) Snow deposition fences are typically erected a more or less calculated distance windward of the cornice-forming area with the intent to disturb the natural windflow-snow-fallout pattern so that the snow either deposits before reaching the edge of the ridge or falls vertically past the ridge. Such fence installations are effective once the most advantageous location, height, and density are determined. While guidelines do exist for these three factors, each

installation must be tailored to the specific location because each location is unique in its combination of critical factors: windward and leeward slopes, prevailing storm wind direction and velocities, and annual snowfall and snow types. Most such installations are constructed in stages--a few trial set-ups for experimental purposes, followed by a winter or two of observation and remodeling or relocation--followed by the permanent installations.

(2) Snow blowers--Jet roofs

Snow blowers work on the Venturi principle. They are constructed in such a manner that the wind is accelerated locally and directed down onto the normal cornice-forming point, thus scouring that area free of snow. Critical factors in the design and location of these structures are the same as for snow deposition structures, although the factors applied differently.

b. Advantages of prevention

The principle advantages realized through prevention of cornice formation are elimination of the hazard factor, and elimination of frequent deposits of cornice debris in the ski slopes below. In addition, (1) prevention means one less time-consuming chore for the avalanche crew, and (2) prevention of cornice formations frequently means there will be a usable and popular ski slope of moderate steepness at a location that was previously not used at all. Cornice control structures are not cheap; they require annual maintenance and they must be very stoutly constructed. Such structures represent a capital investment that may be amortized over a period of time through annual savings in labor and materials (explosives) and through the values represented in the other advantages mentioned above.

V. Artillery Control

A. Definition

Fundamentally, artillery represents an extension of the avalanche man's throwing arm. Where access to the trigger zones is unreasonable or hazardous because of terrain, weather, or simply time factors, artillery is the tool that allows the highways to be travelled and the ski slopes enjoyed in safety.

B. History

Mortars were fired on avalanche slopes in Europe for some years before the first artillery shot brought down a slide in the United States. In Alta in 1950 a World War 1 French 75 was fired on a call-when-needed basis by the Utah National Guard until special regulations allowed Forest Service personnel to man the gun themselves in 1952. Since that time experimentation and operational use have proven the avalanche control capabilities of the 75 mm and 105 mm pack howitzers and recoilless rifles. Other weapons were tried and discarded for various reasons: the Mighty Mouse air to air rocket for its poor accuracy, the 3.5" rocket launcher and all U.S. mortars for their dud factors, and the 105 mm self-propelled cannon for its cumbersome weight and lack of mobility.

C. Advantages

1. Ability to engage many targets from one safe position, quickly and easily.

2. Ability to engage targets that would be inaccessible to, or extremely dangerous for hand charge teams on foot or skis.

3. Blind firing capability allows engagement of targets in all weather at any time of day or night.

D. Requirements

Artillery used in avalanche control work must have the following capabilities and characteristics: adequate payload, reliability, accuracy, adequate range, mobility, and simplicity of operation and maintenance.

1. The artillery piece must deliver an explosive payload at least equal to the standard slope charge. The minimum requirement is for two pounds of T.N.T. for most work. With a payload of 1.49 pounds of T.N.T. the 75 mm HE rounds are considered a bit light, but it is felt that the shaped charge effect of these rounds causes a ground wave effect that compensates for the relatively small explosive charge. Therefore, this otherwise superb weapon has been relied upon for many years at many locations.

2. Projectiles must detonate reliably in soft snow. A dud rate in excess of 1% is not acceptable.

3. The weapon must be accurate enough to hit a 100' diameter circle at a range of 3,000 yards. All artillery in use more than fulfills this requirement.

4. Range requirements vary. Few ski area targets are more than 2,500 yards distant from suitable rifle positions, however, efficient operations in highway work require command of a maximum number of targets from a single position, thus, accuracy at 8,000 to 10,000 yards is desirable.

5. The weapon must be mobile enough to be transported from one firing position to another without the use of heavy equipment. In this regard the 75 mm recoilless rifle is the ideal, it being easily handled by two men, and can even be transported in a ski patrol toboggan. Other pieces now in use or recommended can be fired from vehicles or from their own wheel mountings. All can be fired from fixed positions for blind or for visual firing.

6. The weapon must be relatively simple to operate and maintain. Heavy requirements for time and manpower or elaborate maintenance would be impractical in an avalanche control operation.

E. Artillery limitations

1. Artillery must never be fired unless the gunner is certain that the area gun-to-target and the paths of result-ing avalanches are and will remain completely clear of people and vehicles during the shoot.

2. Firing over structures is not desirable, as "short rounds", while rare, are not unknown. If a structure must be fired over, the distance gun-to-structure must not be more than two-thirds the distance gun-to-target. If it is necessary to fire alongside a ski lift or road, the line of fire must diverge from the lift or road line.

3. Artillery may not be used where shrapnel dispersion could harm persons or damage structures, lifts, or vehicles. Shrapnel dispersion varies with the type and size of ammunition used. Artillery field and training manuals define "effective" fragmentation areas but do not refer to actual distances that flying shrapnel may travel. Avalanche control personnel occasionally find steel fragments as much as one-quarter mile to either side of known targets, and it is reasonable to assume that a few high trajectory fragments travel still farther. Fragmentation carries approximately three times farther to the sides of the target then fore and aft. Persons observing artillery operations should observe from the firing position: or, if observing from the side, should be at least 900 yards from the target zone.

Firing positions should be no closer than 500 yards from targets when 75 mm HE ammunition is used, or 700 yards if 105 mm HE ammunition is used. HEPT ammunitions, with a thinner steel jacket than HE ammunition, has a smaller fragmentation area, but this area has not yet been verified through field experience in avalanche work.

4. A final limiting factor in the use of artillery is the recently developed requirement for elaborate security measures. Both artillery and ammunition have been stolen in recent years, emphasizing the need for strict security of all artillery components at all locations, even high on the mountain. Breechblocks must be stored separately under tightest security.

F. Firing positions

The selection of firing positions requires careful analysis for a number of essential factors.

1. All firing positions must be accessible under all conditions of weather and avalanche hazard and they must be safe from avalanche and associated air blast. As a practical matter, access should be as quick and easy as possible commensurate with other requirements. The positions require a maximum field of fire in order to guarantee most efficient use of the site and to minimize the number of positions required. They must be in locations in which muzzle blast will not cause damage.

2. Recoilless rifle positions must be chosen so that backblast cannot damage structures or vehicles, and desirably, will not cause undue anxiety to persons within the structures. Extent of backblast damage varies with terrain configurations, tree cover, and the rifle used. In most circumstances life shack windows 100 yards behind a 75 mm will not be broken: behind a 105 mm there might be damage as far away as 200 yards. If a target is so located that backblast must be directed toward dwellings, not less than 700 yards clearance is a minimum requirement for all recoilless weapons. Recoilless rifle concussion, not backblast, is known to have broken large windows 250 yards in all directions from the rifle, thus at least this much horizontal separation from dwellings is required.

3. In ski areas fixed rifle positions must be raised well above maximum snow depths or backblast will be a problem to the gun crew.

CHARACTERISTICS OF ARTILLERY RECOMMENDED FOR USE IN AVALANCHE CONTROL WORK

Weapon	Approx. Wt. (lb) Weapon + mount	Maximum Range approx. (yds)	Muzzle Velocity (fps)	Wt. of Round (lb)		Explosive Payload (lb)		Mobility *	Fired from †	# of Crew Required
				HE	HEP-T	HE	HEP-T			
Recoilless rifle 75 mm R.R.	170	6900	990	29	26	1.49	3.00+	1	A	2
Recoilless rifle 105 mm	700	8400	1120	50	37	5	classified	3	B	2
Recoilless rifle 106 mm	460	8400	1650	none	37	none	classified	2	A	2
75 mm pack howitzer	500	9600	1250	18	none	1.49	none	3	C	2
105 mm howitzer	5000	13900	1550	42	none	5+	none	3	C	5-8
Avalauncher	200 + gas bottle	3000	variable 440 fps @ 200 lb pressure	variable 1-4 lbs		variable 1-4 lbs		2	A	2

*1 = Maximum mobility, transportable by ski patrol toboggan, road, or oversnow vehicle
2 = Excellent mobility, transportable by road or oversnow vehicle
3 = Good mobility, transportable by road vehicle or on own wheels

† A Fired from tripod, fixed mount, road, or oversnow vehicle
B Fired from fixed mount, or road vehicle
C Fired from road level only, fixed or semi-fixed positions, on own wheels

4. Recoilless rifles can be fired from any vehicle that will carry them; firing pedestals are routinely attached to pickup trucks. Where truck-mounted weapons are used, semi-fixed positions are provided by marking the wheel positions of the truck on the road surface with paint or steel pins.

Howitzer positions can be chosen without regard for backblast: howitzers may be fired from near or even from inside a shelter. Procedures should guarantee prevention of damage or shifting of fixed or semi-fixed positions by road maintenance equipment.

G. Weapon types (continued from table)

Avalauncher: The avalauncher is a commercially available compressed gas projectile launcher capable of propelling a two-pound fin stabilized projectile up to 3,000 yards. Projectiles with heavier explosive loads can be propelled shorter distances. The propellant pressure can be varied, giving the avalauncher short and long range capabilities not available with military artillery. Thus, it can be fired over intervening terrain into nearby targets. It has no backblast or muzzle blast, and can be fired from a vehicle or from within a building. Maximum fragmentation zone is approximately 100 yards. Recently developed impact detonating fuses provide crew safety features comparable to military artillery. The avalauncher, with necessary accoutrements, can be transported in a pickup truck or over-snow vehicle, and can be fired blind from fixed positions. Accuracy of the launcher is adequate to avalanche control requirements where cross winds are not a serious factor.

H. Ammunition

Of military ammunition used in avalanche control

1. The warheads are "bore-safe" This means that they cannot detonate until they have travelled a safe distance out of the barrel. (For instance, 75 mm HE ammunition does not become armed until it has travelled 400 yards from the rifle or howitzer.)

2. The propellant charge can detonate if the shell is flagrantly mishandled.

3. Most ammunition comes equipped for S.Q. (superquick, instantaneous) detonation and .05 second delay capabilities. All rounds are preset for S.Q. detonation at the factory. Delay detonation can be set with a small screwdriver

or a thin key. Use of the .05 second delay setting occasionally causes duds as the projectile apparently penetrates shallow snow covers to the ground, knocking the fuse off the warhead before detonation can occur.

4. HE (High Explosive) rounds have historically been used for avalanche control work with all artillery, both howitzers and recoilless rifles. HE ammunition is used by the military principally for fragmentation and mining effects. Another type of recoilless rifle ammunition, HEP-T (High Explosive Plastic-Tracer) has recently become available in 75 mm, 105 mm and 106 mm sizes. HEP-T rounds are used by the military for anti-tank and cratering purposes, carry approximately twice the explosive payload of HE rounds, are available with PD (point detonating) and BD (base detonating) fuses. The BD fuse has a tracer element, does not have a delay setting.

5. All components of the variable propellant charge in 75 mm pack howitzer ammunition must be used to insure detonation in soft snow. The capability of variation in the propellant charge was designed to fulfill specific military needs and is not applicable to avalanche control work.

VI. Duds

Dud is the term used to describe any handcharge thrown, or artillery projectile fired on a slope or cornice that fails to detonate. Procedures for dealing with duds:

A. Dud retrieval, Handcharge duds

Wait 15 minutes, then approach and either:

1. Relight the fuse
2. Place another charge alongside and fire it
3. Retrieve and disarm the misfire

Belay all personnel handling duds on avalanche slopes or cornices. Duds that cannot be located and retrieved immediately must be sought when weather and snow conditions allow. Handcharge duds found late in the snow season or as the snow melts are safe to handle. The cap and fuse should be removed from the charge if the dud will not be destroyed in place. All duds should be destroyed, either in place or at another (fire hazard free) location.

B. Dud retrieval, Artillery duds

Artillery duds enter the snowpack at high velocity, penetrate to the ground, and remain in place. They will occasionally ricochet short distances within the snow pack if the ground surface is hard rock. Point detonating fuse assemblies are usually, but not always, knocked off the warhead upon contact with the ground.

The impact point of the dud must be carefully recorded. If the dud occurs during a blind firing operation, the target number must be recorded. An artillery dud must always be considered armed, dangerous, and touchy. It must be diligently sought as snow depths and weather permit. Once found, the dud must be destroyed in place immediately with two to four pounds of high velocity explosive. If the dud is found in a dry area, electric detonation should be used to provide better control of detonation and to minimize fire hazard. The blaster must take full defilade behind a large rock or tree. After detonation the blaster should check to be certain the dud has been destroyed.

OPTIMIZATION OF CONTROL PROCEDURES FOR SKI AREAS

To bring avalanche control procedures to their optimum level of efficiency is to achieve coordinated performance of a wide range of specialized tasks by trained personnel using specialized equipment. This requires a detailed plan, with detailed assignments. Each such plan is unique, tailormade for the specific local situation of time and distance, terrain and weather, and needs and priorities. Each such plan must be flexible in some degree, to provide for varying weather conditions.

Avalanche control at ski areas differ from avalanche control at highway locations primarily as follows: at ski areas the avalanche forecaster is able to "get on the ground" for close observations of the avalanche fracture zones; he is thus able to perform test and protective skiing at many locations and can usually selectively test portions of the ski area with hand placed explosives to further his evaluation of the incipient hazard. The highway avalanche forecaster usually does not have ready access to his fracture zones, is therefore denied the degree of intimacy with his avalanche paths that the ski area forecaster enjoys. The ski area forecaster must beware of small avalanche slopes that can loose avalanches large enough to bury skiers, but which may be of no concern to a highway man because they would not slide down to highway elevations. Where the highway forecaster is normally concerned only with natural avalanche occurrences, the ski area man must also consider the presence of perhaps thousands of artificial triggers skiing around his avalanche paths, and must design his forecasting and control procedures appropriately. Most ski area control is done with hand placed explosives; most highway control is done with explosive projectiles. These differing aspects require specialized modification of the basic control procedures, which remain the same for both; clear the avalanche zone of people and property when hazard occurs, then exercise the most effective means of control.

1. Establish Goals, Priorities, and Responsibility

   Which lifts and slopes to be available under:

   1. Zero

   2. Moderate

   3. High avalanche hazard conditions.

Sequence of control operations and order of opening of lifts and slopes. This portion of the procedures may be dictated entirely by terrain factors. In some areas it will not be possible to control portions of a mountain in a selected order; however, if that is possible, priorities should be established.

Person responsible for public safety must have authority to coordinate the efforts of all departments and personnel involved with avalanche control, and operation and maintenance of facilities, slopes, and roadways. Manpower and equipment requirements must be determined by the responsible person.

II. <u>Develop Necessary Routines and Procedures</u>

A. Observation, recording and evaluation of Snow, Weather, and Avalanche Occurrences. Snow Study Plot observations and data from instruments.

1. Ski Patrol-Avalanche Crew leader and assistants gather, correlate, and evaluate this information. Leader makes avalanche hazard forecasts.

Study plot should be convenient to leader's office. A second, high level plot may be useful. Charts, logs, other records should be maintained where crew can look at them and assist with their maintenance.

B. Records and reporting system

Mountain observations by avalanche crew leader, ski patrol, other crews and skiers.

These observations are made part of the Snow-Weather Avalanche Occurrence records. Such information as sluffs, sun ball activity, wet releases, wind deposition or scouring, snow surface conditions, information from formal and informal stratigraphy studies, excessive creep movement, cornice falls, etc., should all be passed on to the avalanche forecaster for entry into the record. Observation should include the visible surrounding area. Occurrences, conditions, etc., should be pinpointed by slope name or on area photograph.

C. Control--Test patterns, Preventive measures, incipient avalanche hazard

Use of selected indicator slopes, test and protective skiing throughout operating day.

Ski patrol-avalanche crew should routinely test and protective ski certain slopes when conditions warrant. All skiable avalanche slopes should be routinely and regularly skied until the snow is thoroughly packed, to lessen the chance of deep avalanching. During hazard buildup periods, certain test slopes should be checked as often as conditions warrant--every half hour if necessary--for indication of hazard buildup, possible cause for closure of selected lifts or slopes. This applies to thaw periods as well as storm periods. Thawing snow slopes can be stabilized, in many cases, by aggressive and well-timed side slipping techniques. Stratigraphy studies and Snow, Weather, Avalanche Occurrence charts may indicate need for deep explosive charges at certain points.

D. Correlation of weather events, Avalanche occurrence records, Results of Test Patterns

Forecaster evaluates all criteria, including weather forecast, plans and initiates control measures. At this time the avalanche control leader plots his control action and the timing of the action. He may choose to exercise standard control procedures, testing avalanche paths in a standard sequence with standard amounts and placements of explosives, projectiles, or ski checking; or, snow and weather conditions may cause him to modify the control procedure to provide for specific temporary needs or hazards.

E. Control--Alert Stage

1. Notification of public and personnel

Routine temporary slope, lift closures, organization or equipment, explosives, personnel assignments. Area personnel and skiers informed of incipient avalanche hazard.

High hazard areas may be closed at routine closure points. The public is held to minimum hazard areas and final preparations and assignments for the major control action are completed.

F. Control--Action Stage

1. Hazard zones are closed. Crew covers control routes, uses explosives, test and protective skiing where applicable, maintains selected closures if necessary.

The avalanche crew is issued predetermined amounts of explosives for placement in predetermined targets. Their assignments should include blasting where necessary, followed by test and protective skiing of small avalanche slopes. The protective skiing procedure continues until the hazard condition ends.

Lifts and slopes are opened for public use as the hazard is controlled. The avalanche control leader should evaluate the effectiveness of the control action each time control is performed and record results he observes and results reported by the crew. The leader should check to be certain that charges have been placed in best locations and that protective skiing is carried out.

Control procedures would include making maximum use of communications: results of hand charges or test skiing, particularly at early or key targets, should be made known to the entire avalanche crew immediately so they can modify their procedures to suit specific conditions; the leader's latest evaluation of the hazard and time estimated for control should be made known to other ski area personnel to assist them in their planning, timing, and public relations.

G. Timing of control operations

1. Estimate of natural avalanche occurrence, liklihood of artificial triggers, time of day, weather prediction, demand.

The forecaster must time his control action--closures and/or active methods--in the knowledge that skiers can act as artificial triggers, thus cause premature avalanche activity. Therefore he must commence his control action <u>before</u> he would expect natural avalanche occurrence.

Numerous practical considerations will influence his decision on what action to take. If the operations day is drawing to an end as the hazard is reaching full deve opment, he may simply close selected lifts or slopes and do nothing further until next morning, especially if the storm is predicted to last all night. If the operations day is young as the hazard develops, he may call for aggressive protective skiing, with selected closures and possibly some hand charging and reopening of certain slopes.

In the event of rapidly developing hazard or a prediction of extreme weather conditions or rain he may have to resort to complete closure of all avalanche zones and full-scale control operations. Skier demand will also affect his decision; the more skiers the greater the effort to maintain open lifts and slopes.

During thaw conditions the forecaster must organize and time his closure and/or protective skiing--sideslipping efforts most carefully to coincide with the onset of the hazard period. This requires close observation and evaluation of all elements--snow depth, snow temperature, snow type, and snow surface, air temperature, and the weather.

III. Communications

Telephone communications should connect all headquarters points, manned stations, and other key offices. Headquarters should be connected with commercial telephone services.

Radio communications are essential to the efficiency and safety of the avalanche crew. The avalanche forecaster and crew should have instant communication with one another, with a manned base station and with road maintenance vehicles.

IV. Personnel training

Maximum efficiency will be realized if the crew is thoroughly trained in all phases of avalanche control and is intimately familiar with the control routines and avalanche paths. Training should include safety procedures such as not wearing ski pole straps during avalanche work; having a spare pair of gloves during avalanche work; not ski checking above cliffs; choice of safe positions to throw charges from and in which to await detonation; how to be certain the fuse is burning before throwing the charge, etc.

CHOICE OF EXPLOSIVES

Several types of explosives can be used for avalanche blasting. Each type has something to offer in terms of performance, safety, storage, handling, and cost.

Two fundamental properties of an explosive largely determine its performance; detonation speed and density.

> Detonation speed is the rate of propagation of the explosive reaction through the explosive material (measured in sec^{-1}).

> Density is the mass to volume ratio of the explosive (measured in $g\ cm^{-3}$, the density of water is $1\ g\ cm^{-3}$).

From detonation speed and density it is possible to compute a performance index known as the detonation pressure of the explosive. Detonation pressure varies approximately as the square of the detonation speed, and directly with the density. Thus, an explosive that is twice as fast as another has roughly four times its detonation pressure. The higher the detonation pressure, the greater the shattering effect of the explosive.

For performance, avalanche workers generally prefer explosive mixtures with high detonation pressures, the denser and faster explosives. It is claimed that higher detonation pressures are more effective in activating instability, all other factors equal. There is not an obvious explanation for this claim since "low pressure" explosives are known to be quite effective for blasting soft rock. The difference may be that avalanche charges are normally detonated as unconfined surface blasts (external charge), while rock blasting is normally conducted in confined bore-holes. Certainly more studies are needed to confirm the advantage of a high detonation pressure for avalanche blasting.

In choosing an explosive for avalanche work, the following other requirements should also be considered:

1. The explosive and its detonation system should be safe, simple, and usable under severe winter conditions.

2. Properties of the explosive should not be adversely effected by moisture, cold, frost, and other strains of the winter environment.

3. Misfires (or duds) should be infrequent. If a misfire is lost on a slope, exposed to the elements, it should not become shock sensitive.

4. The explosive should be packaged in a non-shrapnel container.

5. The explosive should be reasonably non-toxic under normal outdoor handling. Headache effects should be minimum.

6. The explosive should have a high density so that field loads are not overly bulky.

Most military demolition explosives adequately meet these requirements. Avalanche blasting is in fact very similar to military demolition work wherein explosive charges are applied externally to the target, rather than buried.

Many commercial explosives have been tested and found satisfactory for avalanche blasting. At present, the preferred avalanche explosives are known commercially as <u>primers</u> or boosters, a class of explosives used principally to detonate insensitive blasting agents. Primers are conventionally divided into two categories: non-nitroglycerin (Non NG) primers, and nitroglycerin (NG) primers. The composition of primers varies according to manufacturer.

<u>Non NG-primers</u> are usually high density, pressed or cast cylinders of TNT and PETN. TNT and PETN are fast, powerful explosives which are quite insensitive to accidental detonation by shock. They were developed by the military to withstand the rigors of the battlefield. They do not produce headaches. Their fumes are toxkc, but this is not a problem in normal outdoor application. The detonation system for cast TNT primers is easy to prepare, simple, compact, and comparatively safe. TNT has the peculiarity of reacting with atmospheric oxygen. This reaction adds some energy to the blast, especially when the charge is detonated on the surface. One disadvantage of TNT is that it leaves a messy black crater; another disadvantage is high cost.

<u>NG-primers</u> are cheaper and do not leave a black crater. They usually consist of about 80 percent gelatin dynamite, which is as fast as TNT, but slightly more bulky. They share the disadvantage of all nitroglycerin mixtures. They produce headaches, deteriorate, and are more shock sensitive than primers which consist, for example, of TNT.

NG- and Non NG-primers are classified as high explosives and must be stored and handled according to strict codes (see section 6.7). Storage is expensive. Where there is a limited need for explosives, avalanche workers may wish to avoide storage requirements by using a "two-component system." Stored separately, the components are not high explosives. They are classified as high explosives only when mixed. The storage advantage is offset by higher costs, lower detonation speeds, bulkier charges, the inconvenience of mixing the explosive in the field, and the requirement of a mixing time of about 1/2 hour to bring the mixture to full strength.

FIELD ASSEMBLY OF EXPLOSIVES

Avalanche blasting is based on <u>nonelectric detonating systems.</u> The reasons are, first, that casualties have been caused by the static electricity of snowstorms unexpectedly setting off electric detonation systems; second, the electric intensity of the atmosphere in the vicinity of ridge crests is prohibitively high; and third, electric blasting is not practical for the severe weather and terrain problems normally encountered in avalanche blasting operations. For safety purposes, the <u>non-electric</u> system must be as simple and foolproof as possible. The recommended system includes the following elements: EXPLOSIVE CHARGE, BLASTING CAP, SAFETY FUSE, and SAFETY FUSE IGNITER. Some general considerations for charge preparation are as follows:

1. <u>Blasting cap</u>. The explosive charge is detonated by a <u>nonelectric</u> cap which contains explosives that are more heat and shock sensitive than the main explosive charge. It is important to select a cap size that is large enough to reduce the misfire incidences to a minimum. <u>Misfires</u> are explosives that are thrown onto a slope, but for one reason or another do not detonate. Many <u>misfires</u> can be traced back to undersized caps. In general, most avalanche explosives can be detonated by a size No. 6 cap; however, under severe winter conditions, a No. 8 cap gives more assurance of detonation. Some military explosives require the equivalent of No. 10 cap. It is best to determine the appropriate cap size in consultation with the explosive manufacturer.

2. <u>Safety fuse.</u> It is recommended that the highest quality safety fuse be employed in avalanche work. The fuse should have excellent water resistance and flexibility. The <u>standard</u> burning rate of fuse marketed in the United States is 0.5 meter/65 seconds (40 seconds per foot) $\pm$ 10 percent at sea level. At elevation 2,500 meters, <u>standard</u> fuse burns at about 0.5 meter/70 seconds (47 seconds per foot) $\pm$ 10 percent. After the fuse is purchased, a test segment should be ignited, and the burning rate timed. Fuse that burns faster than 0.5 meter/minute (40 seconds per foot) should not be used.

The minimum length of the safety fuse will depend on the time needed to escape from the blasting location. UNDER

NO CIRCUMSTANCES SHOULD A FUSE LENGTH BE LESS THAN ONE-HALF METER (18-20 inches, or about 70 seconds burning time). In some cases where the escape route is comparatively complex, it will be necessary to use lengths in excess of one-half meter.

3. Safety fuse/cap assembly. Safety fuse should be stored, uncoiled, and assembled to the cap at room temperatures. This will keep the fuse flexible and prevent brittle cracks from forming in the fuse. A break in the powder train of the fuse is another important cause of misfires. Any fuse section that has a kink or a sharp bend should be destroyed.

Before inserting the fuse into the cap, it is important that the tip of the fuse be clipped square. The fuse is then gently inserted into the cap until flush against the inside wall of the cap. There should be no gap between the fuse and cap wall. The cap is then crimped onto the fuse with, AND ONLY WITH, a cap crimper (hand type). Religious observance of these details will minimize misfires.

4. Fuse, cap, explosive assembly--general considerations.

As soon as the cap is inserted into the explosive, the system is armed. At this instant, the relatively insensitive explosive contains a sensitive cap, and is henceforth vulnerable to accidental detonation if mishandled. For this reasons, the assembly of fuse, cap, explosive should be delayed as long as possible in the field operation. In some cases it is possible to arm the explosive just before tossing the charge onto the target. In other cases, wind and temperature conditions on the control route are quite severe, and overall safety is optimum if the explosives are armed in a shelter before starting out on the control route. The moment in the operation when the cap is inserted into the explosive is left to the judgement of the field team.

Three specific examples of explosive assemblies are presented below.

5. Arming of Non NG-primer. Most Non NG-primers are manufactured with two axial holes, a central hole, and an off-center hole. The central hole is designed to be detonated by high explosive detonating cord (primacord). The off-center hole is usually lined with PETN, a cap-sensitive explosive. Thus, it is essential to place the cap in the proper hole (usually the off-center hole), or a misfire is likely to occur. In avalanche work, it is convenient to lace the safety fuse through the central hole and then into the off-center hole.

Ideally, the base charge section of the cap should end up about half-way down the off-center hole. The assembly is then taped securely, avoiding sharp bends in the safety fuse. Because of its simplicity, this assembly lends itself nicely to "field mass production" where the control team assembles, say, 100 or more charges for a morning operation. Considering the shock insensitivity of the Non NG-primer, and the fact that the cap is protected in the middle of the charge, this assembly today represents the safest armed charge that can be carried on a control mission.

6. Arming of gelatin-primer. Gelatin-primers do not have precast holes; it is necessary to punch two diagonal holes as follows. First, a diagonal hole is punched through the charge with the punch end of the crimper. Next, the charge is rotated one-fourth turn, and a second diagonal hole is punched slightly deeper than the length of the cap. The fused cap is then laced through the first hole and the cap inserted into the latter hole. Care should be taken to avoid sharp bends or kinks in the fuse. The assembly is taped securely. A disadvantage to this system is: increased headache factor due to the additional holes in the explosive. Another method: make a diagonal hole in the explosive with the pointed end of the crimping tool. The hole should be approximately three inches from the end of the explosive cartridge and roughly centered in the circular dimension. Make the hole deep enough so the entire cap will go inside it. Insert the cap, place the thumb over the cap hole, and loop the fuse over the end and back along the length of the cartridge. Then tape securely. The fuse loop should be at least two inches in diameter. This method of arming yields approximately one half the headache likelihood as the lacing method.

7. Arming of detonating cord. Some explosives, for example, military tetrytol, are detonated by a high explosive cord known as detonating cord or primacord. The method of arming such charges consists of either taping the cap to the detonating cord or joining the cap and cord with special connectors. The explosive end of the cap must point along the detonating cord toward the main charge. In both cases, the final connection of cap and detonating cord should be made only at the blasting position, because in these systems the cap is exposed and vulnerable to accidental shock on the control route.

8. Assembly of safety fuse igniter. This final step in the assembly is made only at the blasting position, and only after the crewman is standing in the position from which he will throw his charge. First, about 1 cm. (½" - 1") of the exposed end of the safety fuse is clipped off squarely. The fuse core should be shielded from the wind. The squared end is pushed firmly into the safety fuse igniter. The system is now ready for detonation.

9. Detonation. Before the igniter is attached to the fuse, a quick visual check is made of the blasting area and the escape route. The igniter is then attached and the fuse is ignited. Before tossing the charge, the crewman makes certain the fuse is burning. The charge is then tossed onto the target.

The information presented here and recommendations made in these pages are intended to provide knowledge that will enable the avalanche worker to work confidently and safely with explosives. The worker should know that if he handles his explosive "tools" in the manner normal to avalanche control operations he can do so with confidence. The avalanche worker is urged to use explosives with confidence and respect, not with fear. Explosives become dangerous when prescribed handling procedures are not followed.

CHARACTERISTICS OF MILITARY AND COMMERCIAL EXPLOSIVES
RECOMMENDED FOR AVALANCHE CONTROL WORK
TNT = 1.00

Explosive	Principle Uses*	Smallest cap required for detonation	Unconfined detonating velocity fps.	Relative effectiveness as external charge	Availability through	Stability	Shelf life (simple storage no extra care required)
TNT	1,2,3	#8 or military	21,000	1.00	Military only	Superior Y	Unlimited
Tetrytol	1,2,3	#8 or military	23,000	1.20	Military only	Superior Y	Unlimited
C-3, C-4	1,2,3	#8 or military	26,000	1.34	Military only	Superior Y	Unlimited
85% Gelatin dynamite	1,2,3	#6	21,000+	1.00+	Commercially available in various sizes	Excellent	Winter Season
75%	1,2,3	#6	21,000+	1.00+	Commercially available in various sizes	Excellent	Winter Season
60%	2,3	#6	16,000	0.76	Commercially available in various sizes	Excellent	Winter Season
40%	3	#6	8,000	0.12	Commercially available in various sizes	Excellent	Winter Season
TNT Boosters Non-nitroglycerin primers	1,2,3	#6	24,000	1.10	Commercial – 1 lb blocks	Superior Y	Unlimited
Two component explosives**	Not tested	#6	20,500	[illegible]	Commercially available in various sizes	Superior Y	Unlimited
Detonating cord	Not applicable	#8 or two #6	21,000	Not applicable	Spools – 500' or 1,000'	Superior Y	Unlimited

* 1 = standard slope charge (soft or hard slab)
2 = buried charge – hard slab
3 = cornice removal

Y = will not detonate under impact of standard rifle bullet.

** Not necessary to store separate components in magazine, although security is recommended.

November 1974

LIST OF INSTRUMENTS

Cost are estimates and are included to indicate their magnitude. The cost shown are neither list prices nor offers.

Thermometers

Maximum thermometer, range approx. -35° F to +110° F
Minimum thermometer, range approx. -60° F to +90° F
divisions in 1° F

Supplier: Goertz or Atmospheric Environment Service (AES)
Cost: $30.00 each from commercial source,
$10.00 each from A.E.S.

Snow thermometer: pocket thermometer with metal case, range -35° C to +50° C, division in 1° C; order also refills (thermometer without case).

Supplier: WASC, Canlab (cat. no. T2134-10), Goertz, Fisher 6
Cost: $6.00, refills $3.50.

Thermograph

Several models available; recommended is weekly chart.

Supplier: Goertz, Canlab 1
Cost: $200.00

Instrument Shelter (Stevenson screen)

Supplier: Goertz or Atmospheric Environment Service
Cost: $80.00

The shelter may also be home-made, but it is usually not worth the effort and cost.

Folding Ruler

Metric or metric + english, 200 cm long. 6

Supplier: WACS, Hughes-Owens or Keuffel & Esser
Cost: $4.00

Snow depth marker

Wood, 2" x 4", painted glossy white, calibration in cm may be painted or a refill of a tape measure may be attached.

Rain gauge

Various types depending on capacity.

Supplier: Goertz or Atmospheric Environment Service
Cost for small-type: approx. $30.00

Snow density samplers

Aluminum tubing, DURAL, I.D. 60 mm, cut to a length of 177 mm (=7 inch) for 500 cm³ sampler. Bevel one end and add handle if desired. Stainless steel is also suitable, but not as good as aluminum; select pipe diameter 2 inch or greater and cut to correct length.

Ramsonde

1 rod graduated in cm with cone, 100 cm
2 extension rods, 100 cm
1 guide rod for hammer
1 kg hammer

Suppliers: a) W. Buser
Karstlernstrasse 5
8048 Zurich
Switzerland

b) Geotest

Cost: $300.00

Crystal Screens

Plate, anodically oxydized, black ground with white inscription, 178 mm x 96 mm x 0.5 mm

Supplier: Hans Meierhofer or WACS
Schilderfabrik
5507 Mellingen
Switzerland

Cost: $4.00

Magnifying Glass

a) AGFA Lupe 8x
Available at stores for photographic supplies, and WACS

Cost: $3.00

b) Tube magnifier, 7x, with case, without scale.

Supplier: Bausch & Lomb, Optical Co., Vancouver

Cost: $18.00

c) Double convex lens reading glass, about $2\frac{1}{2}$" diameter.

Supplier: Canlab, Fisher

Cost: $3.00

Complete snow observation kit

A complete kit is available which includes sampling tubes, scale, crystal screen, magnifying glass, thermometers, carrying case.

Supplier: Geotest

Cost: $550.00

Shear frame

Box shear apparatus, 100 cm^2, stainless steel, about U.S. gauge 21, connections welded. To be manufactured in suitable local workshop.

Spring balance

a) OHAUS, Model 8012 metric, capacity 500 gram, divisions 5 gram

Supplier: CANLAB, FISHER

Cost approx.: $6.00

b) Chatillon instrument push-pull gage, capacity 500 gram, division of 5 gram; with dial Model DPP, cost $130.00; without dial, with maximum reading pointer, cost $35.00.

The chatillon push-pull gage, capacity 1000 gram, division 10 gram, is used for the observation of the shear strength of snow.

Supplier: J. Chatillon

Beam balance

Triple beam balance, metric, OHAUS, Model 720 with removable scoop and counter weight.
Maximum capacity 2610 gram, divisions 0.1 gram.

Supplier: CANLAB, FISHER, or local scale shops

Cost: $60.00

Wind equipment

a) Hand-held wind meter.

Supplier: Goertz

Cost: $10.00

b) Hand anemometers, portable air meters, several models available.

Supplier: Goertz

Cost: $180.00

c) Combined cup anemometer with transmitter, combined recorder with spring wound clock or synchronous motor.

Cost: $2,000.00
Cable between anemometer and recorder, 7 conductor, No. 18 gauge, heavily coated PVC.
Cost: $0.50 per lin. ft.
Supplier: Goertz

d) Aerovane system Bendix with windspeed and direction transmitter, support, recorder.

Cost: $5,000.00
Cable as above.
Supplier: Aviation Electric Pacific

e) Standard MSC anemometer, anemovane and recorder.
Supplier: Atmospheric Environment Service.

SKADI	-	Lawtronics Inc. 326 Walton Drive, Buffalo, N.Y. 14226, U.S.A.
PIEPS	-	For organizations: Mike Wiegele Box 1824, Banff, Alberta, ToL 0C0
		For individuals: Skishops
AUTOPHON	-	Western Avalanche Control Specialists P.O. Box 176, Stewart, B.C.
SKILOK	-	Aspen Guides Ltd., Box 440, Aspen Colorado [illegible], U.S.A.

W.A.C.S: Western Avalanche Control Specialists Co.
P.O. Box 176,
Stewart, B.C.

Frederic Goertz Ltd.,
1328 West Pender Street,
Vancouver 1, B.C.

CANLAB: Canadian Laboratory Supplies Ltd.,
790 Alderbridge Way, Richmond, B.C.

also at Calgary and Edmonton.

Fisher Scientific Co. Ltd.,
196 West 3rd St.,
Vancouver, B.C.

also at Calgary and Edmonton

John Chatillon & Sons
Kew Gardens
New York, U.S.A.
represented by: The Scale Shop Ltd.,
757 Cordova Street,
Vancouver 4, B.C.

Industrial Scale Co.,
Edmonton, Alberta

Aviation Electric Pacific Limited
Vancouver Airport
Richmond, B.C.

Regional Director
Atmospheric Environment Service
Environment Canada,
739 West Hastings Street,
Vancouver 1, B.C.

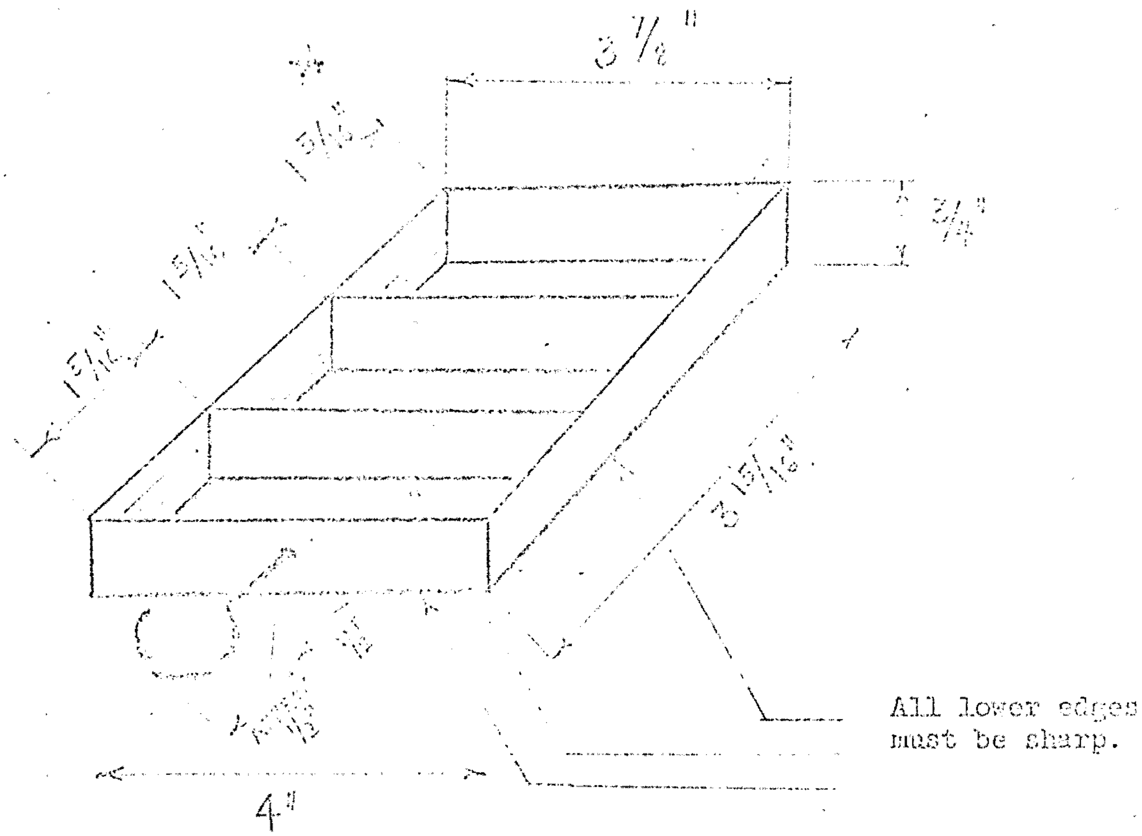
or

Federal Building
9820 - 107th Street
Edmonton, Alberta

Note! The Atmospheric Environment Service supplies government departments and universities only, but does not sell equipment to private companies. Private and public organizations may obtain the equipment free of charge by becoming a co-operative weather station.

Geotest Instrument Corp.
Box 551,
[illegible], Illinois 60060, U.S.A.

[illegible] FRAME FOR [illegible]



MATERIAL: Stainless steel, approximately U.S. gauge 21.
All connections welded.
The hook may be any suitable type readily available.